

Application Note AN-1601

SCALE Family



Controlling SiC MOSFET Power Switches with SCALE-2 and SCALE-2+ Gate Drivers Cores and SCALE-iDriver Gate Driver ICs

Abstract

Besides driving conventional Si-based power devices like IGBTs and MOSFETs, which require turn-on and turn-off gate voltages of 15 V / -10 V and 10 V through 20 V / 0 V respectively (1), SCALE™-2 and SCALE-2+ gate driver cores plus SCALE-iDriver™ gate driver ICs are also able to drive SiC MOSFET power switches. However, SiC switches often require turn-on and turn-off voltage levels which are different from those required by Si-based devices.

This application note discusses procedures to optimize use SCALE gate drivers with SiC MOSFET switches. Two gate driver families, 2SC0106T and 2SC0108T, are not discussed.

Gate Turn-On and Turn-Off Voltages

SiC MOSFET switches from different suppliers and of different generations have different requirements for gate turn-on and turn-off voltage levels. Some devices are able to operate with 15 V / -10 V while others, for example, operate at 19 V / -6 V. Furthermore, some devices require a regulated turn-on voltage while others need a regulated negative turn-off voltage to ensure that they do not exceed the gate-source safe operating area as given in the respective data sheets (typically, only one voltage can be regulated, while the other depends on the actual load conditions).

To adjust SCALE gate drivers to the different requirements, the control of the voltage partitioning for the positive and negative voltage rails related to the gate turn-on and turn-off levels must be overruled. Responsible for the control of the voltage partitioning is the so-called VEE-regulator.

VEE-Regulator

All SCALE gate drivers within the scope of this document are able to operate from a unipolar supply voltage V_{tot} (Figure 1) for the secondary-

side, which is derived from an isolated DC/DC converter (V_{tot} is the applied voltage between pins VISOx / VISO and COMx / COM in Figure 2). From this unipolar voltage a positive and negative voltage partition is generated with the help of an internal VEE-regulator. This regulator generates a fixed 15 V voltage (V_{VISO}) between VISOx / VISO and the emitter (or source) potential (pin VEx / VEE). The negative voltage between COMx / COM and the emitter (or source) amounts to:

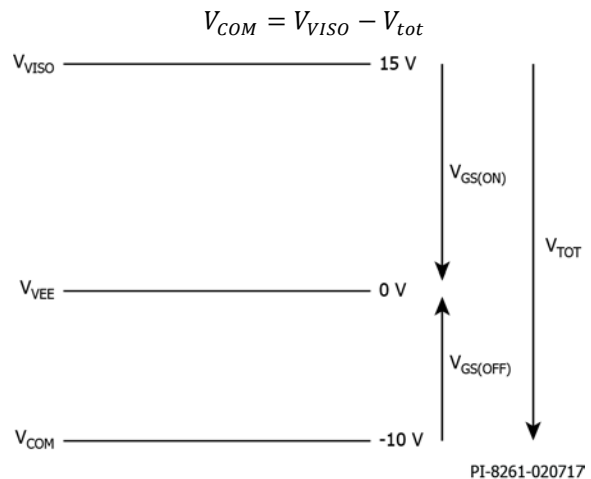


Figure 1. Voltage Partitioning (example for +15 V / -10 V Gate Turn-On / Off Voltages).

The voltage V_{COM} is not regulated and has its maximum negative value under no-load conditions. With increasing load, the voltage shifts towards the voltage at pin VEx / VEE as stated in the respective data sheets of the SCALE gate driver.

For gate voltage requirements other than those typically used for IGBT switches, the internal VEE-regulator should be decoupled. Additional circuitry is required to establish the desired voltage levels.

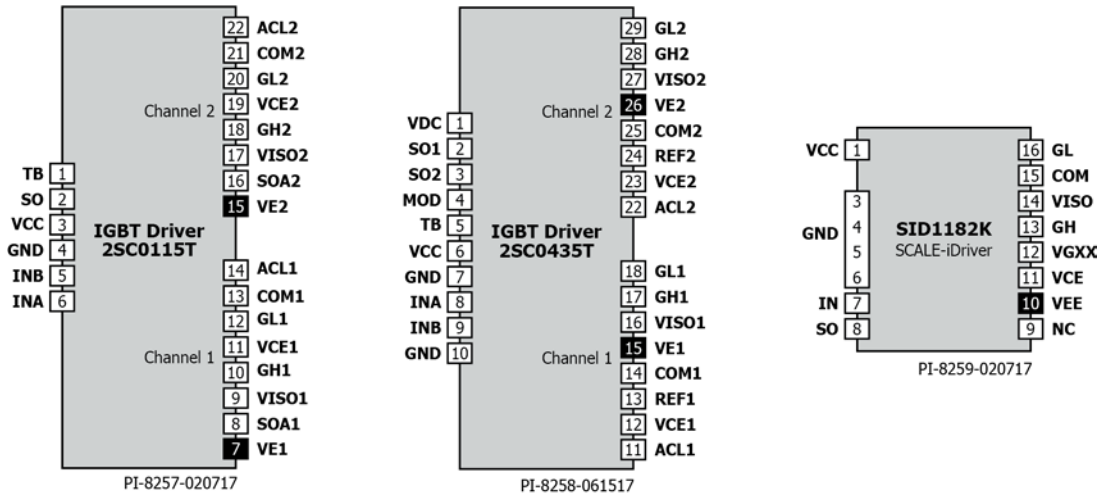


Figure 2. Pinning of Different SCALE Gate Drivers with Marked VEX / VEE Pins (Gate Driver Cores 2SC0115T and 2SC0435T and Driver IC SID1182K).

VEE-Regulator for SiC MOSFET Switches

The basic principle for a substitution of the internal VEE-regulator of the SCALE gate drivers is described in the following procedure:

- Do not connect the VEX pin for SCALE-2 and SCALE-2+ gate drivers. When using the SCALE-iDriver gate driver, connect 100 nF capacitors between the VISO and VEE pin and between VEE and COM pins (refer to Figure 3). No other VEE pin modifications are required.
- A voltage divider between VISO pin and COM pin must be created. To achieve this, either a combination of a Zener diode and a series resistor, or a shunt regulator can be used to establish a regulated voltage. Note that a two resistor voltage divider is not suitable, as this would not regulate either the positive or negative rail.
- An impedance transformer (IC1 in Figure 4 and Figure 5) is placed between the midpoint of the voltage divider and the new emitter (or source) reference VEE* to provide sufficient current sink and sourcing to regulate the voltage rails.

Figure 4 shows an example of a regulated positive voltage rail using a combination of a Zener diode D1 and series resistor R2. Figure 5 shows an

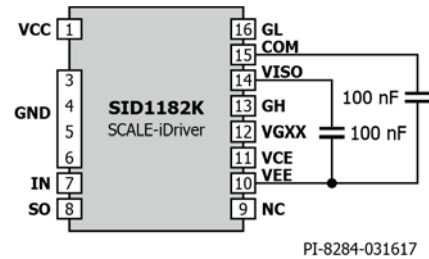


Figure 3. VEE-Regulator Capacitor Connection for the SCALE-iDriver IC.

example for a regulated negative voltage rail using a shunt regulator S1.

Note: In general shunt regulators provide a more stable voltage than Zener diodes across load and temperature.

Details of both circuits are described in the following sections.

Common for both designs is the setting of the buffer capacitors C3 and C4. These should be selected according to the data sheet / application manual of the selected gate driver.

Example:

Consider the case where the data sheet of a SiC MOSFET power module states a (total) gate charge Q_G of 1.4 μC . The following minimum total capacitances (including those already used in the driver core) must be used for a 2SC0435T SCALE driver:

$$C_3 = C_4 = Q_G \times \frac{3 \mu\text{F}}{1 \mu\text{C}} = 1.4 \mu\text{C} \times \frac{3 \mu\text{F}}{1 \mu\text{C}} = 4.2 \mu\text{F}$$

If the given gate charge is not referenced to the voltage level of V_{tot} , a conversion factor should be used. For example, if the gate charge is given in the data sheet at a voltage of 30 V and V_{tot} is set to 25 V the conversion factor is 0.83 (this conversion factor is based on a simple interpolation using a linear calculation, i.e. it disregards any potential effects of the Miller capacitance):

$$C_3 = C_4 = \frac{25 V}{30 V} \times 1.4 \mu C \times \frac{3 \mu F}{1 \mu C} = 0.83 \times 4.2 \mu F = 3.5 \mu F$$

Regulated Positive Rail

Referring to Figure 4, the positive rail voltage V_{VISO} is calculated using the following formula:

$$V_{VISO} = V_{Z(D1)},$$

where $V_{Z(D1)}$ is the nominal Zener voltage of the diode D1.

Accordingly, the negative rail voltage V_{COM} is determined by:

$$V_{COM} = V_{VISO} - V_{tot}$$

To achieve good results, the following settings should be selected:

- Current I_{D1} should be set in the range of 4 mA to 6 mA to operate the diode in the linear region

Example for 18 V / -7 V:

$V_{VISO} = V_{Z(D1)} = 18 V$, e.g. BZX84-A18 Zener diode

$$V_{COM} = V_{VISO} - V_{tot} = 18 V - 25 V = -7 V$$

$$R_2 = \frac{|V_{COM}|}{I_{D1}} = \frac{7 V}{5 mA} = 1.4 k\Omega$$

The voltage V_{COM} has its maximum negative value under no-load conditions and will shift towards VEE* with increasing load.

Resistors R1 and R5 are chosen according to the data sheet and application notes of the operational amplifier IC1.

Regulated Negative Rail

Referring to Figure 5, the negative rail voltage V_{COM} is calculated using the following formula and based on the data sheet and application notes of the shunt regulator TL431BFDT (S1):

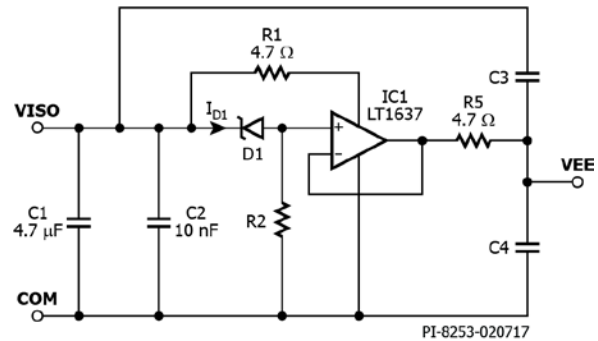


Figure 4. VEE-Regulator for SiC MOSFET Switches with Regulated Positive Rail.

$$V_{COM} = -2.495 V \times \left(1 + \frac{R3}{R4}\right)$$

So, the positive rail voltage V_{VISO} is determined by:

$$V_{VISO} = V_{COM} + V_{tot}$$

To achieve good results the following settings should be selected in accordance to the data sheet and application notes of the shunt regulator S1:

- Current I_{R2} should be set in the range of 1 mA to 3 mA
- As guidance, the current through the resistors R3 and R4 should be in the range of 0.15 mA to 0.30 mA
- Current I_{S1} must be larger than 0.6 mA

Example for 20 V / -5 V:

$$\begin{aligned} V_{COM} &= -2.495 V \times \left(1 + \frac{R3}{R4}\right) \\ &= -2.495 V \times \left(1 + \frac{15 k\Omega}{15 k\Omega}\right) = -5 V \end{aligned}$$

$$V_{VISO} = V_{COM} + V_{tot} = -5 V + 25 V = 20 V$$

$$I_{R3,R4} = \frac{5 V}{R3 + R4} = \frac{5 V}{15 k\Omega + 15 k\Omega} = 0.17 mA$$

$$R_2 = \frac{V_{VISO}}{I_{R2}} = \frac{20 V}{2 mA} = 10 k\Omega$$

$$I_{S1} = I_{R2} - I_{R3,R4} = 2 mA - 0.17 mA = 1.83 mA$$

The voltage V_{VISO} has its maximum under no-load conditions and will shift towards VEE* with increasing load.

Resistors R1 and R5 are chosen according to the data sheet and application notes of the operational amplifier IC1.

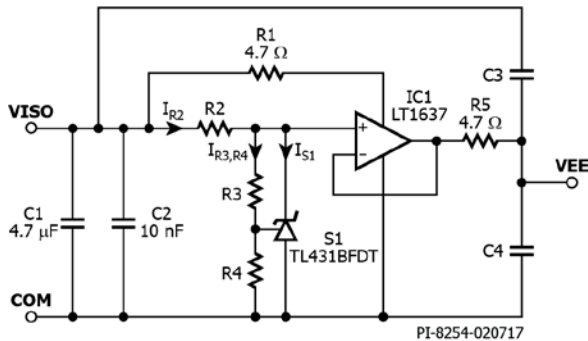


Figure 5. VEE-Regulator for SiC MOSFET Switches with Regulated Negative Rail.

Short-Circuit Monitoring

SiC MOSFETs have a considerable smaller short-circuit safe operating area (SCSOA) than Si-based IGBTs. The typical short-circuit withstand time for

IGBTs is 10 μ s. In comparison, SiC MOSFETs are often rated for 2 μ s only.

All SCALE gate driver cores are able to detect and safely turn-off a short-circuit condition within this 2 μ s time frame. To achieve this, only minor adaptations to the standard setting for IGBTs are required, as demonstrated in the following example using a 2SC0115T SCALE gate driver core. Figure 6 illustrates the typical settings for short-circuit monitoring circuitry as can be found in the corresponding manual (2) (only one channel shown). The response time is set by capacitor Ca and resistor Ra. Typical values for DC-link voltages greater than 550 V are, for instance, Ca = 22 pF and Ra = 120 k Ω , which provide a response time of 5.9 μ s (2).

For the operation of SiC MOSFETs, it is recommended that an additional diode D2 (BAS416, same as D1) is added as shown in Figure 7. This diode clamps potential oscillations during turn-on transients to V_{COM} and reduces the response time if such oscillations are present. In some cases it may also be necessary to add a resistor Rc. This resistor is only required if large oscillations are present during turn-on events.

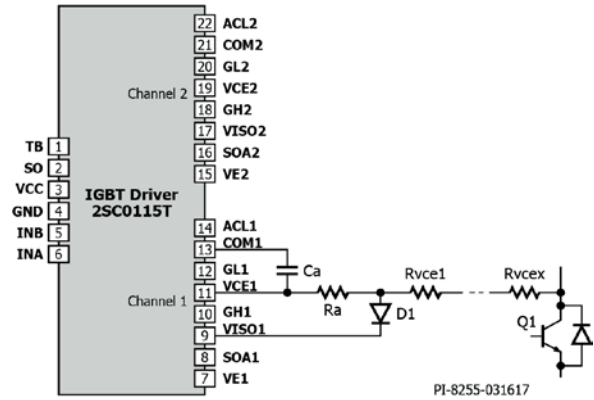


Figure 6. Standard Setting for IGBT Short-Circuit Detection.

In this case, Rc will damp the oscillations and, in combination with Ca, improves the response time. The value of Rc shall be determined by tests as it depends on the actual application conditions. If required, typical values are in the range of several 100 k Ω .

Note: Depending on the actual application conditions and values of R1 and Rvce1 through Rvcex, the short-circuit monitoring will become dependent on the DC-link voltage. Therefore, tests at DC-link voltage levels relevant to the application must be conducted to verify that the short-circuit protection is provided.

Capacitor Ca can be removed or set to values in the range of 1 pF to 10 pF (specific value needs to be determined by actual testing which also considers parasitic effects and tolerances).

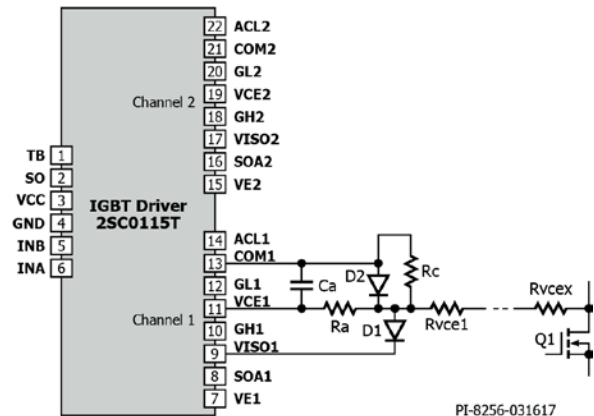


Figure 7. Modified Setting for SiC MOSFET Short-Circuit Detection.

Reference Voltage

SCALE gate drivers compare the actual voltage level at pin VCE with a reference voltage V_{ref} (V_{ref} is typically referenced to V_{EE}). In the case that the voltage at pin VCE is higher than the reference voltage, the gate drivers recognize this as a short-circuit event and shut down the related power switch. As the reference voltage is tied to the internal VEE-regulator voltage a conversion of the actual reference voltage V_{ref*} is required:

$$V_{ref*} = V_{ref} + (V_{VEE} + V_{VEE*})$$

with V_{VEE} and V_{VEE*} referenced to V_{COM} .

Example acc. to Figure 8:

The reference voltage V_{ref} is set to 10.2 V with respect to VEx / VEE, and the new VEE* potential is set to 5 V with respect to V_{COM} (i.e. $V_{COM} = -5$ V). The actual reference voltage V_{ref*} in this case is calculated as:

$$\begin{aligned} V_{ref*} &= V_{ref} + (V_{VEE} + V_{VEE*}) \\ &= 10.2 \text{ V} + (0 \text{ V} + 5 \text{ V}) = 15.2 \text{ V} \end{aligned}$$

Therefore, in certain applications, it may be necessary to reduce the V_{ref*} voltage by reducing the corresponding resistor at pin REFx (available with most of the SCALE gate driver cores, e.g. 2SC0435T in Figure 2). Alternatively, V_{ref} may be directly referenced to V_{COM} instead of V_{EE} .

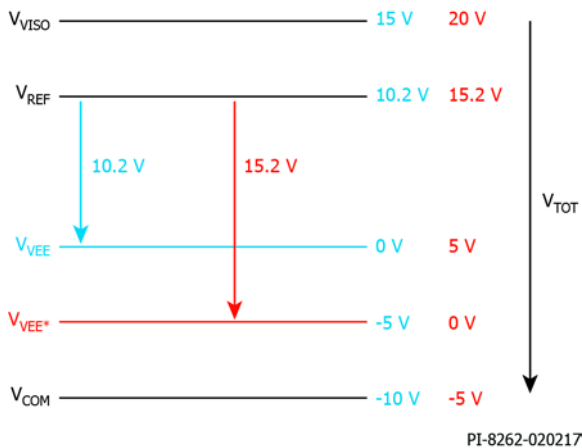


Figure 8. Example of Reference Voltage V_{ref} in Relations to V_{VEE} and V_{VEE*} .

References

1. Application Note AN-1101, "Application with SCALE-2 and SCALE-2+ Gate Driver Cores", Power Integrations
2. "SCALE-2+ 2SC0115T Description and Application Manual", Power Integrations

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| Revision | Notes | Date |
|----------|---|-------|
| 1.0 | Released by Power Integrations | 03/17 |
| 1.1 | Corrected pin designations in middle IGBT Driver for Figure 2: Pin 26 from VCE to VE2 and Pin 15 from VCE to VE1. | 06/17 |

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