DESIGN OPTIONS FOR WOLFSPEED® SILICON CARBIDE MOSFET GATE BIAS POWER SUPPLIES

Gate voltage and power requirements are crucial in driving Silicon Carbide MOSFETs used in high-speed switching applications. In order to fully utilize the potential of Silicon Carbide devices to enable high power density and high efficiency, the gate power supplies need to be optimized as well. The amount of power required scales with the die size and switching frequency, so the power supply should be sized accordingly. There is also a range of different gate drive voltage requirements depending on the generation of the Silicon Carbide MOSFET and the manufacturer. Many design engineers are required to support multi-sourcing of key components to ensure supply-chain robustness. This requirement creates the need for designs to support different gate voltage levels in a single design.

To ensure high compatibility between Silicon Carbide MOSFETs and high-speed gate drivers, power system designers must have the necessary understanding of gate bias supply methods and related cost, efficiency, multi-sourcing, and reliability aspects.

For instance, in single-ended topologies such as boost, buck, and flyback, 0-V turn-off may be utilized. However, in half-bridge configurations, high dV/dt can potentially induce a parasitic turn-on and cause shoot-through conditions. Here, utilizing –2 V to –4 V turn-off voltage in half-bridge configurations provides higher immunity against parasitic turn-on compared with 0 V.

This application note provides basic design information demonstrating several different gate bias supply circuit implementations. Additionally, several approaches for implementing flexible gate-source voltage (V_{gs}) drive levels are demonstrated to support different Silicon Carbide MOSFET gate requirements.

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1. GATE BIAS REQUIREMENTS

Due to the faster switching speeds of Silicon Carbide MOSFETs and high-speed gate drivers, transient conditions on the gate may exceed the specified static drive levels. However, the designer must ensure that these transients are as short as possible and never exceed the maximum ratings of 19 V/–8 V for Wolfspeed® 3rd generation devices. Here, a –3-V turn-off can be utilized to provide additional headroom to the -8V limit in high-speed designs in which a low R_g is used. It provides 5 V of margin to the negative limit and 5 V of margin to the minimum threshold voltage.

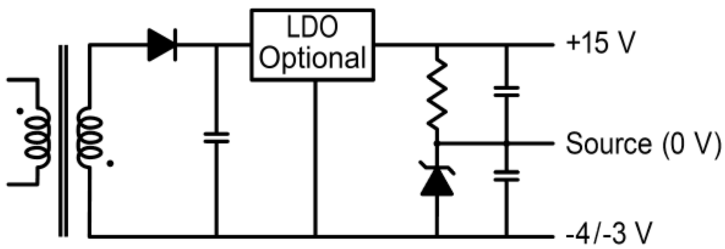

Figure 1: A resistor and Zener diode can be used to easily generate a split +15/-3 V (or -4 V) supply from a single output of a DC/DC converter.

Moreover, a low-inductance gate layout and a small capacitor or RC between the gate and Kelvin source can help reduce overshoot and undershoot conditions and improve overall dynamic performance. It's worth noting here that power system designers must not use an external capacitor between gate and source on devices without a Kelvin source such as a TO-247 three-lead as this can result in increased gate oscillation and overshoot.

Nevertheless, operating voltage outside the recommendation can negatively impact the performance, lifetime, and reliability of the power devices. As such, Wolfspeed recommends operating V_{gs} (+) = 15 V and V_{gs} (–) = –3 V to –4 V to take full advantage of the company's process technology. Wolfspeed's C3M™ MOSFETs are optimized for these gate drive voltage levels, and operation beyond this range could affect reliability. Additionally, ±5% tolerance is recommended on both supply rails.

There are many ways to generate gate bias power supply rails, and the best option depends on individual application requirements. Regardless of the gate bias topology, the designer must ensure that the coupling capacitance between the input and output is very low. The high dV/dt switching in a Silicon Carbide MOSFET can drive large currents through the isolation capacitance, potentially leading to noise and EMC problems. The following section provides an overview of the methods commonly used to create isolated gate power supplies; it also outlines the design pros and cons of each method.

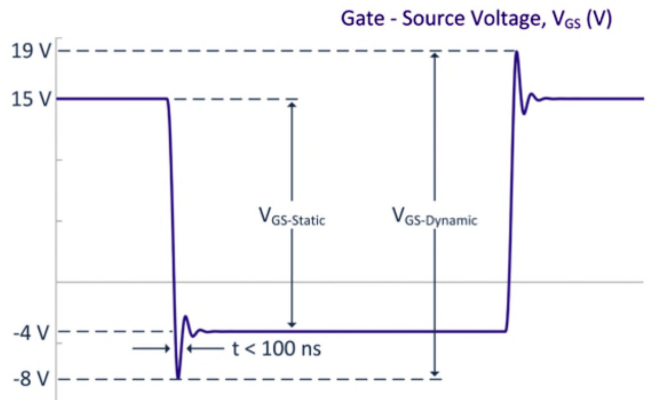

Figure 2: Transient conditions on the gate should be as short as possible.

2. GATE BIAS SUPPLY METHODS

A number of unique isolated supply designs exist, and the best one for an application depends on the topology and physical layout of a design. Both single- and multi-output supplies may be utilized as needed.

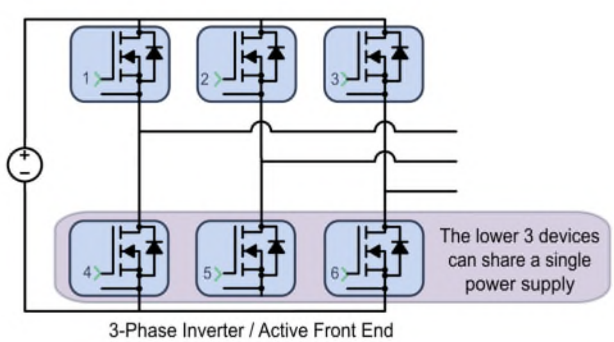

Figure 3: A three-phase inverter topology in which three lower Silicon Carbide MOSFETs can share a single gate bias supply.

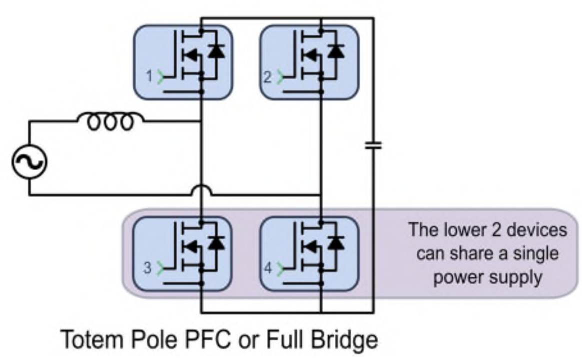

Figure 4: A totem-pole PFC or full bridge inverter in which two lower Silicon Carbide MOSFETs can share a single gate bias

The low-side devices may share a single gate power supply and utilizing a single supply for multiple devices can reduce cost. However, due to high dV/dt and parasitic inductances in the printed circuit board (PCB), it is advised to place decoupling resistors between each driver to avoid circulating currents during switching transients.

Several methods are available for providing isolated gate bias supplies, including a power supply module comprising a packaged DC/DC converter; a single-channel DC/DC converter using fly-back, push-pull and LLC topologies; and a multiple-output DC/DC converter employing flyback and bridge topologies.

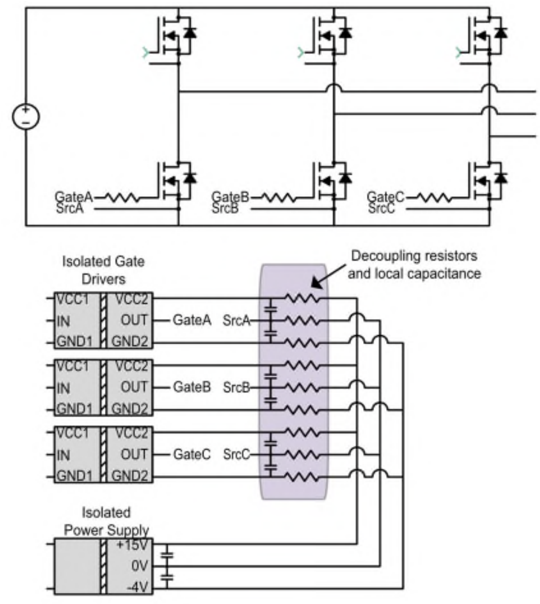

Figure 5: Decoupling resistors placed between each driver help avoid circulating currents during switching transients.

It's worth noting that a single channel can make layout easier, but it generally consumes more space and costs more overall than a multi-output solution. Furthermore, each method involves a multitude of manufacturers and control ICs. Therefore, this application note covers each method's general attributes and design principles; designers may consult specific part datasheets for further design information.

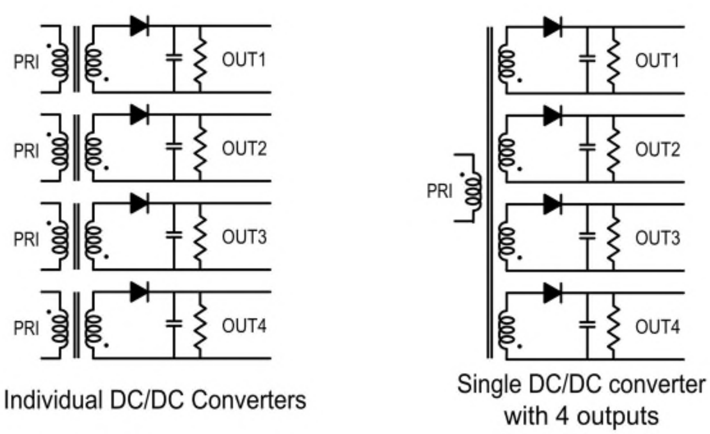

Figure 6: Four individual DC/DC converters or a single DC/DC converter with 4 outputs can be utilized to provide gate power for a 3-phase bridge.

Power Supply Module

Power supply modules — for instance, Recom's RxxP21503D, Murata's MGJ2D series, and Mornsun's QA15115R2 — are simple to implement and feature low-isolation capacitance. They are also pre-qualified and agency-certified. However, power supply modules may be more expensive than discrete solutions and generally come with unregulated output.

Single-channel DC/DC flyback

A variety of flyback control ICs are available in the market, while some gate-driver ICs like Analog Devices ADuM4138 or Skyworks Solutions Inc. Si828x come integrated with a controller. These flyback control solutions are flexible in terms of input voltage range and primary-side regulation and can easily achieve split output rails. On the other hand, flyback supplies can lead to high-isolation capacitance, larger transformer form factor, and high electromagnetic interference (EMI).

Single-channel DC/DC push-pull

Power system designers can either use push-pull control ICs such as TI's SN6501/6505 and Analog Devices LT3999 or the solution can be implemented with a simple PWM output using a microcontroller. These solutions boast small transformers and high efficiency, but they offer limited controller options and have a single output rail.

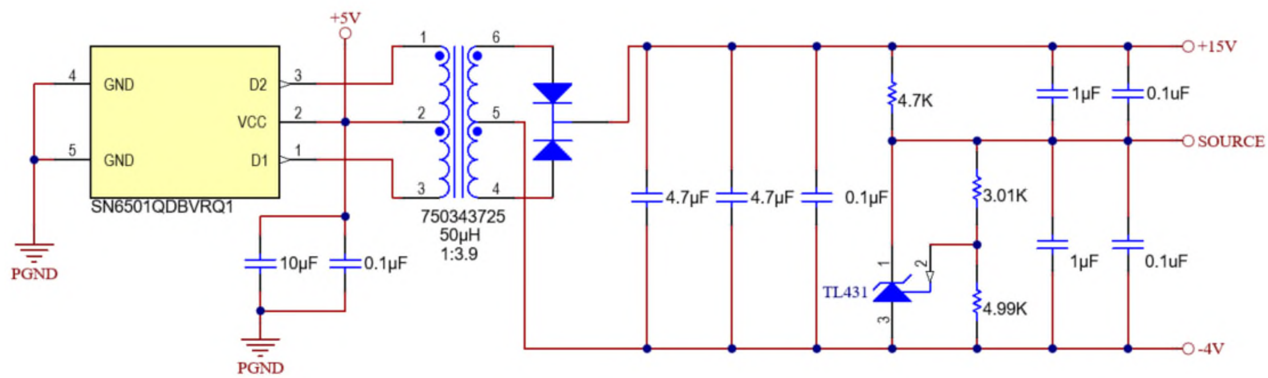

Figure 7: The single-channel DC/DC push-pull topology is based on TI's TIDA-01605 reference design.

Single-channel DC/DC LLC

Control ICs such as TI's UCC25800 are available to implement this topology. The benefits of this topology are very low EMI, very low isolation capacitance, and smaller transformer size. However, such solutions require specialized control.

Multiple-channel DC/DC flyback

In this topology, two, three, four, or six individually isolated outputs are possible, while the input supply may be low-voltage control power or can come directly from high-voltage bus to avoid double processing of the power; this, in turn, leads to higher efficiency and lower cost. Other advantages of this topology include low cost, fewer components, and smaller space. However, PCB layout creates challenges for distributing isolated outputs, and cross-regulation issues may require a secondary low dropout regulator (LDO).

Multiple-channel DC/DC bridge
Control ICs are available in the market to implement this topology. It can also be used with a simple PWM output from a microcontroller while employing a two-channel driver with external PWM such as TI's UCC27524. In this topology, two, three, four, or six individually isolated outputs are possible, while input supply must be low-voltage regulated control power. The open-loop operation is performed at about 50% duty cycle.

This topology is a low-cost topology that requires fewer components and features a smaller transformer than the flyback topology. That, however, also creates PCB layout challenges for distributing isolated outputs. Moreover, cross-regulation issues may require a secondary LDO. Additionally, this topology is not well suited to operating directly from a high-voltage bus on the input side, so an additional step-down power supply may be needed.

The following table provides relative comparisons of some of the main design considerations between the topologies.

	DC/DC Module	Single Channel Flyback	Single Channel Push-Pull	Single Channel LLC	Multi-channel Flyback	Multi-Channel Bridge
Relative Cost for 6 Channels	High	Medium	Medium	Medium	Low	Low
Relative size for 6 Channels	Medium	Medium	Medium	Medium	Low	Low
Isolation Capacitance	Low	Medium	Low	Low	High	Medium
Direct Operation from HV Bus	No	Possible	No	No	Possible	No
Difficulty of Layout	Lowest	Low	Low	Low	High	High

3. FLEXIBLE VGS CIRCUIT IMPLEMENTATION EXAMPLES

The following example circuits show different options that may be used to provide alternative gate supply rails to accommodate different recommended levels from different Silicon Carbide MOSFET manufacturers. This allows design engineers to develop a single PCB that supports multiple sourcing options of the Silicon Carbide MOSFET with minor bill of material (BOM) changes. Many of these options utilize regulation or reconfiguration of the secondary side of the isolated supply, allowing them to be used with any of the isolated DC/DC converter topologies presented above.

Example circuit 1

A fixed-output DC/DC converter along with the resistor-Zener regulator creates split supply rails. It's a simple and low-cost approach, but it offers a limited number of configurations.

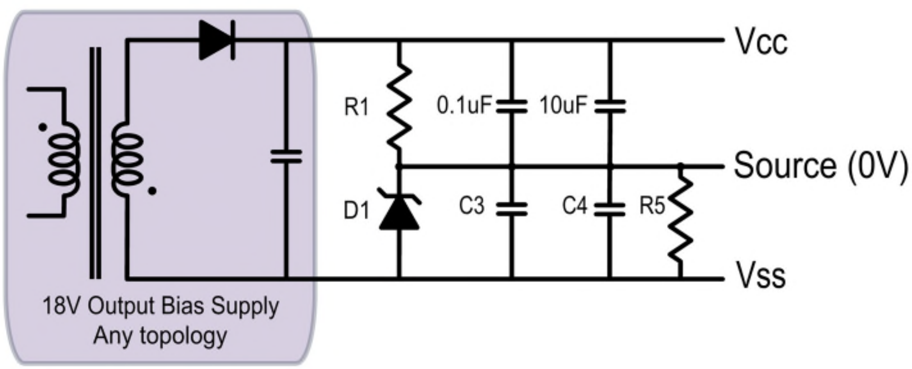

Figure 8: The design approach based on a fixed-output DC/DC converter is simple and low-cost.

Compatible Vcc/Vss	R1	D1	C3	C4	R5
+15 / -3	4.99k	3V	0.1uF	10uF	DNP
+18 / 0	DNP	DNP	DNP	DNP	0 Ohm

Example circuit 2

A fixed-output DC/DC converter with a linear regulator to adjust total Vcc-Vss voltage, along with the resistor-Zener regulator to create split supply rails. It's a very flexible approach that is well suited for multi-output flyback designs, ensuring regulation on all outputs. However, additional space is required for the linear regulator.

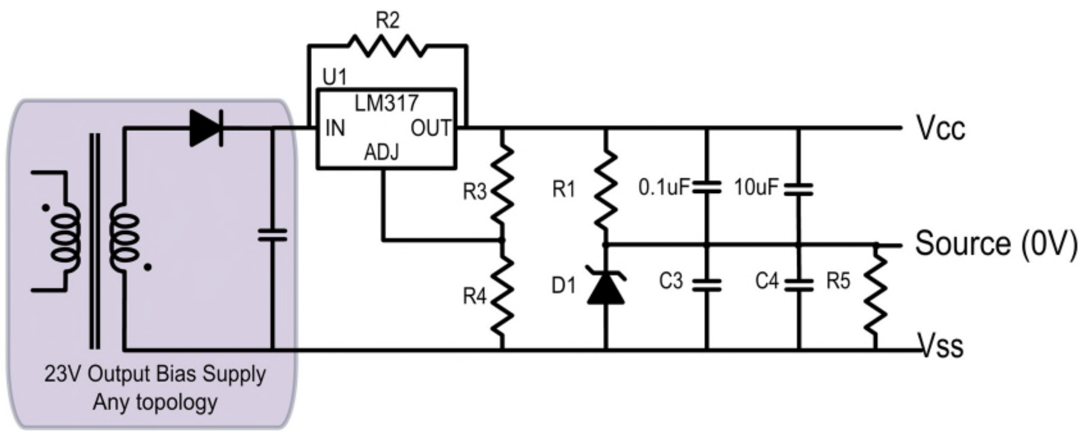

Figure 9: A linear regulator ensures regulation of all outputs in multi-output flyback topology.

Compatible Vcc/Vss	U1 Setpoint	R1	D1	C3	C4	R5	R2
+15 / -5	20	4.99k	5V	0.1uF	10uF	DNP	DNP
+15 / -4	19	4.99k	4V	0.1uF	10uF	DNP	DNP
+15 / -3	18	4.99k	3V	0.1uF	10uF	DNP	DNP
+15 / -2	17	4.99k	2V	0.1uF	10uF	DNP	DNP
+15 / 0	15	DNP	DNP	DNP	DNP	0 Ohm	DNP
+18 / 0	18	DNP	DNP	DNP	DNP	0 Ohm	DNP
+18 / -2	20	4.99k	2V	0.1uF	10uF	DNP	DNP
+18 / -5	DNP	4.99k	5V	0.1uF	10uF	DNP	0 Ohm

Example circuit 3

An adjustable-output DC/DC converter like flyback, along with the resistor-Zener regulator, creates split supply rails, making it a very flexible and low-cost approach. Designers must ensure that the DC/DC converter can operate over a wide output range.

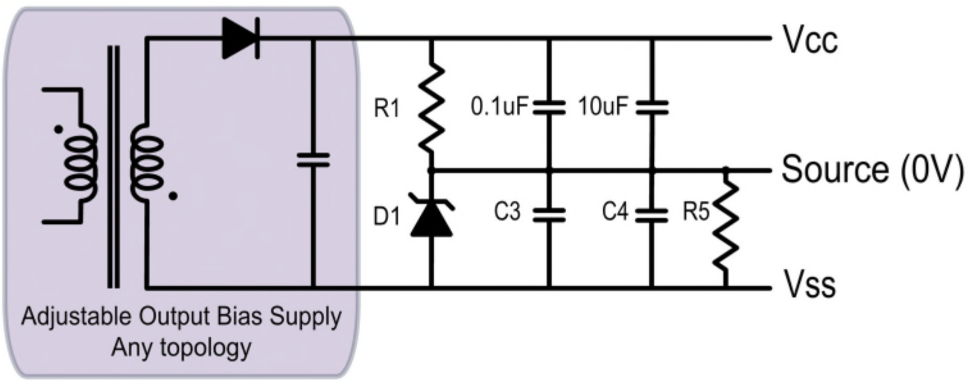

Figure 10: Adjustable rails make this design approach highly flexible.

Compatible Vcc/Vss	DC/DC Setpoint	R1	D1	C3	C4	R5
+15 / -4	19	4.99k	4V	0.1uF	10uF	DNP
+15 / -3	18	4.99k	3V	0.1uF	10uF	DNP
+15 / -2	17	4.99k	2V	0.1uF	10uF	DNP
+15 / 0	15	DNP	DNP	DNP	DNP	0 Ohm
+18 / 0	18	DNP	DNP	DNP	DNP	0 Ohm
+18 / -2	20	4.99k	2V	0.1uF	10uF	DNP
+18 / -5	23	4.99k	5V	0.1uF	10uF	DNP
+20 / -5	25	4.99k	5V	0.1uF	10uF	DNP

Example circuit 4

A dual fixed-output DC/DC converter, along with the resistor-Zener regulator, creates split supply rails and provision to use single or dual outputs. Again, it's a simple approach, but it requires a more expensive transformer.

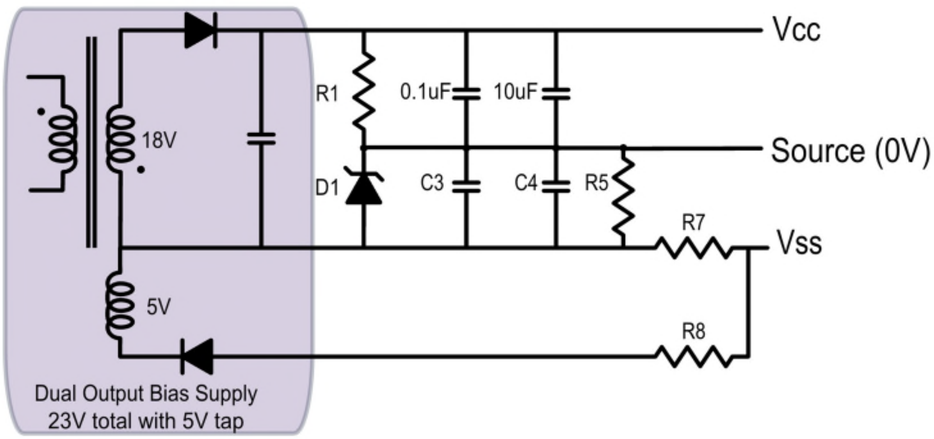

Figure 11: Split supply rails make it a simple circuit implementation.

Compatible Vcc/Vss	R1	D1	C3	C4	R5	R7	R8
+15 / -3	4.99k	3V	0.1uF	10uF	DNP	0 Ohm	DNP
+18 / -5	DNP	DNP	DNP	DNP	0 Ohm	DNP	0 Ohm

4. SUMMARY

There are numerous methods to generate the isolated gate bias power supplies for Silicon Carbide MOSFETs. The different design approaches presented here allow the designer to select the most appropriate topology for a given design. Wolfspeed recommends that designers who desire higher compatibility between Silicon Carbide MOSFETs consider the example circuits highlighted in this application note, which will allow designers to simplify the differences between the BOMs while supporting multi-sourcing.