

Advancing Gate Driver Performance: Miller Clamp vs Bipolar Output



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Introduction

As power electronics evolve toward higher efficiency and density, robust gate driver design becomes essential, especially for SiC MOSFETs and IGBTs in high-power applications. This note compares traditional Miller clamp techniques with bipolar output gate drivers, highlighting how bipolar drive improves noise immunity, prevents false turn-on, and enhances switching performance. Through comparative analysis and real-world applications such as EV traction inverters, solar inverters, and motor drives, this application note discusses adopting bipolar gate drivers in modern, high-performance power systems.

Silicon carbide (SiC), with the wide bandgap of 3.26eV, offers significant advantages over traditional silicon (Si) in high-power, high-frequency, and high-temperature applications. The breakdown voltage of silicon carbide, lower on-state resistance, and better thermal conductivity enable operation at voltages up to 10kV and temperatures up to 200°C, with reduced switching and conduction losses.

While Si MOSFETs and IGBTs are widely used in power systems, they differ in performance. IGBTs handle higher currents with lower conduction losses, while MOSFETs offer faster switching but are limited in current capacity. SiC MOSFETs combine the high-frequency advantages of MOSFETs with the high-voltage capabilities of IGBTs, resulting in higher efficiency, greater power density, and lower thermal stress. These characteristics make SiC a choice for applications such as electric vehicles, renewable energy systems, and high-efficiency power supplies.

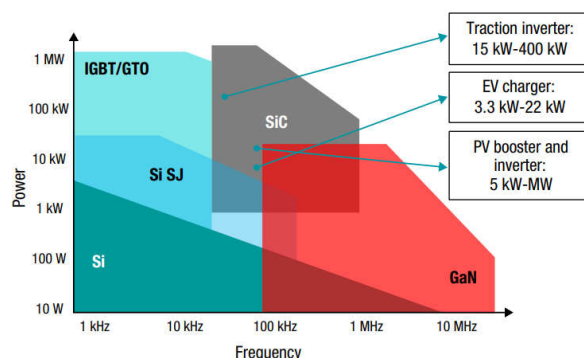


Figure 1. Power Semiconductor Device Application Based on Power and Frequency Levels

End Equipment

Equipment	Power Switch	Rating
EV Traction Inverter	SiC	400V – 1200V
On Board Charger (OBC)	SiC	400V – 800V
DC-DC Converter in EV	SiC	400V – 800V
Fast DC Charging Stations	SiC	Up to 1500V
Solar Inverters	SiC / IGBT	600V – 1500V
Data Center Power Supplies (PFC)	SiC	380V – 480V
Industrial Motor Drives	IGBT	600V – 1700V
Welding Machines	IGBT	600V – 1200V
Uninterruptible Power Supplies	IGBT	600V – 1700V
HVAC Power Supplies	IGBT	600V – 1200V
Rail Traction and Locomotive Drives	SiC/IGBT	1200V – 3300V
Aerospace Power Systems	SiC	270V – 1000V+
Elevator Drives and Cranes	IGBT	600V – 1700V

dV/dt Induced Turn On

In high-power applications such as inverters, power converters, and motor drives, IGBTs and SiC MOSFETs are commonly exposed to fast switching transitions that generate large voltage (dV/dt) and current (di/dt) transients. While such fast switching improves efficiency, fast switching can interact with parasitic elements in the circuit and lead to unintended device behavior. A notable issue is **dV/dt-induced turn-on**, where a rapid increase in drain-to-source voltage (V_{ds}) causes displacement current to flow through the **Miller capacitance** (C_{gd} or C_{ge}) of the device.

This Miller current creates a voltage drop across the gate resistance, and if the resulting gate-source voltage (V_{gs}) exceeds the threshold voltage of the device (V_{th}), it can unintentionally turn on the switch. In a half-bridge configuration, this can lead to **shoot-through**, where both upper and lower devices conduct simultaneously, causing excessive current and thermal stress. To prevent such failures, gate drivers often employ negative gate bias or integrated Miller clamp circuits to suppress parasitic turn-on and verify reliable operation under high dV/dt conditions.

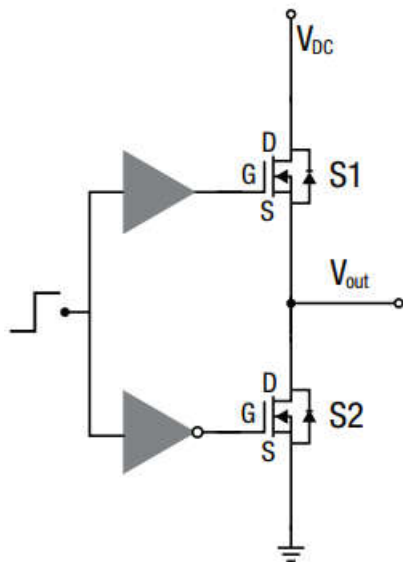


Figure 2. MOSFET Half Bridge

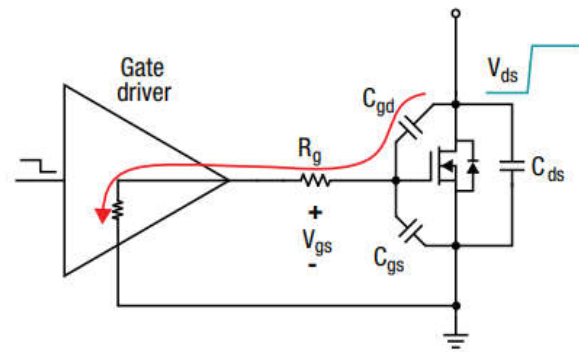


Figure 3. Miller Current Path of S2

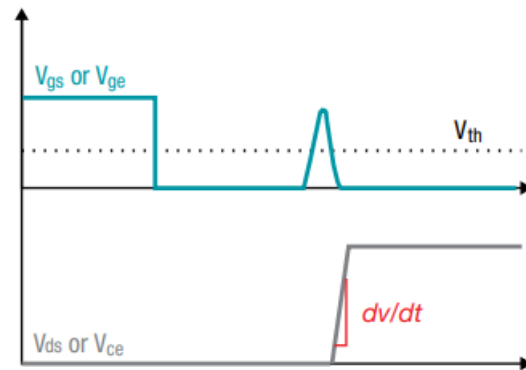


Figure 4. Effect of Miller Current on the Gate Voltage of S2

Miller Current

In high-speed power switching applications, the voltage transient (dV/dt) across a device can couple through the parasitic Miller capacitance (C_{gd}), generating a gate current that can inadvertently turn the device on. Since C_{gd} is an intrinsic physical property of the power semiconductor and cannot be modified, one common mitigation approach is to reduce dV/dt by increasing the gate resistance (R_g) of the corresponding FET. However, this method slows down switching transitions and increases switching losses, presenting a trade-off between noise immunity and efficiency. To overcome this limitation, Miller clamps are employed. A Miller clamp is a low-impedance switch placed close to the gate, which provides a direct path to ground or a negative voltage rail during turn-off. This prevents the gate voltage from rising due to dV/dt -induced currents. The integration of a Miller clamp in gate driver architectures enables independent control of the turn off resistance of the gate without compromising the Miller immunity of the circuit. The effectiveness of a Miller clamp depends primarily on the placement which determines the impedance and the pull-down

current capability. A high impedance or insufficient pull-down current can render the clamp ineffective, failing to suppress false turn-on events. As a result, careful design of the Miller clamp circuit is essential for maintaining both noise immunity and switching efficiency in modern gate driver architectures.

Internal vs External Miller Clamp

The effectiveness of a Miller clamp is highly dependent on the proximity to the power switch, as the clamp must present a lower-impedance path to ground for the Miller current than the gate driver. Parasitic series resistance (R_p) and inductance (L_p) in the clamps connection can substantially degrade the performance if the clamp is remote from the device. Internal Miller clamps (integrated within the gate-driver IC) minimize component count but can suffer from these parasitic effects if the IC package and board layout place the Miller clamp at a distance from the switch. Conversely, an externally implemented Miller clamp, though requiring additional components, can be positioned immediately adjacent to the power switch, minimizing R_p and L_p and ensuring robust suppression of dV/dt -induced gate transients. For applications exhibiting high dV/dt , external clamps are preferred to verify the low-impedance current return path required to prevent false turn-on.

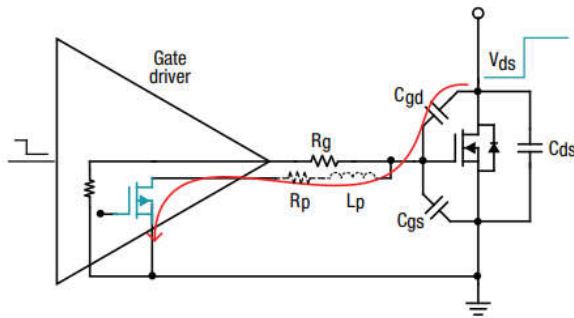


Figure 5. Internal Miller Clamp

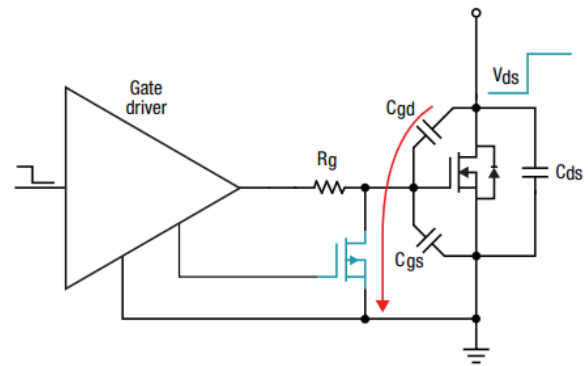


Figure 6. External Miller Clamp

Bipolar Outputs

Gate drivers play a crucial role in controlling the switching behavior of power semiconductors such as MOSFETs and IGBTs. A conventional gate driver typically uses a unipolar output, driving the gate from 0V to a positive voltage (for example, 15V). However, in high-power and high-speed switching environments, this approach can lead to reliability concerns due to unwanted turn-on events caused by parasitic effects. Bipolar gate drivers capable of providing both positive and negative gate voltages mitigate *false turn on* and *false turn off* challenges.

A bipolar gate drive applies a positive voltage (for example, 15V) during turn-on and a negative voltage (for example, -5V) during turn-off, with respect to the source or emitter of the switching device. This dual-rail approach enhances immunity to noise and dV/dt -induced false turn-on, especially in half-bridge and full-bridge configurations where the transition of the high-side switch can induce current through the Miller capacitance (C_{gd}) of the low-side device. In a unipolar scheme, the gate can be pulled only to 0V, and any additional voltage from dV/dt coupling can push the gate above the threshold voltage (V_{th}), inadvertently turning the device on. In contrast, a negative gate voltage shifts the effective turn-on threshold further away, significantly improving noise robustness.

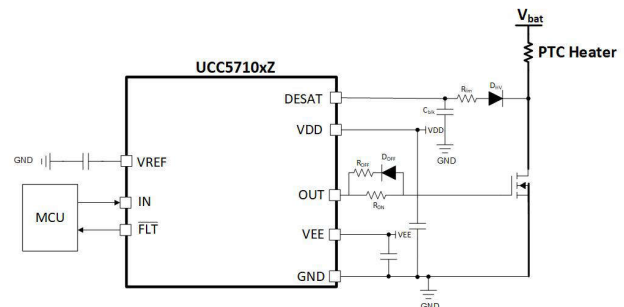


Figure 7. Application Diagram for UCC5710xC showing Bipolar output

The UCC510xB/Z offers support for external negative voltage generation, allowing designers to implement a bipolar gate drive by supplying a dedicated negative voltage pin (VEE). This feature enables flexible adjustment of the negative bias during turn-off, which is critical for enhancing noise immunity and preventing unwanted turn-on events caused by Miller capacitance. By using an external negative voltage source, the driver can accommodate a wide range of gate drive requirements across different power switching applications.

The advantages of bipolar gate driving are multifaceted. Bipolar gate driving offers dV/dt immunity by actively opposing gate bounce and parasitic turn-on, verifies a safer and more reliable turn-off by firmly pulling the gate below ground potential, and reduces the risk of shoot-through in complementary switch configurations. Additionally, the negative voltage accelerates gate charge removal, facilitating faster switch turn-off. For IGBT devices, bipolar gate driving also helps manage tail current behavior and dV/dt during the turn-off event, improving overall switching performance and reducing energy losses.

Negative voltage bias can be used to prevent voltage spikes from reaching the turn-on threshold, making sure that the SiC MOSFET stays off. The graph below shows us how this works.

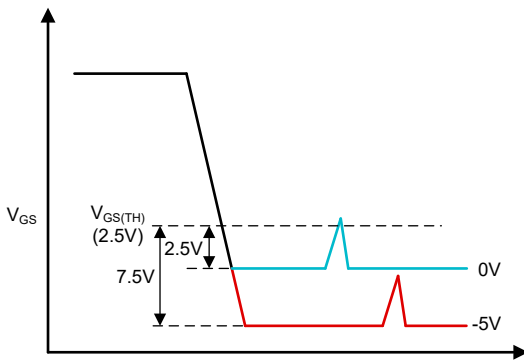


Figure 8. Comparison of Different Turn-Off Levels

Difference Between Bipolar Output and Miller Clamp

Aspect	Bipolar Gate Drive	Miller Clamp
Basic Operation	Applies -ve voltage (e.g., -5V) to gate during turn-off.	Clamps gate to source (0V) during turn-off using internal low-resistance MOSFET.
Protection Level	Higher immunity due to negative bias.	Moderate immunity, depends on clamp strength.
Voltage Levels	Requires -ve supply rail .	Works with unipolar (0V/+15V) supplies.

Aspect	Bipolar Gate Drive	Miller Clamp
Complexity and cost	More complex due to dual rails.	Simpler, often integrated in gate driver.
Use Case	Harsh switching environments, fast dV/dt circuits, high voltage systems.	General-purpose, cost-sensitive designs.

In summary, bipolar gate drive techniques are essential in modern high-speed power electronic systems, offering enhanced control, reliability, and protection against parasitic-induced switching anomalies that are common in fast-switching and high-voltage environments.

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Last updated 10/2025