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Gate Driver Design and Mitigation of Voltage Glitch in SiC MOSFET Using Miller Clamp

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Abstract. This work provides a detailed discussion about power converter circuits using SiC MOSFET, a classical approach to designing gate drivers for SiC MOSFET, and mitigation of voltage glitch and crosstalk voltage in SiC MOSFET using active as well as passive miller clamp. Different type of gate driver configuration has been discussed in this work. Crosstalk voltage exits on the gate-source terminal of SiC power MOSFET. Active and passive miller clamps are used to eliminate any crosstalk voltage which is available in the switching the MOSFET. As a result of the rapid growth of semiconductor technology, a variety of high-performance semiconductor devices are becoming available for purchase. In recent years, the silicon carbide SiC MOSFET and the junction barrier Schottky diode (JBS) have been created and are now commercially accessible. SiC MOSFETs outperform their silicon counterparts in terms of performance. The voltage and current ratings of the SiC MOSFET have also been shown to be significantly higher than those of the Si MOSFET.

Keywords. Miller clamp, Gate driver, SiC MOSFET, Voltage Glitch

1. Introduction

Due to rapid advancement of semiconductor technology, different high performance semiconductor devices are coming to the market. Silicon carbide SiC MOSFET and junction barrier schottky diode (JBS) diode has been developed and commercially available. SiC MOSFET provides superior performance than Si based power. The voltage and current rating of the SiC MOSFET also has been far greater than Si MOSFET. The operating principle and advantages of SiC MOSFET has been discussed in [1-3]. Parameter extraction process of SiC MOSFET has been discussed in [4-7]. A comparative analysis of different semiconductor materials has been summarized in Table 1. Voltage and current rating of Si and SiC power devices have been summarized in Table 2.

Table 1. Properties of Different Semiconductor

Properties	Unit	Si	GaAs	SiC-4H	GaN
Bandgap energy	eV	1.12	1.42	3.2	3.44
Breakdown voltage	MV/cm	0.3	0.4	3.5	3.3
Electron saturation velocity	cm/s	10-7	1.8*10-7	2.2*10-7	2.5*10-7
Electron mobility	Cubic cm/Vs	1450	8000	950	2000
Thermal Conductivity	W/cmK	1.5	0.55	5	1.3

Table 2. Voltage and Current Rating of Si and SIC power Devices

	Si MOSFET	Si IGBT	SiC MOSFET
Voltage rating	20 V to 650 V	More than 650 V	More than 650 V
Switching frequency	More than 20 kHz	5 kHz to 20 kHz	More than 50 kHz
Power level	Less than 3 kW	More than 3 kW	More than 5 kW
$\frac{V_{gs}}{V_{ge}}$	0 to 15 V (20 V)	-10 V to 15 V	-5 V to 20 V

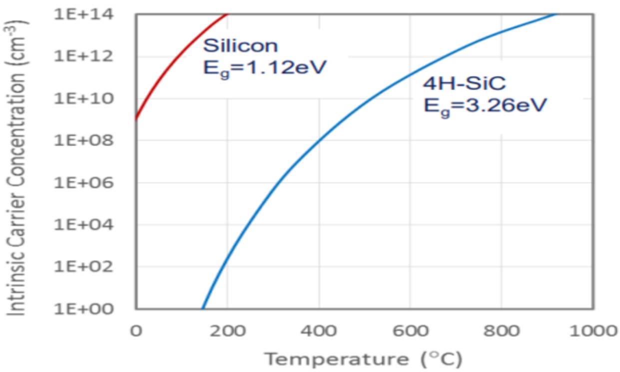


Figure 1. Temperature sensitivity of intrinsic carrier concentration for Si and 4H-SiC

Intrinsic carrier concentration of semiconductor material is temperature dependent [8-10]. The plot of temperature sensitivity of intrinsic carrier concentration for Si and 4H-SiC has been shown in Figure 1. For the hardware implementation of power converter system comprises of different parts such as (a) power converter circuit with load, (b) control IC, and (c) gate driver IC. Power converter circuit is made up with SiC MOSFET and the control circuit can be ASIC or a digital processor i.e. DSP, microcontroller or FPGA [11-15]. Most of the digital processor have voltage level of 5V, 3.3V or 1.8 V. The other important component is gate driver. The main functionality of gate driver are as follows

a. Provide sufficient current or voltage control signals for power switching devices
b. Provide isolation and protection for control IC from large signal swings of the power switching devices
c. Provide protection for power switching devices under certain condition

Figure 2 provides a comprehensive block diagram of gate driver IC and other auxiliary components which drive a switching power device.

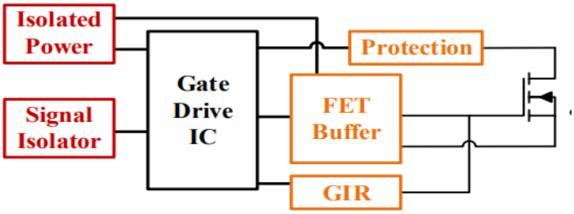


Figure 2. Block diagram of gate driver circuit

A detailed review of SiC-MOSFET and its associate gate driver system has been discussed in [4]. The failure modes of gate driver and reliability-based design of SiC MOSFET has been discussed in [5]. The design details of SiC MOSFET module for application over 1200 V has been discussed in [6].

This paper provides a detailed analysis of different gate driver topology required for SiC MOSFET. Different gate driver concept has been discussed along with their features. The functionality of Miller clamp circuit has been discussed which is used to mitigate any voltage spike in the gate terminal of the SiC MOSFET [9-14].

2. Design of Gate Driver for Power Converter

Figure 3 provides the schematic of direct gate driver where the gate terminal of MOSFET is connected with PWM controller using simple devices such as zener diode, inductor, capacitor and resistance. Figure 4 provides the totem-pole gate driver which provides bidirectional current capability. Totem-pole gate driver provides better performance than direct gate driver.

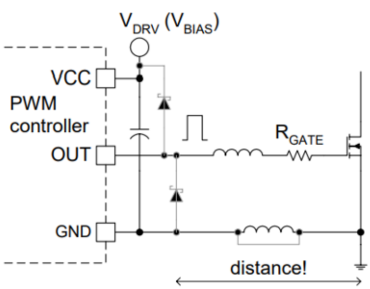


Figure 3. Circuit diagram of direct gate driver circuit

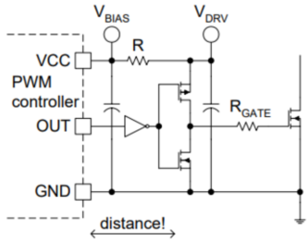


Figure 4. Circuit diagram of totem-pole gate driver circuit

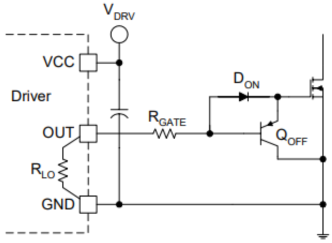


Figure 5. Gate driver circuit with dv/dt protection

Figure 5 provides the dv/dt protection concept for a power switching device where a BJT and diode are connected to the switching circuit to protect the adverse effect of dv/dt. Figure 6 provides the gate driver design for driving p-channel MOSFET whereas Figure 7 provides bootstrap implementation of gate driver.

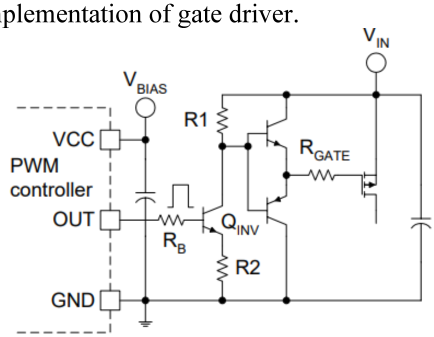


Figure 6. Block diagram of p-channel gate driver circuit

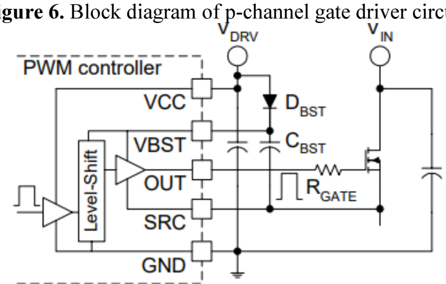
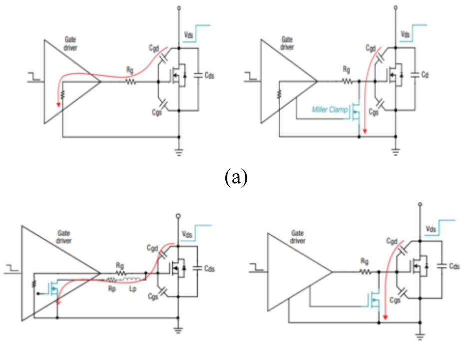


Figure 7. Block diagram of bootstrap gate driver circuit

3. Miller Clamp in Gate Driver

To suppress the unintentional voltage spike, the concept of miller clamp is used. The miller clamp may be internal to the gate driver or an external device. The voltage spike is produced due to parasitic capacitance involved in the power MOSFET. There are three parasitic capacitances involved in the MOSFET. Figure 8 shows the effect of miller clamp in gate driver and how miller clamp is used to mitigate the voltage spike. The active or passive miller clamp improves the reliability of the power MOSFET.



(a)

(b)

Figure 8. Miller clamp in gate driver (a) withoiut miller and with external miller clamp, (b) internal and external miller clamp

4. Conclusion

This paper provides design details of gate driver for SiC MOSFET. Different configuration of gate drivers and features of these gate drivers have been discussed in this work. The use of miller clamp circuit to mitigate the unwanted voltage spike and crosstalk voltage in the gate terminal of SiC MOSFET has been discussed. Different type of miller clamp such as active miller clamp and passive miller clamp has been discussed in this work. Different high-performance semiconductor devices are entering the market as a result of the rapid growth of semiconductor technology. Engineers have produced silicon carbide (SiC) MOSFET and the junction barrier schottky diode (JBS) commercially. SiC MOSFETs outperform Si-based power devices. SI MOSFET has a voltage and current rating significantly lower than that of SiC MOSFET.

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