Quasi-Resonant Controller BD768XFJ-LB for 1700V SiC MOSFET

Design Considerations on the Gate Driving Circuit of Quasi-Resonant Controller for 1700V SiC MOSFET

Introduction

With the Increasing demand for SiC (Silicon Carbide) MOSFETs, High Voltage Super Junction MOSFETs and IGBTs are giving way to SiC MOSFETs in a variety of applications where faster switching speeds and higher breakdown voltages are required, and additionally, the size of the system matters accordingly. However, designing the gate driving circuit for a SiC MOSFET should be approached in a way that differs from the conventional Silicon Power Device, because the operating range of the gate source voltage is different from Si MOSFETs and IGBTs. In this Application Note, we will discover SiC MOSFET switching characteristics, how to optimize them with the Quasi Resonant controller in the line-up of Rohm Power Management IC ACDCs, and finally attempt to design a circuit with a calculation example.

Characteristics of SiC MOSFETs

SiC MOSFETs have lower R_{dson} than Silicon MOSFETs. SiC MOSFETs are made with dielectric breakdown field strength, much higher than Silicon MOSFETs. In some high-voltage devices it is possible to place a thinner drift layer that determines R_{dson}, so that R_{dson} is lower in SiC MOSFETs in comparison to Silicon MOSFETs, if the chip size is the same. The SiC MOSFET has further advantages when used as an IGBT replacement: The IGBT has a good cost performance with higher breakdown voltage and lower resistance, but the parameters of both E_{on} an E_{off} have to be taken into account when designing a driver to reduce switching loss, and lower switching speed limits the IGBT to usage in high switching applications only. In contrast, the SiC MOSFET is also a majority carrier device and E_{on}, E_{off} are no longer an issue, such that it can cover most of the playfield where IGBT has been playing so far. SiC MOSFET can operate with less loss at higher temperatures. Unlike Silicon devices, whose R_{dson} is higher and shows sudden jumps as the drain source voltage (for IGBT, Collector-Emitter voltage) increases, the R_{dson} of SiC devices performs better in Vd-Id characteristics, as shown in Fig1. This phenomenon is intensified as the operating temperature rises. The slope of Vd/Id corresponds to R_{dson}; at 150°C the slope is not as steep as it is at 25°C. The change of R_{dson} by temperature increase in SiC MOSFETs is less significant than in Silicon devices. In the case of IGBTs, experience has shown that the efficiency in the lower Vd and Id area is not good, as seen in Fig 1, so IGBTs are more suitable for high power applications. SiC MOSFETs, on the other hand, have a good efficiency in a wide power range of applications.

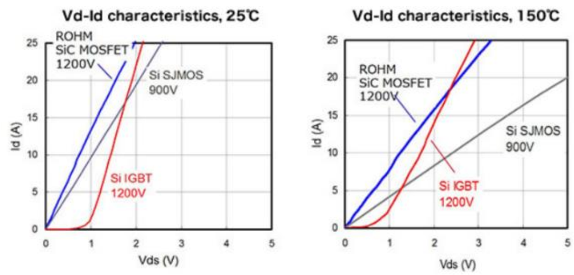

Fig.1: Vd-Id Characteristics at 25degC (left) vs 150degC (Right)

Design Considerations on the Gate Driving Circuit of SiC MOSFET

As mentioned previously, the SiC MOSFET has a thinner drift layer, meaning a lower R_{dson}, whereas it has a higher channel resistance. Therefore, there is an obvious necessity to bring V_{gs} (gate source voltage) above a certain level in order to drive the device; preferably for SiC MOSETs as high as 18V is reasonable, as the slope of R_{dson} per V_{gs} at 18V to 20V becomes less variable and remains at the minimum value, regardless of the operating temperature as seen in Fig 2. This is one of the aspects where IGBTs differ from Si MOSFETs, where V_{gs} = 10V to 15V is applied, and it is an important point when optimizing a gate driver with SiC MOSFETs.

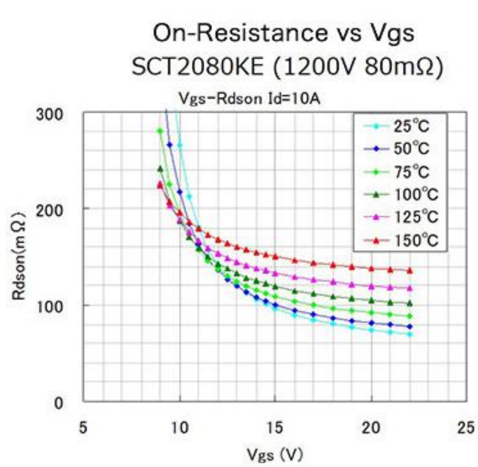

Fig. 2: Rdson – Vgs Characteristics SCT2080KE

Apart from the fact that SiC MOSFETs require higher V_{gs} voltages for full driving mode, making use of negative V_{gs} tends to be interesting for some applications. This is because SiC MOSFETs have comparatively lower thresholds of V_{gs}. The low-side FET in the bridge model is usually turned ON, forced by the input capacitance C_{gd}, and so-called 'shoot-through' occurs due to the lower V_{gs}, even when its status is OFF and High Side FET status is ON. Thus, both high and low sides are ON simultaneously, and consequently they are damaged by the higher current. However, system damage can be avoided by driving negative voltage on the gate driving circuit, and this improves the turn-OFF behavior as well. That is the reason why a suitable gate driver IC is required for SiC MOSFETs. The switching speed of SiC MOSFETs can be faster or slower by adjusting the external gate resistors. Lower resistances lead to faster device switching, however, the internal resistance of SiC MOSFETs is generally very high due to small chip size in contrast with silicon device chips. On the other hand, the gate capacitance (Qg) is lower. As the parameters Qg, R_{g_in} and R_{g_ex} determine the switching speed for the circuit, they should be understood prior to taking on the gate driver design with SiC MOSFETs.

The basic steps to design gate driving circuits with turn-off Schottky diodes and BD7682FJ-LB are introduced here:

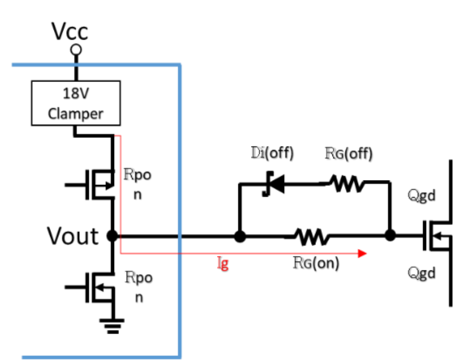

Fig. 3: Gate Circuit with BD7682FJ-LB

Define the gate resistor $R_{G(on)}$ & I_g according to equation(1):

Equation (1)

$$R_{on} = R_{pon} + R_{G(on)} = \frac{V_{CC} - V_{gs(th)}}{I_g}$$

$$I_g = \frac{Q_{gs} + Q_{gd}}{t_{sw}}$$

$$R_{G(on)} = \left(V_{CC} - V_{gs(th)}\right) \times \frac{t_{sw}}{Q_{gs} + Q_{gd}} - R_{pon}$$

Ig: Gate current to SiC MOSFET (A)
Qgs: Charge of gate and source of SiC MOSFET (nC)
Qgd: Charge of gate and drain of SiC MOSFET (nC)
Rpon: ON resistance of PMOSFET (Ω)
Vgs(th): Threshold voltage of SiC MOSFET (V)
tsw: Switching time (nS)

Note: t_{SW} is the time it takes to reach the end of the plateau voltage and 1~2% of the switching period.

The turn-on speed can be controlled by adjusting $R_{G(on)}$ and t_{sw} is induced from the switching frequency of the gate driving circuit. Selecting a turn-off gate resistor, on the other hand, should be taken well into account for C_{gd} (capacitance of the MOSFET's gate drain), as the gate current flows into C_{gd} at the turn-on stage, so it is fully charged. If the value is set too high for the turn-off resistor, and the turn-off speed is slow, V_{gs} begins to rise to the threshold and the 'shoot-through' occurs across the devices in the bridge model. However, as already mentioned, in a single-MOSFET model with a flyback topology, 'shoot-through' does not occur, so this is not applicable to this case. Nonetheless, it is meaningful to design the turn-off gate resistor with a Schottky diode to improve the switching-off speed. The next step in designing a turn-off gate resistor is shown in equation (2):

Equation (2)

$$V_{gs(th)\_min} = \left(R_{non} + R_{G(off)}\right) \times I_g$$
$$= \left(R_{non} + R_{G(off)}\right) \times C_{gd}\frac{dVout}{dt}$$

$$\frac{dVout}{dt} = \frac{Ig}{Cgd}$$

$$R_{G(off)} = V_{gs(th)\_min} \div C_{gd}\frac{dVout}{dt} - R_{non}$$

Rnon: ON Resistance of NMOSFET (Ω)
Vout: Output terminal voltage of BD7682FJ-LB (V)
Cgd: Capacitance of Gate and Drain of SiC MOSFET

If $R_{G(off)}$ is set too low, Turn-off voltage overshooting may occur due to high di/dt on the switching device. A Schottky diode is reasonable in order to speed up the turn-off transients; the recommended rated reverse voltage and forward current are larger than V_{gs} and I_g, respectively.

In the meantime, since a gate loop exists along the path where the gate current flows, the loop should be designed as short as possible to minimize parasitic inductance effects on the circuit.

Introduction of BD768XFJ-LB

The BD768XFB-LJ series is a group of Quasi-Resonant (QR) controllers. QR controllers offer a popular driving method for flyback topologies across middle to lower power applications. The advantage of the QR is the soft switching that is enabled by its internal logic to determine a switch-on point. As input voltage and load current vary in a system, the switching frequency varies accordingly, and the controller catches a point where voltage ringing in the drain source of the switching device is at its lowest and decides to switch on at a desired point. Hence, switching loss is significantly lower compared with PWM controllers as shown in Fig 4.

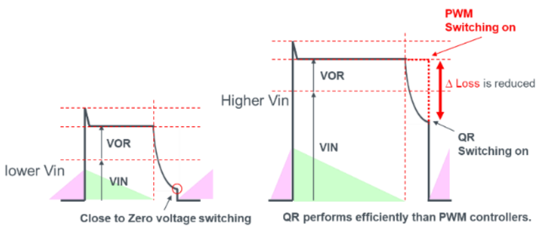

Fig 4. QR Drain Source Voltage Waveform analysis

In the case of a flyback topology, instead of the double switching devices in series, which are acceptable to support higher input voltages up to 900VDC, the single switching device is reasonable here thanks to the 1700V SiC MOSFET. The bridge circuit is not required in this case, but there still is a need for either a Schottky diode or a PNP transistor to accelerate the turn-off speed. Once the IC is started up successfully, VCC begins to supply voltage to the IC via auxiliary windings$_{tart}$). The gate voltage of BD768XFJ-LB is supplied partially from auxiliary windings (VCC voltage) and clamped to 18V_typ by an internal 18V clamp (Fig 5. Block Diagram of BD768XFJ-LB). The IC provides an operation voltage range of 16V to 20V. By clamping it to 18V internally, no additional clamping circuit for Over-Voltage Protection (OVP) is needed and VCC UVLO is achieved by an internal voltage comparator with reference to 14V. Therefore, BD768XFB-LJ is a suitable solution to drive SiC MOSFETs whose gate voltage is designed up to 22V. (Rohm SiC MOSFET SCT2H12NZ, TO-3PFM)

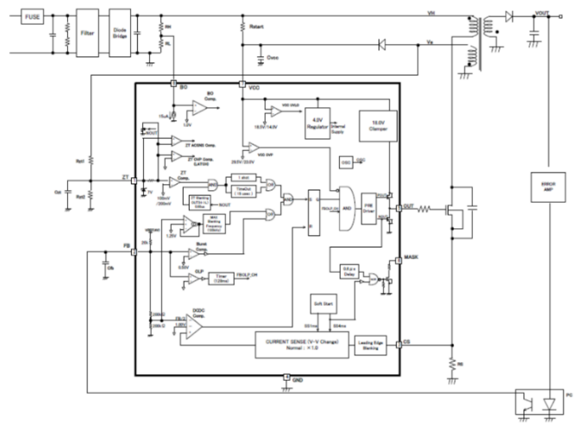

Fig 5. Block diagram of BD768XFJ-LB

Design Example of Gate Driving Circuit

SCT2H12NZ (1700V, 1.15Ω_typ) and BD7682FJ-LB are selected for the design. The required Parameters are as follows.

BD7682FJ-LB (QR Controller, Rohm)

Vout: 18V

Rpon: 15Ω

Rnon: 4.6Ω

SCT2H12NZ (1700V, 1.15Ω_typ, Rohm)

Vgs(th)_min: 1.6V

Vgs(th): 4.0V

Qgs: 4nC

Qgd: 5nC

Cgd: 6pF

t_{sw} is set to 100ns, since this equals 1% of the switching frequency of the gate driving circuit, which is set to 100kHz as a rule of thumb.

$$I_g = \frac{Q_{gs}+Q_{gd}}{t_{sw}} = \frac{4nC+5nC}{100ns} = 90mA,$$

$$R_{G(on)} = \left(V_{CC} - V_{gs(th)}\right) \times \frac{t_{sw}}{Q_{gs} + Q_{gd}} - R_{pon}$$

$$= \frac{18V - 4V}{90mA} - 15\text{W} = 140.5\text{W}$$

$$\frac{dVout}{dt} = \frac{Ig}{Cgd} = \frac{90mA}{6pF}$$

$$R_{G(off)} = V_{\text{gs(th)}\_min} \div C_{\text{gd}} \frac{dVout}{dt} - R_{non}$$

$$= 1.6V \div 90mA - 4.6\text{W} = 13.2\ \text{W}$$

The Schottky diode is RB160M-60 (60V, 1A). Rated reverse voltage and forward current of the diode are reasonable for this circuit. A pulldown resistor 10kΩ is added across gate and source for the MOSFET. As an initial gate driver for SCT2H12NZ, the 1700V SiC MOSFET is designed with BD7682FJ-LB in Fig 6.

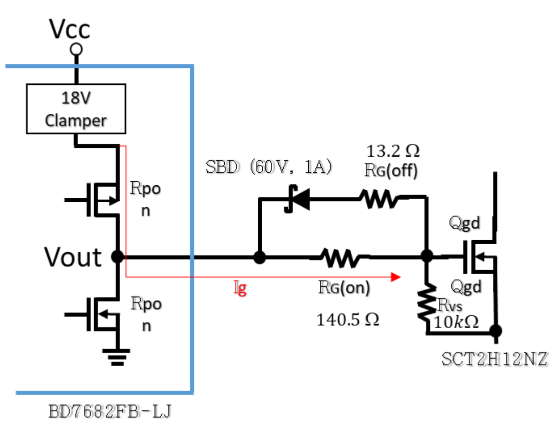

Fig 6. Gate Driver for SCT2H12NZ with BD7682FJ-LB

Finally, if over/undershooting voltage exists, the waveform should be observed on both turn-on and turn-off, since the switching behavior may be affected by the values of the gate resistors.

Conclusion

A gate driving circuit is very demanding and the design process entails many pre-conditions for drawing the circuitry. What is the target switching frequency? Is the switching frequency suitable for the system? What kinds of switching devices are to be used? Is there protection such as gate voltage UVLO/OVP and thermal design? In this article, some fundamental points essential to the driving circuit and device, especially SiCs, were discussed. Rohm's DCDC converter solution to 1700V SiC MOSFET was introduced and an example of how to build up the gate driving circuit with BD768XFJ-LB was shown. For further information on datasheets as well as evaluation boards of BD7682FJ-LB and SCH2H12NZ, please visit ROHM's homepage.

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Reference

(1) Application Note 'SiC Power Devices and Modules', Rohm

(2) User Guide for BD7682FJ-LB-EVK-302 Evaluation Board, Rohm

(3) BD768XFB-LJ Datasheet, Rohm.

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