Application Note

Extremely compact, Isolated Gate Driver Power Supply for SiC-MOSFET (6 - 10 W)

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1 Introduction

Wide bandgap power semiconductor devices like Silicon Carbide (SiC) MOSFETs are enjoying growing popularity in many modern power electronic applications like E-mobility and renewable energy. Their extremely fast switching speed capability helps to increase efficiency and reduce the overall size and cost of the system. However, fast switching together with high operating voltages and increasing switching frequencies presents important challenges to the gate driver system. Rugged galvanic isolation, compliance with safety standards, control signal noise immunity and EMI performance are just some of the most important aspects to consider. An optimal design of the isolated auxiliary supply providing the voltage and current levels to drive the SiC/GaN device is critical to help the full gate driver system meet the many requirements set by state-of-the-art applications.

2 Overview and requirements for gate control of HV SiC / GaN FET devices

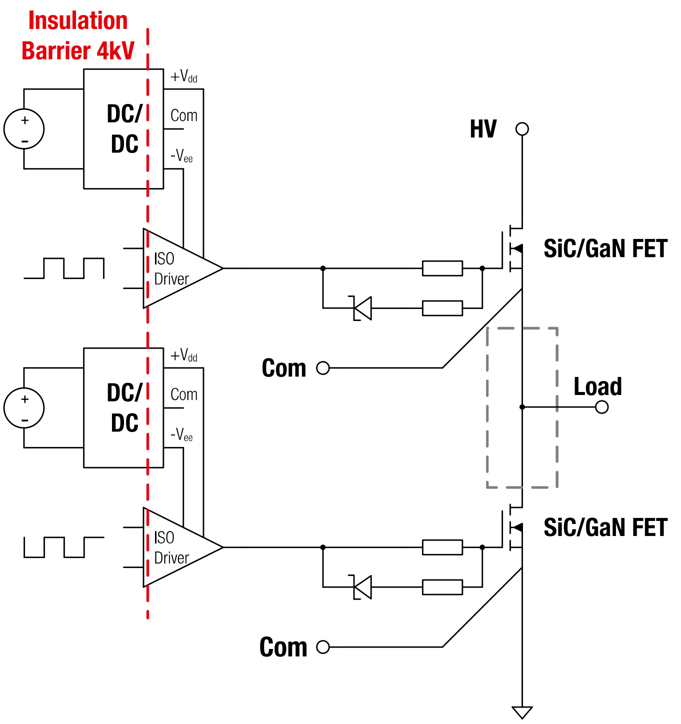

Figure 1: Overview of a HV half-bridge control of the High-side & Low-side SiC-MOSFET.

In applications using SiC/GaN high-voltage semiconductor devices under hard-switching operation, galvanic isolation is a common requirement for safety and functional reasons, and depending on the application, a basic or a reinforced insulation will be required. The operating voltage, insulation material, pollution degree and the applicable regulatory standards set the minimum creepage and clearance distances as well as the dielectric isolation voltage requirement affecting the components placed across the isolation barrier. The high-speed isolated gate driver IC (e.g. TI UCC21520) and the transformer in the isolated auxiliary power supply (DC/DC Block in figure 1) both 'bridge' this isolation barrier, thus having to meet stringent safety and functional requirements.

Some of the latest SiC-MOSFET devices require typical gate voltages of +15 V for full turn-on and -4 V for reliable turn-off. For a GaN-FET usually only +5 V and 0 V are required respectively, although a small negative voltage can also be applied to ensure turn-off in presence of excessive gate voltage ringing. Please note that these values may vary depending on manufacturer. In figure 1, a half-bridge configuration is shown, and several of these stages are typically required in an inverter circuit to drive AC-motors in the kW range. Each SiC/GaN FET would require an independent gate driver stage with its own isolated auxiliary supply. This not only enables individual control of each SiC/GaN device, but also helps to keep the gate current loop small and local to the device, minimizing the adverse effects of parasitic loop inductance and ground bounce caused by the very high ΔI/Δt generated during the switching transition (figure 2 and figure 3).

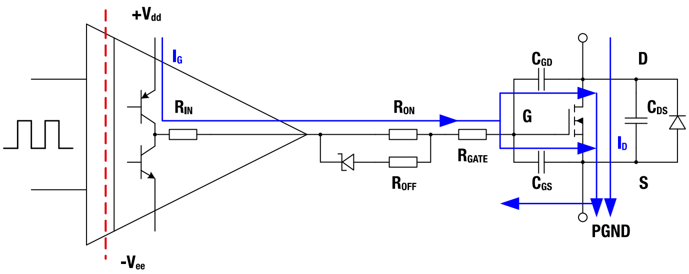

Figure 2: High ΔI/Δt current paths on turn-ON of SiC/GaN FET.

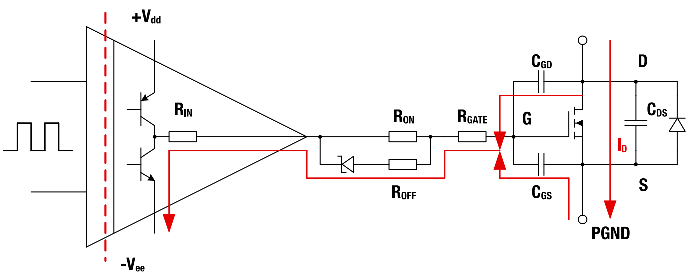

Figure 3: High ΔI/Δt current paths on turn-OFF of SiC/GaN FET.

Otherwise, this may cause uncontrolled turn-on/off of the MOSFET and thermal issues. Some SiC MOSFETs are designed with an additional low impedance Kelvin source connection (figure 4) for a gate current return path. This connection does not carry the high switching current and therefore has a lower interference potential than the source connection, which significantly improves gate driving. (e.g. Infineon IMZ120R045M1 1200 V / 52 A),

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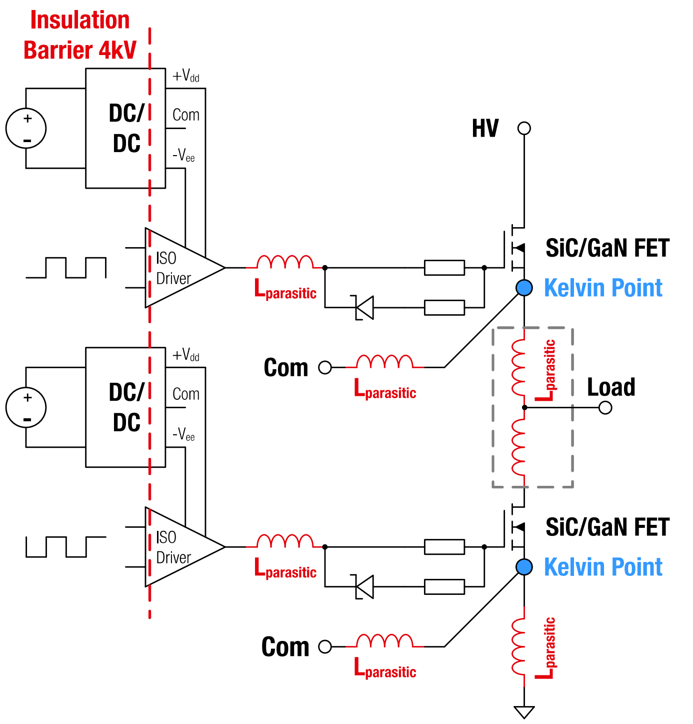

Figure 4: Kelvin connections and critical parasitic inductances in a half-bridge configuration.

Regarding the auxiliary supply, it should be compact with its output capacitors (with minimal ESL and ESR) placed very close to the gate driver and SiC/GaN device to minimize the gate current loop and associated parasitic effects.

3 Requirements of the Isolated Gate Driver Power Supply for SiC-MOSFETs

There is currently a large selection of compact, isolated 1 – 2 W DC/DC converters available on the market. For a SiC-MOSFET like the Infineon IMZ120R045M1 1200 V / 52 A, up to 1 W power requirement per device can be estimated (see example calculation (1)). However, an application with over 5 kW load power would require the use of either a SiC-MOSFET module (e.g. ROHM BSM600D12P3G001 1200 V / 600 A) or alternatively several discrete SiC-MOSFETs in parallel (current sharing). In a module solution, several semiconductor dies are paralleled to form the final SiC-MOSFET. This technique reduces the effective $R_{DS(ON)}$ but results in a very high "Total Gate Charge", which places a higher power requirement on the gate driver system power supply (example calculation (2)). Above 2 W of power, there is only a very limited selection of off-the-shelf isolated DC-DC converter modules, which despite their convenience, are often large, weighty, expensive and with efficiencies lining under 79%.

$$P_{GATE} = P_{Driver} + (Q_{Gate} \cdot F_{SW} \cdot \Delta V_{Gate})$$

P_{Gate}	Total power required to drive the SiC device gate
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P_{Driver}	Power loss in the gate driver section (approx. 0.3 W)
Q_{Gate}	Total Gate Charge value (from datasheet)
F_{SW}	Maximum switching frequency
ΔV_{Gate}	Maximum voltage swing at the gate from $-V_{ee}$ to $+V_{dd}$ (e.g. -4 V to +15 V = 19 V)

Example calculation (1) with Infineon IMZ120R045M1 1200 V / 52 A:

$$P_{GATE} = 0.3\ W + (62\ nC \cdot 100\ kHz \cdot 19\ V) = 0.42\ W$$

Example calculation (2) with ROHM BSM600D12P3G001 1200 V / 600 A:

$$P_{GATE} = 0.3\ W + (1900\ nC \cdot 100\ kHz \cdot 19\ V) = 3.91\ W$$

The SiC-MOSFET modules currently available feature a total gate charge of 3000 nC. With an increase in the switching frequency or load power (requiring more paralleled SiC-devices with the corresponding increase of the total gate charge), 6 - 10 W of driver system power can be expected for the most demanding present and near-future applications.

Amongst the solutions available meeting the above specification, one of the best 6 W isolated converter modules on the market currently has the following specification:

- Input voltage range: 9 – 18 V
- Output voltage: +15 V / -5 V @ 6 W
- Size: 40 x 28 x 9 mm
- Efficiency: 76 - 79%
- Parasitic coupling capacitance: 15 pF
- Weight: 12 g
- Basic insulation for V_{Bus}: 800 V

Efficiency, weight and especially the parasitic coupling capacitance are often critical parameters in high-performance systems. Especially at higher switching frequencies of the converters and the resulting very steep switching edges, the harmonics must be capacitively decoupled between the converter output stage/gate driver and the system power supply, i.e. from the DC-DC converter.

The parasitic capacitance (C_P) between primary and secondary sides is mainly set by the interwinding capacitance of the DC/DC power transformer device. With latest SiC-MOSFETs switching at ΔU/Δt slew-rates of 100 kV/us, 10 pF parasitic capacitance across the barrier would cause a peak displacement current of 1 A which is coupled by the switching transistor across the isolation barrier. A high dielectric displacement current degrades the insulation barrier in the long run, disturbs the control signals and leads to common mode currents in the corresponding device, which can be seen as typical EMC problems.

$$I_P = C_P \cdot \frac{\Delta U}{\Delta t}$$

I_P electrical displacement current

C_P parasitic coupling capacitance

It is recommended to keep C_p in the auxiliary supply below 10 pF.

Würth Elektronik has addressed all these requirements and it is presenting an optimized solution with its new SiC gate driver power supply reference design.

4 Würth Elektronik Solution up to 6W (10W)

The high-performance bipolar isolated auxiliary power supply design of Würth Elektronik features the following specifications:

- Input voltage range: 9 - 18 V
- Output voltage: bipolar +15 V / -4 V or Unipolar 15 - 20 V
- Power up to 6 W
- Peak efficiency of up to 86% (83% @ 6 W)
- Parasitic coupling capacitance less than 7 pF
- Size: 27 x 14 x 14 mm (L x W x H)
  → Over 50% smaller than similar DC/DC converters currently on the market
- Weight: < 4 g
- Basic insulation for V_{Bus}: 800 V
- 4000 V_{rms} insulation voltage Pri-sec

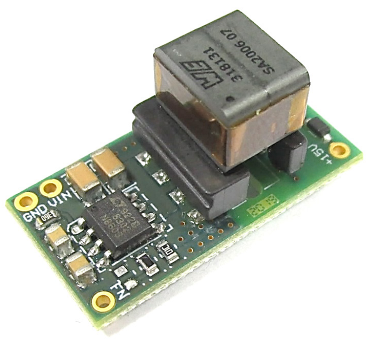

Figure 5: Würth Elektronik reference design for a compact, isolated DC/DC converter for HV SiC/GaN/IGBT Gate Driver

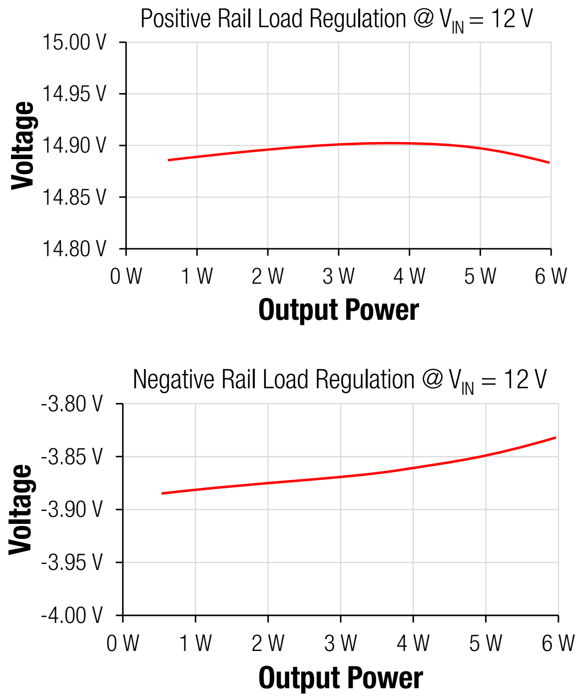

Figure 6: Voltage of Positive and Negative rails versus load power (@ V_{IN} (nominal) = 12 V)

In addition to the controller (Analog Devices), the key component in the design is the new power transformer (WE-AGDT-750318131). A compact EP7 customized package was used and optimized to meet the following requirements:

- Wide Input Voltage Range: 9 - 36 V
- High saturation current of 4.5 A
- Very low interwinding capacitance typ. 6.8 pF
- Very low leakage inductance for highest efficiency
- SMD Pick & Place ready
- Creepage & Clearance distance min. 5 mm
- Safety Standard IEC-62368-1, IEC-61558-2-16
- Basic Insulation
- Dielectric Isolation min. 4 kV AC
- Temperature Class B 155 °C
- AEC-Q200 Qualification

A comprehensive reference design document **RD001** is available for download (6 W bipolar solution for SiC-MOSFET), alongside with the corresponding PCB Layout design files.

Please note that the power capability can be easily scaled to 10 W with an EP10 transformer core and appropriate uprating of some components.

The new **WE-AGDT** Gate Driver Transformer series from Würth Elektronik features six different transformers, each of them optimized for different specifications and their own reference design. These transformers offer flexibility, ease of use and a combination of bipolar and unipolar output voltage rail options, covering the gate-drive requirements not only of state-of-the-art SiC-MOSFETs, but also GaN-FETs and widespread silicon IGBT and power-MOSFET devices.

5 Summary

With the new transformer series WE-AGDT, Würth Elektronik is demonstrating its innovative strength addressing the future challenges in the field of power electronics. For the first time, the developer has the possibility to easily implement a compact and efficient gate driver supply with up to 6 W output power capability and top performance.

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