EVAL-FFXMR12KM1DR user guide

Evaluation board for 1200 V CoolSiC™ MOSFET 62 mm half-bridge modules

About this document

The purpose of this board is to enable the evaluation of the FF6MR12KM1, FF3MR12KM1 and FF2MR12KM1 CoolSiC™ MOSFET modules. The evaluation board allows users to evaluate the device performance via double-pulse measurements.

Scope and purpose

The properties of this board are described in the design features' chapter of this document. The remaining sections provide information to enable designers to copy, modify and qualify the design for production, according to the customer-specific requirements.

Environmental regulations have been considered in the design of the EVAL-FFXMR12KM1DR board. Components qualified for a lead-free, reflow soldering process have been selected. The design has been tested as described in this document, but not qualified regarding manufacturing and operation over the whole operating temperature range or lifetime.

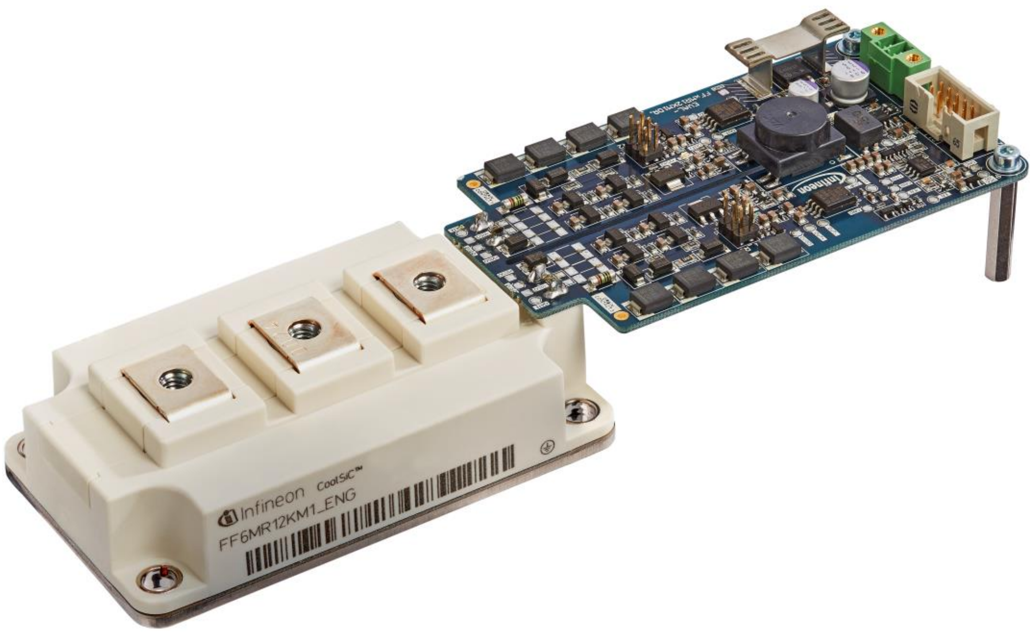
Intended audience

This document is intended for engineers who want to document and evaluate the switching performance of Infineon CoolSiC™ 62 mm modules.

Evaluation board

This board will be used during design-in, for evaluation and measurement of characteristics, and proof of datasheet specifications.

Note: *PCB and auxiliary circuits are NOT optimized for final customer design.*



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	Warning: *The DC link potential of this board is up to 1000 V_{DC}. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	Warning: *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Caution: *Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.*
	Caution: *The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	Caution: *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

Table of contents

1 The board at a glance

An industrial benchmark technology in a 62 mm package, the CoolSiC™ Trench MOSFET opens and enlarges the semiconductor module market for high-volume applications. CoolSiC™ Trench MOSFETs allow modern inverter designs with never-before-seen levels of efficiency and power density. The evaluation board allows the customer to begin initial characterization measurements very quickly.

1.1 Delivery content

The board appears as shown in Figure 1. It is important to note that the gate resistors are left empty to be equipped with individual values in line with the customer's needs. The recommended resistor type is shown in Chapter 2.2. A suitable connection of the active-clamp solder pins has to be established to use this function and make the device safe in case of an overvoltage event at turn-off.

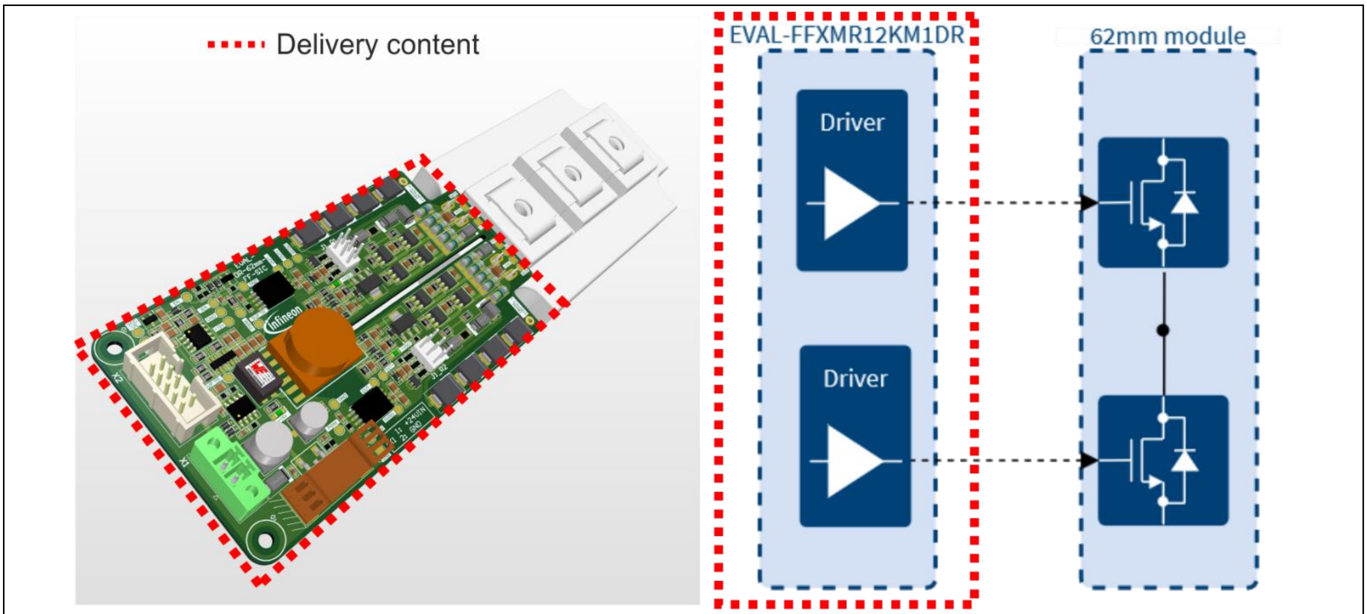

Figure 1 EVAL-FFXMR12KM1DR connected to a 62 mm CoolSiC™ Trench MOSFET moduleBlock diagram

1.2 Main features

- Half-bridge driver for 62 mm modules with CoolSiC™ Trench MOSFET technology
- Electrically and mechanically suitable for 600 V 62 mm modules with CoolSiC™ Trench MOSFET technology
- Negative voltage adjustment from -5 V to 0 V
- Positive voltage adjustment for high switching frequencies
- Proper PCB design to limit the PCB heating during operation

1.3 Typical applications

- High frenquency switching applications
- DC/DC converter
- Solar application
- UPS systems

1.4 Board parameters and technical data

The EVAL-FFXMR12KM1DR is a gate driver board for driving 62 mm modules with our latest CoolSiC™ Trench MOSFET technology in a half-bridge configuration. It shows a reliable and fast controllability of such devices using the famous 1EDI20I12AH compact driver together with a booster stage to increase the driver output power.

The EVAL-FFXMR12KM1DR operates with a supply voltage of up to 24 V. It generates an output voltage of up to 18 V at the gate terminals, depending on the load conditions. To switch the device, a pulse width modulation (PWM) for both, the top and the bottom side need to be applied at the connector input. A negative signal at the enable pin turns off the device. The detailed description of the functional blocks is shown in the next chapter.

Table 1 Parameter

Parameter	Symbol	Conditions	Value	Unit
Input voltage	Vin		+24	V
PWM input for top switch	PWMTOP		0/+15	V
PWM input for bottom switch	PWMBOT		0/+15	V
Enable signal	ENABLE	Set to 0V to disable	0/+15	V
Negative gate source voltage	$V_{GS,neg}$		-5,9…0	V
Positive gate source voltage	$V_{GS,pos}$		+15…+18	V

2 System and functional description

2.1 Commissioning

The EVAL-FFXMR12KM1DR is powered up at the phoenix-MCV, two-pin connector as shown in Figure 2. The input signals are attached by using a 10-pin, flat cable connector. Further details about the pin connector are shown in Chapter 3.4.

Proper gate resistors need to be soldered onto the board, based on the customer switching conditions. A detailed explanation for selecting the suitable resistors is explained in the next chapter.

The module is soldered onto the gate terminals of the 62 mm module. A suited probe tip adaptor can be soldered next to the gate terminals to measure the gate source voltage (V_{GS}).

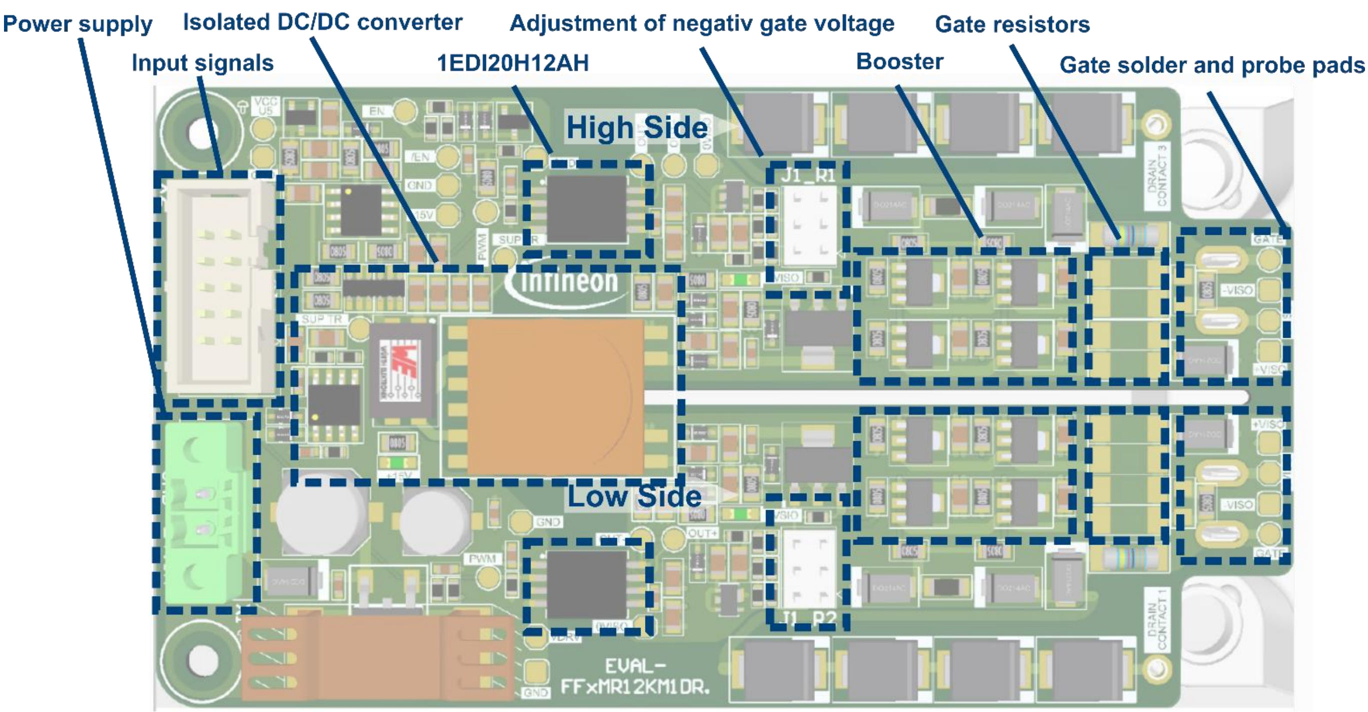

Figure 2 **Overview of the functional blocks of the EVAL-FFXMR12KM1DR**

2.2 Description of the functional blocks

The most important functional blocks are shown in Figure 2.

The on-board isolated DC/DC converter generates an output voltage of up to 18 V depending on the load conditions. The transformer used has a working voltage of 848 V_{rms}, providing a sufficient safety margin to handle our 62 mm devices. The positive voltage is fed to the secondary side of the driver circuit directly, whereas the negative voltage is adjustable from -5.9 V to -0.4 V by using the jumper settings shown in Figure 4.

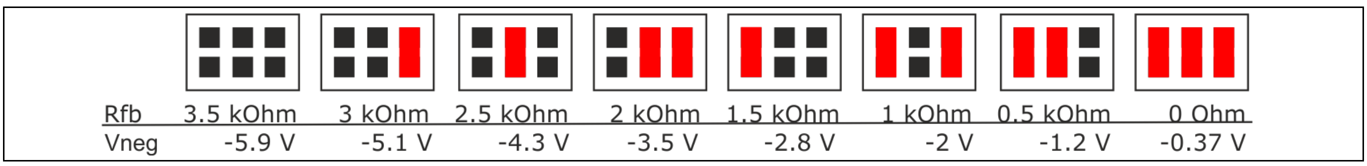

Figure 3 **Jumper settings for the negative voltage adjustment V_{neg}**

The adjustable output voltage (Vneg) can be calculated by the equation given in Figure 4.

$$Vneg = -1.25V * \left(1 + \frac{R2'}{R1'}\right) - 65^{e-6}A * R2 + 5V, where\ R2' = 2.2k\Omega + 390\Omega + Rfb$$

Figure 4 Equation to calculate *Vneg* for the negative gate voltage adjustments

The EVAL-FFXMR12KM1DR is equipped with the single-channel isolated gate driver 1EdI20H12AH. This compact driver has two input modes IN+ and IN- to control the switch. The PWM is connected to the IN+ pin, whereas the IN- pin is used for the enable signal. The enable signal can be used to switch off the device with an external signal that is set to low.

The output of the driver is connected to a push-pull booster stage to increase the output power of the driver stage. Further details about the design of booster stages can be found in *External Booster for Driver IC* [1].

The gate resistors are not included and need to be soldered on the board according to customer needs. Metal electrode leadless faces (MELF) packages are recommended, since they are very robust in terms of impulse currents, and offer a long-term reliability under thermal stress. Two resistors can be attached in parallel for both the external gate turn-on resistance ($R_{G,on}$) and the external gate turn-off resistance ($R_{G,off}$) signal path.

2.3 Active voltage clamping

Please make sure to also connect the drain sense contacts of the EVAL-FFXMR12KM1DR driver board as shown in Figure 5. This picture shows a vertical positioning of the driver board that is also possible in case other components, e.g. the DC link do not allow a horizontal placement of the driver that is close to the module.

Active clamping is used to keep the V_{DS} overvoltage below V_{DSS} when switching off the MOSFET. A series connection of TVS diodes is used to protect the device once an overvoltage occurs while turning off a short cicuit or overcurrent. During such an event, a current is shared between the gate of the MOSFET and the driver output once the overvoltage is exceeding the breakdown voltage of the diodes. This leads to an increasing gate source voltage and the turn off event is interrupted.

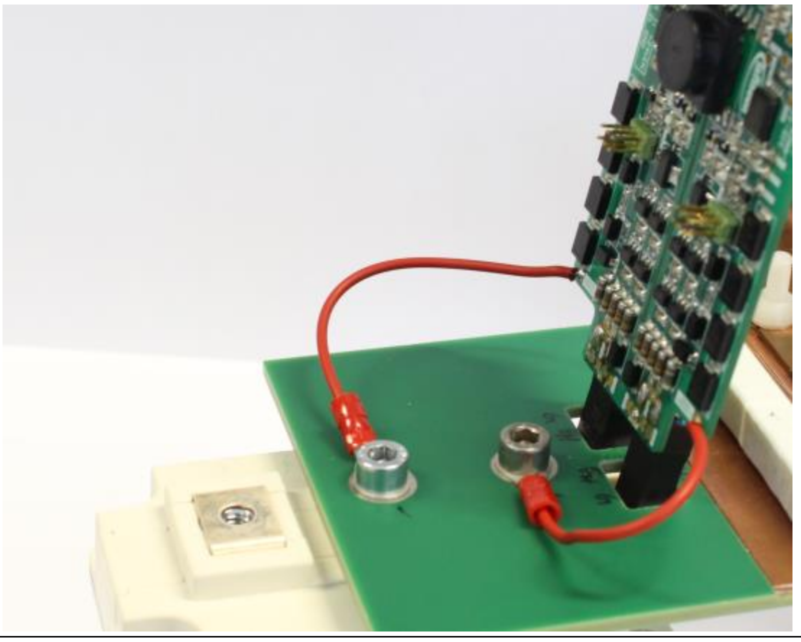

Figure 5 Example of a vertical connection and the drain sense connection of the driver board.

3 System design

The FFXMR12KM1DR is a simple driver board for evaluating the switching performance of our 62 mm module including our new CoolSiC™ Trench MOSFET technology. All functional blocks are designed to show a simple circuit approach to accommodate the best performance of our new SiC devices.

3.1 Schematics

The schematics that are shown here are just an excerpt from the entire documentation that can be found in the PCB design data of the EVAL-FFXMR12KM1DR board homepage at www.infineon.com.

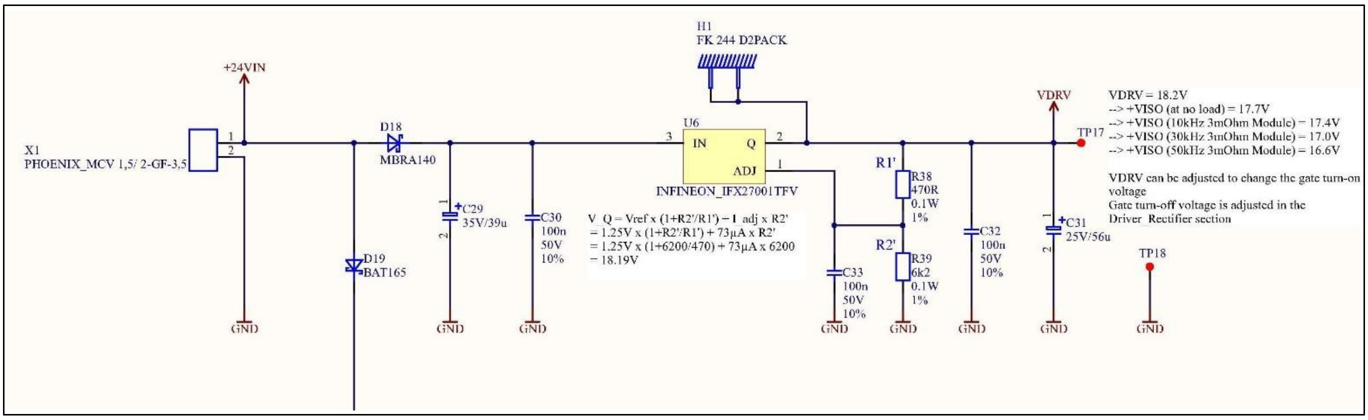

Figure 6 **Positive power supply VDRV**

The linear voltage regulator IFX27001 in a DPAK package is used to deliver an accurate supply voltage (VDRV), which is used as supply voltage of the push-pull stage at the isolated DC-DC converter. The positive voltage (VDRV) can be adjusted by the external voltage devider of R1′ and R2′ as shown in Figure 7. Please also see the datsheet of the IFX27001 for additional information. Please consider that the actual isolated supply voltage of the driver section (VISO) depends on the load conditions.

$$V_Q = \mathrm{Vref} * \left(1 + \frac{\mathrm{R2'}}{\mathrm{R1'}}\right) + \mathrm{I_{adj}} * R2'$$

Figure 7 **Calculation to set the positive output voltage of the IFX27001**

The widely-known IR2085S is used as half-bridge driver as shown in Figure 8. This approach can also be used to generate a galvanic isolation of two independent driver stages, e.g. of a full bridge or a 3-phase topology as shown in the CoolSiC™ MOSFET motor drives evaluation board for 7.5 kW [2].

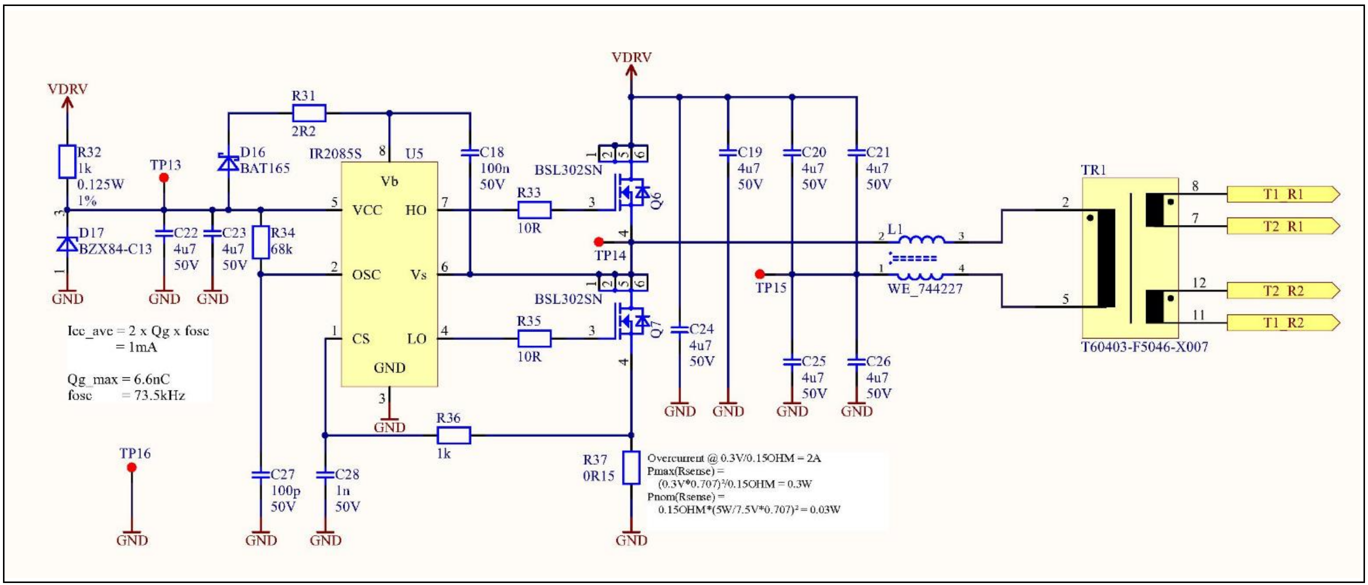

Figure 8 Isolated DC-DC converter using the IR2085S

3.2 Layout

The layer stack of the board consists of four layers, including the top, bottom and two internal layers. The top layer is used for the direct connection of signals of most of the components as shown in Figure 9. The bottom layer is used to feed in the negative output signals –VISO on the secondary side that is the driver output side of the board. The internal layers 1 and 2 are used to improve the driver output signals against noise as shown in Figure 11 and Figure 12. The internal layer 1 is used for the ground signal of the secondary side and to route the signals of the driver output to the booster stage. The Gerber and ODB++ files can also be accessed via the PCB design data tab of the EVAL-FFXMR12KM1DR board homepage at www.infineon.com.

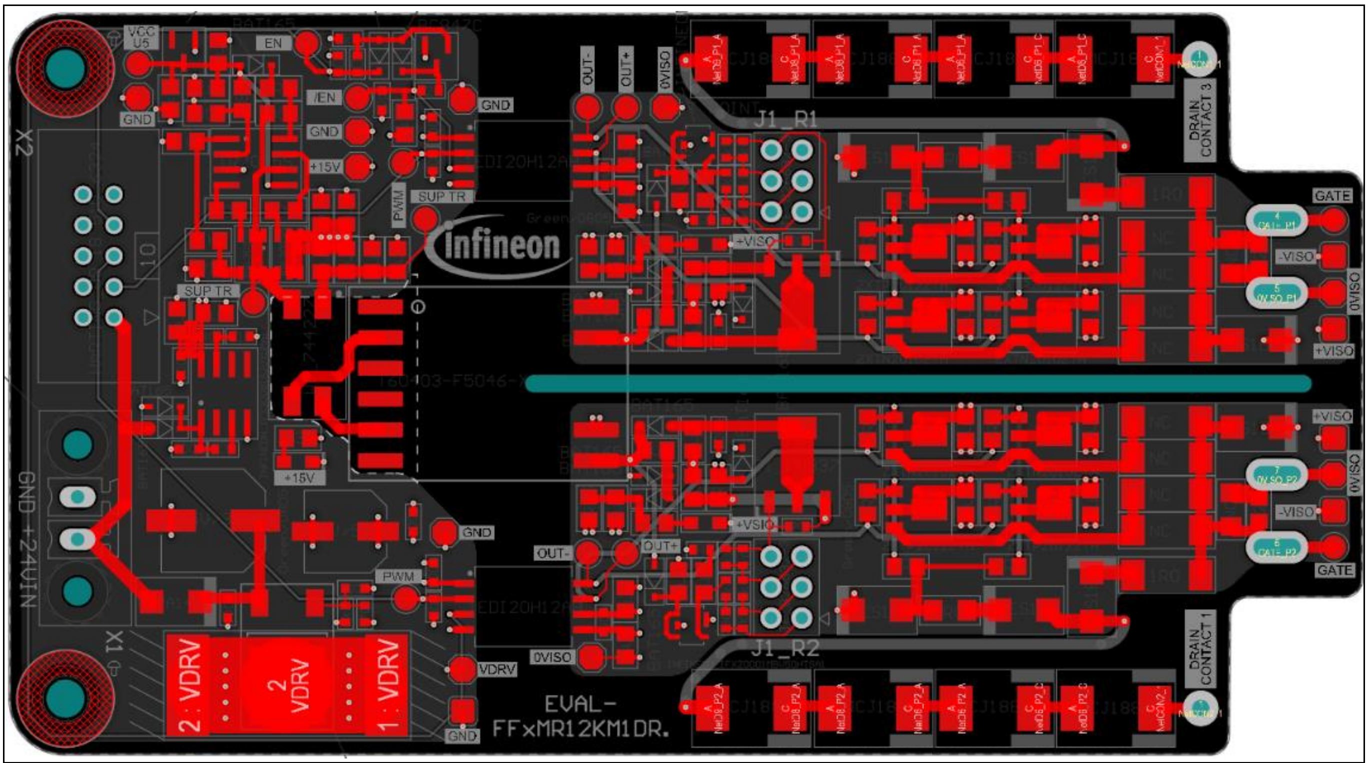

Figure 9 FFXMR12KM1DR with the top layer highlighted

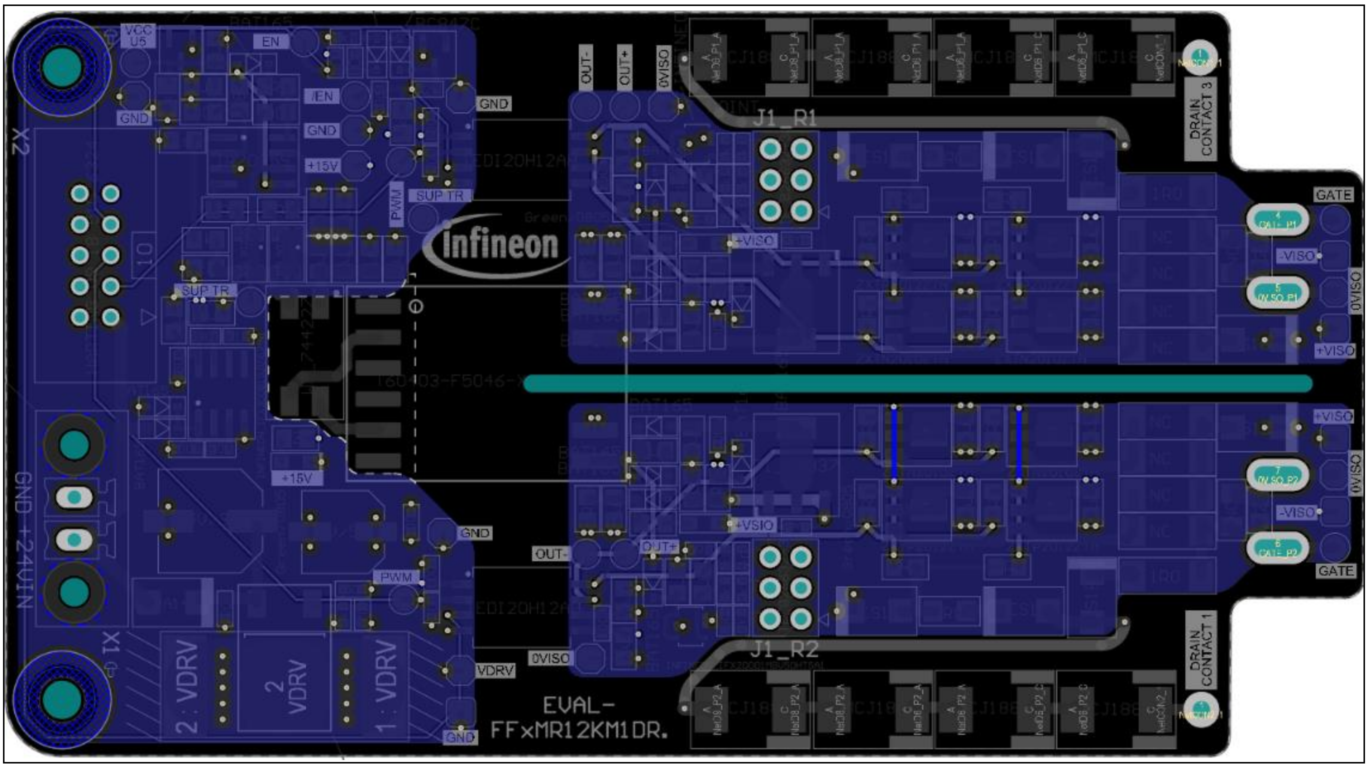

Figure 10 FFXMR12KM1DR with the bottom layer highlighted

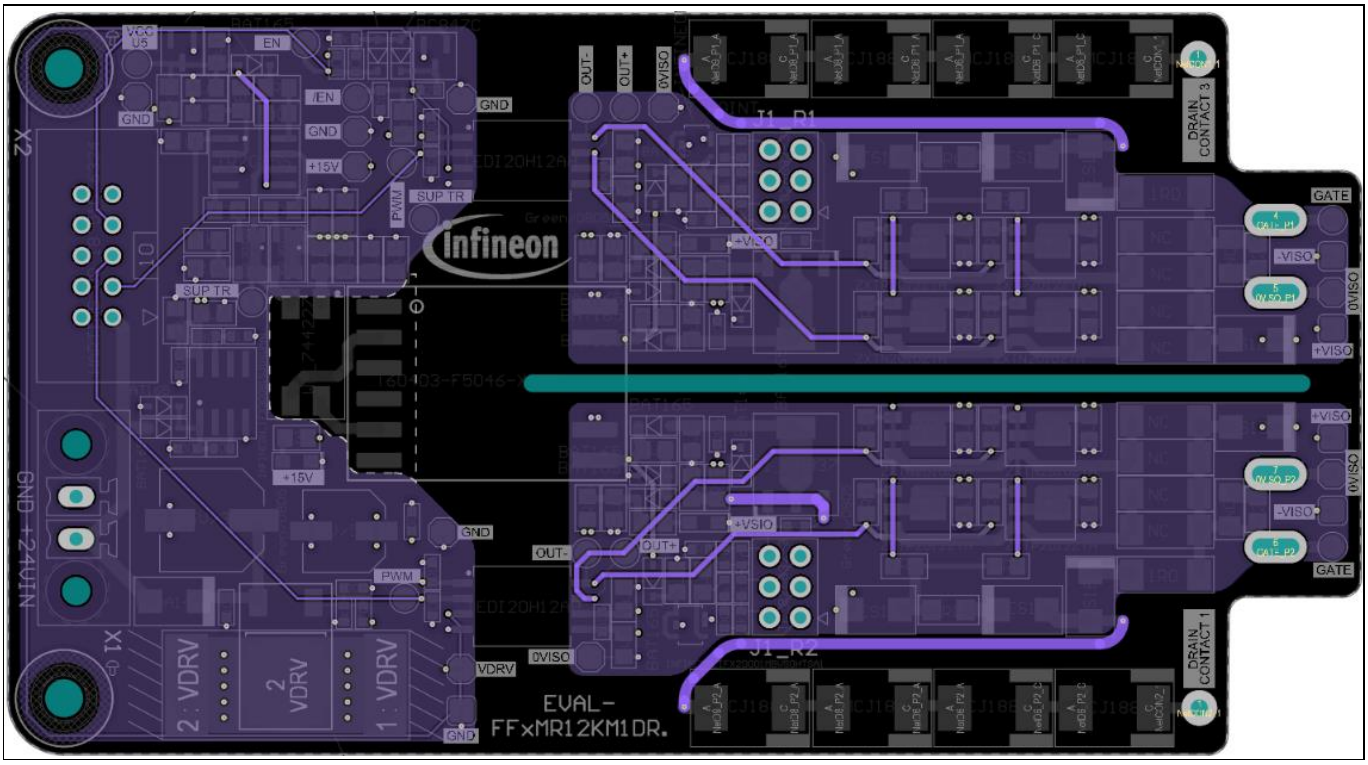

Figure 11 FFXMR12KM1DR with the internal layer 1 highlighted

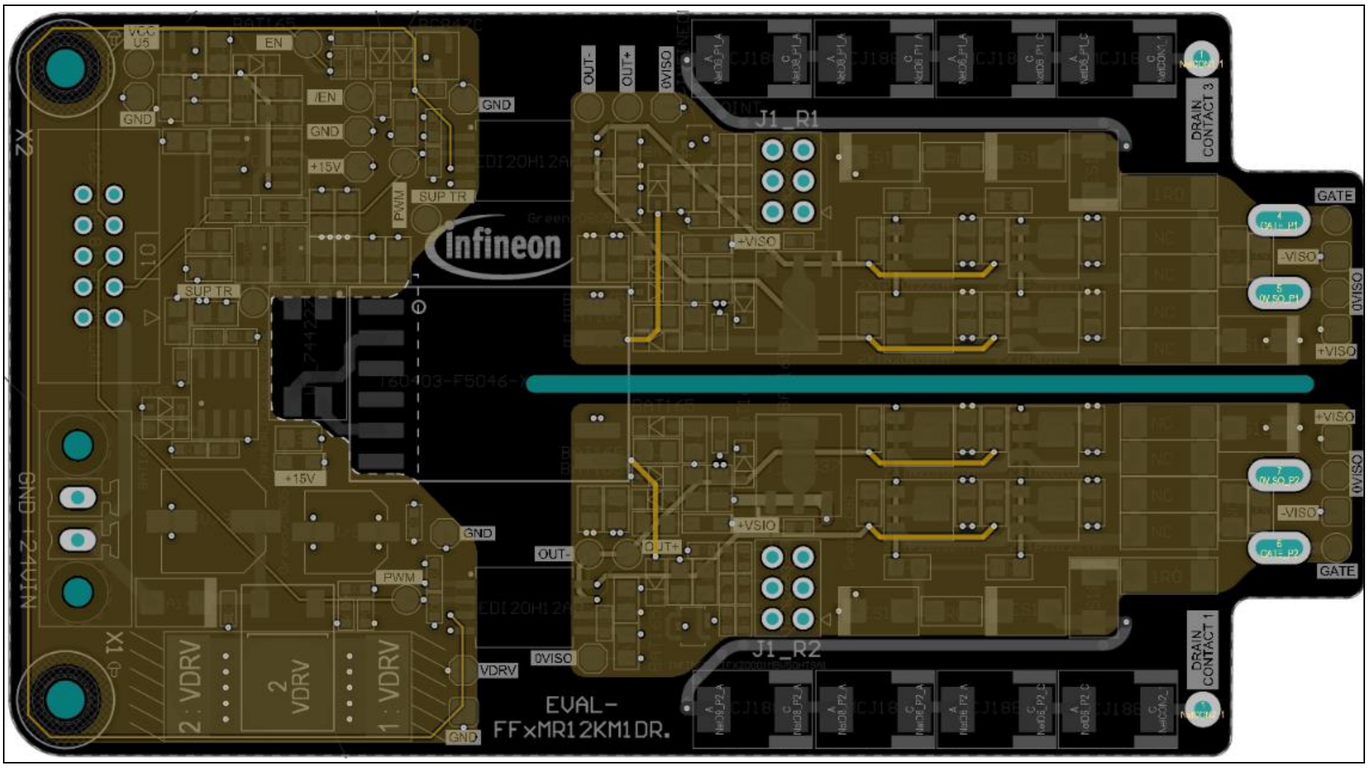

Figure 12 **FFXMR12KM1DR with the internal layer 2 highlighted**

3.3 Bill of material

Please see the most important components of the board in Table 2. Please note that the detailed BOM of the EVAL-FFXMR12KM1DR is available at www.infineon.com.

Table 2 **BOM of the most important/critical parts of the evaluation or reference board (example)**

S. No.	Ref Designator	Description	Manufacturer	Manufacturer P/N
55	U1	INFINEON_SiC_62mm_Module	Infineon	FF6MR12KM1
56	U2_R1, U2_R2	INFINEON_IFX20001MBV50HTSA1	Infineon	IFX20001MBV50HTSA1
58	U4_P1, U4_P2	INFINEON_1EDI20H12AH	Infineon	1EDI20H12AH
59	U5	IR2085S	Infineon	AUIR2085STR
60	U6	INFINEON_IFX27001TFV	Infineon	IFX27001TFV
61	U7	INFINEON_IFX30081SJVXUMA1	Infineon	IFX30081SJVXUMA1

3.4 Connector details

Table 3 **Connector X1**

PIN	Label	Function
X1.1	+24VIN	24 V input
X1.2	GND	Input ground

Table 4 Connector X2

PIN	Label	Function
X2.1	+24VIN	24 V output
X2.2	GND	Input ground
X2.3	PWMTOP	PWM for high side
X2.4	GND	Input ground
X2.5	PWMBOT	PWM for bottom side
X2.6	GND	Input ground
X2.7	ENABLE	Enable signal // *Set to low to disable the output of the drivers*
X2.8	GND	Input ground
X2.9	+15V	15 V output
X2.10	GND	Input ground

4 System performance

Figure 13 captures the test setup and voltage measurement techniques for double-pulse testing. The first turn-on pulse of the low-side device (S2) establishes the desired current value (e.g. nominal data sheet current in this case) in the inductive load, and the turn-off pulse makes the current flow in the freewheeling diode (e.g. body diode of the top device S1 in this case). An external inductance value was used in the actual test setup.

The second turn-on pulse measures the low-side device turn-on characteristics, which also include the reverse recovery of the freewheeling body diode.

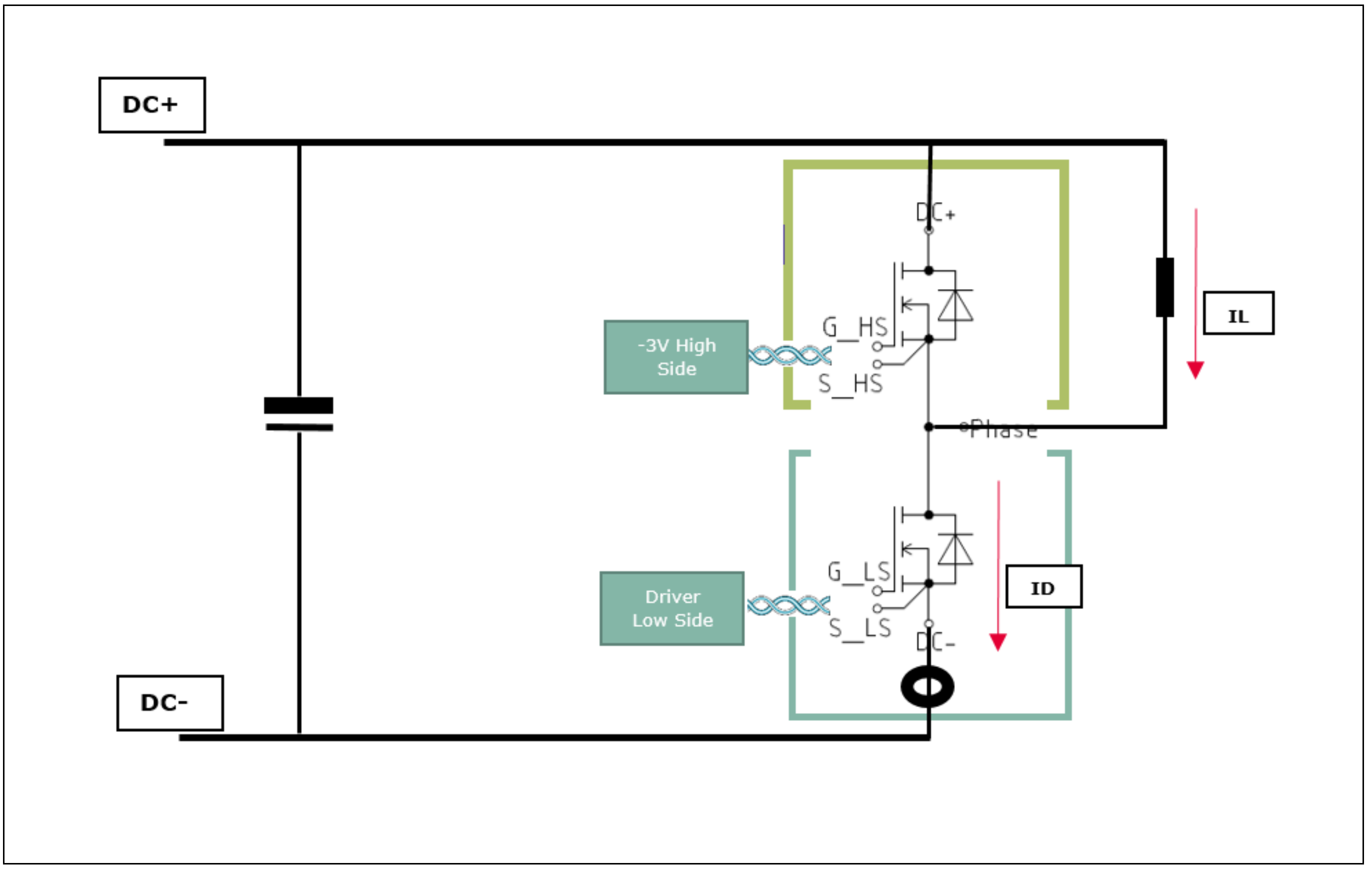

Figure 13 Test setup and voltage measurement techniques

4.1 Switching performance

This chapter presents some examples of extracted waveforms of the module FF2MR12KM1, which has been characterized with the help of the evaluation board.
One key aspect in designing half-bridge topologies with SiC MOSFET devices is to investigate the parasitic turn-on of the upper switch during switching of the lower switch, and vice versa. This effect may be caused by a high dv/dt of a SiC MOSFET, which can exceed 50 kV/µs for a CoolSiC™ MOSFET.
To mitigate the situtation, two approaches have been considered here.

As a first approach, different gate source voltages (V_{GS} = -5…0 V / +15…18 V) are used to drive the gate of the device. In the case of unipolar switching, the dv/dt can be reduced by using larger gate resistance to mitigate the parasitic turn-on events. This is a significant advantage demonstrating the simple gate controllability of CoolSiC™ MOSFET devices.

4.1.1 MOSFET switch-on behavior

The negative output voltage of the board was adjusted from -5 V to 0 V as shown in Figure 14.
The closer the voltage gets to the edge of a gate source voltage of 0 V, the fewer oscillations can be observed for the drain current (I_D) and the drain source voltage (V_{DS}).

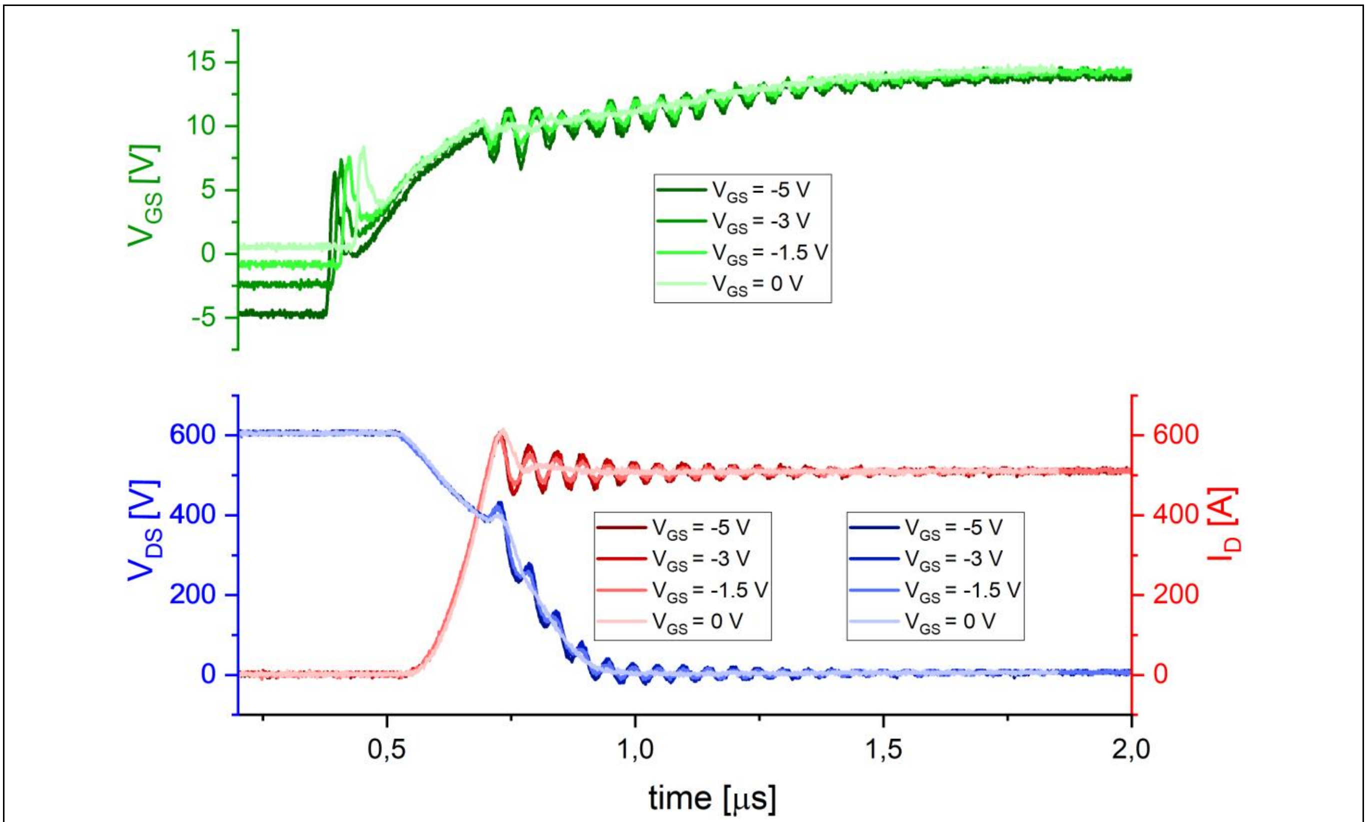

Figure 14 Turn-on waveforms with different gate source voltages(V_{GS} = -5 … 0 V / +15 V)

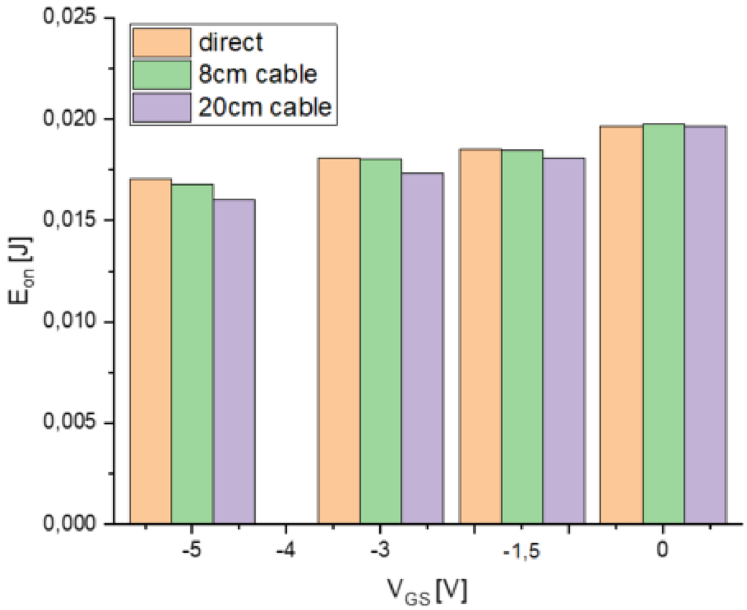

Figure 15 Turn-on losses (E_{on}) with different gate source voltages (V_{GS} = -5V … 0 V/ +15 V) and different driver cable lengths

The influence of the length of the gate cable was observed by soldering drilled cables (8 cm/ 20 cm) onto the gate-source terminals of the board and the gate-source terminals of the module. The results of the measured turn-on losses (E_{on}) are shown in Figure 15. One can see the influence of both, the different negative gate source voltages V_{GS} and the different cable lengths from the driver to the device. The influence of the negative value of V_{GS} has a small impact on the switching curves and therefore on the switching losses. The influence of the length of the gate/ source connection remains within the range of measurement uncertainty. Figure 16 shows the influence of a typical value for V_{GS}, where a higher value for the positive voltage leads to faster switching, reducing the turn on losses with a smaller $R_{DS\ on}$.

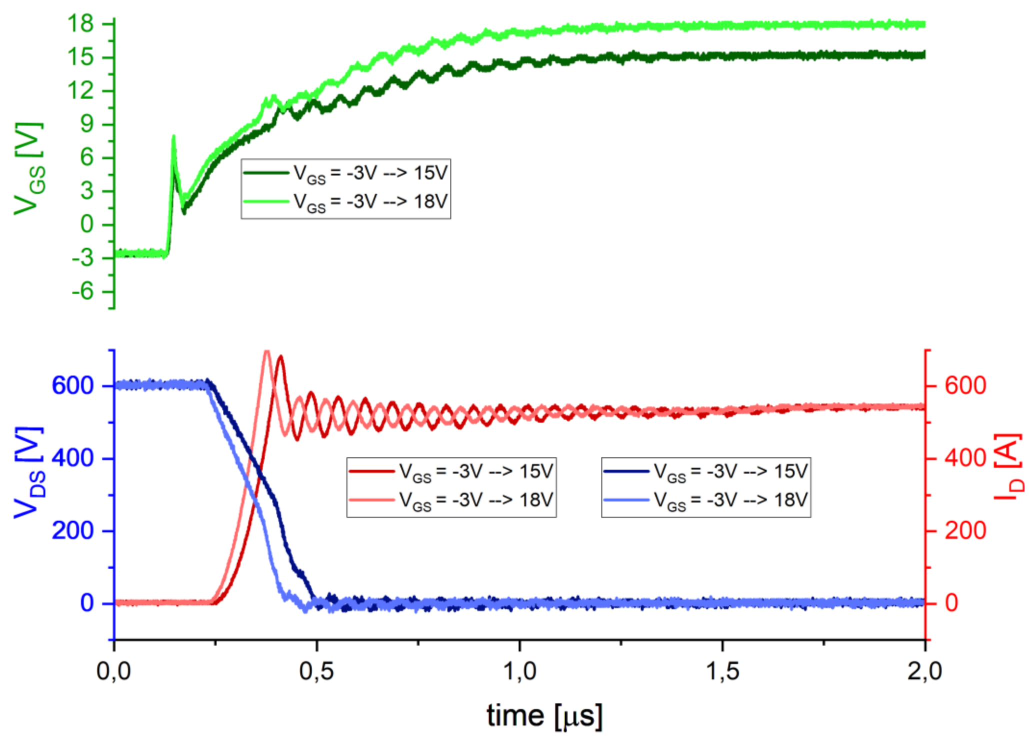

Figure 16 Turn on waveforms of typical bipolar voltage values with V_{GS} = -3…+15 V /…+18 V.

4.1.2 MOSFET switch-off behavior

The turn-off switching with different bipolar voltage levels was observed by changing the $R_{G,off}$ in a way that the gate current stays the same for each testing sequence. The waveforms during turn-off are shown in Figure 17 showing the same course of the current and voltage curves for the different negative values of V_{GS}.

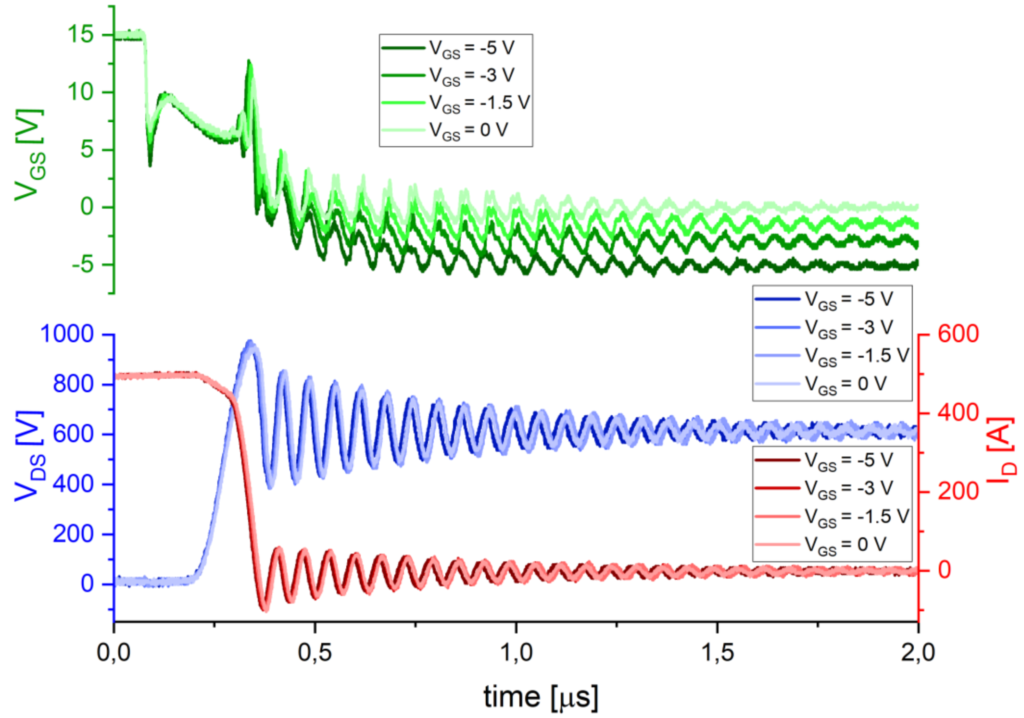

Figure 17 Turn-off waveforms with different gate source voltages (V_{GS} = -5… 0 V/ +15 V)

The previous findings can also be applied when considering Figure 18, where the turn-off losses (E_{off}) for different negative gate source voltages and different lengths of the driver connection are shown. Please notice that for each individual negative gate-source voltage, the gate current was the same by adjusting the $R_{G,off}$.

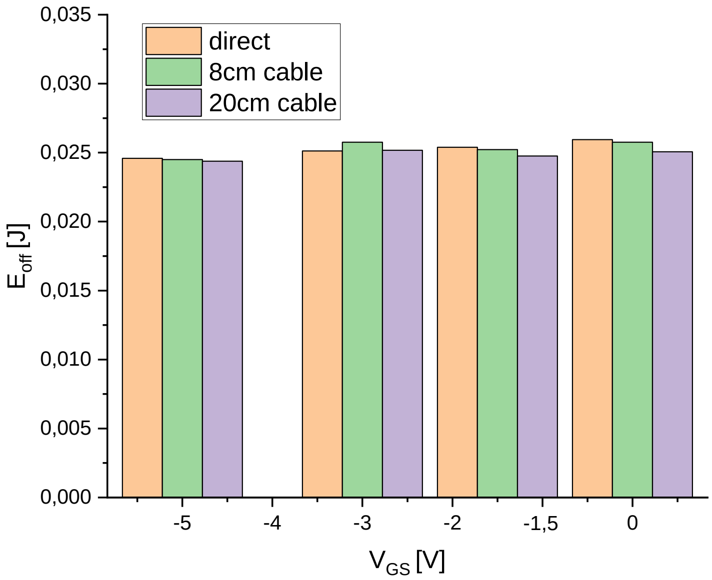

Figure 18 Turn-off losses with different gate-source voltages (V_{GS} = -5… 0 V/ +15 V) and different driver cable lengths

4.1.3 Switching behavior of body diode

Although the body diode causes few losses, it is a good illustration of parasitic switch-on. Observing the switching curves during the recovery of the body diode, one can see that both the curve of the drain current as well as the drain-source voltage become very smooth. This is dependent on the value of the negative V_{GS}, leading to a parasitic switch-on.

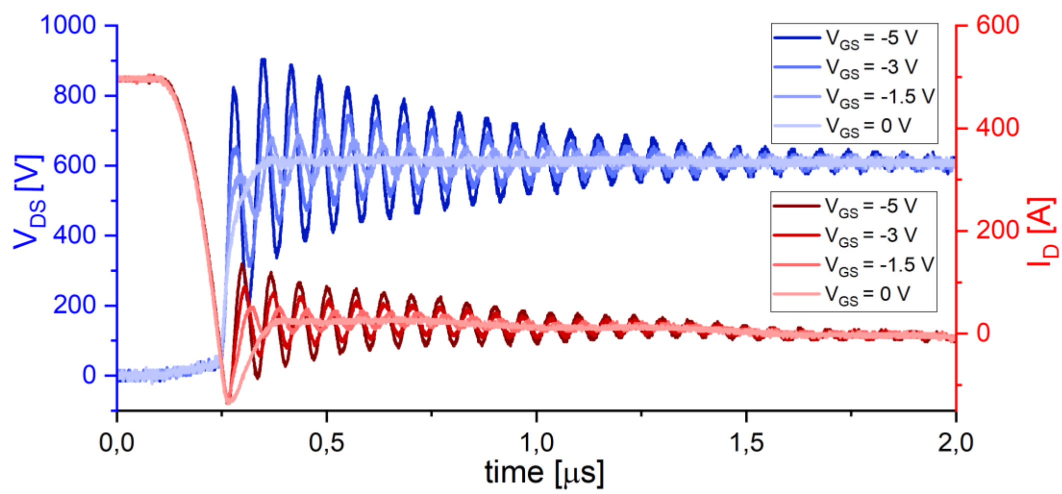

Figure 19 Body diode turn-off with different gate source voltages (V_{GS} = -5…0 V /+15 V)

The influence of the cable length on the parasitic switch-on was observed, and shows an influence on the recovery losses (E_{rec}) of the body diode as illustrated in Figure 20. Although the influence of the cable length on the recovery losses is relatively high, the total value of E_{rec} is still very low in comparison to the total switching losses. The recovery losses are not shown in the datasheets, since the typical recovery losses are close to zero.

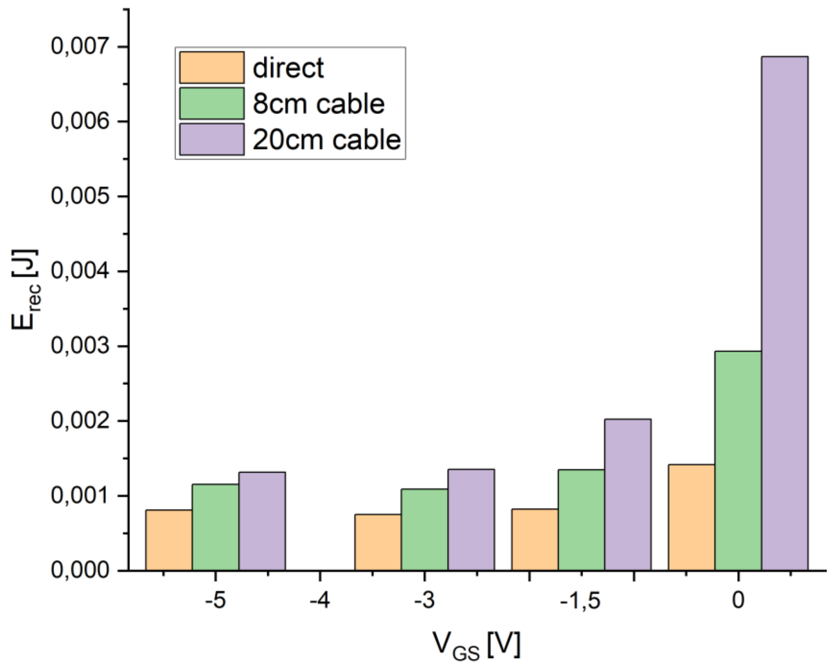

Figure 20 Recovery losses of body diode with different gate source voltages (V_{GS} = -5…0 V /+15 V) and different cable length

4.1.4 Conclusion of the measurement results:

- Adapted gate-source voltage (V_{GS} = -5… 0 V / +15… +18 V)
  - Turn-on losses rise slightly with higher V_{GS} going from -5 V to 0 V
  - Turn-off losses at the same level (same gate current modified with R_g)
  - Turn-on losses with a gate-source voltage of 18 V for faster switching and lower conduction losses due to lower $R_{DS\,on}$
  - We recommend switching to a device with a gate-source voltage that is V_{GS} = -3 V/+18 V to gain the highest power-handling capability (lowest $R_{DS\,on}$)

- Different gate-cable lengths (direct / 8 cm / 20 cm)
  - Turn-on losses and turn-off losses at the same level
  - Gate cable length longer than 20 cm were not considered

- Parasitic turn-on
  - Parasitic turn-on rises from V_{GS} = -3…0 V leading to a reduction of oscillations and slightly higher turn-on losses
  - Turn-off losses at the same level (gate current modified with R_{goff})
  - A slight parasitic turn-on can be targeted to keep oscillation low, with slightly higher losses. CoolSiC™ MOSFET technology has a high robustness against parasitic turn-on

4.2 Thermal performance

The thermal performance of the device for switching a FF2MR12KM1 with up to 40 kHz was tested. The module was attached to a heat plate. The temperature of the heat plate (T_H) was set to 80°C, 105°C and 125°C for 10 minutes each, before the observation of the board was recorded. The surface of the evaluation board was scanned with an IR camera to observe the temperature of the components, e.g. the driver IC, booster stage and the gate resistors. The gates were switched with an amplitude of -5 V to +18 V. The results of the thermal analysis is shown in Figure 21. The observed temperatures of the components remain far below the critical value of 105 °C.

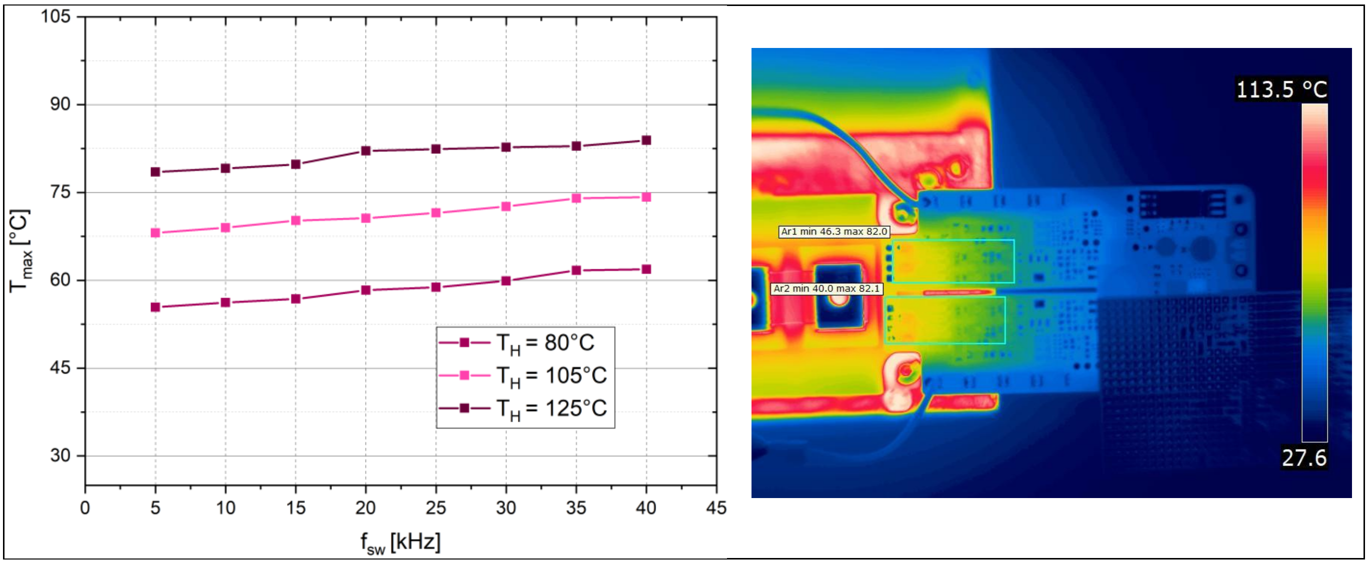

Figure 21 Thermal performance of the board (left) and an IR picture of the setup (right).

5 References and appendices

5.1 Abbreviations and definitions

Table 5 Abbreviations

Abbreviation	Meaning
CE	Conformité Européenne
TVS	Transient Voltage Suppressor
PWM	Pulse Width Modulation
UL	Underwriters Laboratories

5.2 References

[1] Infineon Technologies AG. AN2013-10 (Rev. 2014): *External Booster for Driver IC* V 1.6 www.infineon.com

[2] Infineon Technologies AG. AN2019-25: *CoolSiC™ MOSFET motor drives evaluation board for 7.5 kW* - Eval-M5-E1B1245N-SiC www.infineon.com

5.3 Additional information

The power board is now available for customers in small order quantities.

Revision history

Document version	Date of release	Description of changes
1.0	2020-10-20	Initial version

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