EVAL_2KW_SiC_IH

Evaluation board of 650 V G2 CoolSiC™ MOSFET for induction heating

About this document

Scope and purpose

The EVAL_2KW_SiC_IH Evaluation Board features the new 650 V G2 family of CoolSiC™ MOSFETs, specifically designed for induction heating application comprising the resonant topology for switching up to 150 kHz. This application note demonstrates the functionality and key features of the G2 CoolSiC™ MOSFETs (IMW65R020M2H) in combination with the level-shift EiceDRIVER™ ICs (2ED21824S06J, 2ED21844S06J) based on SOI technology.

Intended audience

- Engineers who want to learn how to use the Infineon G2 CoolSiC™ MOSFETs in combination with EiceDRIVER™ 2ED2x families
- Experienced design engineers who design circuits with Infineon EiceDRIVER™ and CoolSiC™ MOSFETs
- Design engineers who develop power electronic devices, such as inverters

Evaluation board

This board is 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.

Keypoints

- Demonstrates the functioning of 650 V G2 CoolSiC™ MOSFETs and level-shift EiceDRIVER™ ICs in resonant induction heating applications
- Demonstrates the capability of 650 V G2 CoolSiC™ MOSFETs operating in half-bridge resonant topology for switching frequencies up to 150 kHz
- Demonstrates ultra-high efficiency of 99.7% at 2 kW output power
- Achieves 1.3–1.8% higher efficiency with 650 V CoolSiC™ G2 MOSFET compared to IGBT solutions

About this product family

Product family

Infineon's CoolSiC™ MOSFETs offer exceptional performance in switching behavior and total losses. These devices are designed to offer high efficiency and optimal reliability, while also boasting a low on-resistance that remains stable and reproducible even in large-scale production. It's ability to turn off the device with zero gate bias makes the CoolSiC™ transistor concept the only true "normally-off" device.

Target applications

- Energy Storage Systems
- Industrial drives

- Motor control and drives
- Renewables
- UPS

Safety precautions

Note: *Please note the following warnings regarding the hazards associated with development systems.*

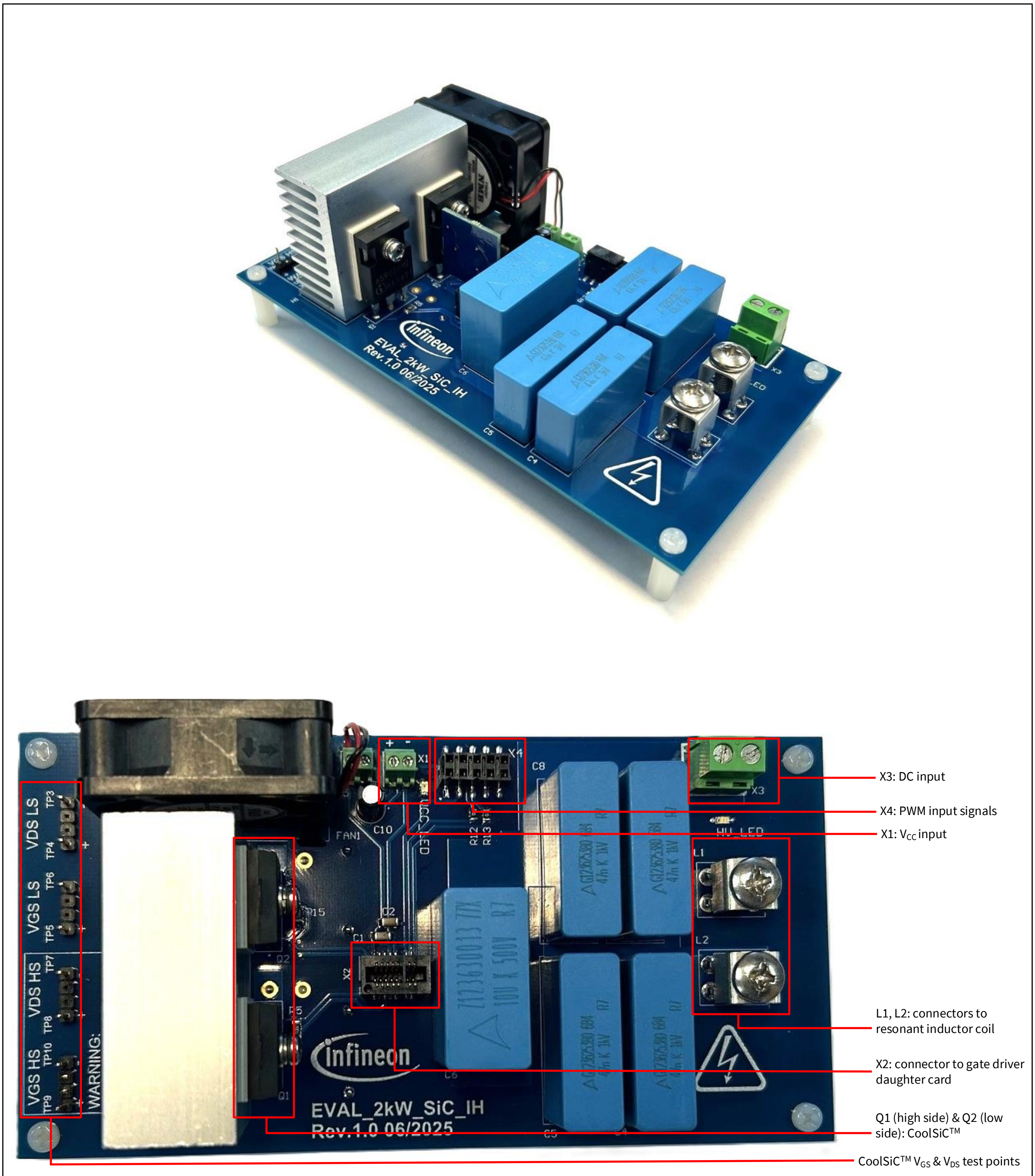
Table 1 Safety precautions

	Warning: *The DC link potential of this board is up to 1000 VDC. 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 contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. 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.*
	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.*
	Warning: *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	Caution: *The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.*
	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: *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	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 EVAL_2KW_SiC_IH Evaluation Board

This application note describes the EVAL_2KW_SiC_IH Evaluation Board that is intended for the evaluation of Infineon's 650 V G2 CoolSiC™ MOSFET in the half-bridge series resonant inverter for induction heating applications.



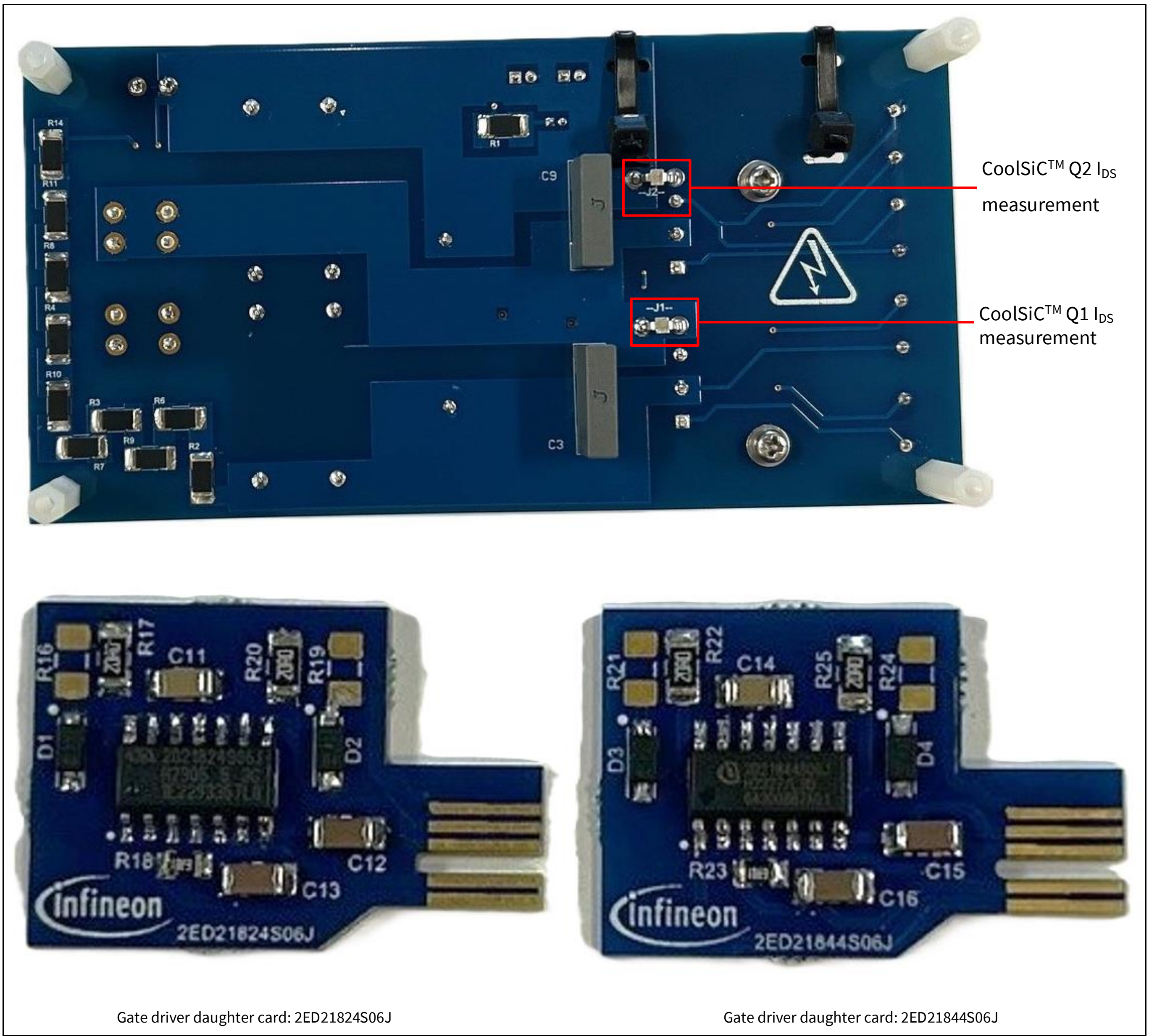


Figure 1 EVAL_2KW_SiC_IH Evaluation Board and gate driver daughter cards

This board is suited for double-pulse testing as well as continuous operation mode. The board has been designed and the components selected to reflect a typical, state-of-the-art induction cooking system based on a half-bridge topology. The main difference when compared to a complete system is the absence of a rectifier, filter stage, and auxiliary power supply regulator stage. Hence, the inverter must be supplied with a DC voltage for the main power and an additional low DC voltage (up to 20 V) must be provided to supply the gate driver IC and the cooling fan.

The control interface has been designed so that it can be easily connected to the Infineon BootKit XMC1300 MCU board[1,2]. Alternatively, it can also be connected to a pulse generator or to any other digital circuits which can generate the PWM signals.

The board has been tested with input power up to 2000 W, with a DC input voltage of 320 V-340 V and an auxiliary voltage supply of 18 V.

1.1 Gate driver daughter cards and resonant coil

This board is designed to offer layout guidance for incorporating IMW65R020M2H into a half-bridge resonant inverter. The gate driver stage is implemented on two separate daughter cards, each featuring a different driver IC model. Even though this approach is not the most common for typical induction cooking designs, particular care has been taken to optimize the gate driving loops, and therefore to minimize parasitic inductances. Thus, the layout of the daughter cards can still be considered as a guideline for implementing the gate driving stage in a real application design.

The evaluation board kit also contains the resonant coil that must be connected to the board. Different coils can be connected to the board to test different load variants. The electrical characterization of the evaluation board was done using the coil that comes with the evaluation board.

1.2 Block diagram

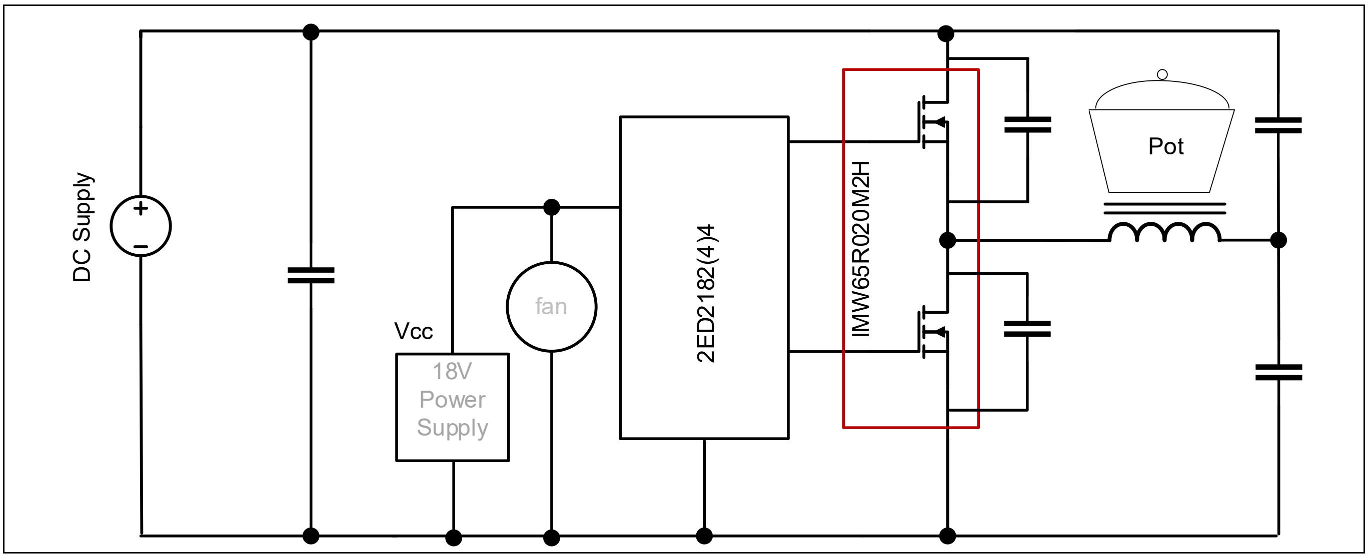


Figure 1 EVAL_2KW_SiC_IH

The detailed operating principles of the half-bridge resonant inverter can be found in Chapter 3.3 of AN201401.

[1] Additional information about the XMC board can be found here: https://www.infineon.com/cms/en/product/evaluation-boards/kit_xmc13_boot_001/.

[2] The complete software for the MCU can be downloaded on the Infineon website upon registration of the board. See 5.2 for further details.

1.3 Board parameters and technical data

Table 2 EVAL_2KW_SiC_IH Evaluation Board specifications

Parameter	Symbol	Value	Unit	Note
Auxiliary supply voltage	V_{CC}	18	V	Auxiliary supply for both gate driver and cooling fan
PWM input signal	*LIN*, *HIN*	5	V	For 2ED21844S06, *LIN* is connected to shutdown pin (active low); in normal operation, *LIN* needs to be pulled up to 5 V
DC main supply voltage	V_{DC}	0 ~ 340	V	DC supply for the main power. The input voltage depends on the load conditions, including the resonant coil and pot used
Switching frequency	f_{sw}	100 ~ 140	kHz	The higher switching frequency leads to lower output power. The dead-time on gate driver cards is designed to accommodate the whole switching frequency range
Main power	*P*	0 ~ 2000	W	The power output depends on the DC input voltage, switching frequency and load conditions
Output resonant current	I_{AC}	0 ~ 20	A_{rms}	The output AC current depends on DC input voltage, switching frequency and load conditions

2 System and functional description

2.1 Board commissioning

Follow the steps below to set up and power up the board, and to perform initial evaluations.

Prerequisites

Ensure to have the following:

- An isolated low-voltage DC power supply ready for V_{CC}
- A high-voltage DC power supply ready for V_{DC} between *X3+ (DC+)* and X3- *(DC-)*
- The provided resonant coil ready, or any other coil that is suitable for induction cooking application
- The BootKit XMC1300 board ready and programmed (or, as an alternative, a signal generator for half-bridge PWM input)

Attention: ***Before operating the board, make sure that a gate driver daughter card is properly inserted in the connector X2.***

Power-up sequence

1. Connect the V_{CC} auxiliary supply ground to connector *X1-* and 18 V to connector *X1+*
   The VCC_LED will turn on
2. Connect JP104 of the BootKit XMC1300 to the connector X4 of the evaluation board, as indicated in Figure 2. (Alternatively, connect the first PWM output of the signal generator to X4.3 (LIN) and X4.2 (VSS) and the second PWM output between X4.8 (HIN) and X4.2 (VSS) if 2ED21824S06 is used. If 2ED21844S06 is used, connect the PWM output of the signal generator to X4.8 (HIN) and X4.2 (VSS) and connect X4.3 (LIN) to 5 V)
3. Connect the negative terminal of the V_{DC} main supply to connector *X3-* and the positive terminal to connector *X3+*
4. Connect one end of the resonant coil to *L1* and the other end to *L2*
5. Turn on the V_{DC} main supply
   The HV_LED will turn on

Safe power-down sequence

1. Turn-off the V_{DC} main supply and verify that the HV_LED is off
2. Check the DC-link voltage with e.g., a digital multimeter or an oscilloscope
3. Turn-off the V_{CC} auxiliary supply and verify that the VCC_LED is off

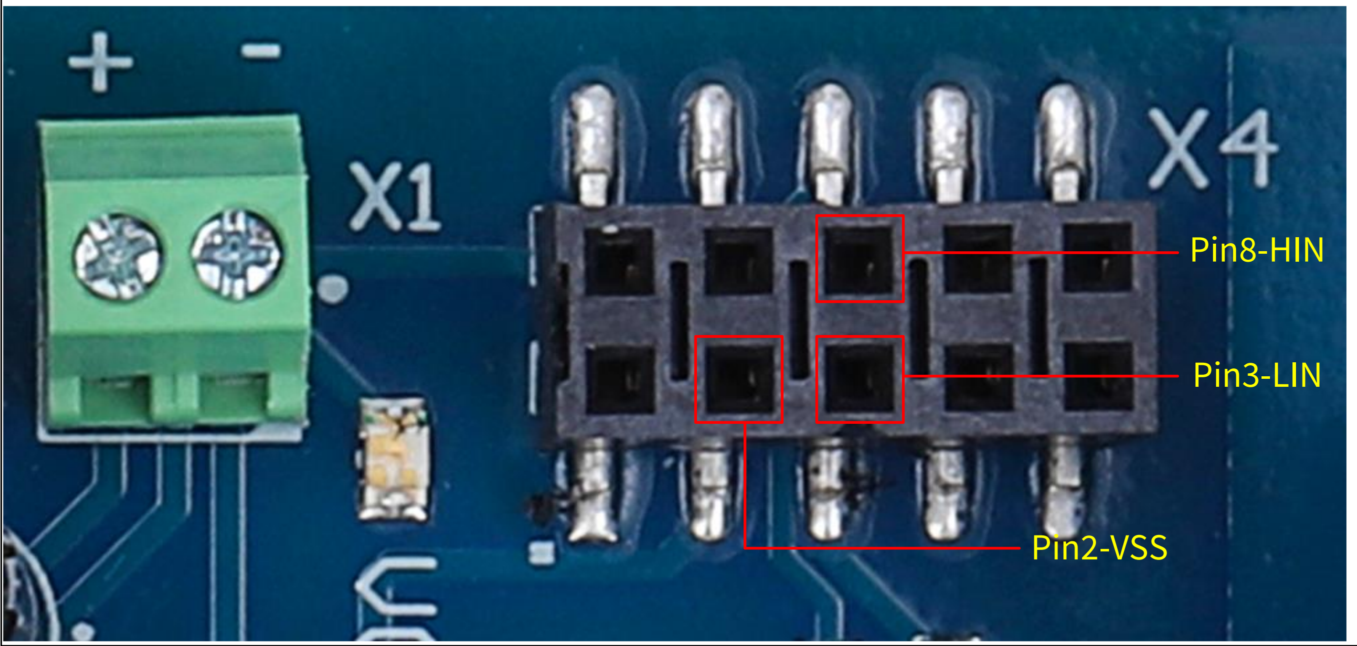


Figure 2 Connection of digital interface X4 to the BootKit XMC1300

2.2 Connection of measurement probes

The evaluation board offers dedicated measurement points for the SiC MOSFET's gate and drain terminal voltages with respect to the source terminal. The test points are marked with the following labels:

- **VDS_LS:** drain-to-source voltage of low-side SiC MOSFET
- **VGS_LS:** gate-to-source voltage of low-side SiC MOSFET
- **VDS_HS:** drain-to-source voltage of high-side SiC MOSFET
- **VGS_HS:** gate-to-source voltage of high-side SiC MOSFET

Assuming that the oscillope ground is connected to the ground of the digital interface (either the BootKit XMC1300 or the signal generator), the different voltages can be measured by means of the following probes:

- **VDS_LS:** "high-voltage" passive probe (with attenuation of 100X or more)
- **VGS_LS:** "low-voltage" passive probe (with attenuation of 10X or more)
- **VDS_HS:** differential voltage probe (with attenuation of 100X or more and a maximum common mode voltage >400 Vdc)
- **VGS_HS:** differential voltage probe (with attenuation of 10X or more and a maximum common mode voltage >400 Vdc)

In addition to the voltage measurements, the evaluation board comes with jumpers to measure directly the current of the SiC MOSFET flowing from/to the source terminal. The two jumpers, one for the high-side and one for the low-side, are placed on the bottom side of the board and are suitable to be used with Rogowski coil current probes, as shown in Figure 3.

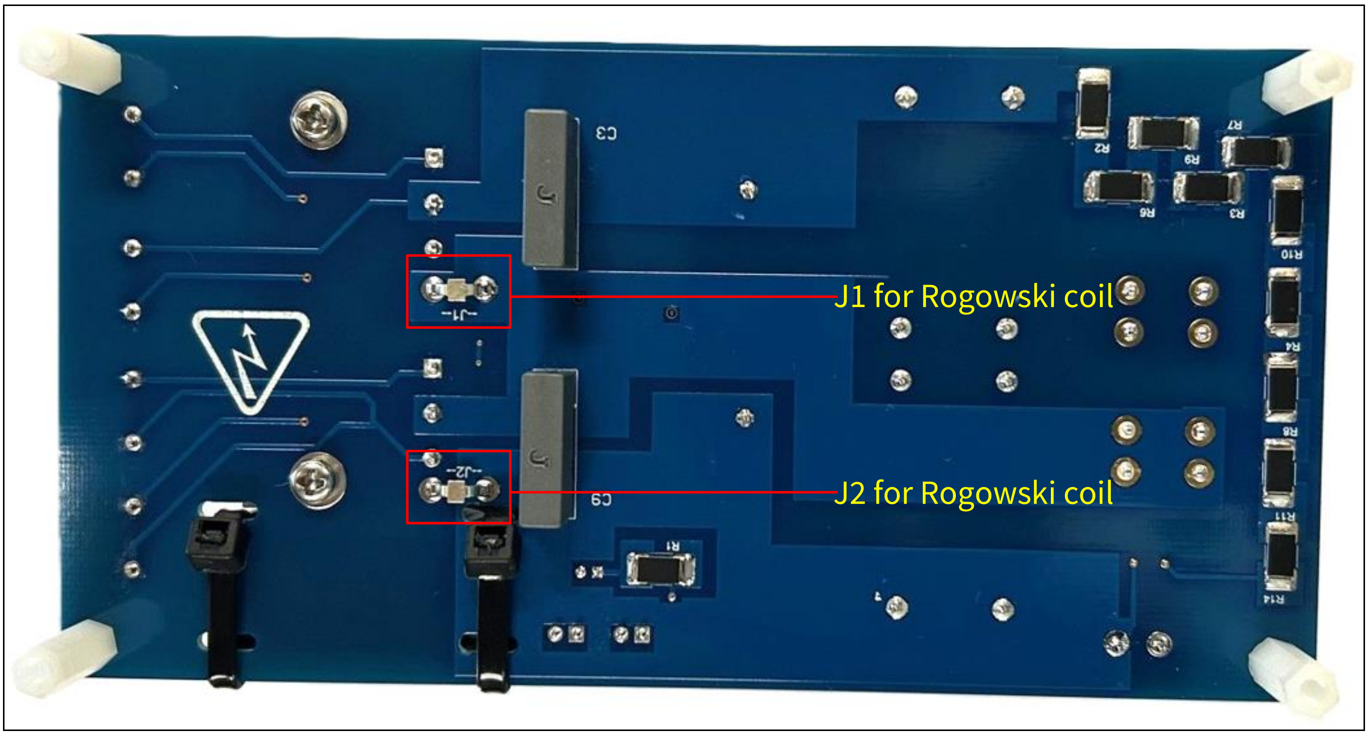


Figure 3 Example of connection of a Rogowski coil to measure the source current of SiC MOSFETs

3 System design

This section provides details of the schematics, layout, bill of material, and connectors. Note that the schematics, PCB, and Gerber files are generated in Altium® Designer. For more details, download the design files after logging in to myInfineon account.

3.1 Schematics

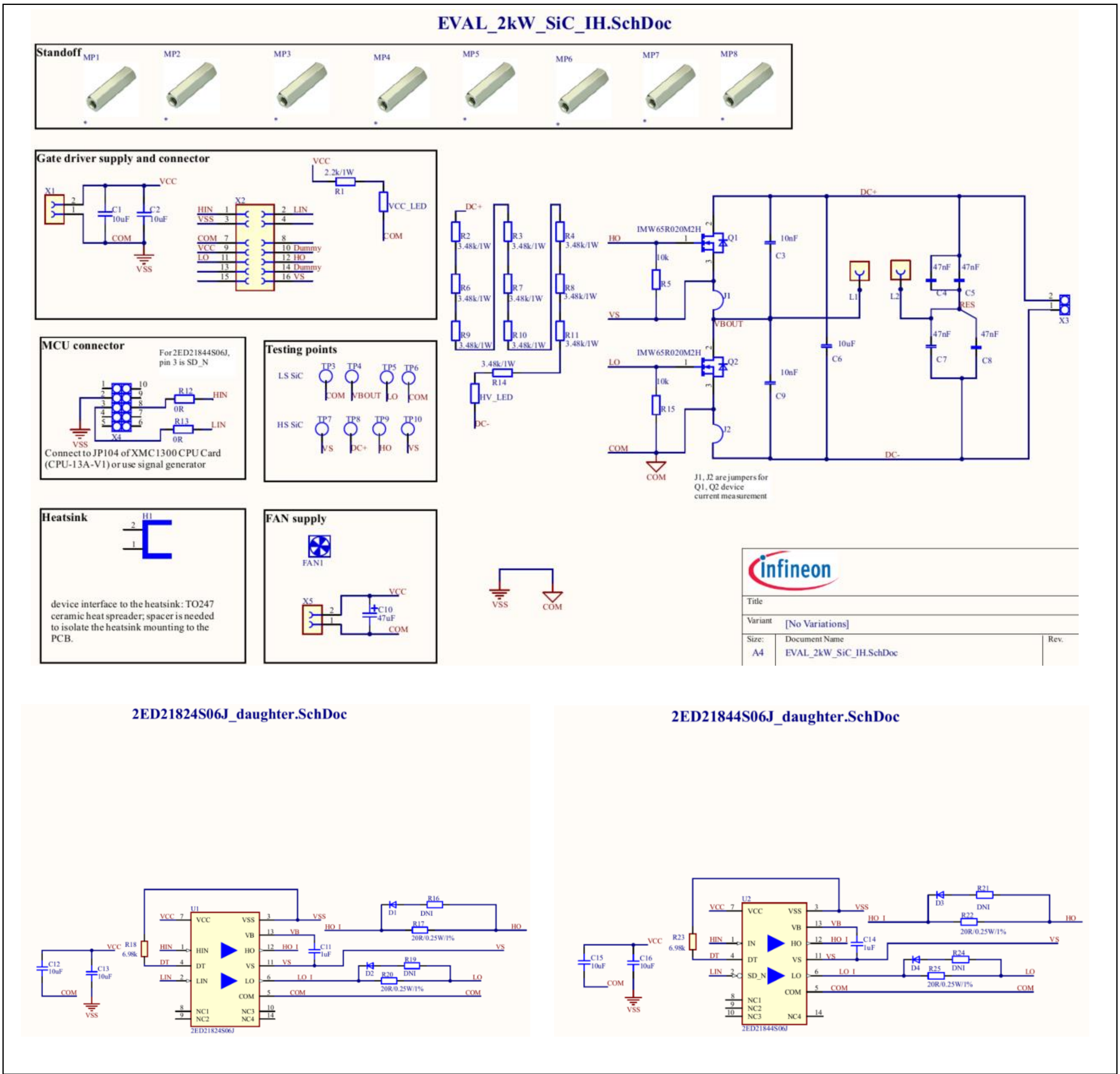


Figure 4 **Schematic of EVAL_2KW_SiC_IH**

3.2 Layout

The board is designed in two layers, with dimensions of 152 mm × 78 mm. The board is manufactured with copper thickness of 2 oz.

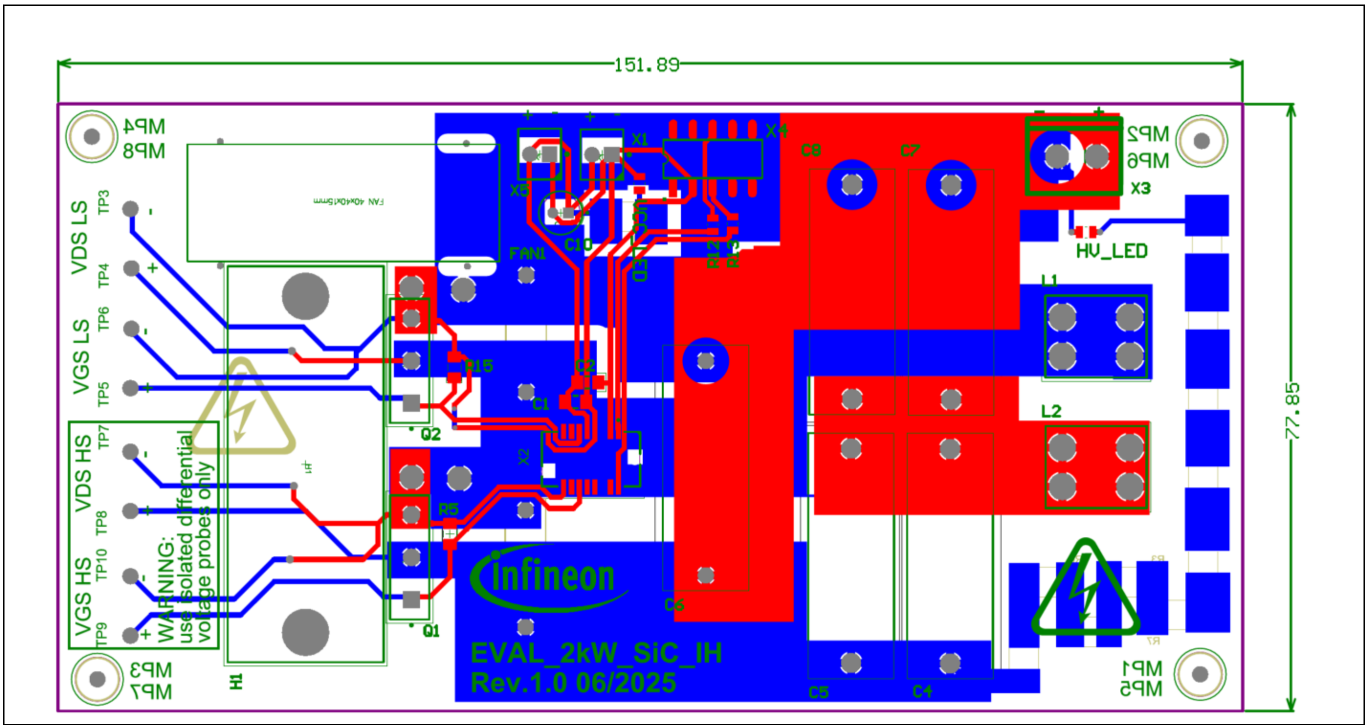


Figure 5 PCB layout of EVAL_2KW_SiC_IH

3.3 Bill of material

The complete bill of material is available after logging in to myInfineon account.

Table 3 BOM of the most important/critical parts of the evaluation board

S. No.	Ref. designator	Description	Manufacturer	Manufacturer P/N
2	Q1, Q2	SiC MOSFET G2 650V 20mΩ	Infineon Technologies	IMW65R020M2HXKSA1
1	U1	Half-bridge high voltage, high speed power MOSFET and IGBT driver	Infineon Technologies	2ED21824S06JXUMA1
1	U2	Half-bridge high voltage, high speed power MOSFET and IGBT driver	Infineon Technologies	2ED21844S06JXUMA1
2	C3, C9	Capacitor Unpolarized	Kemet	R76QI2100SE30J
4	C4, C5, C7, C8	Capacitor Unpolarized	EPCOS/TDK	B32684A0473K000
1	C6	Capacitor Unpolarized	EPCOS/TDK	B32774X4106K000
1	FAN1	Fan	NMB Technologies	04015SS-24N-AT-00

3.4 Connector details

Table 4 Connectors and pin assignment

Connector	Pin	Marking/ function	Note
X1	+	VCC	Positive terminal for auxiliary power supply voltage
	-	COM	Ground terminal for auxiliary power supply voltage
X2	/	–	Connector for gate driver daughter card board
X3	+	DC+	Positive terminal for DC high-voltage supply voltage
	-	DC-	Ground terminal for DC high-voltage supply voltage
X4	1	NC	–
	2	VSS	Signal Ground
	3	LIN	Digital input signal for low-side SiC MOSFET
	4	NC	–
	5	NC	–
	6	NC	–
	7	NC	–
	8	HIN	Digital input signal for high-side SiC MOSFET
	9	NC	–
	10	NC	–
X5	+	FAN	Positive terminal for fan supply
	-	COM	Ground terminal for fan supply
L1	/	Coil 1	Resonant coil terminal 1
L2	/	Coil 2	Resonant coil terminal 2
VDS_LS	/	/	Measurement points for the VDS of the low-side SiC MOSFET
VGS_LS	/	/	Measurement points for the VGS of the low-side SiC MOSFET
VDS_HS	/	/	Measurement points for the VDS of the high-side SiC MOSFET
VGS_HS	/	/	Measurement points for the VGS of the high-side SiC MOSFET

4 System performance

This section shows the switching waveforms, efficiency, and temperature charts of EVAL_2KW_SiC_IH. In order to make both the top and bottom switches reach ZVS, the PWM duty cycle is maintained at 50%. The power adjustment is realized through switching frequency variation. Figure 6 represents the low-side SiC MOSFET V_{DS}, V_{GS}, I_{DS}, and output resonant I_{AC} waveforms, where the system operates at an input power of 2 kW and switching frequency 100 kHz. The specification of the resonant coil and vessel assembly are provided in Section 5.1. As can be seen from Figure 6, ZVS is achieved since V_{DS} drops to zero before V_{GS} is provided. In addition, at the turn-off trasition, it's clear that with the help of snubber capacitor, the overlap of I_{DS} and V_{DS} is greatly reduced to minimize the turn-off loss.

Figure 7 shows the efficiency and case temperature charts under both with or without cooling fans. Power meters are used to measure the input DC power, the output AC power, and the auxiliary power respectively. A thermocouple is attached to the case of the high-side device to monitor the case temperature (Tc). The ambient temperature (Ta) is 21°C. The switching frequency is from 100 kHz to 140 kHz. The efficiency of the inverter under test can be expressed as η = AC power/(DC power + Aux power) X 100%. As can be seen from the chart, the peak efficiency of SiC MOSFET is 99.7% at full power. Comparing the efficiencies of SiC MOSFET with and without fans, it can be seen that it is similar as the fan losses offset the efficiency boost achieved by its implementation. SiC solution can potentially eliminate the fan, which results in lower system cost, less noise and higher system reliability.

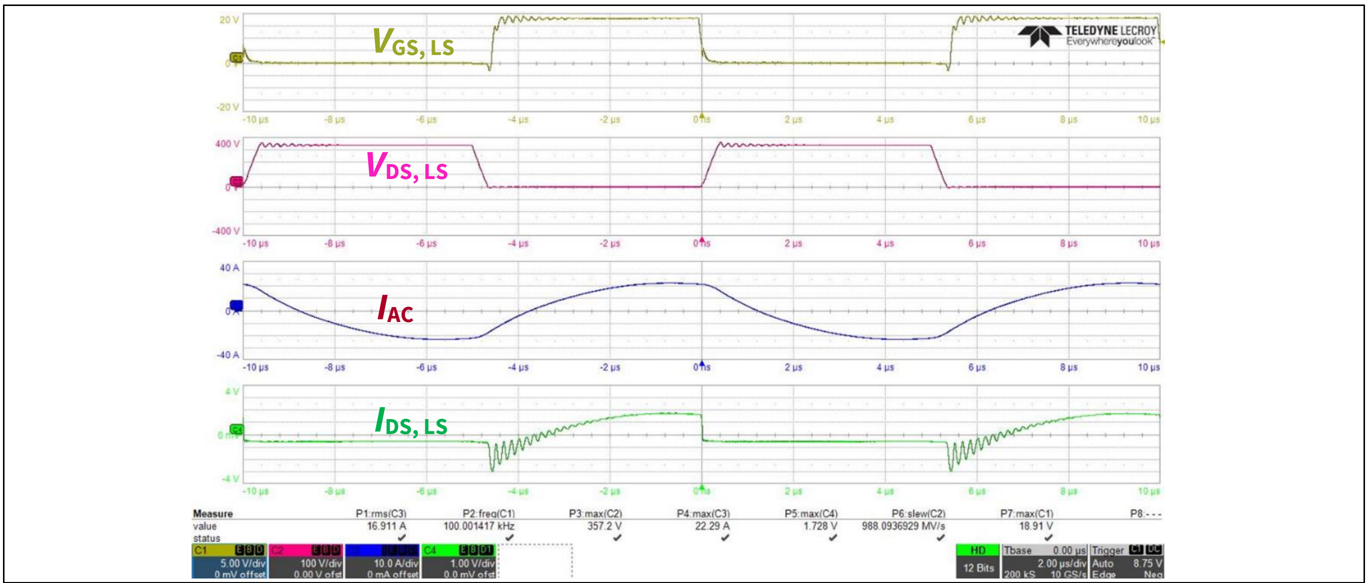


Figure 6 **Typical switching waveforms**

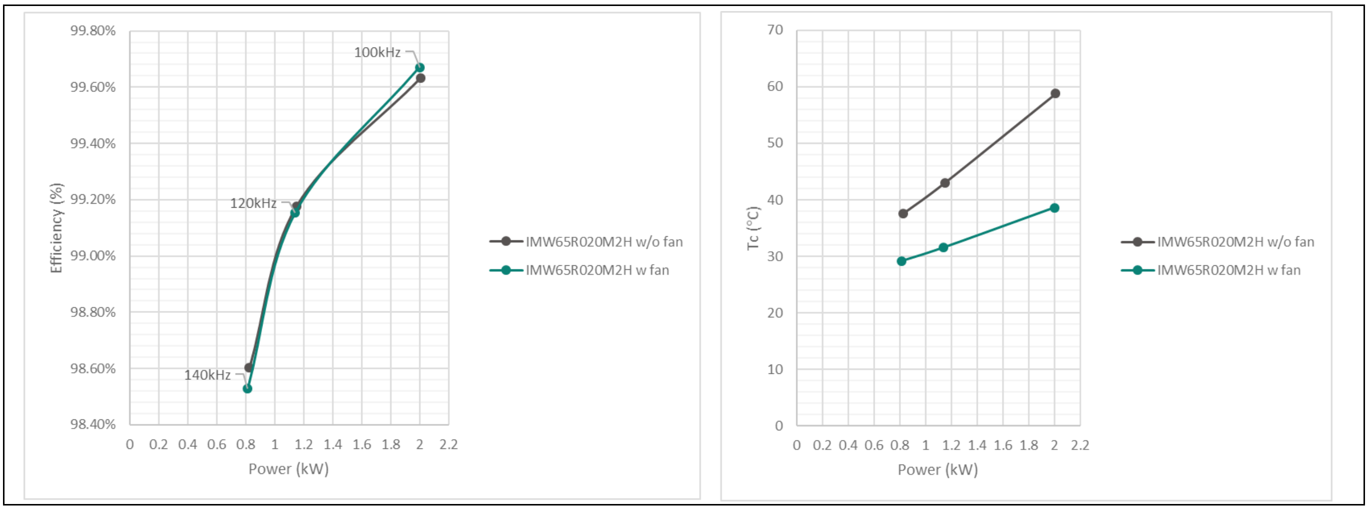
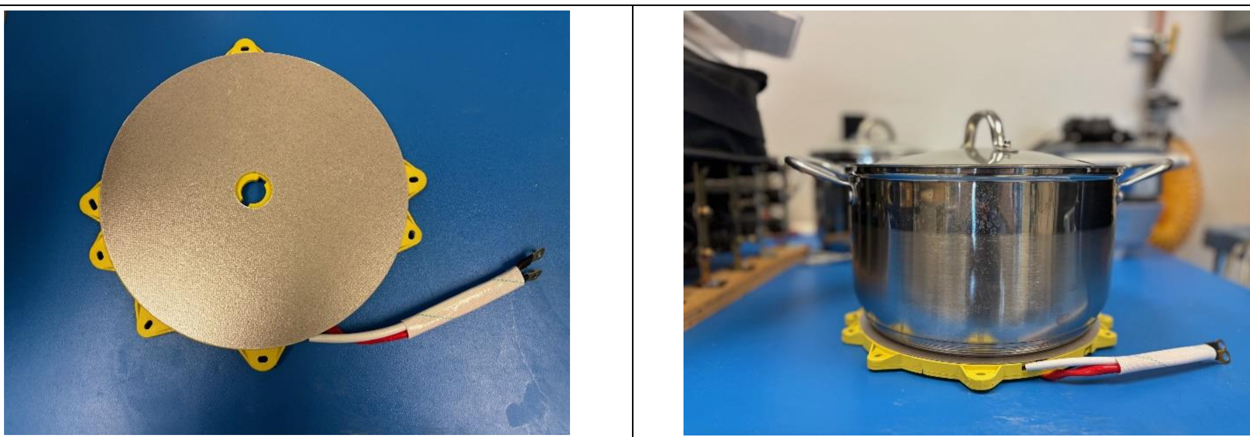


Figure 7 Efficiency and case temperature charts

5 Appendices

5.1 Resonant load specification

The experiment results presented in this document were conducted with the resonant coil provided with the evaluation board and with cookware suitable for induction cooking systems. The behavior of the power inverter is largely dependent on the particular coil and cooking vessel used. In particular, the coil inductance, diameter, and distance to the cooking vessel are important factors to consider in the design of an induction cooking system. The design of the resonant coil is not included in the scope of this document. However, in order to provide a reference for the results presented, the details of the resonant coil are shown in Figure 8. Figure 8 depicts the provided coil and the positioning of the pot placed on top of the coil. Finally, Figure 9 shows the frequency dependence of the series resistance and inductance values of the coil, without the pot, and with the pot positioned on top.



a)	b)

Figure 8 (a) Pictures of the resonant coil; (b) positioning of the cooking vessel

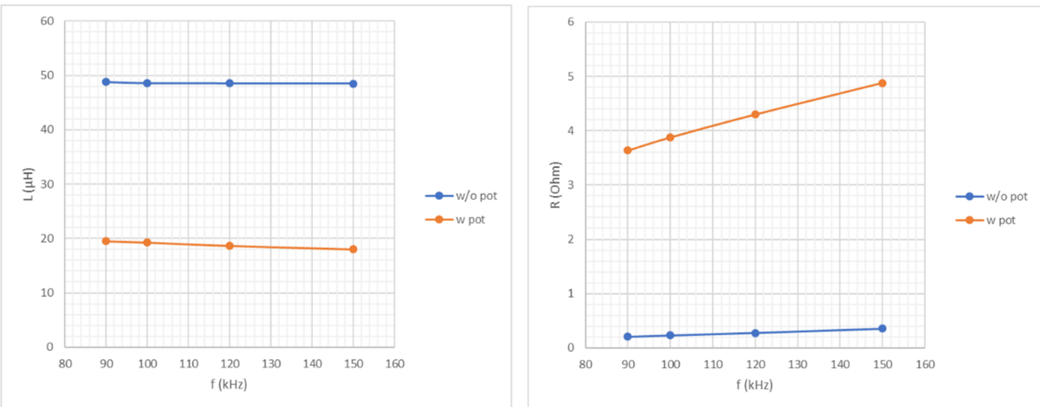


Figure 9 Values of the equivalent series resistance and inductance of the resonant coil without the pot (blue line) and with the pot (orange line)

5.2 Usage of external software to control the evaluation board

The EVAL_2KW_SiC_IH Evaluation Board does not include any microcontroller. The signals to control the gate driver, and consequently the SiC MOSFETs, can be either provided by means of a signal generator or of a microcontroller unit.

In order to set up and implement the evaluation board more quickly, firmware and a user-interface (UI) have been developed[1] that can be used in combination with the Infineon BootKit XMC1300 [1] MCU board.

This chapter provides information on how to program, connect and control the MCU board.

5.2.1 Programming the BootKit XMC1300 board

The firmware on the XMC1300 MCU can be programmed by using the Infineon XMC™ Flasher tool [5]. The user must install the software and connect the Boot Kit XMC1300 board to the computer. Once the connection is established, the file with the firmware (provided as *.hex*) can be selected and loaded in the MCU by using the button "Program."

5.2.2 Connecting the BootKit XMC1300 board

The connector (X4) on the board has been designed to provide an easy connection to the Infineon BootKit XMC1300 [1]. A standard 10-wire ribbon cable can be used to connect the evaluation board with the boot kit, as shown in Figure 10. Ensure that pin *X4.1* of the evaluation board is connected to pin *0.8* of the JP104 port on the MCU board.

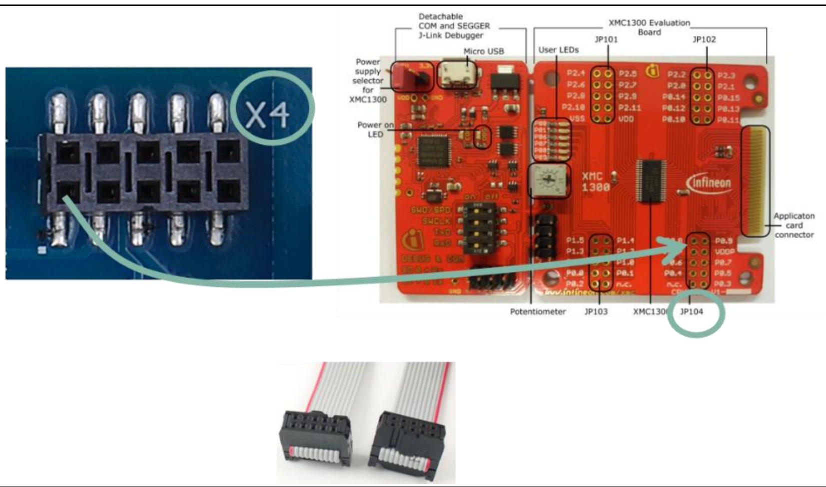


Figure 10 How to connect the BootKit XMC1300 MCU board to the evaluation board

5.2.3 Controlling the BootKit XMC1300 board

Once the XMC microcontroller on the BootKit XMC1300 is programmed with the provided firmware, it can be controlled by means of a graphical user interface (GUI). The GUI has been developed to provide an easy way to:

- Select the right PWM configuration for each of the gate driver IC models that are provided with the board

[1] The firmware and the user interface software can be downloded from the website of the EVAL_2KW_SiC_IH after having logged in with myInfineon account.

- Select and configure the switching frequency, the duty cycle and the dead-time between the driving signals of the two SiC MOSFETs on the board[1]

The main window of the user interface is shown in Figure 11. It consists of different sections, each dedicated to a specific function.

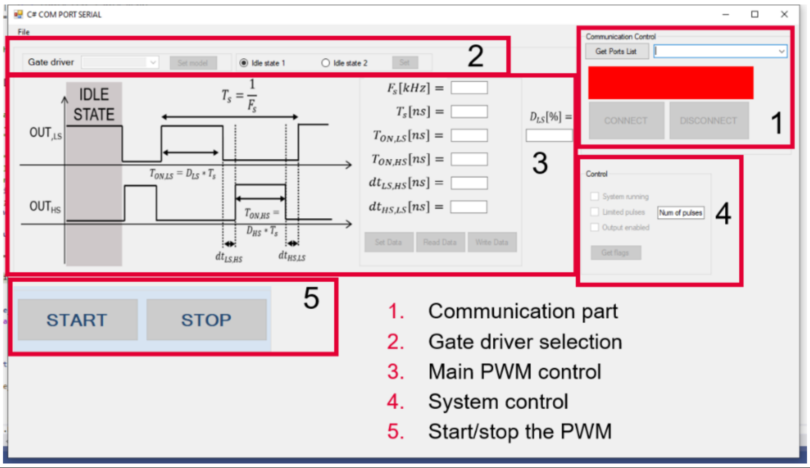


Figure 11 Main window of the user interface to control the XMC

Once the BootKit XMC1300 is connected to the computer, the serial communication between the computer and the board can be performed as follows (refer to Figure 12):

1. Press the **Get Port List** button
   The available COMs are displayed in the drop-down menu
2. Select **JLink port**
3. Press **CONNECT** and check that the bar turns green, and the text "Connected to Port xyz" appears

[1] Note that for the 2ED21824S06J and the 2ED21844S06J, the minimum dead time is to be set by means of an external resistor. In this case, the software can force a dead-time value only if this is higher than the one set by the hardware. Please refer to the specific gate driver datasheet for further information.

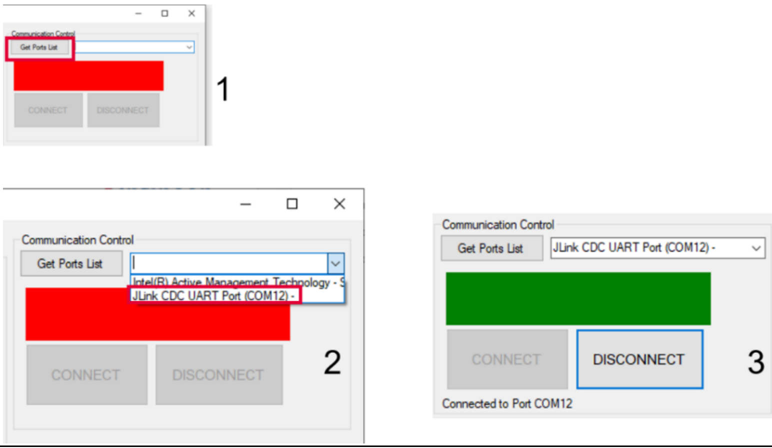


Figure 12 Procedure to establish communication between the computer and the XMC microcontroller

The user interface provides an easy way to select the right gate driver IC model to configure properly the driving PWM signals generated by the MCU. The model of gate driver must be selected in accordance with the specific daughter card used. To select a gate driver model, the procedure is shown in Figure 13. Changing the gate driver model in the software is allowed only when the system is not running.

Attention: Selecting a gate driver model that does not match the model mounted on the board is likely to result in incorrect signal generation, and consequently in a high risk of SiC MOSFET failure.

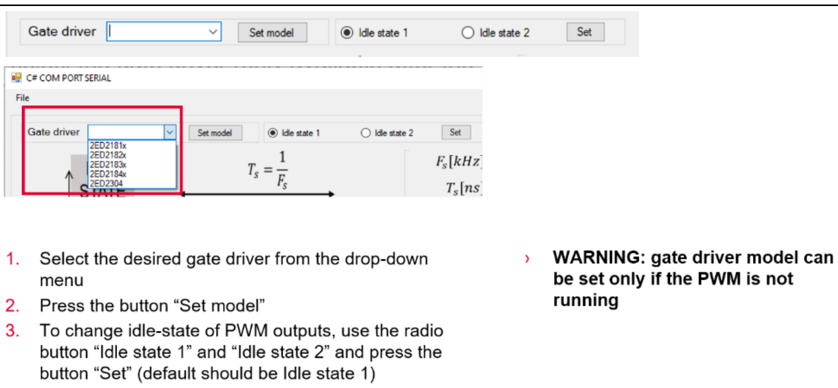
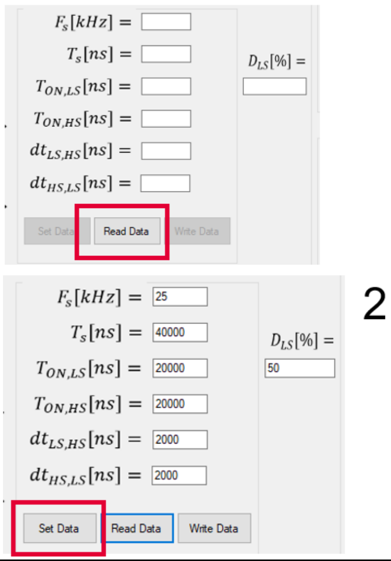


Figure 13 Procedure to select and configure the MCU to operate with a specific gate driver model

The software also allows for an easy change of PWM signals parameters (e.g., frequency, duty cycle, dead-time), as shown in Figure 14. The MCU, once programmed for the first time, contains default values that can be retrieved using the button **Read Data**. Any modification of the default parameters can be temporarily set in the MCU by using the button **Set Data**. The temporary setting is valid until the MCU is powered on. In case the MCU is turned off, the values of the parameters return to the default values. The user can always save new default values in the MCU flash memory by using the button **Write Data**.



1. Press button "Read data" → the values currently stored in the MCU are loaded (2)
2. To change any value, write the new one in the corresponding field and press enter
3. To set the value in the MCU, press the button "Set Data" → values are set but not memorized in the MCU memory
4. To save the new values in the MCU memory, press the button "Write Data". In these way, the new values are stored in the MCU flash and they can be loaded at a new device boot

- Note 1: some parameters are connected
  - E.G.:
    - by changing the Fs, also Ts is changing accordingly
    - Same is for parameters $T_{ON,LS}$, $T_{ON,HS}$, and D_{LS}

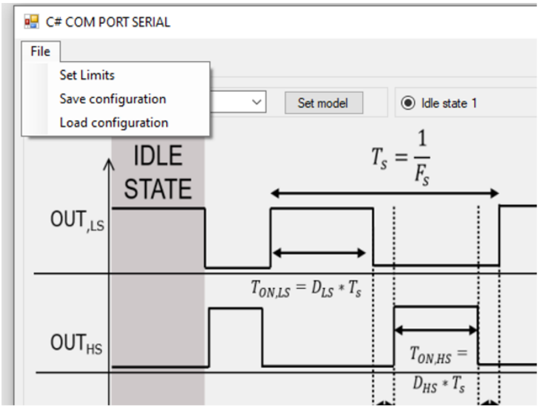
Figure 14 Procedure to modify PWM signal settings

Table 5 lists and describes the PWM parameters that can be configured. Note that some parameters are related to each other (e.g., switching frequency is the reciprocal of the switching period), so they cannot be changed independently.

Table 5 Explanation of PWM parameters

Parameter name	Parameter description	Parameter unit
F_S	Switching frequency of the PWM signal	kHz
T_S	Period of the PWM signal – reciprocal of F_S	ns
$T_{ON,LS}$	On-time duration of the PWS signal that drives the low-side SiC MOSFET – related to $T_{ON,HS}$ and to T_S/F_S	ns
$T_{ON,HS}$	On-time duration of the PWS signal that drives the high-side IGBT – related to $T_{ON,LS}$ and to T_S/F_S	ns
$dt_{LS,HS}$	Dead-time between low-side turn-off and high-side turn-on	ns
$dt_{HS,LS}$	Dead-time between high-side turn-off and low-side turn-on	ns

At any time, the given parameter configuration of the GUI can also be saved in the computer and loaded later. This may be particularly convenient if a given test configuration has to be reused multiple times. To save and load the configuration, refer to Figure 15. This figure also shows how to set the limits for the PWM parameters, which is particularly useful to prevent entering unwanted values accidentally.



1. Press "File" button → the available sub-menus are available:
   1. Set limits → to set min/max for each PWM parameter
   2. Save configurations → to save all the relevant parameters in a config file
   3. Load configurations → to load the relevant parameters from a config file

Figure 15 Saving and loading configuration and setting limits for the parameters

Once the MCU has been properly set, the generation of the PWM signals can be enabled or disabled by pressing the **START** and **STOP** buttons.

Additionally, the user interfaces provide an additional control section that is used for:

- Providing visual feedback on whether the PWM signals are being generated
- Setting the PWM signals to be operated only for a limited number of pulses (e.g., to perform a start-up test of the system)
- Enabling/disabling the MCU to output the signals (this option can be useful to verify the idle states of the SiC MOSFET driving signals)

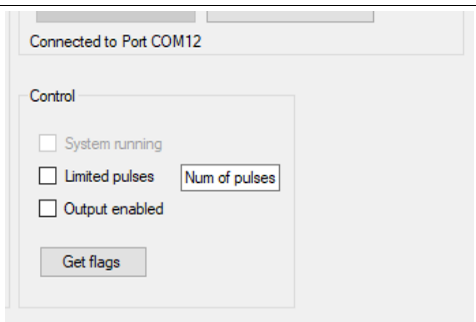


Figure 16 Saving and loading configuration and setting limits for the parameters

6 Related resources

- Silicon carbide MOSFET discretes
- SiC MOSFET CoolSiC™ MOSFET 650 V G2 datasheet
- Developer Community
- Application note

References

[1] Infineon Technologies AG: *KIT_XMC13_BOOT_001*; Available online

[2] Infineon Technologies AG: *IMW65R020M2H*; Available online

[3] Infineon Technologies AG: *2ED2182 (4) S06F (J)*; Available online

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[5] Infineon Technologies AG: *XMCFlasher*; Available online

Revision history

Document revision	Date	Description of changes
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