User guide for REF-SMD5KIMSQM2INV

Reference design for motor integrated servo drive with top-side-cooled Q-DPAK

About this document

Scope and purpose

This user guide provides an overview of the REF-SMD5KIMSQM2INV reference design for a motor-integrated servo drive including its main features, key data, pin assignments, and mechanical dimensions.

REF-SMD5KIMSQM2INV is a reference board for motor-integrated servo drives with a small heat sink and without the need for a cooling fan. It is a single 4-layer FR4 PCB that contains a complete 3-phase inverter for motor-drive applications with an interface to a controller board.

The driver circuit is based on the EiceDRIVER™ 1ED3322MC12N Enhanced (1ED-F3) single-channel isolated gate driver with DESAT protection and Miller clamp. The power switch is a CoolSiC™ IMSQ120R012M2H MOSFET G2 in top-side-cooled Q-DPAK dual half-bridge package.

This reference design enables you to quickly realize a compact servo motor solution with Infineon CoolSiC™ MOSFET G2 in top-side cooled Q-DPAK dual half-bridge package and EiceDRIVER™ F3 Enhanced gate driver.

Note: This product is not qualified according to the AEC Q100 or AEC Q101 specifications.

Intended audience

The REF-SMD5KIMSQM2INV board provides initial support to customers in designing servo motors with motor-integrated inverters using EiceDRIVER™ ICs and CoolSiC™ MOSFETs.

About this product group

Target applications

- Motor integrated servo drives
- Robotics drives

Product family

- Power semiconductors:

CoolSiC™ IMSQ120R012M2HH 1200 V discrete MOSFETs in top-side-cooled Q-DPAK dual half-bridge package offers reduced system cost by enabling easier assembly with outstanding thermal performance.

- Gate driver ICs:

EiceDRIVER™ 1ED3322MC12N Enhanced (1ED-F3) single-channel isolated coreless transformer (CT) gate driver, which is housed in a DSO-16 wide-body package with large creepage distance (>8 mm) for driving up to 2300 V IGBTs, Si, and SiC MOSFETs.

Reference board/kit

Infineon product(s) embedded on this PCB have functions and form factor close to a commercial design. PCB and auxiliary circuits are optimized for the final design.

Note: *Boards do not necessarily meet safety, EMI, and quality standards (for example UL, CE) requirements.*

Safety precautions

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

Table 1 Safety precautions

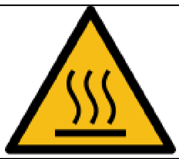
	**Warning:** *The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.*
	**Warning**: *The evaluation or reference board contains DC bus capacitors which 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 The board at a glance

REF-SMD5KIMSQM2INV is a 3-phase inverter power board to demonstrate an integrated servo motor and drive. The driver circuit is based on the EiceDRIVER™ 1ED3322MC12N Enhanced (1ED-F3) single-channel isolated gate driver, and offers short-circuit protection (SCP) [2]. The second-generation CoolSiC™ IMSQ120R012M2HH MOSFET is the main component in the 3-phase inverter [1].

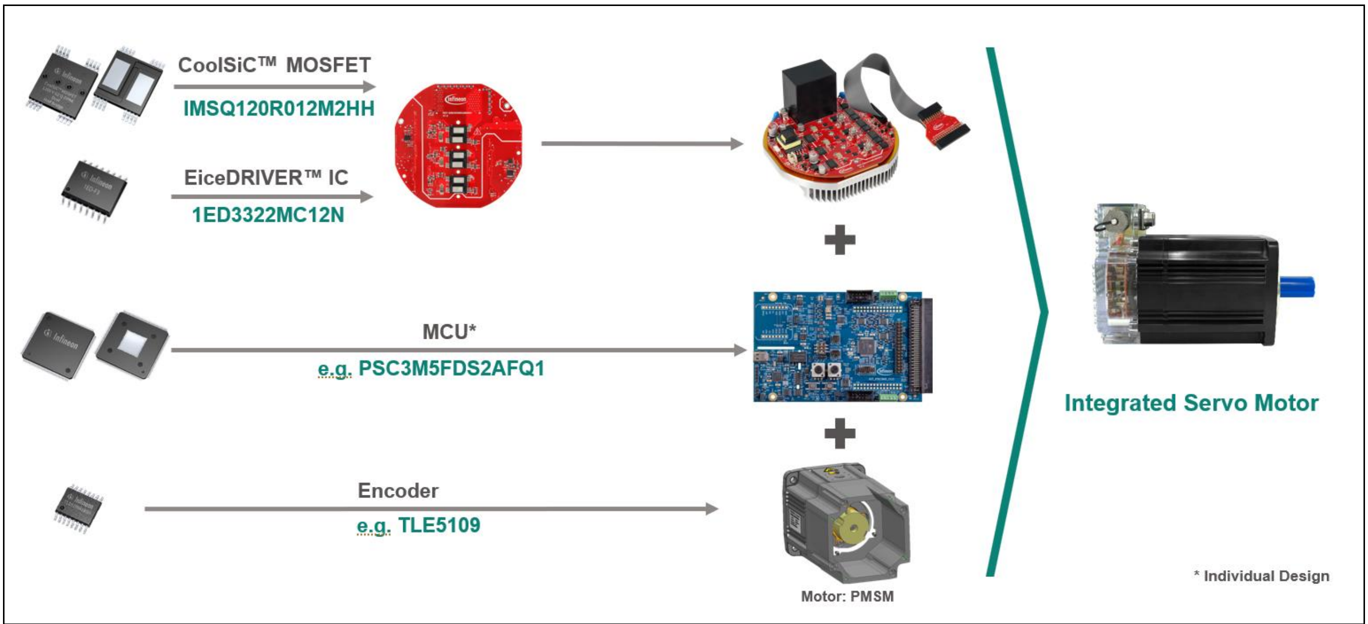


Figure 1 **Integrated servo motor with drive**

The reference board has a heat sink for power switch cooling. No additional cooling fan is required for rated operating conditions (see Table 2). It includes an adapter cable to connect to an Infineon motor controller board based on the PSOC™ C3 microcontroller (KIT_PSC3M5_CC2) shown in Figure 1. The control board and the motor are not part of the reference design.

1.1 Delivery contents

The REF-SMD5KIMSQM2INV reference design is delivered together with an adapter cable in an environmentally friendly carton box.

As shown in Figure 2, the kit contains:

- Inverter power board with heat sink. The PCB diameter (without heat sink) is 11 cm
- An adapter cable for connecting to the controller board

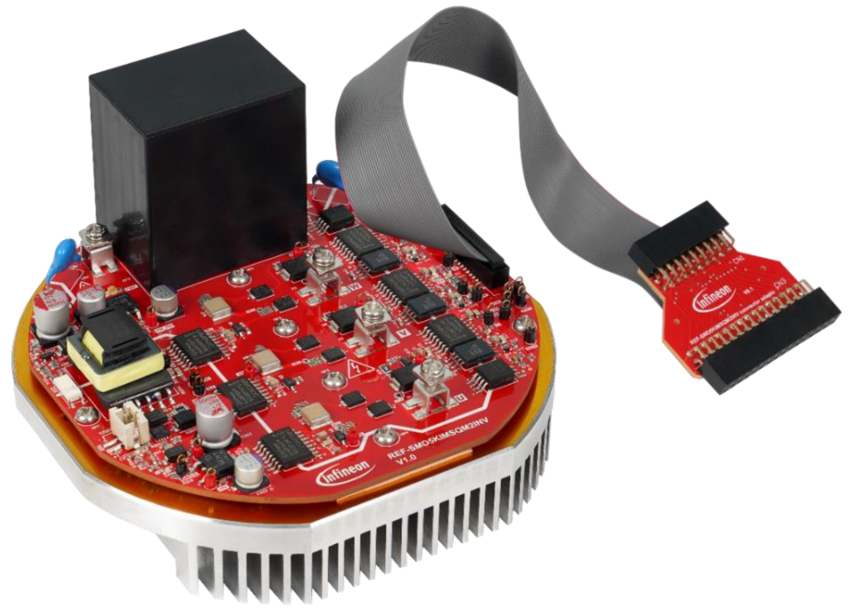


Figure 2 **Delivery contents**

1.2 Block diagram

The inverter is a standard 3-phase, 2-level topology with a DC-link capacitor and three Infineon CoolSiC™ IMSQ120R012M2HH G2 dual half-bridge MOSFETs in Q-DPAK packages, forming the three phase legs, with components soldered onto both sides of a single FR4 board.
With the advantage of top-side cooling, the switches and the PCB can remain cooler during operation, as most of the heat is directly transferred to the heat sink rather than into the board. The CoolSiC™ MOSFETs are each driven by an isolated EiceDRIVER™ 1ED3322MC12N gate driver IC with DESAT short-circuit protection.

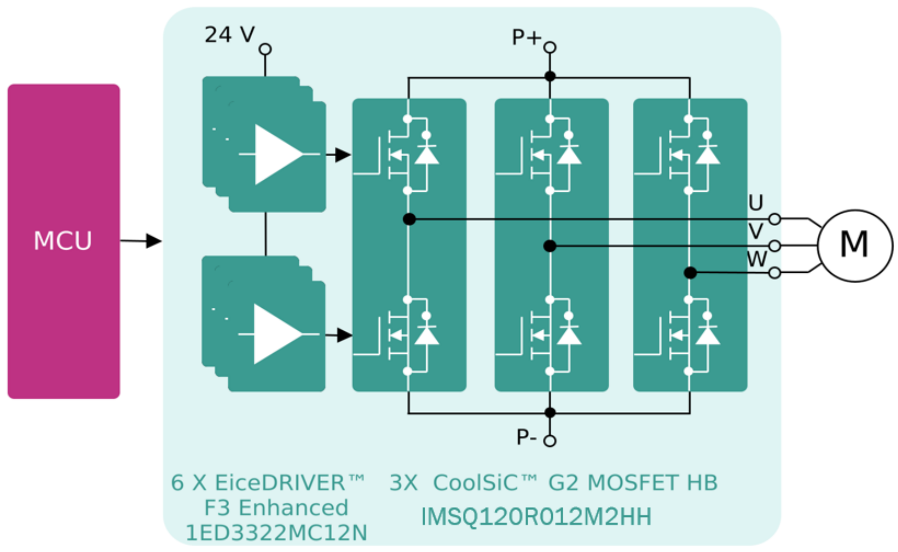


Figure 3 **Block diagram**

1.3 Main features

- 3-phase inverter ready for servo motor integration
- CoolSiC™ MOSFET 1200 V G2, 12 mΩ in Q-DPAK package
- Compact design: PCB diameter 110 mm, 120 mm considering the heat sink
- Single FR4 PCB with a heat sink
- Operation without a fan, cooling just by natural convection
- Short-circuit protection via DESAT
- Overcurrent detection and overtemperature detection
- Input voltage: 350 V to 800 V (DC)

1.4 Board parameters and technical data

Table 2 Key parameters

Parameter	Value	Condition
Input voltage range (DC)	350 V to 800 V	–
Switching frequency f_{sw}	4 kHz to 16 kHz	With derating for f_{sw} > 8 kHz
Output frequency f_{out}	0 Hz to 599 Hz	–
Nominal output current (AC, 3-phase)	9 A_{rms}	f_{sw} = 8 kHz, V_{DC}= 600 V
Output max current (AC, 3-phase)	27 A_{rms}	f_{sw} = 8 kHz, V_{DC}= 600 V, 250 ms
Output power P_{out}	6.5 kW	f_{sw} = 8 kHz, V_{DC}= 600 V
Auxiliary power supply	24 V ± 20%	External input, safety extra-low voltage (SELV)
Ambient temperature T_A	0°C to 40°C	–

2 System and functional description

The REF-SMD5KIMSQM2INV board is intended for evaluating Infineon CoolSiC™ MOSFETs G2 in an integrated servo drive application.

Note: The control of the servo motor is not included in the scope of this document.

2.1 Power inverter board connections

The following minimum connections are required for running this power inverter board (see Figure 4):

- An auxiliary power supply connection (input): 24 VDC from an external power supply
- Controller board connection: PSOC™ Control C3 controller board (KIT_PSC3M5_CC2)
- A DC link connection (input): 350 VDC ~ 800 VDC from an external power supply
- A 3-phase AC (output) connection to a 3-phase motor or resistor-inductor (RL) load

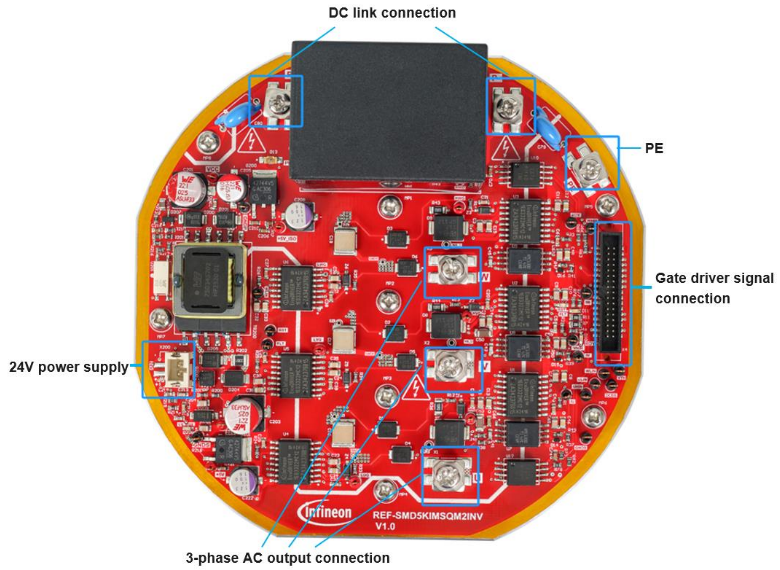


Figure 4 Power inverter board connections

Figure 5 Power inverter board bottom

2.1.1 I/O connectors and test points

The following tables provide the general information about the connectors of the REF-SMD5KIMSQM2INV evaluation board.

Table 3 Board connectors

Pin	Label	Function
P+, P-	P+, P-	Power supply input for DC link
PE	PE	Protective earthing
U, V, W	U, V, W	AC power output for motor
24V	P24V	Auxiliary power supply input

Table 4 Test points

Pin	Label	Function
HUG, HVG, HWG	GH	High-side gate test point
LUG, LVG, LWG	GL	Low-side gate test point
IU+, IV+, IW+	I+	Current signal test point
UHIN, VHIN, WHIN, ULIN, VLIN, WLIN	PWM	Gating PWM signal test point
US_D, VS_D, WS_D	U, V, W	High-side source test point
P+, GNDP	P+, GNDP	Power supply test point
FLT	FLT	Gate driver FLT test point
RST	RST	Gate driver RST test point
RDY	RDY	Gate driver RDY test point
DCBSENSE	DCBS	DC bus sensor test point
VTH	VTH	NTC test point
VCC	VCC	18 V test point
24V	24V	24 V test point
GNDS	GNDS	Signal GND test point
+5V	+5V	+5 V test point
+5V_ISO	+5V_ISO	Isolation 5 V test point

2.1.2 Control interface

Table 5 34-pin interface connector for the control board

Pin number	Pin	Details
1	BRD_INF	Not connected (NC)
2	RDY	Gate driver ready output
3	STOBTN#	Not connected
4	FLT	Gate driver fault output, active LOW
5	I2C_CLK	Not connected
6	WHN	High-side gate driver input, phase W
7	I2C_DATA	Not connected
8	WLIN	Low-side gate driver input, phase W
9	BRD_INFO2	Not connected
10	VHIN	High-side gate driver input, phase V
11	RST	Gate driver reset input, active LOW
12	VLIN	Low-side gate driver input, phase V
13	RELAY_CTRL	Not connected
14	UHIN	High-side gate driver input, phase U
15	STO_ACK	Not connected
16	ULIN	Low-side gate driver input, phase U
17	WAC_W/NTC_BR	Not connected
18	DSD_CLK	Not connected
19	IW+	Phase W current positive
20	IW_DSD2	Not connected
21	IV+	Phase V current positive
22	IV_DSD1	Not connected
23	IU+	Phase U current positive
24	IU_DSD0	Not connected
25	VAC_V/VPFC	Not connected
26	DCBSENSE	DC bus voltage
27	VAC_U/IPFC	Not connected
28	VTH	Board temperature
29	PFC_GATE_M5	Not connected
30	BRAKE_GATE_M5	Not connected
31	GNDS	Ground
32	+5V	+5 V
33	NC	Not connected
34	NC	Not connected

2.2 Power and gate driver stage

2.2.1 CoolSiC™ IMSQ120R012M2HH MOSFET power switches

IMSQ120R012M2HH is a CoolSiC™ MOSFET G2 in single half-bridge configuration. On this board, there are three devices used to achieve a full three-phase bridge inverter.

Main features include:

- Half-bridge with CoolSiC™ MOSFET 1200 V G2, 121 A, 12 mΩ (at V_{GS} = 18 V, T_{vj} = 25°C)
- Optimized internal layout for fast switching
- Very low switching losses
- Short-circuit withstand time 2 µs
- Robust body diode for hard commutation
- Robust against parasitic turn on; 0 V turn-off gate voltage can be applied
- .XT interconnection technology for leading thermal performance

2.2.2 EiceDRIVER™ 1ED3322MC12N gate driver

For driving CoolSiC™ MOSFETs, EiceDRIVER™ 1ED3322MC12N Enhanced (1ED-F3) single-channel isolated gate drivers are used.

Key features include:

- Integrated protection features such as short-circuit protection (DESAT), soft-off, active Miller clamp, and active shutdown
- Up to +6 A/–8.5 A typical output peak current
- 40 V absolute maximum output supply voltage V_{CC2}
- High common-mode transient immunity (CMTI) > 300 kV/µs
- 3.3 V and 5 V input supply voltage V_{CC1}
- DSO-16 wide-body package with 8 mm creepage distance
- Certifications: UL 1577 with V_{ISO} = 5.7 kV(rms) and IEC 60747-17 with V_{IORM} = 1767 V (peak, reinforced)

2.2.3 Auxiliary power supply

For auxiliary power supplies, connect the REF-SMD5KIMSQM2INV board to an external 24 V SELV power supply input. Using this 24 V supply, the following power outputs are generated:

- An isolated 18 V output is provided through a flyback converter, which is used as the high-voltage-side gate driver supply (V_{CC2}) and for other circuits requiring isolation
- An isolated 5 V output is generated from the same flyback converter, which is used as the isolated power supply for the high-voltage side of isolation amplifier ICs for voltage and temperature sense
- A non-isolated 5 V output is generated using an LDO and is used as the low-voltage-side gate driver supply (V_{CC1}) and for other circuits that do not require isolation

2.3 Board protection and sensing

On this board, hardware-based short-circuit protection is provided, which enables a rapid safe shutdown with adjustable turn-off time. This board also supports the measurement of the input DC voltage, phase currents, and PCB temperature.

2.3.1 Short-circuit protection

The EiceDRIVER™ 1ED3322MC12N Enhanced (1ED-F3) gate drivers [2] used on this board are optimized for driving SiC MOSFETs and offer accurate short-circuit protection via DESAT detection to protect the SiC switches from destruction during short-circuit events.

2.3.1.1 How to trigger DESAT protection

The simplified sequence for the desaturation protection is as follows:

1. When a short-circuit occurs, the current flowing through the SiC MOSFET increases rapidly
2. The DESAT pin is connected to the drain of the SiC MOSFET. Therefore, its voltage V_{DESAT} depends on the drain current (I_D) and the on-state resistance ($R_{DS(on)}$) of the MOSFET, $V_{DESAT} = I_D \times R_{DS(on)}$
3. The voltage at the DESAT pin reaches the DESAT threshold level $V_{DESATth} = 9$ V
4. The gate driver IC switches off the SiC MOSFET and pulls the FLT signal on FLT_N LOW to indicate the fault and latches the signal
5. The red LED D11 (FLT) turns on and the green LED D12 (RST) turns off

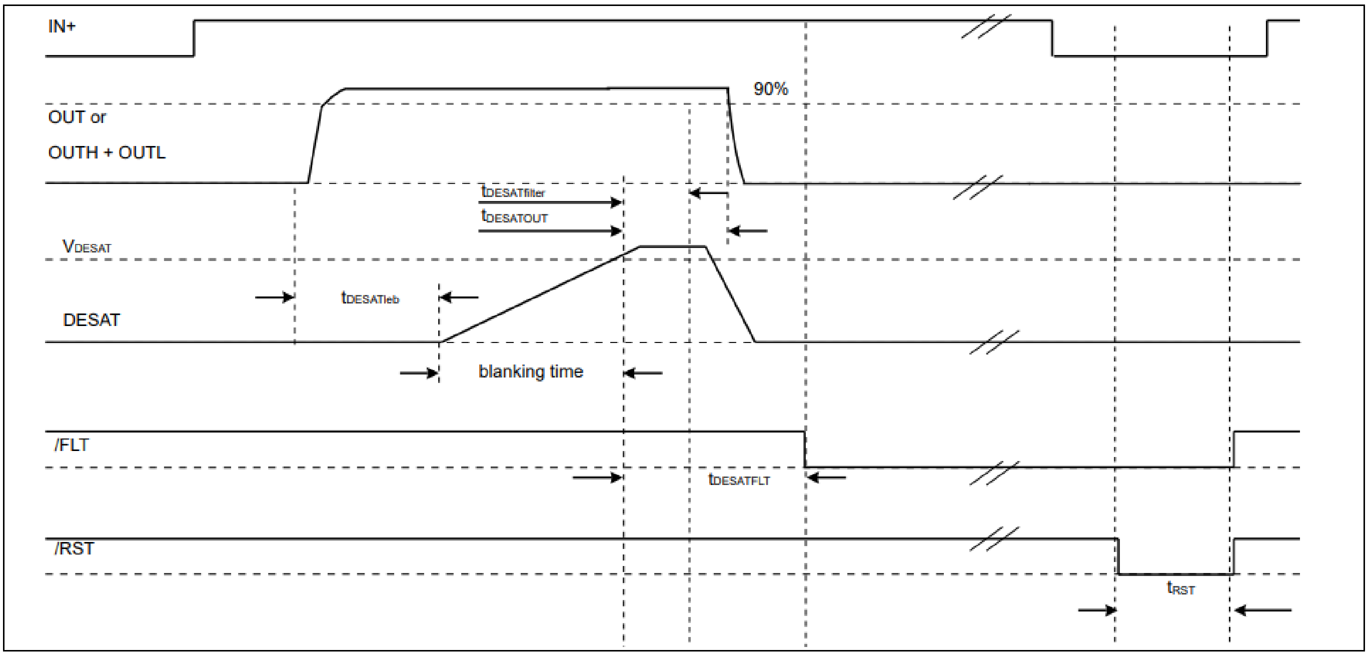


Figure 6 **DESAT hard-off behavior**

2.3.1.2 DESAT blanking time

A high current through the SiC MOSFET causes an increase of V_{DS}. Due to the presence of the diode (D_{DESAT}), after the leading-edge blanking time ($t_{DESATleb}$) elapses, an internal current source (I_{DESATC}, 510 µA) starts charging up the external capacitor (C_{DESAT}). When the DESAT voltage at C_{DESAT} rises and reaches the DESAT reference level ($V_{DESATth}$, 9 V), the gate is turned off by the digital core of the output section.

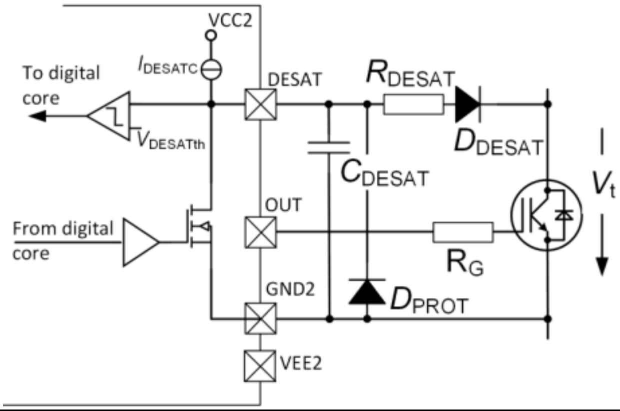


Figure 7 **DESAT circuit snippet**

The external capacitor (C_{DESAT}) defines the DESAT blanking time ($t_{DESATBLANK}$) as shown in the following equation [3]:

$$C_{DESAT} = \frac{I_{DESATC} \times t_{DESATBLANK}}{V_{DESATth}}$$

Equation 1 **External capacitor (C_{DESAT})**

On this board, C_{DESAT} = 33 pF is selected, corresponding to a blanking time ($t_{DESATBLANK}$) of about 700 ns, which results in a total gate turn off time of <2 µs (see Section 5.2.2 for details).

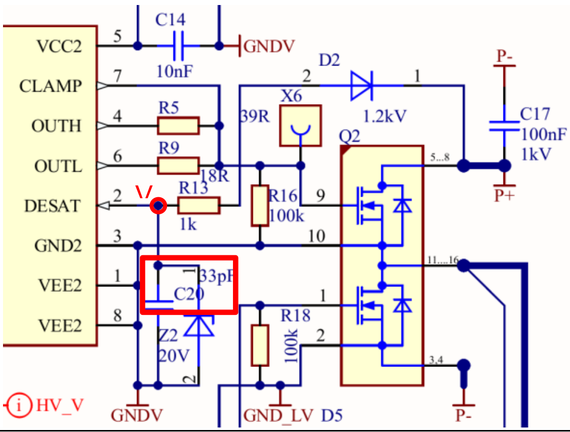


Figure 8 **DESAT circuit**

2.3.1.3 Clear DESAT status

Do the following to clear the fault:

1. Ensure that the gate of the external power transistor is completely discharged and it is turned off
2. Remove the source of the short-circuit
3. Apply LOW signal to the gate driver reset input pin (pin 11, RST) for longer than 800 ns

The fault signal (pin 4, FLT) will then be cleared on the rising edge of the reset signal.

Note: *The DESAT status can also be cleared by interrupting the gate driver power supply.*

2.3.2 Current sense

Phase-current sensing is realized by shunt measurements where the current signals are routed to the control interface connector via a reinforced isolation amplifier.

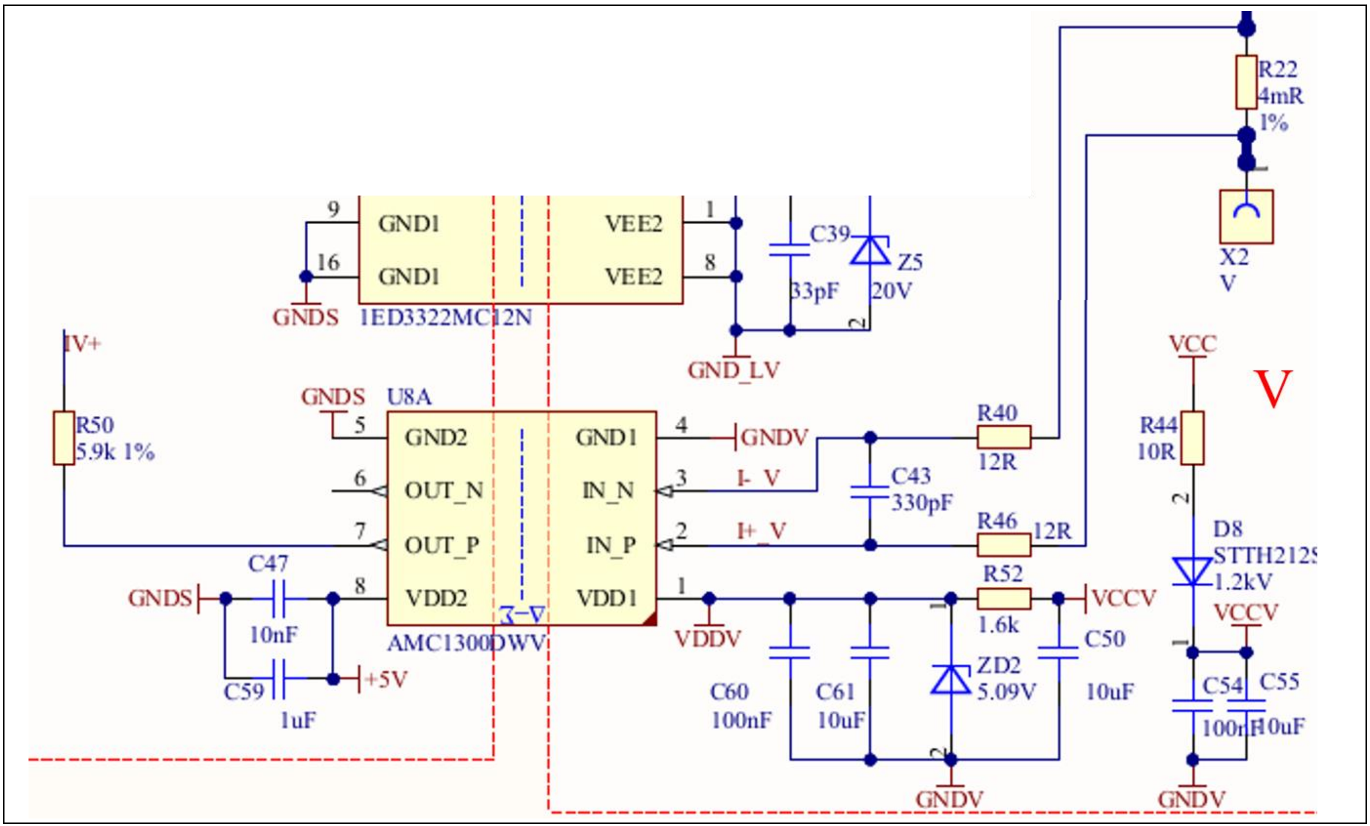


Figure 9 **Current sense circuit**

The current sampling shunt resistor is 4 mΩ. The differential input voltages ($V_{INP} - V_{INN}$) of the isolated operational amplifier are in the range from –250 mV to +250 mV. The device provides a linear response with a nominal gain of 8.2. Therefore, the maximum current measurable range results into:

$$I_{\max\_range} = \pm\frac{250\ mV}{4\ \text{m}\Omega} = \pm 62.5\ \text{A}$$

Equation 2 **Maximum current measurable range**

2.3.3 Voltage and temperature sense

To implement DC bus voltage sensing, a resistive voltage divider is used to obtain a suitable voltage input range for the ACPL-C87A-500E reinforced isolation amplifier, which provides a differential output voltage proportional to the DC bus voltage. The voltage signal is then processed by an operational amplifier and passed to the interface connector.

The isolated operational amplifier input voltage divider value is calculated as follows:

$$V_{\text{DC}} = \frac{2\ k\Omega}{6 \times 120\ \text{k}\Omega + 2\ \text{k}\Omega} \times V_{\text{BUS}}$$

Equation 3 **Isolated operational amplifier input voltage divider**

Voltage conversion through operational amplifier leads to the following relationship between the voltage sense signal $V_{DCBSENSE}$ and the actual DC bus voltage V_{BUS}:

$$V_{\mathrm{DCBSENSE}} = \frac{5.7\ k\Omega}{3\ \mathrm{k}\Omega} \times V_{\mathrm{DC}} = \frac{5.7\ k\Omega}{1083\ \mathrm{k}\Omega} \times V_{\mathrm{BUS}}$$

Equation 4 Voltage conversion

Temperature sensing is realized in a similar way whereas the voltage input for the isolation amplifier comes from the NTC-type thermistor mounted on the PCB near the middle CoolSiC™ switch. Both isolation amplifier and operational amplifier gains are 1 V/1 V.

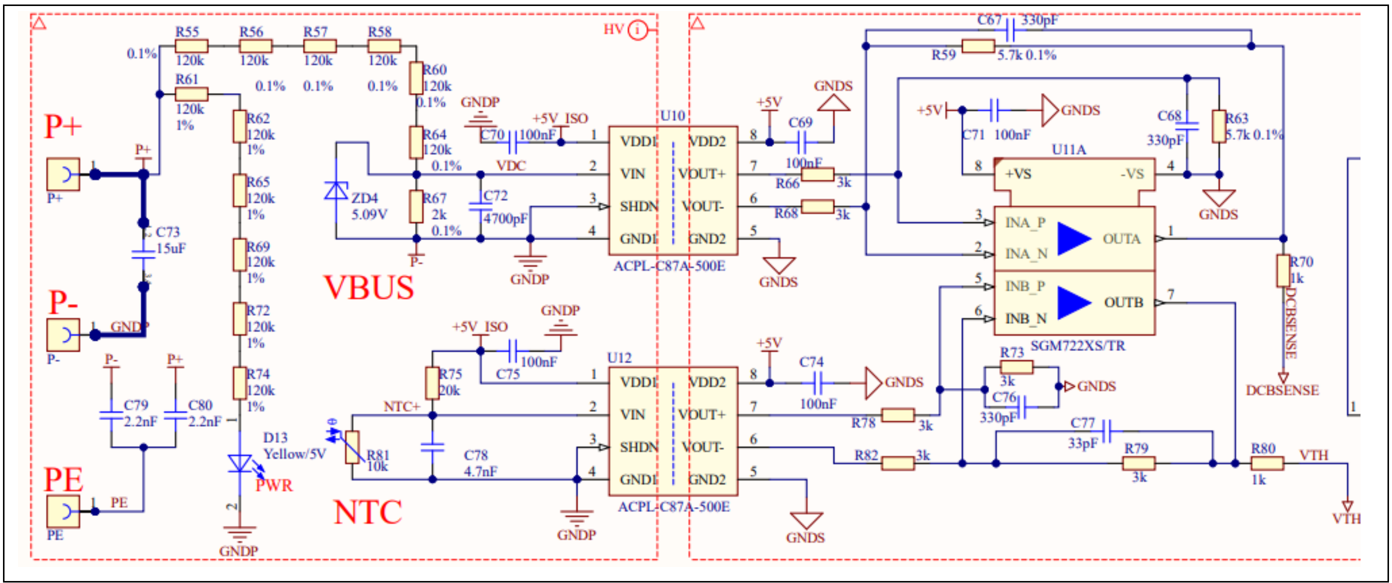


Figure 10 DC bus voltage sense and NTC temperature sense circuit

3 Basic operation using a PSOC™ Control C3 controller

The REF-SMD5KIMSQM2INV board uses the PSOC™ Control C3M5 Motor Drive Control Card (KIT_PSC3M5_CC2) to demonstrate how to use this board to drive a motor.

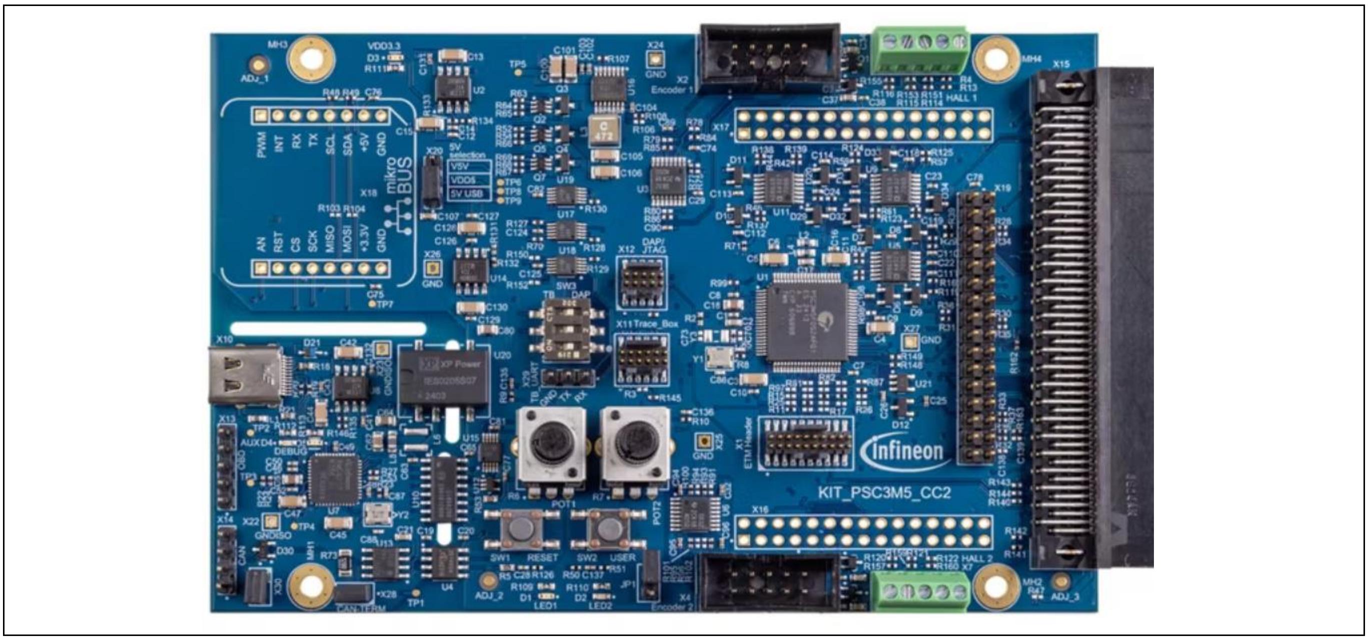


Figure 11 PSOC™ Control C3M5 Motor Drive Control Card (KIT_PSC3M5_CC2)

3.1 Hardware connection

The connection between REF-SMD5KIMSQM2INV and KIT_PSC3M5_CC2 requires an adaptor cable to connect these two boards because the pin spacing is different.

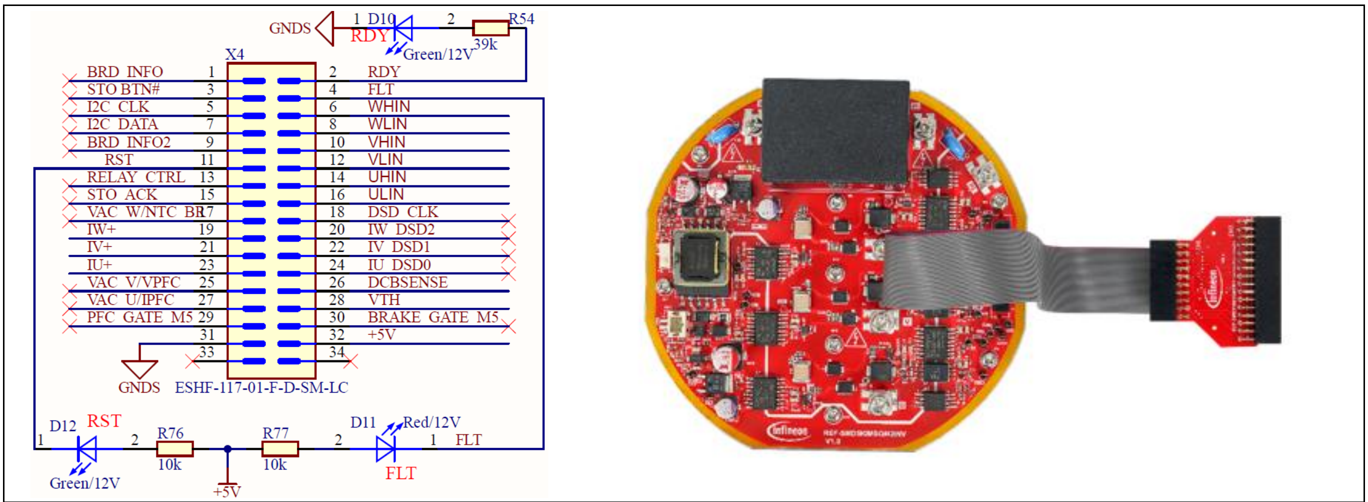


Figure 12 REF-SMD5KIMSQM2INV connection

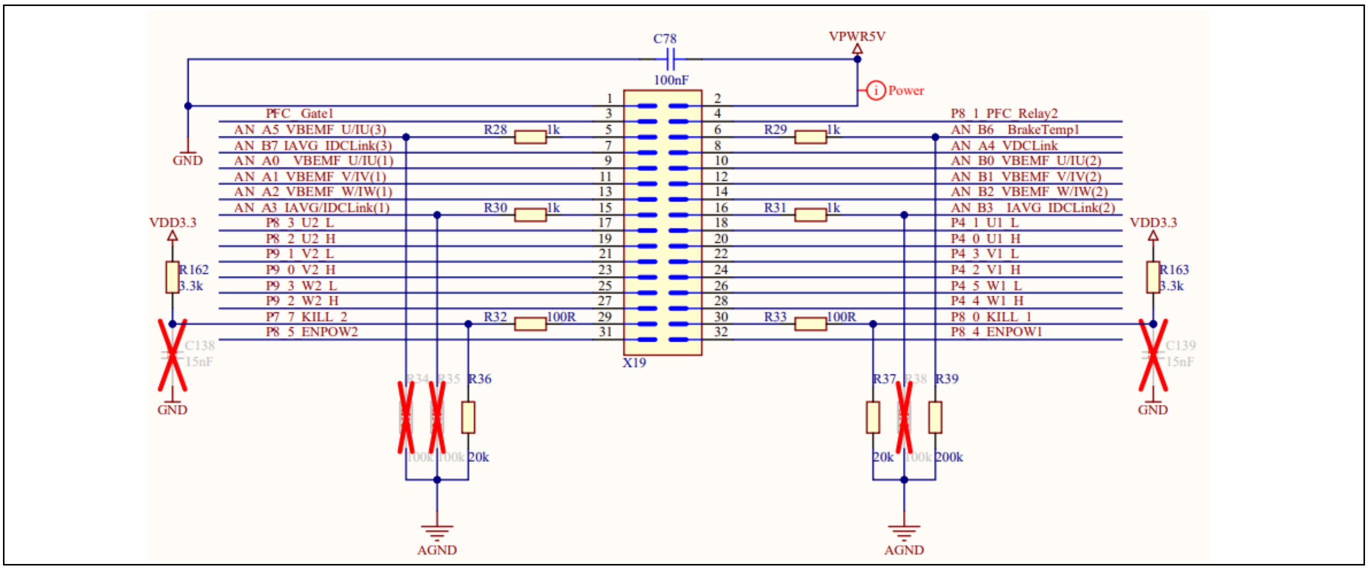


Figure 13 KIT_PSC3M5_CC2 connection

3.2 Create a motor control demo

1. Download and install ModusToolbox™ software (v3.6 or later)
2. Download the ready-to-use example code (*Motor_Control_code.zip*) from the **Design resources** section of the REF-SMD5KIMSQM2INV page and extract it to your local system
3. Open Eclipse for ModusToolbox™ and select a new empty folder as workspace
4. Select **Import Existing Application In-Place** from the **Quick Panel**, select the *PMSM_FOC_SL_with_3-shunt* project, and then click **Finish**

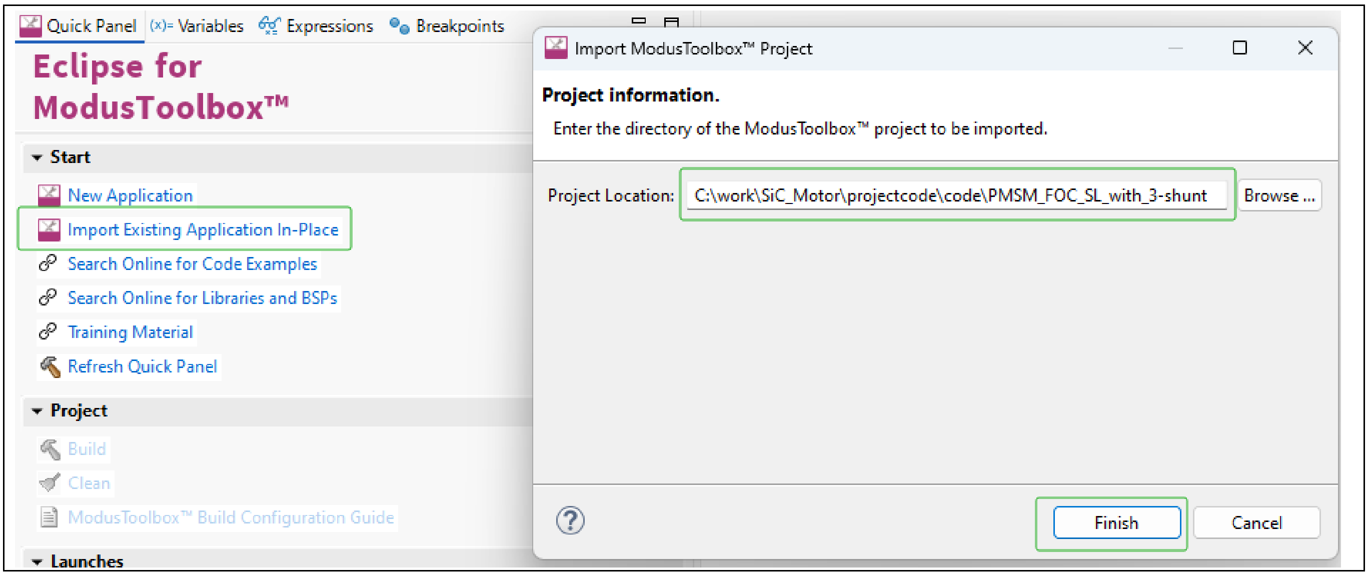


Figure 14 Import Existing Application in ModusToolbox™

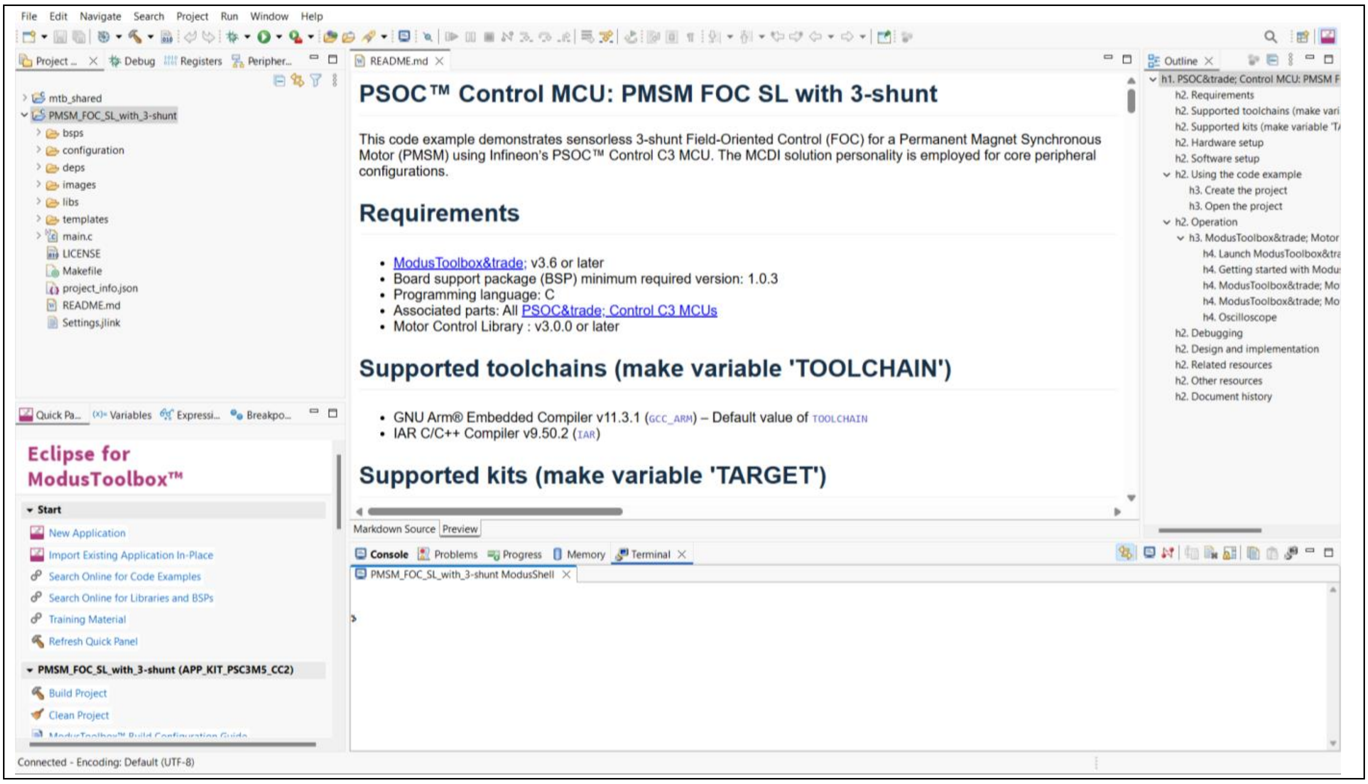


Figure 15 **Application created successfully**

3.3 Run the motor control demo

After importing the project into the ModusToolbox™ application, follow the instructions in the code example README to run the Motor Control Suite.

4 System design

4.1 Schematics

Figure 16 shows the schematics of the auxiliary power supply.

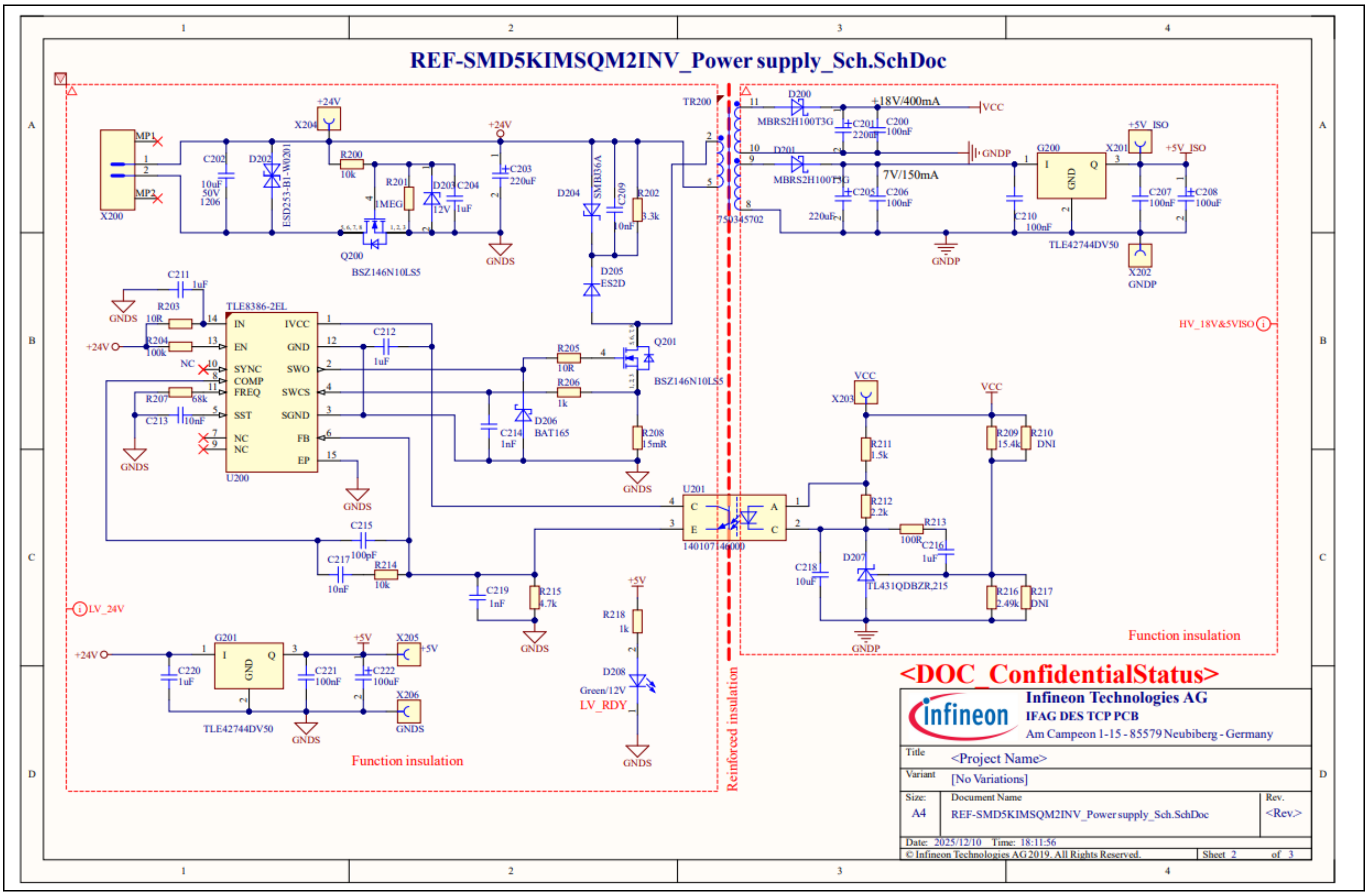


Figure 16 Auxiliary power supply (REF-SMD5KIMSQM2INV)

Figure 17 shows the schematics of the inverter power and gate driver board.

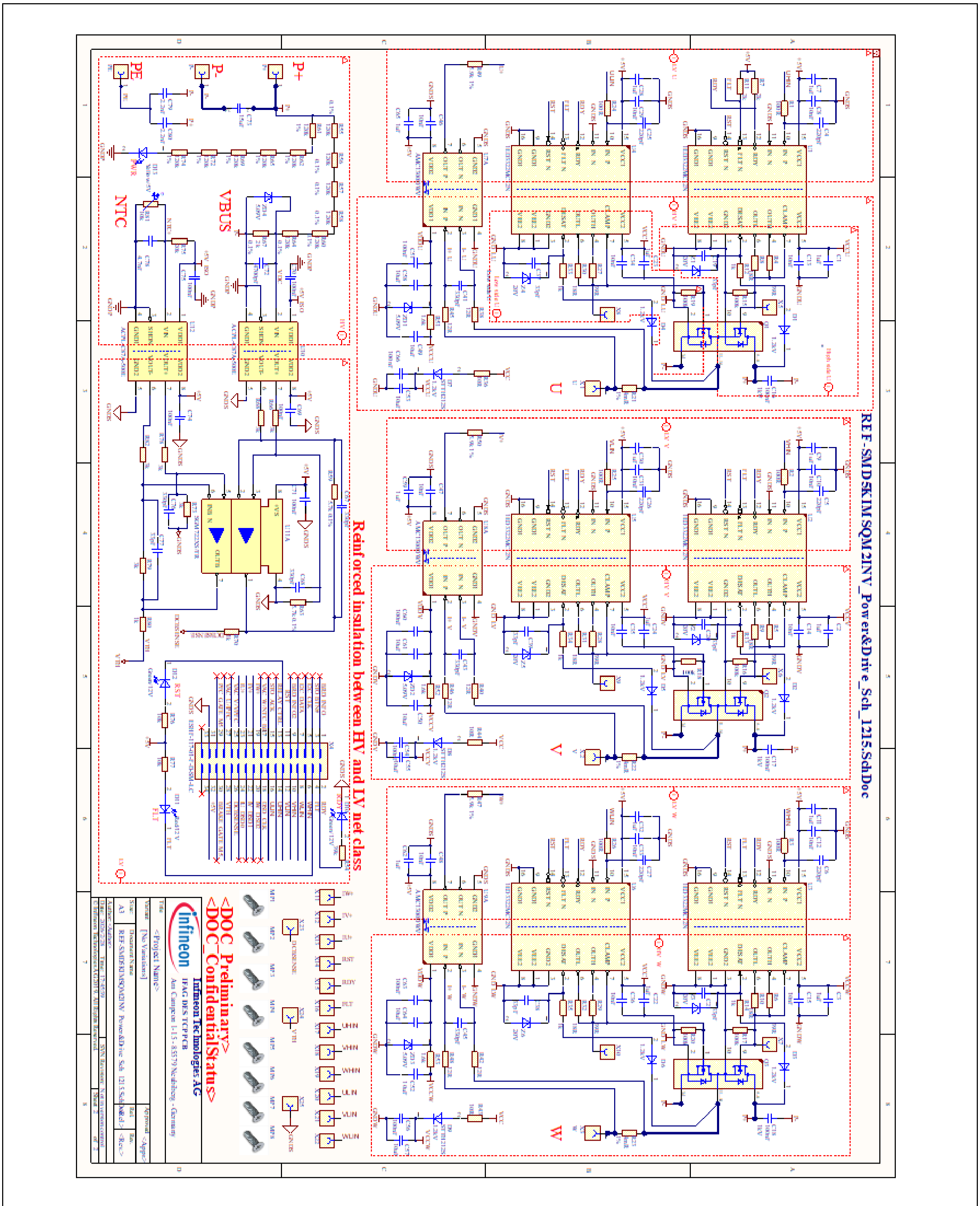


Figure 17 Schematics of power and drive (REF-SMD5KIMSQM2INV)

4.2 Layout

The inverter power and gate driver board is a 4-layer FR4 PCB. The top, bottom, and inner-layer layouts are shown in Figure 18 to Figure 21.

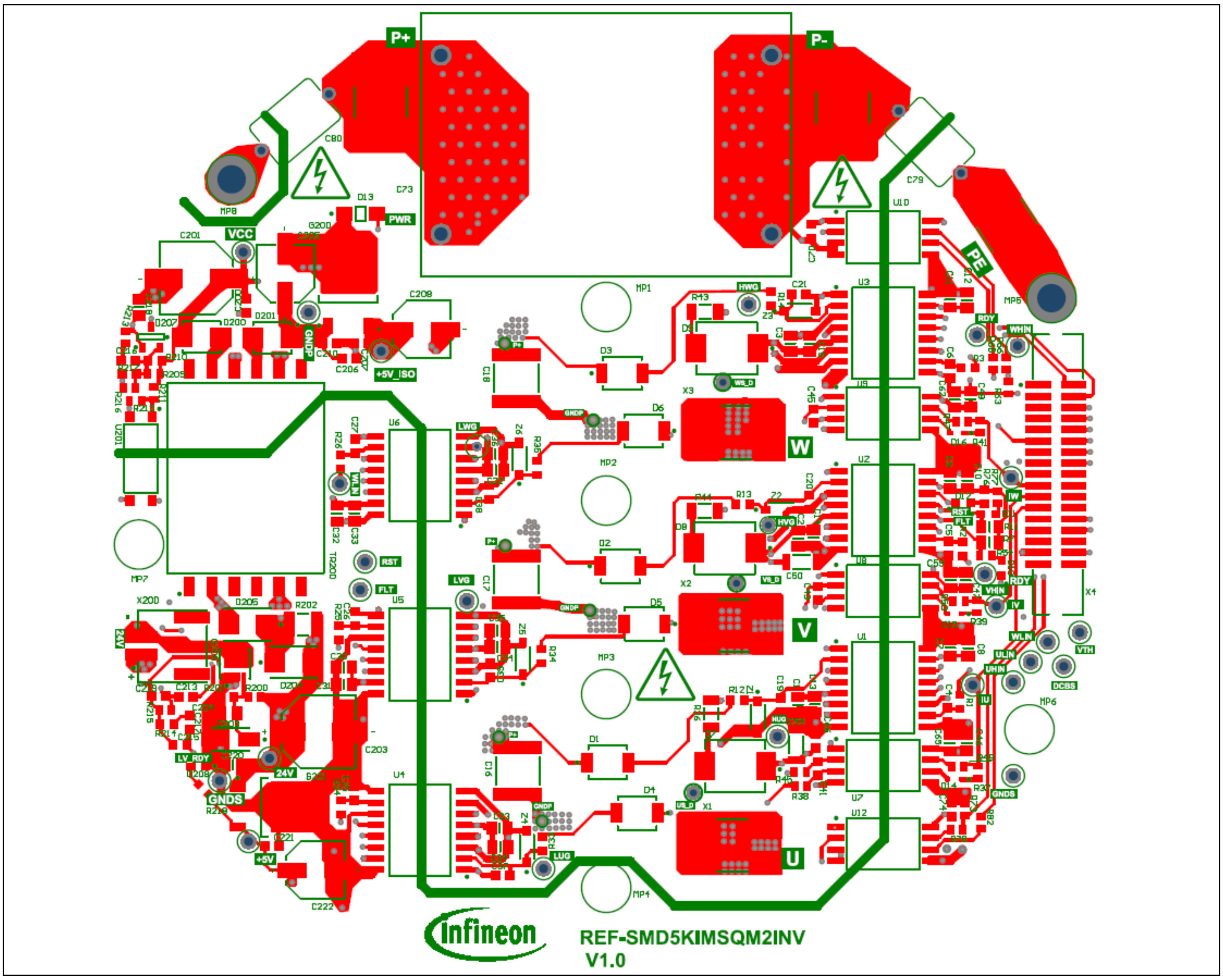


Figure 18 Top layer REF-SMD5KIMSQM2INV

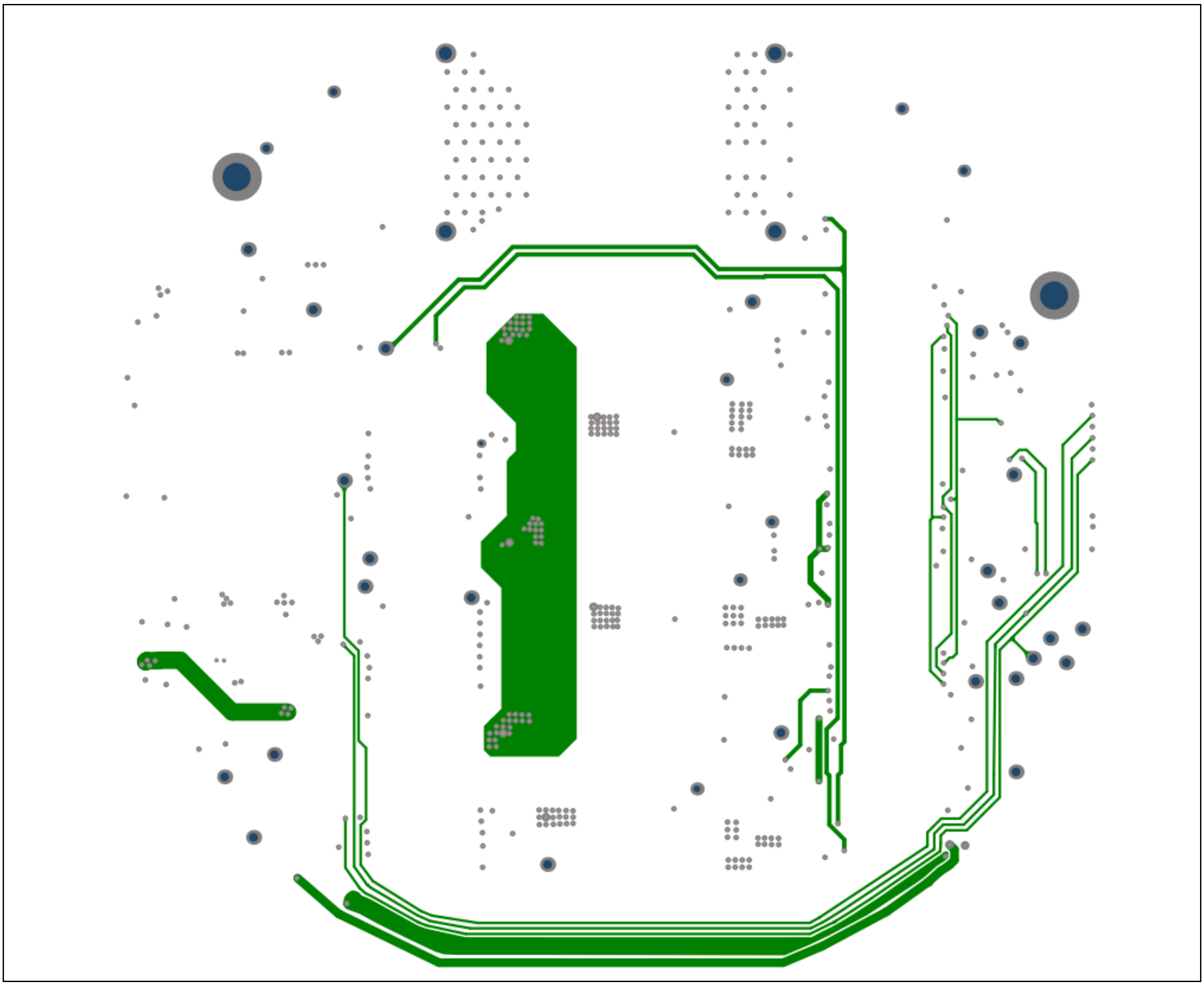


Figure 19 **Inner layer 1 REF-SMD5KIMSQM2INV**

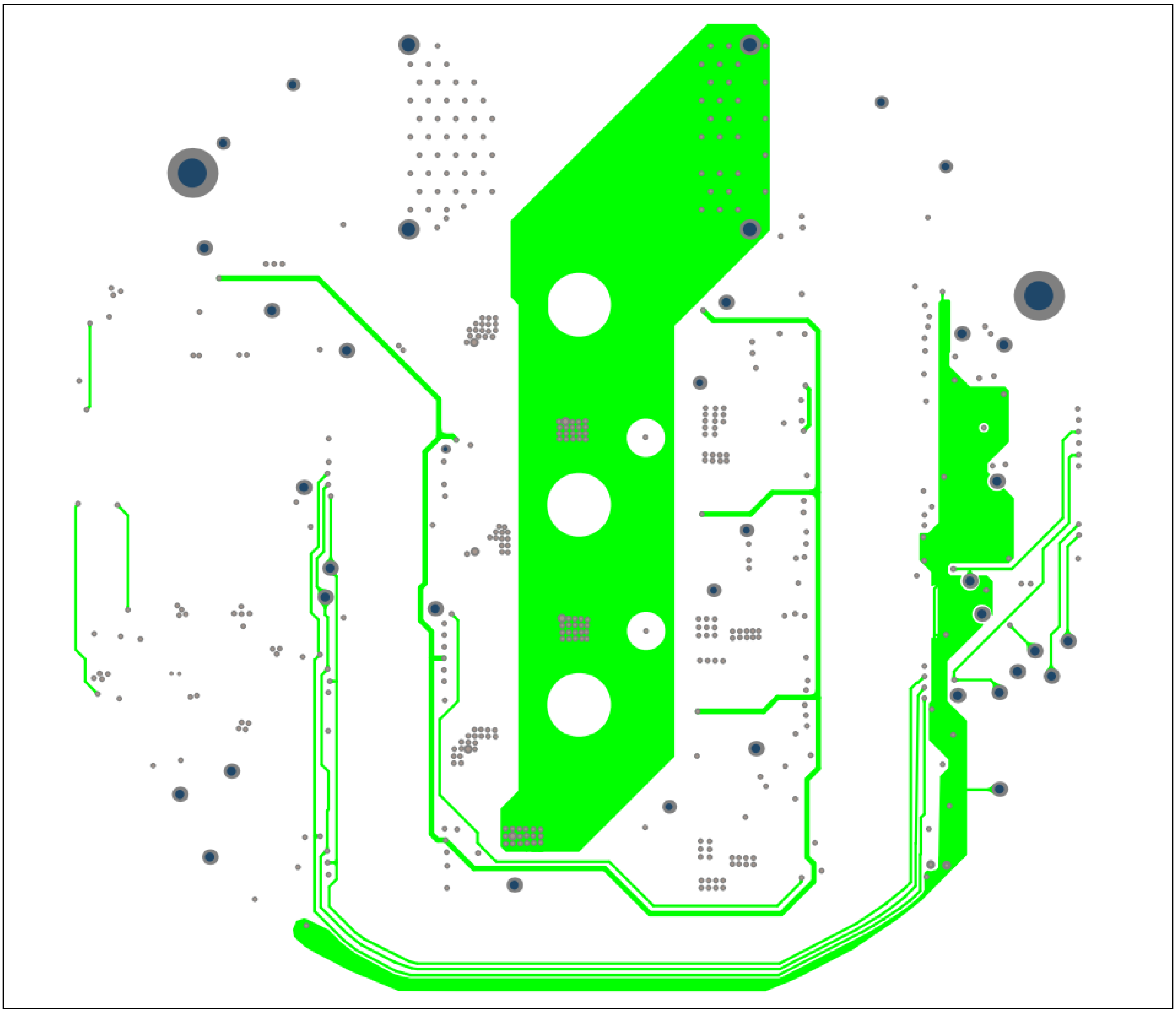


Figure 20 Inner-layer 2 REF-SMD5KIMSQM2INV

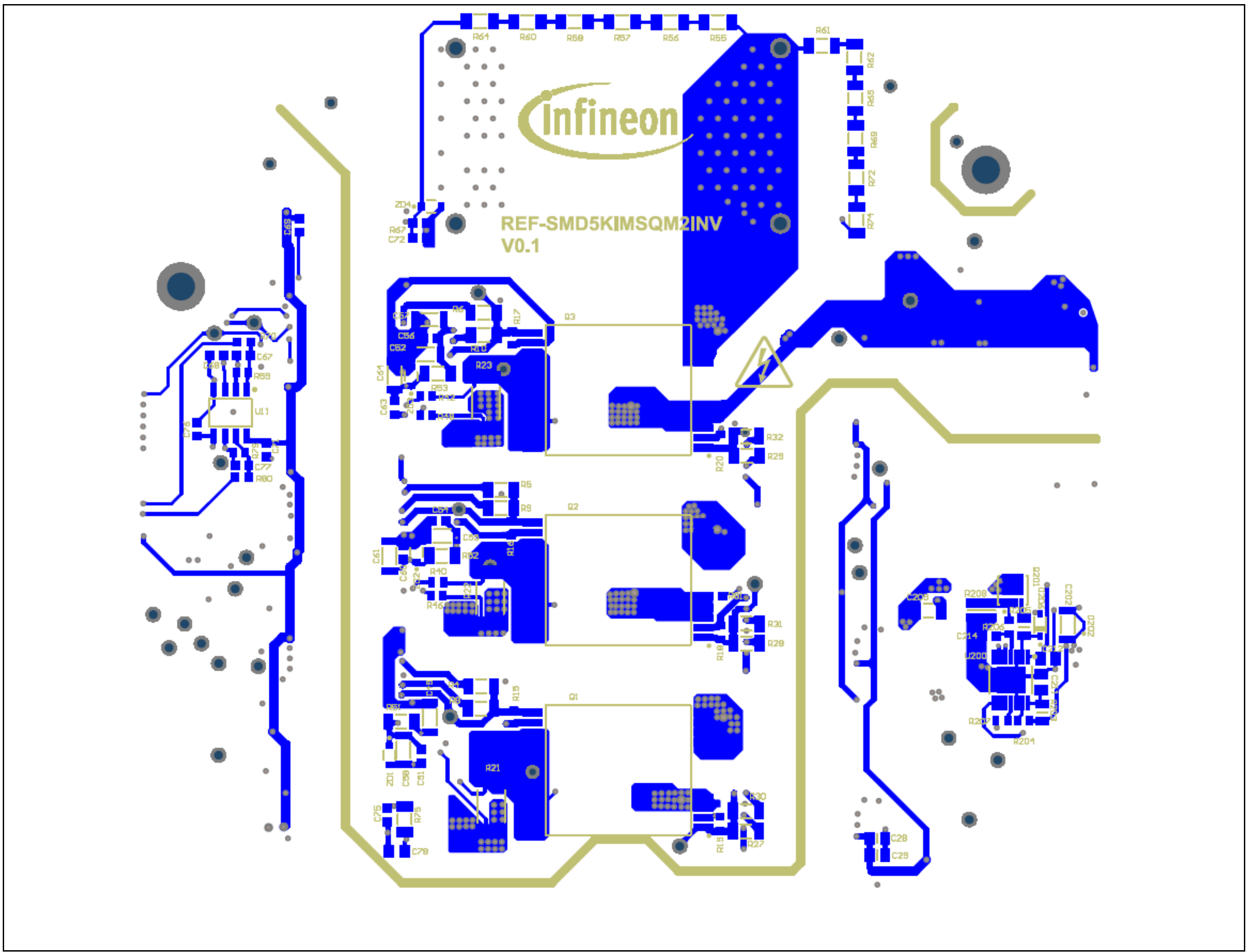


Figure 21 Bottom layer REF-SMD5KIMSQM2INV

4.3 Bill of materials (BOM)

The complete bill of materials is available on the reference board webpage.

Table 6 BOM of the power board

No.	Designator	Value	Description	Manufacturer	Manufacturer order number
1	C73	15µF	CAP / FILM / 15µF / 1.1kV / 5% / MKP (Metallized Polypropylene) / -40°C to 105°C / Capacitor, Non-polarized, Radial, 4 pin, 42.00 mm L X 30.00 mm W X 46.00 mm H body / THT / -	Würth Elektronik	890734428004CS

No.	Designator	Value	Description	Manufacturer	Manufacturer order number
2	D1, D2, D3, D4, D5, D6	1.2kV	Automotive high voltage ultrafast rectifier	STMicroelectronics	STTH112UFY
3	D7, D8, D9	1.2kV	High Voltage Ultrafast Diode	STMicroelectronics	STTH212S
4	D200, D201	MBRS2H100T3G	Surface Mount Schottky Power Rectifier, 2.0A/100V	ON Semiconductor	MBRS2H100T3G
5	D202	ESD253-B1-W0201	Bi-directional TVS Protection Device	Infineon Technologies	ESD253-B1-W0201
6	D203	12V	3.0 Watt Surface Mount Silicon Zener Diode, 12V	Micro Commercial Components	3SMAJ5927B-TP
7	D204	SMBJ36A	600 Watt Transient Voltage Suppressor, Uni-directional, 36V	ON Semiconductor	SMBJ36A
8	D205	ES2D	Fast Rectifier	ON Semiconductor	ES2D
9	D206	BAT165	Medium Power AF Schottky Diode	Infineon Technologies	BAT165
10	D207	TL431QDBZR,215	Adjustable Precision Shunt Regulator	Nexperia	TL431QDBZR,215
11	G200, G201	TLE42744DV50	Low Dropout Linear Voltage Regulator, 5.0V Output	Infineon Technologies	TLE42744DV50
12	Q1, Q2, Q3	–	Small Signal Dual N-Channel Enhancement Transistor, Pin 1 Gate, 2 Kelvin Sense, 3 Source, 4 Source, 5 Drain, 6 Drain, 7 Drain, 8 Drain, 9 Gate, 10 Kelvin Sense, 11 Source, 12 Source, 13 Drain, 14 Drain, 15 Drain, 16 Drain 16 Pins	Infineon Technologies	IMSQ120R012M2HH
13	Q200, Q201	BSZ146N10LS5	OptiMOS™ 5 Power-Transistor, 100V	Infineon Technologies	BSZ146N10LS5

No.	Designator	Value	Description	Manufacturer	Manufacturer order number
14	R21, R22, R23	4mΩ	RES / STD / 4mΩ / 3W / 1% / 75ppm/K / -65°C to 170°C / 2512(6432) / SMD / -	Isabellenhutte	BVT-I-R004
15	R208	15mΩ	RES / STD / 15mΩ / 1W / 5% / 300ppm/K / -55°C to 155°C / 612 / SMD / -	Vishay	RCWE061215L0JMEA
16	R209	15.4kΩ	RES / STD / 15.4k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060315K4FK
17	TR200	750345702	Transformer, 46uH	Würth Elektronik	750345702
18	U1, U2, U3, U4, U5, U6	1ED3322MC12N	Single-Channel Isolated Gate Driver IC with DESAT and Soft-off	Infineon Technologies	1ED3322MC12N
19	U7, U8, U9	AMC1300DWV	250mV Input, Reinforced Isolated Amplifier	Texas Instruments	AMC1300DWV
20	U10, U12	ACPL-C87A-500E	Precision Optically Isolated Voltage Sensor	Broadcom Inc.	ACPL-C87A-500E
21	U11	SGM722XS/TR	11MHz, Rail-to-Rail I/O CMOS Operational Amplifier	SGMICRO	SGM722XS/TR
22	U200	TLE8386-2EL	Basic Smart Boost Controller	Infineon Technologies	TLE8386-2EL
23	U201	140107146000	Optocoupler Phototransistor	Würth Elektronik	140107146000
24	Z1, Z2, Z3, Z4, Z5, Z6	20V	Zener Voltage Regulator	ON Semiconductor	MMSZ5250BT1G
25	ZD1, ZD2, ZD3, ZD4	5.09V	Zener Voltage Regulator, 5.09V, 200mW	–	LUDZS5.1BT1G

5 System performance

5.1 dV/dt and dead-time optimization with double-pulse test

The drive is designed for short motor cable lengths under 10 m. For this reason, set the voltage slope dV/dt to approximately 10 V/ns by selecting the gate resistors $R_{G(on)}$ and $R_{G(off)}$ as applicable.

For double-pulse test at gate S2, set the following:

- S1, S3, S4, S5, S6 = Off
- DC connected to PE (measurement without different probe at gate possible)
- M3 = PE, DC, and GND HV-side

Voltage measurement

- V_{DS} measurement at M1 and M3
- V_{GS} measurement at M2 and M3

Current measurement

- I_L measurement M4

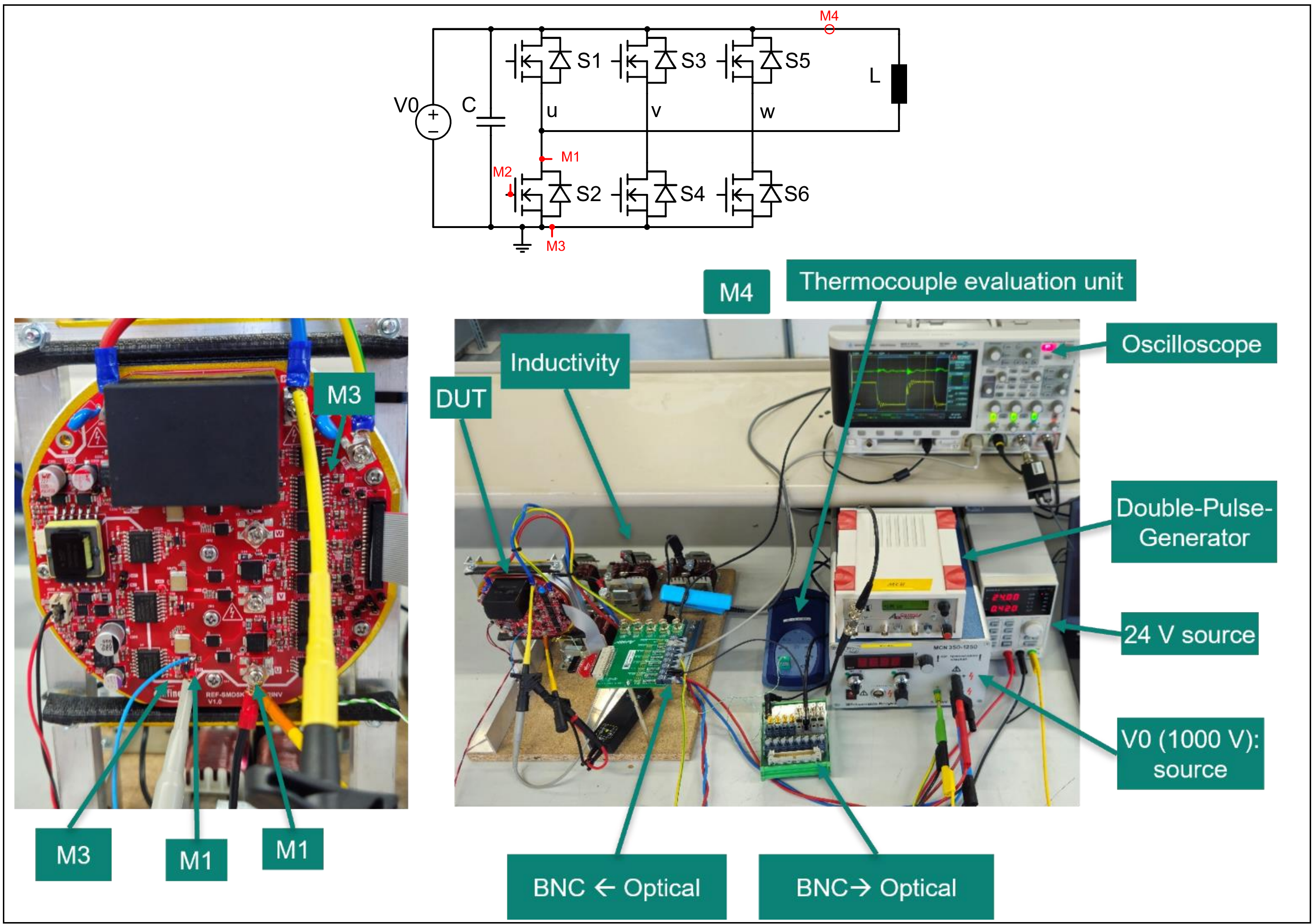
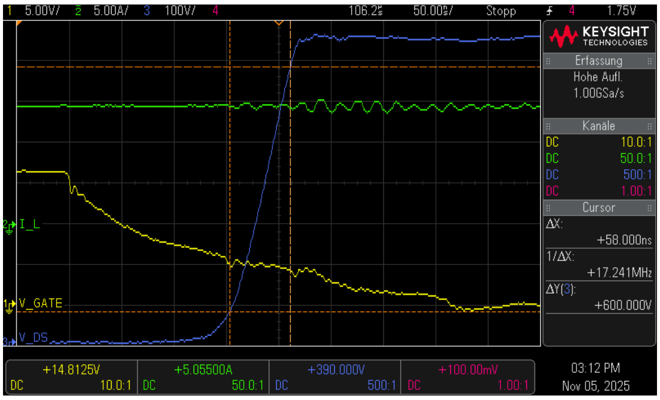
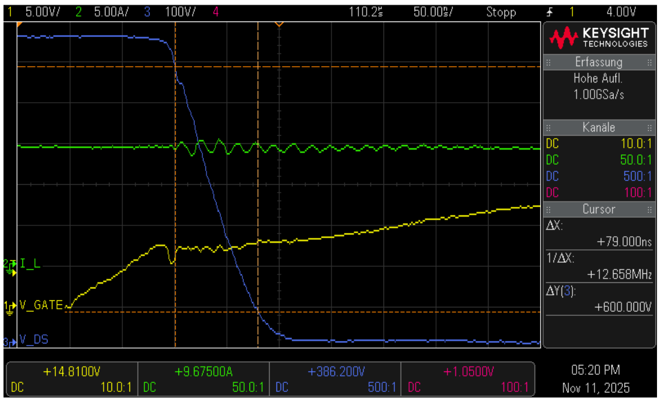


Figure 22 **Double-pulse test setup**

- dV/dt at $I_{L,peak}$ = 15 A, V_{DS} = 750 V, T = 25°C



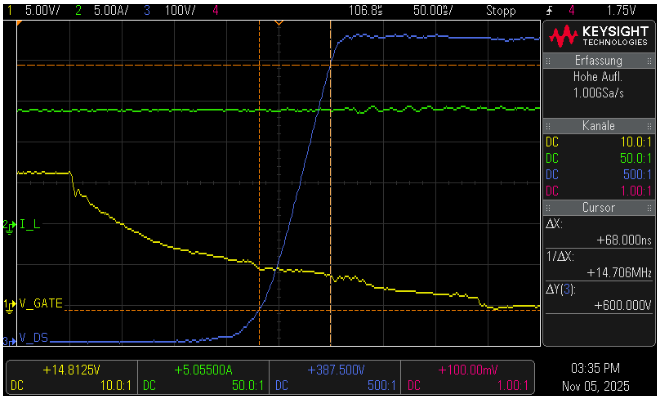
- $R_{G(off)}$ = 18 Ω
- At 10%, $V_{DS,peak}$, Y1 ≈ 75 V
- At 90%, $V_{DS,peak}$, Y2 ≈ 675 V
- ΔV = 600 V, Δt = 58 ns
- dV/dt(off) = 10.34 V/ns



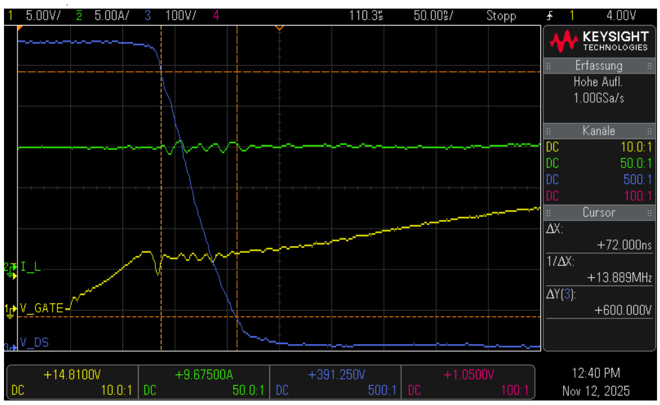
- $R_{G(on)}$ = 39 Ω
- At 10%, $V_{DS,peak}$, Y1 ≈ 75 V
- At 90%, $V_{DS,peak}$, Y2 ≈ 675 V
- ΔV = 600 V, Δt = 79 ns
- dV/dt(on) = 7.59 V/ns

Figure 23 **dV/dt at $I_{L,peak}$ = 15 A, V_{DS} = 750 V, T = 25°C: Switch off vs. switch on**

- dV/dt at $I_{L,peak}$ = 15 A, V_{DS} = 750 V, T = 100°C



- $R_{G(off)}$ = 18 Ω
- At 10%, $V_{DS,peak}$, Y1 ≈ 75 V
- At 90%, $V_{DS,peak}$, Y2 ≈ 675 V
- ΔV = 600 V, Δt = 68 ns
- dV/dt(off) = 8.82 V/ns



- $R_{G(on)}$ = 39 Ω
- At 10%, $V_{DS,peak}$, Y1 ≈ 75 V
- At 90%, $V_{DS,peak}$, Y2 ≈ 675 V
- ΔV = 600 V, Δt = 72 ns
- dV/dt(on) = 8.33 V/ns

Figure 24 **dV/dt at $I_{L,peak}$ = 15 A, V_{DS} = 750 V, T = 100°C: Switch off vs. switch on**

The results confirm that with the gate resistor selection of $R_{G(on)}$ = 39 Ω and $R_{G(off)}$ = 18 Ω, a dV/dt limitation of about ≤ 10 V/ns is obtained.

The double-pulse test measurements have shown that the dead-time switching between half-bridge high-side (HS) to low-side (LS) and vice versa can be set to 500 ns.

5.2 Short-circuit protection with DESAT test

For DESAT pulse test at gate S2, set the following:

- S1, S3, S4, S5, S6 = Off
- DC connected to PE (measurement without different probe at gate possible)
- M3 = PE, DC, and GND HV side
- M1 = Probe with small coupling capacity

Voltage measurement

- V_{DESAT} measurement at M1 and M3
- V_{GS} measurement at M2 and M3
- V_{BUS} measurement at M5 and M3

Current measurement

- I_L measurement at M4

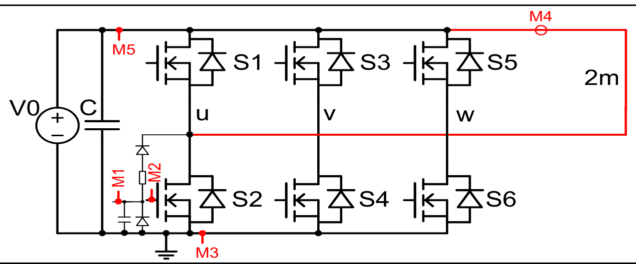


Figure 25 DESAT test setup

5.2.1 DESAT circuit: C_{DESAT} and R_{DESAT}

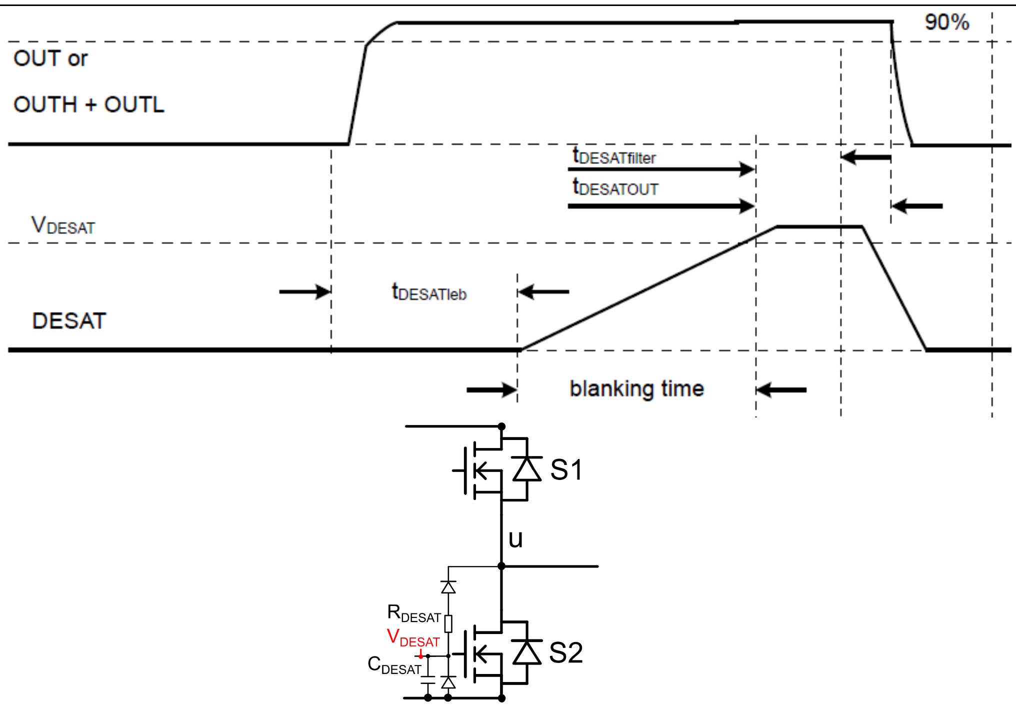


Figure 26 DESAT circuit

5.2.2 DESAT configuration

The total DESAT protection time (t_{total}) is defined as the time from the occurrence of a short-circuit event to the gate driver switching off the SiC MOSFET which is determined by the sum of the leading-edge blanking time ($t_{DESATleb}$), the adjustable blanking time ($t_{DESATBLANK}$), and the desaturation sensing delay ($t_{DESATOUT}$), see Figure 26. For proper protection, t_{total} has to be smaller than the short-circuit withstand time of the MOSFET.

$$t_{total} = t_{DESATleb} + t_{DESATBLANK} + t_{DESATOUT} < t_{sc}$$

Equation 5 Total time

In the CoolSiC™ IMSQ120R012M2HH MOSFET datasheet, the MOSFET short-circuit withstand time t_{sc} = 2 µs. To achieve a total DESAT protection time less than t_{SC}, the blanking time can be adjusted by selecting an appropriate value for the external capacitor (C_{DESAT}). Using the selected C_{DESAT} value of 33 pF and the specified I_{DESAT} (510 µA) and V_{DESAT} (9 V) parameters from the 1ED332xMC12N gate driver datasheet, the blanking time is calculated to be:

$$t_{DESATBLANK} = \frac{V_{DESAT} \times C_{DESAT}}{I_{DESAT}} = \frac{9\,V \times 33\,pF}{510\,\mu A} = 582\,ns$$

Equation 6 Blanking time

Considering a 20% tolerance for C_{DESAT}, the maximum blanking time would be approximately 699 ns. Using $t_{DESATleb}$ (500 ns) and $t_{DESATOUT}$ (430 ns) from the datasheet, the total DESAT protection time is estimated as follows:

$$t_{total} = 500\,ns + 699\,ns + 430\,ns = 1629\,ns < 2\,\mu s$$

Equation 7 Total DESAT protection time

For the external decoupling resistor (R_{DESAT}) a value of 1 kΩ is used, which correspond to the recommended value for a half-bridge topology. See also [3] for details.

The DESAT short-circuit protection test is performed with two different DC bus voltages: V_{BUS} = 500 V and V_{BUS} = 800 V.

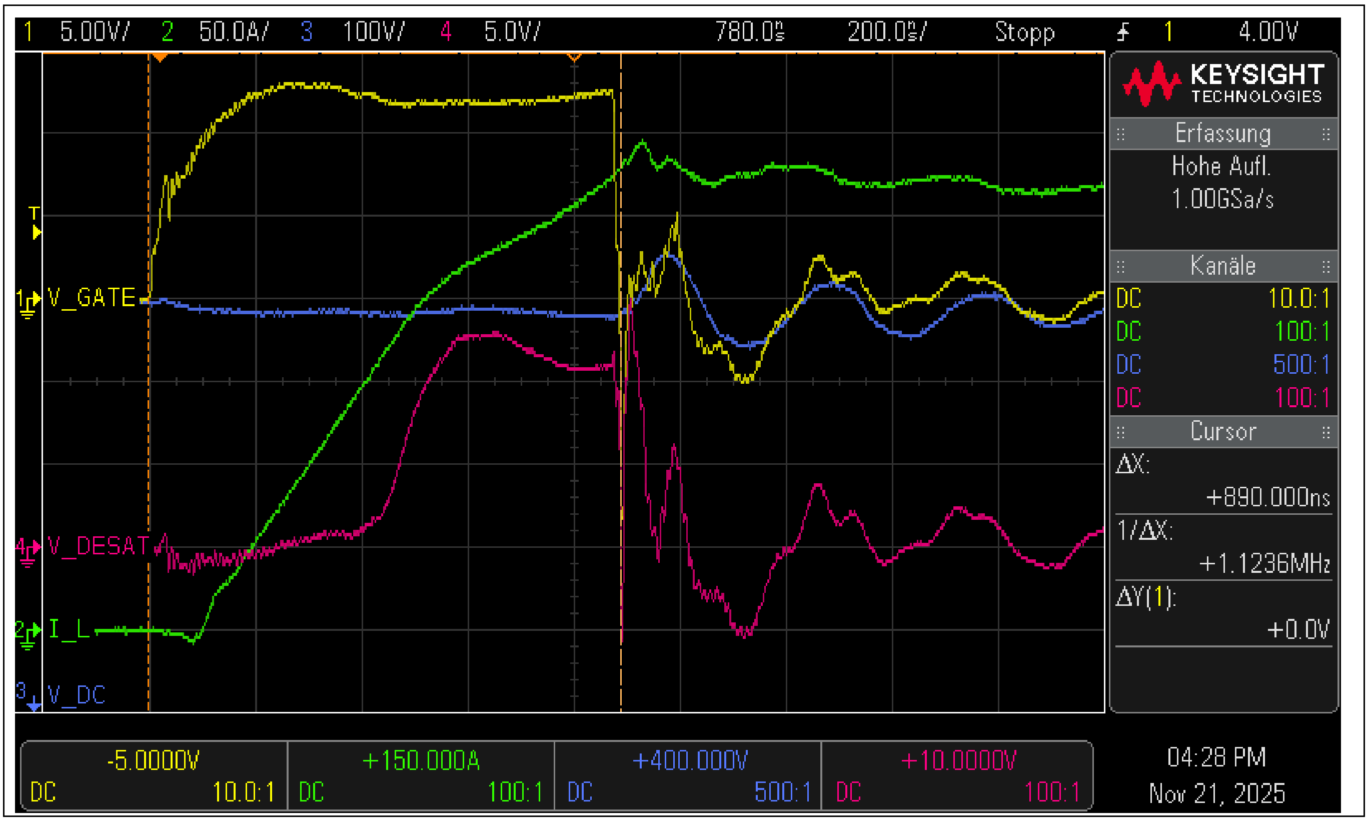


Figure 27 **DESAT short-circuit protection test at V_{BUS} = 500 V**

For V_{BUS} = 500 V, the time until switch-off the MOSFET gate by DESAT protection is 890 ns.

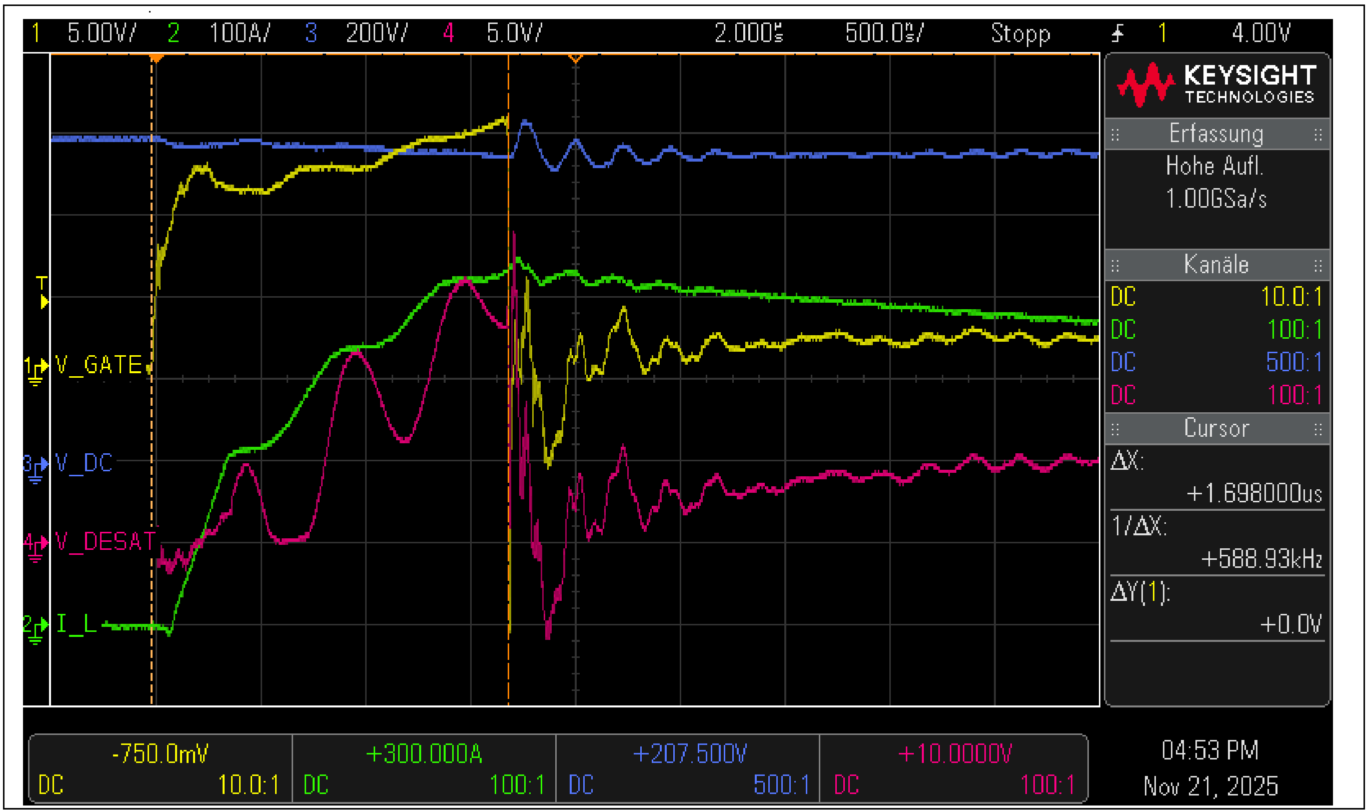


Figure 28 **DESAT short-circuit protection test at V_{DC} = 800 V**

For V_{BUS} = 800 V, the time until switch-off the MOSFET gate by DESAT protection is 1.698 µs.

5.3 Performance evaluation

Voltage measurement

- V_{BUS} (measurement M1 to M2)
- $V_{rms\,1}$ (measurement M4 to M5)
- $V_{rms\,2}$ (measurement M5 to M6)
- $V_{rms\,3}$ (measurement M6 to M4)

Current measurement

- I_{DC} (measurement M3)
- $I_{rms\,1}$ (measurement M7)
- $I_{rms\,2}$ (measurement M8)
- $I_{rms\,3}$ (measurement M9)
- Capacitor ripple current measurement (M10)

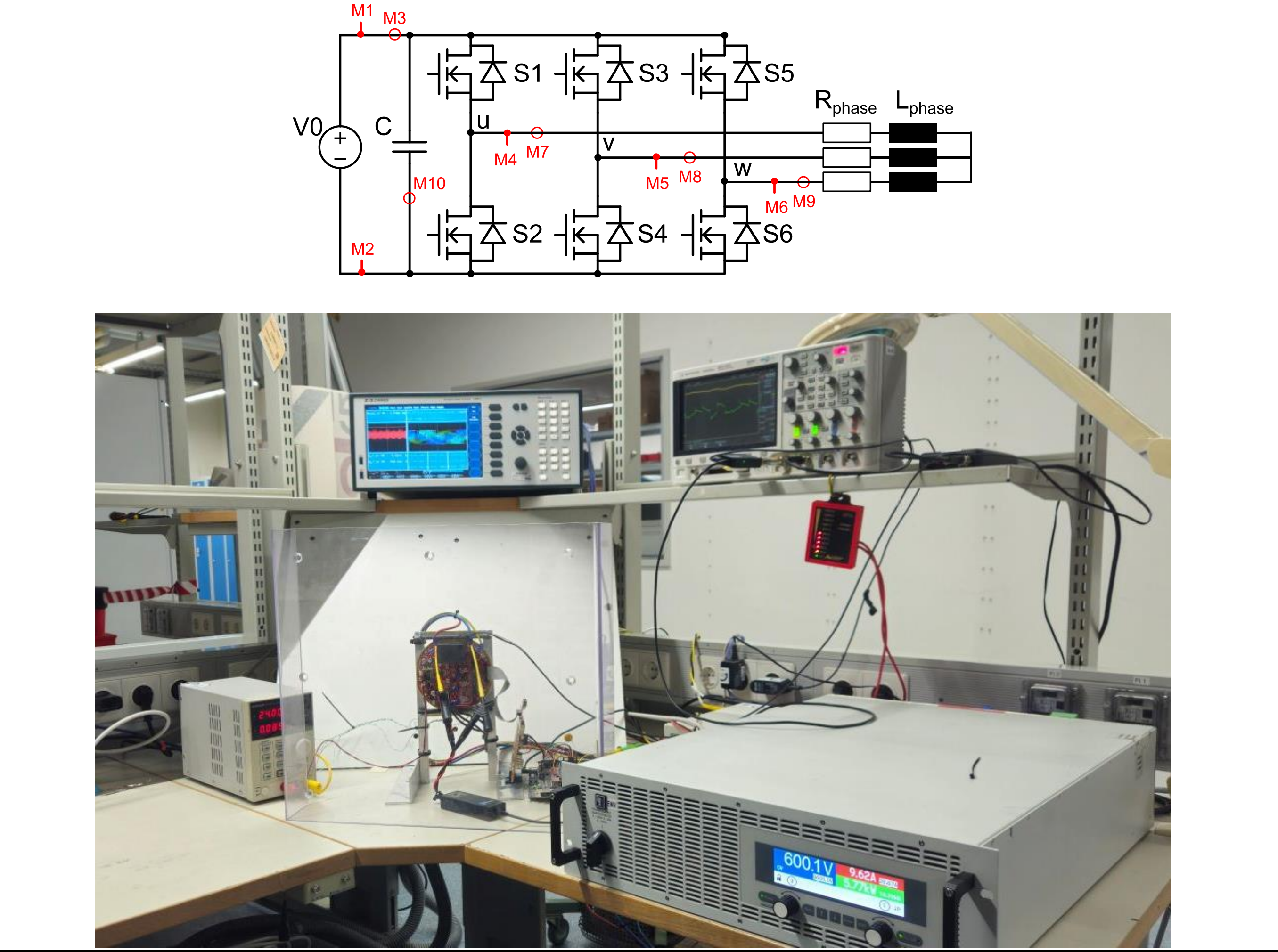


Figure 29 Measurement setup

Junction temperature (T_{vj}) and thermal resistance (R_{th}) calculations:

As an indirect measurement of the MOSFET's junction temperature, the temperature at the heat sink (T_{HS}) is measured using a thermocouple (Type K) positioned between the heat sink and the thermally conductive gap filler material. The gap filler, an electrically insulating and thermally conductive sheet supplied by HALA, is inserted between the heat sink and the exposed pad of the MOSFET, ensuring efficient thermal management while maintaining electrical isolation.

To determine the virtual junction temperature (T_{vj}) of the power MOSFET from the measured heat sink temperature (T_{HS}) the following calculation is used, adding 10 °C as a margin to account for potential inaccuracies in the heat sink temperature measurement:

$$T_{vj} = P_{loss}/6 \times R_{th,total} + T_{HS} + 10°C = P_{loss}/6 \times (R_{th,j-c} + R_{th,GapFiller}) + T_{HS} + 10°C$$

Equation 8 Junction temperature calculation

Where,

P_{loss} = Total power loss of all six MOSFETs

$R_{th,total}$ = Total thermal resistance from the MOSFET junction to the heat sink

$R_{th,j-c}$ = Thermal resistance from the junction to the case (exposed pad) of the MOSFET, which is specified in the MOSFET datasheet as 0.2°C/W

$R_{th,GapFiller}$ = Thermal resistance of the gap filler

To calculate $R_{th,GapFiller}$:

Use the gap filler sheet with an uncompressed thickness of 1 mm and is compressed to approximately 0.42 mm under a contact pressure of approximately 60 PSI. Per the gap filler sheet specification (see Table 7), this results in a thermal resistance (R-value) of 0.1°C-inch^2/W. To calculate the thermal resistance of the gap filler, divide the R-value by the area of the MOSFET exposed pad, which is 43.862 mm^2 (or 0.068 inch^2).

$R_{th,GapFiller}$ = (0.1 K inch^2/W)/0.068 inch^2 = 1.47°C/W

Finally, calculate the total thermal resistance:

$R_{th,total} = R_{th,j-c} + R_{th,GapFiller}$ = 0.2°C/W + 1.47°C/W = 1.67°C/W

This calculated value of $R_{th,total}$ can be used in the equation above to estimate the MOSFET's junction temperature (T_{vj}).

Table 7 Gap filler material specifications

Property	TGF-WP1000-SI	Unit
Material		
Color	Apricot	–
Density	3.3	g/cm^3
Thickness	1.0 ± 0.10	mm
Hardness	40	Shore 00
Shelf life (<40°C)	12	Months
UL flammability	V0	UL 94
RoHS conformity	Yes	2015/863/EU
Thermal		
Resistance at 60 PSI	0.10 (0.42)	°C-in^2/W (mm)
Resistance at 30 PSI	0.16 (0.75)	°C-in^2/W (mm)
Resistance at 10 PSI	0.25 (0.93)	°C-in^2/W (mm)
Thermal conductivity	6	W/mK
Operating temperature range	–40 to +150	°C

Conditions for power test measurement

A sinus PWM was generated and a dead-time of 500 ns was selected.

- V_{BUS} = 600 V
- f_{SW} = 4/8/16 kHz
- f_{out} = 50 Hz
- L_{phase} = 1.6 mH, R_{phase} variable[1]
- T_A = 22°C

Figure 30 and Figure 31 show the influence of the switching frequency on MOSFET junction temperature and losses. The default switching frequency of the drive was defined to be 8 kHz to enable sufficient motion control performance.

[1] Resistor R_{phase} and modulation index/output voltage are adjusted to set the output current.

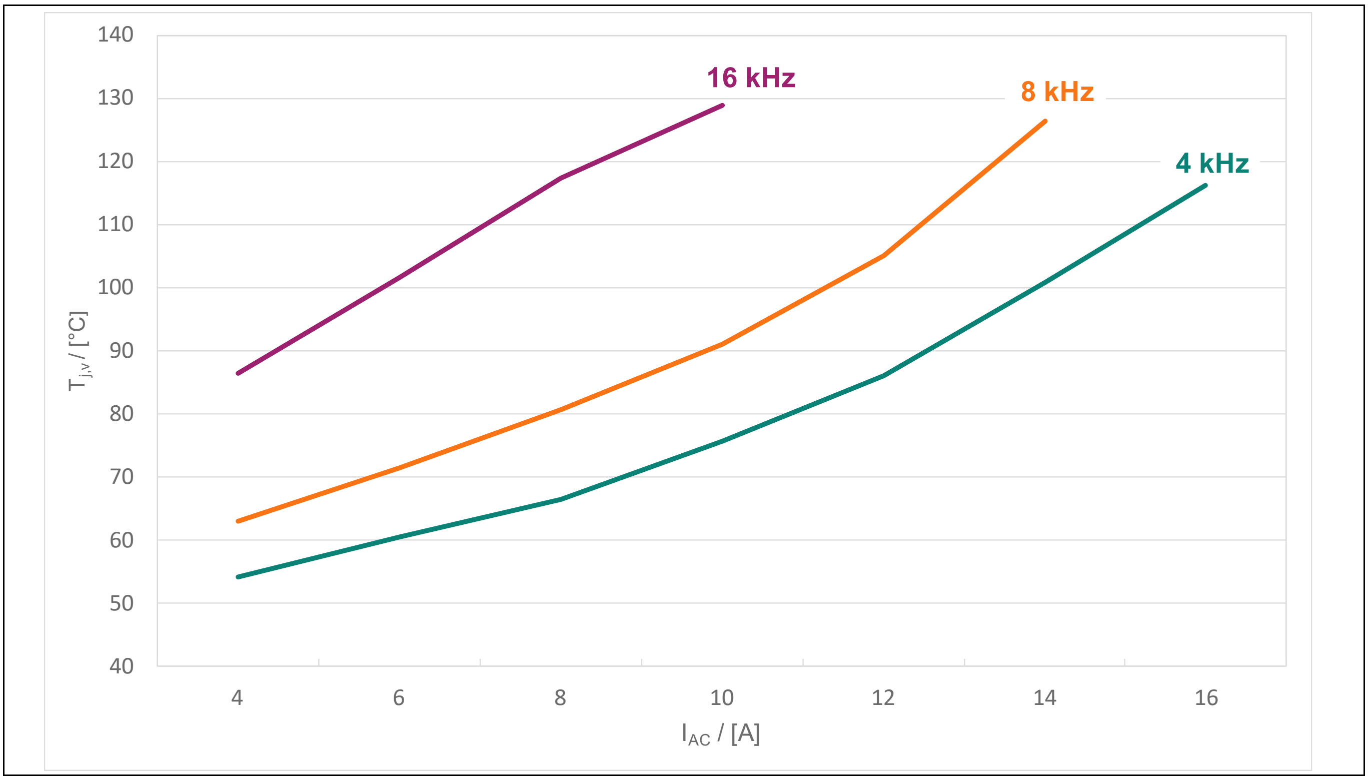


Figure 30 **Performance evaluation: T_{vj} vs. output currents I_{AC}**

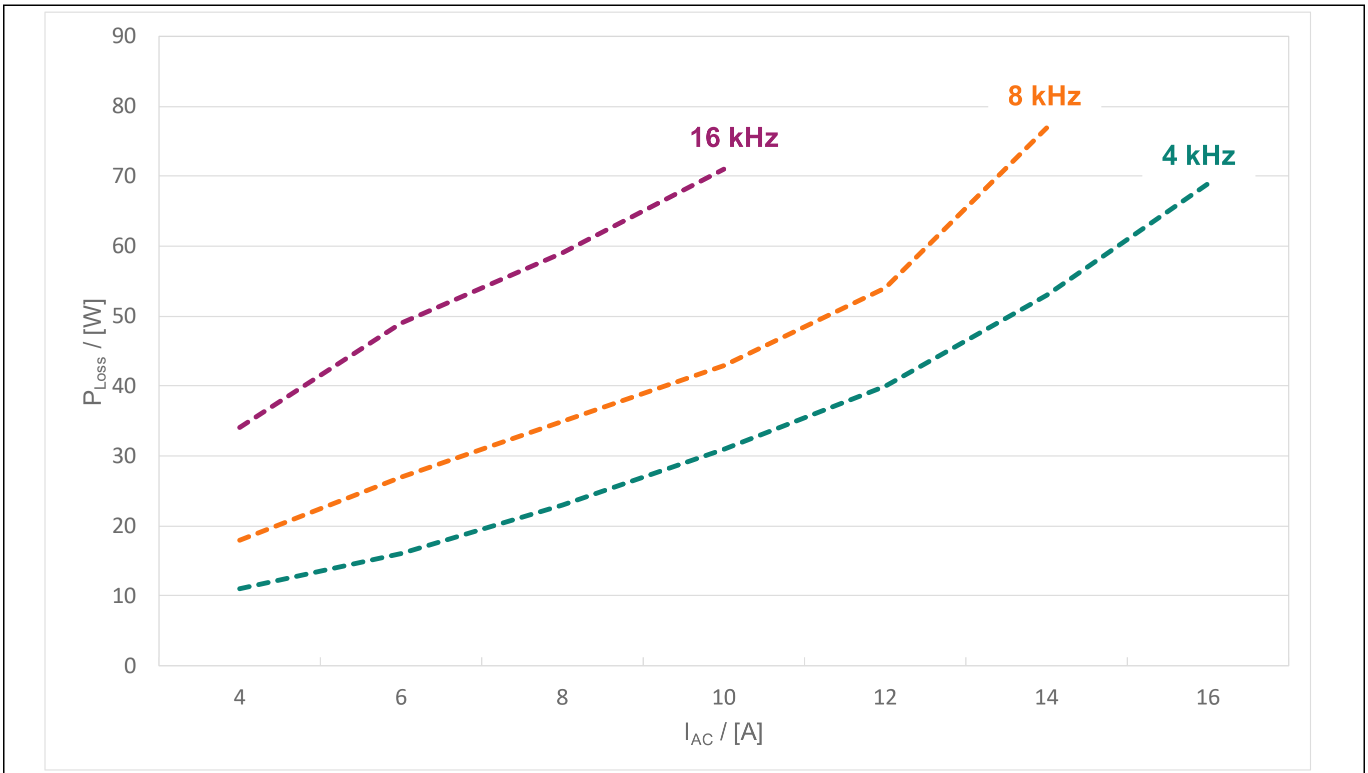


Figure 31 **Performance evaluation: P_{Loss} vs. output currents I_{AC}**

The performance test confirms the rated current of 9 A at 8 kHz. At this point, the junction temperature is approximately 85°C. When scaled to a higher ambient temperature of 40°C by adding 18°C, it would result in a junction temperature of approximately 103°C.

5.4 Overload test

Overload test conditions

A sinus PWM was generated and a dead-time of 500 ns was selected.

- V_{BUS} = 600 V
- f_{SW} = 8 kHz
- f_{out} = 50 Hz
- L_{phase} = 1.6 mH, R_{phase} variable[2]
- T_A = 22°C

Overload profile

- I_N = 9 A
- 10 s: 2 x I_N = 18 A
- 50 s: 0.7 x I_N = 6.3 A

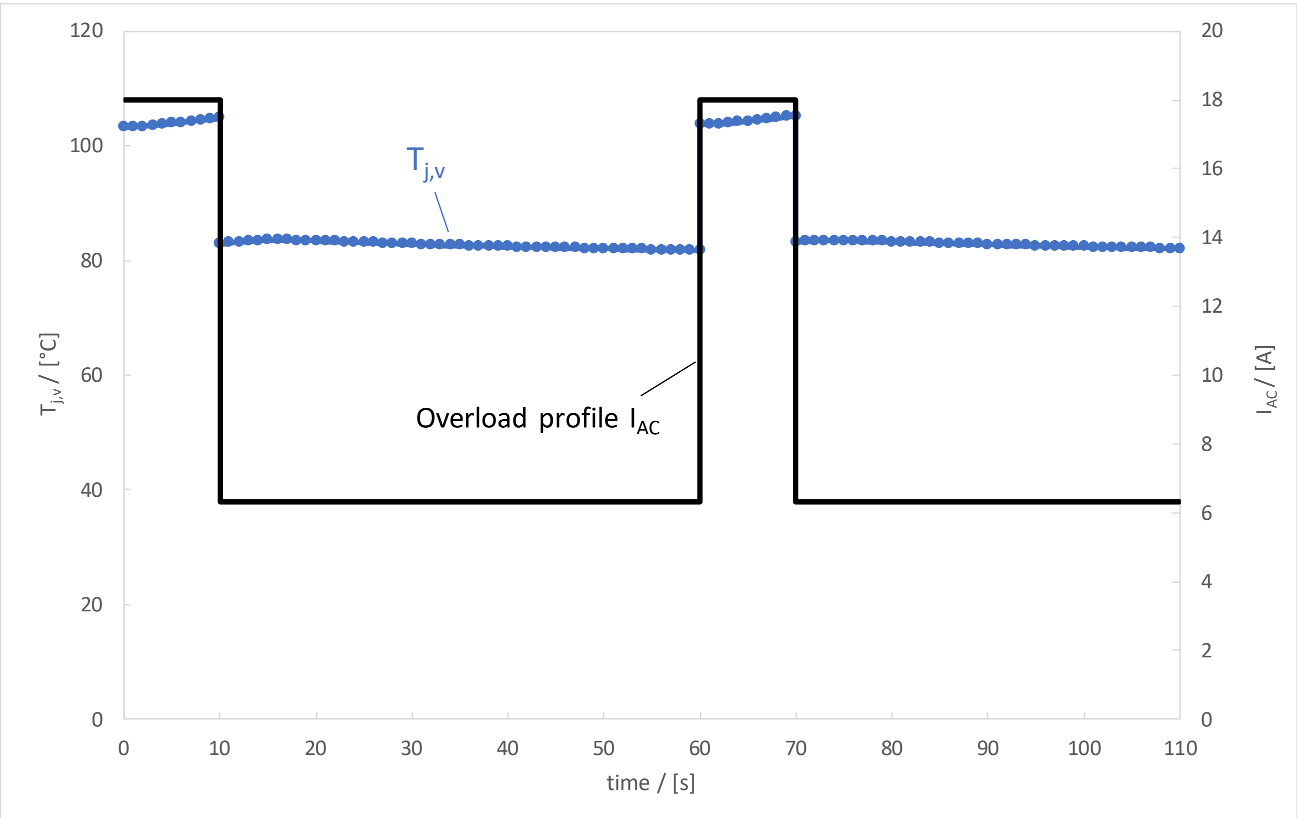


Figure 32 Overload test: T_{vj} over time

The measurement confirms the overload capability of Q-DPAK half-bridges. The increase in the junction temperature T_{vj} of approximately 25°C is relatively small, suggesting that higher overload values can likely be achieved.

[2] Resistor R_{phase} and modulation index/output voltage are adjusted to set the output current.

6 Related resources

- Silicon carbide MOSFET discretes
- Isolated Gate Driver ICs
- AN_2101_PL52_2103_112902: Innovative top-side cooled package solution for high voltage applications
- REF-SMD5KIMSQM2INV reference board
- KIT_PSC3M5_CC2: PSOC™ Control C3M5 Motor Drive Control Card
- Gate Driver ICs forum on Infineon Developer Community
- MOSFET (Si/SiC) forum on Infineon Developer Community
- ModusToolbox™ software
- ModusToolbox™ documentation

References

[1] Infineon Technologies AG: *IMSQ120R012M2HH*; Available online

[2] Infineon Technologies AG: *1ED3322MC12N*; Available online

[3] Infineon Technologies: *AN-2022-03: EiceDRIVER™ F3 – Single-channel enhanced isolated gate driver family with short-circuit protection;* Available online

Glossary

DESAT
Desaturation protection

IMS
Insulated metallic substrate

LDO
Low dropout regulator

NTC
Negative temperature coefficient

PCB
Printed circuit board

PWM
Pulse width modulation

SiC
Silicon carbide

SMD
Surface mounted device

Revision history

Document revision	Date	Description of changes
1.00	2026-03-02	Initial version

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