Highly paralleled transistors in motor drive evaluation board with low voltage CoolGaN™

About this document

Scope and purpose

This document provides an overview of the DEMO_MTR_72V200A_GaN CoolGaN™ motor drive evaluation board for low-voltage applications and provides information on the hardware, mechanical structure, and test setup.

Intended audience

This document is intended for system application engineers who want to improve space utilization and seek inspiration for their next motor drive designs, for low voltage applications up to 72 V and 200 A_{RMS} motor phase current.

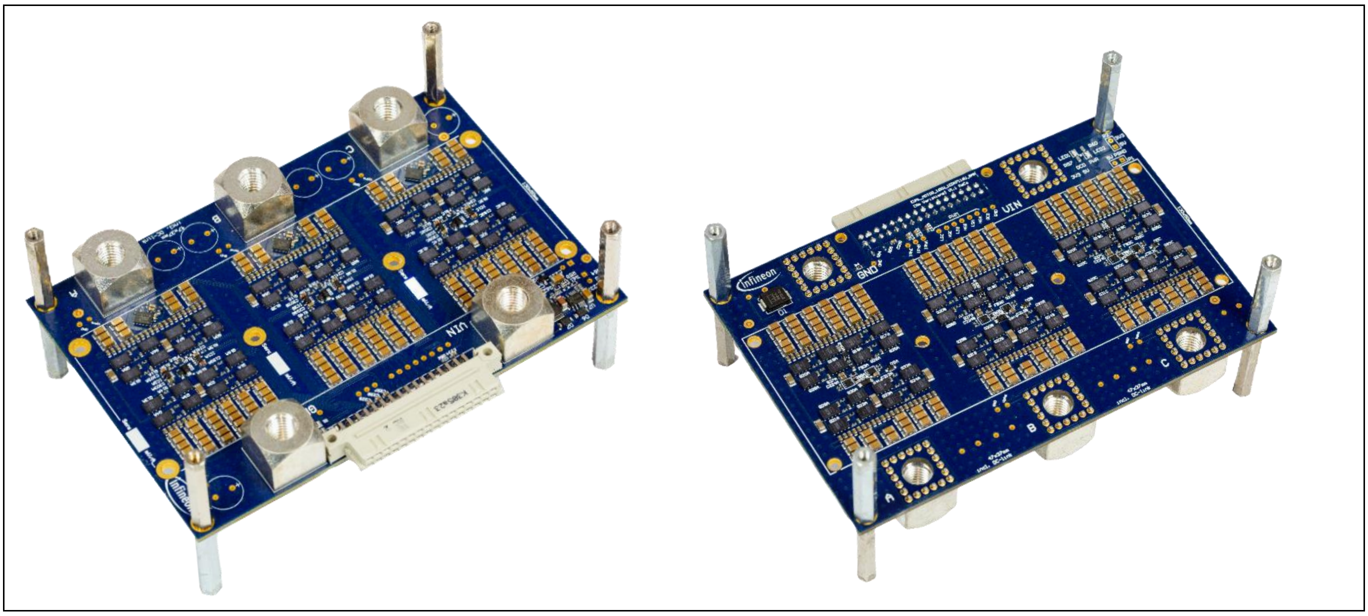

Figure 1 Evaluation board DEMO_MTR_72V200A_GaN

Note: This document is for the DEMO_MTR_72V200A_GaN reference board. The product name (EVAL_MOTOR_16KW_1EDN7116U_GaN) shown in the figures of this document are due to variations in the design and manufacturing processes. Both DEMO_MTR_72V200A_GaN and EVAL_MOTOR_16KW_1EDN7116U_GaN refer to the same reference board.

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

Table 1 **Safety precautions**

	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.*

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1 Introduction

DEMO_MTR_72V200A_GaN is a high-power density evaluation board for low-voltage inverter. This board includes 96 numbers of CoolGaN™ Transistor 120 V IGC037S12S1 [1] in a half-bridge configuration with 16 devices in parallel for all sides of the phases. All the transistors in parallel are driven by an EiceDRIVER™ 1EDN7116U gate driver [2], and the output phase current is sensed by a XENSIV™ TLE4972 magnetic current sensor [3].

The board can be connected with different controller cards.

The evaluation board is developed to demonstrate the high power densities achievable within a size of 135 mm × 90 mm and an active area of 130 mm × 50 mm × 6 mm, in which all the transitions and the main components of the three half-bridges are located. This is due to the reduction of bulk capacitance and the high switching frequency operation (≥50 kHz) of the inverter without a big power loss penalty. Moreover, the CoolGaN™ Transistor 120 V IGC037S12S1 is a top-side cooled device, on an exposed-die PQFN package, that can efficiently extract the heat and provide more space for a top-bottom PCB implementation.

DEMO_MTR_72V200A_GaN includes an aluminum heat spreader that can be easily adapted to the frame of a final system or a bigger heatsink. The thermal connection is done with a gap filler.

Each half-bridge is driven by two independent gate drivers, which provides complete independence regarding the preferred switching patterns and dead-times. The power stage is protected against overtemperature with sensors mounted for each half-bridge.

Each current phase of the power stage is sensed with Hall-effect current sensors that are galvanically isolated and protected with overcurrent protection (OCP). The input voltage is sensed with a voltage divider to control the undervoltage and overvoltage conditions.

The block diagram shown in Figure 2 is a schematic of the fundamental circuits.

Note: Environmental conditions were considered in the design of DEMO_MTR_72V200A_GaN. The design was tested as described in this document but not qualified in terms of safety requirements, manufacturing, and operation over the entire operating temperature range or lifetime. The boards provided by Infineon must be used for functional testing only.

Note: Reference boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN), and product discontinuation (PD). Reference boards must be handled by trained specialists only.

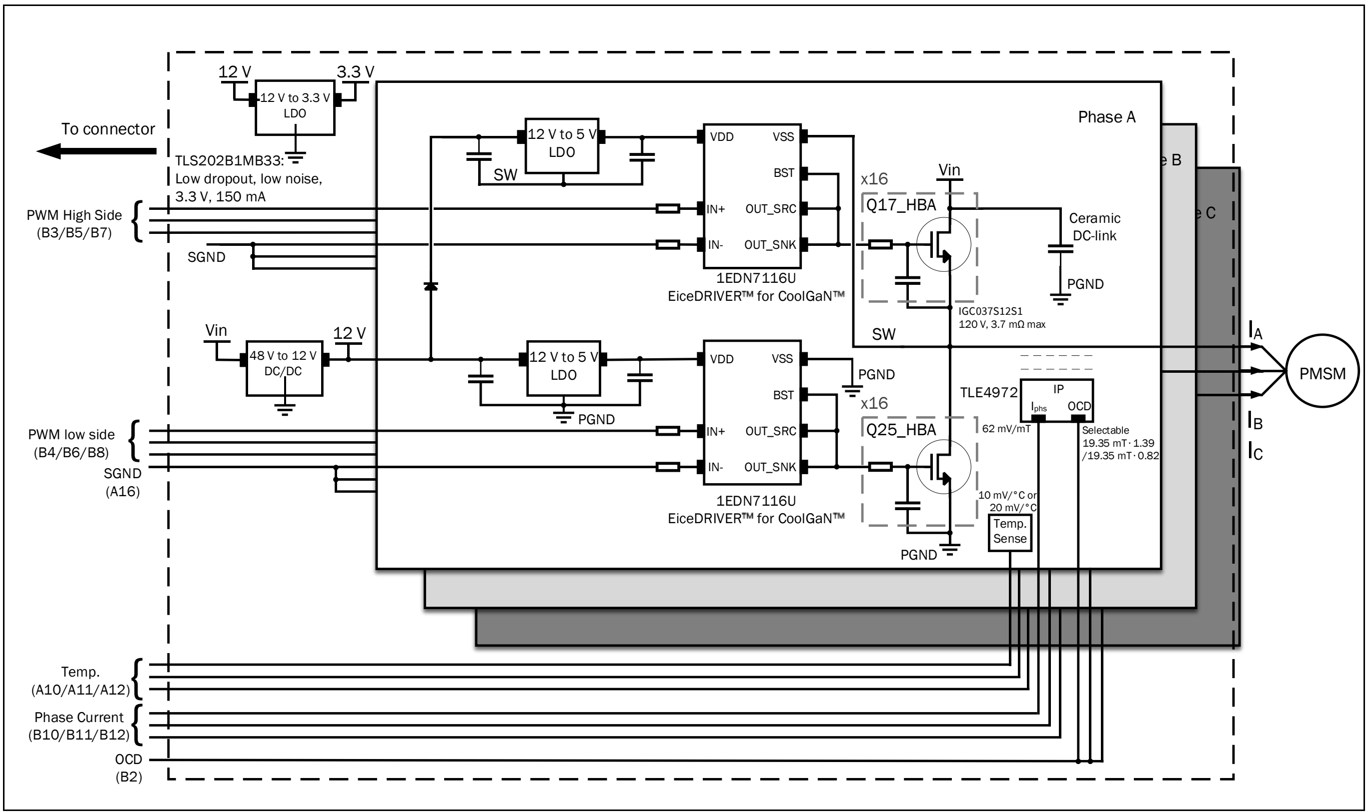

Figure 2 **Block diagram of DEMO_MTR_72V200A_GaN**

2 Design features

DEMO_MTR_72V200A_GaN is an evaluation board equipped with the latest generation of Infineon's CoolGaN™ Transistors in combination with a complementary EiceDRIVER™ gate driver and XENSIV™ current sensor with current reel out of the chip.

Main components:

- CoolGaN™ Transistors 120 V IGC037S12S1 [1], 3.7 mΩ (max.) in a 3 mm × 5 mm PQFN package
- EiceDRIVER™ 1EDN71x6U [2] gate driver for GaN transistors and MOSFETs
- XENSIV™ TLE4972 [3] magnetic current sensor for AC and DC currents

The reference design characteristics are:

- 72 V nominal input voltage
- High power density design in a 135 mm × 90 mm PCB with twelve layers of 70 µm (2 oz.) copper
- Ceramic capacitor DC link for lowest equivalent series resistance (ESR) and high-current ripple handling
- Optimized power loop inductance allowing for nanosecond switching transients and minimal overshoot
- Auxiliary power supply with 3.3 V and 12 V included
- Overcurrent detection (OCD), selectable as 492 A or 834 A
- Heatsink and mounting hardware included as part of the kit

2.1 Highlighted products

2.1.1 CoolGaN™ Transistors 120 V

CoolGaN™ Transistors [1] offer fundamental advantages over silicon. In particular, the higher critical electrical field makes them very attractive for power semiconductor devices with outstanding specific on-state resistance and smaller capacitances compared to silicon MOSFETs. This makes GaN transistors a great solution for high-speed or high-frequency switching applications. GaN transistors can then be operated with reduced dead-times, which results in a higher efficiency and also enables passive cooling. Operation at high switching frequencies allows the quantity of passive components to shrink, which improves system reliability and density.

2.1.2 EiceDRIVER™ 1EDN71x6U gate driver

EiceDRIVER™ 1EDN71x6U [2] is a single-channel gate driver IC optimized for compatibility with Infineon CoolGaN™ Transistors, and it is also compatible with other GaN transistors and silicon MOSFETs. This gate driver includes several key features that enable a high-performance system design with CoolGaN™ Transistors, including truly differential input (TDI), four driving strength options (from 0.5 A to 2 A depending on the part number), active Miller clamp, and bootstrap voltage clamp.

2.1.3 XENSIV™ TLE4972 magnetic current sensor

XENSIV™ TLE4972 [3] is a high precision miniature coreless magnetic current sensor for AC and DC measurements with an analog interface and two fast overcurrent detection outputs. Infineon's well-established and robust monolithic Hall technology enables accurate and highly linear measurement of the magnetic field caused by currents. With a full scale up to ±31 mT, it is possible to measure currents up to 2,000 amperes. All negative effects (e.g. saturation, hysteresis) commonly known from open loop sensors using flux concentration techniques are avoided.

2.1.4 TLS202B1MBV33 low-dropout voltage regulator

TLS202B1MBV33 [4] is a monolithic integrated fixed linear voltage post regulator for load currents up to 150 mA. The IC regulates an input voltage from 2.7 V to 18 V with a precision of ±3%. TLS202B1MBV33 is specially designed for applications requiring very low standby currents. The device is available in a very small surface-mounted PG-SCT595 package. The device implements circuits for output current limitation and overtemperature shutdown for protection against overcurrent and overtemperature faults.

2.2 Specifications

Table 2 DEMO_MTR_72V200A_GaN board specifications

Parameter	Value	Conditions/Comment
Input		
Nominal input voltage	72 V	–
Maximum input voltage	85 V	Maximum stable voltage before triggering the overvoltage protection (OVP)
Maximum input operating voltage	80 V	Maximum input operating voltage acquired from the battery through the voltage divider (R1, R2, and R3)
Undervoltage lockout (UVLO)	14 V	Minimum voltage to turn off the DC-DC converter
Maximum input current	200 A	Maximum in steady state; limit depends on the amount of copper and the dissipation of the board NOTE: The board does not have any current protection on the input side
Power max (electrical input)	14 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Output		
Power max (per one phase)	4.5 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Current per phase leg (max)	140 A_{RMS}	48 V, Ta = 25°C, natural convection, no heat spreader, and no forced air (in steady state)
	220 A_{RMS}	48 V, Ta = 25°C, natural convection, no heat spreader and forced air 5 m/s (in steady state)
	260 A_{RMS}	48 V, Ta = 25°C, natural convection, with heat spreader and forced air 5 m/s (in steady state)
	300 A_{RMS}	48 V, Ta = 25°C, no forced air with heat spreader, ≤30 seconds
Switching frequency		
Nominal switching frequency	50 kHz	For higher value need external 12V supply
Minimal switching frequency	30 kHz	May require additional DC capacitance
Current feedback		
Sensitivity	2 mV/A	±2%
Overcurrent detection (OCD)	492 A	Reconfigurable to 834 A by user
Offset	1.65 V	
DC link voltage feedback		
Sensitivity	50 mV/V	±1%

Parameter	Value	Conditions/Comment
Onboard supply		
+12 V	±2%	Used for LDO that supplies the gate drivers. Also supplies the 3.3 V regulator.
+3.3 V	±3%	Used for the TLI4972 current sensor
System environment		
Ambient temperature	From 0°C to 85°C	Non-condensing, maximum relative humidity of 95%
Temperature limit	Up to 130°C	The temperature is acquired by the sensor (U6)
PCB characteristics		
Material	High TG FR4 material (PCL370HR)	12 layers (1 PTH via), 70 µm copper each for a total board thickness of 2.5 mm
Dimensions	135 mm × 90 mm × 18 mm	Height with connector

2.3 Board description

Figure 3 and Figure 4 show the bottom and top sides of the DEMO_MTR_72V200A_GaN evaluation board, respectively.

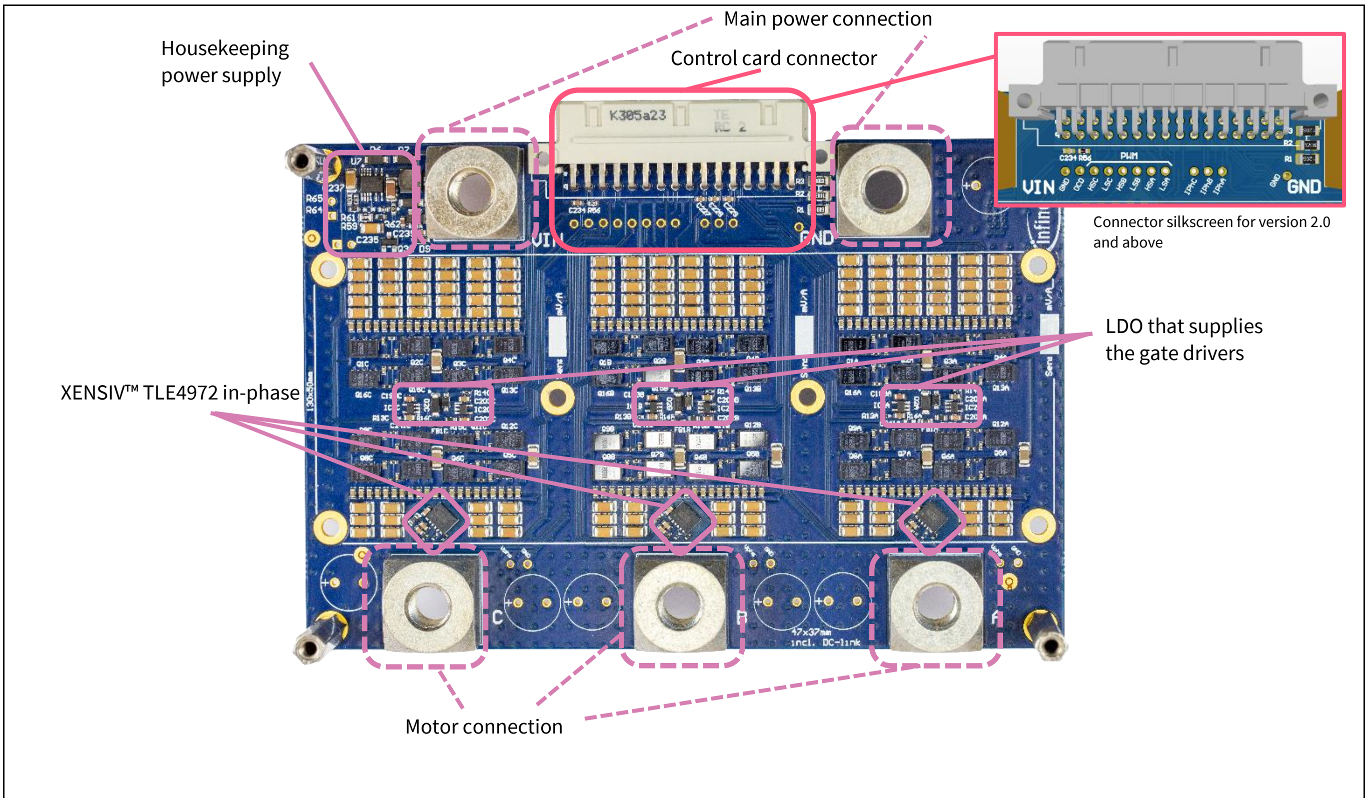

Figure 3 Overview of the top part of DEMO_MTR_72V200A_GaN board

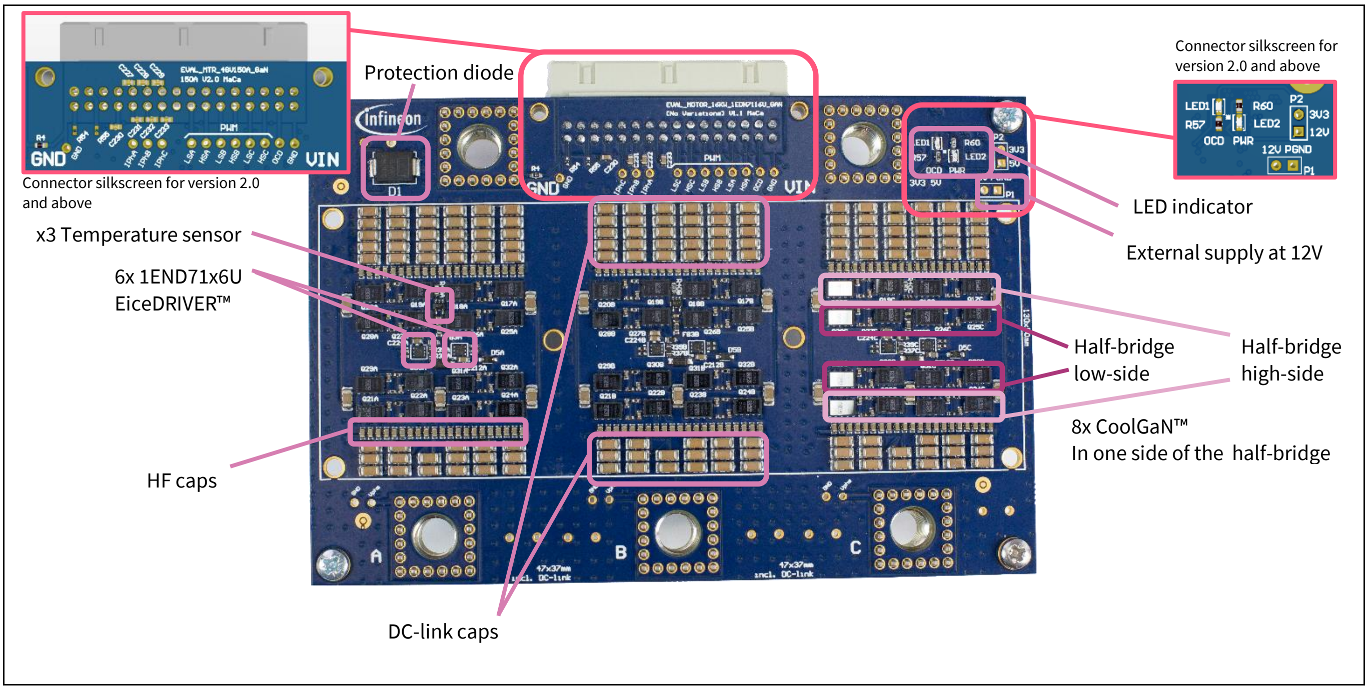

Figure 4 Overview of the bottom part of DEMO_MTR_72V200A_GaN board

Table 3 gives an overview of the pinout of the 32-pin female connector for board below version 2.0, whereas Table 4 applies to the board above or equal versions 2.0. The female connector can be used to connect to the XMC™ drive card or other external controller boards. It is important to remember that pin numbering on the external XMC™ drive card will be reversed on DEMO_MTR_72V200A_GaN, compared to X9.

Table 3 X9 pinout, for connection to external control card for board below version 2.0

Pin no.	Description	Details
A1	Not Connected (NC)	–
A2	NC	–
A3	NC	–
A4	NC	–
A5	NC	–
A6	NC	–
A7	NC	–
A8	NC	–
A9	NC	–
A10	Temp. A	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
A11	Temp. B	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
A12	Temp. C	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
A13	NC	–
A14	NC	–
A15	NC	Can connect to the 3.3 V rail via solder jumper; max. 50 mA load
A16	GND	–

Pin no.	Description	Details
B1	EN	Active HIGH with internal pull-up; driving the pin to 0 V disables the 5 V rail
B2	OCD	Motor phase OCD. Active LOW; all phases ORed together
B3	PWM HS A	Active HIGH, 3.3 V
B4	PWM LS A	Active HIGH, 3.3 V
B5	PWM HS B	Active HIGH, 3.3 V
B6	PWM LS B	Active HIGH, 3.3 V
B7	PWM HS C	Active HIGH, 3.3 V
B8	PWM LS C	Active HIGH, 3.3 V
B9	NC	–
B10	Iphs A	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B11	Iphs B	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B12	Iphs C	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B13	V_{IN} sense	V_{IN} voltage divider, 50 mV/V ±1%
B14	NC	–
B15	NC	–
B16	NC	Can connect to the 5 V rail via solder jumper; max. 50 mA load

Table 4 X9 pinout, for connection to external control card for board above or equal versions 2.0

Pin no.	Description	Details
A1	Not Connected (NC)	–
A2	NC	–
A3	NC	–
A4	NC	–
A5	NC	–
A6	NC	–
A7	NC	–
A8	NC	–
A9	NC	–
A10	Iphs C and 3	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
A11	Iphs B and 2	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
A12	Iphs A and 1	2 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
A13	NC	–
A14	NC	–
A15	NC	Can connect to the 3.3 V rail via solder jumper; max. 50 mA load
A16	GND	–
B1	EN	Active HIGH with internal pull-up; driving the pin to 0 V disables the 5 V rail
B2	OCD	Motor phase OCD. Active LOW; all phases ORed together

Pin no.	Description	Details
B3	PWM HS C and 3	Active HIGH, 3.3 V
B4	PWM LS C and 3	Active HIGH, 3.3 V
B5	PWM HS B and 2	Active HIGH, 3.3 V
B6	PWM LS B and 2	Active HIGH, 3.3 V
B7	PWM HS A and 1	Active HIGH, 3.3 V
B8	PWM LS A and 1	Active HIGH, 3.3 V
B9	NC	–
B10	Temp. C and 3	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
B11	Temp. B and 2	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
B12	Temp. A and 1	750 mV or ≈1V at 25°C, 10 or 19.5 mV/°C
B13	V_{IN} sense	V_{IN} voltage divider, 50 mV/V ±1%
B14	NC	–
B15	NC	–
B16	NC	Can connect to the 5 V rail via solder jumper; max. 50 mA load

2.4 Heat spreader mounting

For evaluation, the DEMO_MTR_72V200A_GaN board includes a metal heat spreader to emulate mounting the PCB to a metal chassis. The following items are provided for mounting the heat spreader on to the PCB:

- Six M3 × 12 mm screws
- Six thermal interface material (TIM) pads, each of 35 mm × 30 mm (T-Global TG-A1250, 500 µm thickness) or gap filler
- Two aluminum heat spreader/heatsink with integrated standoffs and alignment pins
- Four pieces of Kapton tape (15 mm × 122 mm and 12 mm × 122 mm)

The heat spreader guarantees heat extraction from the top of the device, as shown in Figure 5. The TIM needs to be compressed to 50% of the normal thickness (500 µm). Usually, the distance between the top of the device and the heatsink ranges from 200 to 300 µm. It is recommended to tighten the mounting screws carefully by hand with a screwdriver. A torque wrench is required for safe assembly to avoid over-tightening.

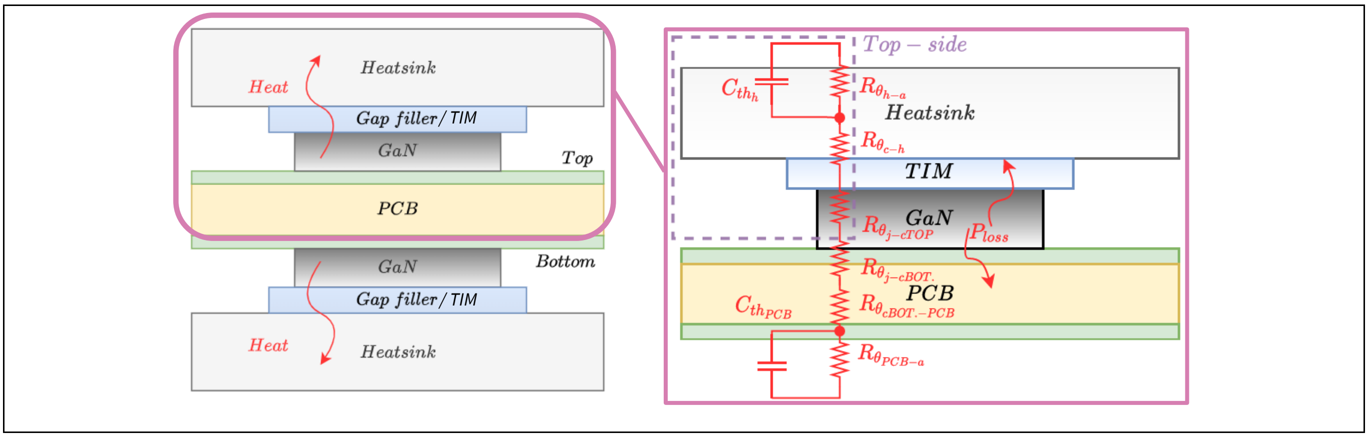

Figure 5 **Cross-section showing the assembly of heat spreader with TIM applied to top-side and bottom side for cooling**

The placement of the TIM is shown in Figure 6 (left). The protective plastic film on the TIM must be removed before use. A Kapton tape is used to avoid short circuits via the heat spreader and the DC link caps. The assembled reference board with the heat spreader is shown in Figure 6, on the right.

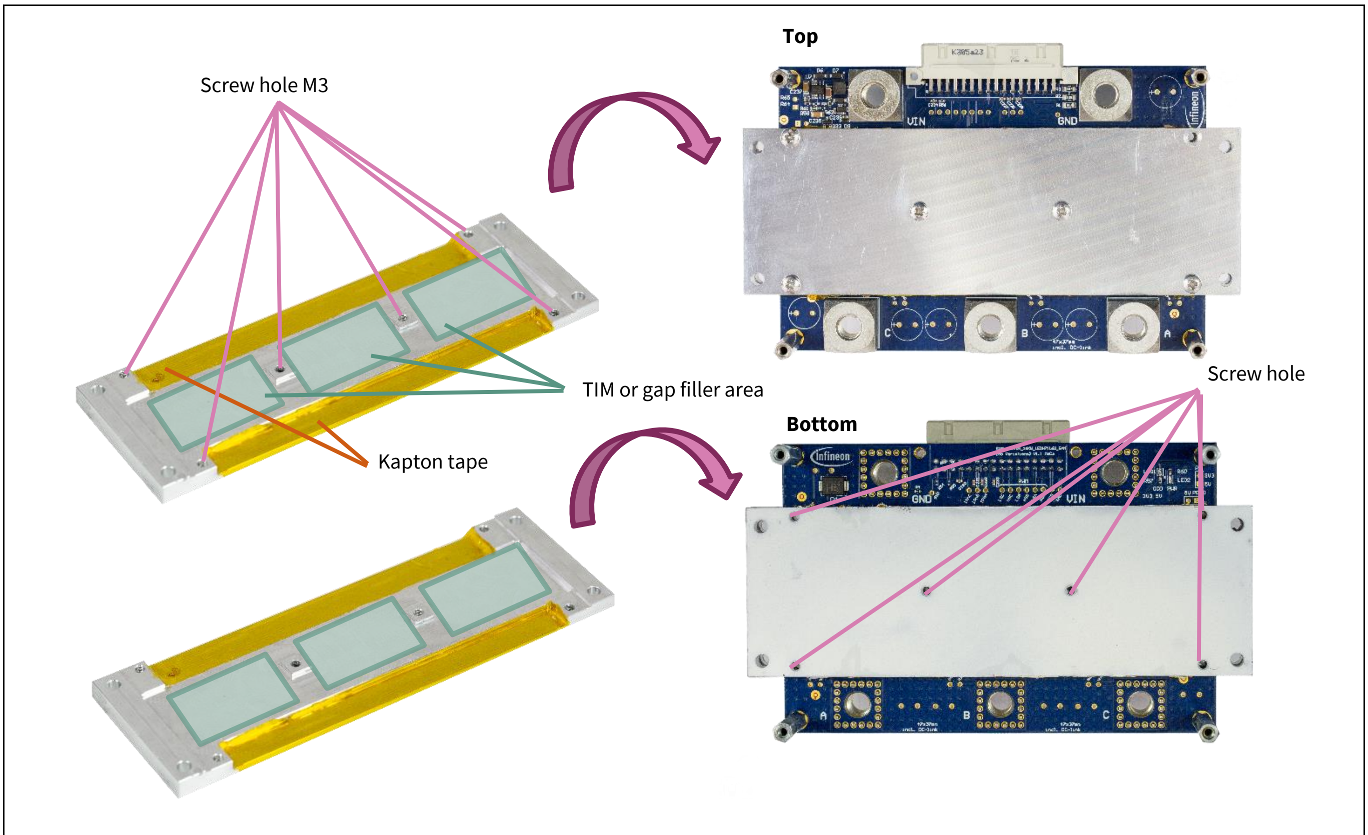

Figure 6 **Left: Placement of TIM across CoolGaN™ half-bridge and Kapton tape to avoid a short on DC link caps; right: Fully assembled top and bottom evaluation board with heat spreader**

3 Schematic and layout

3.1 Overview

A schematic overview of the motor drive is shown in Figure 7. The schematic can be divided into three core components:

- **Half-bridge (HB):** This block has the CoolGaN™ half-bridge with current sensing and the DC-link/HF capacitors (shown once in the schematic in Figure 7, but repeated thrice as identical phases 1, 2, and 3).
- **Auxiliary supply (AuxSup):** This block has all the housekeeping supplies. The 5 V supplies the gate driver, and the 3.3 V for the current sensors.
- **Control:** This block contains the pinout of the M5 connector (32 pins), which contains all the main signals from the three in-phase current sensors and the PWM for the gate driver.

In addition, press-fit connectors X4 and X8 are used for the battery input of the board. The phases connections to the motor (phases 1, 2, and 3) are connected through X4, X6, and X7.

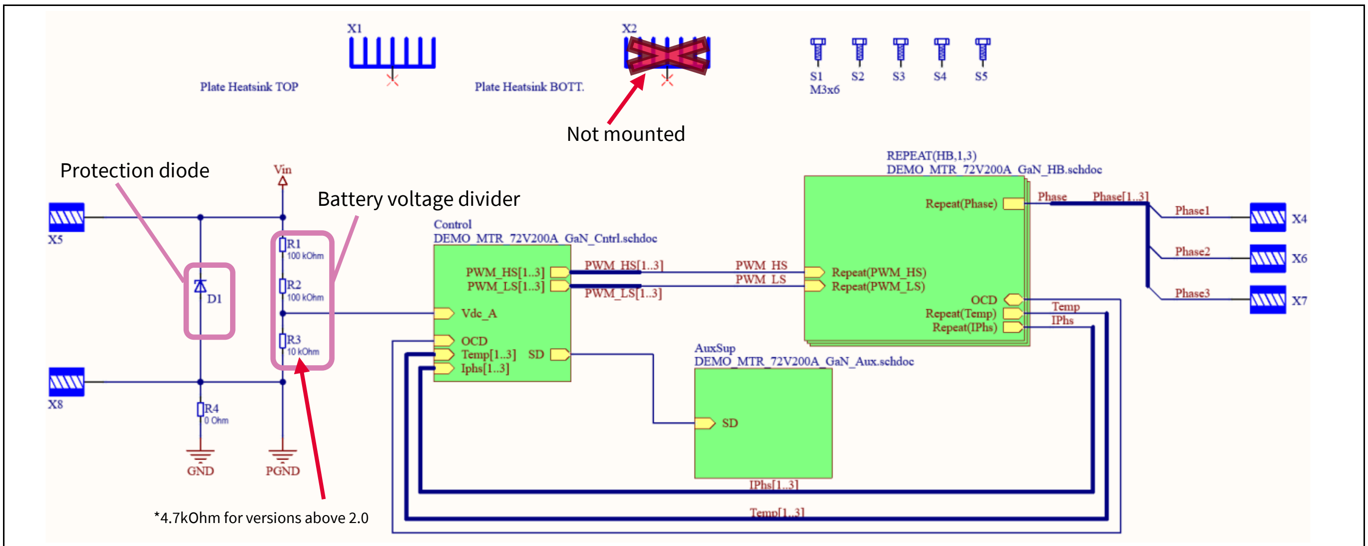

Figure 7 System-level overview of the motor drive schematic

3.2 Half-bridge (HB)

The schematic of a single CoolGaN™ half-bridge is shown in Figure 8. The primary building block for the motor drive is an optimized half-bridge circuit, with sixteen numbers of CoolGaN™ Transistors 120 V 3.7 mΩ (max.) in 3 mm × 5 mm PQFN lead-frame packages with exposed dies for dual-sided cooling. The half-bridge design was optimized for low-power loop inductance by coplanar field compensation, achieving an inductance of less than 500 pH for each pair of low-side and high-side transistors. The gate loops are also designed to minimize common-source inductance while optimizing the gate driver circuits by reducing the number of connections. A single path from the gate driver to the transistors is provided so as to reduce or increase the turn-on and turn-off transition, with a gate resistor and an external C_{gs} capacitor placed for each device.

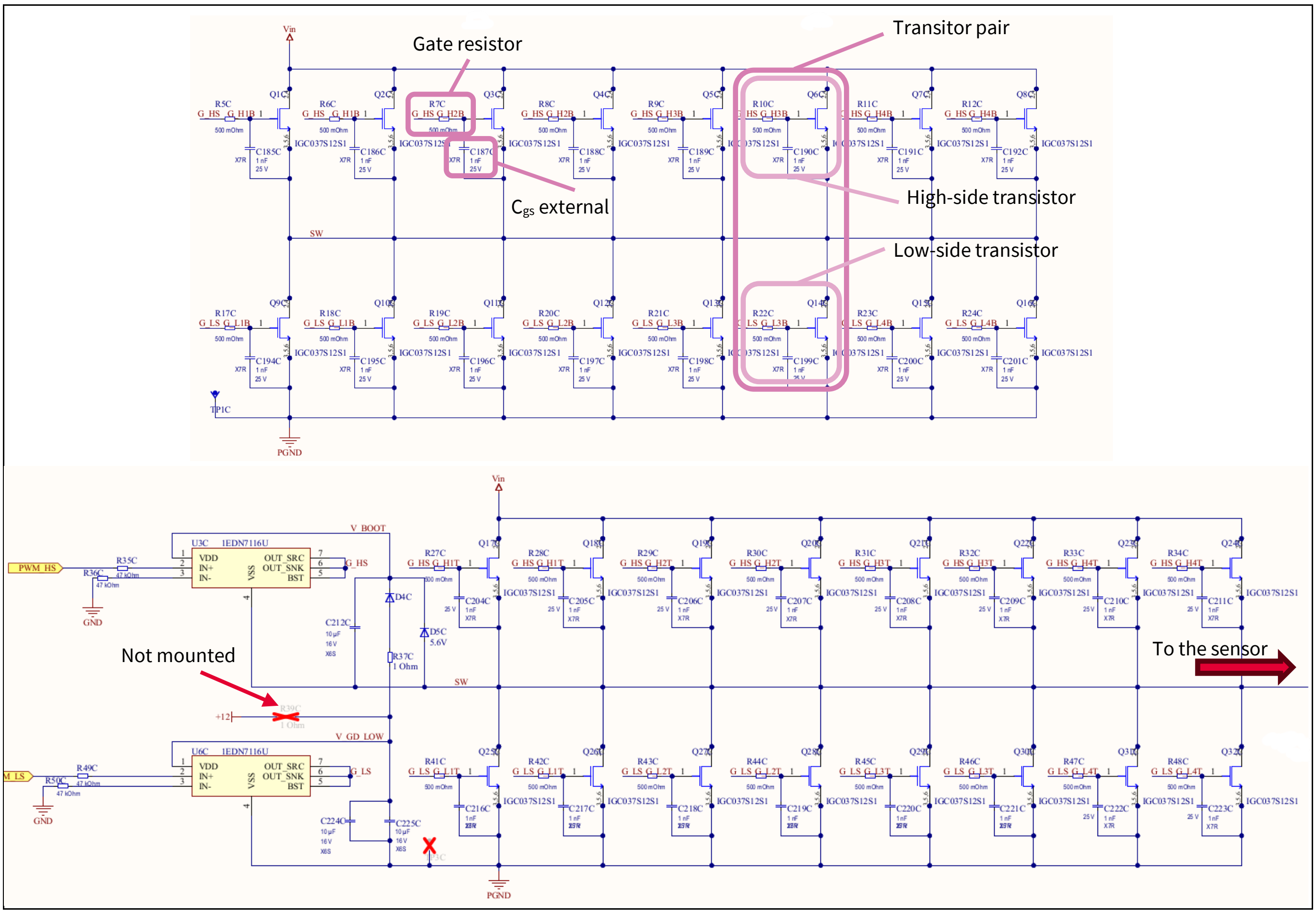

Figure 8 Schematic of power stage including gate driver a single half-bridge

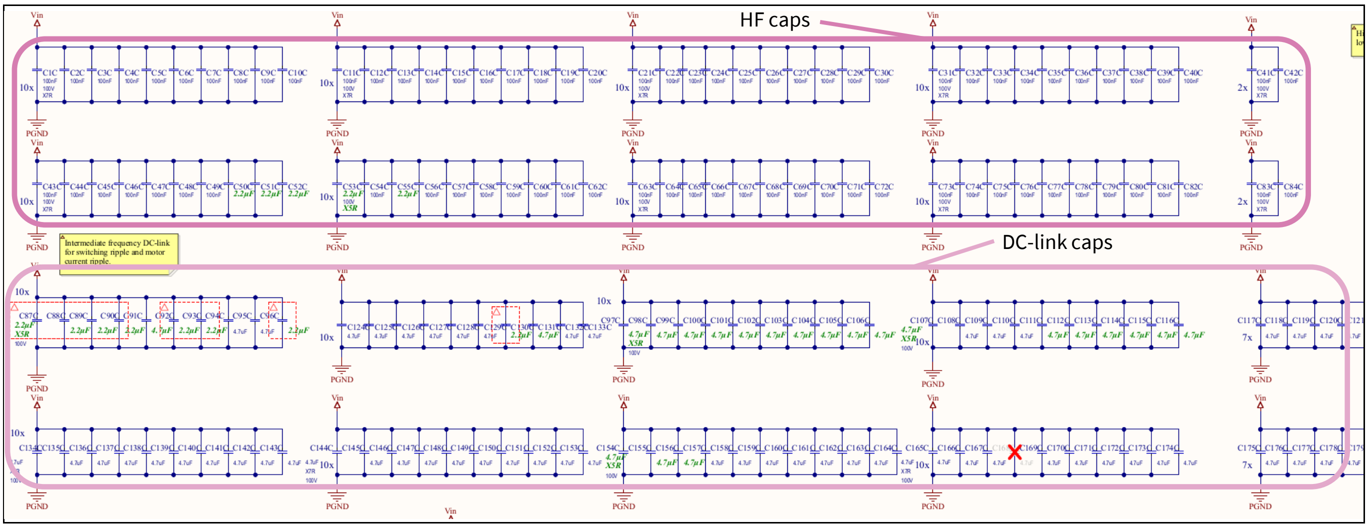

Figure 9 Schematic of the bulk capacitance for a single half-bridge, 100V version

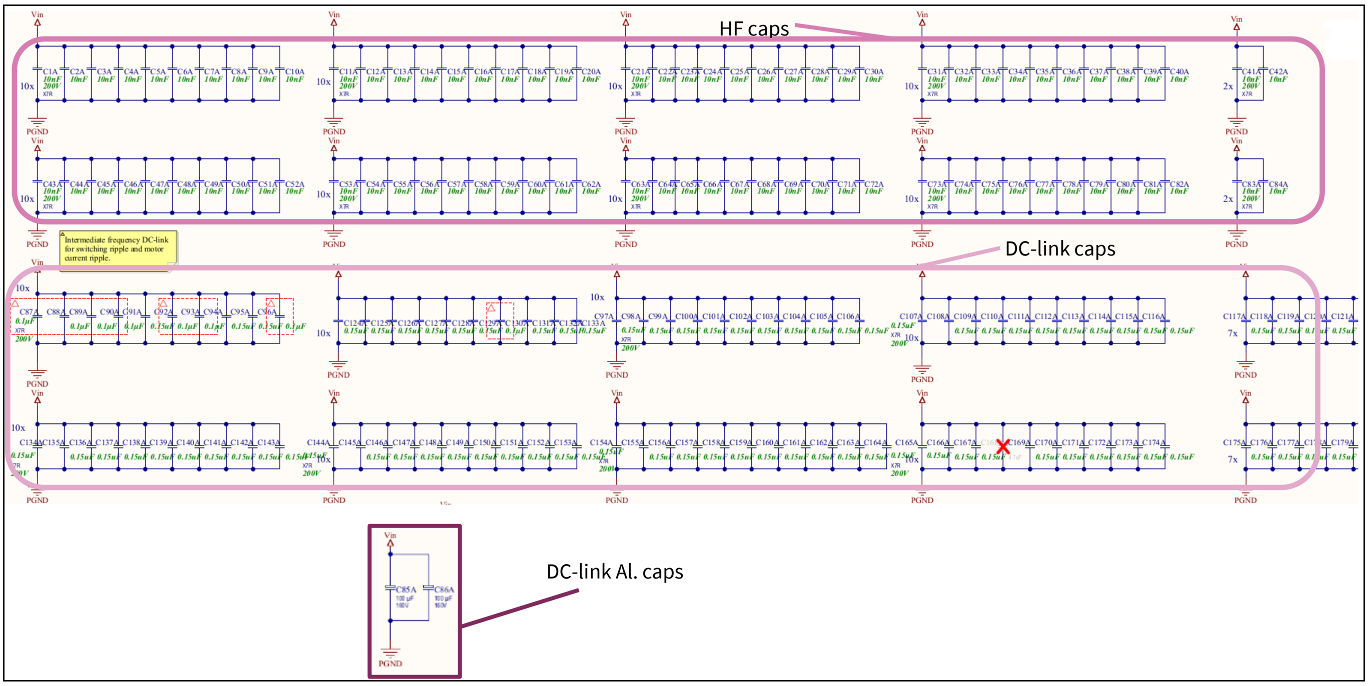

Figure 10 Schematic of the bulk capacitance for a single half-bridge, 200 V version

3.2.1 Gate driver

The EiceDRIVER™ 1EDN7116U gate driver incorporates several key features intended for GaN gate driving. One such feature is the truly differential input (TDI), which provides common-mode voltage rejection to the high-side during switching. TDI also provides ground-bounce immunity for the low-side, thereby guaranteeing stable operation even during fast switching transients.

1EDN7116U is used in this design as it offers a 2 A peak source/sink current. In addition, this gate driver provides an active Miller clamp in the output stage, which amplifies the pull-down strength to 5 A after the turn-off transition, within 3 ns after the gate voltage has fallen below 0.4 V. After the driver latches in this state, it holds the gate voltage at V_{OFF} with a pull-down resistance of 0.3 Ω. In this way, the designer can adjust the GaN HEMT's turn-off speed without jeopardizing its immunity to induced turn-on.

The schematic of the gate driver section is reported in Figure 11. In this evaluation board, the 1EDN7116U is used to have a configuration that guarantees a peak of 4 A source, this is possible by shorting the BST pin with the source pin (Figure 11). The boost of the source's current disables the option to avoid the overcharge on the high-side V_{gs} (as reported in [2]), which is more sensible with a high phase current and dead time of more than 10 ns, as shown in Figure 11 (left). During the negative part of the phase current, the voltage can drop down to ~4 V, which is almost the value of the UVLO of the 1EDN7116U driver, as reported in Figure 12 on left side.

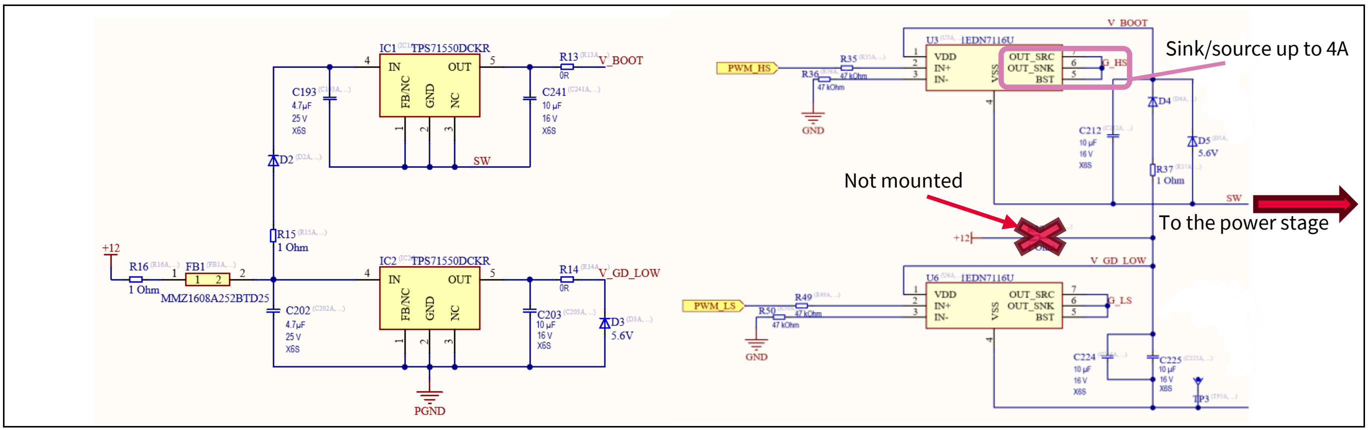

Figure 11 **Schematic of the gate driver and the LDO for a single half-bridge**

The behaviour is corrected with an LDO that regulates the gate driver's supply voltage. The LDO see all the variability of the voltage during the overcharge and discharge. The regulated V_{gs} are reported in Figure 12.

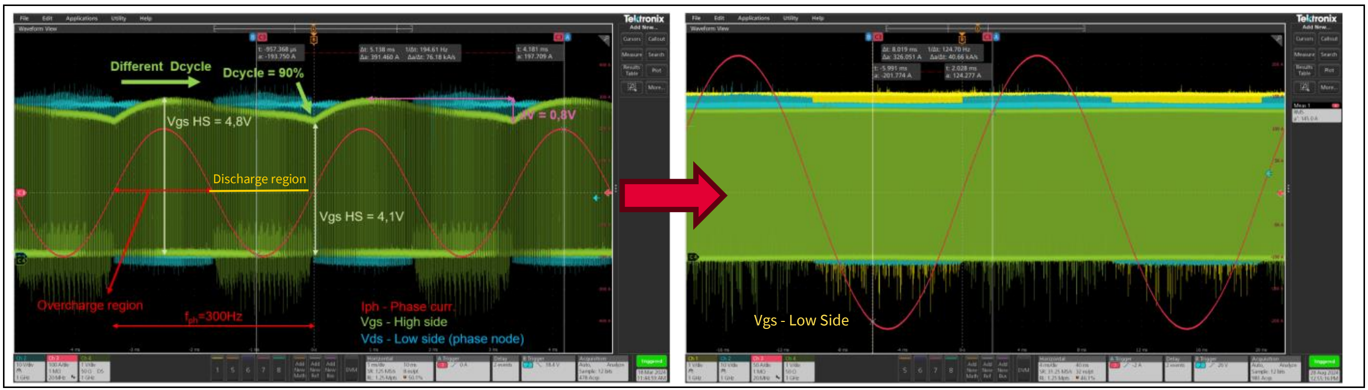

Figure 12 **Left: Waveform without the LDO or BST pin on the high-side gate driver supply with a phase current of 140 A_{rms}; Right: Waveform with the LDO or BST pin on the high-side gate driver supply with a phase current of 140 A_{rms}**

3.2.2 Current sensing

In-phase current sensing was chosen instead of low-side shunt current sensing to fully optimize the high-frequency power loop inductance of the half-bridge and minimize the common-source inductance in gate loops. TLE4972 is a Hall-effect sensor with the current acquired out of the package, which avoids potential common-mode transient immunity issues with differential amplifiers and higher current capability. A well-isolated in-phase current sensor is more immune to voltage transients and provides accurate readings for field-oriented control of the motor.

To provide bidirectional current measurement, the output voltage for 0 A is offset by half of the supply voltage, i.e., 1.65 V under nominal conditions. For the highest accuracy, an offset calibration is recommended before supplying current to the motor. This is typically a part of the control software.

In addition to an isolated readout of the phase current, TLI4971 provides overcurrent detection capabilities on the OCD1 and OCD2 pins, at 834 A and 492 A respectively, using open-drain outputs. A threshold of 492 A is used by default. Figure 13 provides information on how this value can be reconfigured by changing the values of the resistors R51 and R53.

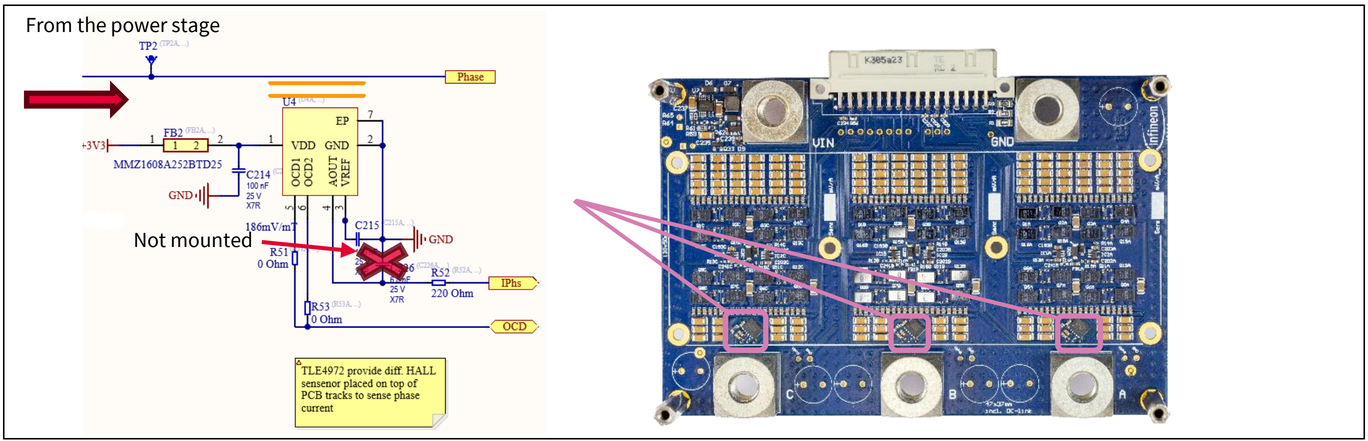

Figure 13 **Schematic of the current sensor and cation in the board**

3.2.3 Half-bridge (HB) layout

The recommended layout for a CoolGaN™ Transistor half-bridge is shown in Figure 14. The two high-frequency loops for gate current and drain current are oriented perpendicular to each other to minimize common-source inductance or cross-coupling.

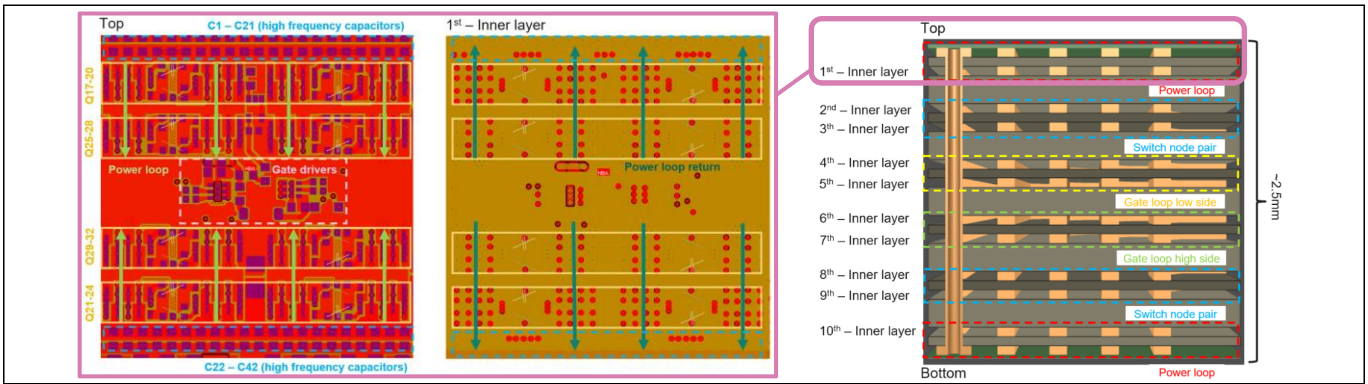

Figure 14 **Half-bridge layout; arrows indicate the flow of drain switching currents and stack-up**

The phase node, shown in Figure 15, is replicated on the second and third inner layers to guarantee less coupling between the layer pair. Moreover, to confine the noise of those layers, two ground planes are placed in the first and the fourth layer with increased space distance (d_1 and d_2) to mitigate capacitive coupling.

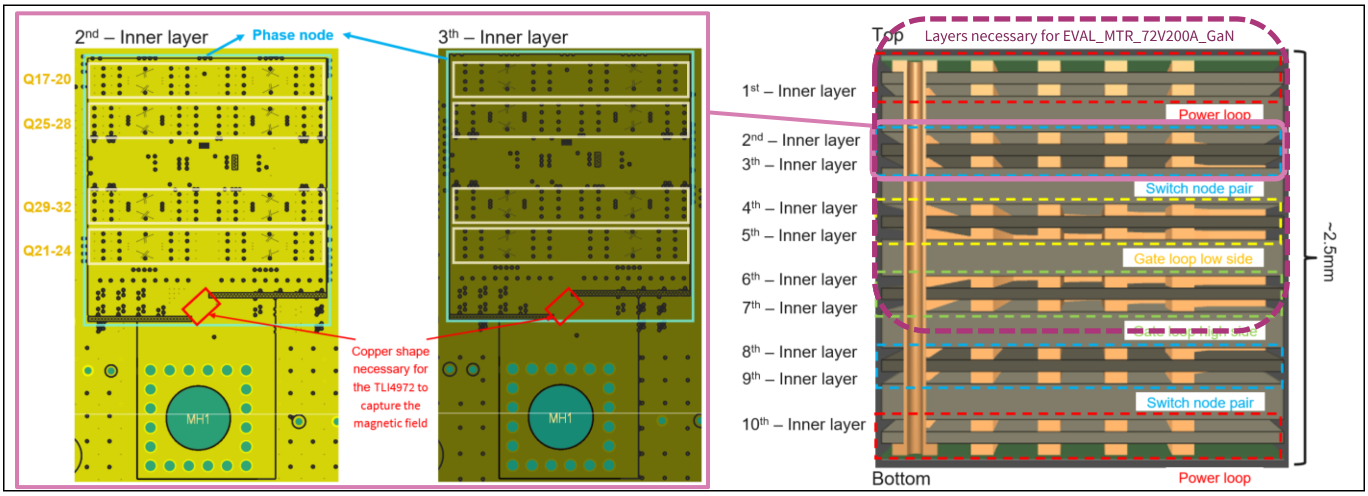

Figure 15 **Layout of the phase node and stack up**

Figure 16 and Figure 17 report the connection from the gate driver to the device in parallel and the return path, for the low-side and high-side respectively.

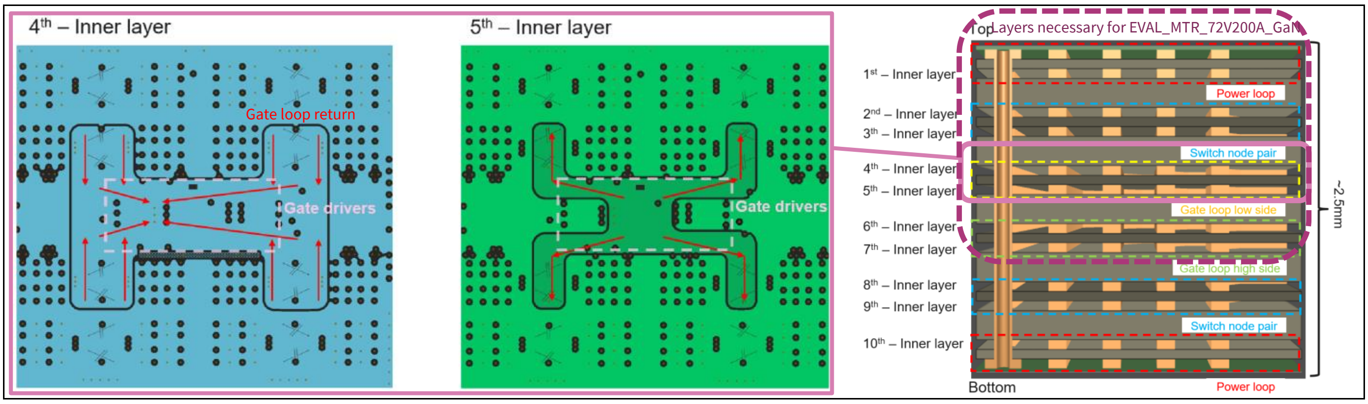

Figure 16 **Layout of the low-side gate loop and stack up**

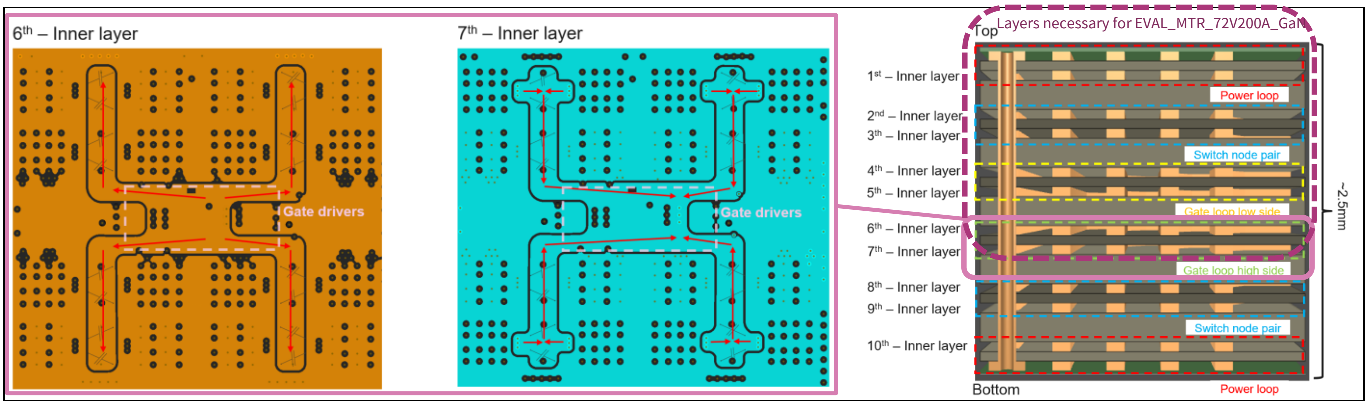

Figure 17 **Layout of of the high-side gate loop and stack up**

3.3 Power supply manager

An onboard DC-DC converter generates the 12 V rail from the VIN supply (see Figure 18). The 12 V rail directly determines the gate voltage applied to the CoolGaN™ Transistors by the 1EDN7116U gate drivers. In addition, the 3.3 V rail is derived from 12 V to supply the current sensors. The DC-DC converter employs UVLO and will only start up when VIN exceeds 34 V. A green LED at the top-left corner indicates the status of the DC-DC converter. The upper limit is defined by the protection diode (D4). A maximum stable voltage from the battery of 60 V is required before triggering the protection. The maximum measurable applied voltage can go up to 52 V.

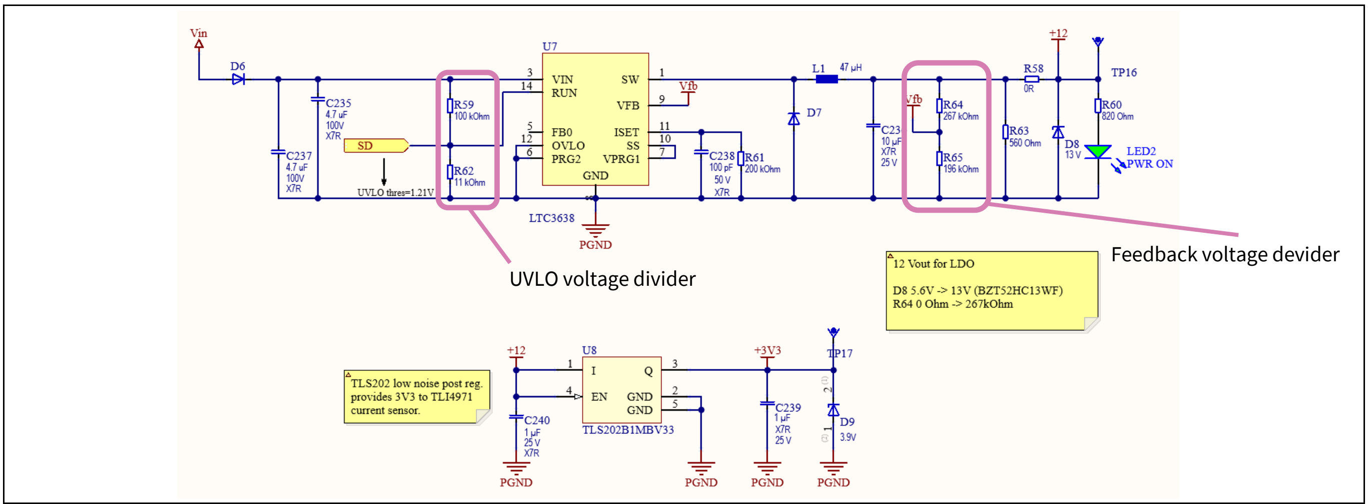

Figure 18 Schematic of the auxiliary power supply, 100V version

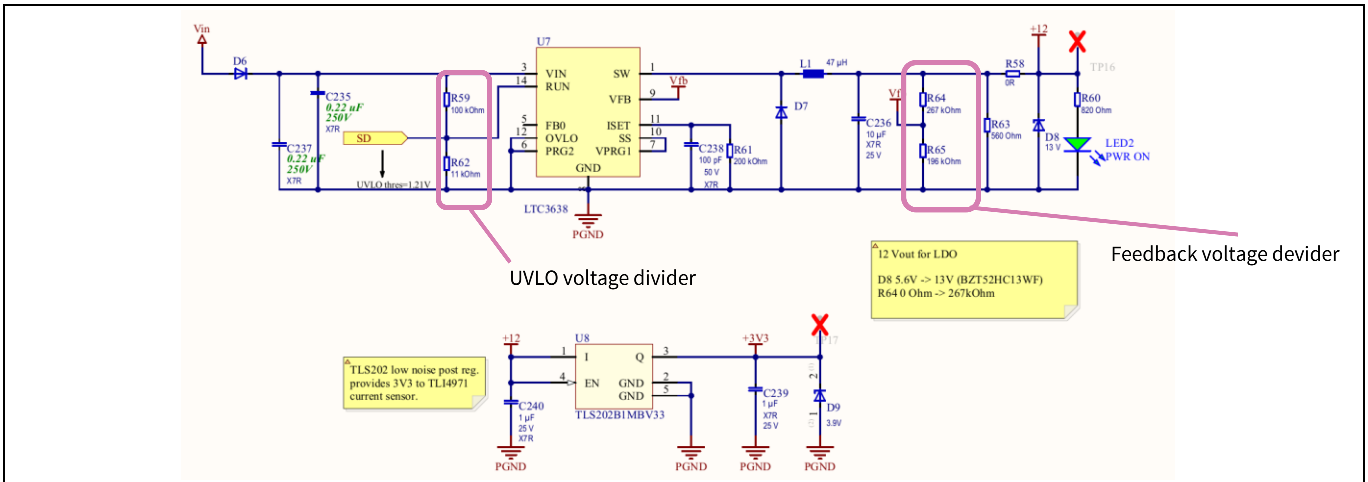

Figure 19 Schematic of the auxiliary power supply, 200V version

3.4 Control

The control card interface (DIN 41612, 32-pin, female) with supporting circuits is shown in Figure 20 for boards earlier than version 2.0 and in Figure 21 for versions 2.0 and later. The pinout is compatible with Infineon's XMC1400 or 4400 control cards, which can also be used with other microcontrollers. The control board can be supplied with less than 25 mA from the onboard DC-DC converter, either from the 12 V or 3.3 V rail, using the solder jumpers R54 or R55, respectively.

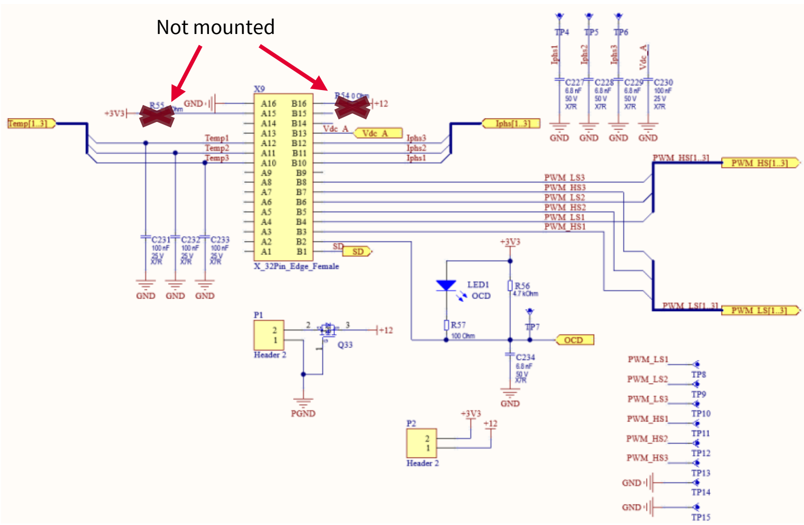

Figure 20 **Schematic of the pin header or control card interface for board versions earlier than 2.0**

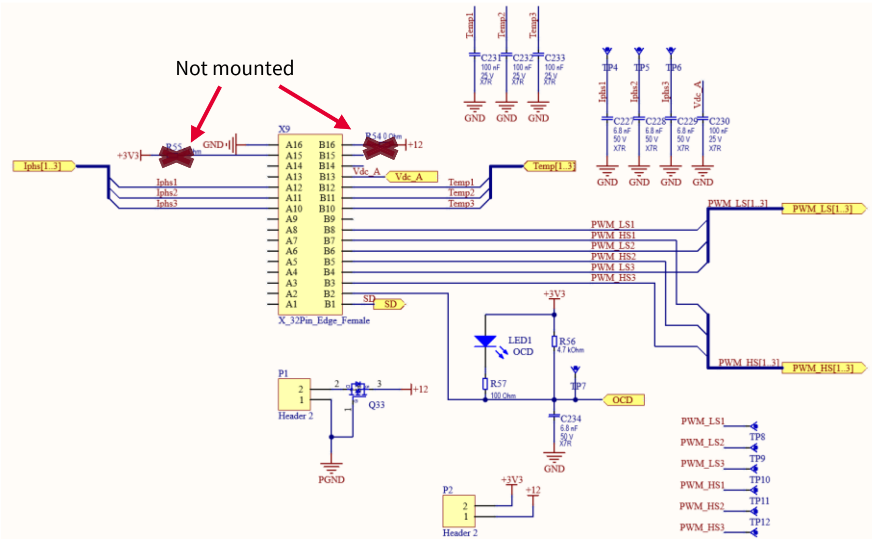

Figure 21 **Schematic of the pin header or control card interface for version 2.0 boards and later**

3.4.1 Temperature sensing

A temperature sensor (Figure 22) is connected directly to the same ground potential as the low-side switch Q2, with a scale factor of 10 mV/°C (or 20 mV/°C depending on the mounted parts, check Section 7) and 750 mV offset at 25°C.

The temperature readout of the sensor is a measurement of the PCB near the CoolGaN™ Transistors, but it is not a direct readout of their junction temperatures. Therefore, it is recommended to choose a conservative threshold, e.g., 80°C or 1.3 V. This value will further depend on the heat spreader design, the selected TIM, and airflow conditions.

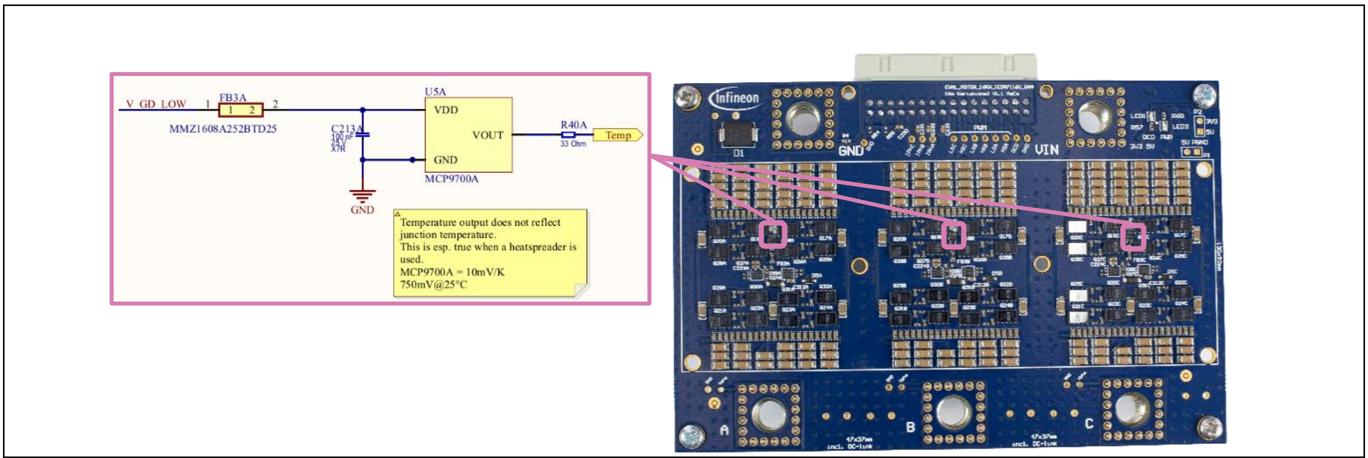

Figure 22 Overview of the bottom part of DEMO_MTR_72V200A_GaN board

4 Supported user modifications

DEMO_MTR_72V200A_GaN is a flexible evaluation board to support designs using CoolGaN™ Transistors in motor drive applications. To cater to different needs, the board supports several user modifications.

4.1 External supply of 12 V rail

For investigation of gate drive patterns and the first-check of the microcontroller, power the DEMO_MTR_72V200A_GaN evaluation board with an external auxiliary supply, as the onboard auxiliary power supply will not be available in this condition. This can be accomplished by desoldering R58 and supplying 12 V directly to the connector, as shown in Figure 23.

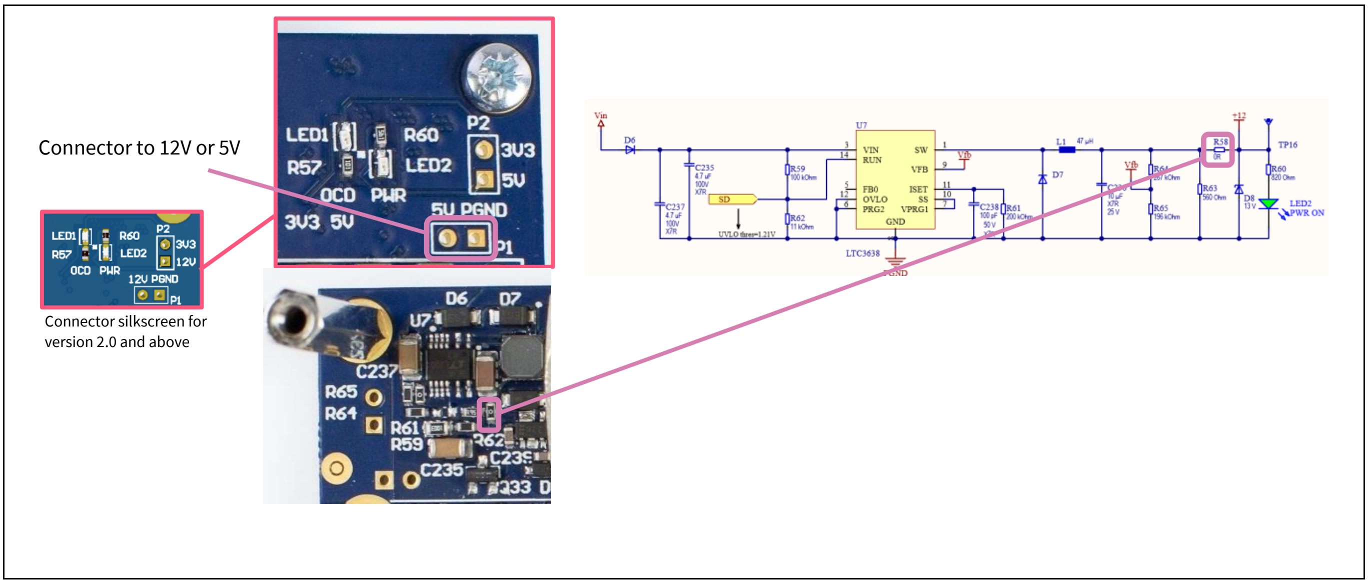

Figure 23 Connection for external 12 V supply

4.2 Additional bulk capacitance

For switching frequencies below 50 kHz, it might be necessary to add additional bulk capacitance, depending on the cable length and impedance of the power supply. This can be accomplished by inserting a leaded electrolytic capacitor in the additional place presented in Figure 24, the silkscreen reports the "–" pin of the capacitors.

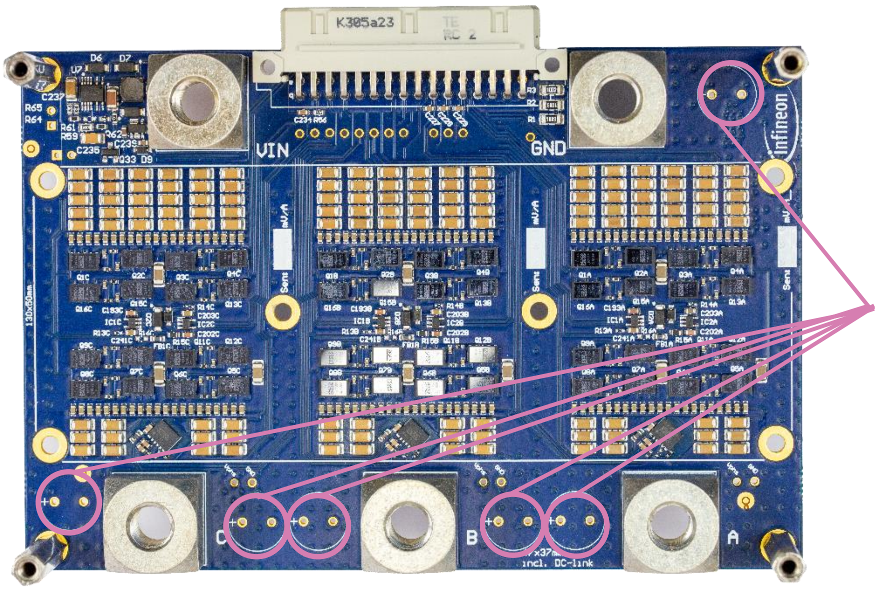

Figure 24 Additional electrolytic capacitor with a step of 7 mm

4.3 V_{DS} and V_{GS} measurements

The DEMO_MTR_72V200A_GaN evaluation board provides onboard probing points of critical waveforms such as V_{DS} and V_{GS}, as shown in Figure 25. To ensure accurate waveforms, a tight probing loop is recommended. For example, a short ground spring can be used between the probe tip and the board. A longer wire connection (more than 1 cm) with ground leads is not recommended, even with a twisted pair connection, because this will significantly worsen the measurement fidelity.

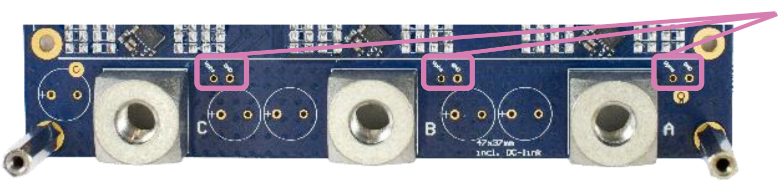

Figure 25 Measurement points for the V_{DS}

4.4 UVLO, heatsink electrical connection, and battery voltage divider

The UVLO of the main DC-DC converter, which steps down the main power connection, can be tuned for a lower battery voltage (e.g., 36 V). To do this, change the resistor R62 with a simple voltage divider relationship as per Equation 1. See Figure 26.

$$V_{UVLO} = \frac{100\ kOhm + R62}{R62} \cdot 1.21\ V$$

Equation 1 Tuning the UVLO for a lower battery voltage

A voltage is acquired at the main battery power connection, which is necessary for the microcontroller to run the FOC algorithm. This partition can be changed by the resistor R3 using the following relationship:

$$V_{input\ max} = \frac{200\ kOhm + R3}{R3} \cdot 3.3\ V$$

Equation 2 Changing the voltage partition at the main battery

The DEMO_MTR_72V200A_GaN board includes a battery voltage divider able to handle a supplied voltage up to 72 V DC, but the protection diode (D1) is rated for 85V that needs to be to disconnected, or R3 should be changed to increase the rating.

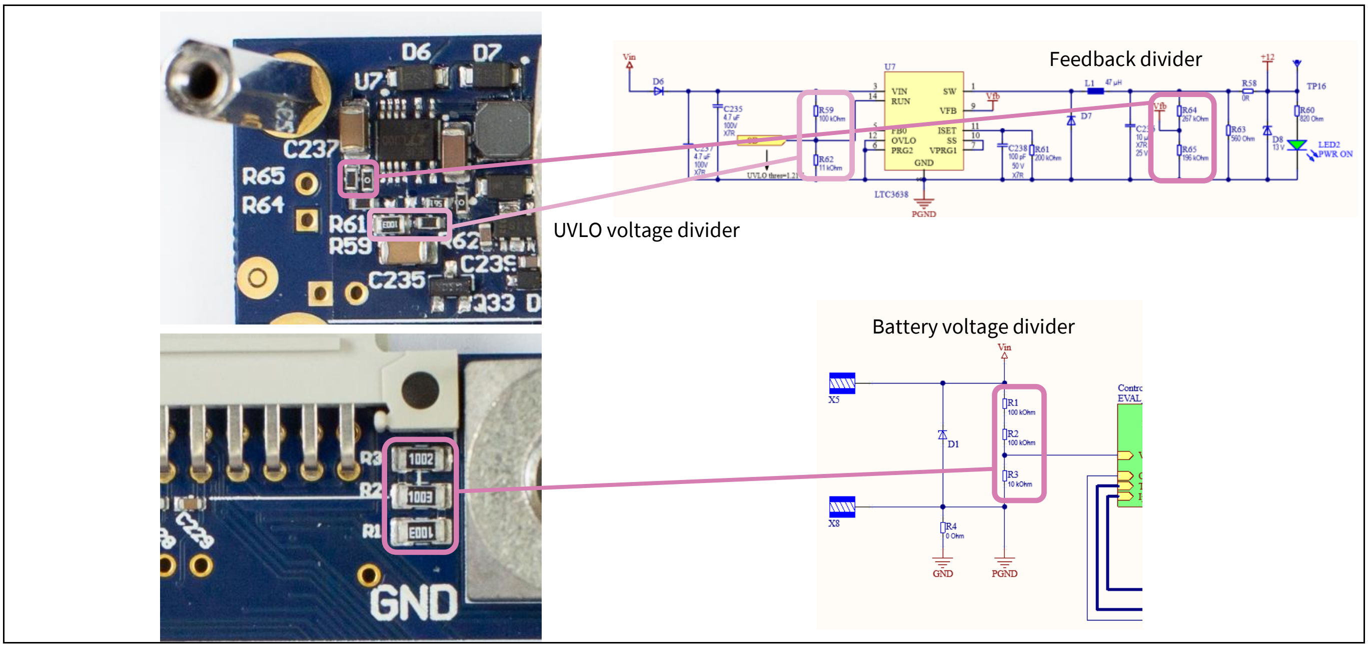

Figure 26 UVLO, feedback divider, and battery voltage divider

4.5 Gate resistor and C_{gs} external replacements

The DEMO_MTR_72V200A_GaN board is equipped with a gate resistor and external Cgs to slow down dV/dt when it is requested. Figure 27 shows where the gate drivers are shown for one half-bridge of the inverter.

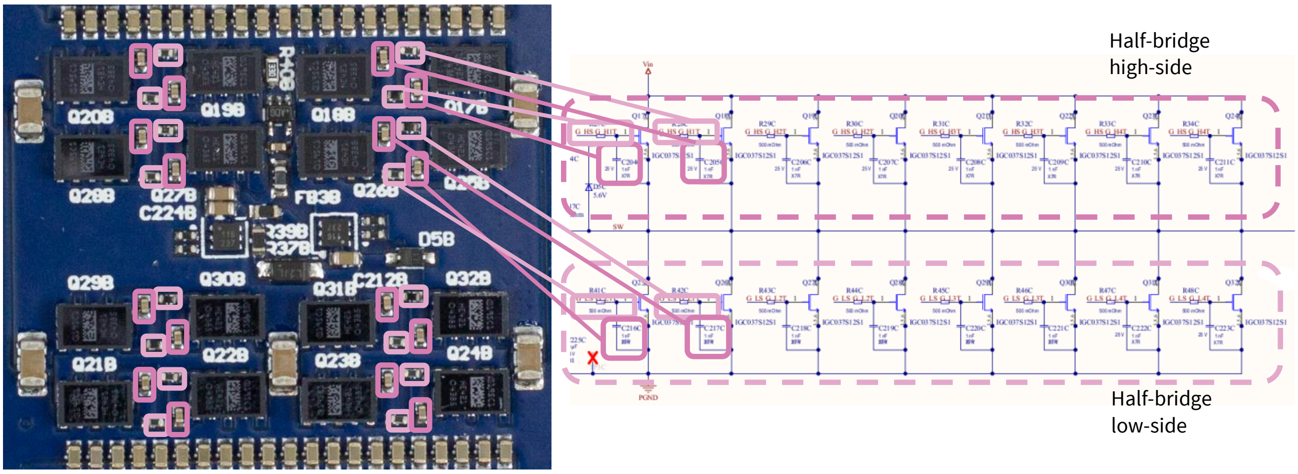

Figure 27 Schematic and of the single half-bridge in the bottom part and gate driver placement

5 Measurements

Here are some typical measurements that can be observed with the DEMO_MTR_72V200A_GaN evaluation board for reference.

5.1 V_{DS} measurement

Figure 28 shows an example measurement of low-side V_{DS} (also called phase node V_{ph})using the test pads shown in Figure 25, and the respective phase current I_{out} at V_{IN} = 72 V. dV/dt is measured between 10% and 90% of the waveform at the I_{out} peak, as well as the max value of this transition (dV/dt (max)). Usually, the board can be set with a dead-time of 50 ns. This option allows improving the efficiency of the inverter's diode mode operation.

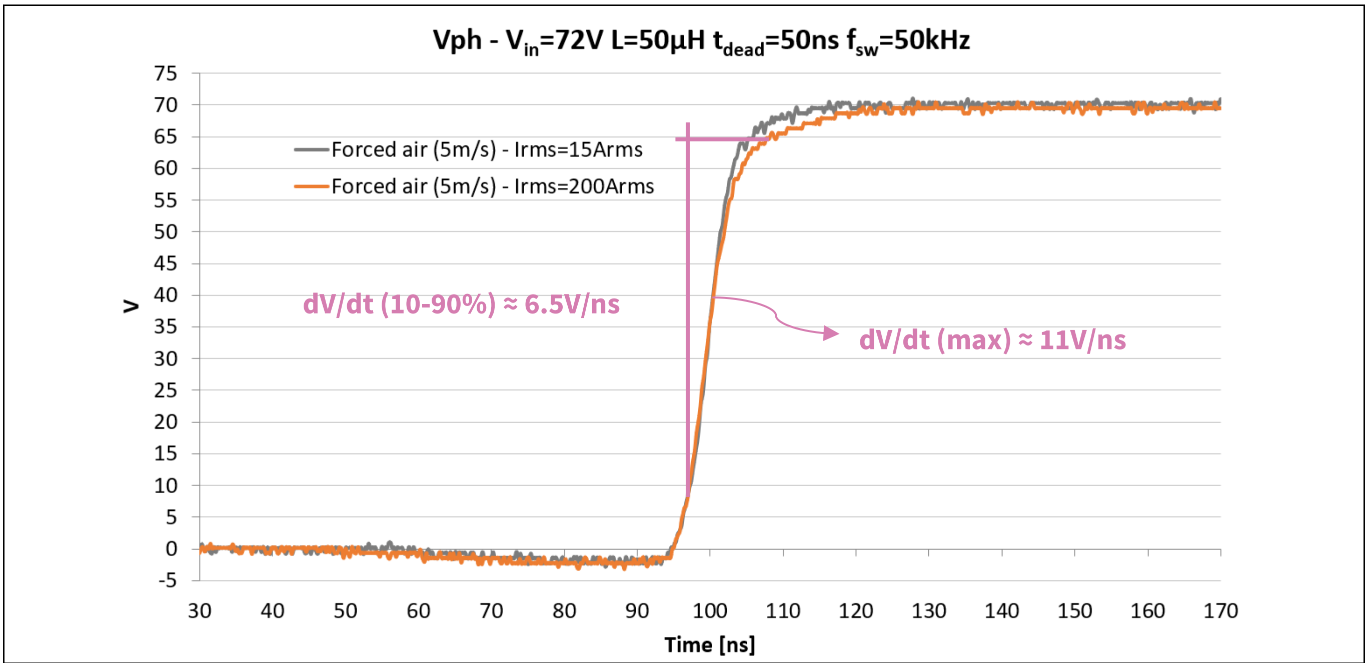

Figure 28 Phase node voltage during high-side hard turn-on

5.2 Measurement of losses: RL load with different gate drive options

Measurements of the RL load with the setup shown in Figure 29 are necessary to evaluate the losses under different conditions, with gate drivers, and the type of cooling used.

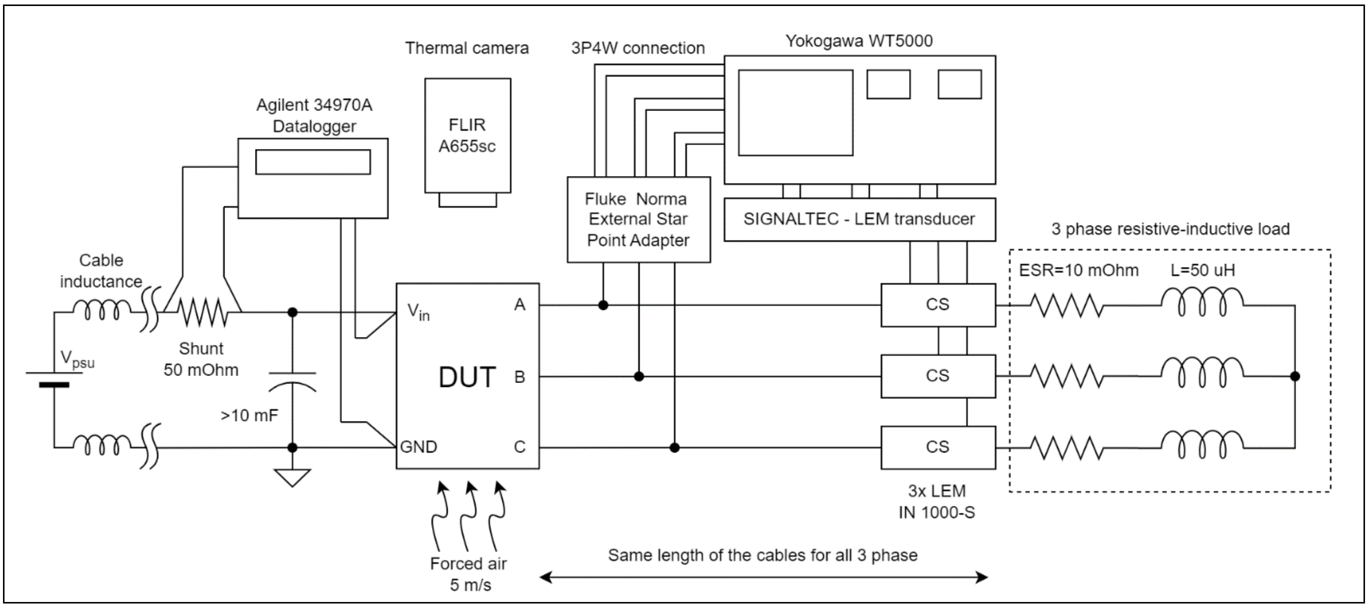

Figure 29 Measurement setup

Figure 30 shows the losses measured with two different dead-times. The plots show the difference in losses at heavy loads for natural convection and forced air. The corresponding temperature variation is also shown in Figure 30, which are captured with a thermal camera as shown in Figure 31 and a temperature of 25°C.

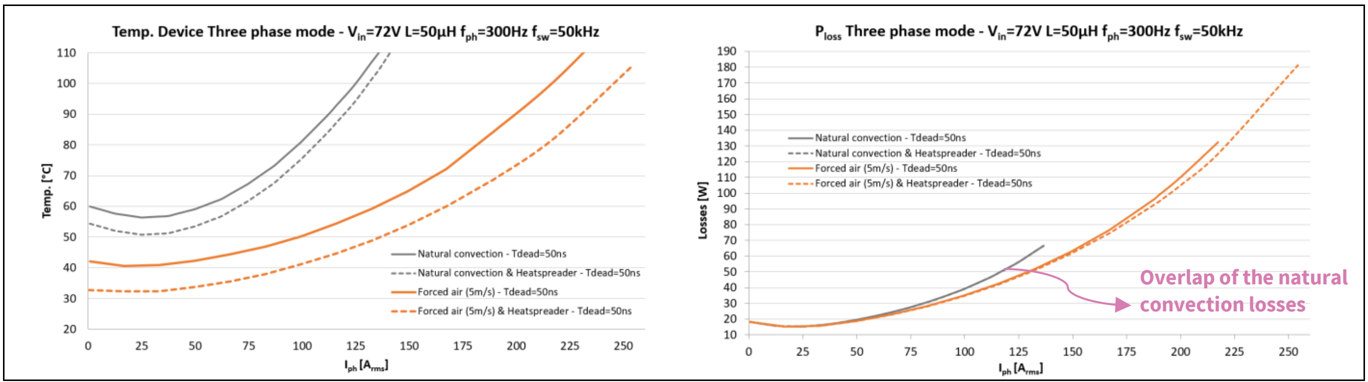

Figure 30 Measurement of losses and temperature of the evaluation design

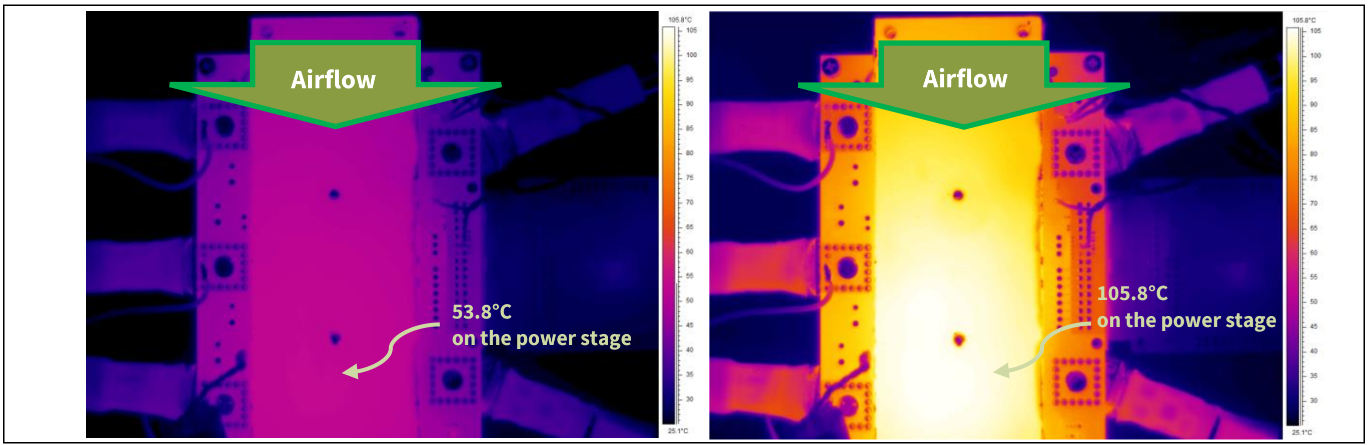

Figure 31 PCB temperature during the test with RL load at fsw=50 kHz and airflow of 5 m/s; (left) phase current of 140 A_{RMS}; (right) phase current of 250 A_{RMS} (right)

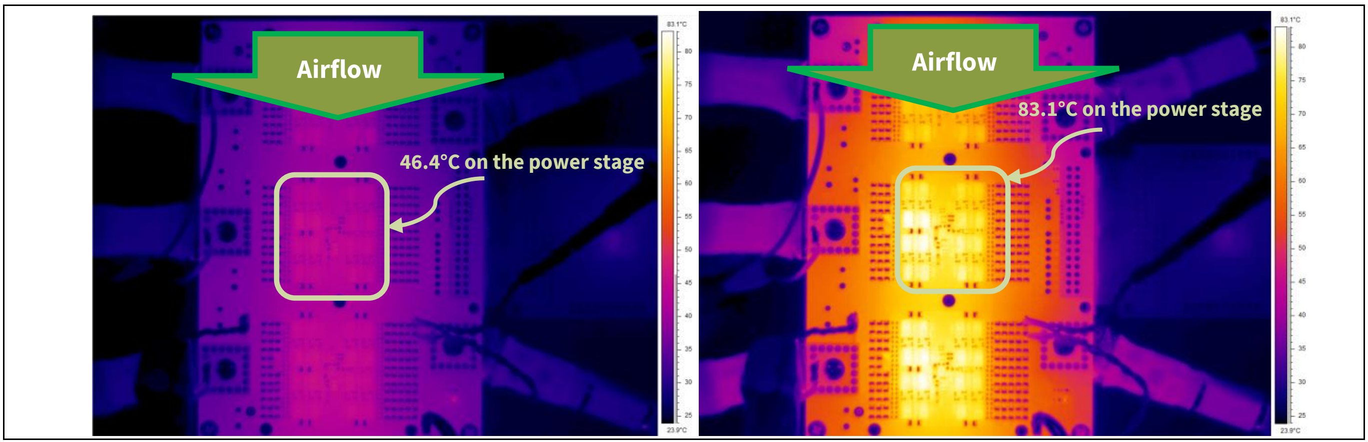

Figure 32 PCB temperature during the test with RL load at fsw=50 kHz and airflow of 5 m/s; (left) phase current of 80 A_{RMS}; (right) phase current of 190 A_{RMS} (right)

6 Note for the first start of the board

The section reports the notes related to the first run of the board and limitations on the control side.

- The duty cycle of the PWM cannot be greater than 97% with a switching frequency PWM of 100kHz.
- The current sensor depends on the PCB manufacturer's pressing process; a first tuning is required for a new board. That can be handled by an open loop control to have a fixed phase current and an external sensor to compare the measured data from the sensor on the board (TLE4972).
- Current is not limited on the board (no current protection). Any inrush current needs to be limited from the power supply.

7 Bill of materials

Table 5 Bill of materials for DEMO_MTR_72V200A_GaN

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
1	19	100 nF/10 nF	C1A, C1B, C1C, C2A, C2B, C2C, C3A, C3B, C3C, C4A, C4B, C4C, C5A, C5B, C5C, C6A, C6B, C6C, C7A, C7B, C7C, C8A, C8B, C8C, C9A, C9B, C9C, C10A, C10B, C10C, C11A, C11B, C11C, C12A, C12B, C12C, C13A, C13B, C13C, C14A, C14B, C14C, C15A, C15B, C15C, C16A, C16B, C16C, C17A, C17B, C17C, C18A, C18B, C18C, C19A, C19B, C19C, C20A, C20B, C20C, C21A, C21B, C21C, C22A, C22B, C22C, C23A, C23B, C23C, C24A, C24B, C24C, C25A, C25B, C25C, C26A, C26B, C26C, C27A, C27B, C27C, C28A, C28B, C28C, C29A, C29B, C29C, C30A, C30B, C30C, C31A, C31B, C31C, C32A, C32B, C32C, C33A, C33B, C33C, C34A, C34B, C34C, C35A, C35B, C35C, C36A, C36B, C36C, C37A, C37B, C37C, C38A, C38B, C38C, C39A, C39B, C39C, C40A, C40B, C40C, C41A, C41B, C41C, C42A, C42B, C42C, C43A, C43B, C43C,	GRM188R72A104KA35D	C0603X103K2RACTU	Murata, Kemet	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
			C44A, C44B, C44C, C45A, C45B, C45C, C46A, C46B, C46C, C47A, C47B, C47C, C48A, C48B, C48C, C49A, C49B, C49C, C54A, C54B, C54C, C56A, C56B, C56C, C57A, C57B, C57C, C58A, C58B, C58C, C59A, C59B, C59C, C60A, C60B, C60C, C61A, C61B, C61C, C62A, C62B, C62C, C63A, C63B, C63C, C64A, C64B, C64C, C65A, C65B, C65C, C66A, C66B, C66C, C67A, C67B, C67C, C68A, C68B, C68C, C69A, C69B, C69C, C70A, C70B, C70C, C71A, C71B, C71C, C72A, C72B, C72C, C73A, C73B, C73C, C74A, C74B, C74C, C75A, C75B, C75C, C76A, C76B, C76C, C77A, C77B, C77C, C78A, C78B, C78C, C79A, C79B, C79C, C80A, C80B, C80C, C81A, C81B, C81C, C82A, C82B, C82C, C83A, C83B, C83C, C84A, C84B, C84C				
2	6	100 µF	C85A, C85B, C85C, C86A, C86B, C86C	–	UCY2C101 MHD1TO	Nichicon	–
3	15	100 nF/10 nF	C50A, C50B, C50C, C51A, C51B, C51C, C52A, C52B, C52C, C53A, C53B, C53C, C55A, C55B, C55C	GRM188R72A1 04KA35D	C0603X103 K2RACTU	Murata, Kemet	–
4	24	2.2 µF	C87A, C87B, C87C, C88A, C88B, C88C, C89A, C89B, C89C,	CL31A225KC9 LNNC	Not mounted	Samsung	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
			C90A, C90B, C90C, C92A, C92B, C92C, C93A, C93B, C93C, C96A, C96B, C96C, C130A, C130B, C130C				
5	14	100 nF	C91A, C91B, C91C, C94A, C94B, C94C, C95A, C95B, C95C, C97A, C97B, C97C, C98A, C98B, C98C, C99A, C99B, C99C, C100A, C100B, C100C, C101A, C101B, C101C, C102A, C102B, C102C, C103A, C103B, C103C, C104A, C104B, C104C, C105A, C105B, C105C, C106A, C106B, C106C, C107A, C107B, C107C, C108A, C108B, C108C, C109A, C109B, C109C, C110A, C110B, C110C, C111A, C111B, C111C, C112A, C112B, C112C, C113A, C113B, C113C, C114A, C114B, C114C, C115A, C115B, C115C, C116A, C116B, C116C, C117A, C117B, C117C, C118A, C118B, C118C, C119A, C119B, C119C, C120A, C120B, C120C, C121A, C121B, C121C, C122A, C122B,	GCM155R71C104KA55D	–	Murata	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
			C122C, C123A, C123B, C123C, C124A, C124B, C124C, C125A, C125B, C125C, C126A, C126B, C126C, C127A, C127B, C127C, C128A, C128B, C128C, C129A, C129B, C129C, C131A, C131B, C131C, C132A, C132B, C132C, C133A, C133B, C133C, C134A, C134B, C134C, C135A, C135B, C135C, C136A, C136B, C136C, C137A, C137B, C137C, C138A, C138B, C138C, C139A, C139B, C139C, C140A, C140B, C140C, C141A, C141B, C141C, C142A, C142B, C142C, C143A, C143B, C143C, C144A, C144B, C144C, C145A, C145B, C145C, C146A, C146B, C146C, C147A, C147B, C147C, C148A, C148B, C148C, C149A, C149B, C149C, C150A, C150B, C150C, C151A, C151B, C151C, C152A, C152B, C152C, C153A, C153B, C153C, C154A,				

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
			C154B, C154C, C155A, C155B, C155C, C156A, C156B, C156C, C157A, C157B, C157C, C158A, C158B, C158C, C159A, C159B, C159C, C160A, C160B, C160C, C161A, C161B, C161C, C162A, C162B, C162C, C163A, C163B, C163C, C164A, C164B, C164C, C165A, C165B, C165C, C166A, C166B, C166C, C167A, C167B, C167C, C169A, C169B, C169C, C170A, C170B, C170C, C171A, C171B, C171C, C172A, C172B, C172C, C173A, C173B, C173C, C174A, C174B, C174C, C175A, C175B, C175C, C176A, C176B, C176C, C177A, C177B, C177C, C178A, C178B, C178C, C179A, C179B, C179C, C180A, C180B, C180C, C181A, C181B, C181C, C182A, C182B, C182C, C183A, C183B, C183C, C184A, C184B, C184C				

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
6	25	4.7 µF/150 nF	C91A, C91B, C91C, C97A, C97B, C97C, C98A, C98B, C98C, C99A, C99B, C99C, C100A, C100B, C100C, C101A, C101B, C101C, C102A, C102B, C102C, C103A, C103B, C103C, C104A, C104B, C104C, C105A, C105B, C105C, C106A, C106B, C106C, C107A, C107B, C107C, C111A, C111B, C111C, C112A, C112B, C112C, C113A, C113B, C113C, C114A, C114B, C114C, C115A, C115B, C115C, C116A, C116B, C116C, C131A, C131B, C131C, C154A, C154B, C154C, C155A, C155B, C155C, C156A, C156B, C156C	GRJ31CC72A475KE01K	C1206X154K2RACTU	Murata/ Kemet	Soft termination
7	96	1 nF	C185A, C185B, C185C, C186A, C186B, C186C, C187A, C187B, C187C, C188A, C188B, C188C, C189A, C189B, C189C, C190A, C190B, C190C, C191A, C191B, C191C, C192A, C192B, C192C, C194A, C194B, C194C, C195A, C195B, C195C,	04023C102J4T2A	04023C102J4T2A	AVX	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
			C196A, C196B, C196C, C197A, C197B, C197C, C198A, C198B, C198C, C199A, C199B, C199C, C200A, C200B, C200C, C201A, C201B, C201C, C204A, C204B, C204C, C205A, C205B, C205C, C206A, C206B, C206C, C207A, C207B, C207C, C208A, C208B, C208C, C209A, C209B, C209C, C210A, C210B, C210C, C211A, C211B, C211C, C216A, C216B, C216C, C217A, C217B, C217C, C218A, C218B, C218C, C219A, C219B, C219C, C220A, C220B, C220C, C221A, C221B, C221C, C222A, C222B, C222C, C223A, C223B, C223C				
8	6	4.7 µF	C193A, C193B, C193C, C202A, C202B, C202C	GRM188C81E475KE11D	GRM188C81E475KE11D	Murata	–
9	15	10 µF	C203A, C203B, C203C, C212A, C212B, C212C, C224A, C224B, C224C, C225A, C225B, C225C, C241A, C241B, C241C	CM105X6S106K16AT	CM105X6S106K16AT	AVX	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
10	3	100 nF	C213A, C213B, C213C	GRM155R71E104KE14D	GRM155R71E104KE14D	Murata	–
11	10	100 nF	C214A, C214B, C214C, C215A, C215B, C215C, C230, C231, C232, C233	CGA3E2X7R1E104K080AA	CGA3E2X7R1E104K080AA	TDK	–
12	7	6.8 nF	C226A, C226B, C226C, C227, C228, C229, C234	CGA3E2X7R1H682K080AA	CGA3E2X7R1H682K080AA	TDK	–
13	2	4.7 µF/ 220 nF	C235, C237	GRM31CC72A475KE11L	C1206X224KARACTU	Murata	–
14	1	10 µF	C236	C3216X8L1E106K160AC	C3216X8L1E106K160AC	Murata	–
15	1	//	C238	Not mounted	Not mounted	–	–
16	2	10 µF	C239, C240	C1608X7R1E105K080AB	C1608X7R1E105K080AB	TDK	–
17	1	TVS	D1	1.5SMC91CA	1.5SMC91CA	Littlefuse	–
18	6	Bootstrap diode	D2A, D2B, D2C, D4A, D4B, D4C	MBR2H200SFT1G	MBR2H200SFT1G	onsemi	–
19	6	5.6 V Zener	D3A, D3B, D3C, D5A, D5B, D5C	BZX384B5V6	BZX384B5V6	Vishay	–
20	1	Diode	D6, D7	CDBMS1200-HF	CDBMS1200-HF	Comchip	–
21	1	13 V Zener	D8	BZT52HC13WF-7	BZT52HC13WF-7	Diodes Inc.	–
22	1	3.9 V Zener	D9	BZX384C3V9-HG3-08	BZX384C3V9-HG3-08	Vishay	–
23	9	Ferrite	FB1A, FB1B, FB1C, FB2A, FB2B, FB2C, FB3A, FB3B, FB3C	MMZ1608A252BTD25	MMZ1608A252BTD25	TDK	–
24	6	LDO	IC1A, IC1B, IC1C, IC2A, IC2B, IC2C	TPS71550DCKR	TPS71550DCKR	TI	–
25	1	Inductor	L1	IFSC1515AHER470M01	IFSC1515AHER470M01	Vishay	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
26	1	LED	LED1	AA1608SURSK	AA1608SURSK	Kingbright	–
27	1	LED	LED2	AA1608CGSK	AA1608CGSK	Kingbright	–
28	96	GaN HEMT	Q1A, Q1B, Q1C, Q2A, Q2B, Q2C, Q3A, Q3B, Q3C, Q4A, Q4B, Q4C, Q5A, Q5B, Q5C, Q6A, Q6B, Q6C, Q7A, Q7B, Q7C, Q8A, Q8B, Q8C, Q9A, Q9B, Q9C, Q10A, Q10B, Q10C, Q11A, Q11B, Q11C, Q12A, Q12B, Q12C, Q13A, Q13B, Q13C, Q14A, Q14B, Q14C, Q15A, Q15B, Q15C, Q16A, Q16B, Q16C, Q17A, Q17B, Q17C, Q18A, Q18B, Q18C, Q19A, Q19B, Q19C, Q20A, Q20B, Q20C, Q21A, Q21B, Q21C, Q22A, Q22B, Q22C, Q23A, Q23B, Q23C, Q24A, Q24B, Q24C, Q25A, Q25B, Q25C, Q26A, Q26B, Q26C, Q27A, Q27B, Q27C, Q28A, Q28B, Q28C, Q29A, Q29B, Q29C, Q30A, Q30B, Q30C, Q31A, Q31B, Q31C, Q32A, Q32B, Q32C	IGC037S12S1	IGC037S12S1	Infineon	–
29	1	MOS. p Ch	Q33	BSS314PE	BSS314PE	Infineon	–
30	2	100 kOhm	R1, R2	ERJ-8ENF1003V	ERJ-8ENF1003V	Panasonic	–
31	1	10 kOhm	R3	ERJ-8ENF1002V	ERJ-8ENF1002V	Panasonic	–
32	1	0 Ohm	R4	ERJ3GEY0R00V	ERJ3GEY0R00V	Panasonic	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
33	96	0.5 Ohm	R5A, R5B, R5C, R6A, R6B, R6C, R7A, R7B, R7C, R8A, R8B, R8C, R9A, R9B, R9C, R10A, R10B, R10C, R11A, R11B, R11C, R12A, R12B, R12C, R17A, R17B, R17C, R18A, R18B, R18C, R19A, R19B, R19C, R20A, R20B, R20C, R21A, R21B, R21C, R22A, R22B, R22C, R23A, R23B, R23C, R24A, R24B, R24C, R27A, R27B, R27C, R28A, R28B, R28C, R29A, R29B, R29C, R30A, R30B, R30C, R31A, R31B, R31C, R32A, R32B, R32C, R33A, R33B, R33C, R34A, R34B, R34C, R41A, R41B, R41C, R42A, R42B, R42C, R43A, R43B, R43C, R44A, R44B, R44C, R45A, R45B, R45C, R46A, R46B, R46C, R47A, R47B, R47C, R48A, R48B, R48C	RCC04020000Z0ED	RCC04020000Z0ED	Vishay	–
34	6	0 Ohm	R13A, R13B, R13C, R14A, R14B, R14C	RCC04020000Z0ED	RCC04020000Z0ED	Vishay	–
35	3	1 Ohm	R15A, R15B, R15C	RCS06031R00FKEA	RCS06031R00FKEA	Vishay	–
36	3	1 Ohm	R16A, R16B, R16C	RCS06031R00FKEA	RCS06031R00FKEA	Vishay	–
37	12	47 kOhm	R35A, R35B, R35C, R36A, R36B, R36C, R49A, R49B, R49C, R50A, R50B, R50C	RC0402FR-0747KL	RC0402FR-0747KL	Vishay	–
38	3	1 Ohm	R37A, R37B, R37C	RCS06031R00FKEA	RCS06031R00FKEA	Vishay	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
39	3	33 Ohm	R40A, R40B, R40C	ERJ-3GEYJ330V	ERJ-3GEYJ330V	Panasonic	–
40	3	220 Ohm	R52A, R52B, R52C	ERJ-H2RF2200X	ERJ-H2RF2200X	Panasonic	–
41	3	0 Ohm	R53A, R53B, R53C	RCC04020000Z0ED	RCC04020000Z0ED	Vishay	–
42	1	4.7 kOhm	R56	ERJ-3GEYJ472V	ERJ-3GEYJ472V	Panasonic	–
43	1	100 Ohm	R57	ERJ-3GEYJ101V	ERJ-3GEYJ101V	Panasonic	–
44	1	0 Ohm	R58	ERJ-3GEY0R00V	ERJ-3GEY0R00V	Panasonic	–
45	1	100 kOhm	R59	ERJ-6ENF1003V	ERJ-6ENF1003V	Panasonic	–
46	1	820 Ohm	R60	ERJ-H3GJ821V	ERJ-H3GJ821V	Panasonic	–
47	1	200 kOhm	R61	ERJ-3EKF2003V	ERJ-3EKF2003V	Panasonic	–
48	1	11 kOhm	R62	ERJ-3EKF1102V	ERJ-3EKF1102V	Panasonic	–
49	1	560 Ohm	R63	ERJ-3GEYJ561V	ERJ-3GEYJ561V	Infineon	–
50	1	267 kOhm	R64	CR0603-FX-2673ELF	CR0603-FX-2673ELF	Bourns	–
51	1	196 kOhm	R65	CR0603-FX-1963ELF	CR0603-FX-1963ELF	Bourns	–
52	6	Gate driver	U3A, U3B, U3C, U6A, U6B, U6C	1EDN7116U	1EDN7116U	Infineon	–
53	3	Current sensor	U4A, U4B, U4C	TLE4972-AE35S5	TLE4972-AE35S5	Infineon	–
54	3	Temp. Sens.	U5A, U5B, U5C	MCP9700AT-E/LT	MCP9700AT-E/LT	Microchip	MAX6612MXK+T
55	1	DCDC	U7	LTC3638EMSE#TRPBF	LTC3638EMSE#TRPBF	Analog Devices	–
56	1	LDO	U8	TLS202B1MBV33HTSA1	TLS202B1MBV33HTSA1	Infineon	–
57	5	Press fit	X4, X5, X6, X7, X8	7461090	7461090	Würth Elektronik	–

No.	Qty.	Part description	Designator	Part No. (100 V)	Part No. (200 V)	Manufacturer	Alternative parts/ comments
58	1	Connector	X9	294722	294722	ERNI	0927232680 1

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Email: erratum@infineon.com

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