Low voltage motor drive evaluation board with CoolGaN™ transistors for high current applications

About this document

Scope and purpose

This document provides an overview of the EVAL_MTR_48V150A_GaN CoolGaN™ motor drive evaluation board for low-voltage applications, including 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 48 V and 150 A_{RMS} motor phase current.

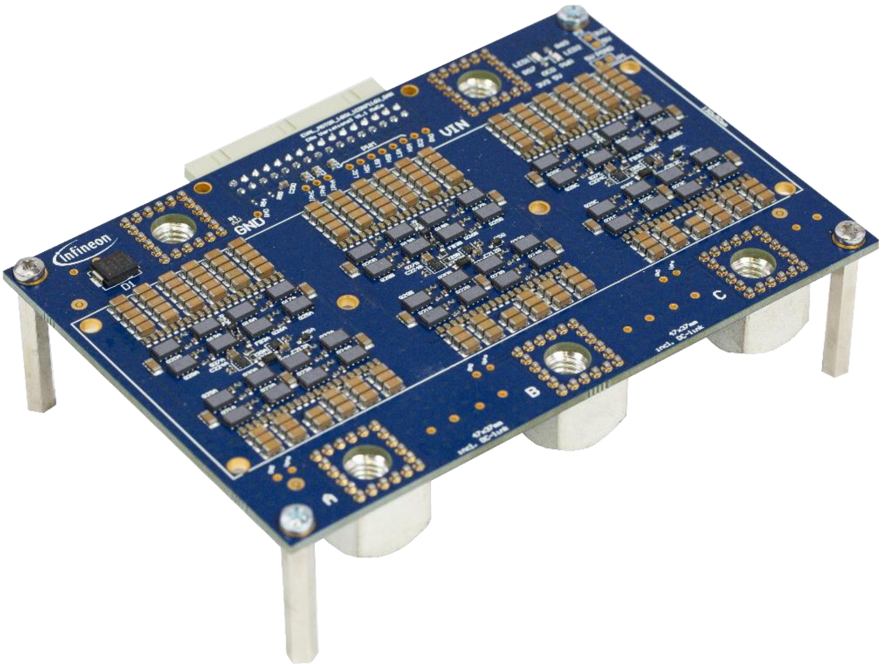

Figure 1 Evaluation board EVAL_MTR_48V150A_GaN

Note: This document is for the EVAL_MTR_48V150A_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 EVAL_MTR_48V150A_GaN and EVAL_MOTOR_16KW_1EDN7116U_GaN refer to the same reference board.

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Safety precautions

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

EVAL_MTR_48V150A_GaN is a high-power density evaluation board for low-voltage inverters. This board includes 48 numbers of CoolGaN™ Transistor 80 V IGC025S08S1 in a half-bridge configuration with eight devices in parallel for all sides of the phases. All the transistors in parallel are driven by an EiceDRIVER™ 1EDN7116U gate driver, and the output phase current is sensed by a XENSIV™ TLE4972 magnetic current sensor.

The board can be connected with different controller cards.

The evaluation board was developed to demonstrate the high power densities achievable with a size of 135 mm × 90 mm, and an active area of 130 mm × 50 mm × 6 mm, in which all the transistors and the main components of the three half-bridges are located. This is thanks to the reduction of bulk capacitance and the high switching frequency operation (≥100 kHz) of the inverter without a big power loss penalty. Moreover, CoolGaN™ Transistors 80 V IGC025S08S1 is a top-side cooling device on an exposed-die PQFN package that can efficiently extract heat and provide more space for a top-bottom PCB implementation.

EVAL_MTR_48V150A_GaN includes an aluminum heat spreader that can be easily adapted to the frame of the 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 gives full independence regarding the preferred switching pattern and dead-time. 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 EVAL_MTR_48V150A_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.

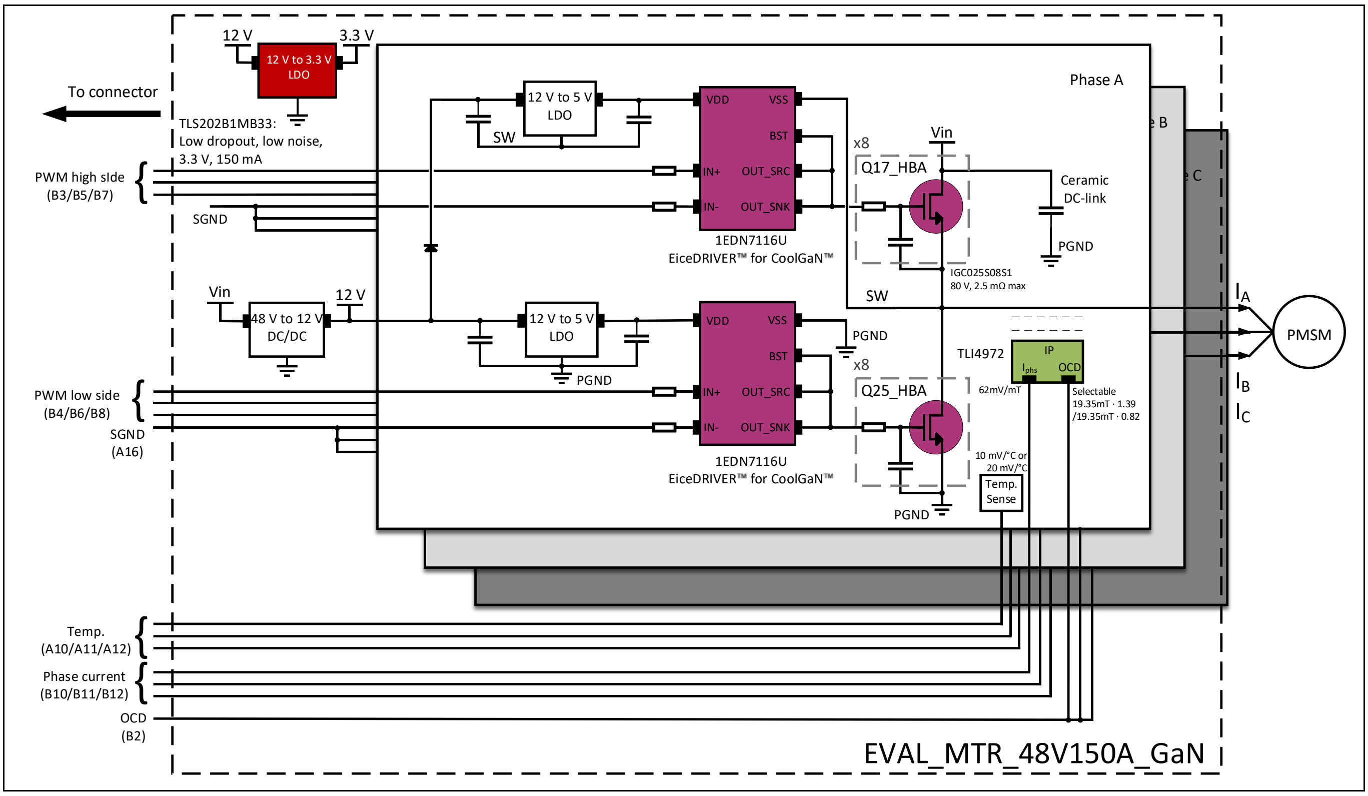

Figure 2 Block diagram of EVAL_MTR_48V150A_GaN including key parameters and pinout

2 Design features

EVAL_MTR_48V150A_GaN is an evaluation board equipped with the latest generation of Infineon's CoolGaN™ Transistors in combination with a complementary EiceDRIVER™ gate driver and current sensor XENSIV™ with current reel out of the chip.

Main components:

- CoolGaN™ Transistors 80 V IGC025S08S1 [1], 2.5 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:

- 48 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
- 3.3 V and 12 V auxiliary supply included
- Overcurrent detection (OCD), selectable as 492 A or 834 A
- Heatsink and mounting hardware included as a part of the kit

2.1 Highlighted products

2.1.1 CoolGaN™ Transistors 80 V

CoolGaN™ Transistors [1] offer fundamental advantages over silicon. In particular, the higher critical electrical field makes them attractive for power semiconductor devices with specific on-state resistance and smaller capacitances compared to silicon MOSFETs – a great solution for high-speed or high-frequency switching applications. GaN transistors can then be operated with reduced dead-times, which result in a higher efficiency and 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 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 ampere. 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 EVAL_MTR_48V150A_GaN board specification

Parameter	Value	Conditions/comment
Input		
Nominal input voltage	48 V	–
Maximum input voltage	68 V	Maximum stable voltage before triggering the overvoltage protection (OVP)
Maximum input operating voltage	66 V	Maximum input operating voltage acquired from the battery through the voltage divider (R1, R2, & R3)
Undervoltage lockout (UVLO)	14 V	Minimum voltage to turn off the DC-DC converter
Maximum input current	160 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)	8 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Output		
Power max (mechanical)	7 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Power max (per one phase)	3 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Current per phase leg (max)	110 A_{RMS}	48 V, Ta = 25°C, Tmax case = 110°C, natural convection, no heat spreader, and no forced air (in steady state)
	160 A_{RMS}	48 V, Ta = 25°C, Tmax case = 110°C, natural convection, no heat spreader, and forced air 2–3 m/s (in steady state)
	200 A_{RMS}	48 V, Ta = 25°C, natural convection, with heat spreader and forced air 2–3 m/s (in steady state)
	180 A_{RMS}	48 V, Ta = 25°C, no forced air with heat spreader, ≤30 seconds
Switching frequency		
Nominal switching frequency	100 kHz	
Minimal switching frequency	50 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	–

Parameter	Value	Conditions/comment
DC link voltage feedback		
Sensitivity	50 mV/V	±1%
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	0°C to 85°C	Non-condensing, maximum relative humidity of 95%
Maximum temperature	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 **NOTE:** Only 8 layers are necessary for the EVAL_MTR_48V150A_GaN
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 EVAL_MTR_48V150A_GaN evaluation board, respectively.

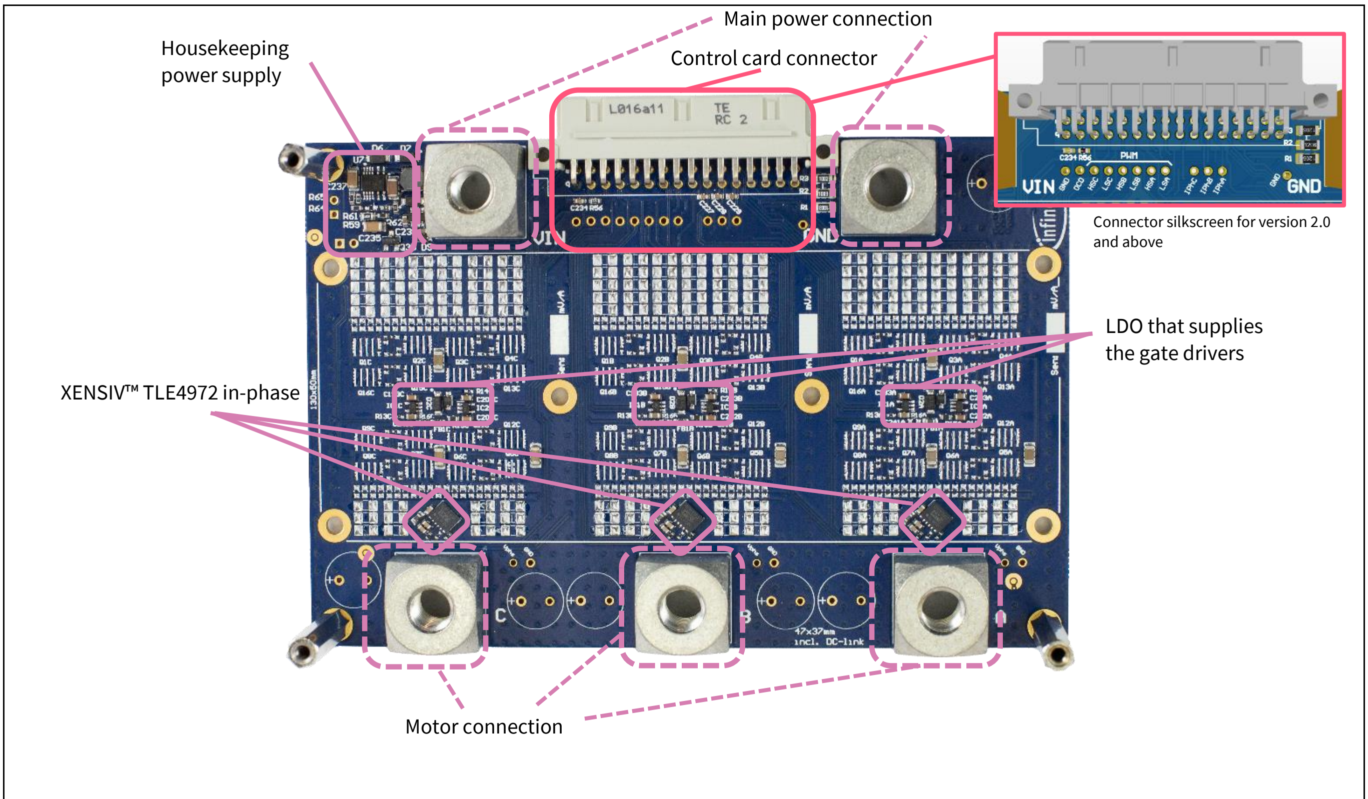

Figure 3 Overview of the top part of the EVAL_MTR_48V150A_GaN board

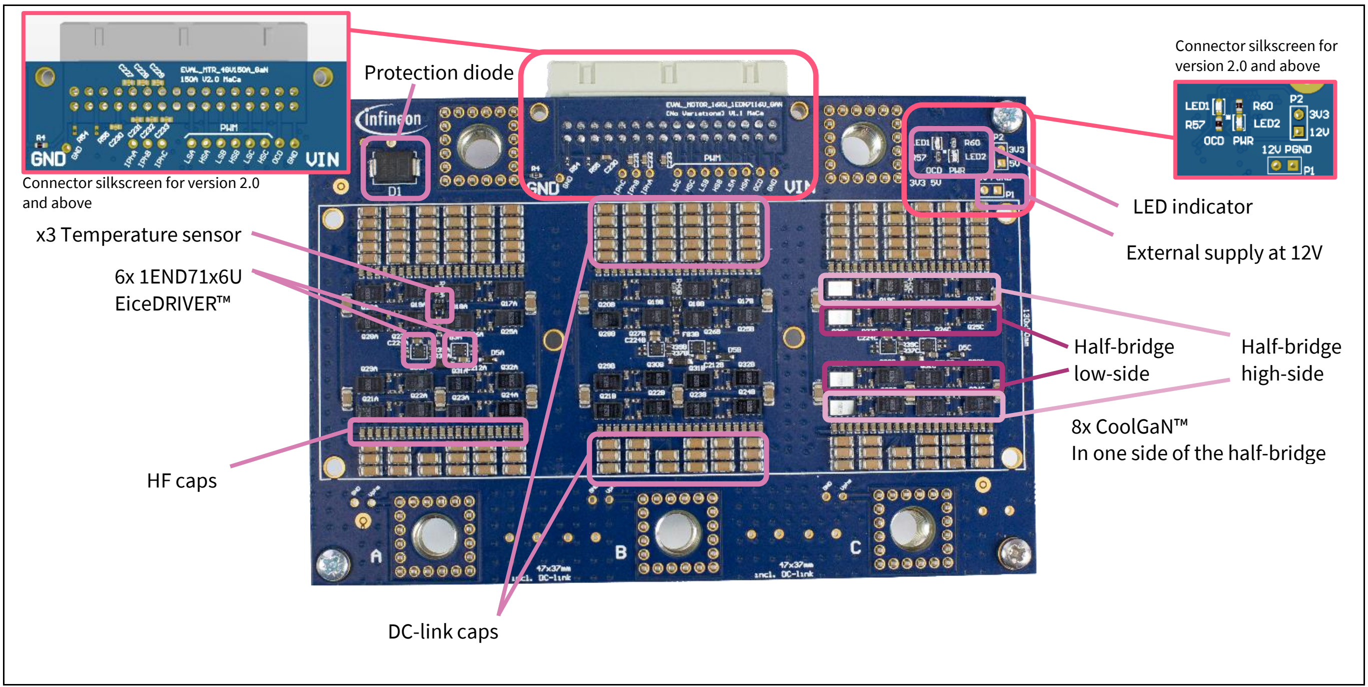

Figure 4 Overview of the bottom part of the EVAL_MTR_48V150A_GaN board

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 EVAL_MTR_48V150A_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 ~1 V at 25°C, 10 or 19.5 mV/°C
A11	Temp. B	750 mV or ~1 V at 25°C, 10 or 19.5 mV/°C
A12	Temp. C	750 mV or ~1 V 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 ~1 V at 25°C, 10 or 19.5 mV/°C
B11	Temp. B and 2	750 mV or ~1 V at 25°C, 10 or 19.5 mV/°C
B12	Temp. A and 1	750 mV or ~1 V 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 EVAL_MTR_48V150A_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 onto the PCB:

- Six M3 × 6 mm screws
- Three thermal interface material (TIM) pads, each of 35 mm × 30 mm (T-Global TG-A1250, 500 µm thickness) or gap filler
- One aluminum heat spreader/heatsink with integrated standoffs and alignment pins
- Two 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 µm 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.

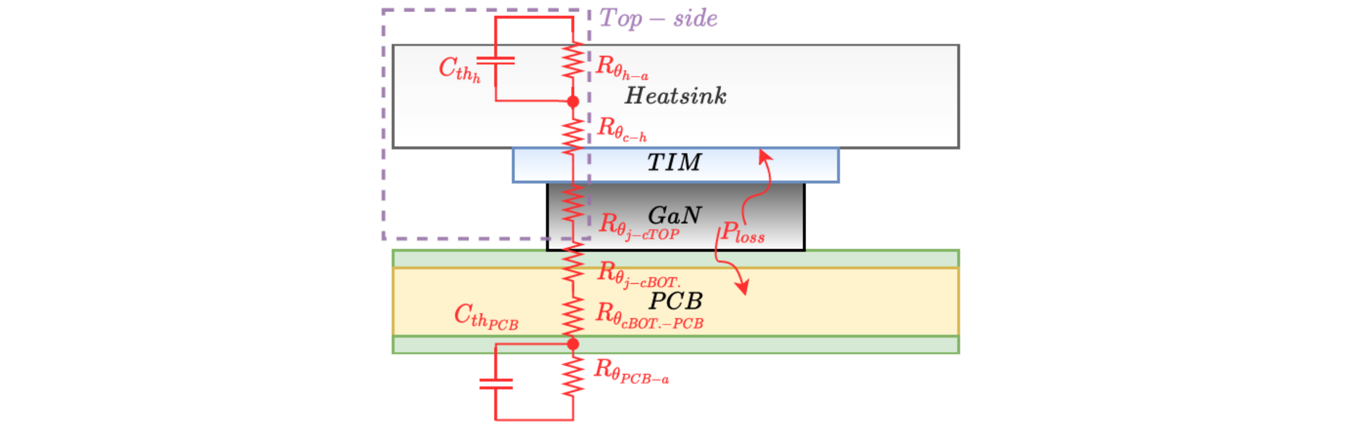

Figure 5 **Cross-section showing the assembly of heat spreader with TIM applied to a single device for top-side cooling**

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.

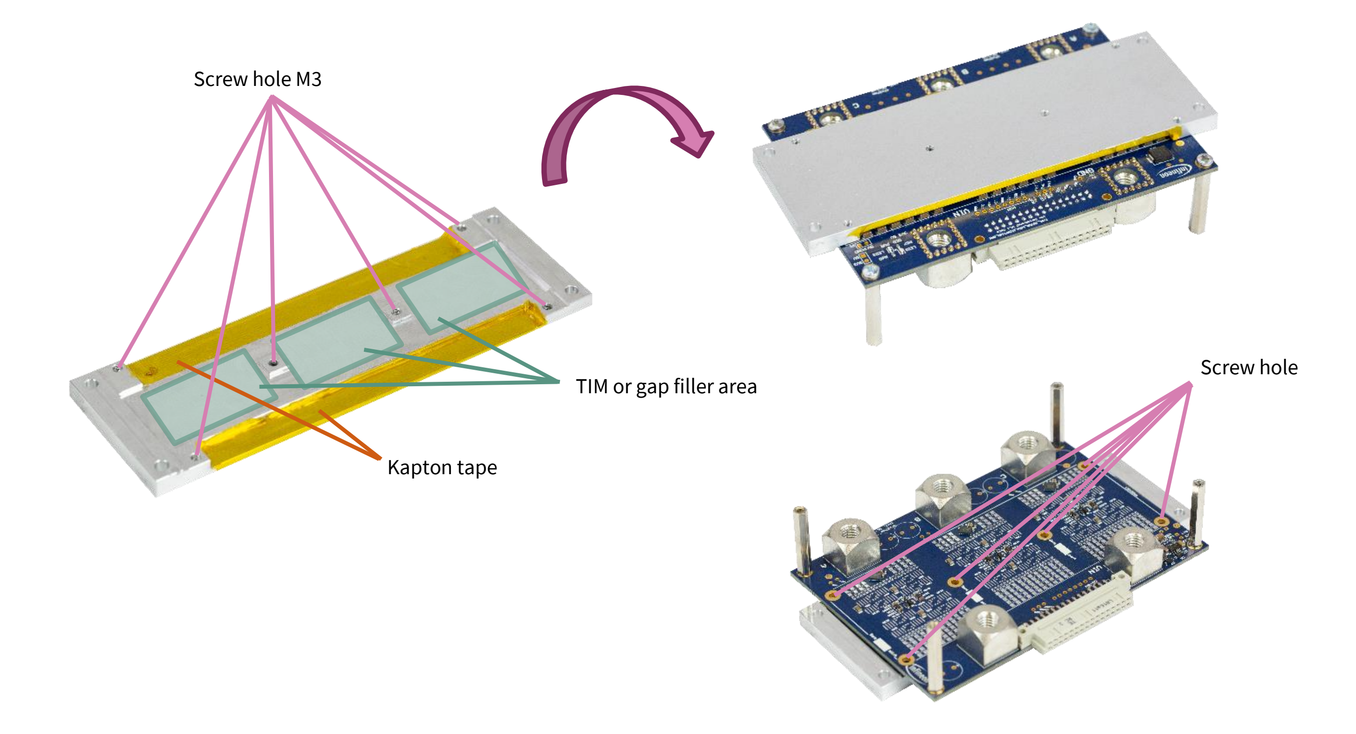

Figure 6 **Left: Placement of TIM across CoolGaN™ half-bridge and Kapton tape to avoid a short on DC link caps. Right: Fully assembled evaluation board with heat spreader**

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 phase connections to the motor (phases 1, 2, and 3) are connected through X4, X6, and X7.

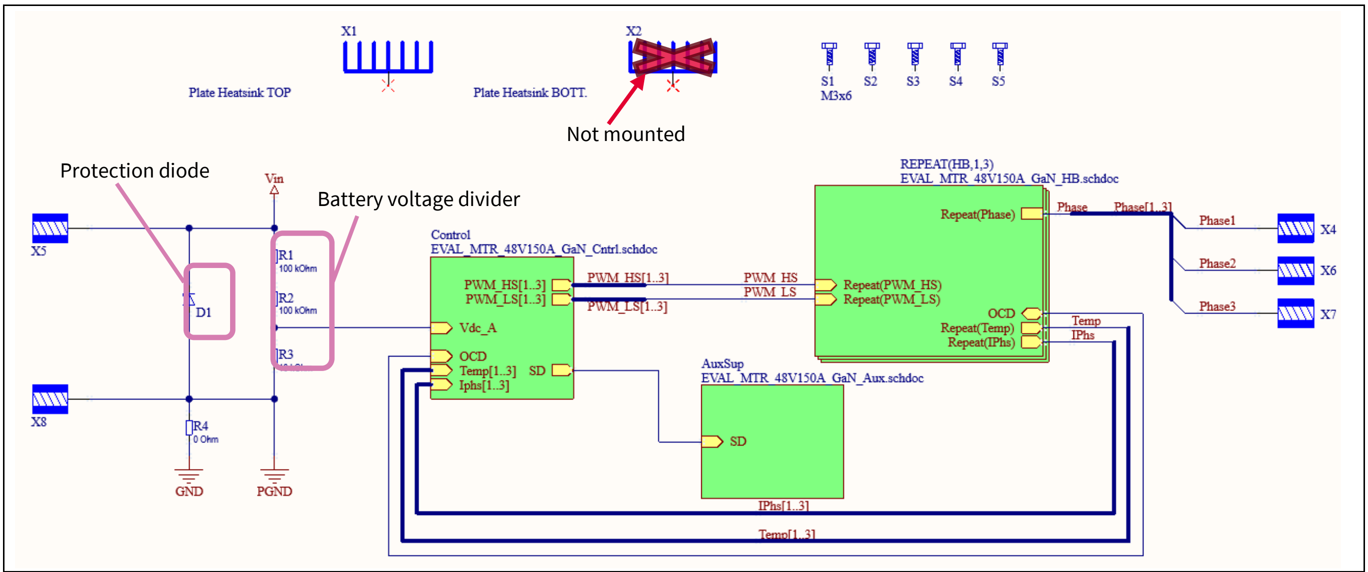

Figure 7 **System-level overview of the motor drive schematic**

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 eight numbers of CoolGaN™ Transistor 80 V 2.5 mΩ (max.) in 3 mm × 5 mm PQFN lead-frame packages with exposed dies for dual-sided cooling. The half-bridge design is 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 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.

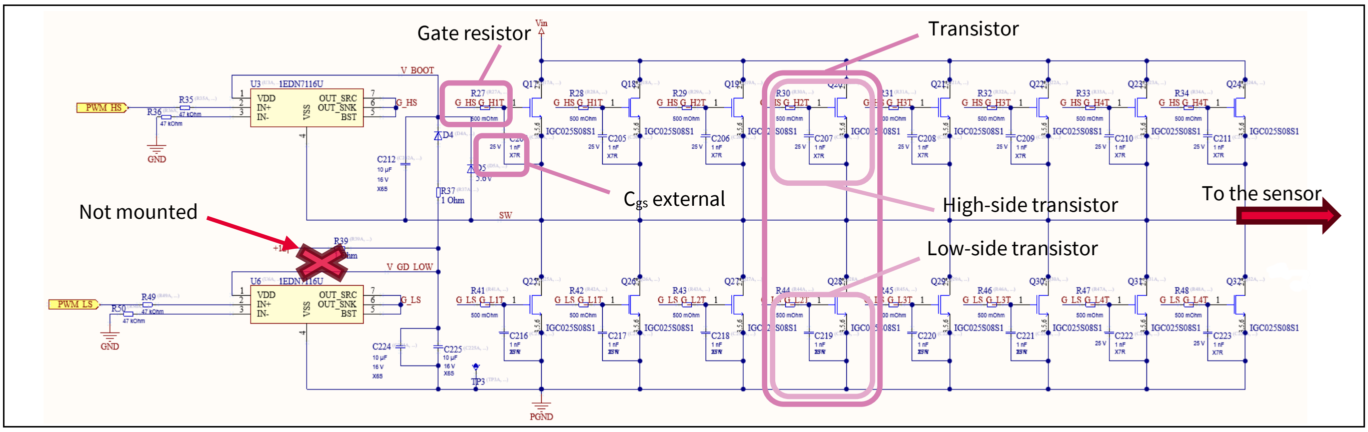

Figure 8 Schematic of the power stage including a gate driver for a single half-bridge

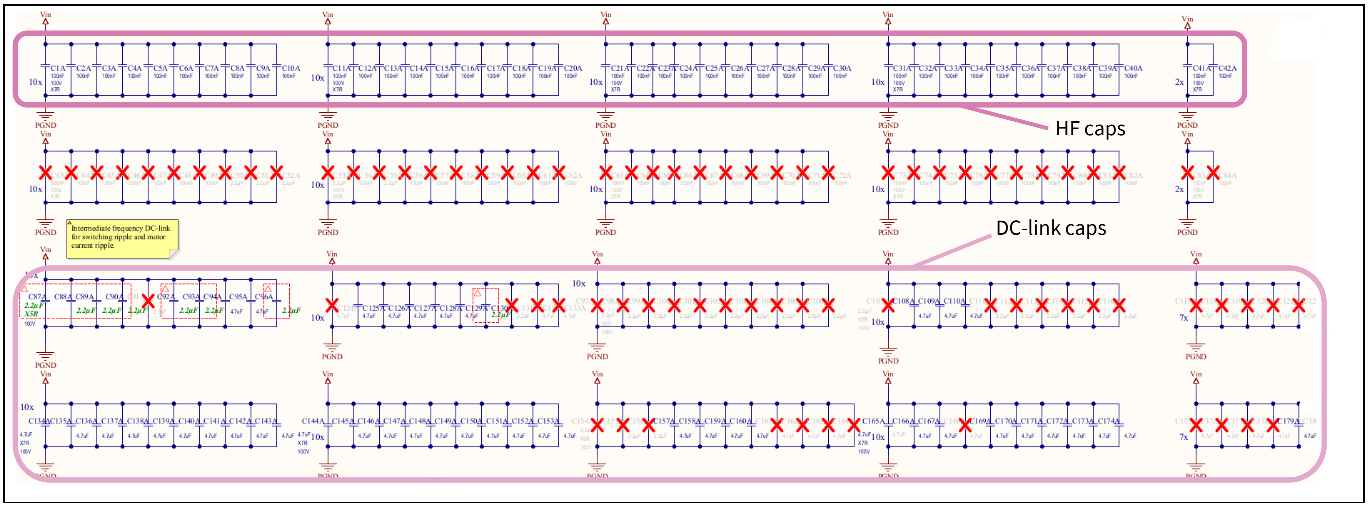

Figure 9 Schematic of the bulk capacitance for a single half-bridge

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, designers 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 10. In this evaluation board, 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 10). 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 a 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 11, left.

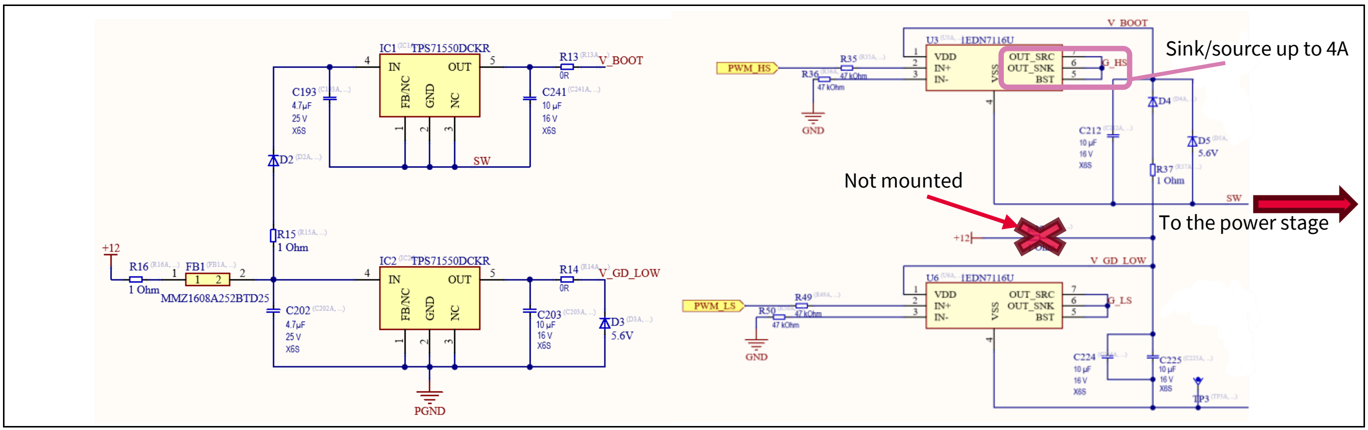

Figure 10 **Schematic of the gate driver and the LDO for a single half-bridge**

The behavior is corrected with an LDO that regulates the gate driver's supply voltage. The LDO observers all the variability of the voltage during overcharge and discharge. The regulated V_{gs} waveforms are reported in Figure 11.

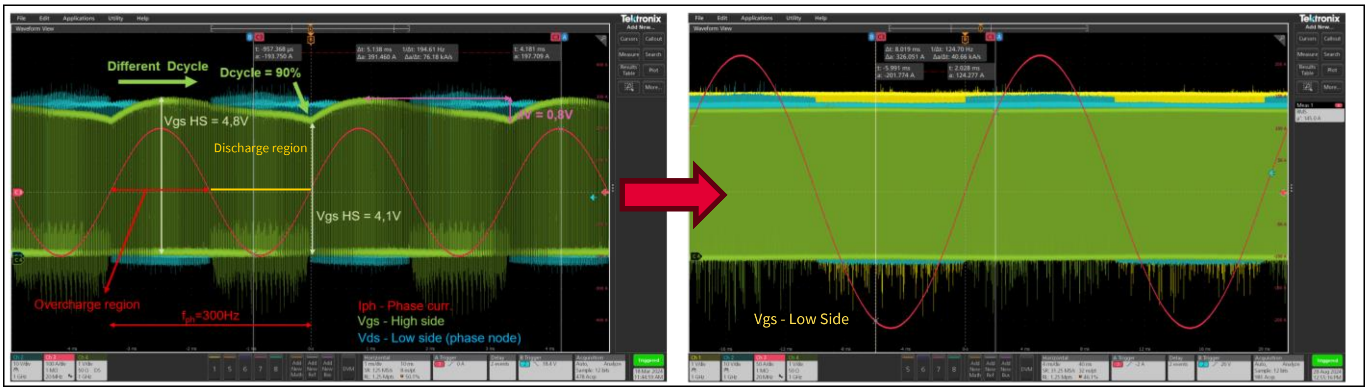

Figure 11 **Left: Waveform without the LDO or BST pin on the high-side gate driver supply with a phase current of 140 A_{rms}; Right: Waveform with the LDO or BST pin on the high-side gate driver supply with a phase current of 140 A_{rms}**

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, TLE4972 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 12 provides information on how this value can be reconfigured by changing the values of the resistors R51 and R53.

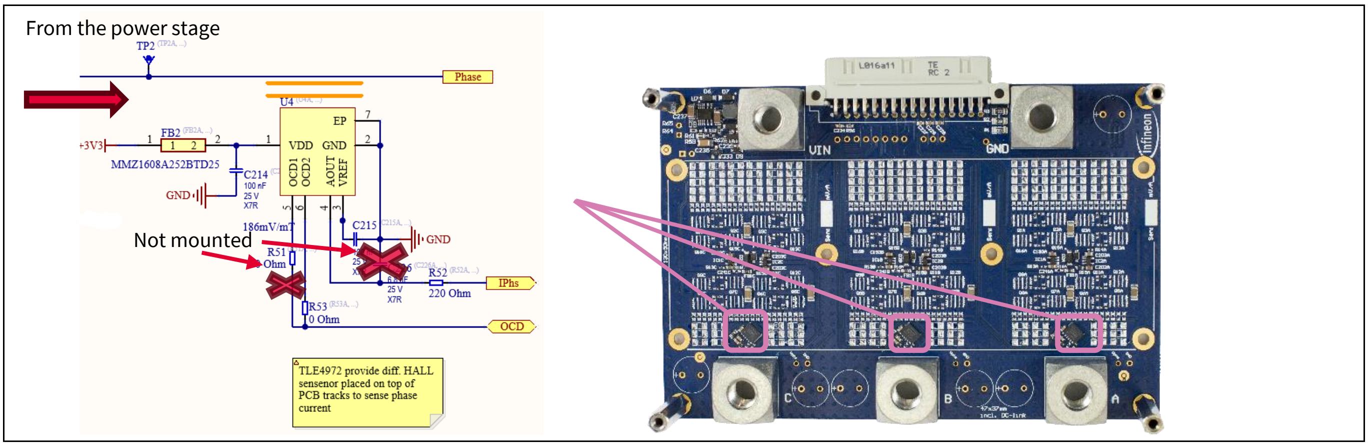

Figure 12 **Schematic of the current sensor and location on the board**

3.2.3 Half-bridge (HB) layout

The recommended layout for a CoolGaN™ Transistor half-bridge is shown in Figure 13. 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.

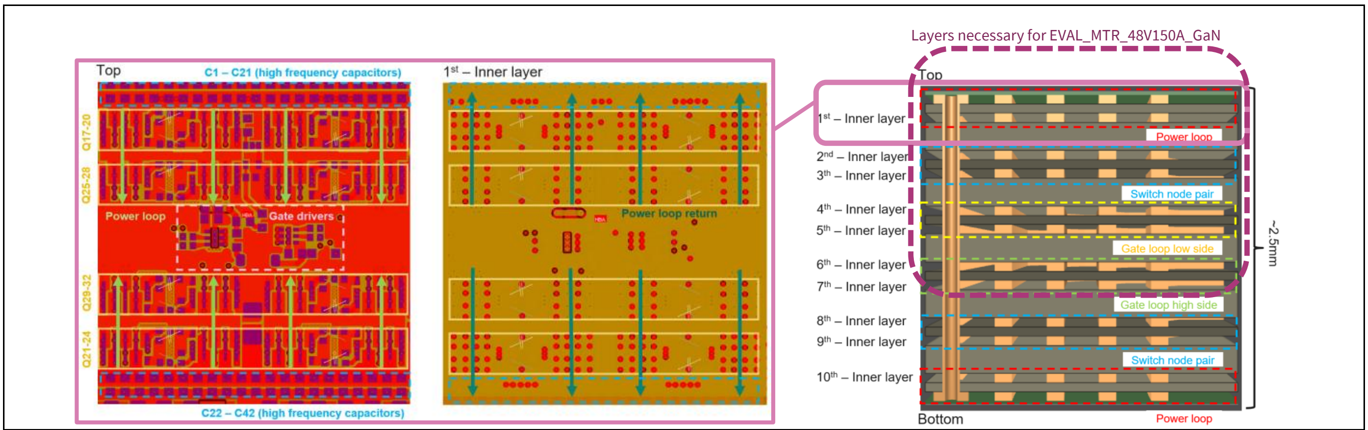

Figure 13 **Half-bridge layout; arrows indicate the flow of drain switching currents and stack-up**

The phase node, shown in Figure 14, 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.

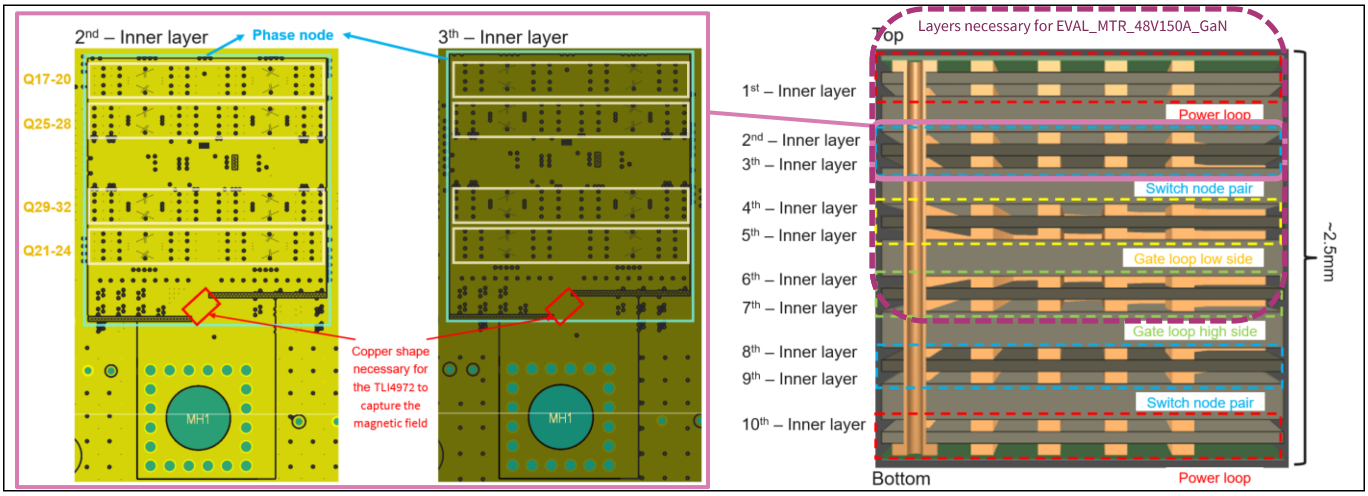

Figure 14 Layout of the phase node and stackup

Figure 15 and Figure 16 report the connection from the gate driver to the device in parallel and the return path, for the low-side and the high-side respectively.

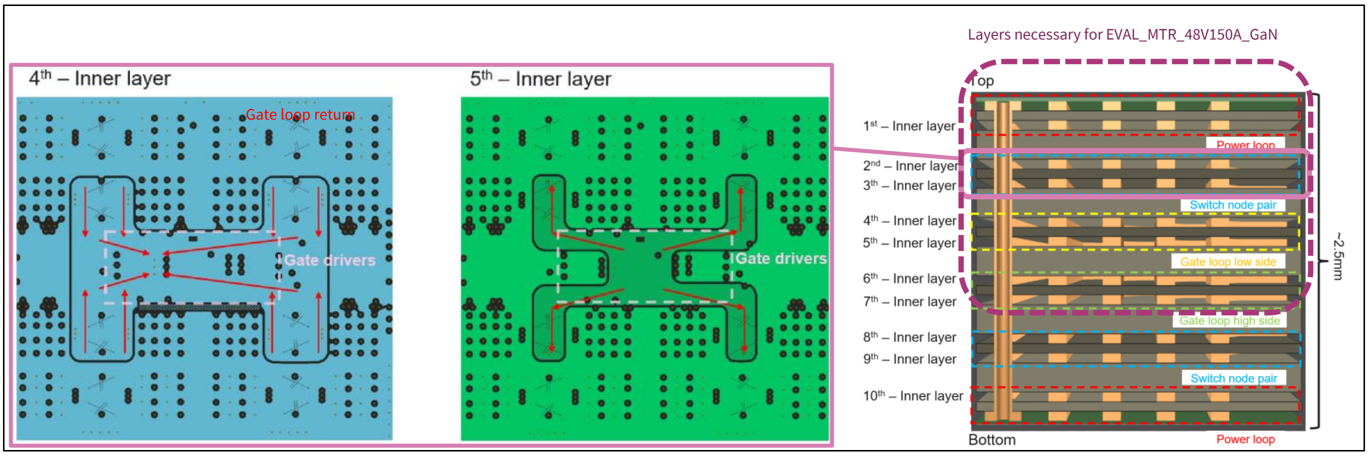

Figure 15 Layout of the low-side gate loop and stack up

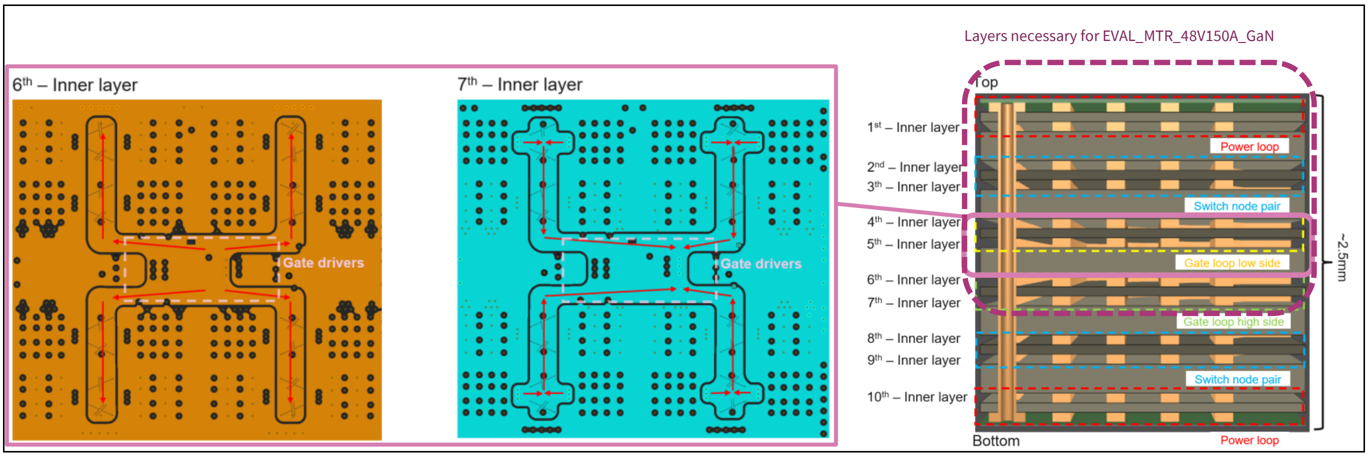

Figure 16 Layout of the high-side gate loop and stack up

3.3 Power supply manager

An onboard DC-DC converter generates the 12 V rail from the VIN supply (see Figure 17). 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.

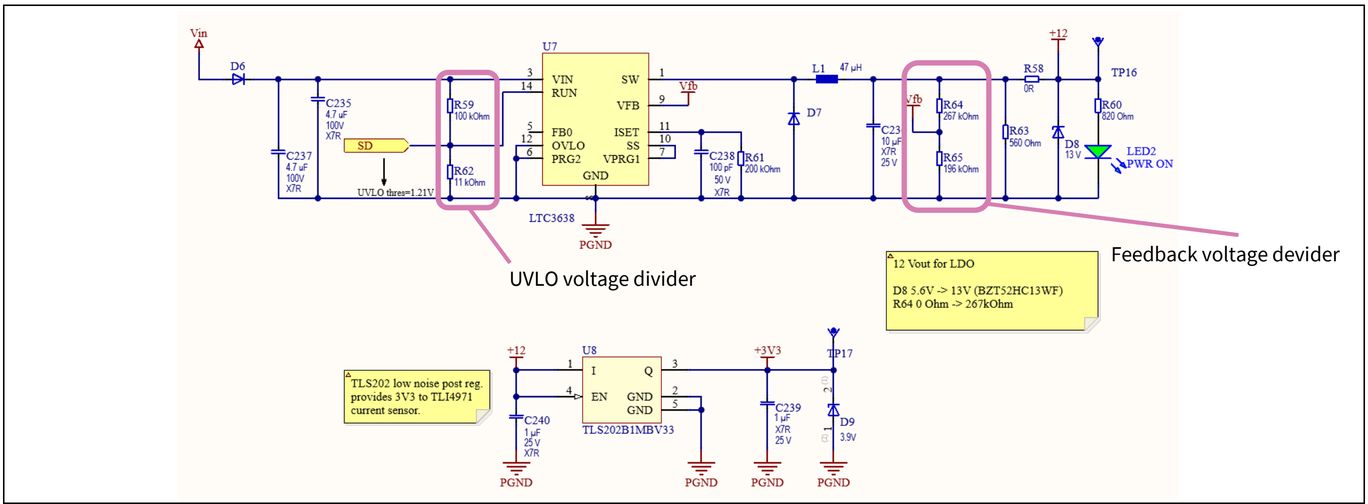

Figure 17 Schematic of the auxiliary power supply

3.4 Control

The control card interface (DIN 41612, 32-pin, female) with supporting circuits is shown in Figure 18 for boards earlier than version 2.0 and in Figure 19 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.

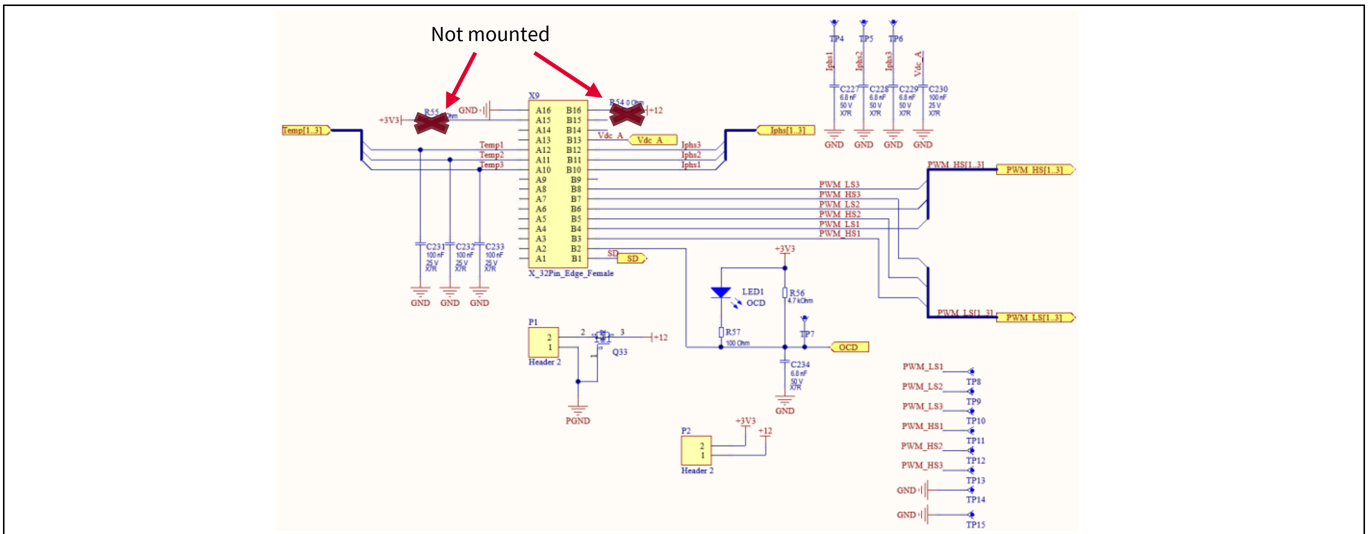

Figure 18 Schematic of the pin header or control card interface for board versions earlier than 2.0

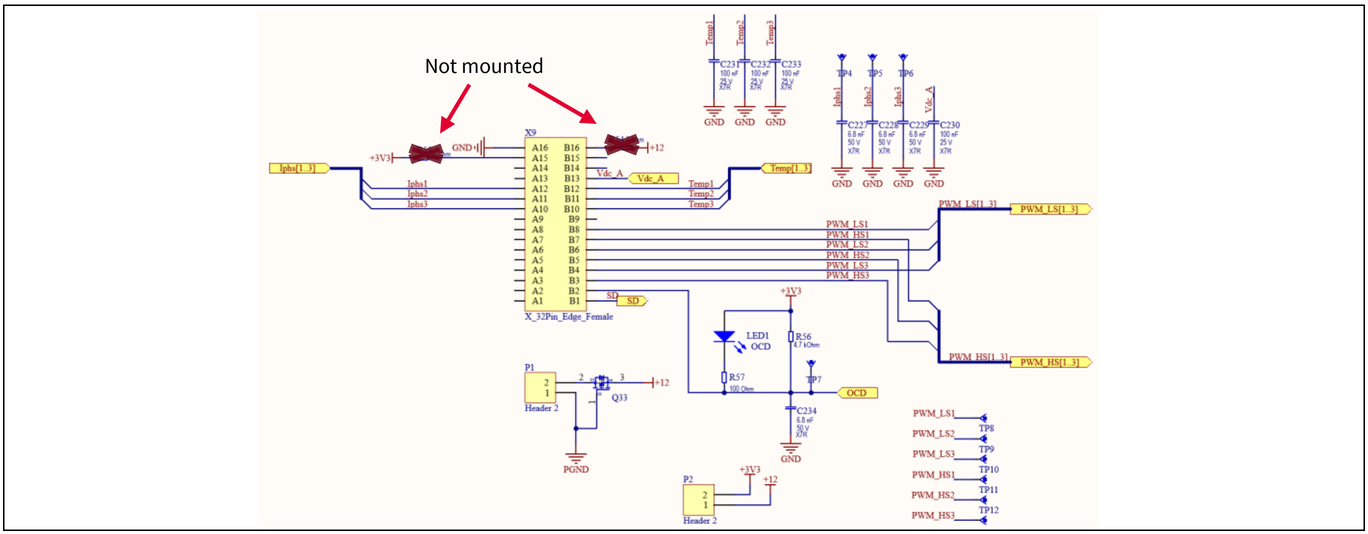

Figure 19 **Schematic of the pin header or control card interface for version 2.0 boards and later**

3.4.1 Temperature sensing

A temperature sensor (Figure 20) 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 Bill of materials) 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.

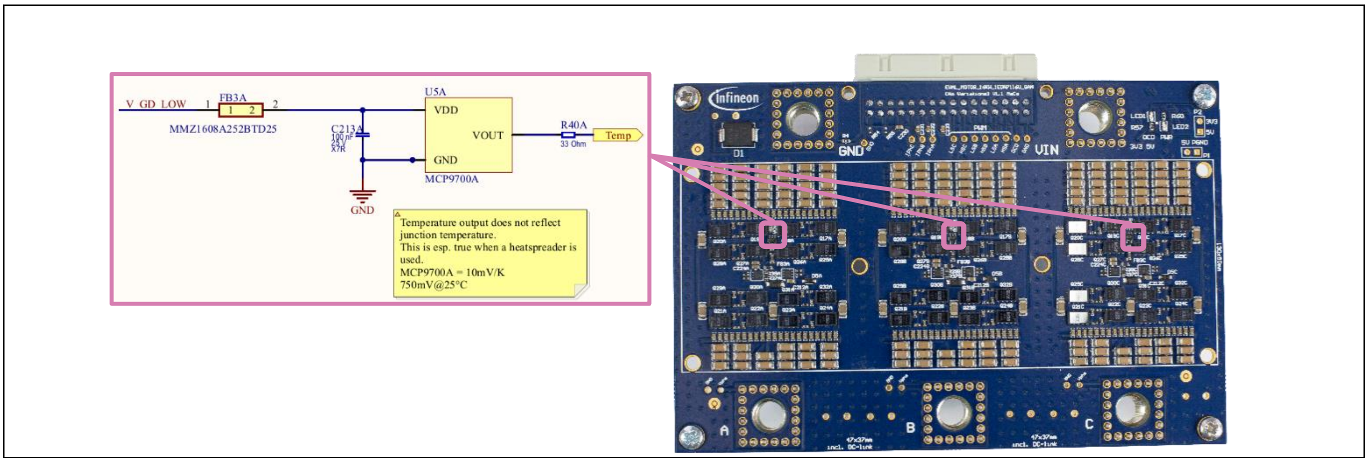

Figure 20 **Overview of the bottom part of EVAL_MTR_48V150A_GaN board**

4 Supported user modifications

EVAL_MTR_48V150A_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 EVAL_MTR_48V150A_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 21.

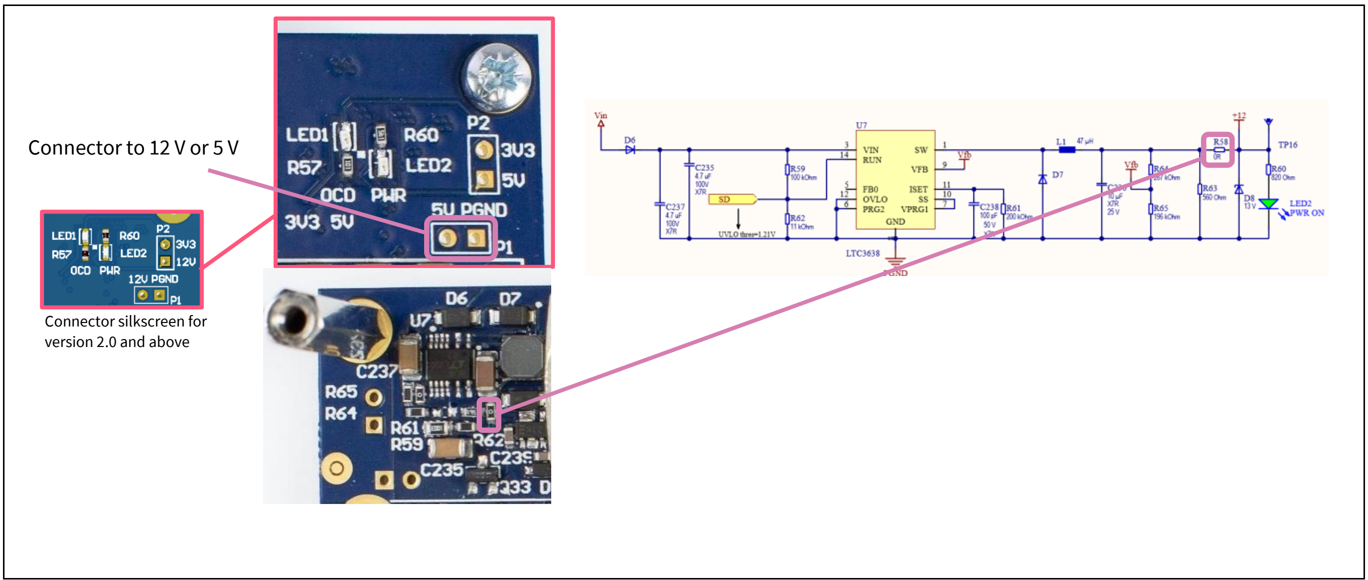

Figure 21 Connection for external 12 V supply

4.2 Additional bulk capacitance

For switching frequencies below 100 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 22; the silkscreen reports the "–" pin of the capacitors.

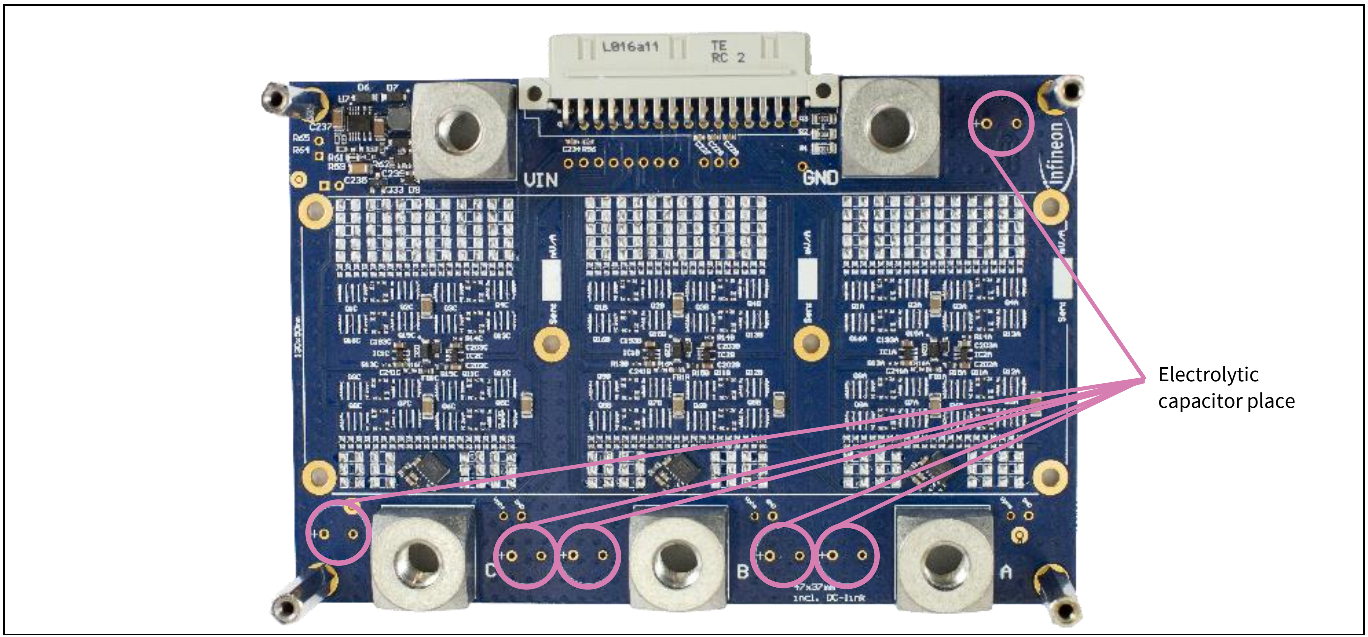

Figure 22 Additional electrolytic capacitor with a step of 7 mm

4.3 V_{DS} and V_{GS} measurements

The EVAL_MTR_48V150A_GaN evaluation board provides onboard probing points of critical waveforms, such as V_{DS} and V_{GS}, as shown in Figure 23. 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.

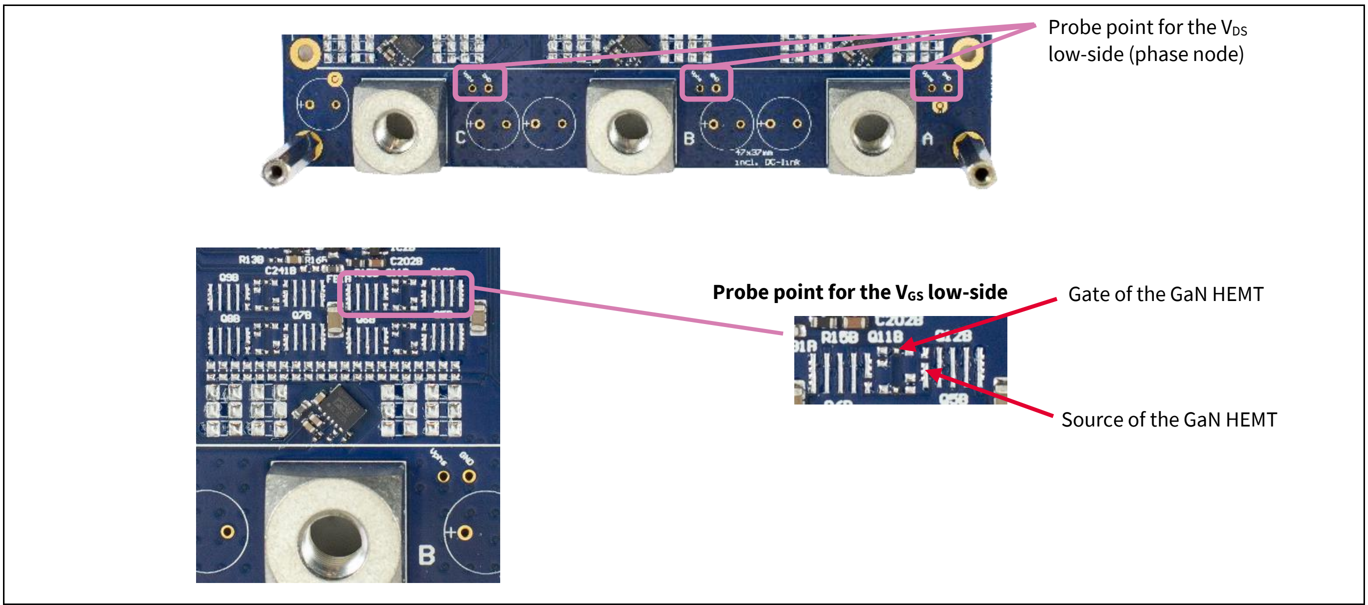

Figure 23 Measurement points for the V_{DS} and V_{GS} low-side

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 24.

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

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 EVAL_MTR_48V150A_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 68 V that needs to be disconnected, or R3 should be changed to increase the rating.

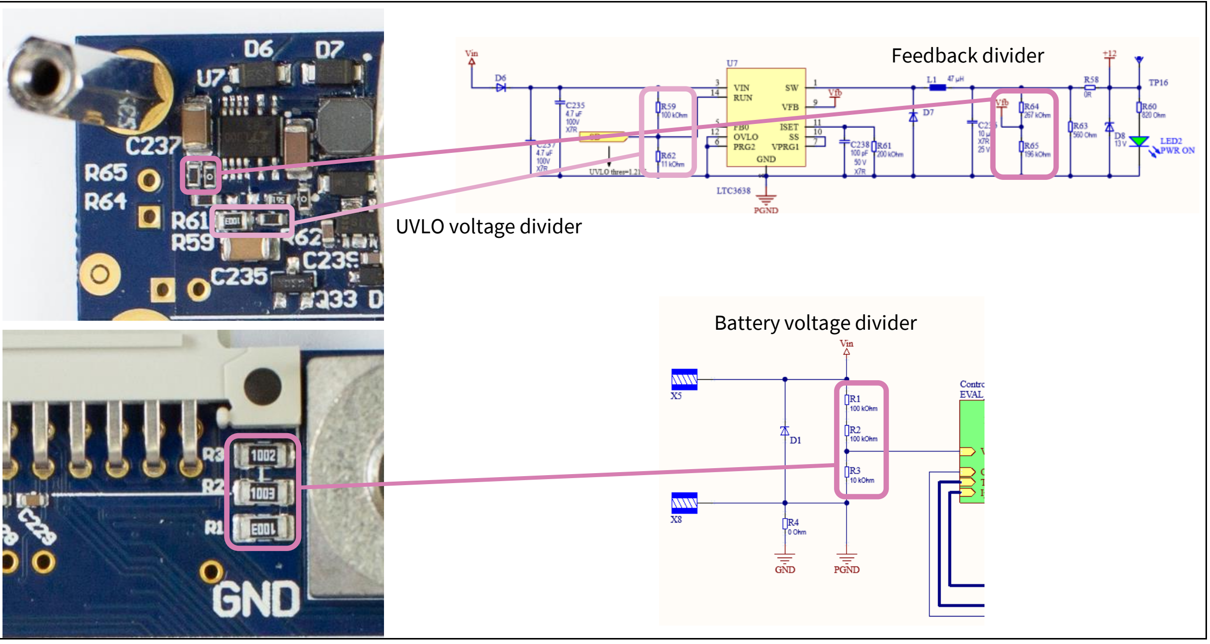

Figure 24 UVLO, feedback divider, and battery voltage divider

4.5 Gate resistor and C_{gs} external replacements

The EVAL_MTR_48V150A_GaN board is equipped with a gate resistor and external C_{gs} to slow down dV/dt when it is requested. Figure 25 shows where the gate drivers are shown for one half-bridge of the inverter.

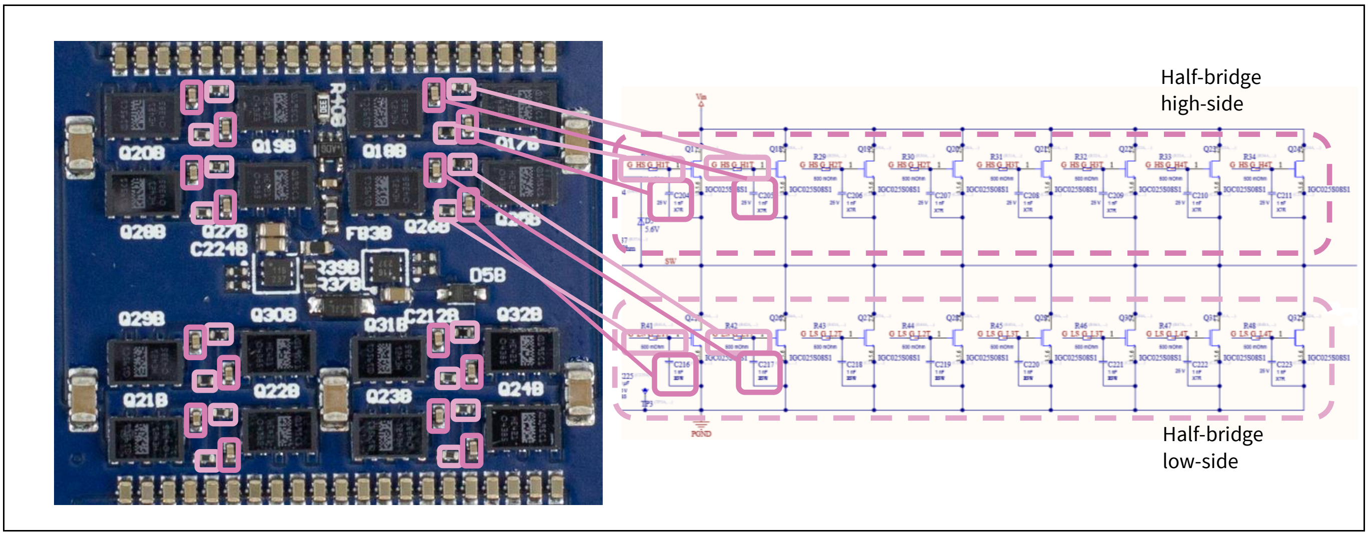

Figure 25 Schematic and of the single half-bridge and gate driver placement

5 Measurements

Here are some typical measurements that can be observed with the EVAL_MTR_48V150A_GaN evaluation board for reference.

5.1 V_{DS} measurement

Figure 26 shows an example measurement of low-side V_{DS} (also called phase node V_{ph}) using the test pads shown in Figure 23, and the respective phase current I_{out} at V_{IN} = 48 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 between 25 ns and 50 ns. This option allows improving the efficiency of the inverter's diode mode operation.

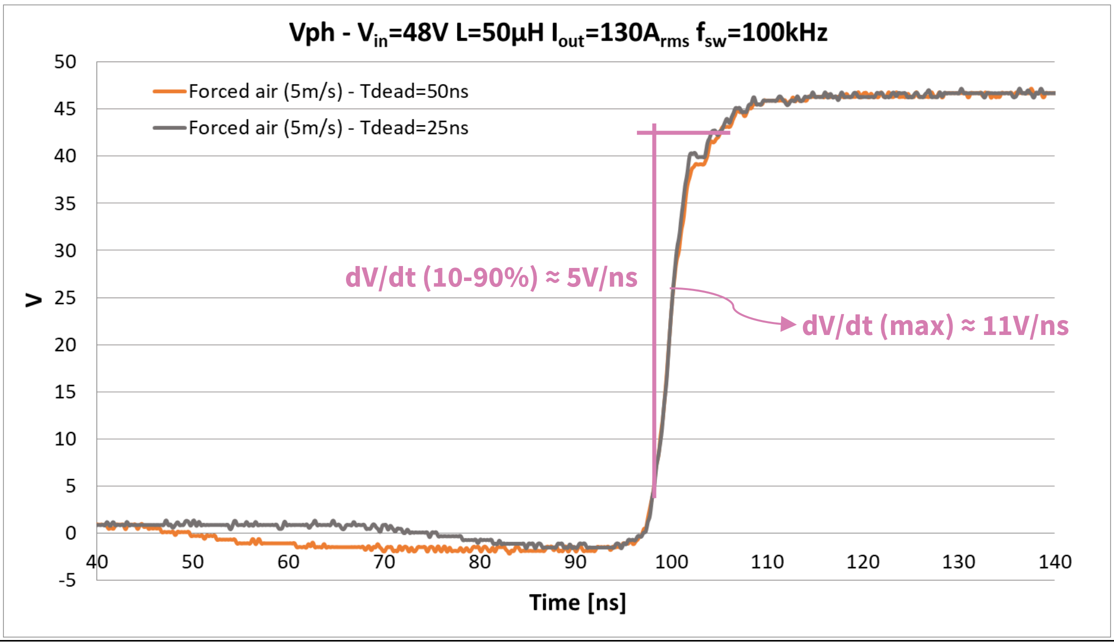

Figure 26 **Phase node voltage during high-side hard turn-on**

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

Measurements of the RL load with the setup shown in Figure 27 are necessary to evaluate the losses under different conditions, with gate drivers, and the type of cooling used.

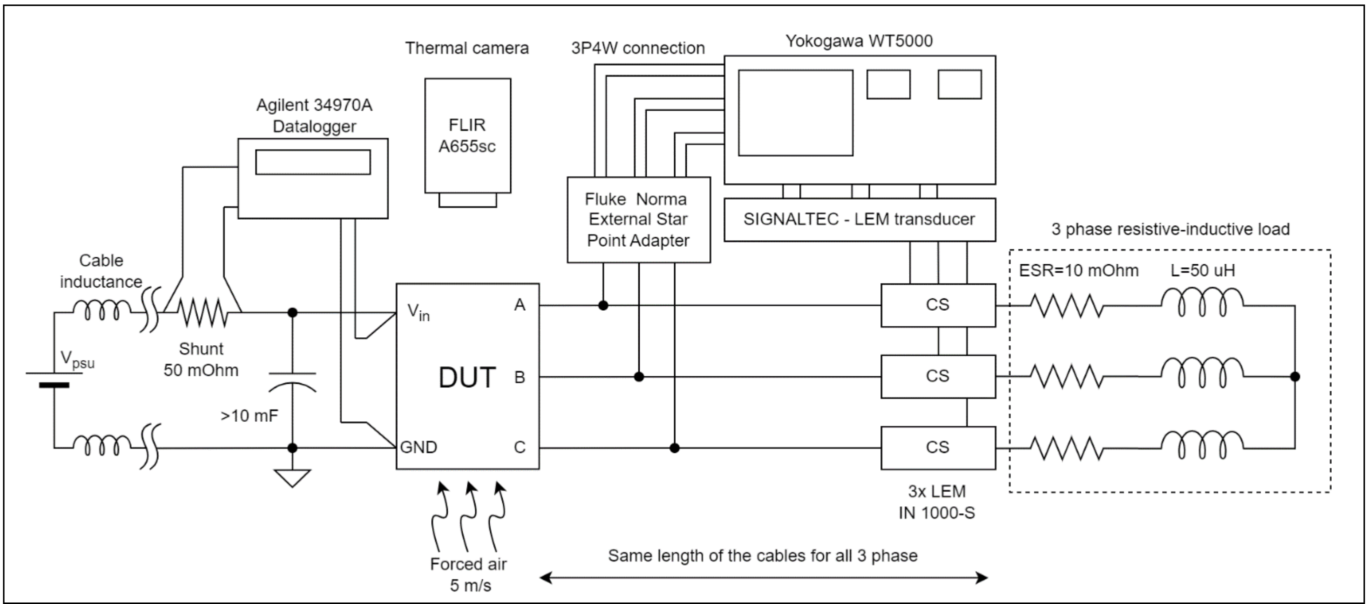

Figure 27 Measurement setup

Figure 28 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 28, which are captured with a thermal camera as shown in Figure 29.

The tests show the highest performance with a strong driver and high dV/dt. However, the loss and temperature penalty of the weakest driver and lowest dV/dt may be acceptable in very noise-sensitive environments or in combination with longer cables.

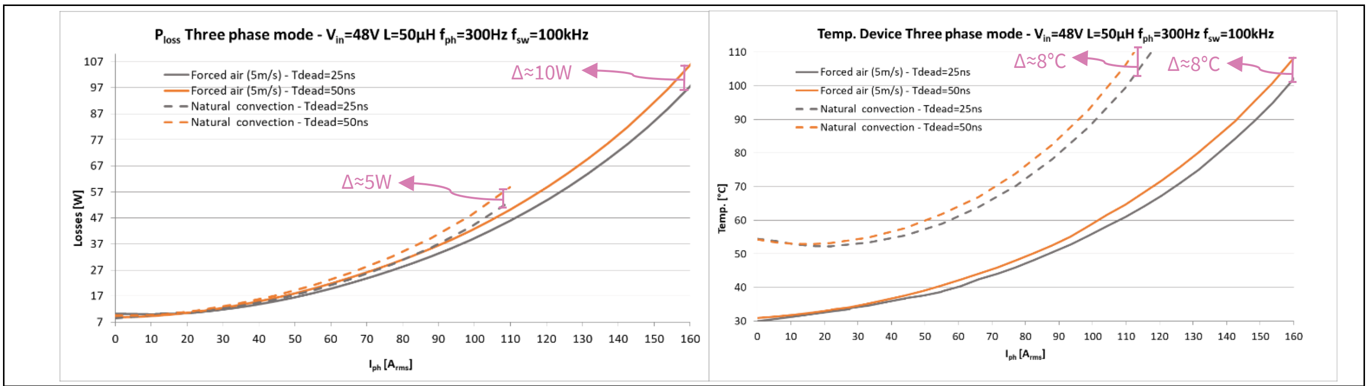

Figure 28 Measurement of losses and temperature of the evaluation design

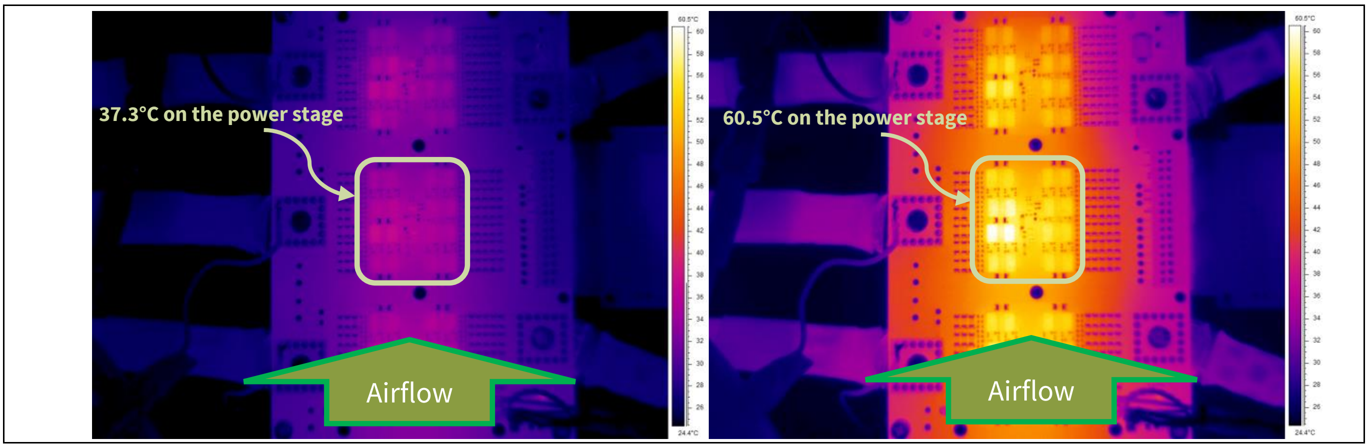

Figure 29 PCB temperature during the test with RL load at f_{sw} = 100 kHz and airflow of 5 m/s; (left) phase current of 50 A_{RMS}; phase current of 110 A_{RMS} (right)

5.3 Measurement of losses and efficiency with a target motor

The measurements with the target motor (U15 II 100KV from T-motor) are obtained using the setup in Figure 30. The cooling condition of the measurement setup is shown in Figure 31, which uses a heatsink mounted on top of the board with natural convection at 25°C, as shown in Figure 31.

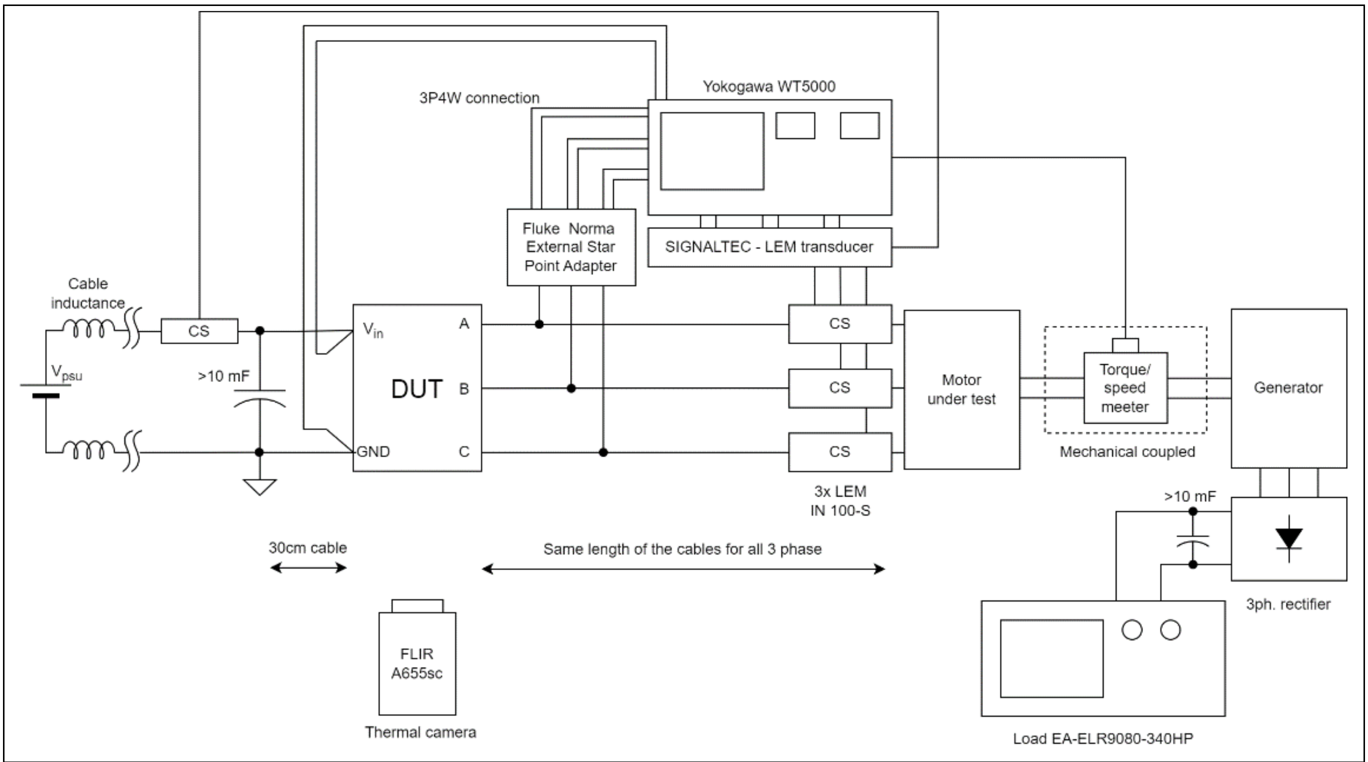

Figure 30 Measurement setup

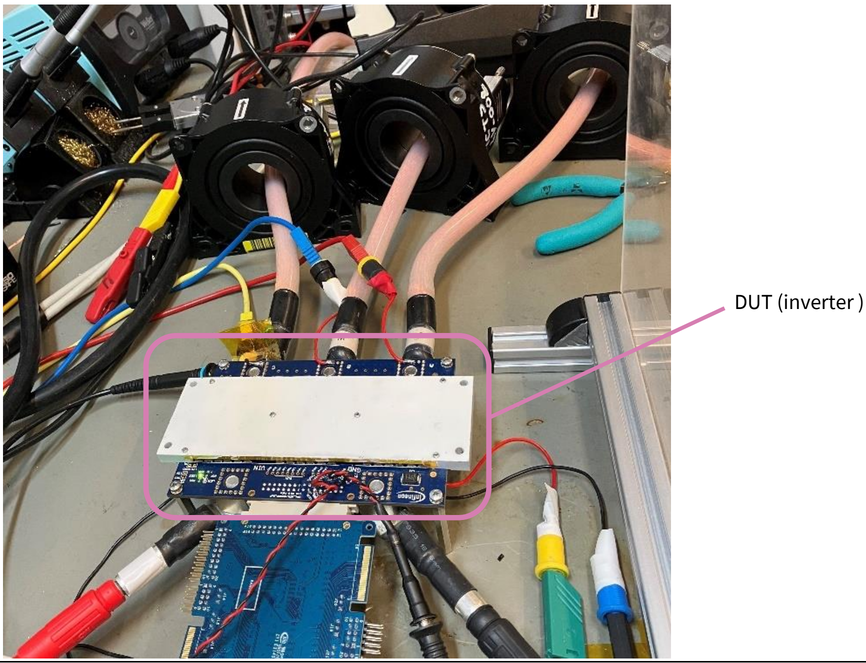

Figure 31 Cooling condition in the measurement setup

Figure 32 shows the efficiency and the losses of the inverter, the motor, and the overall system (motor plus inverter). Figure 33 shows the temperature on top of the heatsink.

The test shows the board's capability to handle almost 90 A_{RMS} and a mechanical power of 3400 W. The inverter efficiency is 99% at the maximum point. This efficiency is not the maximum achievable of this inverter because the maximum V_{ph} achievable for this application at 48 V is 19 V_{RMS}. The values shown on the voltage phase is approximately 18 V_{RMS}.

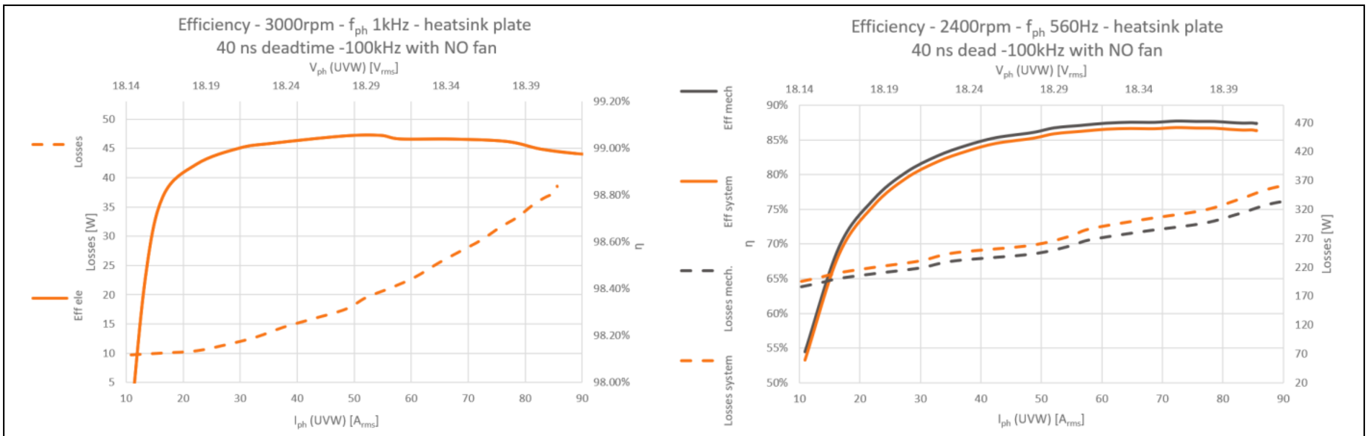

Figure 32 Left: Losses and efficiency of the inverter; Right: Losses and efficiency of the motor and total system (motor plus inverter)

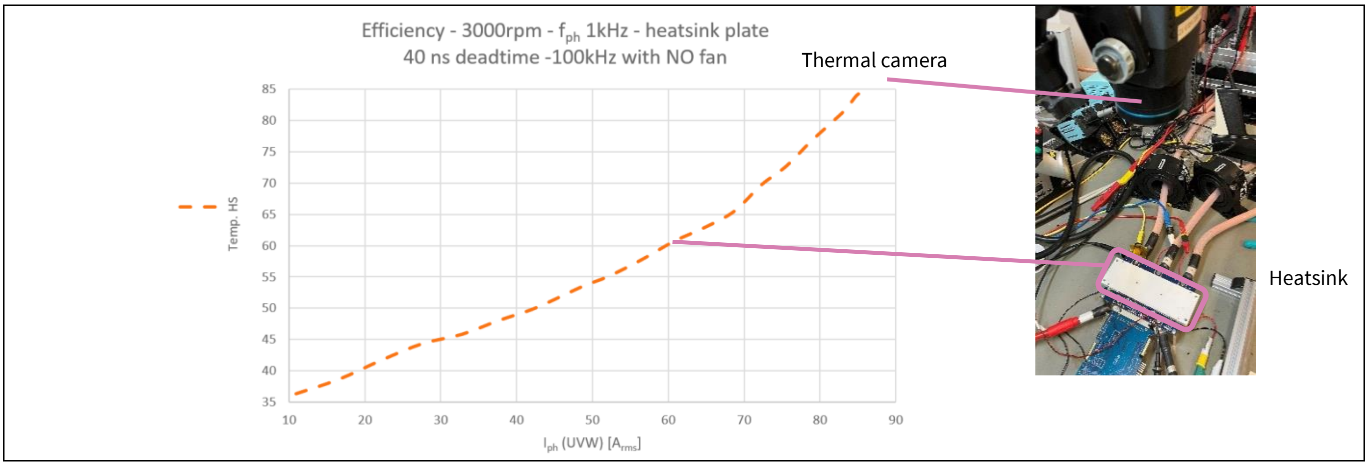

Figure 33 Temperature on top of the heatsink, acquired by a thermal camera

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 100 kHz
- 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 EVAL_MTR_48V150A_GaN

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts/ Comments
1	126	100 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	GRM188R72A104KA35D	Murata	–
2	24	2.2 µF	C87A, C87B, C87C, C88A, C88B, C88C, C89A, C89B, C89C, C90A, C90B, C90C, C92A, C92B, C92C, C93A, C93B, C93C,	CL31A225KC9LNNC	Samsung	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts/ Comments
			C96A, C96B, C96C, C130A, C130B, C130C			
3	141	4.7 µF	C94A, C94B, C94C, C95A, C95B, C95C, C108A, C108B, C108C, C109A, C109B, C109C, C110A, C110B, C110C, C125A, C125B, C125C, C126A, C126B, C126C, C127A, C127B, C127C, C128A, C128B, C128C, C129A, C129B, C129C, 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, C157A, C157B, C157C, C158A, C158B, C158C, C159A, C159B, C159C, C160A, C160B, C160C, 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, C179A, C179B, C179C, C182A, C182B, C182C, C183A, C183B, C183C, C184A, C184B, C184C	GRJ31CZ72A475KE01L	Murata	Should have soft termination
4	6	4.7 µF	C193A, C193B, C193C, C202A, C202B, C202C	GRM188C81E475KE11D	Murata	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts/ Comments
5	15	10 µF	C203A, C203B, C203C, C212A, C212B, C212C, C224A, C224B, C224C, C225A, C225B, C225C, C241A, C241B, C241C	CM105X6S106K16AT	AVX	–
6	48	1 nF	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	AC0402KRX7R9BB102	Yageo	–
7	3	100 nF	C213A, C213B, C213C	GRM155R71E104KE14D	Murata	–
8	10	100 nF	C214A, C214B, C214C, C215A, C215B, C215C, C230, C231, C232, C233	CGA3E2X7R1E104K080AA	TDK	–
9	3	6.8 nF	C226A, C226B, C226C	CGA3E2X7R1H682K080AA	TDK	–
10	4	6.8 nF	C227, C228, C229, C234	CGA3E2X7R1H682K080AA	TDK	–
11	2	4.7 µF	C235, C237	GRM31CC72A475KE11L	Murata	–
12	1	10 µF	C236	C3216X8L1E106K160AC	TDK	–
13	1	100 pF	C238	06035C101MAT2A	AVX	–
14	2	1 µF	C239, C240	C1608X7R1E105K080AB	TDK	–
15	1	68 V	D1	1.5SMC68A	Littelfuse	TVS protection
16	3	Boot diode	D2A, D2B, D2C	MBR2H200SFT1G	Onsemi	–
17	6	5.6 V Zener	D3A, D3B, D3C, D5A, D5B, D5C	BZX384B5V6	Vishay	–
18	3	Boot diode	D4A, D4B, D4C	MBR2H200SFT1G	Onsemi	–
19	1	Diode	D6	CDBMS1200-HF	Comchip Technology	–
20	1	Diode	D7	CDBMS1200-HF	Comchip Technology	–
21	1	13 V Zener	D8	BZT52HC13WF-7	Diodes Incorporated	–
22	1	3.9 V Zener	D9	BZX384C3V9-HG3-08	Vishay	–
23	9	Ferrite	FB1A, FB1B, FB1C, FB2A, FB2B, FB2C, FB3A, FB3B, FB3C	MMZ1608A252BTD25	TDK	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts/ Comments
24	6	LDO	IC1A, IC1B, IC1C, IC2A, IC2B, IC2C	TPS71550DCKR	TI	–
25	1	47 µH	L1	IFSC1515AHER470M01	Vishay	–
26	1	LED red	LED1	AA1608SURSK	Kingbright	–
27	1	LED green	LED2	AA1608CGSK	Kingbright	–
28	48	GaN HEMT	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	IGC025S08S1	Infineon	–
29	1	MOS. p Ch.	Q33	BSS215P	Infineon	BSS314PE
30	2	100 kOhm	R1, R2	ERJ-8ENF1003V	Panasonic	–
31	1	10 kOhm	R3	ERJ-8ENF1002V	Panasonic	–
32	1	0 Ohm	R4	ERJ3GEY0R00V	Panasonic	–
33	6	0 Ohm	R13A, R13B, R13C, R14A, R14B, R14C	RCC04020000Z0ED	Vishay	–
34	3	0 Ohm	R15A, R15B, R15C	RCS06031R00FKEA	Vishay	–
35	3	0 Ohm	R16A, R16B, R16C	RCS06031R00FKEA	Vishay	–
36	48	0.5 Ohm	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	RCWE0402R500FKEA	Vishay	–
37	12	47 kOhm	R35A, R35B, R35C, R36A, R36B, R36C,	RC0402FR-0747KL	Yageo	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts/ Comments
			R49A, R49B, R49C, R50A, R50B, R50C			
38	3	1 Ohm	R37A, R37B, R37C	RCS06031R00FKEA	Vishay	–
39	3	33 Ohm	R40A, R40B, R40C	ERJ-3GEYJ330V	Panasonic	–
40	3	220 Ohm	R52A, R52B, R52C	ERJ-H2RF2200X	Panasonic	–
41	3	0 Ohm	R53A, R53B, R53C	RCC04020000Z0ED	Vishay	–
42	1	4.7 kOhm	R56	ERJ-3GEYJ472V	Panasonic	–
43	1	100 Ohm	R57	ERJ-3GEYJ101V	Panasonic	–
44	1	0 Ohm	R58	ERJ-3GEY0R00V	Panasonic	–
45	1	100 kOhm	R59	ERJ-6ENF1003V	Panasonic	–
46	1	820 Ohm	R60	ERJ-H3GJ821V	Panasonic	–
47	1	200 kOhm	R61	ERJ-3EKF2003V	Panasonic	–
48	1	11 kOhm	R62	ERJ-3EKF1102V	Panasonic	–
49	1	560 Ohm	R63	ERJ-3GEYJ561V	Panasonic	–
50	1	267 kOhm	R64	ERJ-3EKF2673V	Panasonic	–
51	1	196 kOhm	R65	ERJ-3EKF1963V	Panasonic	–
52	1	–	S5	528-744	RS PRO	–
53	1	–	//	970250321	Würth Elektronik	–
54	6	Gate driver	U3A, U3B, U3C, U6A, U6B, U6C	1EDN7116U	Infineon	–
55	3	Current sensor	U4A, U4B, U4C	TLE4972-AE35S5	Infineon	–
56	3	Temp. sensor	U5A, U5B, U5C	MCP9700AT-E/LT	Microchip	MAX6612MXK+T
57	1	DCDC	U7	LTC3638EMSE#TRPBF	Analog Devices/LT	–
58	1	LDO	U8	TLS202B1MBV33HTSA1	Infineon	–
59	5	Press-fit	X4, X5, X6, X7, X8	7461090	Würth Elektronik	–
60	1	M5-32pin	X9	294722	ERNI	–

References

[1] Infineon Technologies AG: *Datasheet for Infineon CoolGaN™ Transistors (2024)*; Available online

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[4] Infineon Technologies AG: *Datasheet for TLS202B1MBV33 post voltage regulator (2023)*; Available online

Revision history

Document revision	Date	Description of changes
V 1.0	2025-03-31	Initial version

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