CoolGaN™ motor drive reference board for battery-powered FOC applications

About this document

Scope and purpose

This user guide helps you get started with the firmware of the REF_MTR_48V30A_GaN CoolGaN™ motor drive reference board for battery-powered FOC applications. This document provides information on the hardware, mechanical structure, and test setup.

Intended audience

This user guide is intended for system application engineers who want to improve space utilization and seek inspiration for their next motor drive designs, for battery-powered applications up to 48 V and 30 A_{RMS} motor phase current.

Figure 1 Reference board REF_MTR_48V30A_GaN

Note: This document is for the REF_MTR_48V30A_GaN reference board. The product name (GaN servo 1kW) shown in the figures of this document are due to variations in the design and manufacturing processes. Both REF_MTR_48V30A_GaN and GaN servo 1kW refer to the same reference board.

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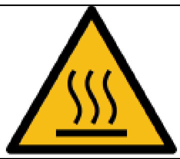
Safety precautions

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

REF_MTR_48V30A_GaN is a compact reference design inverter for low-voltage battery-powered applications. This board includes twelve CoolGaN™ Transistors 100 V IGC033S10S1 in a half-bridge configuration with two devices in parallel for all phases. Each pair of transistors is driven by an EiceDRIVER™ 1EDN7136U gate driver, and the output phase current is sensed by a XENSIV™ TLI4971 magnetic current sensor.

The board is equipped with an XMC4200 microcontroller that can handle field-oriented control (FOC). It interfaces with another board or PC through UART and Controller Area Network (CAN) using the TLT9251VLEXUMA1 high-speed CAN FD transceiver.

The reference design was developed to demonstrate the high power densities achievable within a small size of only 29 x 51 x 9 mm. 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, the CoolGaN™ Transistors 100 V IGC033S10S1 provides a top-side cooling device on an exposed-die PQFN package that can efficiently extract the heat and provide more space for a top-bottom PCB implementation.

REF_MTR_48V30A_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 thermal interface material (TIM).

The reference board is designed to be an all-in-one motor drive. It embeds a control system, comprising an XMC4200 microcontroller and a CAN transceiver, and a power stage composed of the three phases (A, B, and C), based on Infineon's CoolGaN™ Transistors. 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 a sensor mounted next to the CoolGaN™ Transistors.

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 1 is a schematic of the fundamental circuits. The XMC™ Link debug probe is used to program and control the reference design board.

Note: *Environmental conditions were considered in the design of REF_MTR_48V30A_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.*

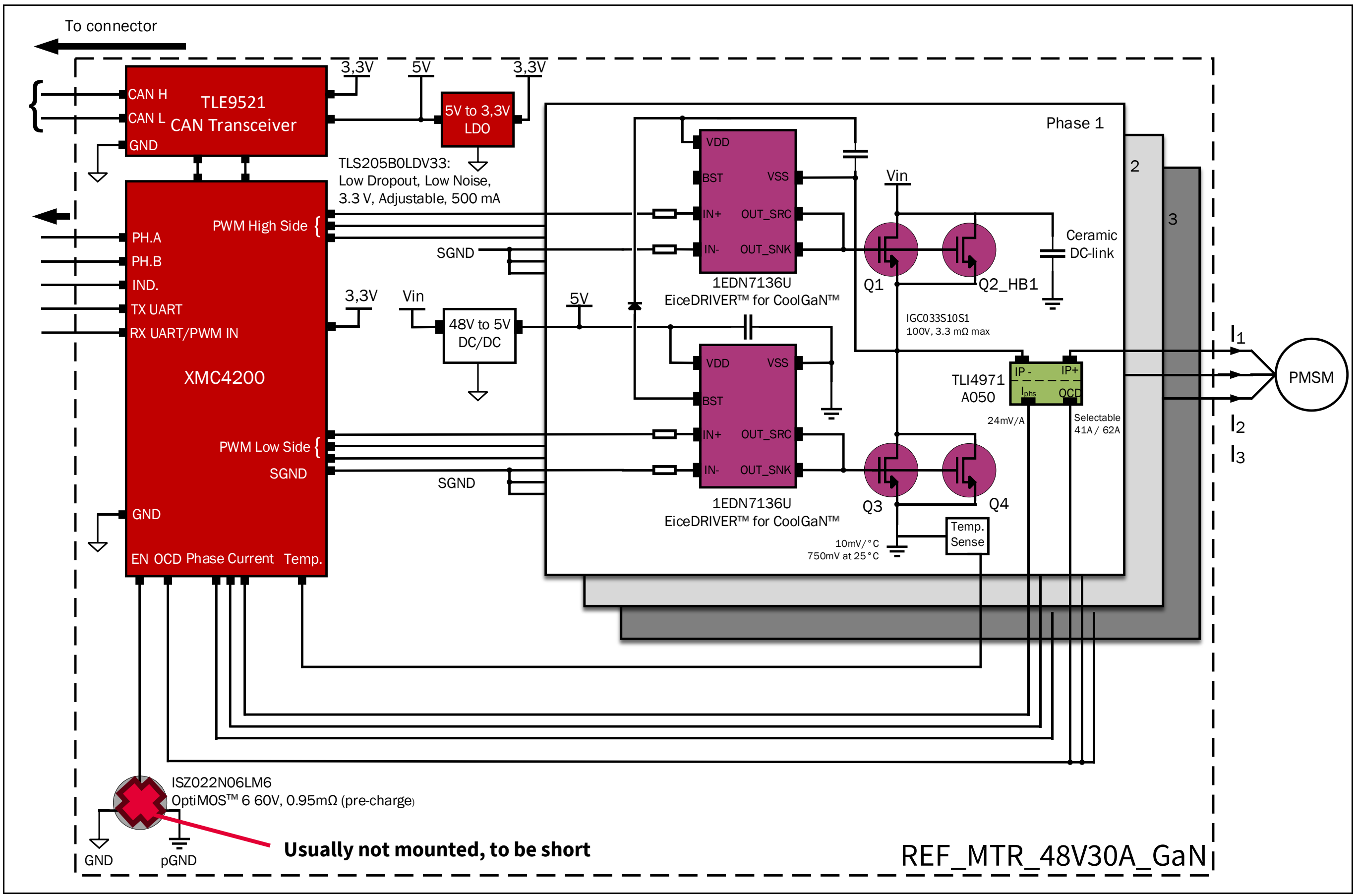

Figure 2 Block diagram of REF_MTR_48V30A_GaN

2 Design features

REF_MTR_48V30A_GaN is a reference design equipped with the latest generation of Infineon's CoolGaN™ Transistors in combination with a complementary EiceDRIVER™ gate driver and Infineon's XMC™ microcontroller to perform field-oriented control (FOC) in battery-powered applications.

Main components:

- CoolGaN™ Transistors 100 V IGC033S10S1 [1], 3.3 mΩ (max.) in a 3 x 5 mm PQFN package
- EiceDRIVER™ 1EDN71x6U [2] gate driver for GaN transistors and MOSFETs
- XENSIVE™ TLI4971 [3] magnetic current sensor for AC and DC currents
- XMC4200 [4] 32-bit industrial microcontroller with Arm® Cortex® M4

The reference design characteristics are:

- 48 V nominal input voltage
- High power density design in a 29 x 51 x 9 mm PCB with eight 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 5 V included
- Overcurrent detection (OCD), selectable as 41 A or 62 A
- Heatsink and mounting hardware included as part of the kit

2.1 Highlighted products

2.1.1 CoolGaN™ Transistors 100 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 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™ TLI4971 magnetic current sensor

XENSIV™ TLI4971 [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 full-scale measurement of currents up to ±120 A. All negative effects commonly known arising from open-loop sensors using flux concentration techniques are avoided, such as saturation and hysteresis. The sensor is equipped with an internal self-diagnostic feature.

2.1.4 XMC4200 industrial microcontroller

The XMC4200 [4] series belongs to the XMC4000 family of industrial microcontrollers based on the Arm® processor core. The XMC4100/4200 series devices combine the extended functionality and performance of the Arm® Cortex® M4 core with powerful on-chip peripheral subsystems and on-chip memory units.

2.1.5 TLS205B0LDV low-dropout voltage regulator

TLS205B0LDV [5] is a monolithic integrated fixed linear voltage post regulator for load currents up to 500 mA. The IC regulates an adjustable output voltage of 1.22 V to 19 V with a precision of ±2.5 percent, supplied by an input voltage up to 20 V. TLS205B0LDV is specially designed for applications requiring very low standby currents. The device is available in a very small surface-mounted PG-TSON-10 package. The device is protected against overload and overtemperature conditions by the implemented output current limitation and overtemperature shutdown circuit.

2.2 Specifications

Table 2 REF_MTR_48V30A_GaN board specification

Parameter	Value	Conditions/Comment
Input		
Nominal input voltage	48 V	–
Maximum input voltage	60 V	Maximum stable voltage before triggering the overvoltage protection (OVP)
Maximum input operating voltage	52 V	Maximum input operating voltage acquired from the battery through the voltage divider (R25, R28)
Undervoltage lockout (UVLO)	34 V	Minimum voltage to turn off the DC-DC converter
Maximum input current	20 A	Maximum in steady state; more current achievable due to the slow-blow fuse for few seconds
Power max (electrical input)	1 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Output		
Power max (mechanical)	700 W	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Power max (three-phase)	1 kW	48 V, Ta = 25°C, forced air 2–3 m/s with heat spreader
Current per phase leg (max)	18 A_{RMS}	48 V, Ta = 25°C, natural convection, no heat spreader, and no forced air (in steady state)
	30 A_{RMS}	48 V, Ta = 25°C, natural convection, no heat spreader and forced air 2–3 m/s (in steady state)
	35 A_{RMS}	48 V, Ta = 25°C, natural convection, with heat spreader and forced air 2–3 m/s (in steady state)
	40 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	24 mV/A	±2.25%

Parameter	Value	Conditions/Comment
Overcurrent detection (OCD)	41 A	Reconfigurable to 62 A by user
Offset	1.65 V	
DC link voltage feedback		
Sensitivity	62.5 mV/V	±1%
Onboard supply		
+5 V	±2%	Used for gate driving and powering the CAN transceiver. Also supplies the 3.3 V regulator.
+3.3 V	±3%	Used for the TLI4971 current sensor
System environment		
Ambient temperature	From 0°C to 85°C	Non-condensing, maximum relative humidity of 95%
Temperature limit	Up to 110°C	The temperature is acquired by the sensor (U6)
PCB characteristics		
Material	High TG FR4 material (PCL370HR)	8 layers (2 blind via – 1 PTH via), 70 µm copper each 2.3 mm total board thickness
Dimensions	29 x 51 x 9 mm	

2.3 Board description

Figure 3 shows the bottom and top sides of the REF_MTR_48V30A_GaN evaluation board, respectively.

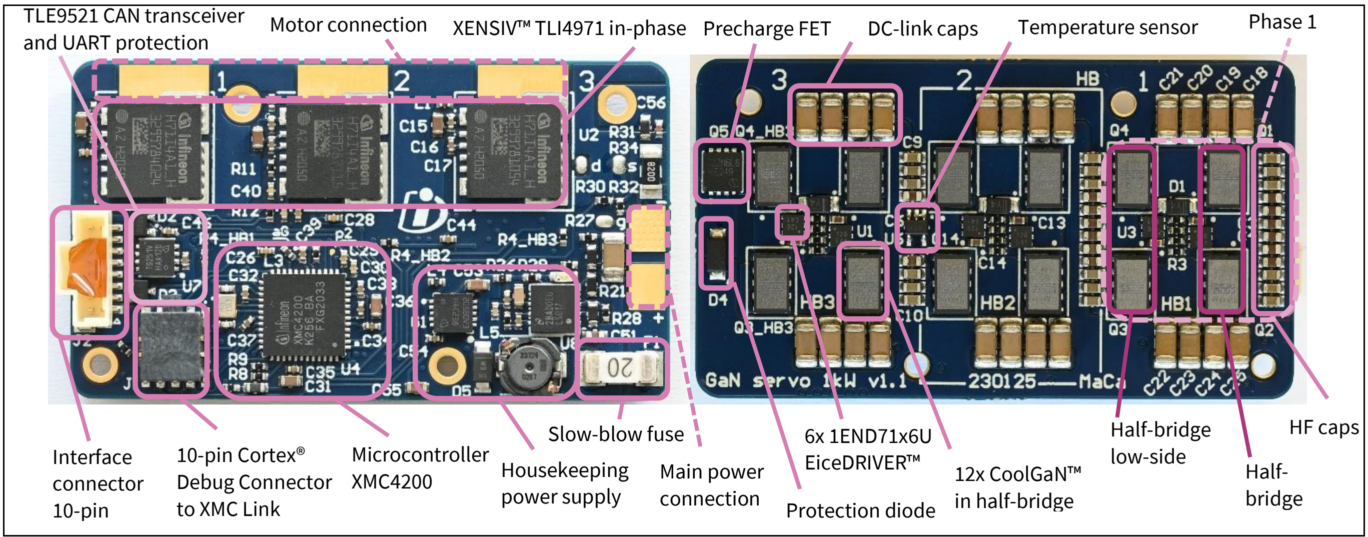

Figure 3 Overview of REF_MTR_48V30A_GaN board

Table 3 gives an overview of the pinout of the 8-pin female connector, which can be used to connect a single-ended encoder and use different communication protocols. The first pin is indicated with a small triangle on the silkscreen of the board.

Table 3 X7 pinout

Pin no.	Description	Details
1	GND	–
2	ENC_1	POSIF0.IN0A (Ph. A) – Voltage input 0–3.3 V
3	ENC_2	POSIF0.IN1A (Ph. B) – Voltage input 0–3.3 V
4	ENC_3	POSIF0.IN2A (Index) – Voltage input 0–3.3 V
5	CAN_H/TX_UART	Voltage input 0–3.3 V
6	CAN_L/RX_UART_&_PWM_IN	Voltage input 0–3.3 V
7	3.3 V	–
8	5 V	–

2.4 Heat spreader mounting

For evaluation, the REF_MTR_48V30A_GaN board includes a metal heat spreader to emulate mounting the PCB to a metal chassis. The following contents are provided for mounting the heat spreader to the PCB:

- Four M1.6 x 6 mm screws
- Thermal interface material (TIM) pad 45 x 15 mm (T-Global TG-A1250, 500 µm thickness)
- One aluminum heat spreader/heatsink with integrated standoffs and alignment pins
- Six pieces of Kapton tape 16 x 8 mm

The heat spreader guarantees heat extraction from the top of the device, as shown in Figure 4. The TIM needs to be compressed to 50 percent 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 not required for safe assembly as long as excessive over-tightening is avoided.

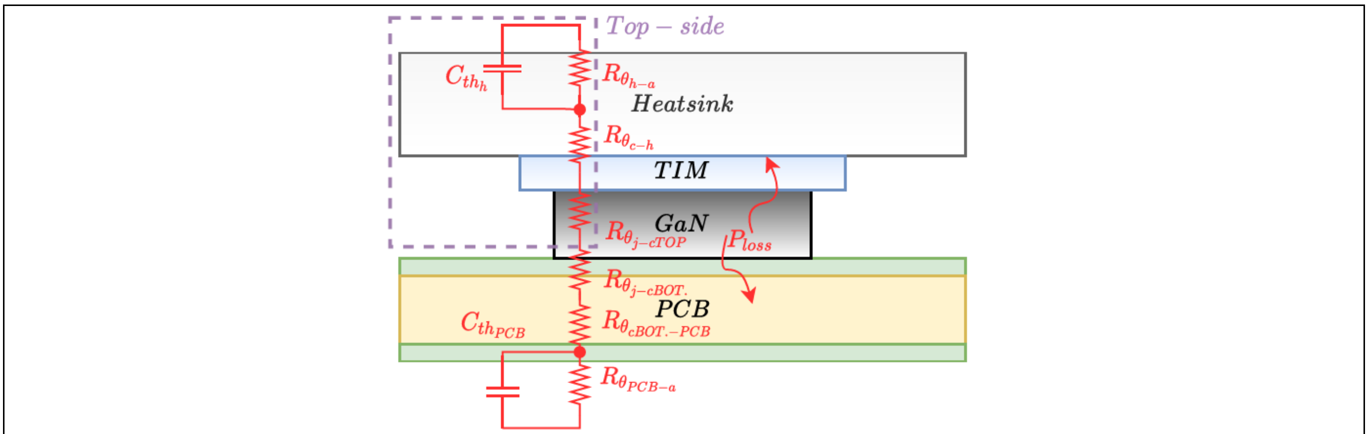

Figure 4 Cross-section showing the assembly of heat spreader with TIM applied to a single device for top-side cooling

The placement of the TIM is shown in Figure 5 (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 5, on the right.

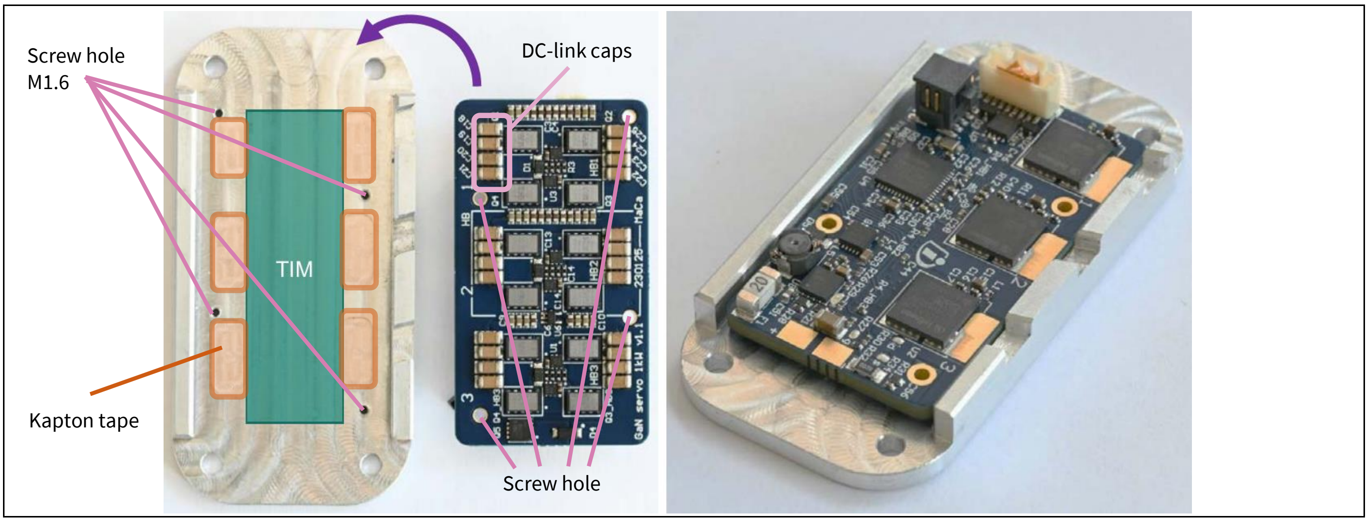

Figure 5 **Left: Placement of TIM across CoolGaN™ half-bridge and Kapton tape to avoid a short on DC link caps. Right: Fully assembled evaluation board with heat spreader**

3 Schematic and layout

3.1 Overview

A schematic overview of the motor drive is shown in Figure 6. The schematic can be divided into three core components:

- **Inverter:** This block has the CoolGaN™ half-bridge with current sensing and the DC-link/HF capacitors (shown once in the schematic, but repeated three times as identical phases 1, 2, and 3).
- **Power supply manager:** This block has all the housekeeping supplies. The 5 V supplies the gate driver, and the 3.3 V for the microcontroller, and current sensors.
- **Microcontroller:** This block contains the XMC™ microcontroller's pinout and connection to the different blocks like the inverter and the power supply manager block. In addition, the CAN transceiver and the temperature sensor are located next to the CoolGaN™ half-bridge.

In addition, connectors J1 and J2 for the debugger and interface connector respectively are present. The main connection to the motor (phases 1, 2, and 3), and the main power connection (battery input), are not explicitly shown in the schematic because they are present only as copper pads with electroless nickel immersion gold (ENIG).

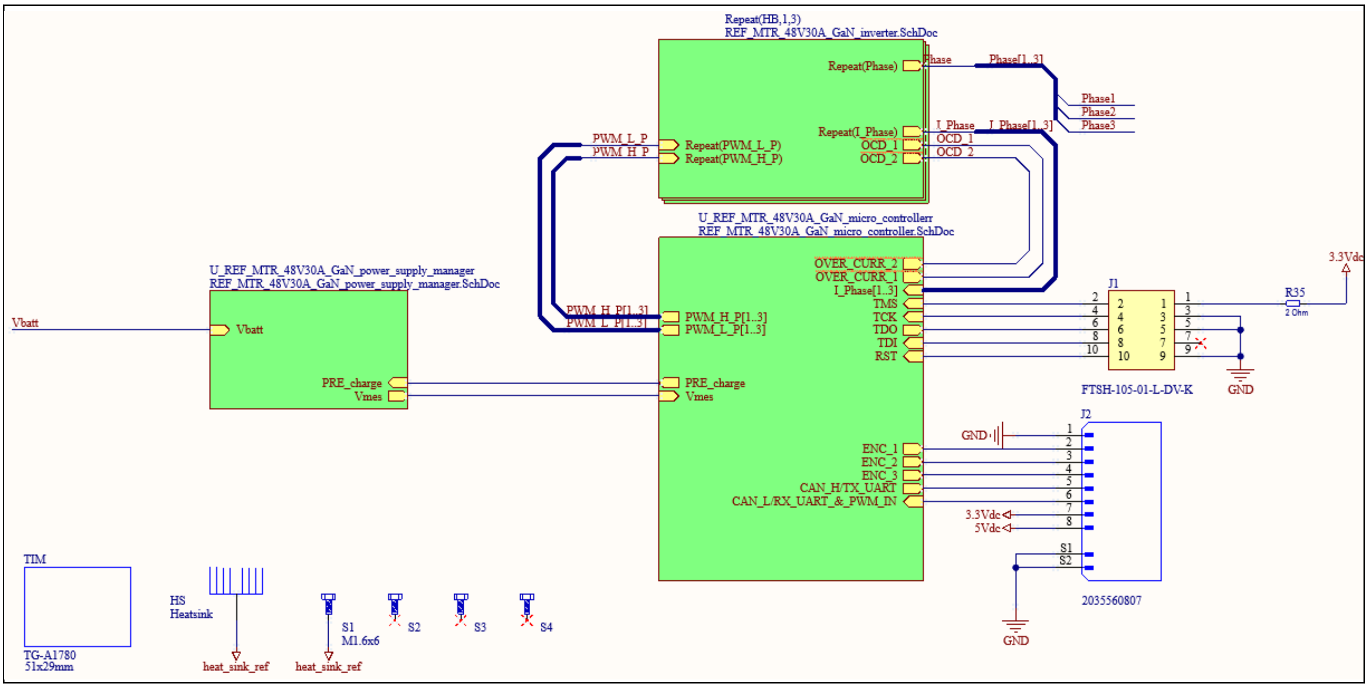

Figure 6 System-level overview of the motor drive schematic

3.2 Inverter

The schematic of a single CoolGaN™ half-bridge is shown in Figure 6. The primary building block for the motor drive is an optimized half-bridge circuit, with two CoolGaN™ Transistors 100 V 3.3 mΩ (max.) in 3 x 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. The gate loops were also designed to minimize common-source inductance while optimizing the gate driver circuits for fast switching without inserting a resistor for the turn-on of the two devices.

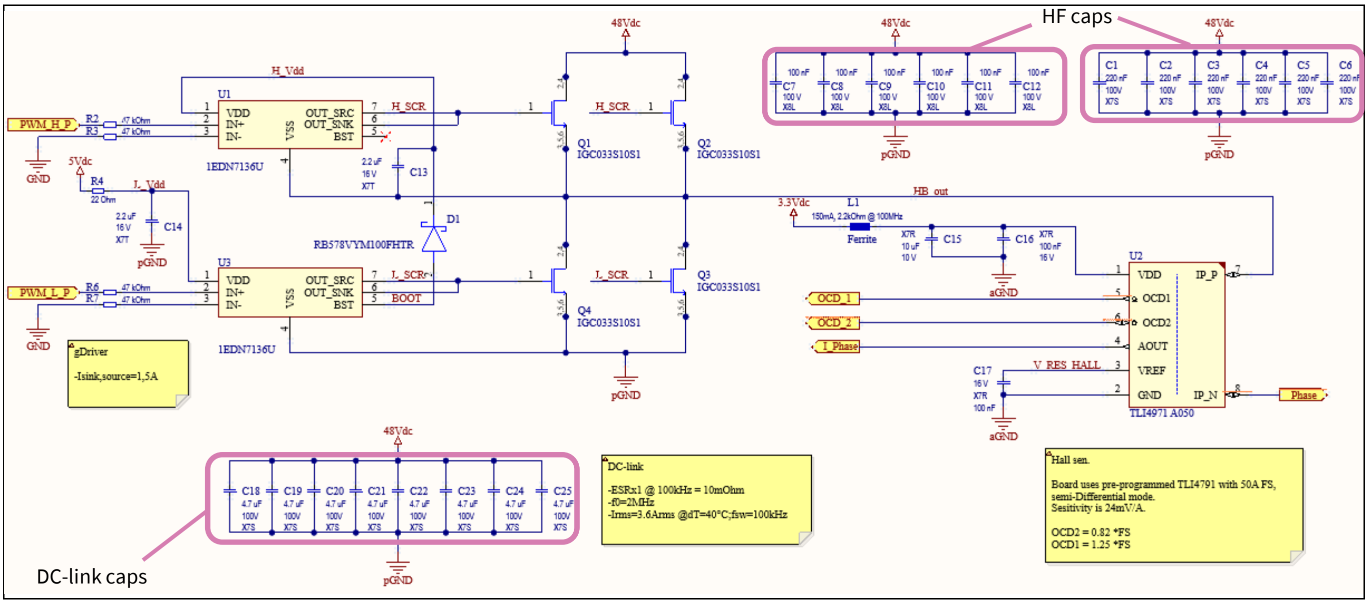

Figure 7 **Schematic of power stage including gate driver, current sensor, and HF and DC link capacitances for a single half-bridge**

3.2.1 Gate driver

The EiceDRIVER™ 1EDN7136U 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.

1EDN7136U was selected in this design as it offers a 1 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.

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. TLI4971 is a Hall-effect sensor, which avoids potential common-mode transient immunity issues with differential amplifiers. 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 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 41 A and 62.5 A respectively, using open-drain outputs. A threshold of 41 A is used by default. Section 4 provides detailed information on how this value can be reconfigured.

3.2.3 Inverter layout

The recommended layout for a CoolGaN™ Transistor half-bridge is shown in Figure 8. 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.

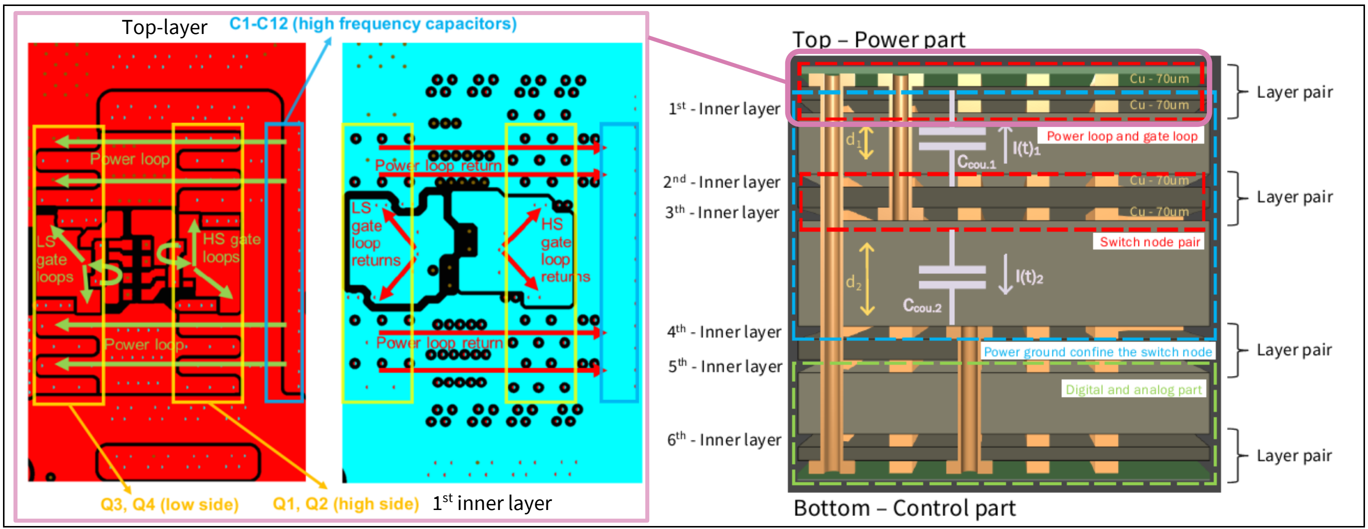

Figure 8 **Half-bridge layout; arrows indicate the flow of gate and drain switching currents and stack-up**

The phase node, shown in Figure 9, 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.

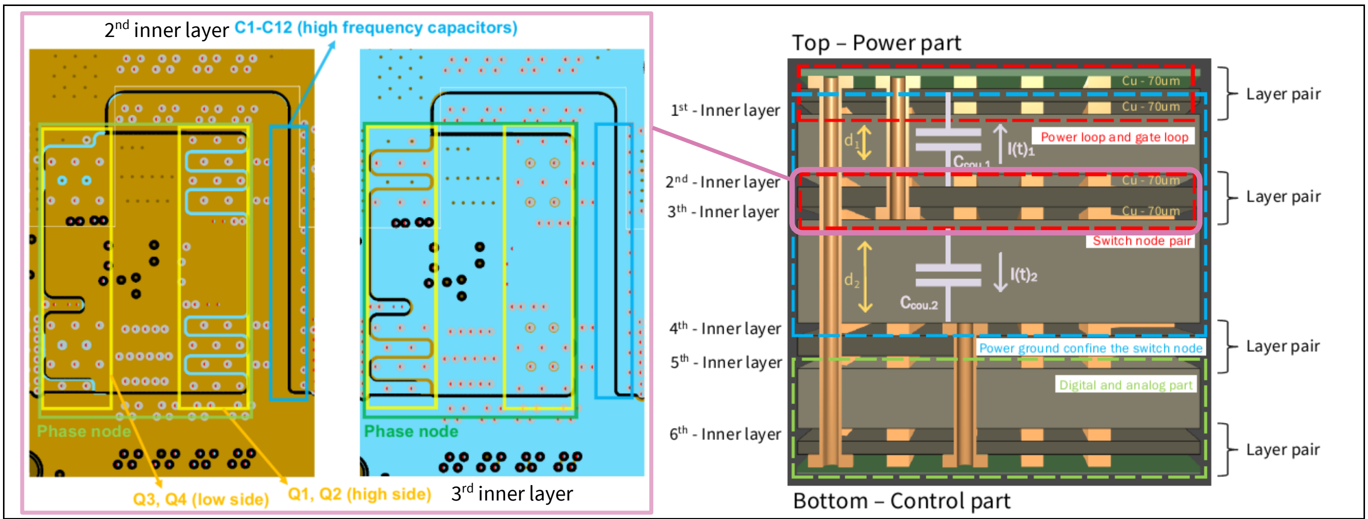

Figure 9 **Layout of the phase node and stackup**

3.3 Power supply manager

An onboard DC-DC converter generates the 5 V rail from the VIN supply (see Figure 10). The 5 V rail directly determines the gate voltage applied to the CoolGaN™ Transistors by the 1EDN7126G gate drivers. In addition, the 3.3 V rail is derived from 5 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.

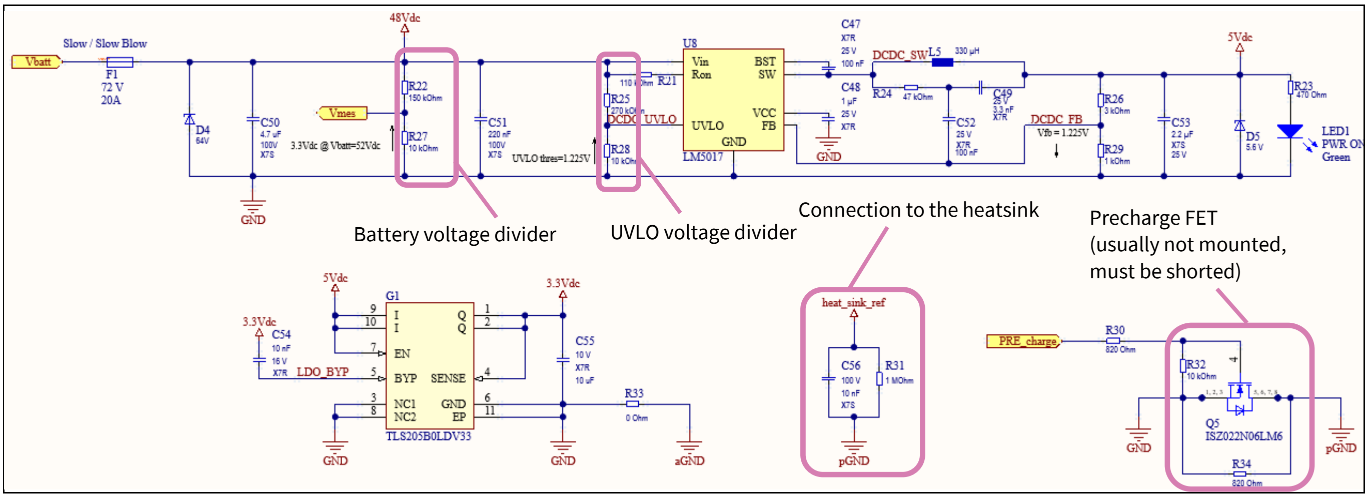

Figure 10 **Schematic of the auxiliary power supply, precharge FET and connection to the heatsink**

3.4 Microcontroller

The microcontroller schematic represents the XMC4200 controller, plus all the discrete components necessary for decoupling and filtering the supply voltage. The XMC4200 microcontroller has a separate reference and ground for the analog part to separate the digital ground (GND) with respect to the analog ground.

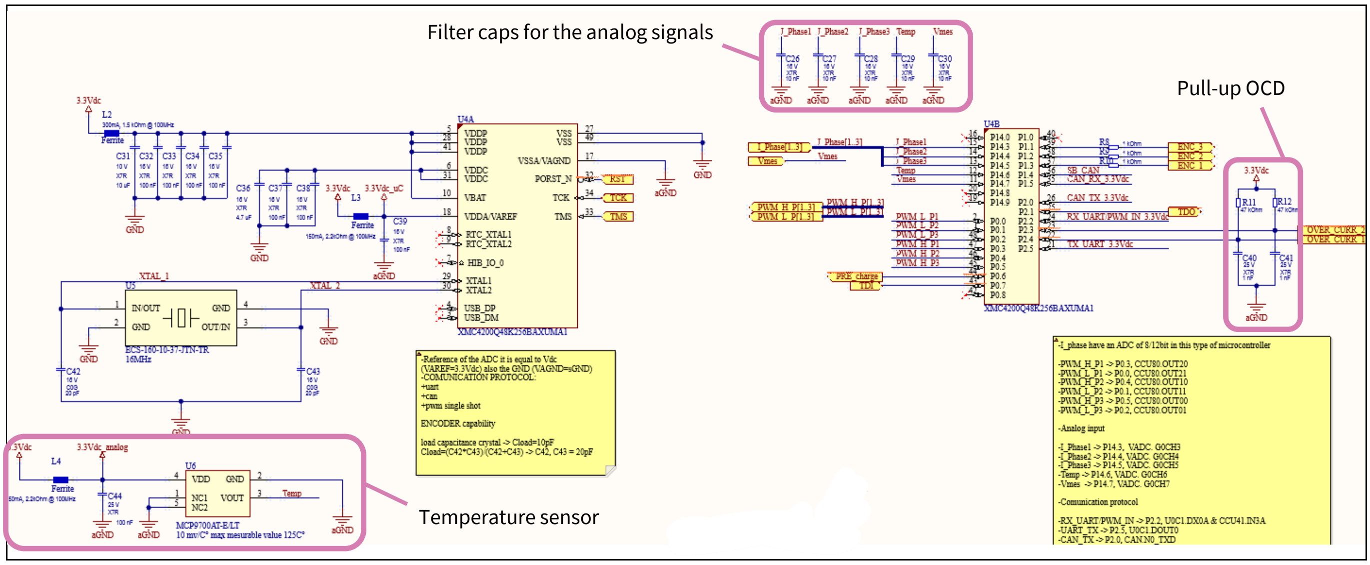

Figure 11 **Schematic of the microcontroller and temperature sensor**

3.4.1 Microcontroller layout

As shown in Figure 12 for the layout for the microcontroller, current sensors and auxiliary power supply are consolidated in the fifth and sixth layers . The main routing is located at the bottom and in the fifth inner layer, where a mecca ground is placed to be able to connect to one point the analog ground to the GND through a resistor. A solid copper plane for the digital ground (GND) is placed at the sixth inner layer.

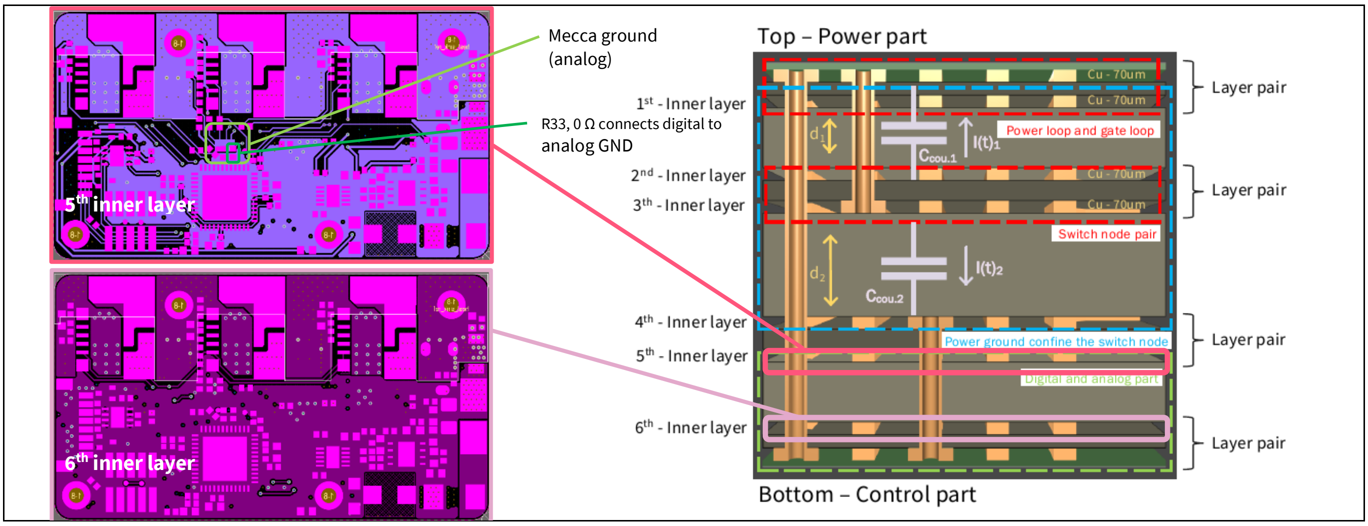

Figure 12 Layout of microcontroller

3.4.2 Temperature sensing

A temperature sensor 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 BOM) 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.

3.4.3 CAN transceiver and UART interface

The REF_MTR_48V30A_GaN board is equipped with a CAN transceiver (TLT9251VLE), which can support a 5 Mbit/s communication speed. The board does not mount the 120 Ω resistor to the CAN cable termination; this termination needs to be provided from the external connection(see Figure 13).

The UART is present on the same pinout, which is directly connected to the microcontroller through a 1 kΩ resistor and is also protected by a protection diode to avoid overvoltage and undervoltage conditions.

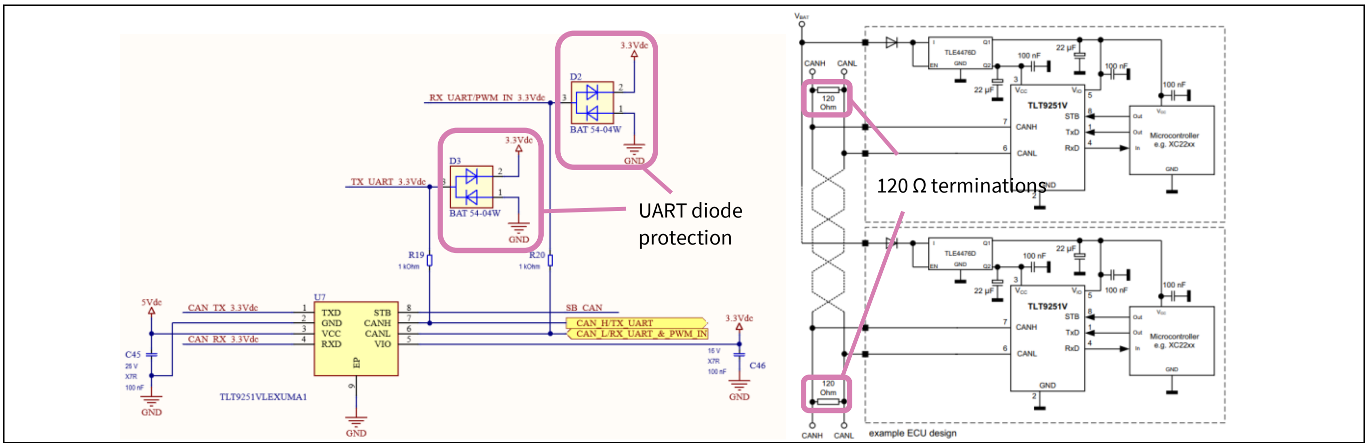

Figure 13 Left: Schematic of the CAN transceiver and UART interface; Right: Example of a connection to the external cable with 120 Ω termination

4 Supported user modifications

REF_MTR_48V30A_GaN is a flexible reference design to support designs using CoolGaN™ Transistors in motor drive applications. To cater to different needs, the evaluation board supports several user modifications.

4.1 External supply of 5 V rail

For investigation of gate drive patterns and the first-check of the microcontroller, run the REF_MTR_48V30A_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 L5 and supplying 5 V directly with a pair of cables, as shown in Figure 14.

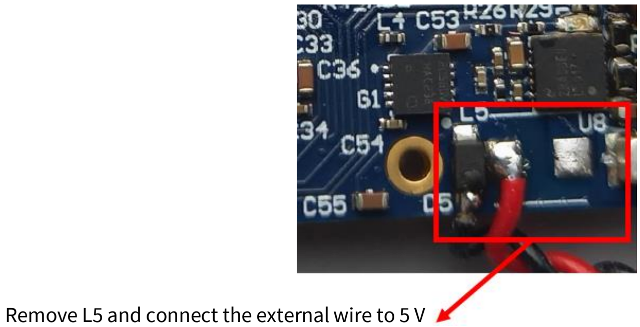

Figure 14 Connection for external 5 V supply

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 between the main power connection pads "+" and "–".

4.3 V_{DS} and V_{GS} measurements

The REF_MTR_48V30A_GaN evaluation board provides onboard probing points of critical waveforms such as V_{DS} and V_{GS}, as shown in Figure 15. 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.

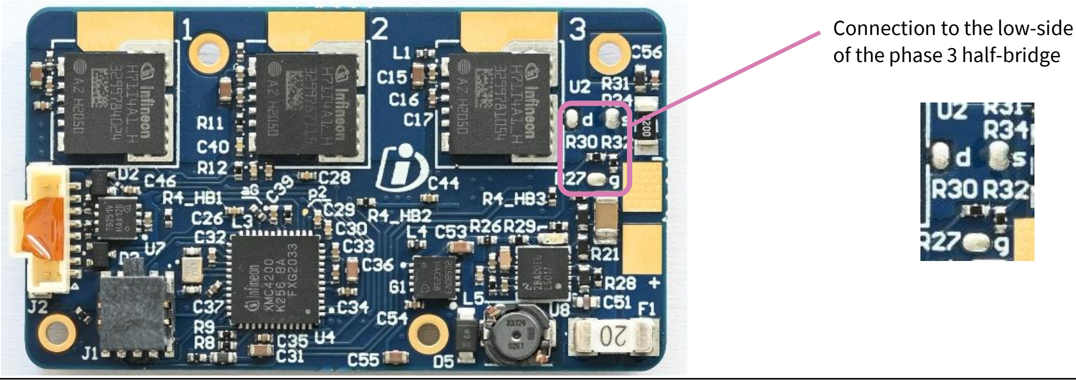

Figure 15 Measurement points for the bottom side of the PCB

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). For this, change the resistor R28 with a simple voltage divider relationship as follows. See Figure 16.

$$V_{UVLO} = \frac{270\ kOhm + R28}{R28} \cdot 1.225\ V$$

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 R27 using the following relationship:

$$V_{input\ max} = \frac{150\ kOhm + R27}{R27} \cdot 3.3\ V$$

Equation 2 Changing the voltage partition at the main battery

The REF_MTR_48V30A_GaN board includes a battery voltage divider able to handle a supplied voltage up to 52 V DC, which corresponds to a battery of 12 cells in series.

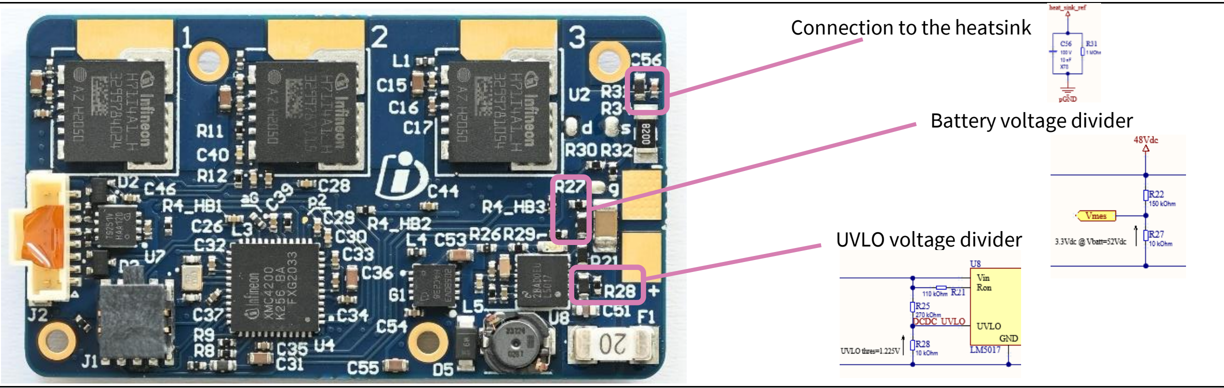

Figure 16 UVLO, precharge FET, and heatsink connection

4.5 CAN transceiver and UART connection

The interface of the CAN and UART blocks are connected to the same pinout of the J2. To use UART, mount R19 and R20, see Figure 17. To use the CAN transceiver, remove the two resistors to avoid interference with the UART.

The microcontroller can also be configured with the pins P2.2 and P2.5 (respectively RX_UART/PWM_IN_3.3Vdc and TX_UART_3.3Vdc) at low level instead of removing R19 and R20 when CAN is used.

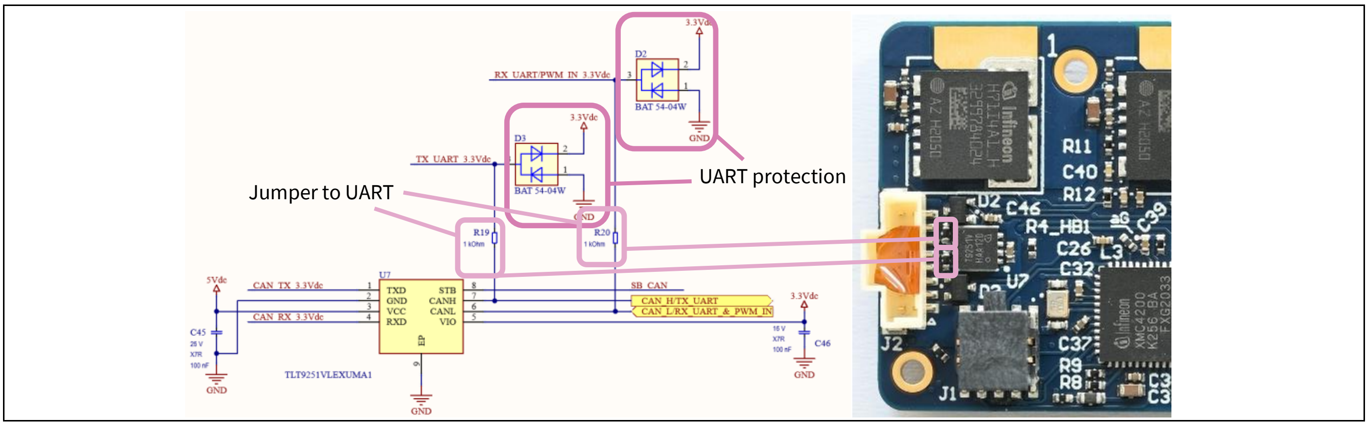

Figure 17 Schematic of the CAN transceiver and UART interface

4.6 Gate driver replacements

The REF_MTR_48V30A_GaN board is not equipped with a gate resistor to slow down dV/dt when it is requested. Figure 18 shows where the gate drivers are shown for one half-bridge of the inverter.

The EiceDRIVER™ gate driver has four different variants that can provide different currents in the source/sink, from 0.5 A up to 2 A. Figure 19 shows how dV/dt changes with different drivers.

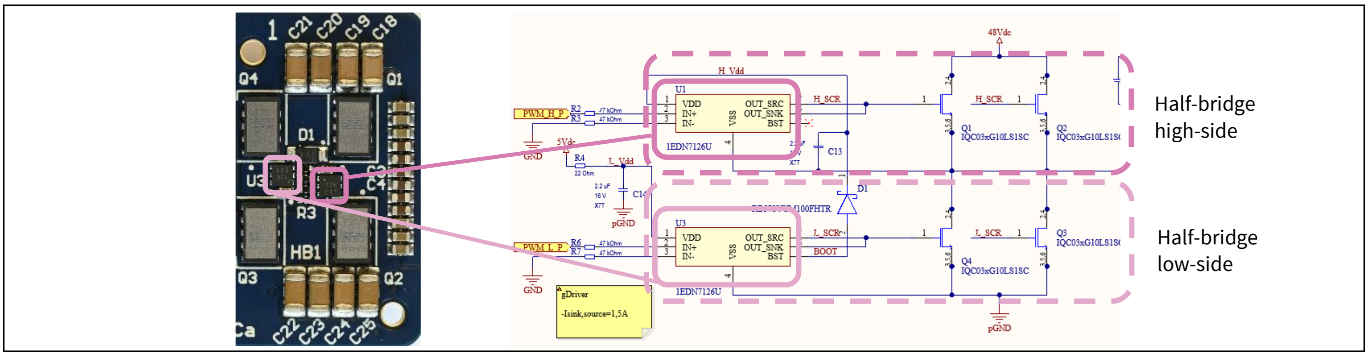

Figure 18 Schematic of the single half-bridge and gate driver placement

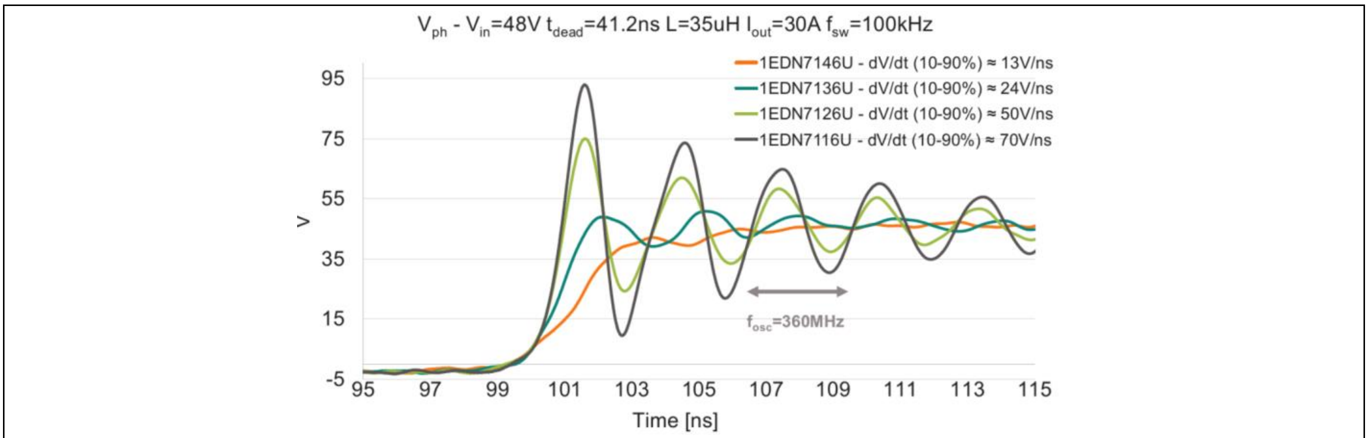

Figure 19 Phase node voltage during high-side hard turn-on

4.7 Bypassing the precharge FET

Note that the low-side precharge MOSFET on the REF_MTR_48V30A_GaN board should be shorted in the latest version of the board (short between drain and source). Create a short on R34 with a thick cable. If Q5 is not mounted, create a short between the drain and source.

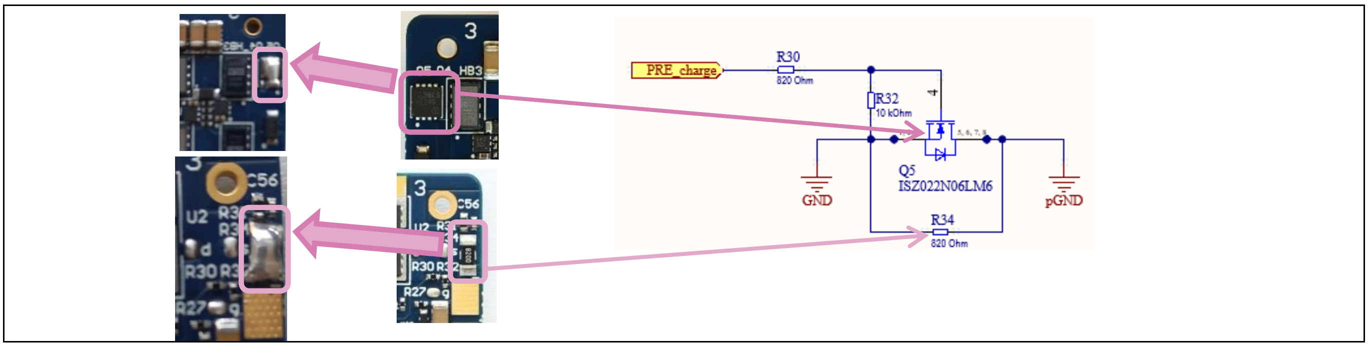

Figure 20 Prechage MOSFET and resistance to be shorted

5 Measurements

Here are some typical measurements that can be observed with the REF_MTR_48V30A_GaN evaluation board for reference.

5.1 V_{DS} measurement

Figure 21 shows an example measurement of low-side V_{DS} using the test pads shown in Figure 15, and the respective phase current Iphs at VIN = 48 V. dV/dt is measured between 10 percent and 90 percent of the waveform. Usually, the board is sealed with the 1EDN7146U and 1EDN7136U gate drivers. This option allows you to improve the efficiency with a faster switching transition.

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

Measurements of the RL load with the setup shown in Figure 21 are necessary to evaluate the losses under different conditions, with gate drivers, and type of cooling used.

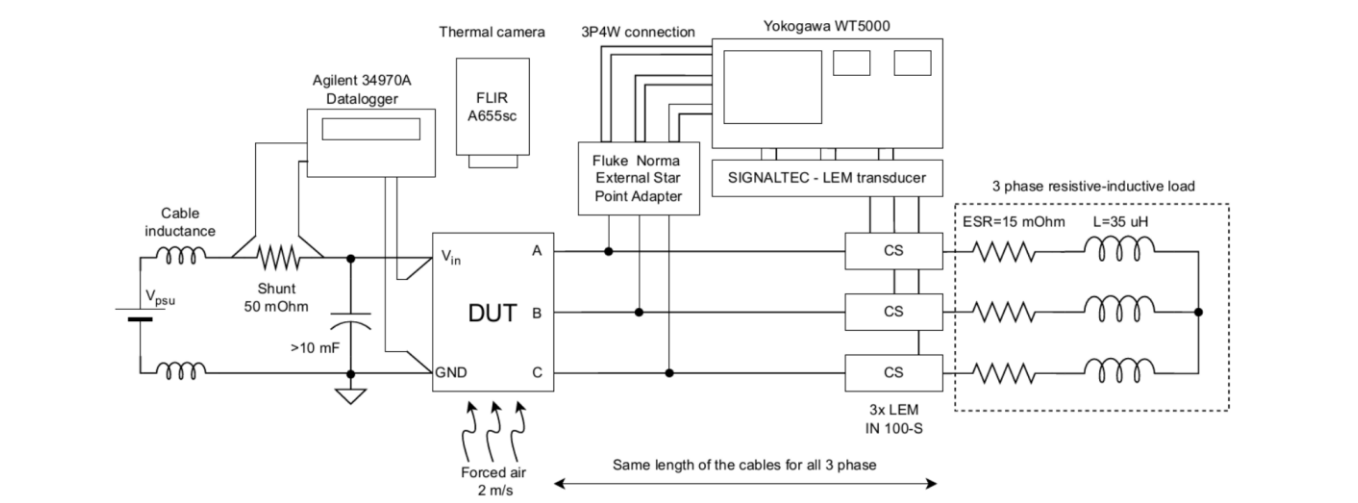

Figure 21 Measurement setup

Figure 22 shows the losses measured with the gate driver that is able to provide a faster switching transition (1EDN7116U), and the slowest driver of the EiceDRIVER™ family (1EDN7146U). 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 22, which are captured with a thermal camera as shown in Figure 23.

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.

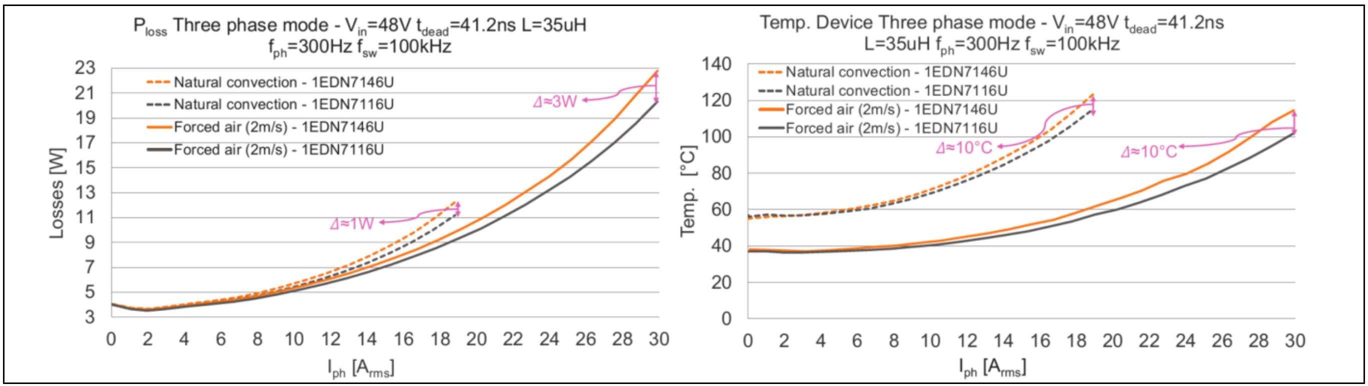

Figure 22 **Measurement of losses and temperature of the reference design**

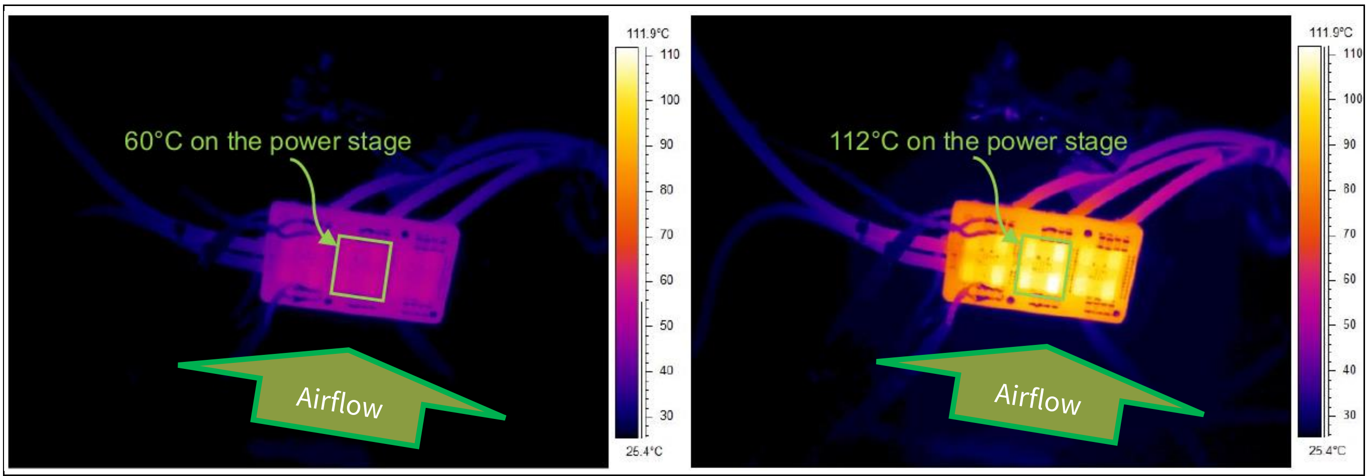

Figure 23 **PCB temperature during the test with RL load at fsw=100 kHz and airflow of 2 m/s; (left) phase current of 17 A_{RMS}; (right) phase current of 30 A_{RMS}**

5.3 Measurement of losses and efficiency with a target motor

The measurements with the target motor (P60 170KV from T-motor) are obtained using the setup in Figure 24. The cooling condition of the measurement setup is shown in Figure 25, which uses forced air of 2–3 m/s passing through the board where the heatsink is mounted, as shown in Figure 5.

The tests are made for a single speed of the motor (2400 rpm) with different torques from 0.7 Nm up to 2 Nm. All the measurements are done in steady state, and thermal equilibrium of the board and heatsink.

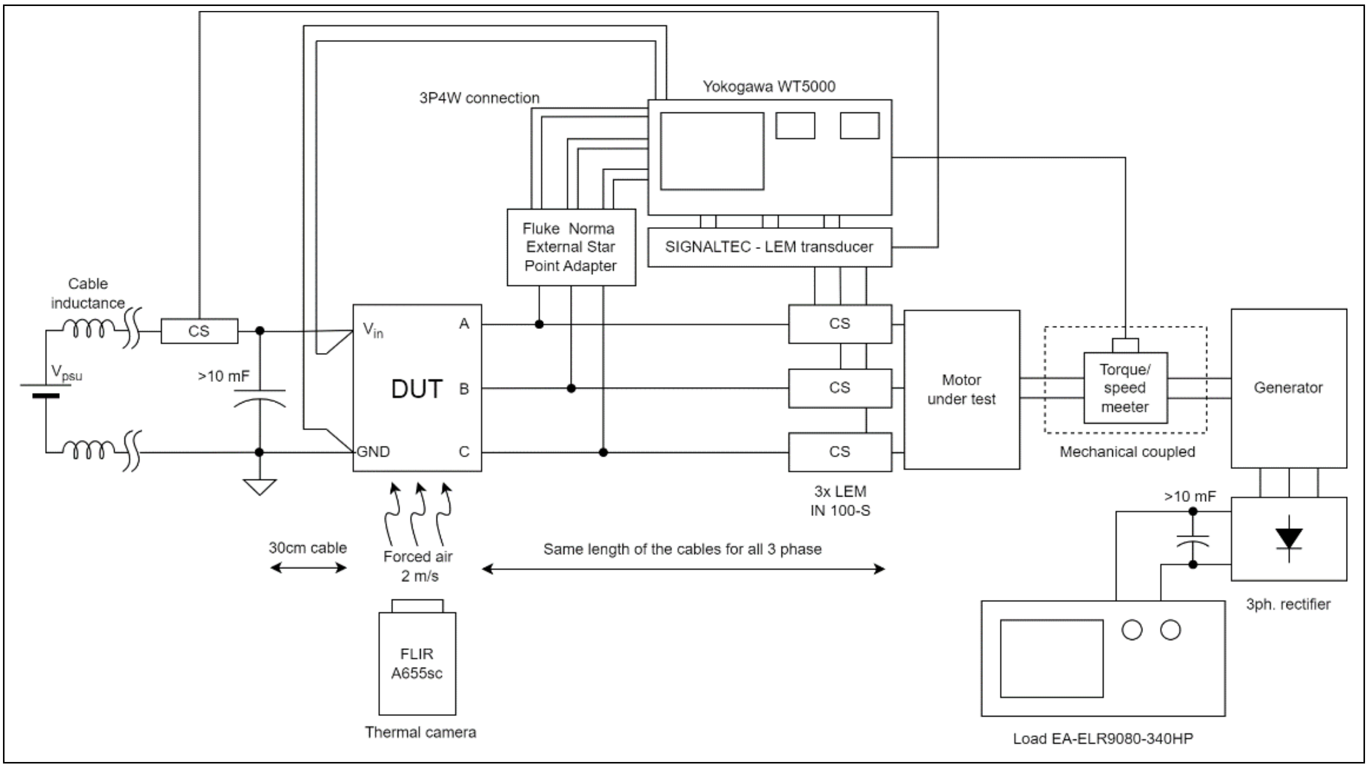

Figure 24 **Measurement setup**

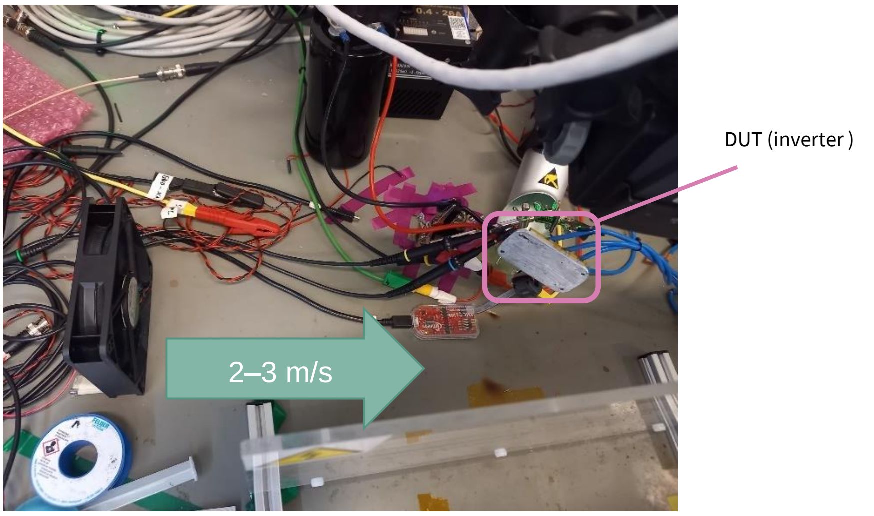

Figure 25 **Cooling condition in the measurement setup**

Figure 26 show the efficiency and the losses of the inverter, the motor and the overall system (motor plus inverter). Figure 27 shows the temperature of the PCB, which needs to remain below 110°C due to the setting in the firmware (templimit).

The test shows the board's capability to handle almost 35 A_{RMS} and a mechanical power of 550 W. The inverter efficiency is 97.7 percent 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 12 V_{RMS}.

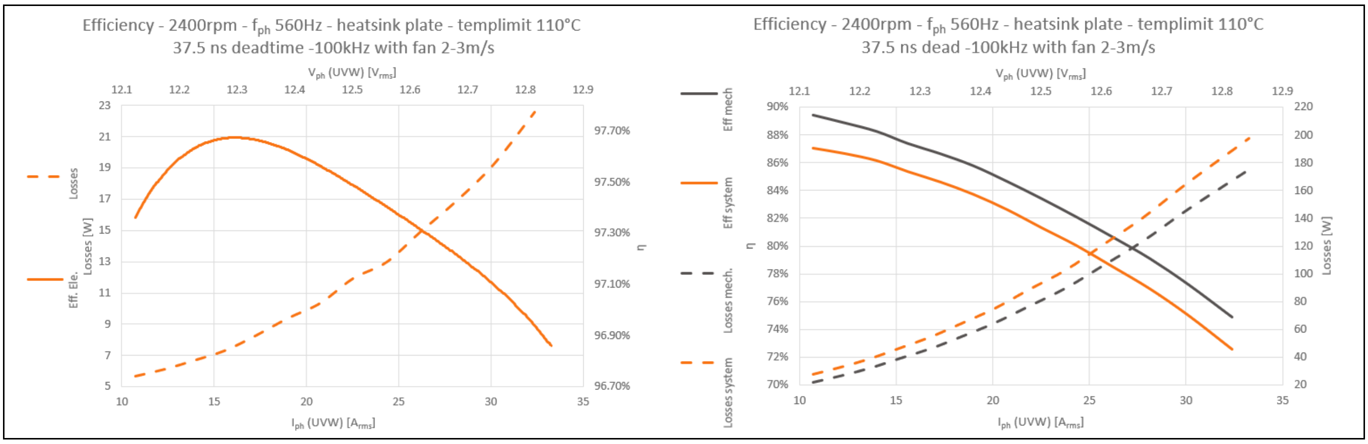

Figure 26 **Left: Losses and efficiency of the inverter; Right: Losses and efficiency of the motor and total system (motor plus inverter)**

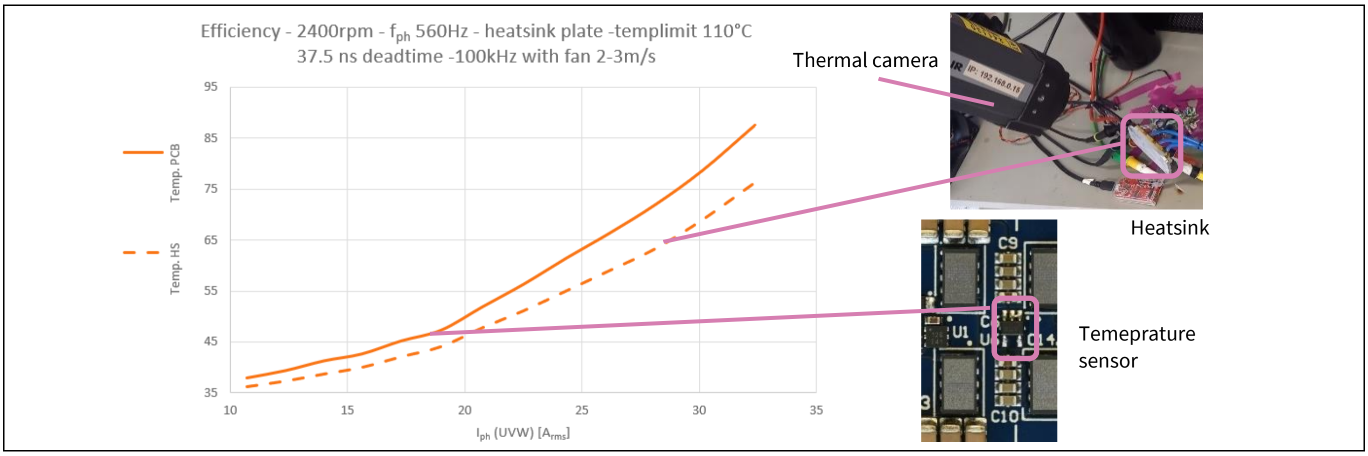

Figure 27 **Temperature on top of the heatsink, acquired by a thermal camera, and temperature on the PCB, measured with the sensor**

6 Bill of materials

Table 4 Bill of materials for REF_MTR_48V30A_GaN

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts
1	19	220 nF	C1_HB1, C1_HB2, C1_HB3, C2_HB1, C2_HB2, C2_HB3, C3_HB1, C3_HB2, C3_HB3, C4_HB1, C4_HB2, C4_HB3, C5_HB1, C5_HB2, C5_HB3, C6_HB1, C6_HB2, C6_HB3, C51	HMK107C7224KAHTE	Taiyo Yuden	
2	18	100 nF	C7_HB1, C7_HB2, C7_HB3, C8_HB1, C8_HB2, C8_HB3, C9_HB1, C9_HB2, C9_HB3, C10_HB1, C10_HB2, C10_HB3, C11_HB1, C11_HB2, C11_HB3, C12_HB1, C12_HB2, C12_HB3	GCJ188L8EL104KA07D	Murata	
3	6	2.2 µF	C13_HB1, C13_HB2, C13_HB3, C14_HB1, C14_HB2, C14_HB3	GRM155D71C225ME11D	Murata	

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts
4	5	10 µF	C15_HB1, C15_HB2, C15_HB3, C31, C55	GRM188Z71A106KA73D	Murata	
5	14	100 nF	C16_HB1, C16_HB2, C16_HB3, C17_HB1, C17_HB2, C17_HB3, C32, C33, C34, C35, C37, C38, C39, C46	GCM155R71C104KA55D	Murata	
6	25	4.7 µF	C18_HB1, C18_HB2, C18_HB3, C19_HB1, C19_HB2, C19_HB3, C20_HB1, C20_HB2, C20_HB3, C21_HB1, C21_HB2, C21_HB3, C22_HB1, C22_HB2, C22_HB3, C23_HB1, C23_HB2, C23_HB3, C24_HB1, C24_HB2, C24_HB3, C25_HB1,	GRJ31CC72A475KE01K	Murata	
7	5	10 nF	C26, C27, C28, C29, C30	GRM155R71C103KA01D	Murata	
8	1	4.7 µF	C36	GRT188C71C475KE13D	Murata	
9	2	1 nF	C40, C41	CL05B102KA5NNWC	Samsung	
10	2	20 pF	C42, C43	0402YA200JAT2A	AVX	
11	4	100 nF	C44, C45, C47, C52	GRM155R71E104KE14D	Murata	–
12	1	1 µF	C48	GCM188R71E105KA64J	Murata	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts
13	1	3.3 nF	C49	04023C332KAT2A	AVX	–
14	1	2.2 µF	C53	GRM188C71E225KE11D	Murata	–
15	1	10 nF	C54	GRT155R71C103KE01J	Murata	–
16	1	10 nF	C56	C1005X7S2A103K050BB	TDK	–
17	3	Bootstrap diode	D1_HB1, D1_HB2, D1_HB3	RB578VYM100FHTR	ROHM Semiconductor	RB168VAM100TR
18	2	UART diode protection	D2, D3	BAT 54-04W	Infineon	–
19	1	TVS	D4	TPSMF4L64A	Littlefuse	–
20	1	5.6 V Zener	D5	BZT52HC5V6WF-7	Diodes Inc.	–
21	1	20 A slow-blow	F1	0ACA-9200-TE	Bel fuse	–
22	1	LDO 3.3 V	G1	TLS205B0LDV33	Infineon	–
23	1	Heatsink, thermal interface materials	HS, TIM	Custom HS, TG-1250	//, T-Global	–
24	1	Debugger connector	J1	FTSH10501LDVK	Samtec	–
25	1	Interface connector	J2	2035560807	Molex	–
26	5	Ferrite: 150 mA, 2.2 kΩ at 100 MHz	L1_HB1, L1_HB2, L1_HB3, L3, L4	MMZ1005A222ET000	TDK	–
27	1	Ferrite: 300 mA, 1.5 kΩ at 100 MHz	L2	MMZ1608Y152BTD25	TDK	–
28	1	330 µH	L5	CLF5030NIT-331M-D	TDK	–
29	1	LED Green	LED1	APHD1608LZGCK	Kingbright	–
30	12	IGC033S10S1	Q1_HB1, Q1_HB2, Q1_HB3, Q2_HB1, Q2_HB2, Q2_HB3, Q3_HB1, Q3_HB2, Q3_HB3, Q4_HB1, Q4_HB2, Q4_HB3	IGC033S10S1	Infineon	–

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts
31	1	ISZ022N06LM6	Q5	ISZ022N06LM6	Infineon	–
32	15	47 kΩ	R2_HB1, R2_HB2, R2_HB3, R3_HB1, R3_HB2, R3_HB3, R6_HB1, R6_HB2, R6_HB3, R7_HB1, R7_HB2, R7_HB3, R11, R12, R24	RCC040247K0FKED	Vishay	–
33	3	22 Ω	R4_HB1, R4_HB2, R4_HB3	RCS040222R0FKED	Vishay	–
34	6	1 kΩ	R8, R9, R10, R19, R20, R29	RCS04021K00FKED	Vishay	–
35	1	110 kΩ	R21	ERJPA3F1103V	Panasonic	–
36	1	150 kΩ	R22	ERJPA3F1503V	Panasonic	–
37	1	470 Ω	R23	RCS0402470RFKED	Vishay	–
38	1	270 kΩ	R25	ERJPA3F2703V	Panasonic	–
39	1	3 kΩ	R26	RCS04023K00FKED	Vishay	–
40	3	10 kΩ	R27, R28, R32	RCC040210K0FKED	Vishay	–
41	1	820 Ω	R30	RCS0402820RFKED	Vishay	–
42	1	1 MΩ	R31	RCC06031M00FKEA	Vishay	–
43	1	0 Ω	R33	RCS04020000Z0ED	Vishay	–
44	1	820 Ω	R34	CRCW1206820RFKEAHP	Vishay	–
45	1	2 Ω	R35	RCS04022R00FKED	Vishay	–
46	4	M1.6x6	S1, S2, S3, S4	M1.6_6mm	–	–
47	6	1EDN7136U	U1_HB1, U1_HB2, U1_HB3, U3_HB1, U3_HB2, U3_HB3	1EDN7136U	Infineon	1EDN7146U
48	3	TLI4971 A050	U2_HB1, U2_HB2, U2_HB3	TLI4971-A050T5-E0001		TLI4971-A075T5-E0001

No.	Qty.	Part description	Designator	Part No.	Manufacturer	Alternative parts
49	1	XMC4200	U4	XMC4200Q48K256BAXUMA1	Infineon	–
50	1	16 MHz	U5	ECS-160-10-37-JTN-TR_ECS-M	ECS International	–
51	1	Temperature sensor	U6	MCP9700AT-E/LT	Microchip	MAX6612MXK+T
52	1	CAN transceiver	U7	TLT9251VLEXUMA1	Infineon	–
53	1	DCDC	U8	LM5017SD/NOPB	TI	–

References

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

[2] Infineon Technologies AG: *Datasheet for EiceDRIVER™ 1EDN71x6U, 200 V high-side TDI gate driver IC for GaN transistors and MOSFETs*; Available online

[3] Infineon Technologies AG: *Datasheet for TLI4971 high precision coreless current sensor for industrial applications in 8x8 mm SMD package;* Available online

[4] Infineon Technologies AG: *Datasheet for XMC4200 industrial microcontroller (2023)*; Available online

[5] Infineon Technologies AG: *Datasheet for TLS205B0LDV post voltage regulator (2015)*; Available online

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