FOC motor drive evaluation board based on CoolGaN™ transistors

About this document

Scope and purpose

This document provides an overview of the EVAL_MTR_48V20A_GaN Evaluation Board, including its main features, configuration for operation, pin assignment, and mechanical dimensions.

The EVAL_MTR_48V20A_GaN Evaluation Board was developed to support customers during their first steps in designing systems with the 100 V, 3.3 mΩ CoolGaN™ transistor in a top-side-cooled 3 mm x 5 mm PQFN package. It is optimized for motor drive applications with a relatively high switching frequency, i.e., 100 kHz or higher.

The evaluation board includes an aluminum heat-spreader, mounting hardware, and three thermal interface material (TIM) pads. This dual-sided cooling approach allows the customer to simulate board attachment to a metal housing and take full advantage of the exposed-die PQFN package.

Intended audience

This user guide is intended for power electronics engineers evaluating the use of CoolGaN™ transistors in motor drive applications.

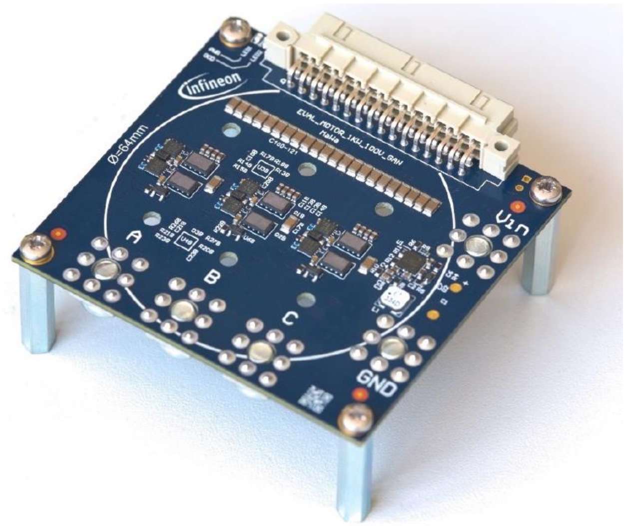

Figure 1 **EVAL_MTR_48V20A_GaN Evaluation Board**

Note: This document is for the EVAL_MTR_48V20A_GaN Evaluation Board. The product name (EVAL_MOTOR_1KW_100V_GaN) shown in the figures of this document are due to variations in the design and manufacturing processes. Both EVAL_MOTOR_1KW_100V_GaN and EVAL_MTR_48V20A_GaN refer to the same evaluation board.

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Safety precautions

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

Table 1 Safety precautions

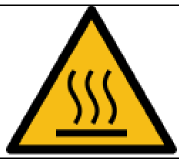
	**Warning**: *The evaluation or reference board contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. 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.*

Table of contents

1 Introduction

EVAL_MTR_48V20A_GaN is a complete evaluation board for field oriented control (FOC) motor drive applications, including six CoolGaN™ 100 V transistors in half-bridge configurations, each using the EiceDRIVER™ 1EDN7126G gate driver. Three in-phase current sensors using the XENSIV™ TLI4971 magnetic current sensor provide accurate phase current measurements at any switching frequency. Designed to interface with control boards such as the XMC4400 drive card via an M5 32-pin connector, the evaluation board demonstrates the capability of Infineon's CoolGaN™ transistors in motor drive applications.

Each half-bridge is driven by two independent gate drivers, giving users full control over the switching pattern and dead-time. In addition, each phase leg is equipped with a temperature sensor, enabling overtemperature protection (OTP) to be implemented on the external controller.

All the phases are also equipped with isolated Hall-effect current sensors, enabling sensored or sensorless FOC. An input voltage divider provides a means to implement undervoltage and overvoltage protection (UVP and OVP) as well as voltage compensation. The design includes an 80 µF DC-link, distributed across the board in low-profile ceramic capacitors. The board uses M5 screw terminals for the DC input and three-phase motor connections for convenient setup and lab evaluation. Environmental conditions were considered in the design of EVAL_MTR_48V20A_GaN.

A block diagram of the EVAL_MTR_48V20A_GaN Evaluation Board is shown in Figure 2. All measurements and control signals are available on a 32-pin M5 drive card interface connector for connection to an external controller, such as the XMC1400 or XMC4400 drive card.

Note: *The design was tested as described in this document, but not qualified in terms of safety requirements, manufacturing, operation over the entire operating temperature range, or lifetime. The boards provided by Infineon are subject to functional testing only.*

Note: *Evaluation boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN), and product discontinuation (PD). Evaluation boards are intended to be used under laboratory conditions and by trained specialists only.*

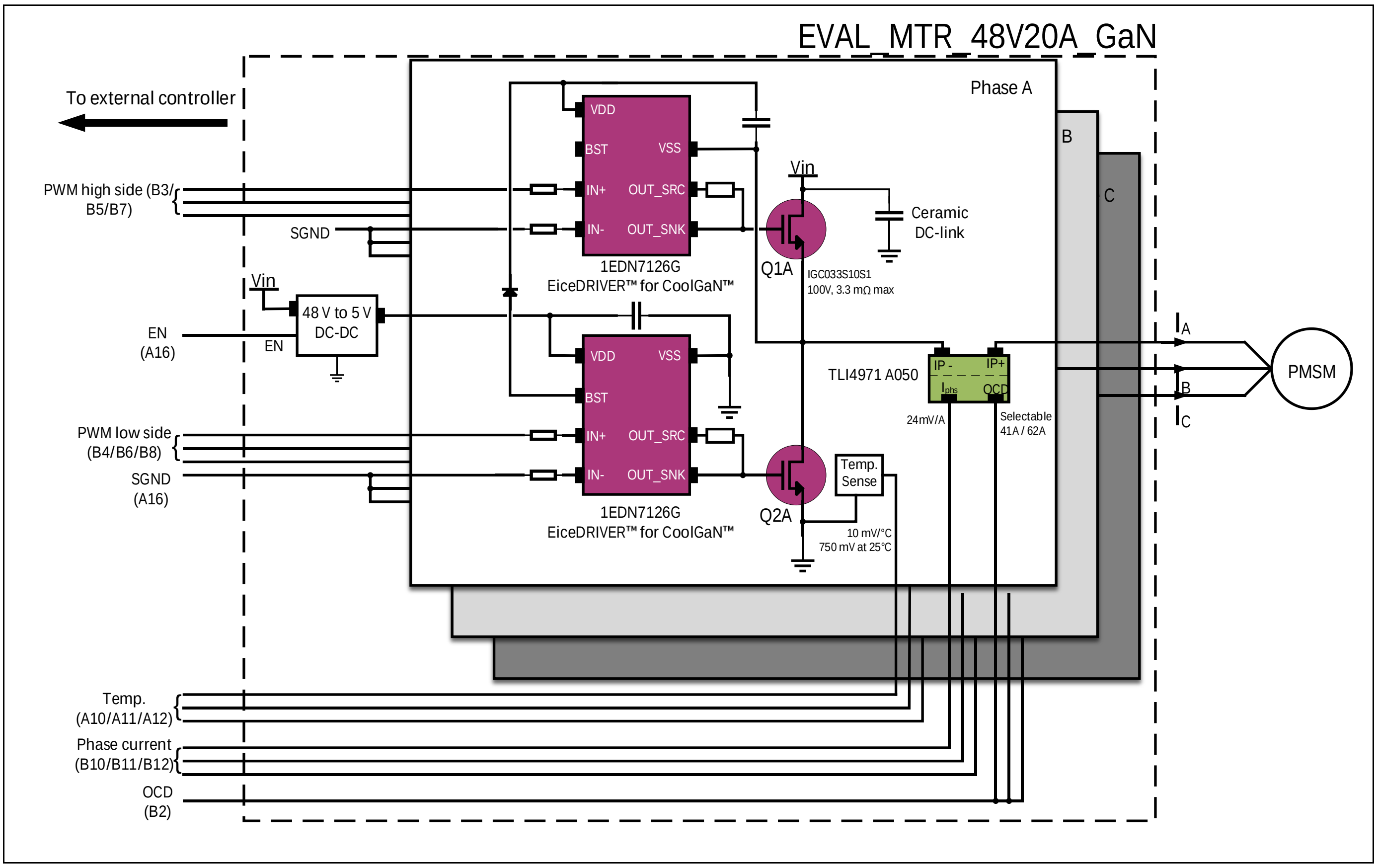


Figure 2 **Block diagram of EVAL_MTR_48V20A_GaN including key parameters and pinout**

2 Design features

EVAL_MTR_48V20A_GaN is an evaluation board for Infineon's CoolGaN™ transistors as well as the complementary EiceDRIVER™ gate driver. When combined with one of Infineon's XMC™ drive cards, it demonstrates GaN technology in FOC motor drive applications.

Main features:

- CoolGaN™ IGC033S10S1 100 V, 3.3 mΩ (max.) transistor in a 3 x 5 mm PQFN package
- EiceDRIVER™ 1EDN71x6G gate driver for GaN transistors and MOSFETs
- XENSIV™ TLI4971 magnetic current sensor for AC and DC currents

The evaluation board characteristics are:

- 48 V nominal input voltage; 60 V maximum input voltage
- Low-profile design with a total thickness of 10 mm when operated with a heat-spreader (3.6 mm without)
- 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
- Overcurrent detection (OCD), selectable as 41 A or 62 A
- Test points at gate, drain, and source at each GaN transistor for waveform capture
- PCB dimensions: 71 x 76 x 1.6 mm with four layers of 70 µm (2 oz.) copper
- Heatsink and mounting hardware included as part of the kit

2.1 Highlighted products

2.1.1 CoolGaN™ 100 V transistors

CoolGaN™ GaN 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 be operated with reduced dead-times, which results in higher efficiency and enables passive cooling. Operation at high switching frequencies in motor drive applications can reduce the DC-link size and enables the use of ceramic capacitors improving power density and lifetime at high temperatures.

2.1.2 EiceDRIVER™ 1EDN71x6G gate driver

1EDN71x6G [2] is a single-channel gate driver IC optimized for compatibility with Infineon CoolGaN™ transistors. It is compatible with other GaN transistors and silicon MOSFETs as well. This gate driver includes several key features that enable a high-performance system design with GaN 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, bootstrap voltage clamp, and adjustable charge pump.

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 analog interface and two fast overcurrent detection outputs. Infineon's well-established and robust monolithic Hall technology enables accurate and highly linear measurement of currents with a full scale up to ±120 A. All negative effects commonly known 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 OPTIREG™ TLS202

TLS202B1 [4] is a monolithic integrated fixed linear voltage post regulator for load currents up to 150 mA. The IC regulates an adjustable output voltage of 1.2 V to 5.25 V with a precision of ±3 percent, supplied by an input voltage up to 18 V. TLS202B1 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 is protected against overload, short-circuit, and overtemperature conditions by the implemented output current limitation and overtemperature shutdown circuit.

2.2 Specifications

Table 2 EVAL_MTR_48V20A_GaN board specifications

Parameter	Value	Conditions/comment
Input		
Nominal input voltage	48 V	–
Maximum input voltage	60 V	–
Undervoltage lockout (UVLO)	12 V	–
Maximum input current	22 A	48 V, T_a = 25°C, natural convection with heat-spreader
Output		
Power (three-phase)	1 kW	48 V, T_a = 25°C, natural convection with heat-spreader
Current per phase leg	 20 A_{RMS} 50 A_{RMS}	48 V, T_a = 25°C, natural convection Continuous Pulsed, less than 10 s
Switching frequency		
Nominal switching frequency	100 kHz	–
Minimal switching frequency	20 kHz	May require additional DC capacitance
Current feedback		
Sensitivity	24 mV/A	±2.25%
Over-current detection (OCD)	41 A	Reconfigurable to 62 A by user
Offset	1.65 V	–
DC-link voltage feedback		
Sensitivity	52.6 mV/V	±1%
Onboard supply		
+5 V	±2%	Used for gate driving, also supplies 3.3 V regulator
+3.3 V	±3%	Used for TLI4971 current sensors
System environment		

Parameter	Value	Conditions/comment
Ambient temperature	0 to 85°C	Non-condensing, maximum relative humidity of 95%
PCB characteristics		
Material	High TG FR4 material (PCL370HR)	Four layers, 70 µm copper each 1.6 mm total board thickness
Dimensions	71 x 76 mm	–

2.3 Board description

Figure 3 shows the top and bottom sides of the EVAL_MTR_48V20A_GaN Evaluation Board, respectively.

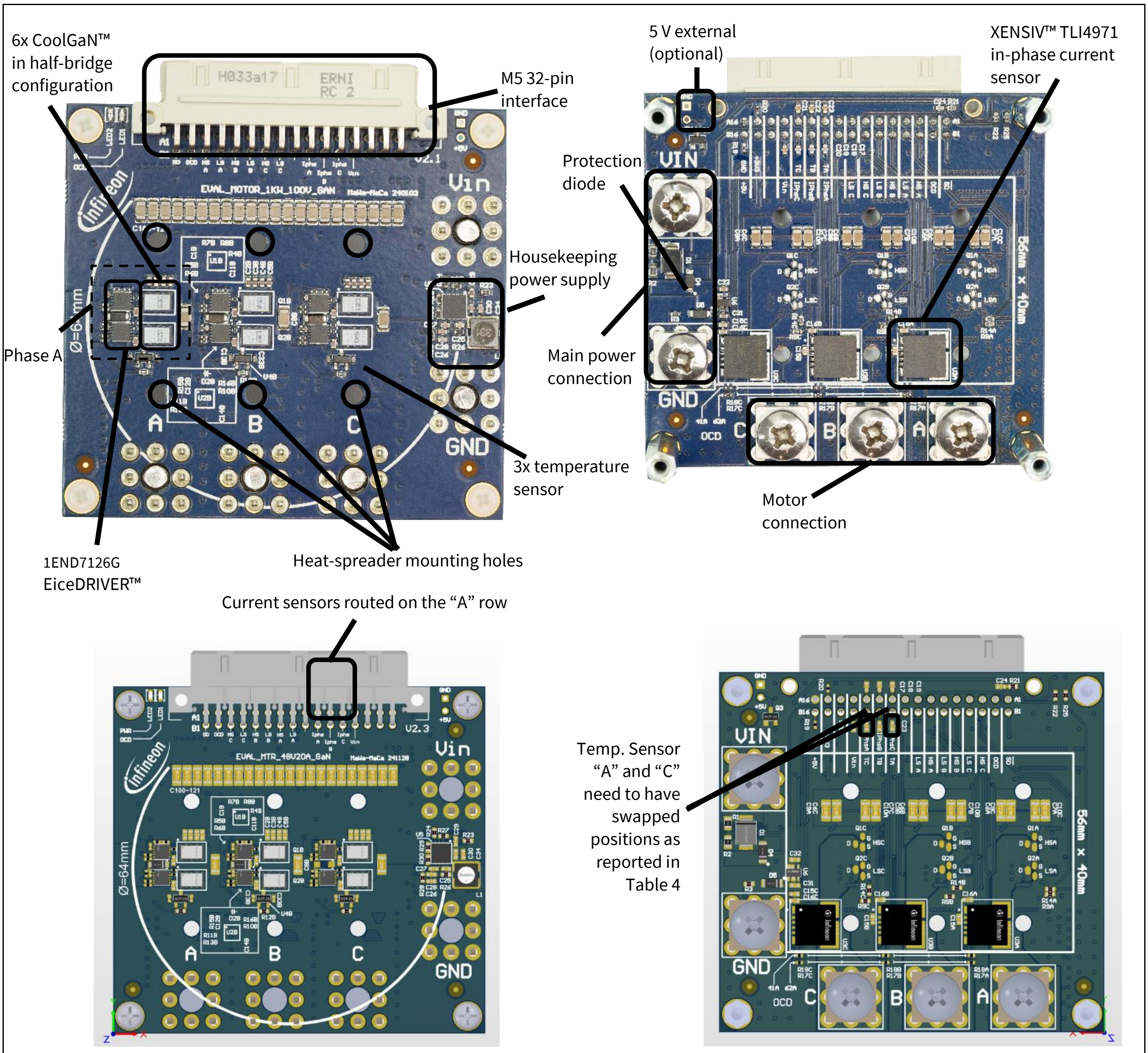


Figure 3 **Overview of the EVAL_MTR_48V20A_GaN board for board versions 2.2 and earlier (top) and for versions 2.3 and later (bottom)**

Table 3 gives an overview of the pinout of the 32-pin female connector for board versions 2.2 and earlier, whereas Table 3 is applicable to board versions 2.3 and later. 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_48V20A_GaN, compared to X7.

Table 3 X7 pinout, for connection to external control card for board versions 2.2 and earlier

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 at 25°C, 10 mV/°C
A11	Temp. B	750 mV at 25°C, 10 mV/°C
A12	Temp. C	750 mV at 25°C, 10 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	–
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	24 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B11	Iphs B	24 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B12	Iphs C	24 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
B13	V_{IN} sense	V_{IN} voltage divider, 52.6 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 X7 pinout, for connection to external control card for board versions 2.3 and later

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	24 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
A11	Iphs B and 2	24 mV/A, 1.65 V ±3% offset, current flowing into inverter is positive
A12	Iphs A and 1	24 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
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 at 25°C, 10 mV/°C
B11	Temp. B and 2	750 mV at 25°C, 10 mV/°C
B12	Temp. A and 1	750 mV at 25°C, 10 mV/°C
B13	V_{IN} sense	V_{IN} voltage divider, 52.6 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_48V20A_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:

- Six nylon washers
- Six M1.6 4 mm screws

- Four thermal interface pads pre-cut to 15 x 15 mm (T-Global TG-A1250, 500 µm thickness)
- One aluminum heat-spreader with integrated standoffs and alignment pins

The integrated standoffs are part of the heat-spreader and ensure self-alignment provides a well-defined 50 percent compression of the thermal pads. 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 shows the recommended assembly of the heat-spreader using the mounting hardware supplied.

In addition to covering the half-bridge with the provided TIM, it is also recommended to use each square pad to cover the MLCC capacitors adjacent to Q1A/B/C for best thermal performance. One spare pad is included in the kit to account for any challenges that you face during assembly.

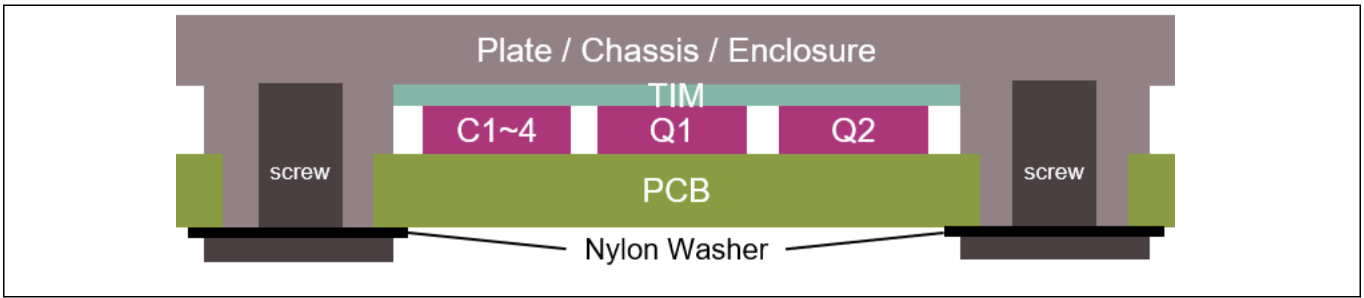


Figure 4 Cross-section showing assembly of heat-spreader with TIM applied to half-bridge

The placement of the TIM is shown in Figure 5 (left). The protective plastic film on the TIM must be removed before use. A nylon washer protects the solder mask and avoids short-circuits via the heat-spreader when screwing down the heat-spreader. The assembled evaluation board with heat-spreader is shown Figure 5, on the right.

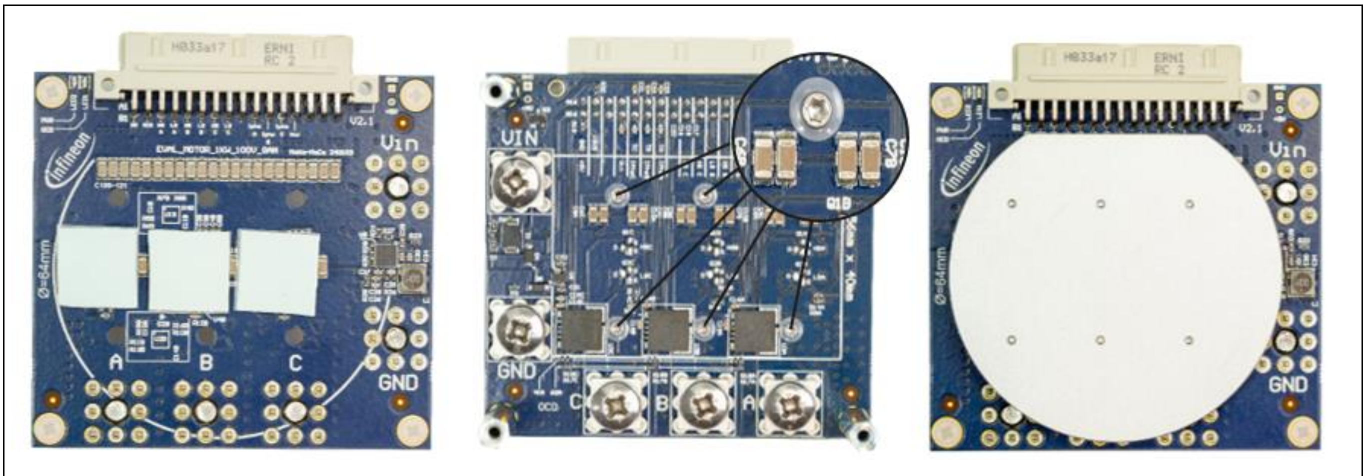


Figure 5 Left: Placement of TIM across the half-bridge with protective films in place, on the top. Center: Assembly of the tightened mounting screw along with a protective washer in place. Right: Fully assembled evaluation board with heat-spreader

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:

- Half-bridge based on CoolGaN™ transistors with current and temperature sensing (shown once in the schematic, but repeated three times as identical phases A, B, and C)
- Connector for the drive card with supporting circuits
- Auxiliary power supply for 5 V and 3.3 V rails

In addition, the top-level schematic shows the input connection (X1 and X2) with the voltage divider and Zener clamping as well as the three-phase connectors X3, X4, and X5. The system includes a total of 80 µF in low-profile ceramic capacitors, but some of this bulk capacitance is omitted from the schematic for simplicity.

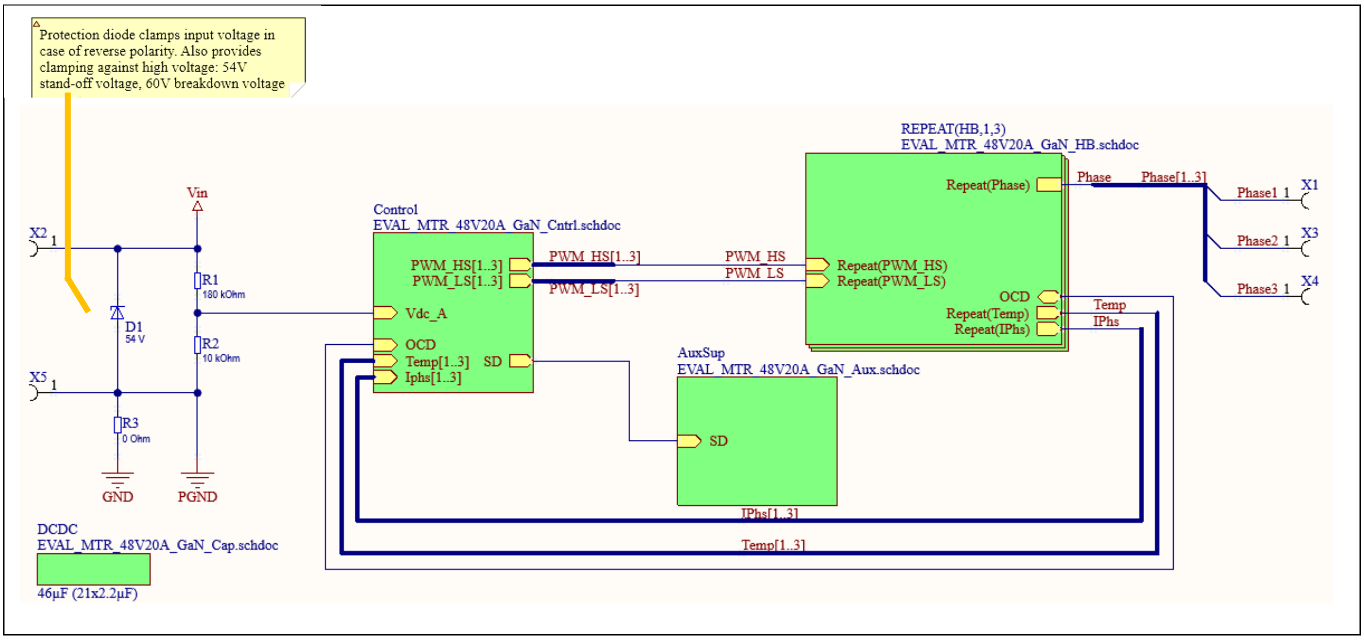


Figure 6 System-level overview of the motor drive schematic

3.2 Half-bridge design

The schematic of a single half-bridge is shown in Figure 7. The primary building block for the motor drive is an optimized half-bridge circuit, with two CoolGaN™ 100 V, 3.3 mΩ (max.) transistors in 3 x 5 mm PQFN lead-frame packages with exposed dies to provide dual-sided cooling. The half-bridge design is optimized for a low-power loop inductance by coplanar field compensation, achieving an inductance of 400 pH. To achieve this, the four-layer PCB uses two cores on the outside with a thickness of 75 µm each.

The cores are attached to either side of a 1100 µm thick preg/infill. Local bypass capacitors to each half-bridge (C2 to C5) are placed closely to the high-side Q1. The gate loops are designed to minimize common-source inductance, while optimizing the gate driver circuits for fast switching.

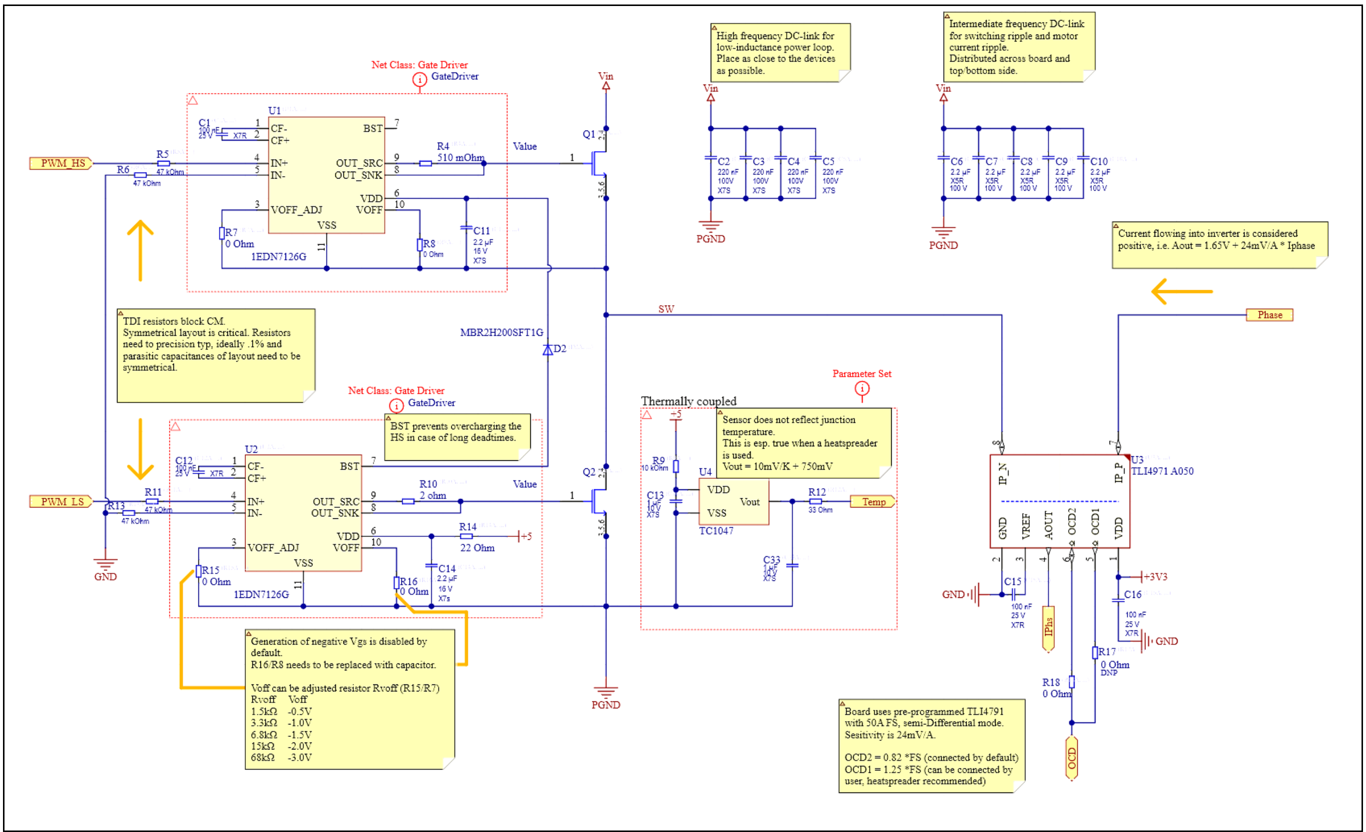


Figure 7 Schematic of the power stage including gate driver, temperature, and current sensor

The EiceDRIVER™ 1EDN7126G gate driver incorporates several key features intended for GaN gate driving. One feature is the truly differential input (TDI), which provides common-mode voltage rejection to the high-side during switching. In addition, these gate drivers provide ground-bounce immunity for the low-side, thereby guaranteeing stable operation even during fast switching transients.

In this design, 1EDN7126G is selected as it offers 1.5 A peak source/sink current. 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 very strong pull-down resistance of 0.3 Ω. In this way, the designer can adjust the turn-off speed of the GaN transistor without jeopardizing its immunity to induced turn-on.

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.

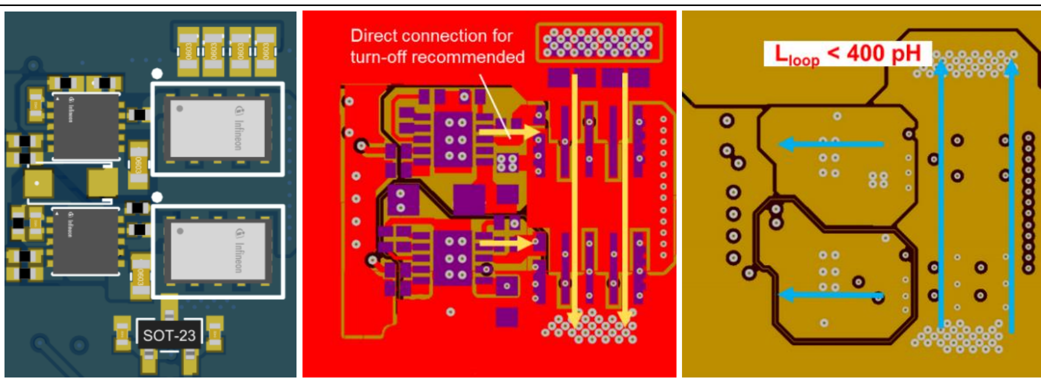


Figure 8 Layout of half-bridge, with arrows indicating the flow of gate and drain switching currents

3.2.1 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 common-source inductance in the gate loops. The TLI4971 sensor is a Hall effect sensor, which avoids potential common-mode transient immunity issues with differential amplifiers. A fully isolated in-phase current sensor is more immune to common-mode voltage transients than a shunt-based solution 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 the isolated readout of the phase-current, TLI4971 provides overcurrent detection capabilities on pins OCD1 and OCD2, 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.

3.2.2 Temperature sensing

A temperature sensor connects directly to the same ground potential as the low-side switch Q2, with a scale factor of 10 mV/°C and 750 mV offset at 25°C. The output signal of the sensor is connected by an RC filter to decouple any ground-bounce effects due to parasitics close to the half-bridge power loop.

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. For this reason, 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.

3.3 Control card interface

The control card interface (DIN 41612, 32-pin, female) with supporting circuits is shown in Figure 9 for versions 2.2 and earlier and in Figure 10 for versions 2.3 and later. The pinout is compatible with Infineon's XMC1400 or 4400 control card, which can also be used with other microcontrollers. Low-power microcontrollers using less than 50 mA can be supplied directly from the onboard DC-DC converter, either from the 5 V or 3.3 V rail, using the solder jumpers R28 or R29, respectively.

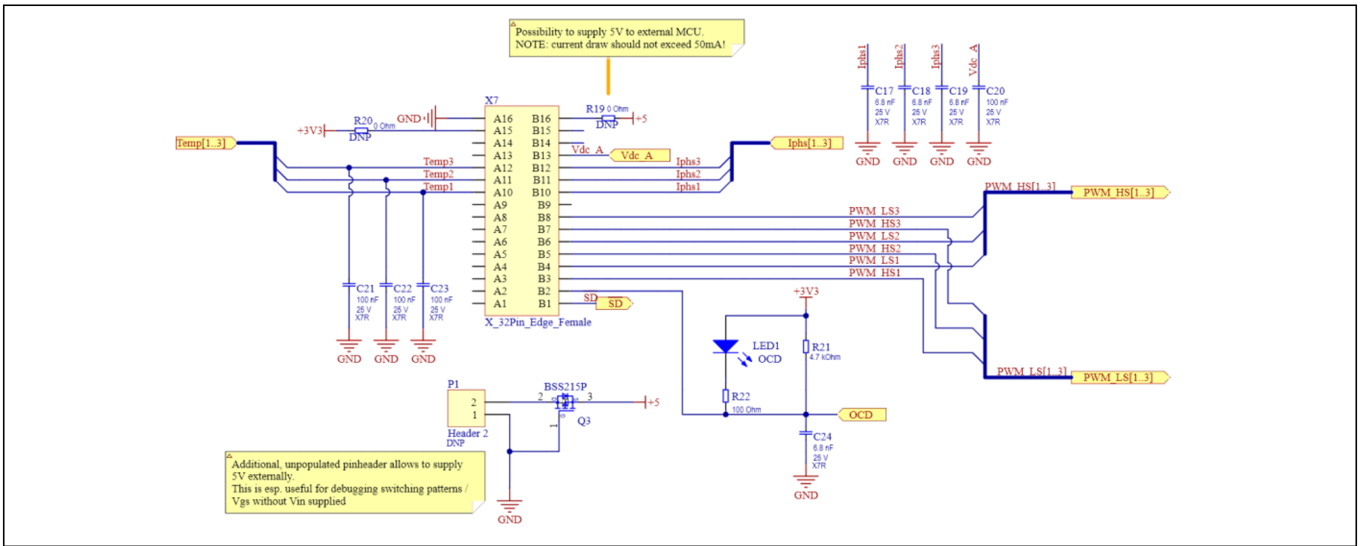


Figure 9 **Schematic of the pin header or control card interface for board versions 2.2 and earlier**

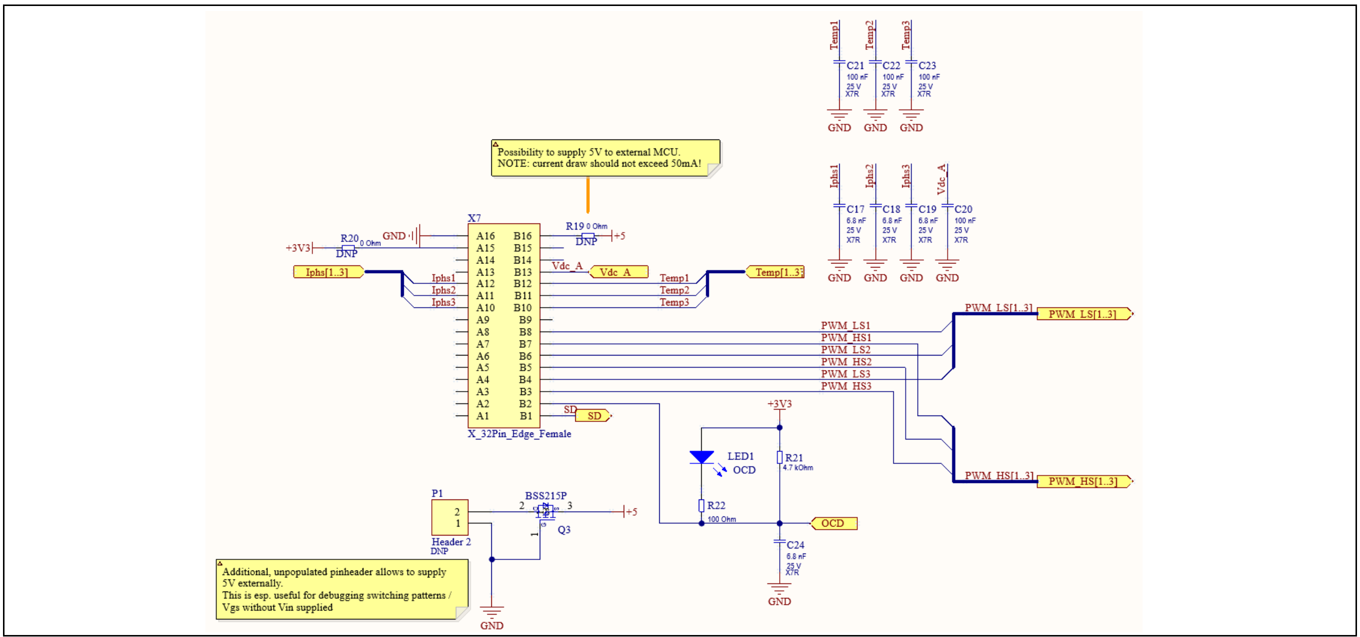


Figure 10 Schematic of the pin header or control card interface for board versions 2.3 and later

3.4 Auxiliary power supply

An onboard DC-DC converter generates the 5 V rail from the V_{IN} supply (see Figure 11). 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 V_{IN} exceeds 12 V. A green LED at the top-left corner indicates the status of the DC-DC converter. To prevent unwanted current flowing through U1 when the input is not powered, a 0 Ω resistor on the input and output allows you to disconnect the regulator circuit entirely. An external 5 V supply can then be used via the P1 pin header. This is especially useful when debugging connections and pin assignment for the external controller.

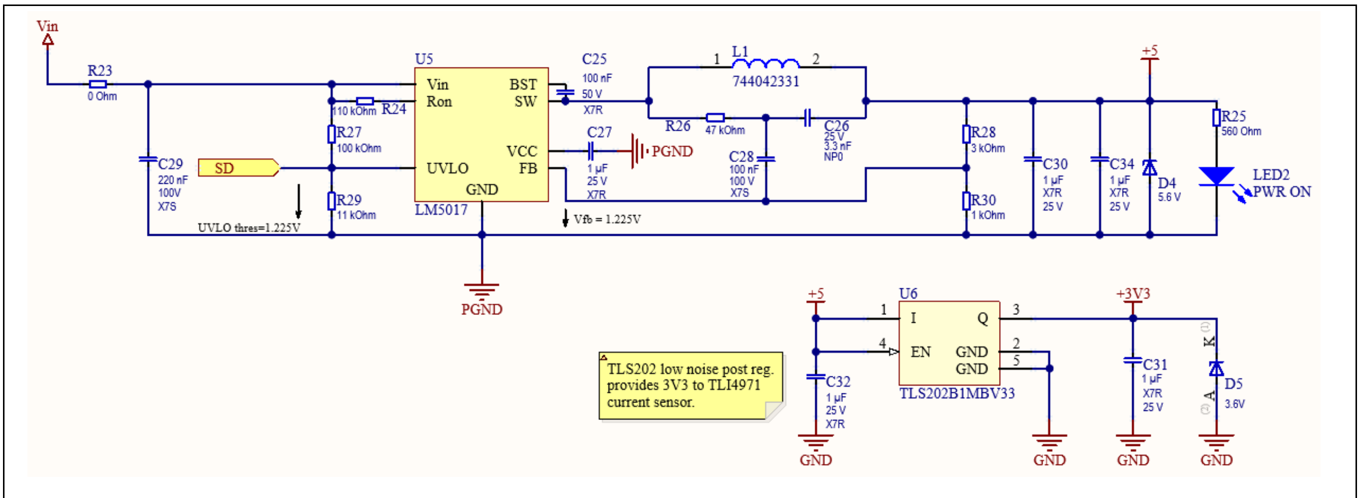


Figure 11 Schematic of the auxiliary power supply

4 Motor control using FOC

The EVAL_MTR_48V20A_GaN Evaluation Board is intended for motor control applications using FOC. As part of the DAVE™ IDE, Infineon provides example projects to accelerate the development of these applications.

This application note will focus on the PMSM_FOC_GAN_XMC44 code, available on the Infineon website for this evaluation board. The code is intended for the XMC4400 drive card [6] and provides easy configuration of the sensorless controller via a graphical user interface (GUI). Similar results can also be achieved on the XMC1300/1400 drive card, but firmware to support this configuration is not yet available.

The PMSM_FOC_GAN_XMC44 firmware is based on the example code available at [5]. A comprehensive overview of the sensorless FOC implementation is outside the scope of this application note and is discussed in detail in [7].

One notable difference is the current direction, which is defined as positive for this evaluation board when flowing from the motor into the inverter phase terminals. The example firmware also does not support a coast-to-standstill functionality. Instead, in case of an error, all windings are shorted through the low-side devices. However, the coast-to-standstill function has been added in the customized PMSM_FOC_GAN_XMC44 firmware.

4.1 DAVE™ IDE configuration

Configuration of the XMC4400 drive card is straightforward thanks to the GUI. The recommended settings for operating the evaluation board are shown in Figure 12.

The minimum supported deadtime by the example project is 50 ns. Due to the lack of Q_{RR}, the dead-time for a half-bridge based on CoolGaN™ transistors can be chosen to be significantly lower than for Si MOSFETs, and therefore 50 ns is a suitable dead-time selection for most motor control applications.

The example project is compatible with the XENSIV™ current sensor used in this evaluation board, even though the firmware was initially designed for a shunt-based current sensing solution. The mV/A ratio should be well-suited, which can be implemented by setting R_{shunt} to 24 mΩ with an amplifier gain of 1. In addition, overvoltage and undervoltage lock out can be enabled to ensure operation conditions within the recommendations.

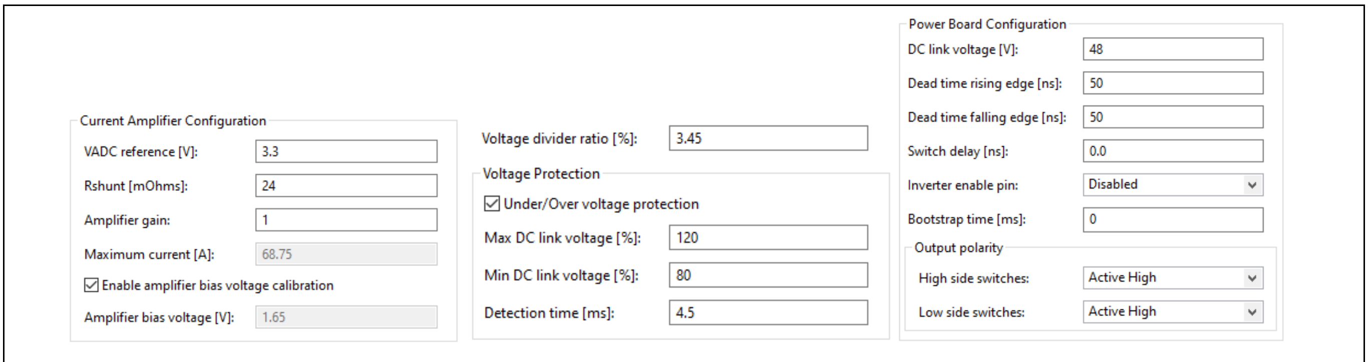


Figure 12 Recommended power board settings; configured via the PMSM_FOC app on the DAVE™ IDE

4.2 Pin assignment for the XMC4400 drive card

The pin assignment of the example project should be configured as shown in Figure 13, using the DAVE™ app GUI.

APP Instance Name	APP Pin Name	Pin Number (Port)
PMSM_FOC_0		
	i_phase_u Pin	#31 (P14.0)
	i_phase_v Pin	#29 (P14.2)
	i_phase_w Pin	#27 (P14.4)
	v_dc_link Pin	#36 (P14.9)
PWM_SVM_0		
	PhaseU_High Pin	#97 (P0.5)
	PhaseU_Low Pin	#100 (P0.2)
	PhaseV_High Pin	#98 (P0.4)
	PhaseV_Low Pin	#1 (P0.1)
	PhaseW_High Pin	#96 (P0.6)
	PhaseW_Low Pin	#95 (P0.11)
	Trap Pin	#89 (P0.7)

Figure 13 Pin assignment of the XMC4400 drive card on the DAVE™ IDE for board versions 2.2 and earlier

4.3 Recommendations for operation with the XMC4400 drive card

- The XMC4400 drive card contains an isolated programmer; thus, an additional external 5 V supply is required to power the MCU. Leaving the MCU unpowered will disable the auxiliary power supply on EVAL_MTR_48V20A_GaN.
- Figure 14 shows the four LEDs which indicate that the evaluation board and XMC™ drive card are correctly powered: two LEDs close to the micro-USB port confirm the connection of the debugger; one LED close to the male pin header confirms the operation of the MCU and one additional LED on EVAL_MTR_48V20A_GaN indicates the active 5 V rail.
- Initially, test the switching patterns on the evaluation board with no load connected to the inverter. Under these conditions, the correct operation of UVLO and OVLO can be confirmed.
- As a second verification, use a resistive load in the star configuration to confirm the correct operation of all phase legs under load.
- Perform the initial tuning of the V/f constant and the offset in the V/f open loop. The software initially calculates the values based on motor parameters provided by you. The default values can be too aggressive for some motors, leading to excessive phase currents. It is strongly recommended to use the provided heat-spreader and observe phase currents closely. In addition, the OCP functionality (CCU8 trap) should be set to **Active LOW**.
- Enable closed-loop sensorless operation after successfully tuning the V/f parameters. Tuning the transition speed is critical for a smooth transition to sensorless FOC. To further improve the performance of the sensorless controller, use Infineon's Micro Inspector Pro software (obtained via the Infineon Development Center [8]) to perform the online tuning of parameters such as Kp and Ki for each of the control loops. Use this tool to read and change the memory of the XMC™ MCU during runtime, enabling the adjustment of controller parameters directly.

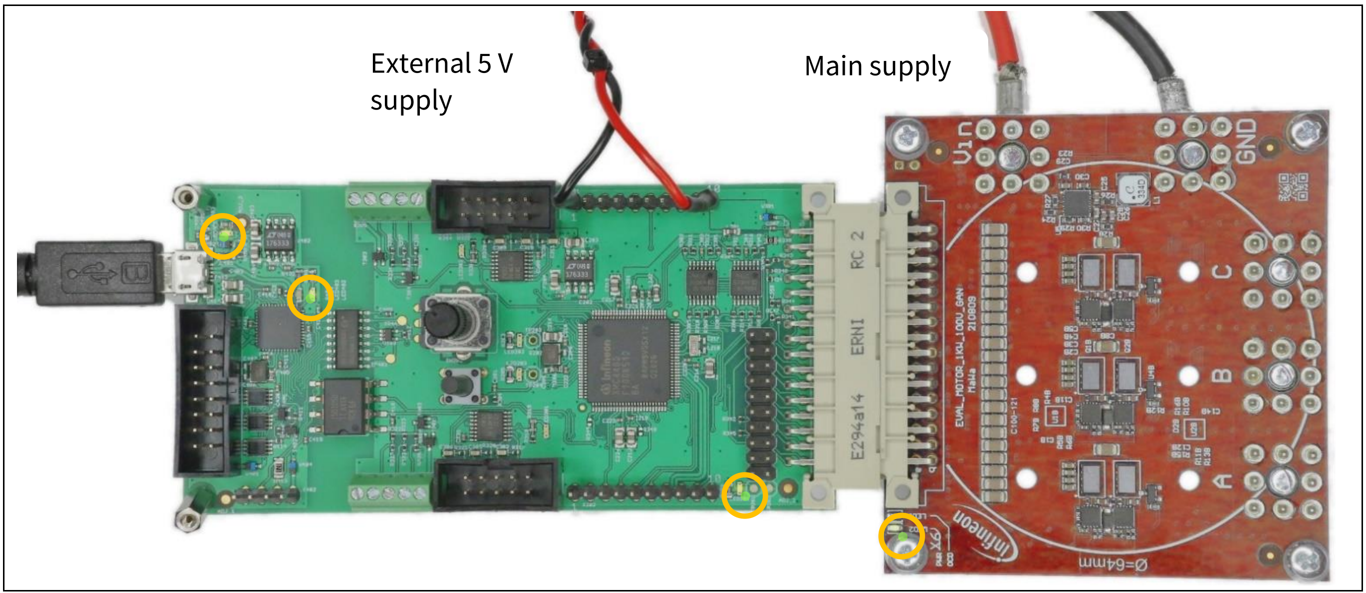


Figure 14 **EVAL_MTR_48V20A_GaN assembled with the XMC4400 drive card. Each board should be supplied individually. Four LEDs confirm correct operation of the drive card and the evaluation board**

5 Supported user modifications

EVAL_MTR_48V20A_GaN is a flexible evaluation board to support you during your first steps towards using CoolGaN™ transistors in motor drive applications. To cater to different needs, the evaluation board supports several user modifications.

5.1 Adjustable overcurrent detection

Infineon's XENSIV™ TLI4971 magnetic current sensors provide two separate open-drain outputs for overcurrent detection (OCD). By default, OCD2 is used, which gives a trigger level of 41 A.

However, if a higher threshold is preferred, you can easily reconfigure it to 62 A using OCD1 of TLI4971. This can be accomplished by desoldering R18A, B, and C, and then resoldering them to R17A, B, and C respectively. In this configuration, the device temperature should be observed more carefully to ensure that the maximum junction temperature of 150°C of the CoolGaN™ transistors is not exceeded. Figure 7 provides further information on this circuit option.

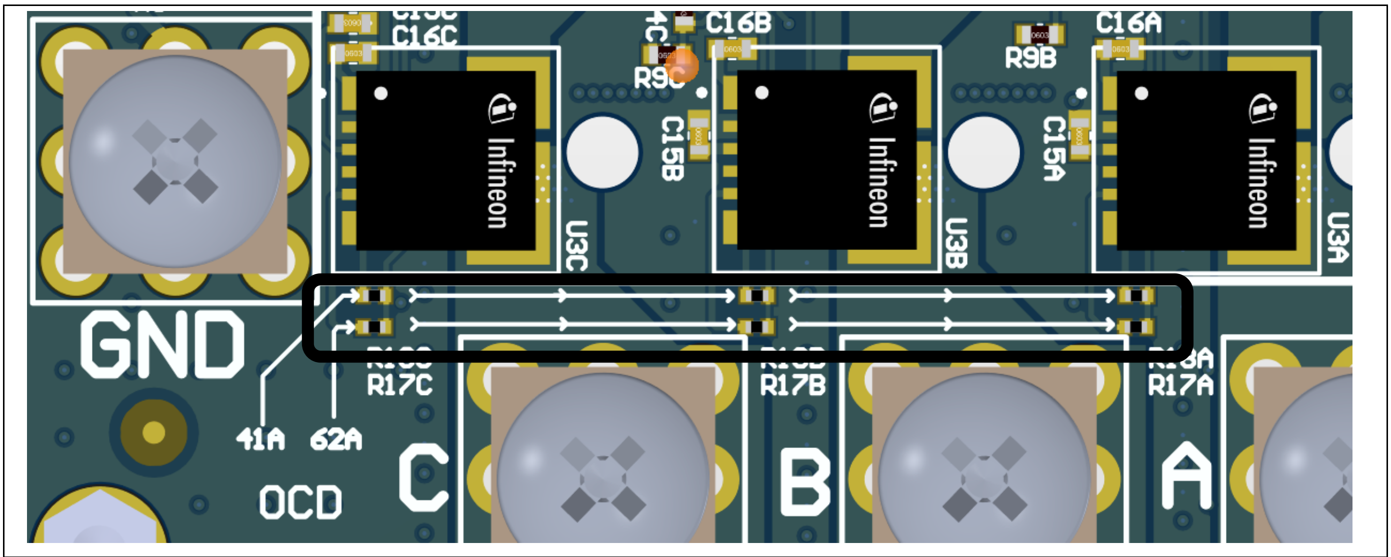


Figure 15 Solder jumpers enable the user to select an OCD threshold of either 41 A or 62 A

5.2 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 input screw terminals V_{IN} and GND.

5.3 External supply of 5 V rail

For investigation of gate drive patterns, run the REF_MTR_48V30A_GaN evaluation board without V_{IN} supplied. This requires an external auxiliary supply as the onboard auxiliary power supply will not be available in this condition. The condition can be accomplished by desoldering R23 and supplying 5 V directly at pin header P1, which is placed next to the control board connector. UVLO should be disabled in the software for this test.

5.4 Supply of external loads

The onboard 5 V or 3.3 V regulator can be used to power an external controller with up to 50 mA, such as the XMC1400 drive card. However, these rails cannot supply sufficient current for the XMC4400 drive card. Therefore, the correlating solder jumpers R20 and R19 are left open. Populating either resistor with a 0 Ω resistor or a solder bridge will connect the respective rail to the controller interface connector, as shown in Figure 9.

5.5 V_{DS} and V_{GS} measurements

The EVAL_MTR_48V20A_GaN Evaluation Board provides onboard probing points of critical waveforms such as V_{DS} and V_{GS}, as shown in Figure 16. To ensure accurate waveforms, a tight probing loop is required. 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. High-side measurements for Q1 A, B, and C are even more sensitive to this connection length; therefore, a high-bandwidth differential probe with optical isolation is recommended.

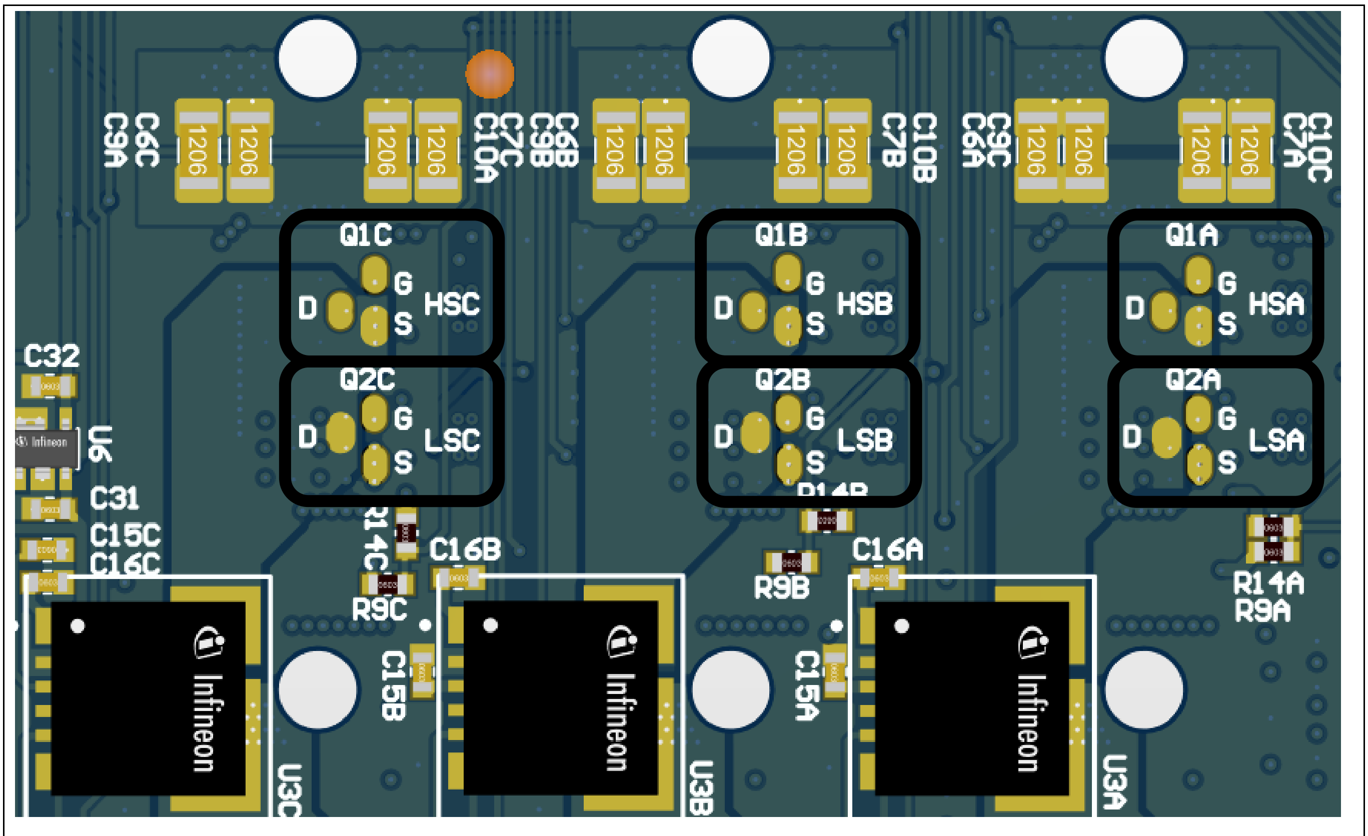


Figure 16 Measurement points for the bottom side of the PCB

5.6 Generating negative V_{GS}

EiceDRIVER™ 1EDN7126G for GaN transistors and MOSFETs has the capability to generate a negative off-state gate voltage with its integrated adjustable charge pump. Figure 7 shows the default configuration of the gate driving circuits for all six GaN transistors on the evaluation board. The charge pump is disabled in this configuration, which means that the charge pump output pin VOFF is floating. It is therefore connected directly to VSS on each gate driver with 0 Ω resistors R8 and R16.

To enable the charge pump feature, change the resistors R7 and R15 according to the table given in the 1EDN71x6G datasheet [2]. These resistors connect to the VOFF_ADJ pin of the drivers to program the charge pump circuits when the ICs are first powered on (at startup of the 5 V rail).

These resistors are both set to 0 Ω by default, which disables the charge pump. When it is enabled, replace resistors R8 and R16 with a capacitor to maintain the negative supply rail, and to provide dynamic gate current during turn-off transitions. A capacitor in the range of 470 nF to 1 µF is recommended here.

It is important to note that enabling the charge pump feature on the high-side transistors (Q1) will cause the respective gate driver U1 to consume more power, which may result in a slight droop of the bootstrap supply voltage.

6 Measurements

This chapter provides some typical measurements made with the EVAL_MTR_48V20A_GaN Evaluation Board for reference.

6.1.1 Low-side V_{DS} and V_{GS} measurements

Figure 17 shows an example measurement of low-side V_{GS} and V_{DS} using the test pads shown in Figure 16, as well as the respective phase current I_{phs} at V_{IN} = 48 V.

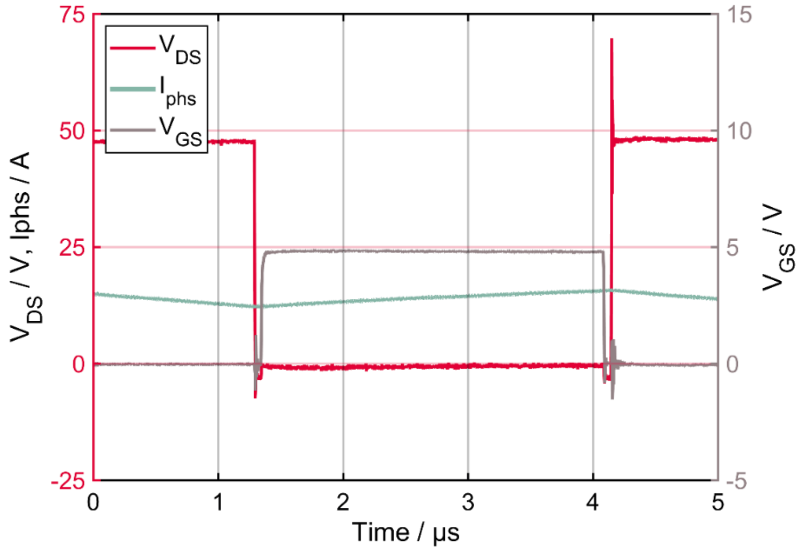


Figure 17 Measurement of low-side V_{DS} and V_{GS} using the test points provided on the PCB

The measurement location is critical for very fast switching semiconductors such as CoolGaN™ transistors, as can be seen in Figure 18 and Figure 19. Measuring using the provided test pads with a GND spring as discussed in Section 5.5 provides an accurate reading of the switching speed and voltage stress across the devices.

Note the following:

- Measuring with a longer GND clip shows increased ringing.
- Measuring the differential phase-to-phase voltage is impacted by wire arrangement (braided vs. parallel) and cable length. In this case, a 40 cm cable has been used.

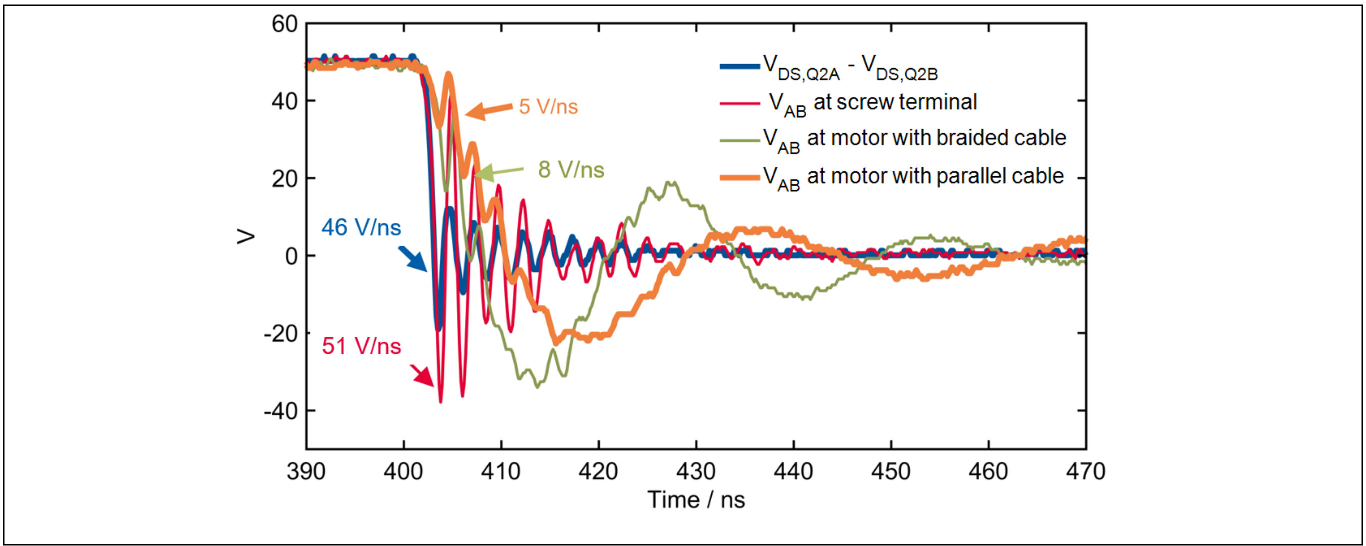


Figure 18 **Falling-edge waveform at the switch node, screw terminals, and motor terminal with the motor connected to the board by a 40 cm cable**

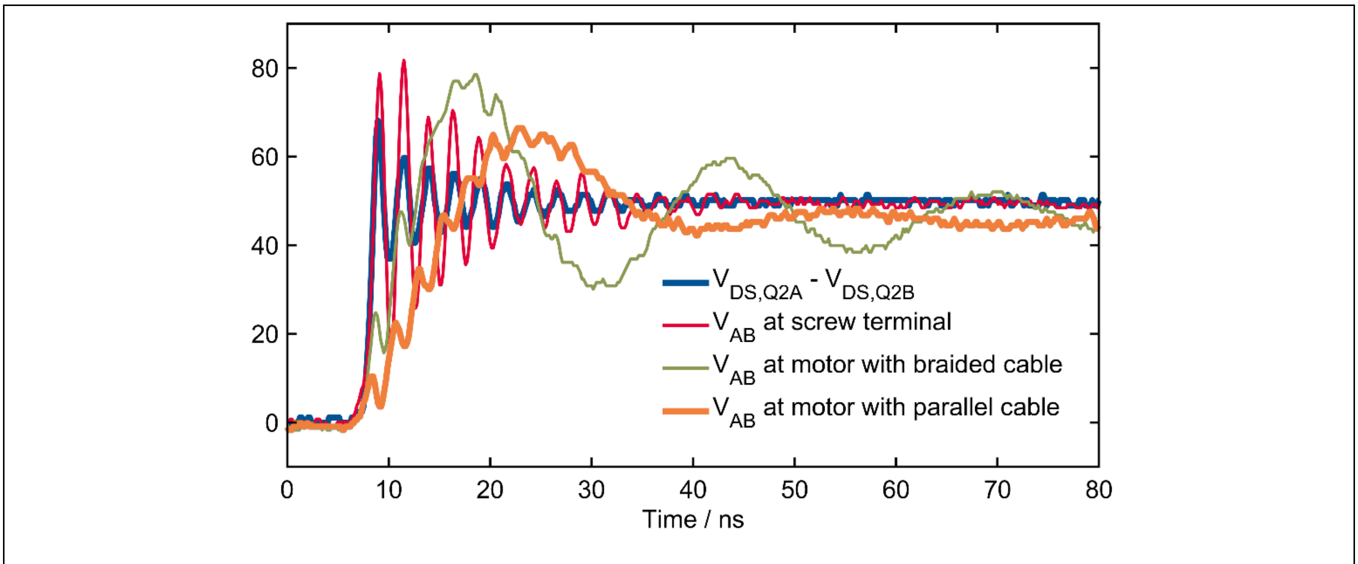


Figure 19 **Rising-edge waveform at the switch node, screw terminals, and motor terminal, with the motor connected to the board by a 40 cm cable**

6.2 Influence of dead-time

The dead-time should be carefully chosen to maximize input voltage utilization, reduce loss in the motor drive, and avoid distortion in the phase current. Figure 20 shows the impact of dead-time on the phase current at 100 kHz. The optimal dead-time for the lowest power loss depends on the RMS current due to the tradeoff between dead-time reverse conduction loss and switching loss.

For EVAL_MTR_48V20A_GaN, a dead-time of 50 ns is recommended for initial evaluations; further optimization can be performed for the desired operating conditions.

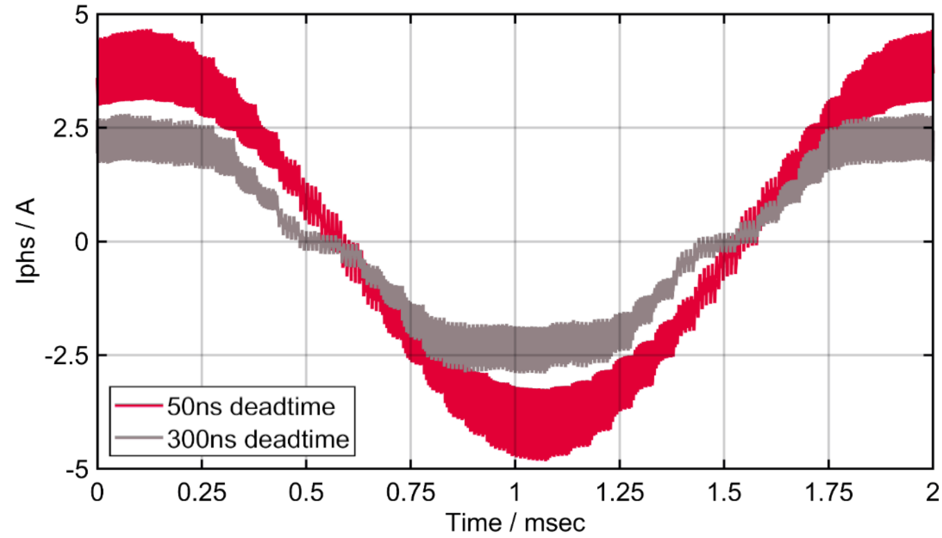


Figure 20 Impact of dead-time on the current waveform at a 100 kHz switching frequency

6.3 Overload capability

The EVAL_MTR_48V20A_GaN Evaluation Board can provide significant overload capability thanks to the dual-side cooling with the heat-spreader provided. Figure 21 demonstrates the overload capability with an initial temperature of the power stage and a heat-spreader of 38°C. This evaluation board can provide an average of 50 A_{RMS} for 10 seconds. The temperature is derived from output of the PCB temperature sensors on each phase, with significant margin added to account for differences between the PCB and junction temperatures. Overcurrent protection (OCP) on the XMC4400 drive card has been disabled specifically for this test. Under normal operation conditions, it is always recommended to leave this function enabled.

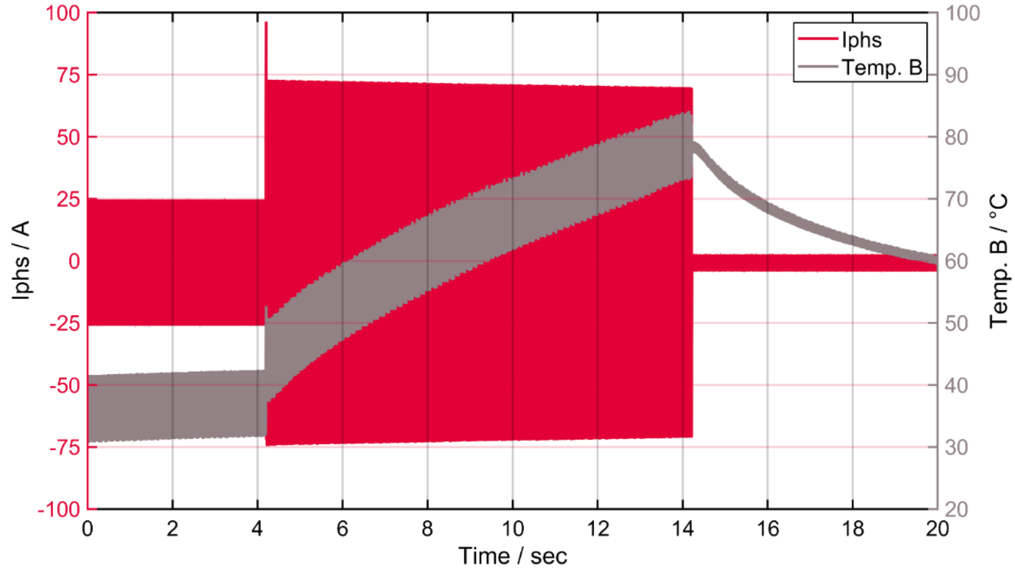


Figure 21 Phase current and temperature readout during 10 s overload condition

6.4 Inverter efficiency vs. frequency

Figure 21 shows the inverter efficiency when operated with 48 V input voltage and 50 ns dead-time at different switching frequencies. The peak efficiency drops only by 0.3 percent (99.5 percent to 99.2 percent), so the frequency can be optimized for overall system performance without concern for switching losses.

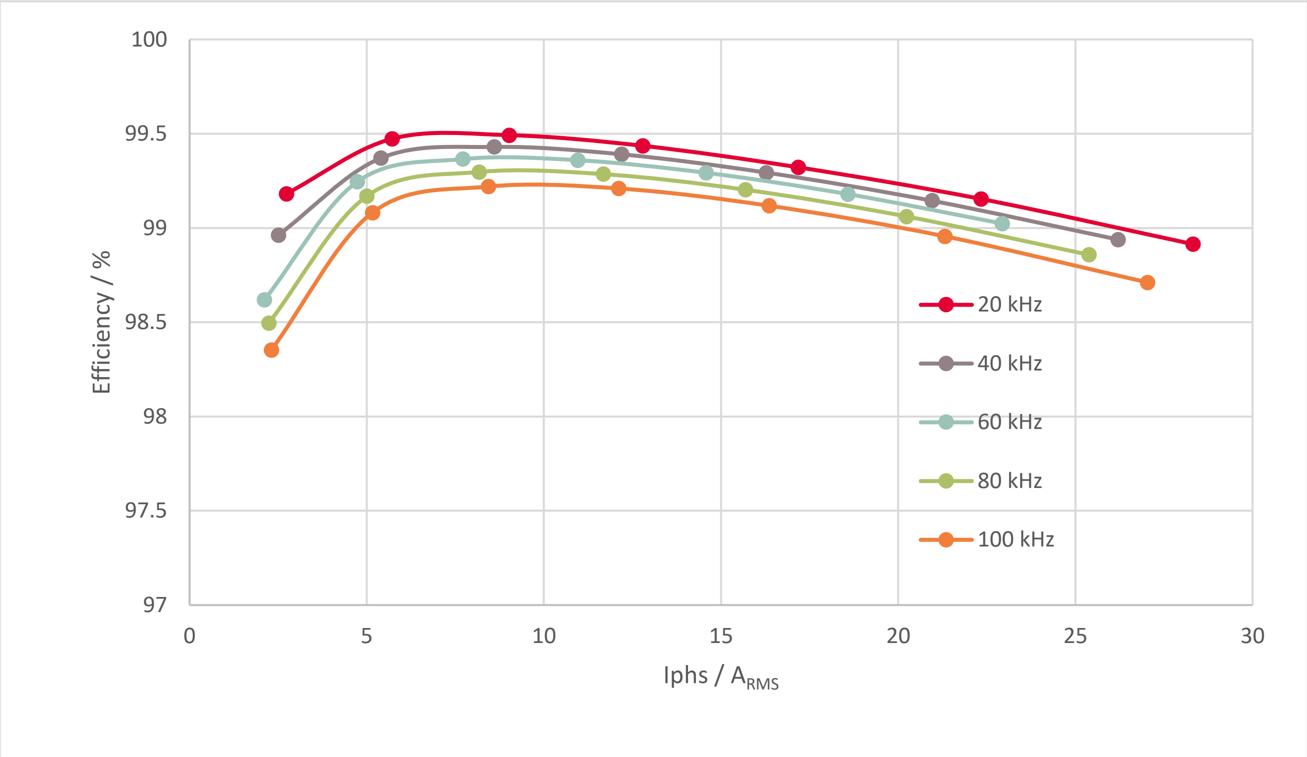


Figure 22 **Inverter efficiency from 20 to 100 kHz as a function of output phase current**

7 Bill of materials

Table 5 Bill of materials for EVAL_MTR_48V20A_GaN

No.	Qty.	Part description	Designator	Part number	Manufacturer
1	6	100 nF	C1A, C1B, C1C, C12A, C12B, C12C	C1005X7R1E104K050BB	TDK
2	13	220 nF	C2A, C2B, C2C, C3A, C3B, C3C, C4A, C4B, C4C, C5A, C5B, C5C, C29	HMK107C7224KAHTE	Taiyo Yuden
3	37	2.2 µF	C6A, C6B, C6C, C7A, C7B, C7C, C8A, C8B, C8C, C9A, C9B, C9C, C10A, C10B, C10C, C100, C101, C102, C103, C104, C105, C106, C107, C108, C109, C110, C111, C112, C113, C114, C115, C116, C117, C118, C119, C120, C121	CL31A225KC9LNNC	Samsung Electro-Mechanics
4	6	2.2 µF	C11A, C11B, C11C, C14A, C14B, C14C	C1608X7S1C225K080AC	TDK
5	6	1 µF	C13A, C13B, C13C, C33A, C33B, C33C	C1005X7S1A105K050BC	TDK
6	11	100 nF	C15A, C15B, C15C, C16A, C16B, C16C, C20, C21, C22, C23, C25	C1608X5R1H104K080AA	TDK
7	4	6.8 nF	C17, C18, C19, C24	C1608NP01H682J080AA	TDK
8	1	3.3 nF	C26	C1608NP01H332J080AA	TDK
9	4	1 µF	C27, C30, C31, C32	C1608X7R1E105K080AB	TDK
10	1	100 nF	C28	C1608X7S2A104K080AB	TDK
11	1	SMBJ54CA-13-F	D1	SMBJ54CA-13-F	Diodes Incorporated
12	3	MBR2H200SFT1G	D2A, D2B, D2C	MBR2H200SFT1G	ON Semi
13	1	5.6 V	D4	BZT52HC5V6WF-7	Diodes Inc.
14	1	3.6 V	D5	BZT52HC3V6WF-7	Diodes Inc.
15	1	330 µH	L1	744042331	Würth Elektronik
16	1	LED red	LED1	KPHD-1608LVSURCK or AA1608SURSK	Kingbright
17	1	LED green	LED2	KPHD-1608LVCGCK	Kingbright
18	1	Header for ext. supply	P1	100 mil, generic	Generic
19	6	IGC033S10S1	Q1A, Q1B, Q1C, Q2A, Q2B, Q2C	IGC033S10S1	Infineon
20	1	-20 V, 150 mΩ	Q3	BSS215P	Infineon
21	1	180 kΩ	R1	ERJ6ENF1803V	Panasonic
22	1	10 kΩ	R2	ERJ6ENF1002V	Panasonic

No.	Qty.	Part description	Designator	Part number	Manufacturer
23	2	0 Ω	R3, R23	ERJ3GEY0R00V	Panasonic
24	3	510 mΩ	R4A, R4B, R4C	ERJ-2BQFR51X	Panasonic
25	12	47 kΩ	R5A, R5B, R5C, R6A, R6B, R6C, R11A, R11B, R11C, R13A, R13B, R13C	ERJ3RBD4702V	Panasonic
26	12	0 Ω	R7A, R7B, R7C, R8A, R8B, R8C, R15A, R15B, R15C, R18A, R18B, R18C	ERJ2GE0R00X	Panasonic
27	3	10 kΩ	R9A, R9B, R9C	ERJ3GEYJ103V	Panasonic
28	3	2 Ω	R10A, R10B, R10C	ERJ-2GEJ2R0X	Panasonic
29	3	33 Ω	R12A, R12B, R12C	ERJ3GEYJ330V	Panasonic
30	3	22 Ω	R14A, R14B, R14C	ERJ3GEYJ220V	Panasonic
31	3	0 Ω	R16A, R16B, R16C	ERJ2GE0R00X	Panasonic
32	0	0 Ω	R17A, R17B, R17C, R19, R20	ERJ2GE0R00X	Panasonic
33	1	4.7 kΩ	R21	ERJ3GEYJ472V	Panasonic
34	1	100 Ω	R22	ERJ3GEYJ101V	Panasonic
35	1	110 kΩ	R24	ERJ3EKF1103V	Panasonic
36	1	560 Ω	R25	ERJ3GEYJ561V	Panasonic
37	1	47 kΩ	R26	ERJ-PA3F4702V	Panasonic
38	1	100 kΩ	R27	ERJ3EKF1003V	Panasonic
39	1	3 kΩ	R28	ERJ3EKF3001V	Panasonic
40	1	11 kΩ	R29	ERJ3EKF1102V	Panasonic
41	1	1 kΩ	R30	ERJ3EKF1001V	Panasonic
42	4	M3 x 25	S1, S2, S3, S4	528-744 + 970250321	RS PRO + Würth Elektronik
43	6	M1.6 x 5 mm	S5, S6, S7, S8, S9, S10	–	–
44	3	5 x 5 mm	TIM1,TIM2,TIM3	TG-A1250-15-15-0.5	T-Global
45	6	1EDN7126	U1A, U1B, U1C, U2A, U2B, U2C	1EDN7126	Infineon
46	3	TLI4971 A050	U3A, U3B, U3C	TLI4971-A050T5-E0001	Infineon
47	3	TC1047	U4A, U4B, U4C	TC1047AVNBTR	Microchip Technology
48	1	LM5017	U5	LM5017SD/NOPB	Texas Instruments
49	1	TLS202B1	U6	TLS202B1MBV33HTSA1	Infineon
50	5	REDCUBE M5	X1, X2, X3, X4, X5	74655095R + 483-0243	Würth Elektronik + RS Pro
51	0	Heat-spreader, 64 mm	X6	–	–
52	1	DIN 41612 Connector	X7	294722	ERNI

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Revision history

Document revision	Date	Description of changes
V 1.0	2024-09-12	Initial release
V 1.1	2025-01-21	Pinout and other details for board versions 2.3 and later

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