

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions

About this document

Scope and purpose

This document describes a highly efficient reliable inverter concept (HERIC) evaluation board design EVAL_3kW_GaN_HERIC and its main features, key data, pin assignments, mechanical dimensions, and electrical interfaces. This power conversion evaluation board is modular and the hardware can be reused for various power converter applications and use cases, with a special focus on solar photovoltaic solutions.

Intended audience

This document is meant to demonstrate the advantages of Infineon products to engineers and technical specialists working on solar photovoltaic solutions and similar domains.

About this product group

Target applications

- Solar string inverters
- [Hybrid inverters](#)
- [UPS](#)
- Power factor correction stage

Product family

Infineon's [gallium nitride \(GaN\)](#) transistors are available in voltage ranges from 60 V up to 700 V. The fast turn-on and turn-off speeds with minimal switching losses are crucial for AI data centers, EVs, renewable energy, humanoid robots, consumer applications and many more.

Evaluation Board

This evaluation board design is not a qualified and certified commercial product. The hardware does not necessarily meet any safety, EMI, or quality standard (for example, UL, CE) requirements.

Safety precautions

Safety precautions

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

Table 1 Safety precautions

	Warning: The DC link potential of this board is up to 1000 VDC. When measuring voltage waveforms by oscilloscope, high voltage differential probes must be used. Failure to do so may result in personal injury or death.
	Warning: The evaluation or reference board contains DC bus capacitors which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.
	Warning: The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.
	Warning: Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.
	Caution: The heat sink and device surfaces of the evaluation or reference board may become hot during testing. Hence, necessary precautions are required while handling the board. Failure to comply may cause injury.
	Caution: Only personnel familiar with the drive, power electronics and associated machinery should plan, install, commission and subsequently service the system. Failure to comply may result in personal injury and/or equipment damage.
	Caution: The evaluation or reference board contains parts and assemblies sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.
	Caution: A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.
	Caution: The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.

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1 Introduction

1 Introduction

1.1 HERIC topology

The highly efficient and reliable inverter concept (HERIC) is a type of AC decoupling-based, transformer-less inverter topology that offers high efficiency and constant common-mode voltage. This topology is well-known in string and hybrid inverter applications for achieving high efficiency and low common-mode noise, which is a key requirement in transformer-less PV inverter systems.

HERIC features unipolar modulation, which offers higher efficiency due to lower switching losses, reduced total harmonic distortion (THD). In addition, this topology requires a smaller filter size because the filter sees only unipolar voltage across it compared to bipolar modulation technique. Introduced in 2004 [6], with the recent expiration of its patent, this topology is being widely adopted in residential string and hybrid inverter applications.

Figure 1 shows a basic HERIC topology with traditional semiconductor switches, consisting of a full-bridge inverter (switches S1–S4) and switches (S5 and S6) connected back-to-back. Switches S5 and S6 collectively provide bidirectional voltage and current blocking capability, and are connected between the two switch nodes of the full-bridge inverter. An LC filter is used to filter out high-frequency components. The filtered output of the inverter is fed to the load, coupled through an EMI filter.

As shown in Figure 1, the HERIC topology requires a bidirectional switch (BDS) that can block voltage and current in both directions. Traditionally, it has been implemented using two unidirectional blocking switches connected in a back-to-back (B2B) configuration. With the recent release of CoolGaN™ BDS devices, the B2B devices can be replaced with a single BDS device, which helps to improve the total system efficiency and reduce overall system cost.

EVAL_3kW_GaN_HERIC board is an all-GaN HERIC power stage evaluation board which uses unidirectional switch (UDS) GaN device in full-bridge configuration and a single CoolGaN™ BDS 650 V G5 device in place of back-to-back (B2B) connected switches offering a significant improvement in system efficiency and power density compared to traditional back-to-back unidirectional solutions.

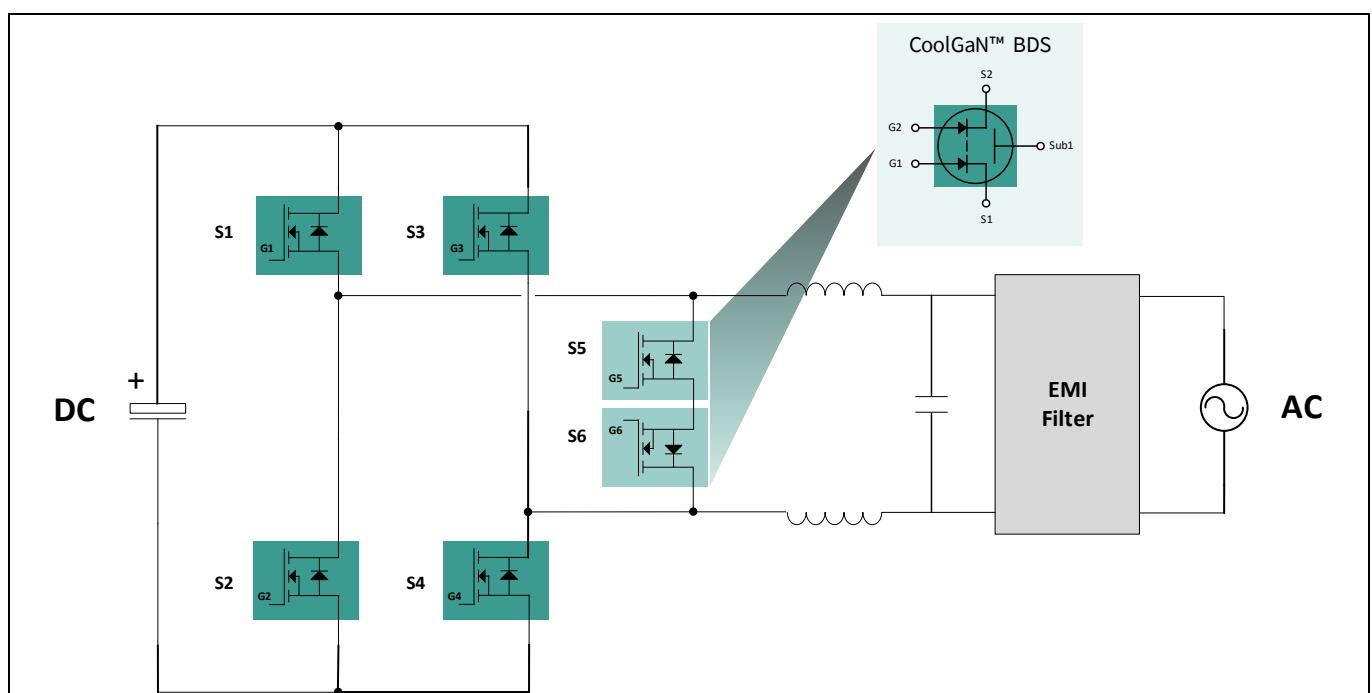


Figure 1 Highly efficient and reliable inverter concept (HERIC) topology

1 Introduction

1.2 Power conversion board

The EVAL_3kW_GaN_HERIC evaluation board is available as a kit and includes different boards that help you build and operate an inverter power stage:

- EVAL_3kW_GaN_HERIC: Inverter power stage main board
- PB-APS-24V-5V ISO: Isolated auxiliary power supply

The EVAL_3kW_GaN_HERIC main board consists of a single-phase power stage based on the HERIC topology and carries power semiconductors, gate drivers, auxiliary power supply, filter elements like DC link capacitors, output inductors, and output capacitors. This topology is efficient as additional BDS is used to manage the freewheeling current while the H-bridge GaN devices are off.

Note: Additionally, you must procure an XMC7200-based control board (REF-CLBXMC7PEC) separately. It comes with all the signal conditioning circuits, power conversion software, and a GUI that allows you to operate and control the inverter in an off-grid operating mode.



Figure 2 Power conversion board EVAL_3kW_GaN_HERIC

Figure 3 shows the completely assembled EVAL_3kW_GaN_HERIC evaluation board.

3 kW all-GaN HERIC evaluation board

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1 Introduction

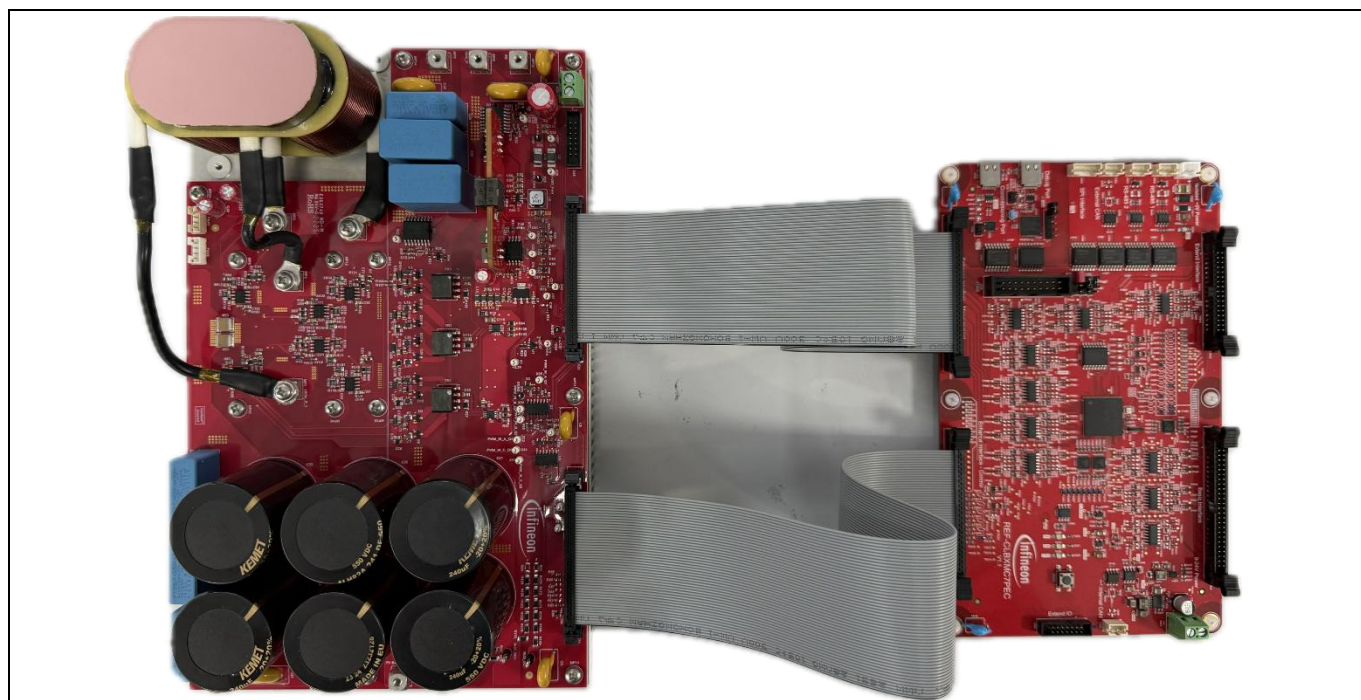


Figure 3 Power conversion evaluation board EVAL_3kW_GaN_HERIC (fully assembled)

1.3 Top-level specifications

Table 2 Specifications

Parameter	Typical	Maximum	Unit
Input voltage	380	510	V DC
Output voltage	230	–	V RMS
Output current	13	16.3	A
Output power	–	3	kW
Switching frequency	50	–	kHz
Output frequency	50/60	–	Hz

1 Introduction

1.4 HERIC inverter design blocks

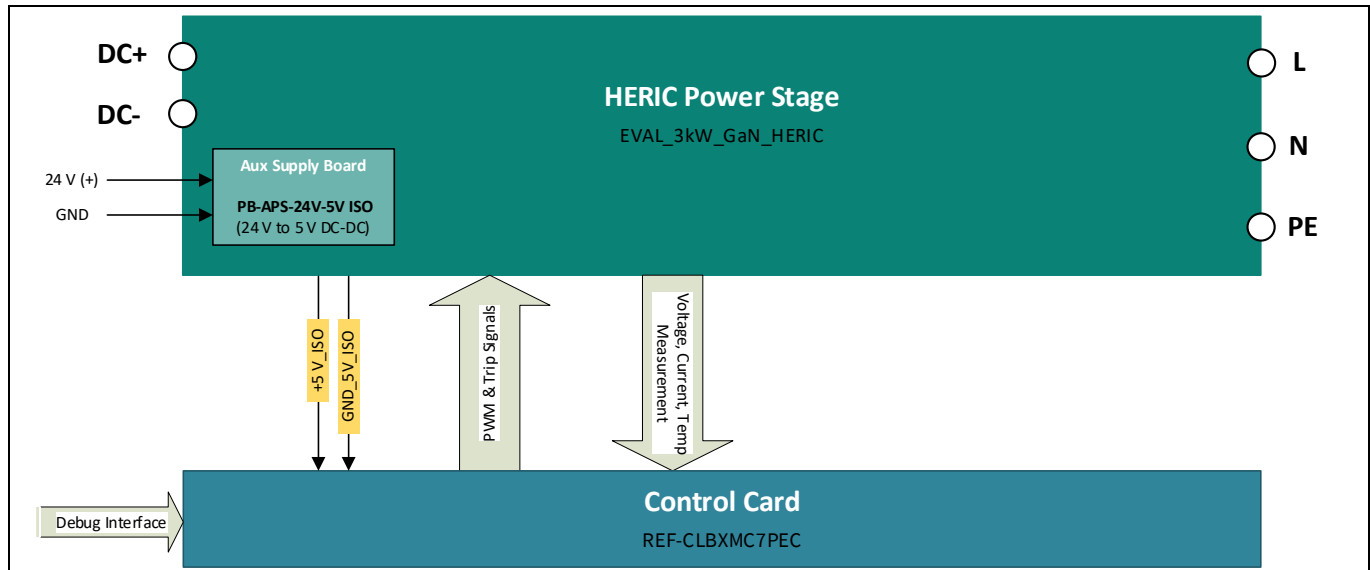


Figure 4 Assembly diagram

Figure 4 shows how the different boards are connected to construct the HERIC inverter. This HERIC reference design consists of the following boards:

- Main HERIC power board
- 24 V DC – 5 V DC isolated aux power supply board
- MCU control board

The DC input power supply and the AC output load are connected to the main board. You must provide an external 24 V DC supply to power all the auxiliary circuits on the main board as well as to power the MCU control board. This auxiliary power board plugged into the main board provides the 5 V isolated supply to power the auxiliary loads on the main board. The control MCU board is connected to the main board via two cables. The MCU board can be connected to a PC to flash the firmware or control the inverter through the GUI.

The following figures (Figure 5 and Figure 6) show the standalone EVAL_3kW_GaN_HERIC and PB-APS-24V-5V ISO boards.

3 kW all-GaN HERIC evaluation board

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1 Introduction

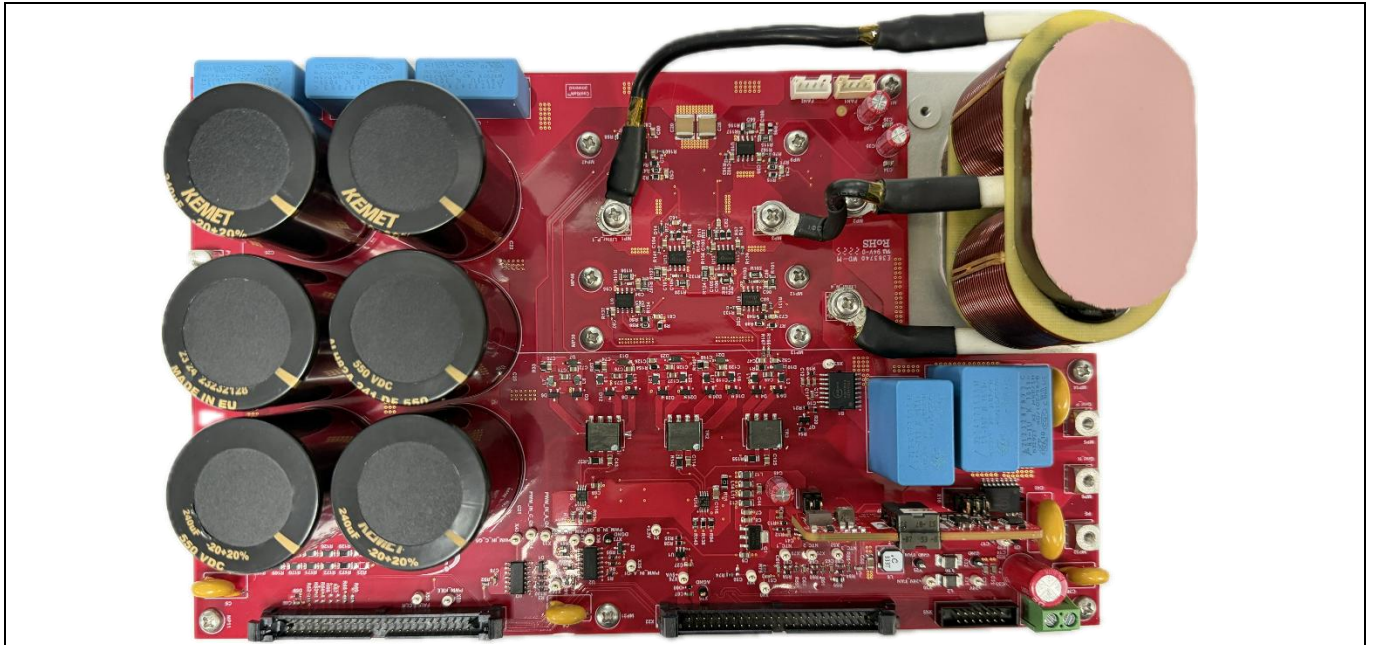


Figure 5 EVAL_3kW_GaN_HERIC

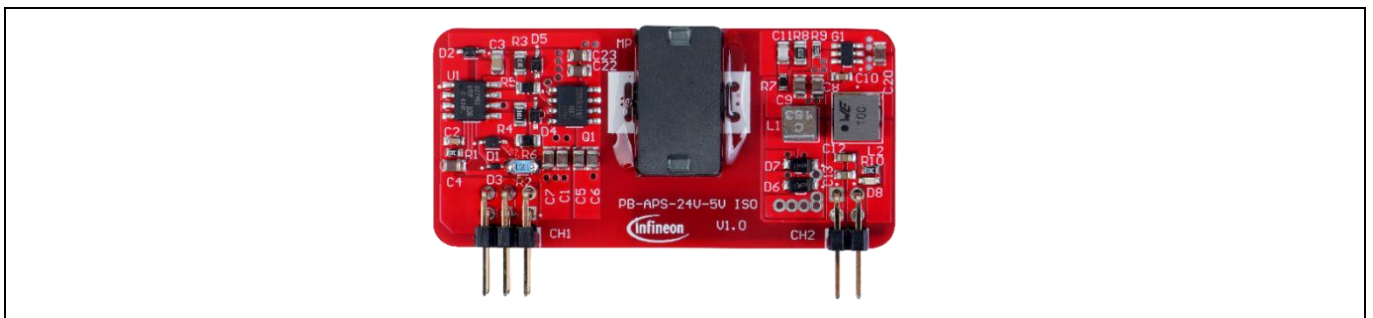


Figure 6 PB-APS-24V-5V ISO

1 Introduction

1.5 Preferred components

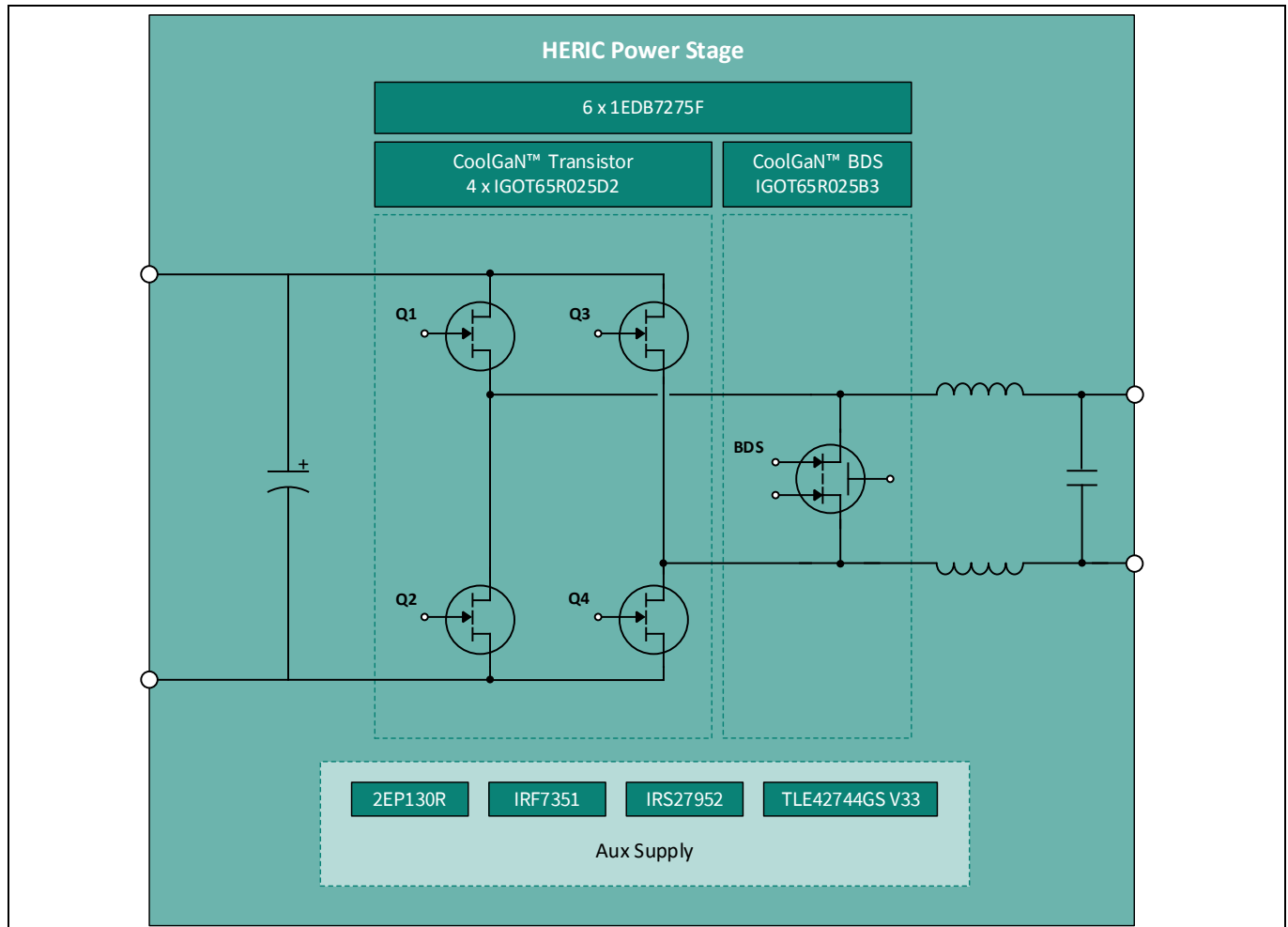


Figure 7 Preferred Infineon components

Figure 7 shows the main semiconductors offered in the 3 kW all-GaN HERIC inverter evaluation board design.

- Power semiconductors:
 - CoolGaNTM bidirectional switch 650 V G5 [IGOT65R025B3](#), 25 mΩ in top-side-cooled DSO-20 package
 - CoolGaNTM Transistor 650 V G5 [IGOT65R025D2](#), 25 mΩ in top-side-cooled DSO-20 package
- Gate driver:
 - EiceDRIVER™ [1EDB7275F](#) single-channel isolated gate driver IC
- Auxiliary power supply:
 - [2EP130R](#): Full-bridge transformer driver
 - [IRS27952](#): Half-bridge controller IC
 - [IRF7351](#): 60 V dual N-channel HEXFET™ power MOSFET
 - [TLE42744GS V33](#): Monolithic integrated low-dropout voltage regulator for load currents up to 400 mA

2 Board functional description and schematics

This section lists the features available in the 3 kW all-GaN HERIC inverter reference design.

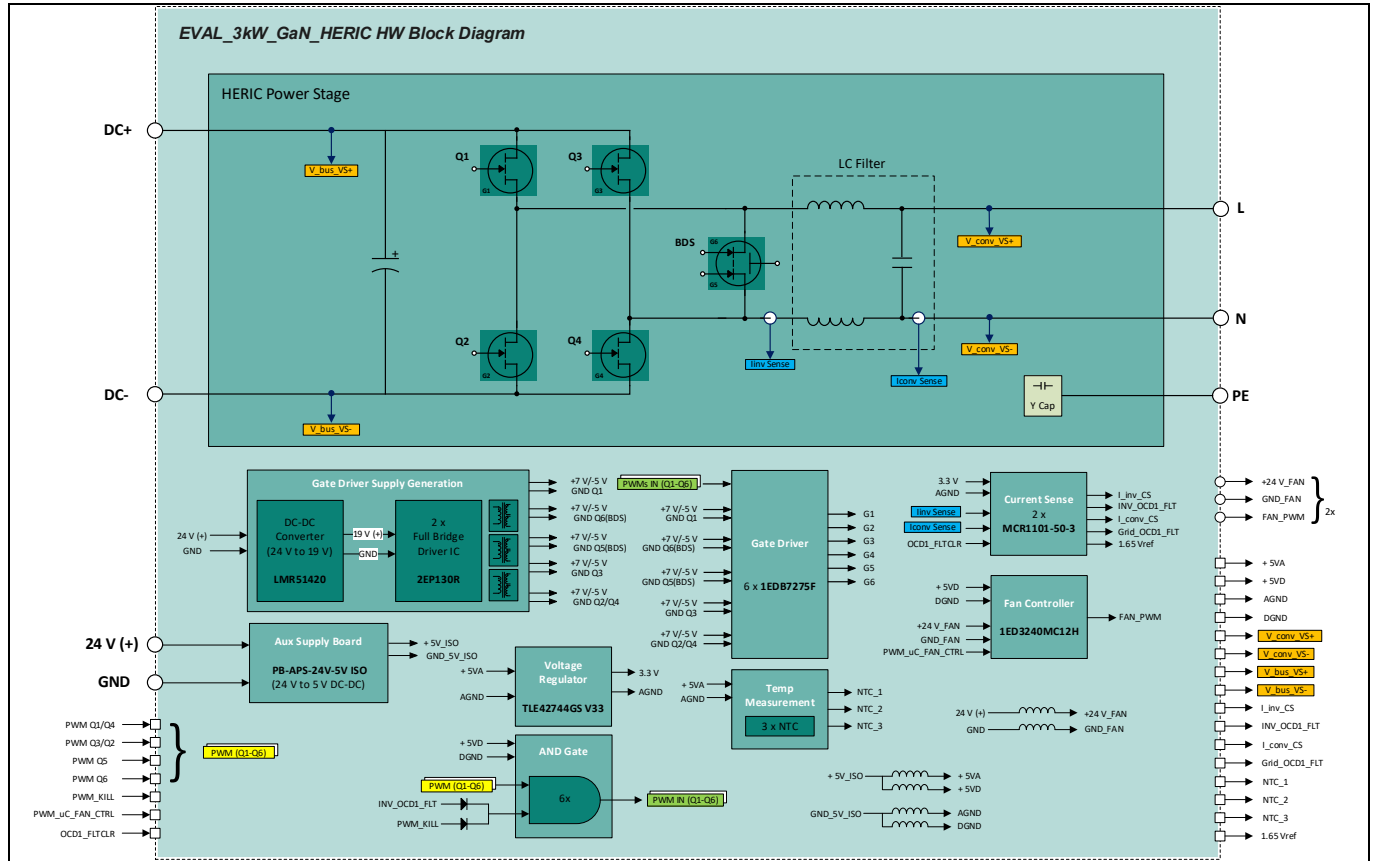


Figure 8 Block diagram of EVAL_3kW_GaN_HERIC evaluation board

2 Board functional description and schematics

2.1 Switching devices

The inverter stage is designed with a CoolGaN™ bidirectional switch 650 V G5 [IGOT65R025B3](#) and four CoolGaN™ Transistor 650 V G5 [IGOT65R025D2](#).

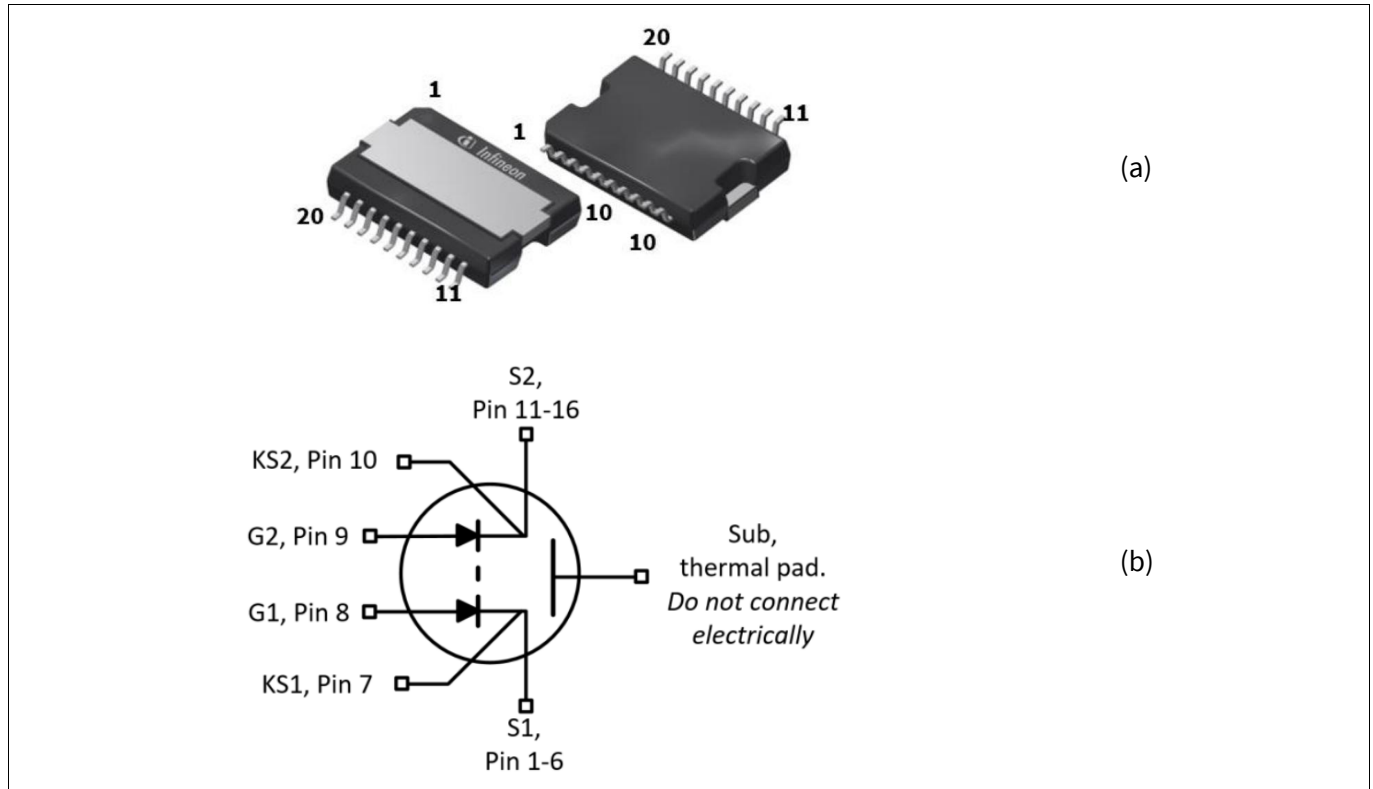


Figure 9 (a) IGOT65R025B3 (b) pin description - CoolGaN™ BDS DSO-TSC-20 package

In all-GaN HERIC, [IGOT65R025B3](#) is used as a AC decouple/freewheeling switch. [IGOT65R025B3](#) belongs to the CoolGaN™ BDS 650 V G5 family. It comprises true normally-off monolithic GaN bidirectional switches with four modes of operation as shown in [Figure 10](#). Each device features two separate gates with substrate terminal and independent isolated control, allowing for a common-drain configuration that utilizes the same drift region to block voltages and current in both directions. By replacing two or four unidirectional switches with a single bidirectional switch, designers can achieve significant cost savings while enabling higher switching frequencies and improved performance. The four modes of operation of CoolGaN™ BDS devices are described below.

2 Board functional description and schematics

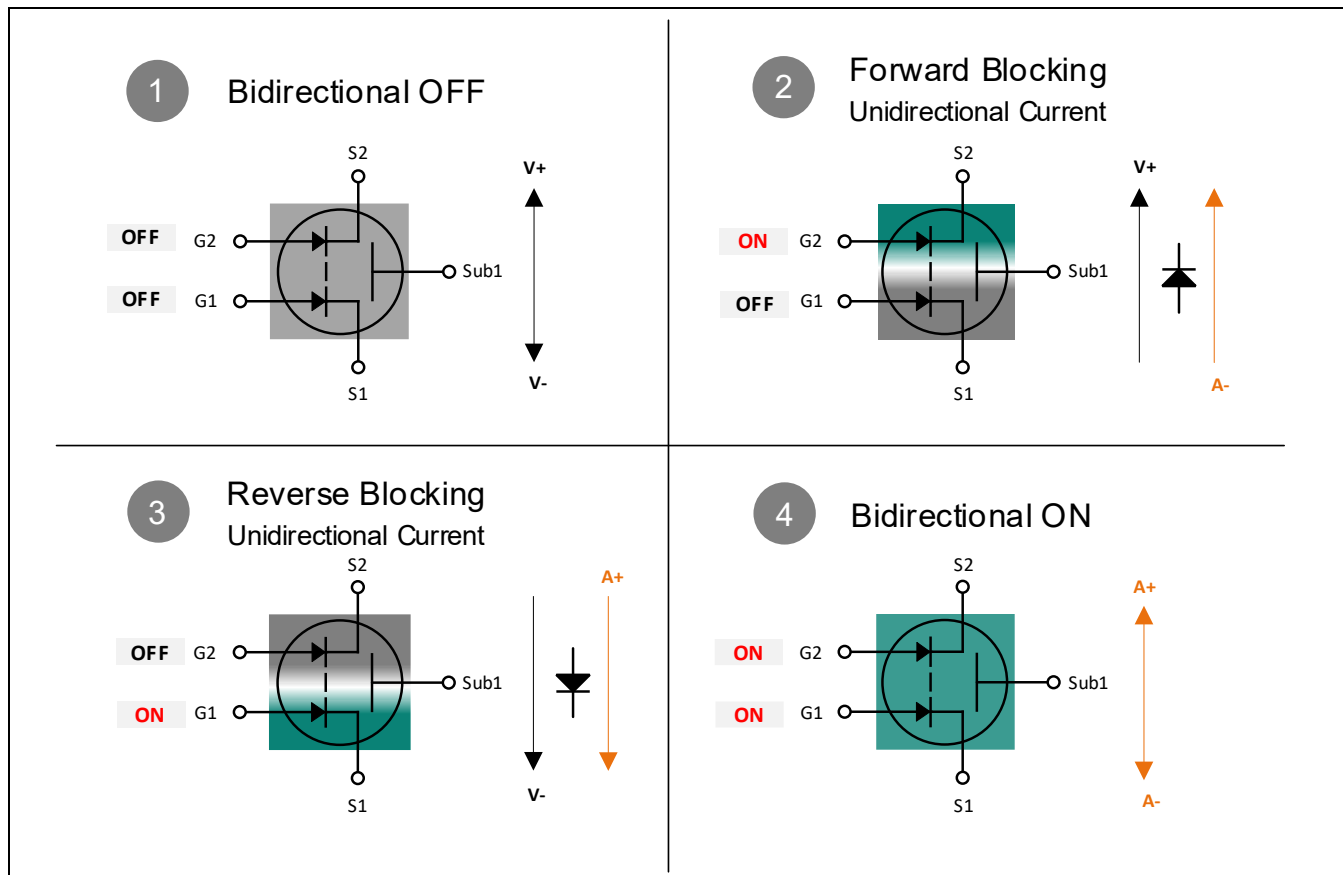


Figure 10 CoolGaN™ BDS modes of operation

2.1.1 Mode 1: Bidirectional OFF (switch mode OFF)

This is the default off-state in which the device blocks voltages in both directions and is the natural mode when zero voltages are applied to both gates (no-power condition). It is essential to avoid unclamped inductive switching in this mode as there is no natural body diode path. The voltage will build up unless an alternative diode path is available within the circuit.

2.1.2 Mode 2: Forward-blocking (diode mode FB)

The forward blocking diode mode is one of the diode states where the device blocks voltage in the forward direction (S2 to S1) but allows current in the reverse direction (S1 to S2). The diode modes are equivalent to the off-state of an N-channel power MOSFET in terms of voltage blocking and permissible current orientation. They are targeted for soft-switching operations where the voltage blocking direction is known, and the output capacitance can be discharged safely, equivalent to the same operation in unidirectional devices.

2.1.3 Mode 3: Reverse-blocking (diode mode RB)

The reverse blocking diode mode is one of the diode states where the device blocks voltages in the reverse direction (S1 to S2) but allows current in the forward direction (S2 to S1).

2.1.4 Mode 4: Bidirectional ON (switch mode ON)

This is the default on-state allowing current to flow in both directions. This mode is equivalent to the on-state mode of a power MOSFET, and the on-state resistance is measured under these conditions.

2 Board functional description and schematics

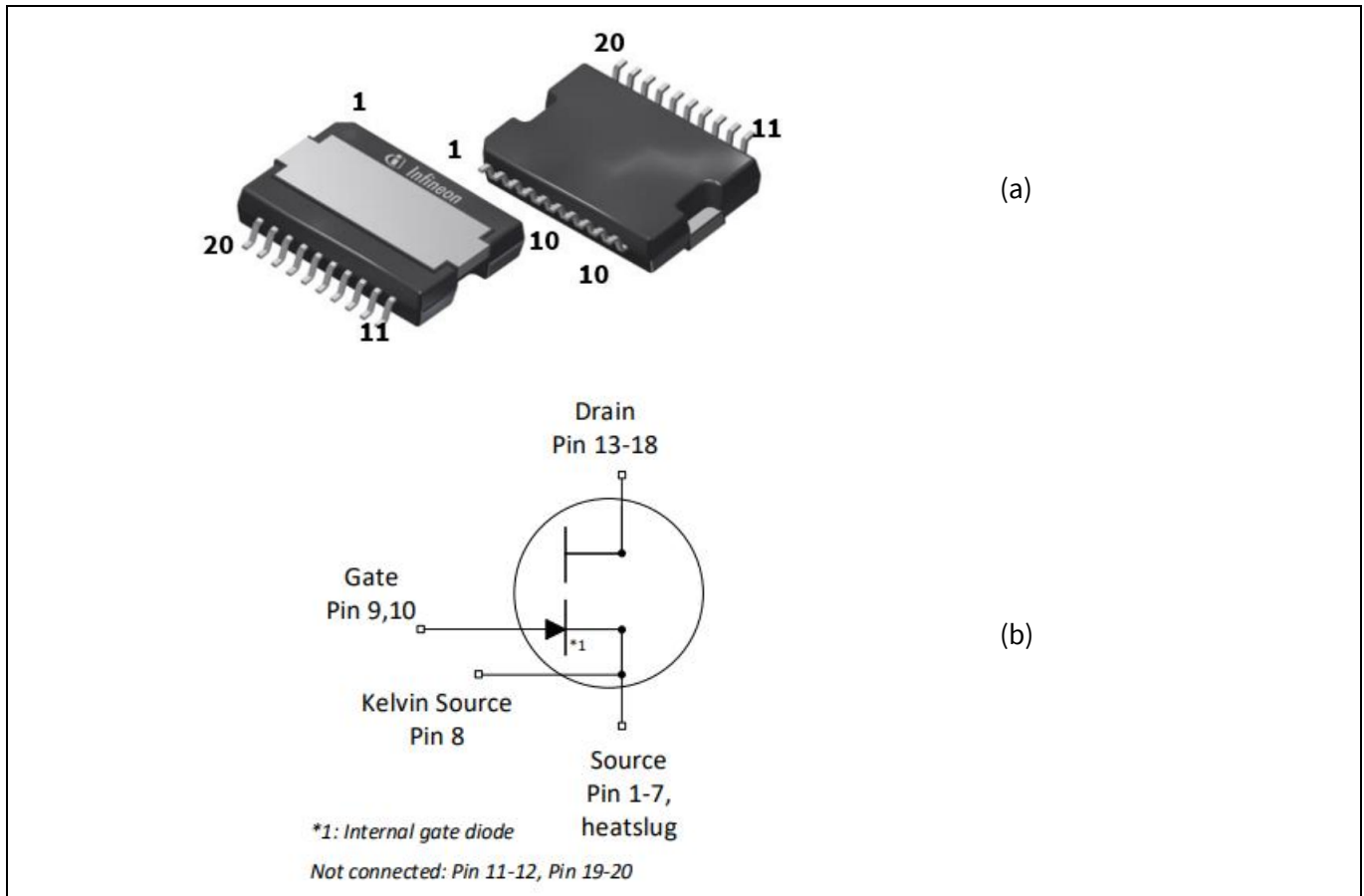


Figure 11 (a) IGOT65R025D2 (b) pin assignment - CoolGaN™ Transistor DSO-TSC-20 package

2.2 Gate driver

Six single-channel isolated gate drivers ([1EDB7275F](#)) are used to drive the six MOSFETs.



Figure 12 1EDB7275F

[1EDB7275F](#) belongs to the EiceDRIVER™ 1EDBx275F family of single-channel isolated gate driver ICs. It is specifically targeted to drive the GaN power switches due to its high source and sink current and optimized UVLO thresholds. It is available in an 8-pin DSO package with 4 mm input-to-output creepage distance. It provides isolation by means of on-chip coreless transformer (CT) technology meeting UL 1577 requirements of 3000 VRMS clearance. A low propagation delay of 45 ns enables the use of this single channel driver to drive inverter topologies where diagonal switches have to be turned on simultaneously. It can be used to drive fast GaN power devices with Kelvin source with its separate low-impedance source and sink outputs. Its high common-mode transient immunity (CMTI) allows robust driving of wide-bandgap GaN power switches with high dV/dt values.

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2 Board functional description and schematics

The externally supplied 24 V power is stepped down and used as an input to the 2EP130R full-bridge transformer driver. A transformer is then used to provide functional isolation and the +7 V/-5 V voltage rails for the six gate drivers driving the four unidirectional GaN FETs (Q1–Q4) and one GaN BDS. The PWM signals coming from the MCU control board are routed to the gate driver.

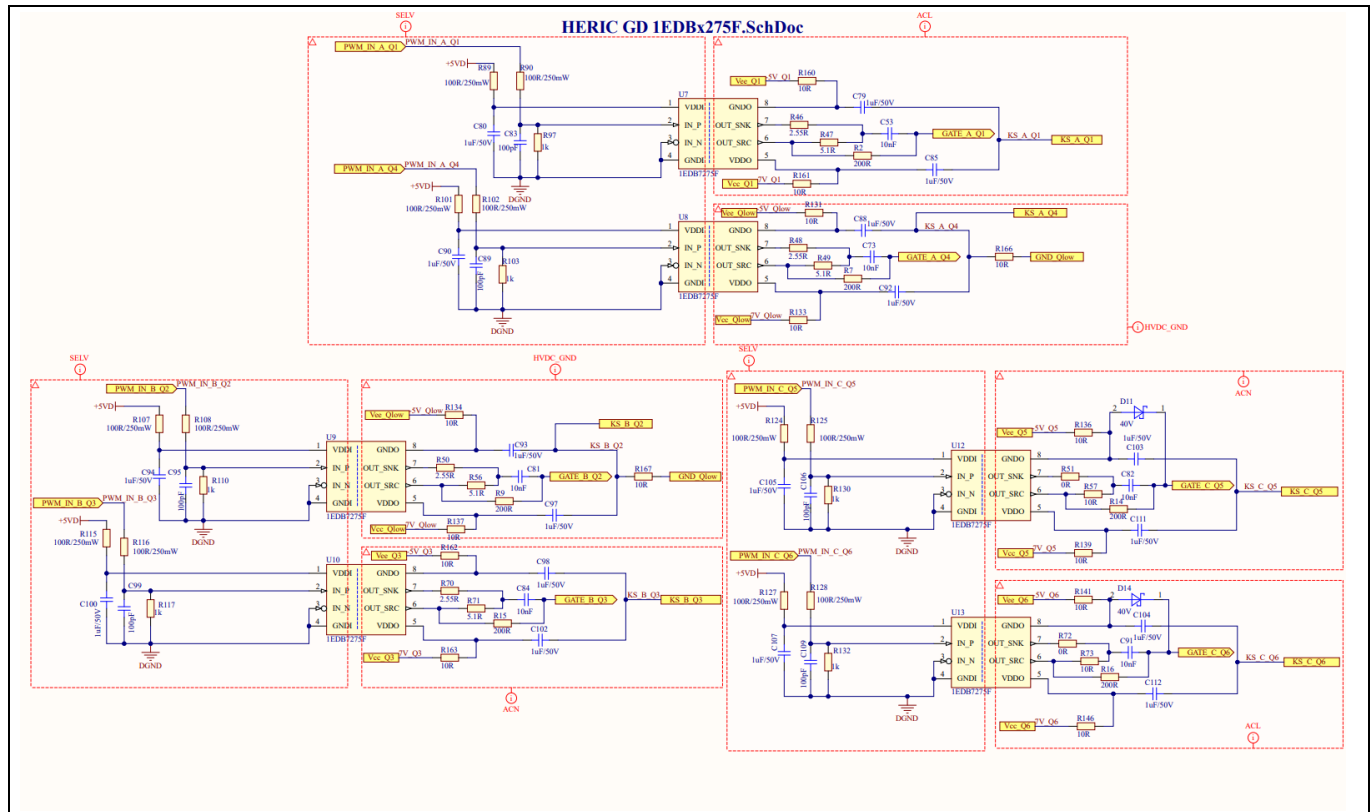


Figure 13 Gate driver (GD) circuitry

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions



2 Board functional description and schematics

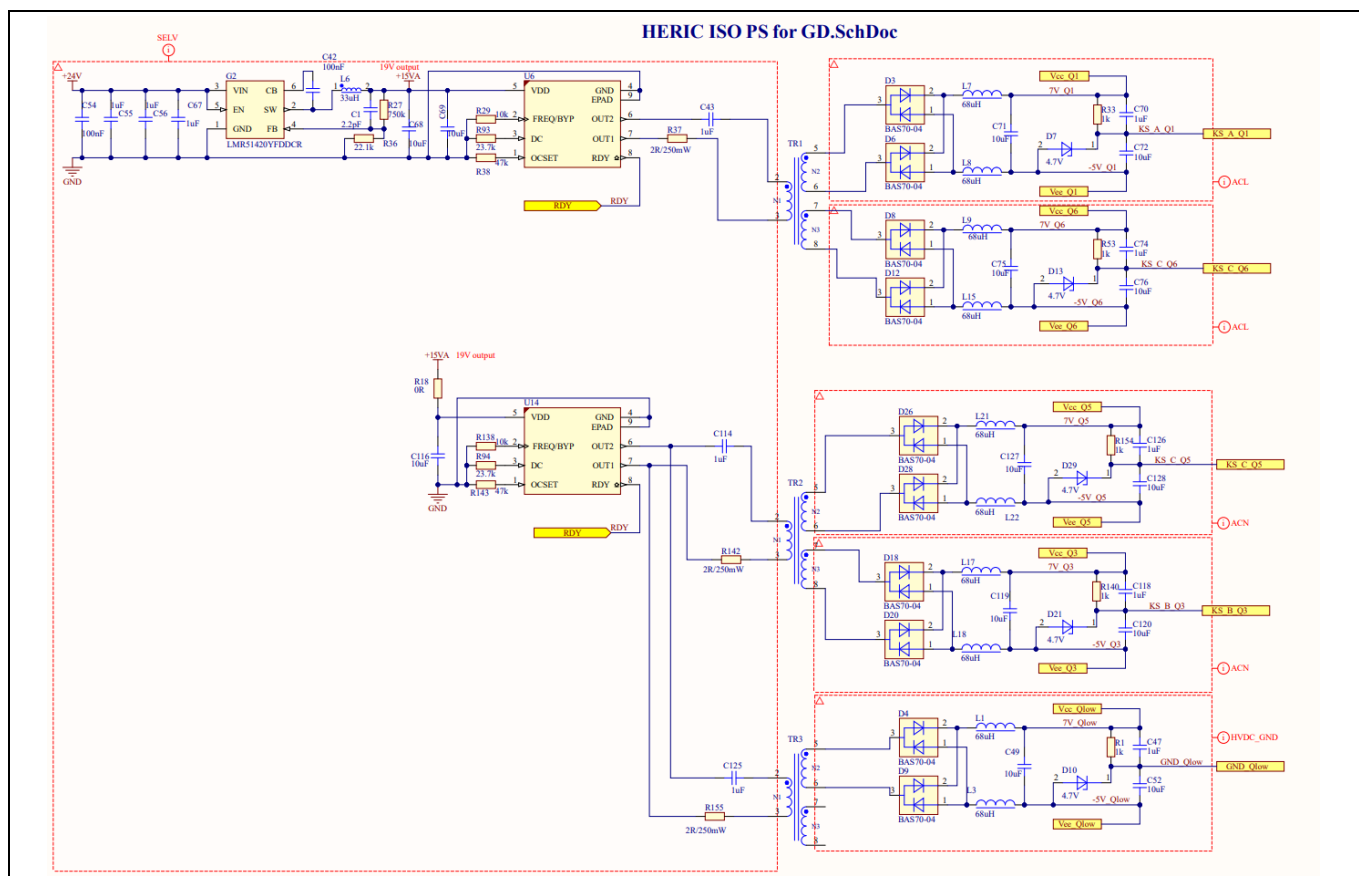


Figure 14 Isolated power supplies (ISO PS) for HERIC gate drivers

2.3 Input and power stage

The input stage consists of a DC capacitor link. The capacitor link has six electrolytic capacitors rated at 240 μ F/550 V and connected to the bus voltage.

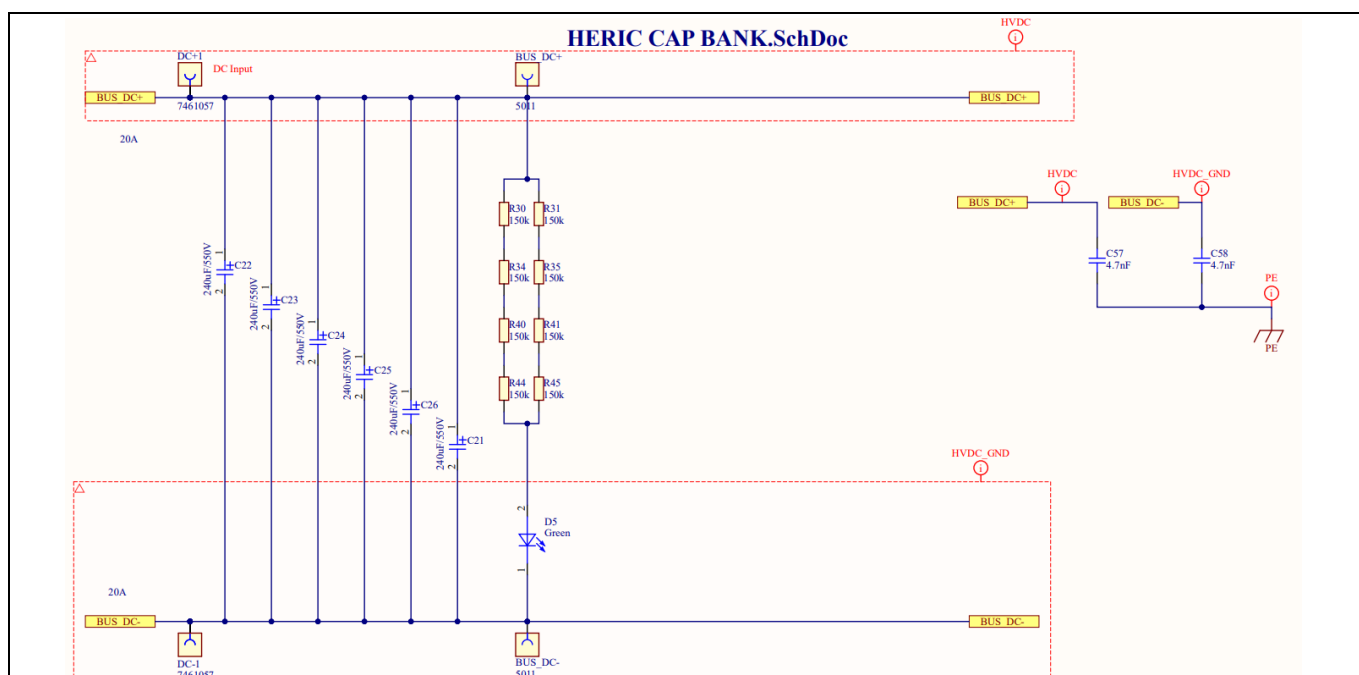


Figure 15 Capacitor bank

3 kW all-GaN HERIC evaluation board

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2 Board functional description and schematics

The power stage has a total of five power devices with voltage rating of 650 V. Four of the unidirectional GaN devices make an H-bridge switching at high frequency. The BDS is used as a freewheeling switch that switches at the same high switching frequency or switch at the grid frequency. The BDS can pass freewheeling current through the shortest route during the period when the output voltage of the H-bridge inverter is zero. Using CoolGaN™ BDS enables switching at a higher frequency resulting in a significant reduction in magnetic size, capacitor filter, and heatsink size.

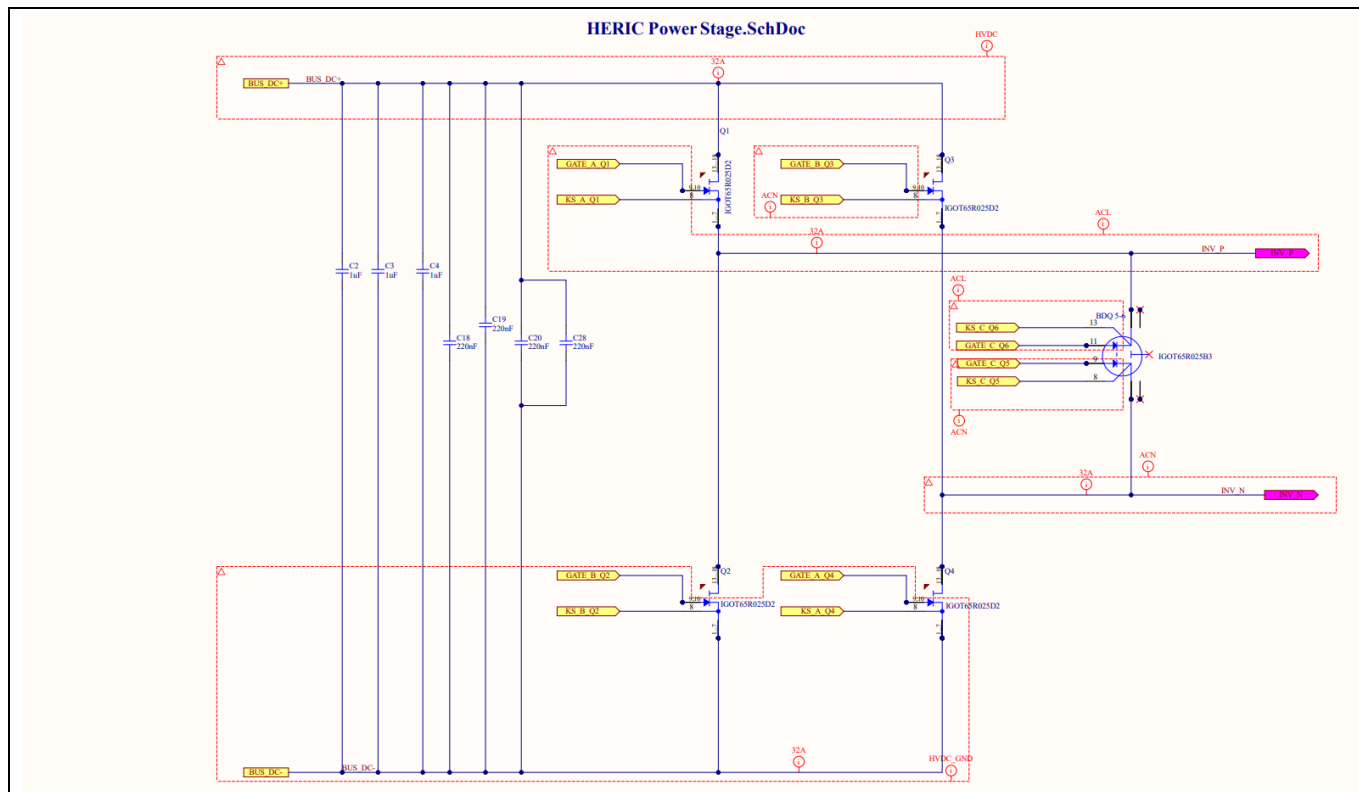


Figure 16 Power stage

2.4 Sensing and filter

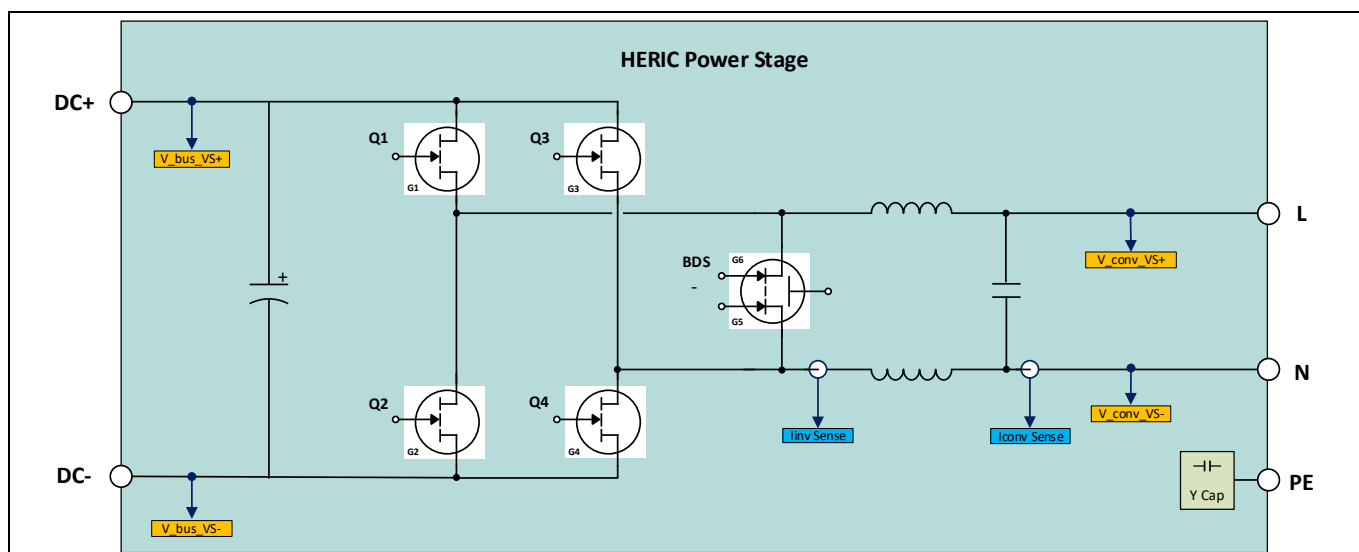


Figure 17 Sensing locations on the HERIC inverter

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions

2 Board functional description and schematics

2.4.1 Voltage sense

The DC-link voltage (V_{bus}) and the AC output voltage (V_{conv}) are measured on the power board.

Attention: *The controller board must be connected with the main power board before powering the power board. Failure to do so can lead to a hazardous situation.*

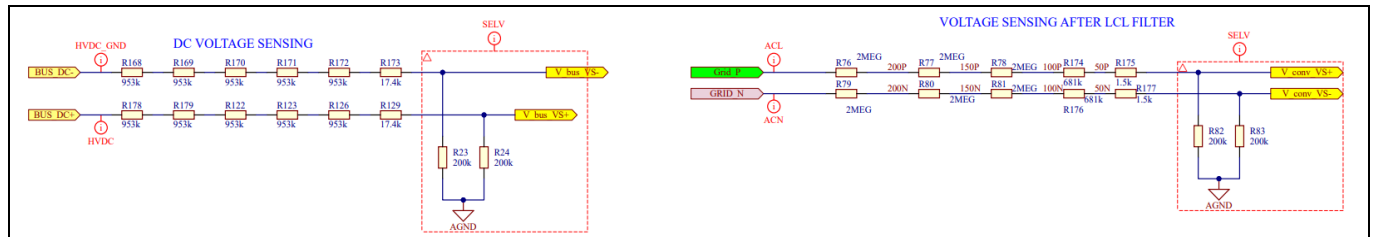


Figure 18 Voltage sense circuit

2.4.2 Current sense

The inductor current (I_{inv}) and AC output current (I_{conv}) are sensed using MCR1101-50-3 current sensors.

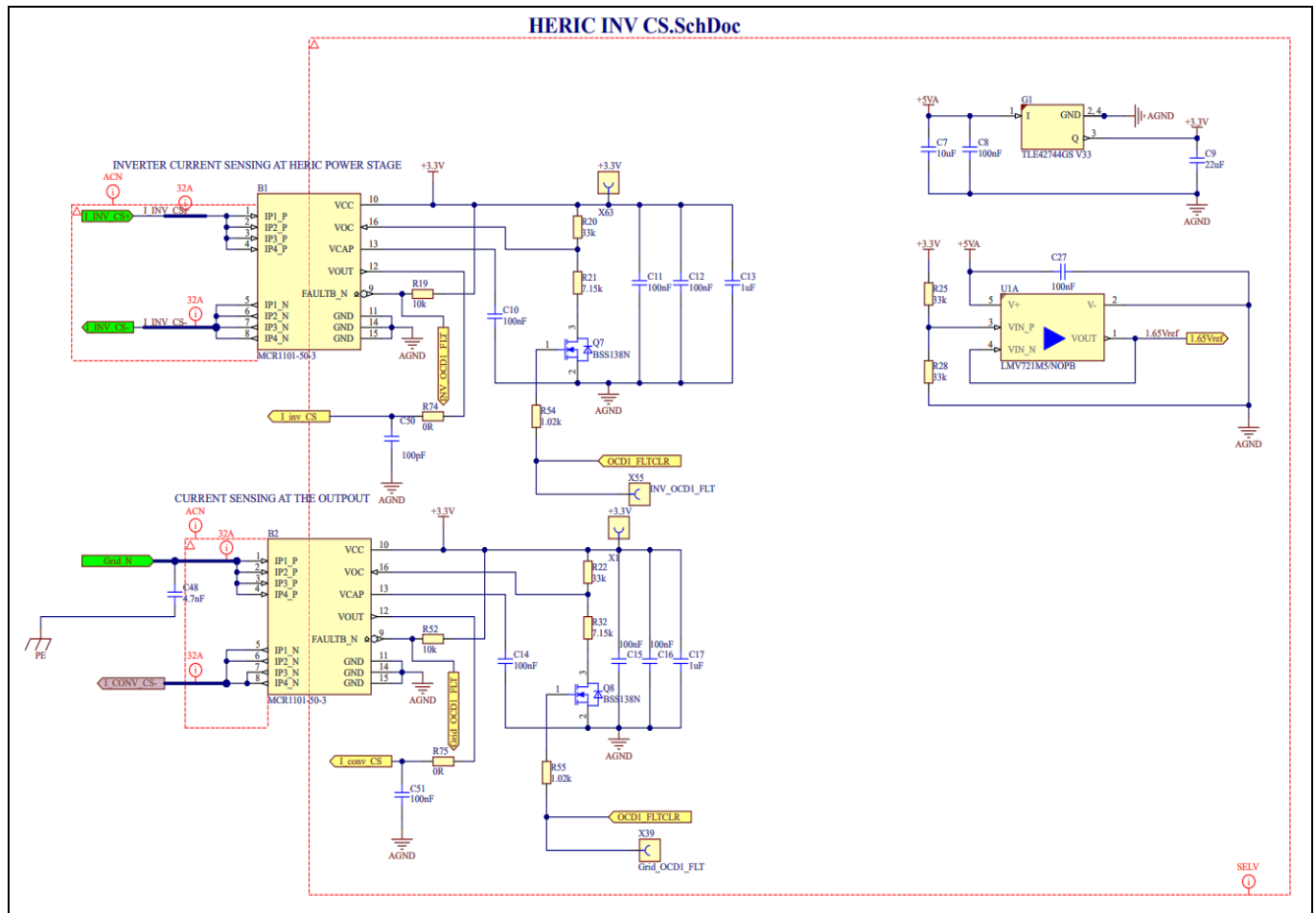


Figure 19 Current sense circuit

2 Board functional description and schematics

2.4.3 Temperature sense

Three temperature measurements are provided on the power board using NTC thermistors. These NTCs can be connected to the heat sink to measure the temperature and feed it back to the connector which can be connected to a control board.

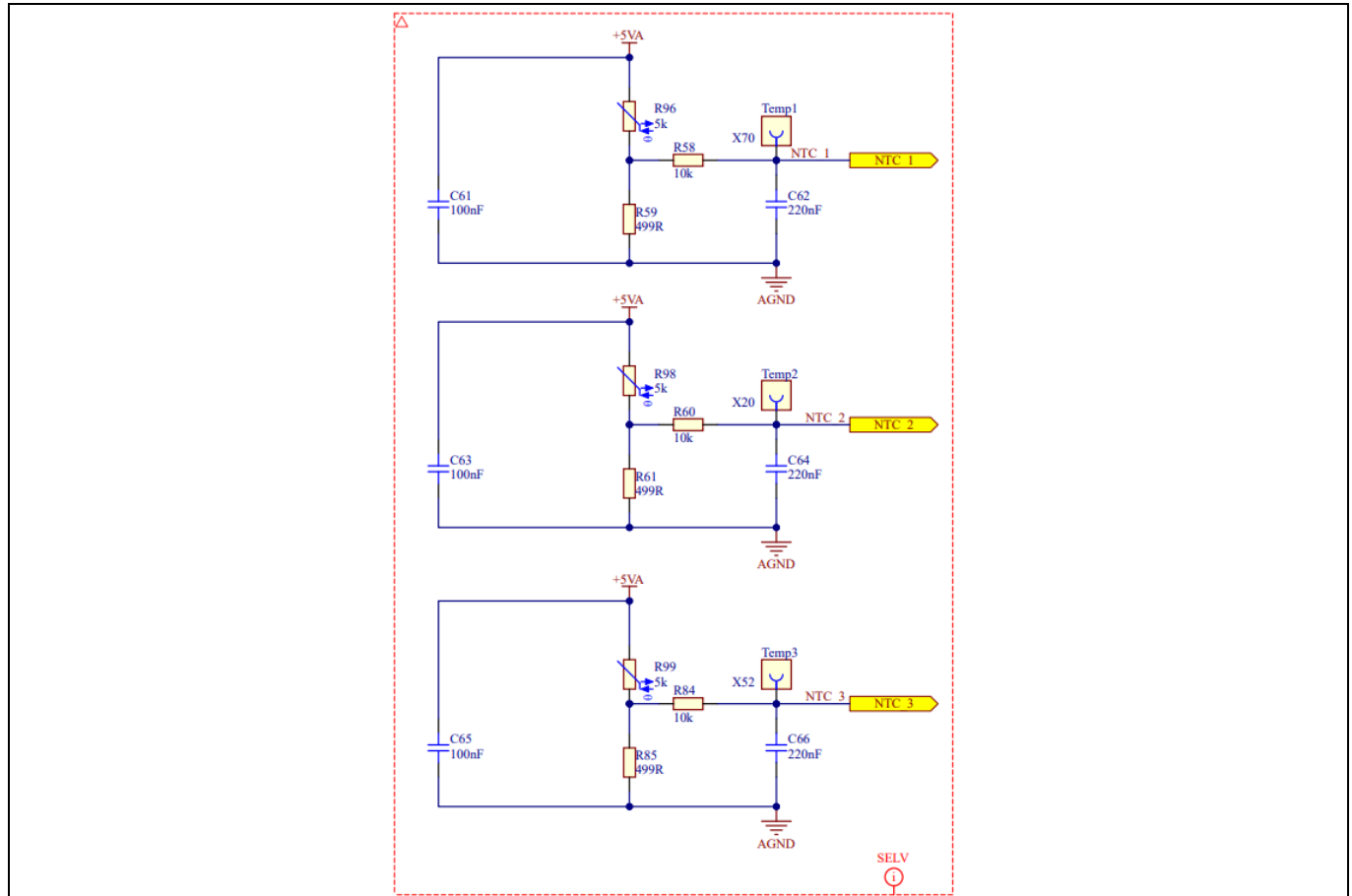


Figure 20 Temperature sense circuit

An LCL filter is located in between the power stage and current sensing circuitry. The inductor that is being used is rated at 110 μ H/45.3A.

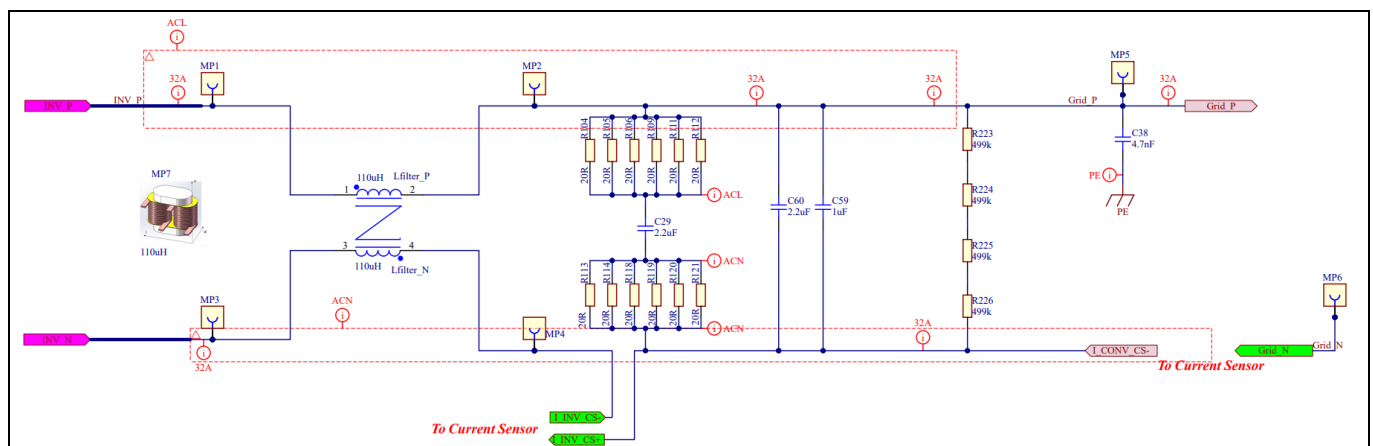


Figure 21 Temperature sense circuit

2 Board functional description and schematics

2.4.4 Gate drive logic

Fault and latch circuits latch the PWMs to the off state in case of a fault. The PWM_KILL or INV_OCD1_FLT signal can hold the logic gates LOW, latching the gate driver input to a LOW state. A “fault clear” signal can then be provided from the MCU to reset the latch.

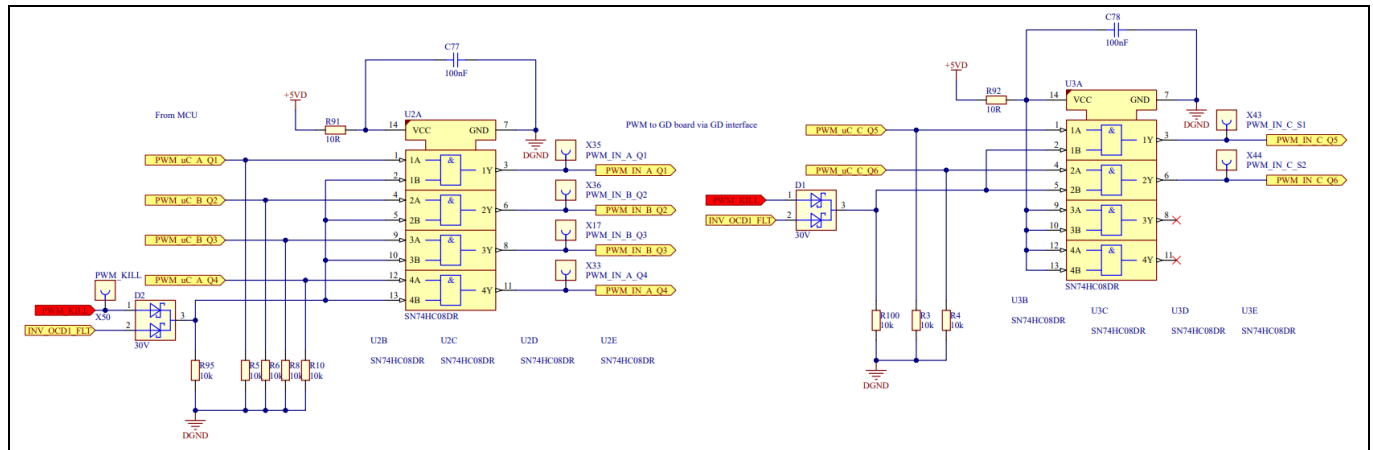


Figure 22 Fault and latch circuit

2.5 Internal power supplies

You must provide a 24 V supply to the main HERIC board. The 24 V is then fed to a power supply card which generates an isolated 5 V. This 5 V supply is then split into two rails:

- 5VA rail for sensing and analog circuits
- 5VD rail for digital circuits like the power for the primary side of the gate driver.

The 24 V is fed to the isolated power stage which generates the isolated 7 V/–5 V for powering the secondary side of the gate driver and driving the GaN devices.

2 Board functional description and schematics

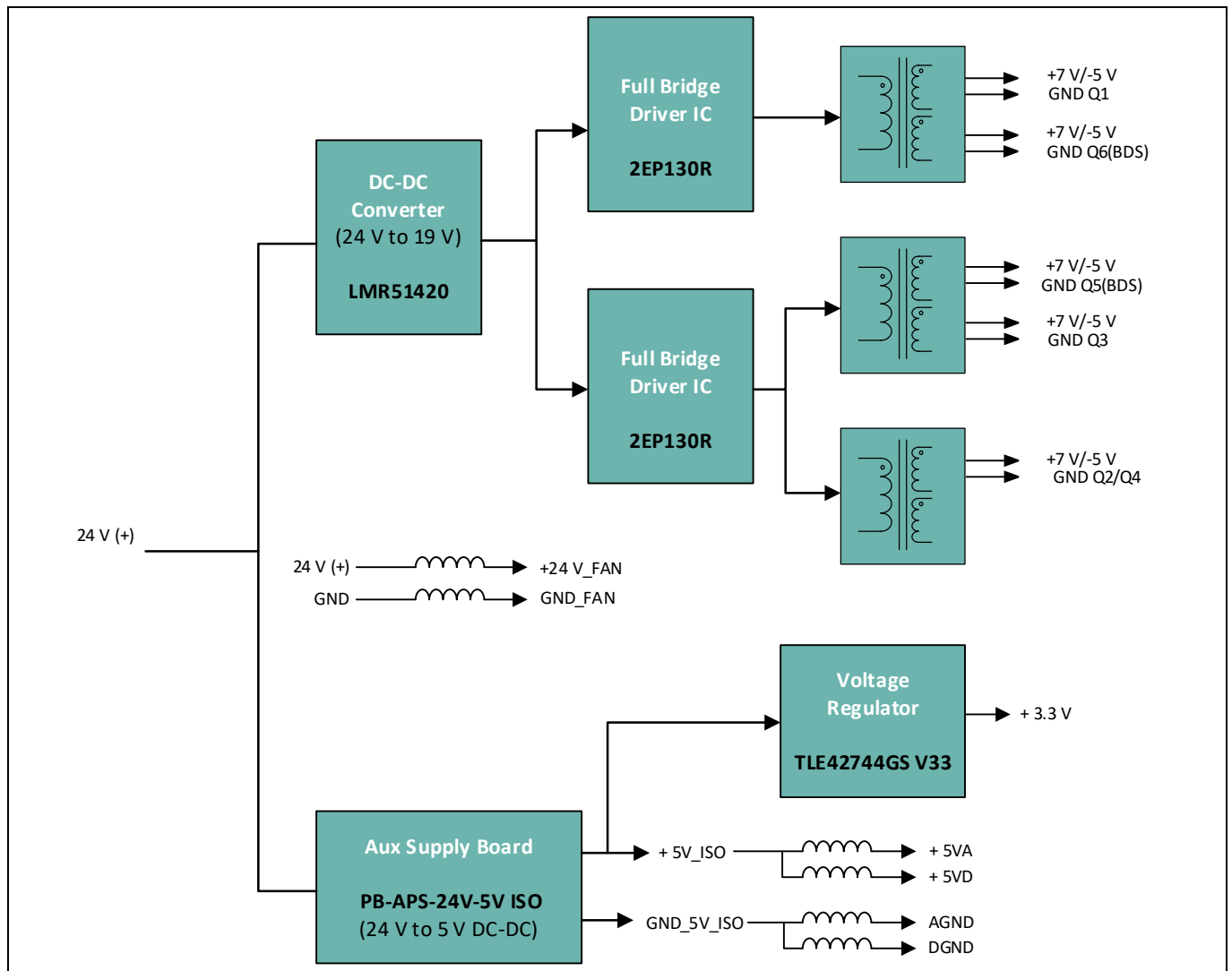


Figure 23 Auxiliary power supply tree

The specifications of the power supply card are as given in the following table.

Table 3 Specifications of the power supply card

Parameter	Minimum	Typical	Maximum	Unit
Input voltage	21.6	24	26.4	V DC
Input current	–	–	0.5	A
Output voltage	4.75	5	5.25	V DC
Output current	–	–	2	A
Switching frequency	–	226	–	kHz
Half-bridge IC used	IRS27952			–

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2 Board functional description and schematics

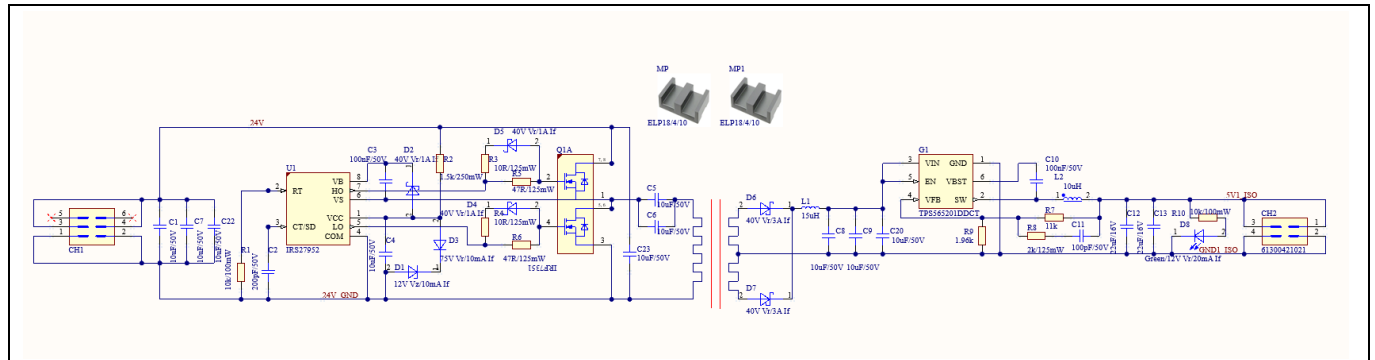


Figure 24 Power supply card schematics

2.6 Connectors

Additional fan control circuits are also provided if you need to use forced air cooling during evaluation.

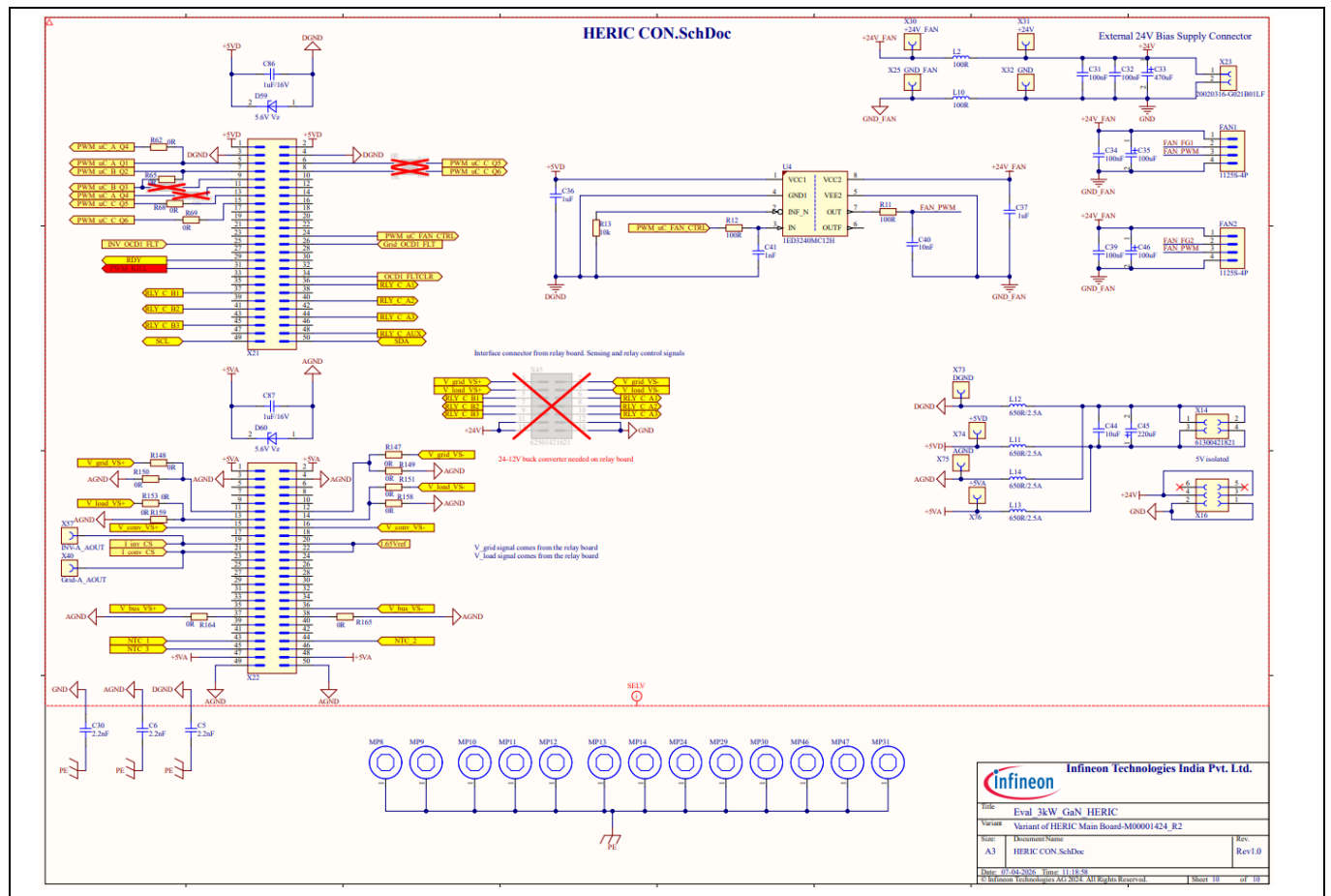


Figure 25 HERIC connections

2 Board functional description and schematics

2.6.1 Enhanced interface for measurements

All the measurement signals are fed to the control board using the X22 connector located on the power board.

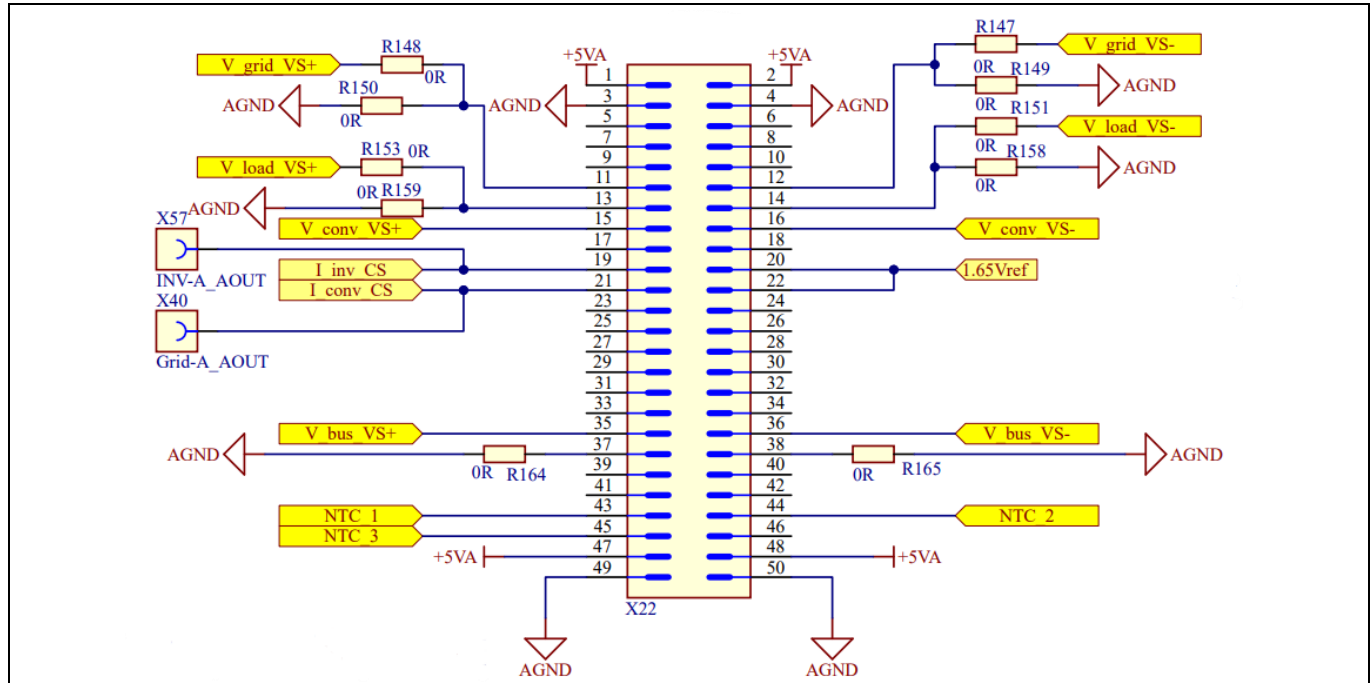


Figure 26 Enhanced interface for measurements

Table 4 Enhanced interface for measurements

Basic interface

Pin	Signal	Description
1	+5VA	Analog power
2	+5VA	Analog power
3	AGND	Analog power ground
4	AGND	Analog power ground
5	NC	NC
6	NC	NC
7	NC	NC
8	NC	NC
9	NC	NC
10	NC	NC
11	V_grid_VS+	Not used
12	V_grid_VS-	Not used
13	V_load_VS+	Not used
14	V_load_VS-	Not used
15	V_conv_VS+	AC voltage P
16	V_conv_VS-	AC Voltage N
17	NC	NC

2 Board functional description and schematics

Basic interface

Pin	Signal	Description
18	NC	NC
19	I_inv_CS	Inductor current
20	1.65Vref	1.65 V reference voltage
21	I_conv_CS	AC output current
22	1.65Vref	1.65 V reference voltage
23	NC	NC
24	NC	NC
25	NC	NC
26	NC	NC
27	NC	NC
28	NC	NC
29	NC	NC
30	NC	NC
31	NC	NC
32	NC	NC
33	NC	NC
34	NC	NC
35	V_bus_VS+	Bus voltage P
36	V_bus_VS-	Bus voltage N
37	NC	NC
38	NC	NC
39	NC	NC
40	NC	NC
41	NC	NC
42	NC	NC
43	NTC1	Temperature sensor 1
44	NTC2	Temperature sensor 2
45	NTC3	Temperature sensor 3
46	NC	NC
47	+5VA	Analog power
48	+5VA	Analog power
49	AGND	Analog power ground
50	AGND	Analog power ground

2 Board functional description and schematics

2.6.2 Enhanced interface - control

Connector X21 contains all the signals related to the PWMs, faults, and relay control.

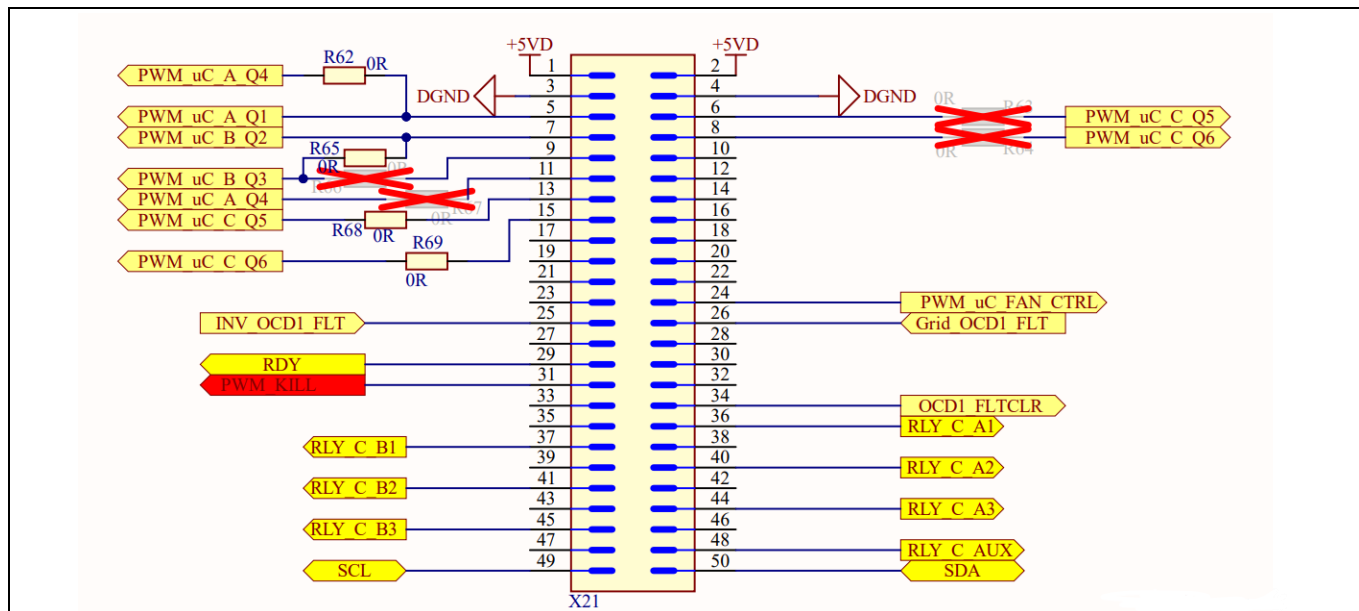


Figure 27 Enhanced interface - control

Table 5 Enhanced interface - control

Basic interface		
Pin	Signal	Description
1	+5VD	Digital power
2	+5VD	Digital power
3	DGND	Digital power ground
4	DGND	Digital power ground
5	PWM_uC_A_Q1/ PWM_uC_A_Q4	MOSFET Q1 and Q4 PWM
6	PWM_uC_A_Q5	NC
7	PWM_uC_A_Q2/ PWM_uC_A_Q3	MOSFET Q2 and Q3 PWM
8	PWM_uC_A_Q6	NCs
9	PWM_uC_A_Q3	NC
10	NC	NC
11	PWM_uC_A_Q4	NC
12	NC	NC
13	PWM_uC_A_Q5	MOSFET Q5 PWM
14	NC	NC
15	PWM_uC_A_Q6	MOSFET Q6 PWM
16	NC	NC
17	NC	NC
18	NC	NC

2 Board functional description and schematics

Basic interface		
Pin	Signal	Description
19	NC	NC
20	NC	NC
21	NC	NC
22	NC	NC
23	NC	NC
24	PWM_uC_FAN_CTRL	FAN control PWM
25	INV_OCD1_FLT	Inductor overcurrent fault signal
26	Grid_OCD1_FLT	AC output overcurrent fault signal
27	NC	NC
28	NC	NC
29	RDY	Not used
30	NC	NC
31	PWM_KILL	PWM shutdown signal
32	NC	NC
33	PWM_uC_INF	Not used
34	OCD1_FLTCLR	Overcurrent fault clear signal from MCU
35	NC	NC
36	RLY_C_A1	Not used
37	RLY_C_B1	Not used
38	NC	NC
39	NC	NC
40	RLY_C_A2	Not used
41	RLY_C_B2	Not used
42	NC	NC
43	NC	NC
44	RLY_C_A3	Not used
45	RLY_C_B3	Not used
46	NC	NC
47	NC	NC
48	NC	NC
49	I2C2_SCL	Not used
50	I2C2_SDA	Not used

2.7 Isolation coordination

The EVAL_3kW_GaN_HERIC design follows a cold-side control structure where all the measurements and the gate-drive power supply offer functional isolation. IEC 62109-1 was used for clearance and creepage requirements.

3 Bills of materials

3 Bills of materials

Table 6 BOM of the power conversion board

#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
1	2	B1, B2	MCR1101-50-3	SOIC127P1031X264-16N-1	High accuracy magnetic current sensor IC with 1.5 MHz 3 dB bandwidth and isolation 50 A	ACEINNA	MCR1101-50-3
2	1	BDQ 5-6	IGOT65R025 B3	SOIC127P1420X350-21N-2	GaN BDS 30 m DSO TSC HanSolo	Infineon Technologies	IGOT65R025B3
3	2	BUS_DC-, BUS_DC+	5011	CON-THT-TP-5011	PC test point-multipurpose THT, Black	Keystone Electronics Corp.	5011
4	1	C1	2.2 pF	CAPC1608X90N-4	CAP / CERA / 2.2pF / 50V / 250fF / C0G (EIA) / NP0 / -55°C to 125°C / 0603(1608) / SMD / -	TDK Corporation	CGA3E2C0G1H2 R2C080AA
5	4	C2, C3, C4, C59	1 uF	CAPRR2250W80L2650T11 00H2050B	CAP / FILM / 1uF / 630V / 10% / MKP (Metallized Polypropylene) / -40°C to 110°C / 22.50mm C X 0.80mm W 26.50mm L X 11.00mm T X 20.50mm H / THT / -	TDK Corporation	B32923C3105K 289
6	3	C5, C6, C30	2.2 nF	CAPRR1000W60L1200T70 0H1500B	CAP / CERA / 2.2nF / / 20% / - / -55jãC to 125jãC / 10.00mm C X 0.60mm W 12.00mm L X 7.00mm T X 15.00mm H / THT / -	Vishay	AY1222M47Y5U C63L0
7	1	C7	10 uF	CAPC2013X145N-0	CAP / CERA / 10uF / 25V / 10% / X7R (EIA) / -55jãC to 125jãC / 805(2012) / SMD / -	Murata	GRM21BZ71E10 6KE15L
8	2	C8, C54	100 nF	CAPC2013X94N	CAP / CERA / 100nF / 25V / 10% / X7R (EIA) / -55jãC to 125jãC / 0805(2012) / SMD / -	AVX	08053C104K4Z2 A
9	1	C9	22 uF	CAPC2013X145N-0	CAP / CERA / 22uF / 25V / 20% / X5R (EIA) / -55jãC to 85jãC / 805(2012) / SMD / -	Murata	GRM21BR61E22 6ME44L
10	8	C10, C11, C12, C14, C15, C16, C27, C51	100nF	CAPC1608X87N	CAP / CERA / 100nF / 16V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Kemet	C0603X104K4R ACTU
11	2	C13, C17	1uF	CAPC1608X90N-4	CAP / CERA / 1uF / 16V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	TDK Corporation	CGA3E1X7R1C1 05K080AC
12	4	C18, C19, C20, C28	220nF	CAPC5750X200N	CAP / CERA / 220nF / 630V / 10% / X7R (EIA) / -55°C to 125°C / 2220(5750) / SMD / -	Murata	GRM55DR72J22 4KW01L
13	6	C21, C22, C23, C24, C25, C26	240 uF/550 V	CAP-THT-ECS2HBB471M350060	CAP / ELCO / 240uF/550V / 550V / 20% / Aluminium electrolytic / -25jãC to 105jãC / 10.00mm Pitch X 36.00mm Dia X 62.00 mm H / THT / -	KEMET	ALH82A241DF5 50

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
14	2	C29, C60	2.2 uF	CAPRR2250W80L2650T14 50H2950B	CAP / FILM / 2.2uF / 630V / 20% / MKP (Metallized Polypropylene) / - / 22.50mm C X 0.80mm W 26.50mm L X 14.50mm T X 29.50mm H / THT / -	TDK Corporation	B32923H3225M000
15	4	C31, C32, C34, C39	100 nF	CAPC2013X135N	CAP / CERA / 100nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	Murata	GRM21BR71H104KA01
16	1	C33	470 uF	CAPPRD500W60D1000H2 150B	CAP / ELCO / 470uF / 35V / 20% / - / -55°C to 105°C / 5.00mm C X 0.60mm W 10.00mm Dia X 21.50mm H / THT / -	Würth Elektronik	8.60081E+11
17	2	C35, C46	100 uF	CAPPRD250W50D630H12 50B	CAP / ELCO / 100uF / 35V / 20% / Aluminium electrolytic / -40jãC to 85jãC / 2.50mm C X 0.50mm W 6.30mm Dia X 12.50mm H / THT / -	Würth Elektronik	8.60011E+11
18	2	C36, C37	1 uF	CAPC1608X50N	CAP / CERA / 1uF / 25V / 10% / X5R (EIA) / -55°C to 85°C / 0603(1608) / SMD / -	Murata	GRM185R61E105KA12
19	4	C38, C48, C57, C58	4.7 nF	CAPRR1000W60L1650T70 0H1950B	CAP / CERA / 4.7nF / / 20% / - / -55jãC to 125jãC / 10.00mm C X 0.60mm W 16.50mm L X 7.00mm T X 19.50mm H / THT / -	Vishay	AY1472M65Y5UC63L0
20	1	C40	10 nF	CAPC1608X90N	CAP / CERA / 10nF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GRM188R71E103KA01
21	1	C41	1 nF	CAPC1608X90N	CAP / CERA / 1nF / 25V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GRM188R71E102KA01
22	1	C42	100 nF	CAPC1608X95N-4	CAP / CERA / 100nF / 50V / 10% / X7R (EIA) / -55jãC to 125jãC / 0603(1608) / SMD / -	Würth Elektronik	8.85012E+11
23	11	C43, C47, C55, C56, C67, C70, C74, C114, C118, C125, C126	1 uF	CAPC2013X135N	CAP / CERA / 1uF / 50V / 10% / X7R (EIA) / -55jãC to 125jãC / 0805(2012) / SMD / -	Würth Elektronik	8.85012E+11
24	1	C44	10 uF	CAPC2012X135N	CAP / CERA / 10uF / 10V / 10% / X7R (EIA) / -55jãC to 125jãC / 0805(2012) / SMD / -	Würth Elektronik	8.85012E+11
25	1	C45	220 uF	CAPPRD250W50D630H12 50B	CAP / ELCO / 220uF / 16V / 20% / Aluminium electrolytic / -40jãC to 85jãC / 2.50mm C X 0.50mm W 6.30mm Dia X 12.50mm H / THT / -	Würth Elektronik	8.6001E+11
26	6	C49, C69, C71, C75, C119, C127	10 uF	CAPC2013X145N-0	CAP / CERA / 10uF / 50V / 10% / X5R (EIA) / -55jãC to 85jãC / 805(2012) / SMD / -	Murata	GRM21BR61H106KE43K

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
27	5	C52, C72, C76, C120, C128	10 uF	CAPC2013X95N	CAP / CERA / 10uF / 25V / 20% / X5R (EIA) / -55jāC to 85jāC / 0805(2012) / SMD / -	Murata	GRM219R61E10 6MA12
28	6	C53, C73, C81, C82, C84, C91	10 nF	CAPC2013X94N	CAP / CERA / 10nF / 50V / 10% / X7R (EIA) / -55°C to 125°C / 0805(2012) / SMD / -	AVX	08055C103K4Z2 A
29	3	C61, C63, C65	100 nF	CAPC1608X90N	CAP / CERA / 100nF / 50V / 5% / X7R (EIA) / -55jāC to 125jāC / 0603(1608) / SMD / -	Murata	GRM188R71H10 4JA93
30	3	C62, C64, C66	220 nF	CAPC1608X90N	CAP / CERA / 220nF / 25V / 5% / X7R (EIA) / -55jāC to 125jāC / 0603(1608) / SMD / -	Murata	GRM188R71E22 4JA88
31	2	C68, C116	10 uF	CAPC3216X180N	CAP / CERA / 10uF / 50V / 10% / X5R (EIA) / -55jāC to 85jāC / 1206(3216) / SMD / -	Murata	GRM31CR61H1 06KA12
32	2	C77, C78	100 nF	CAPC1608X90N	CAP / CERA / 100nF / 16V / 10% / X5R (EIA) / -55jāC to 85jāC / 0603(1608) / SMD / -	Murata	GRM188R61C10 4KA01
33	18	C79, C80, C85, C88, C90, C92, C93, C94, C97, C98, C100, C102, C103, C104, C105, C107, C111, C112	1 uF/50 V	CAPC2013X95N	CAP / CERA / 1uF/50V / 50V / 10% / X5R (EIA) / -55°C to 85°C / 0805(2012) / SMD / -	Murata	GRM219R61H10 5KA73
34	6	C83, C89, C95, C99, C106, C109	100 pF	CAPC1608X87N-1	CAP / CERA / 100pF / 50V / 5% / C0G (EIA) / NP0 / -55jāC to 125jāC / 0603(1608) / SMD / -	Würth Elektronik	8.85012E+11
35	2	C86, C87	1 uF/16 V	CAPC1608X87N-1	CAP / CERA / 1uF/16V / 16V / 10% / X7R (EIA) / -55jāC to 125jāC / 0603(1608) / SMD / -	Würth Elektronik	8.85012E+11
36	2	D1, D2	30 V	SOT95P237X111-3N	Dual Common Cathode Schottky Barrier Diodes	ON Semiconductor	BAT54CLT1G
37	10	D3, D4, D6, D8, D9, D12, D18, D20, D26, D28	BAS70-04	SOT95P240X110-3N-1	Silicon Schottky Diode	Infineon Technologies	BAS70-04
38	1	D5	Green	LED-THT-LTL-4232N	LED, High Intensity, General Purpose Lead	LiteOn Optoelectronics	LTL-4232N
39	5	D7, D10, D13, D21, D29	4.7 V	SOD3716X135N	Zener Voltage Regulator, 4.7V	ON Semiconductor	SZMMSZ4688T1 G
40	2	D11, D14	40V	SOD2513X110N	Medium Power AF Schottky Diode	Infineon Technologies	BAT165
41	2	D59, D60	5.6 V	SODFL1608X70N-1	Small Signal Zener Diodes, 5.6 V	Vishay	BZX584C5V6-V-G
42	9	DC-1, DC+1, MP1, MP2, MP3, MP4, MP5, MP6, MP32	7461057	CON-TER-THT-7461057	WP-BUTR REDCUBE PRESS-FIT, 100 A	Würth Elektronik	7461057
43	2	FAN1, FAN2	1125S-4P	CON-M-THT-1125S-4P	DIP Grove Female Header-White;4P-2.0, Straight	Shenzhen NS-Tech Co. Ltd	1125S-4P

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
44	1	G1	TLE42744GS V33	SOT230P700X180-4N-3	Monolithic integrated low dropout voltage regulator, device is designed for the harsh environment of automotive applications, very low current consumption, output current limitation, reverse polarity protection	Infineon Technologies	TLE42744GS V33
45	1	G2	LMR51420YF DDCR	SOT95P280X110-6N-1	Simple Switcher Power Converter, Synchronous Buck Converter	Texas Instruments	LMR51420YFDD CR
46	10	L1, L3, L7, L8, L9, L15, L17, L18, L21, L22	68 uH	INDC2016X95N_LQH2MC_02	IND / STD / 68uH / 100mA / 10% / -40jãC to 85jãC / 8.58R / 0805(2012) / Inductor, Chip; 2.00mm L X 1.60mm W X 0.95mm H / SMD / -	Murata	LQH2MCN680K 02
47	2	L2, L10	100R	INDC4532X345N	IND / FERR / 100R / 8A / 25% / -55jãC to 125jãC / 6mR / 1812(4532) / Inductor, Chip; 4.50mm L X 3.20mm W X 2.55mm H / SMD / -	Würth Elektronik	74279226101
48	1	L6	33 uH	IND-SMD-LPS6225	IND / STD / 33uH / 1.2A / 20% / -40°C to 85°C / 260mR / SMD / Inductor, SMD; 2 pins, 6.00 mm L X 6.00 mm WX 2.50 mm H body / SMD / -	Coilcraft	LPS6225-333MRB
49	4	L11, L12, L13, L14	650R/2.5 A	INDC3216X130N	IND / FERR / 650R/2.5A / 2.5A / 25% / -55jãC to 125jãC / 70mR / 1206(3216) / Inductor, Chip; 3.20mm L X 1.60mm W X 1.30mm H / SMD / -	Würth Elektronik	742792118
50	1	MP7	110uH	IND-PI240866V1	IND / STD / 110uH / 45.3A / - / - / 7.16mR / THT / IND, 79.50 mm L X 233.122 mm W X 66.82 mm H body / THT / -	POCO Holding Co., Ltd	PI240866V1
51	13	MP8, MP9, MP10, MP11, MP12, MP13, MP14, MP24, MP29, MP30, MP31, MP46, MP47	RM3X10MM 2701	SCREW_M3X10_RM3X10M M 2701	Pan Head Screw, M3X10 mm	APM Hexseal	RM3X10MM 2701
52	4	Q1, Q2, Q3, Q4	IGOT65R025 D2	SOIC127P1420X350-20N-V	CoolGaN™ Transistor 650 V G5	Infineon Technologies	IGOT65R025D2
53	2	Q7, Q8	BSS138N	SOT95P240X110-3N-1-V1	N-channel small signal transistor	Infineon Technologies	BSS138N
54	5	R1, R33, R53, R140, R154	1k	RESC2013X60N-1	RES / STD / 1k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Bourns	CRM0805-FW-1001 E LF

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
55	6	R2, R7, R9, R14, R15, R16	200R	RESC2113X50N	RES / STD / 200R / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Vishay	CRCW0805200R FK
56	11	R3, R4, R5, R6, R8, R10, R58, R60, R84, R95, R100	10k	RESC1608X55N-1	RES / STD / 10k / 100mW / 1% / 100ppm/K / -55jāC to 155jāC / 0603(1608) / SMD / -	Yageo	RC0603FR-0710KL
57	2	R11, R12	100R	RESC1608X55N-1	RES / STD / 100R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo	RC0603FR-07100RL
58	1	R13	10k	RESC1609X50N	RES / STD / 10k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060310K0 FKEA
59	1	R18	0R	RESC3116X65N-6	RES / STD / 0R / 250mW / 5% / - / -55°C to 155°C / 1206(3216) / SMD / -	Yageo	RC1206JR-070RL
60	2	R19, R52	10k	RESC1608X55N-1	RES / STD / 10k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Panasonic	ERJUP3F1002V
61	4	R20, R22, R25, R28	33k	RESC1609X50N	RES / STD / 33k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060333K0 FK
62	2	R21, R32	7.15k	RESC1609X50N	RES / STD / 7.15k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW06037K15 FK
63	1	R27	750k	RESC1609X50N	RES / STD / 750k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW0603750K FK
64	2	R29, R138	10k	RESC2113X50N	RES / STD / 10k / 125mW / 1% / 100ppm/K / -55jāC to 155jāC / 0805(2012) / SMD / -	Vishay	CRCW080510K0 FK
65	8	R30, R31, R34, R35, R40, R41, R44, R45	150k	RESC3216X60N	RES / STD / 150k / 250mW / 1% / 100ppm/K / -55jāC to 155jāC / 1206(3216) / SMD / -	Vishay	CRCW1206150K FK
66	1	R36	22.1k	RESC1609X50N	RES / STD / 22.1k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060322K1 FK
67	3	R37, R142, R155	2R/250mW	RESC3216X60N	RES / STD / 2R/250mW / 250mW / 1% / 100ppm/K / -55jāC to 155jāC / 1206(3216) / SMD / -	Vishay	CRCW12062R00 FK
68	2	R38, R143	47k	RESC2113X50N	RES / STD / 47k / 125mW / 1% / 100ppm/K / -55jāC to 155jāC / 0805(2012) / SMD / -	Vishay	CRCW080547K0 FK
69	4	R46, R48, R50, R70	2.55R	RESC2113X50N	RES / STD / 2.55R / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Vishay	CRCW08052R55 FK

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
70	4	R47, R49, R56, R71	5.1R	RESC2013X70N-1	RES / STD / 5.1R / 500mW / 5% / 600ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Panasonic	ERJP06J5R1V
71	2	R51, R72	0R	RESC2013X60N	RES / STD / 0R / 125mW / 0R / 0ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Yageo	RC0805JR-070RL
72	2	R54, R55	1.02k	RESC1609X50N	RES / STD / 1.02k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW06031K02FK
73	2	R57, R73	10R	RESC2013X60N	RES / STD / 10R / 130mW / 1% / 200ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Yageo	RC0805FR-0710RL
74	3	R59, R61, R85	499R	RESC1609X50N	RES / STD / 499R / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW0603499R FK
75	14	R62, R65, R68, R69, R147, R148, R149, R150, R151, R153, R158, R159, R164, R165	0R	RESC1608X55N-1	RES / STD / 0R / 100mW / 0R / 0ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo	RC0603JR-070RL
76	2	R74, R75	0R	RESC1609X55N-5	RES / STD / 0R / 125mW / - / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	MCT06030Z000 0ZP500
77	6	R76, R77, R78, R79, R80, R81	2MEG	RESC3216X60N	RES / STD / 2MEG / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW12062M0 0FK
78	12	R89, R90, R101, R102, R107, R108, R115, R116, R124, R125, R127, R128	100R / 250 mW	RESC3216X60N	RES / STD / 100R / 250mW / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW1206100R FK
79	16	R91, R92, R131, R133, R134, R136, R137, R139, R141, R146, R160, R161, R162, R163, R166, R167	10R	RESC1608X55N-1	RES / STD / 10R / 100mW / 1% / 200ppm/K / -55°C to 155°C / 0603(1608) / SMD / -, RES / STD / 10R / 100mW / 1% / 200ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo	RC0603FR-0710RL
80	2	R93, R94	23.7k	RESC2113X50N	RES / STD / 23.7k / 125mW / 1% / 100ppm/K / -55°C to 155°C / 0805(2012) / SMD / -	Vishay	CRCW080523K7 FK
81	3	R96, R98, R99	5k	NTCC2013X95N	RES / NTC / 5k / 210mW / 3% / - / -55°C to 150°C / 0805(2012) / SMD / -	Vishay	NTCS0805E350 2HLT
82	6	R97, R103, R110, R117, R130, R132	1k	RESC1609X50N	RES / STD / 1k / 100mW / 1% / 100ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW06031K00 FK

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
83	12	R104, R105, R106, R109, R111, R112, R113, R114, R118, R119, R120, R121	20R	RESC6332X70N	RES / STD / 20R / 1W / 1% / 100ppm/K / -55°C to 155°C / 2512(6432) / SMD / -	Vishay	CRCW251220R0 FK
84	10	R122, R123, R126, R168, R169, R170, R171, R172, R178, R179	953k	RESC3216X60N	RES / STD / 953k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW1206953K FK
85	2	R129, R173	17.4k	RESC3216X60N	RES / STD / 17.4k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW120617K4 FK
86	2	R174, R176	681k	RESC3216X60N	RES / STD / 681k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW1206681K FK
87	2	R175, R177	1.5k	RESC3216X60N	RES / STD / 1.5k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW12061K50 FK
88	4	R223, R224, R225, R226	499k	RESC3216X60N	RES / STD / 499k / 250mW / 1% / 100ppm/K / -55°C to 155°C / 1206(3216) / SMD / -	Vishay	CRCW1206499K FK
89	3	TR1, TR2, TR3	-	WE-GDTI_EP7	WE-GDTI SMT Gate-Drive-Transformer, EP7, 735uH, 1.5:1:1, 80VDC	Würth Elektronik	-
90	1	U1	LMV721M5/ NOPB	SOT95P280X145-5N-2	Low noise, low voltage, and low power operational amplifier	Texas Instruments	LMV721M5/NOPB
91	2	U2, U3	SN74HC08D R	SOIC127P600X175-14N-1	Quadruple 2-Input Positive-AND Gate	Texas Instruments	SN74HC08DR
92	1	U4	1ED3240MC 12H	SOIC127P1030X265-8N-1-V	Single-channel 5.7 kV (rms) isolated gate driver IC with 2L-SRC	Infineon Technologies	1ED3240MC12H
93	2	U6, U14	-	SOP65P490X104-9N-V2	Full-bridge transformer driver for IGBT and SiC MOSFET gate driver supply	Infineon Technologies	2EP130R
94	6	U7, U8, U9, U10, U12, U13	1EDB7275F	SOIC127P600X175-8N-10	Single-channel isolated gate-driver ICs	Infineon Technologies	1EDB9275F

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
95	20	X1, X17, X20, X30, X31, X33, X35, X36, X39, X40, X43, X44, X50, X52, X55, X57, X63, X70, X74, X76	+3.3V, PWM_IN_B_Q3, Temp2, +24V_FAN, +24V, PWM_IN_A_Q4, PWM_IN_A_Q1, PWM_IN_B_Q2, Grid_OCD1_FLT, Grid-A_AOUT, PWM_IN_C_S1, PWM_IN_C_S2, PWM_KILL, Temp3, INV_OCD1_FLT, INV-A_AOUT, Temp1, +5VD, +5VA	CON-THT-TP-5002	Test Point THT, White	Keystone Electronics Corp.	5002
96	1	X14	61300421821	CON-F-THT-61300421821	WR PHD Dual Socket Header, 4Pins, 2.54mm Pitch, 3A, 250VAC	Würth Elektronik	61300421821
97	1	X16	61300621821	CON-F-THT-61300621821	WR-PHD Dual Socket Header, 6 Position, 3A, 250VAC	Würth Elektronik	61300621821
98	2	X21, X22	62505022021	CON-M-THT-62505022021	WR-BHD Male Box Header, 2.00 mm Pitch, 50 Pins, Dual Row, 2A, 250VAC	Würth Elektronik	62505022021
99	1	X23	20020316-G021B01LF	CON-TER-THT-20020316-G021B01LF	Conn Terminal Block 2 POS 5mm Solder ST Thru-Hole 16A/Contact Box	Amphenol	20020316-G021B01LF
100	4	X25, X32, X73, X75	GND_FAN, GND, DGND, AGND	CON-THT-TP-5001	Test Point THT, Black	Keystone Electronics Corp.	5001
101	13	MP8, MP9, MP10, MP11, MP12, MP13, MP14, MP24, MP29, MP30, MP31, MP46, MP47	Screw	-	-	APM Hexseal	RM3X10MM 2701
102	1	HS	Heatsink	-	Anodized Aluminum	Custom Made	-
103	1	TP	Thermal Pad	-	GAP PAD, 8inx16in Sheet	Bergquist Company	951-GPVOUS-060-00
104	1	IB	Inductor Brace	-	LHS/RHS	Custom Made	-
105	2	ST	Stand offs	-	Alum/Hex/.24in/2-.5in	Lyn-tron	AA6980-2.500-00
106	2	STS	Stand off Screws	-	MACH SCREW TRUSS PHIL M2.5X0.45	Kanebridge	4753-MJ2.58MPTA2-ND

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Table 7 BOM of the auxiliary supply board

#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
1	10	C1, C4, C5, C6, C7, C8, C9, C20, C22, C23	10 uF/50 V	CAPC2013X145N-0	CAP / CERA / 10uF/50V / 50V / 10% / X5R (EIA) / -55jāC to 85jāC / 805(2012) / SMD / -	Murata	GRM21BR61H1 06KE43K, GRM21BR61H1 06KE43L
2	1	C2	200 pF/50 V	CAPC1608X90N	CAP / CERA / 200pF/50V / 50V / 5% / COG (EIA) / NP0 / -55jāC to 125jāC / 0603(1608) / SMD / -	Murata	GCM1885C1H20 1JA16
3	1	C3	100 nF/50 V	CAPC2013X88N	CAP / CERA / 100nF/50V / 50V / 10% / X7R (EIA) / -55jāC to 125jāC / 0805(2012) / SMD / -	Würth Elektronik	885012207098
4	1	C10	100 nF/50 V	CAPC1608X90N	CAP / CERA / 100nF/50V / 50V / 5% / X7R (EIA) / -55jāC to 125jāC / 0603(1608) / SMD / -	Murata	GRM188R71H10 4JA93
5	1	C11	100 pF/50 V	CAPC2013X70N-1	CAP / CERA / 100pF/50V / 50V / 5% / COG (EIA) / NP0 / -55jāC to 125jāC / 0805(2012) / SMD / -	Würth Elektronik	885012007057
6	2	C12, C13	22 uF/16 V	CAPC1608X80N	CAP / CERA / 22uF/16V / 16V / 20% / X5R (EIA) / -55jāC to 85jāC / 0603(1608) / SMD / -	Samsung	CL10A226M07J ZNC
7	1	CH1	6130062102 1	CON-M-THT-61300621021	WR-PHD Angled Dual Pin Header	Würth Elektronik	61300621021
8	1	CH2	6130042102 1	CON-M-THT-61300421021	Angled Dual Pin Header, 2.54mm Pitch, 4 Pins	Würth Elektronik	61300421021
9	1	D1	12 V Vz/10 m A If	SOD2513X120N	Surface Mount Zener Diode	Diodes Incorporated	BZT52C12S-7-F
10	3	D2, D4, D5	40 V Vr/1A If	SOD2513X110N-1	Very low VF MEGA Schottky barrier rectifier	Nexperia	PMEG4010BEA, 115
11	1	D3	75 V Vr/10 mA If	SODFL1608X70N	High Conductance Fast Switching Diode	ON Semiconductor	1N4148WT
12	2	D6, D7	40V Vr/3A If	SODFL3618X143N	Schottky Barrier Rectifiers, Surface Mount, 3A, 40V	ON Semiconductor	SS34FA
13	1	D8	Green/12 V Vr/20 mA If	LEDSC160X80X80-2N	Surface Mount LED, Green, 570nm	OSRAM Opto Semiconductors	LG Q971-KN-1
14	1	G1	TPS565201D DCT	SOT95P280X110-6N-1	-	Texas Instruments	TPS565201DDC T
15	1	L1	15 uH	IND_XAL4040-XXXMEX	IND / STD / 15uH / 2.8A / 20% / -40jāC to 125jāC / 120mR / SMD / Inductor, SMD; 2-Leads, 4mm L X 4mm W X 4.1mm H body / SMD / -	Coilcraft	XAL4040-153MEC
16	1	L2	10 uH	IND-SMD-78438367100	IND / STD / 10uH / 4.8A / 20% / -40jāC to 125jāC / 70.2mR / SMD / Inductor, SMD, 3.90 mm Pitch, 2 pin, 5.40 mm L X 5.40 mm W X 3.10 mm H body / SMD / -	Würth Elektronik	78438367100
17	2	MP, MP1	ELP18-4-10	ELP18-4-10	Ferrite Core and Accessories	TDK Corporation	ELP18-4-10
18	1	Q1	IRF7351	SOIC127P600X175-8N-12-V	HEXFET™ power MOSFET	Infineon Technologies	IRF7351

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#	Qty	Designator	Value	Footprint	Description	Manufacturer	Manufacturer order number
19	2	R1, R10	10k/100 mW	RESC1609X50N	RES / STD / 10k/100mW / 100mW / 1% / 100ppm/K / -55jāC to 155jāC / 0603(1608) / SMD / -	Vishay	CRCW060310K0 FKEA
20	1	R2	1k	RESC3216X60N	RES / STD / 1k / 250mW / 1% / 100ppm/K / -55jāC to 155jāC / 1206(3216) / SMD / -	Vishay	CRCW12061K00 FKTA
21	2	R3, R4	10R/125 mW	RESC2113X50N	RES / STD / 10R/125mW / 125mW / 1% / 100ppm/K / -55jāC to 155jāC / 0805(2012) / SMD / -	Vishay	CRCW080510R0 FK
22	2	R5, R6	47R/125 mW	RESC2113X50N	RES / STD / 47R/125mW / 125mW / 1% / 100ppm/K / -55jāC to 155jāC / 0805(2012) / SMD / -	Vishay	CRCW080547R0 FK
23	1	R7	11k	RESC1609X50N	RES / STD / 11k / 100mW / 1% / 100ppm/K / -55jāC to 155jāC / 0603(1608) / SMD / -	Vishay	CRCW060311K0 FK
24	1	R8	2k/125 mW	RESC2113X50N	RES / STD / 2k/125mW / 125mW / 1% / 100ppm/K / -55jāC to 155jāC / 0805(2012) / SMD / -	Vishay	CRCW08052K00 FK
25	1	R9	1.96k	RESC1609X50N	RES / STD / 1.96k / 100mW / 1% / 100ppm/K / -55jāC to 155jāC / 0603(1608) / SMD / -	Vishay	CRCW06031K96 FK
26	1	U1	IRS27952	SOIC127P600X175-8N-12-V	Resonant half-bridge converter control IC	Infineon Technologies	IRS27952

4 All-GaN HERIC switching states

4 All-GaN HERIC switching states

4.1 UPF load operation: Positive half-line cycle

The following five switching states are used in the PWM scheme of the all-GaN HERIC during positive half-line cycle. During the positive half-line cycle, switches Q1, Q4, and BDS are operated while switches Q3 and Q2 remain off.

The switching states shown in Figure 28 to Figure 32 illustrate switching states of switches and flow of current through these switches during unity power-factor (UPF) load operation. During UPF operation, load current polarity is same as the voltage in either of half-line cycle. During this operation, full-bridge switches are hard-switched contributing to switching as well as conduction losses while BDS is soft-switched during this operating condition.

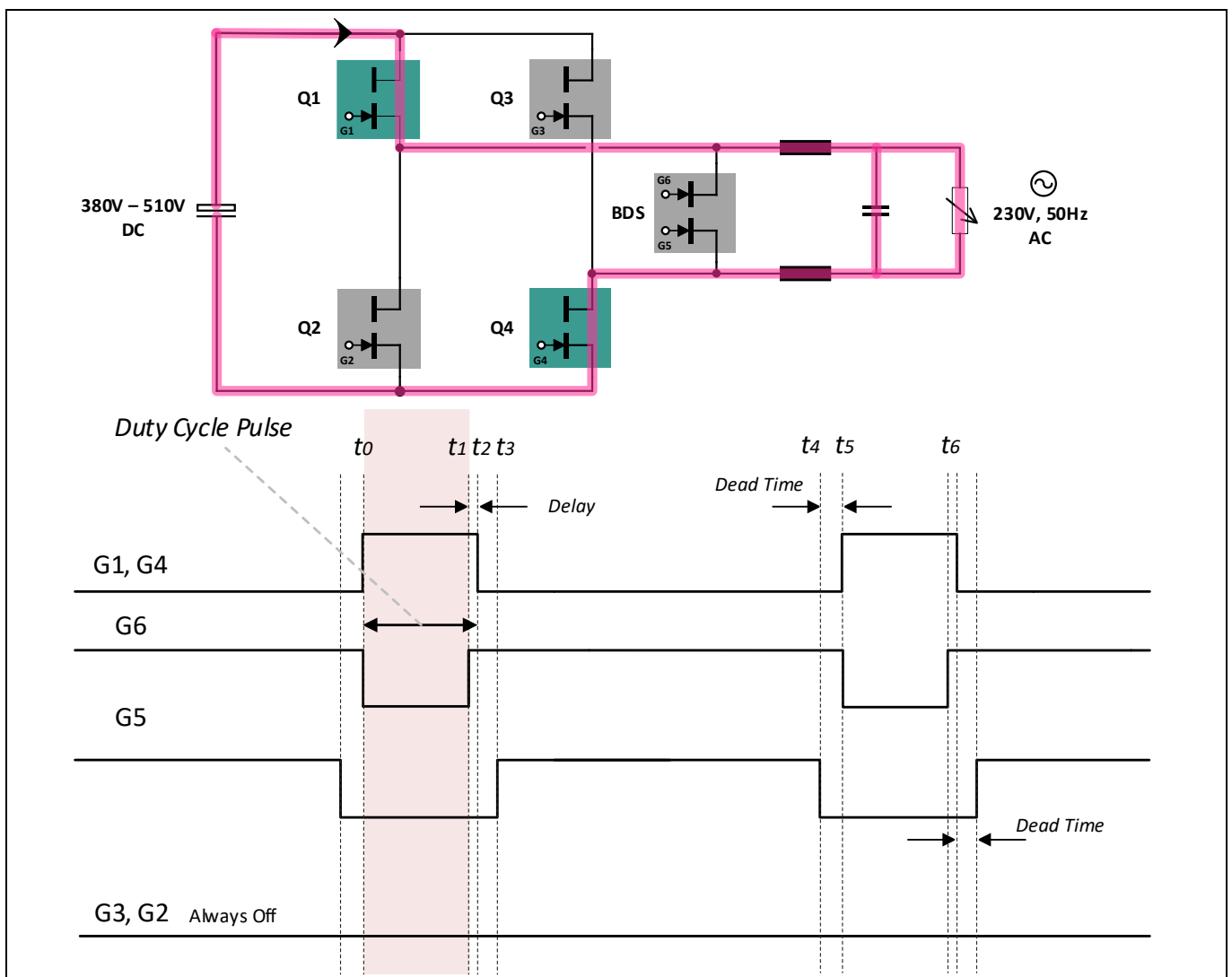


Figure 28 State 1 (Time t_0 to t_1)

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4 All-GaN HERIC switching states

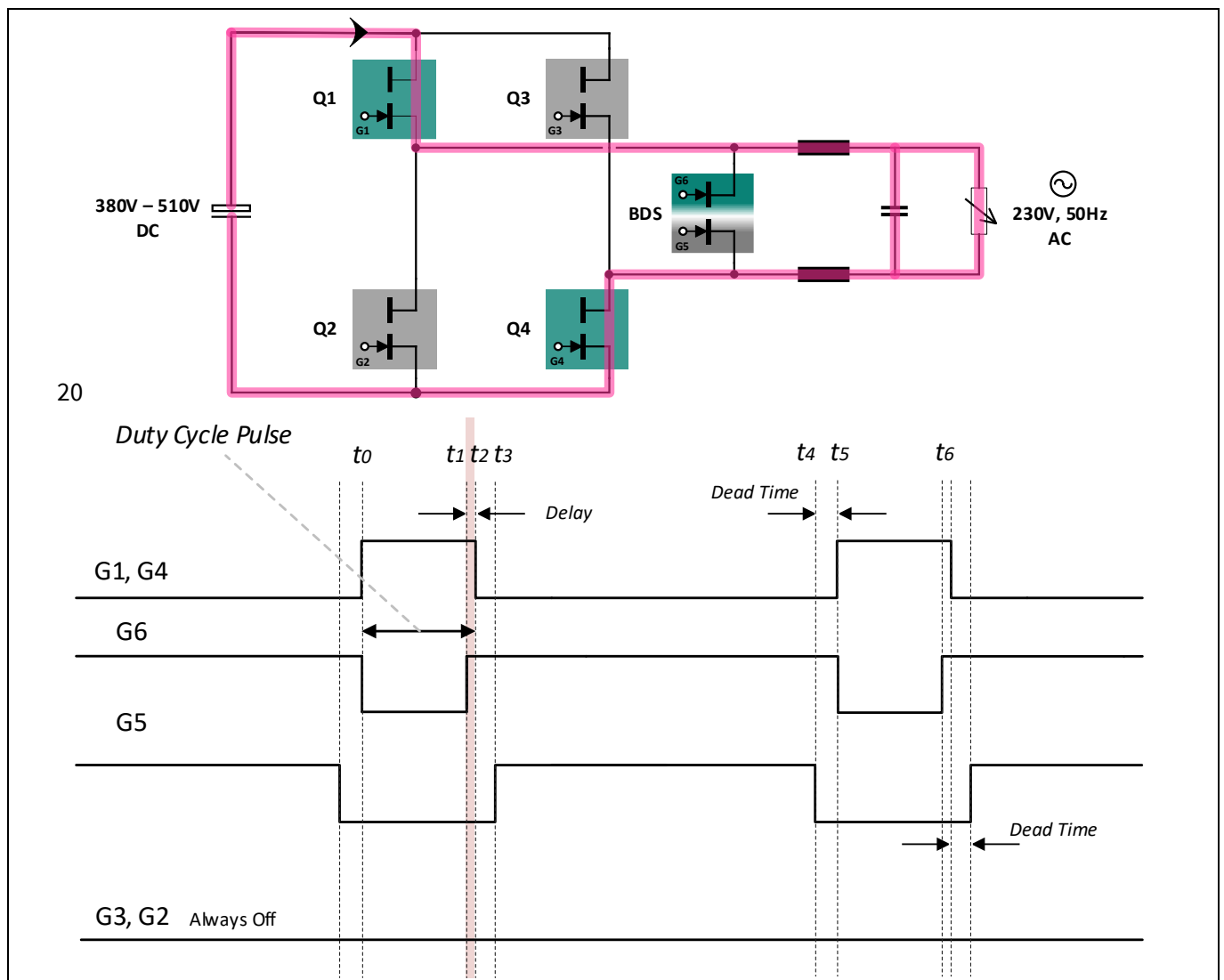


Figure 29 State 2 (Time t_1 to t_2)

4 All-GaN HERIC switching states

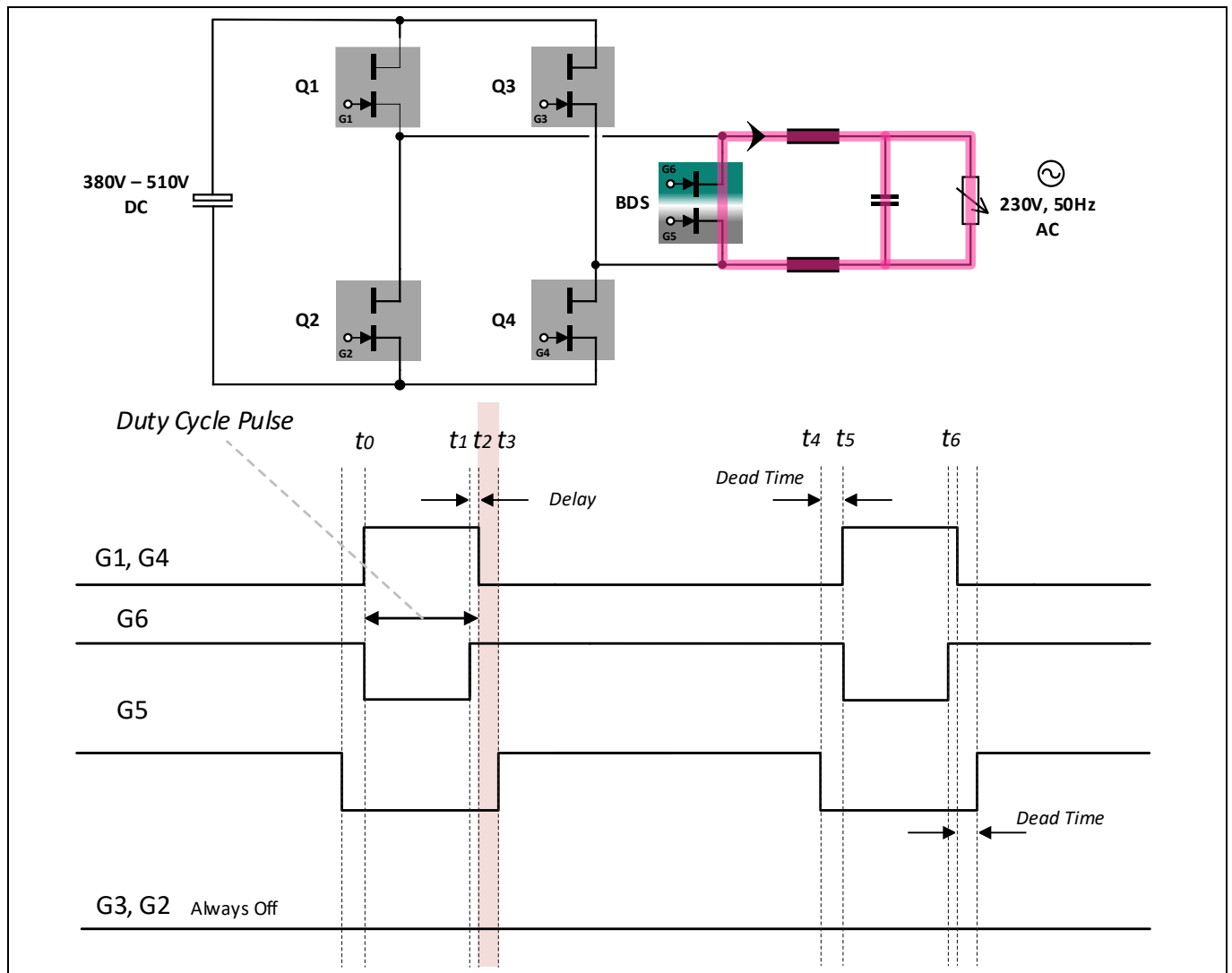


Figure 30 State 3 (Time t_2 to t_3)

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4 All-GaN HERIC switching states

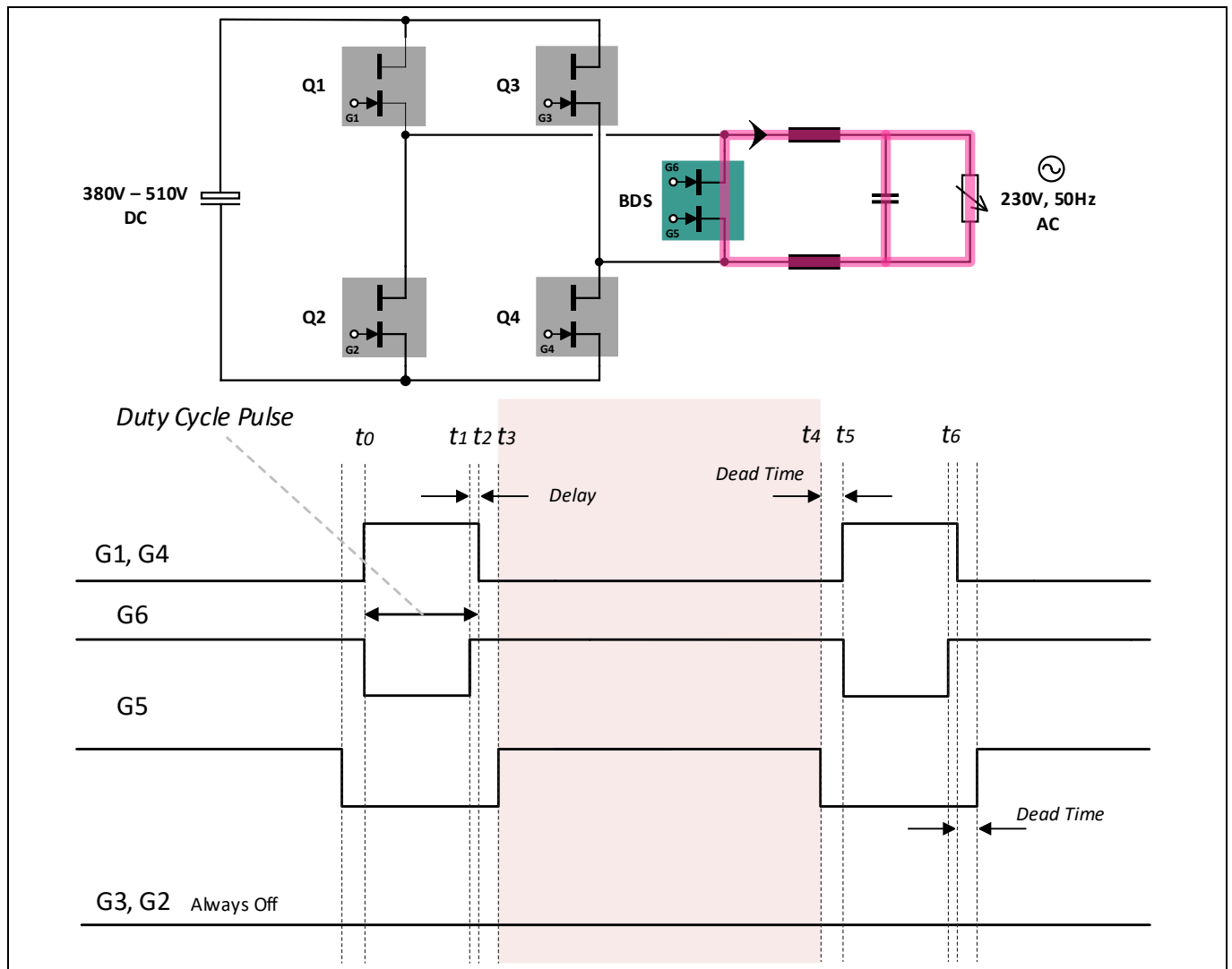


Figure 31 State 4 (Time t_3 to t_4)

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4 All-GaN HERIC switching states

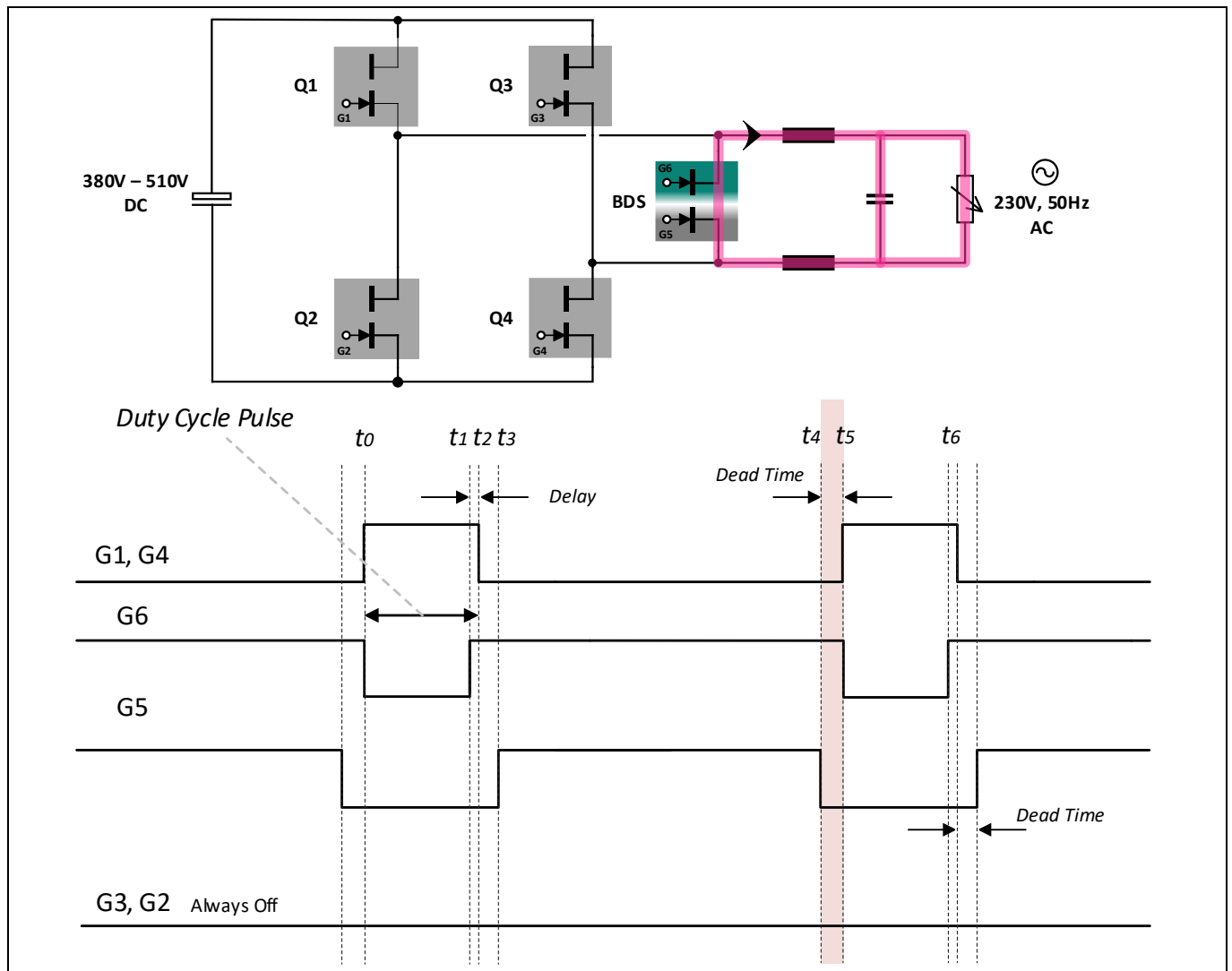


Figure 32 State 5 (Time t_4 to t_5)

4 All-GaN HERIC switching states

4.2 Non-UPF load operation: Negative load current during positive half cycle

Figure 33 to Figure 38 show the operating state of switches during positive half-line cycle with non-unity power factor (UPF) load and in the region where the load current is negative while voltage is positive. Operating region is marked in Figure 32.

During non-UPF operation and in the region where the load current is negative and voltage is positive, full-bridge switches (Q1–Q4) are soft-switched while BDS is hard-switched, contributing to both switching and conduction losses.

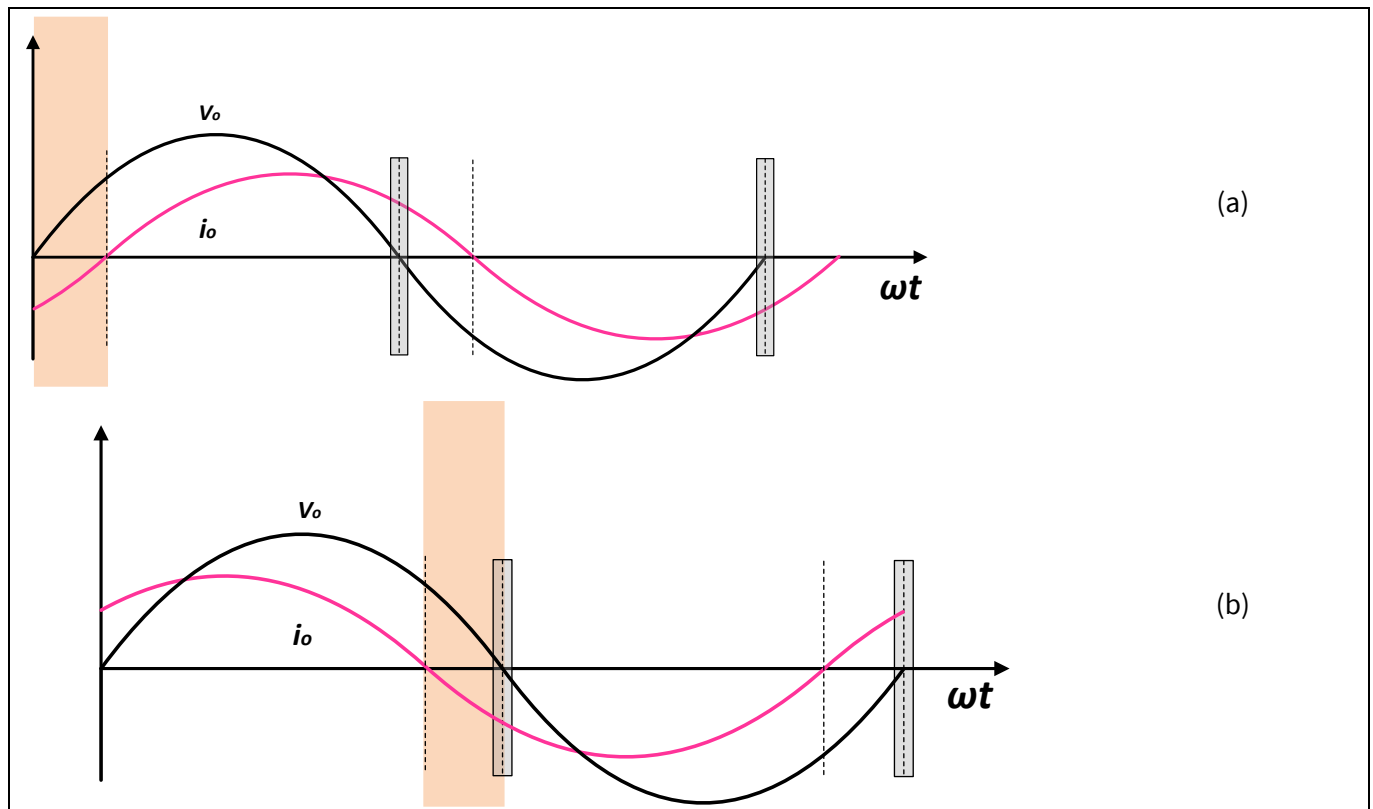


Figure 33 Output voltage and current waveform of inverter with (a) lagging PF (b) leading PF

4 All-GaN HERIC switching states

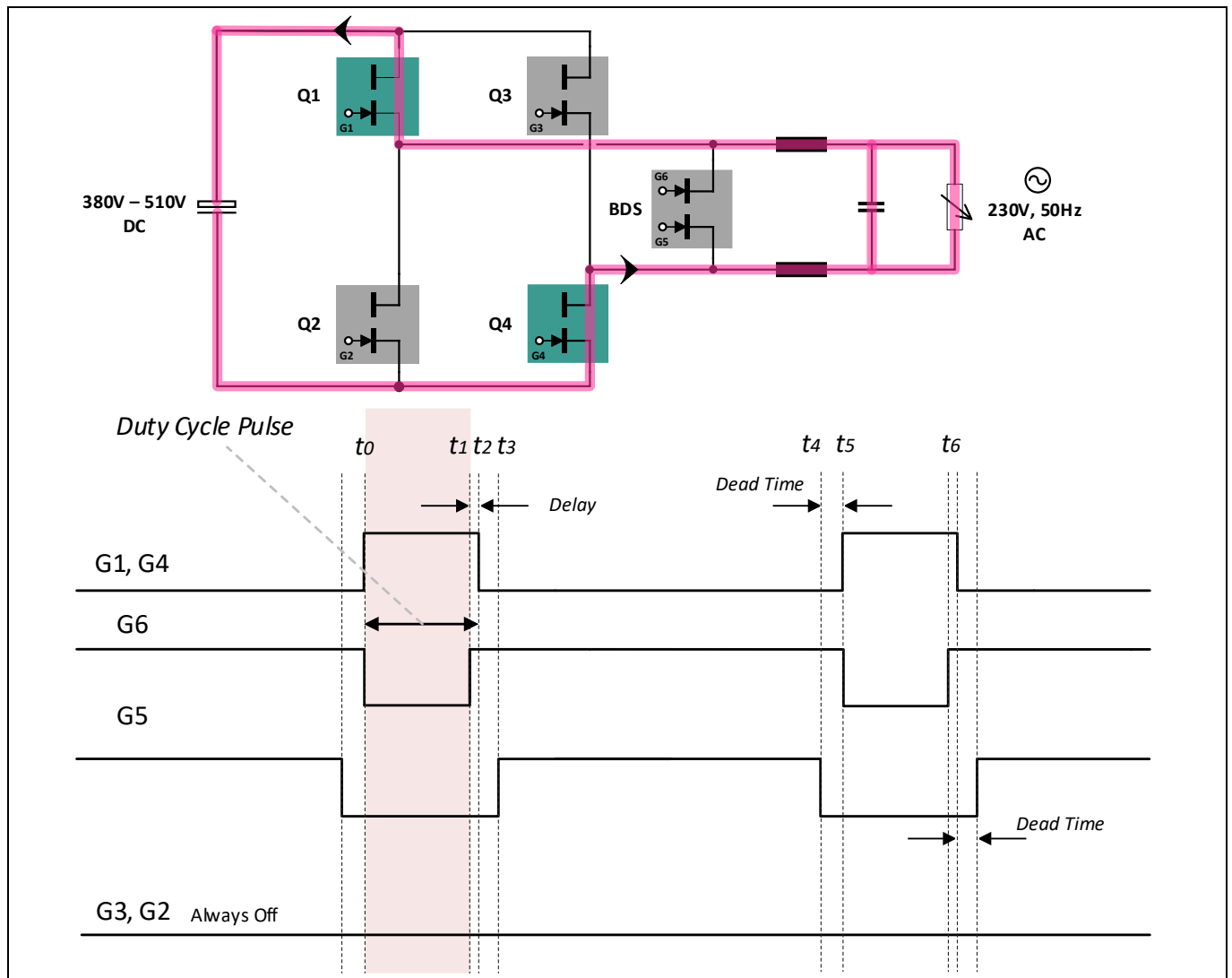


Figure 34 State 1 (Time t_0 to t_1)

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4 All-GaN HERIC switching states

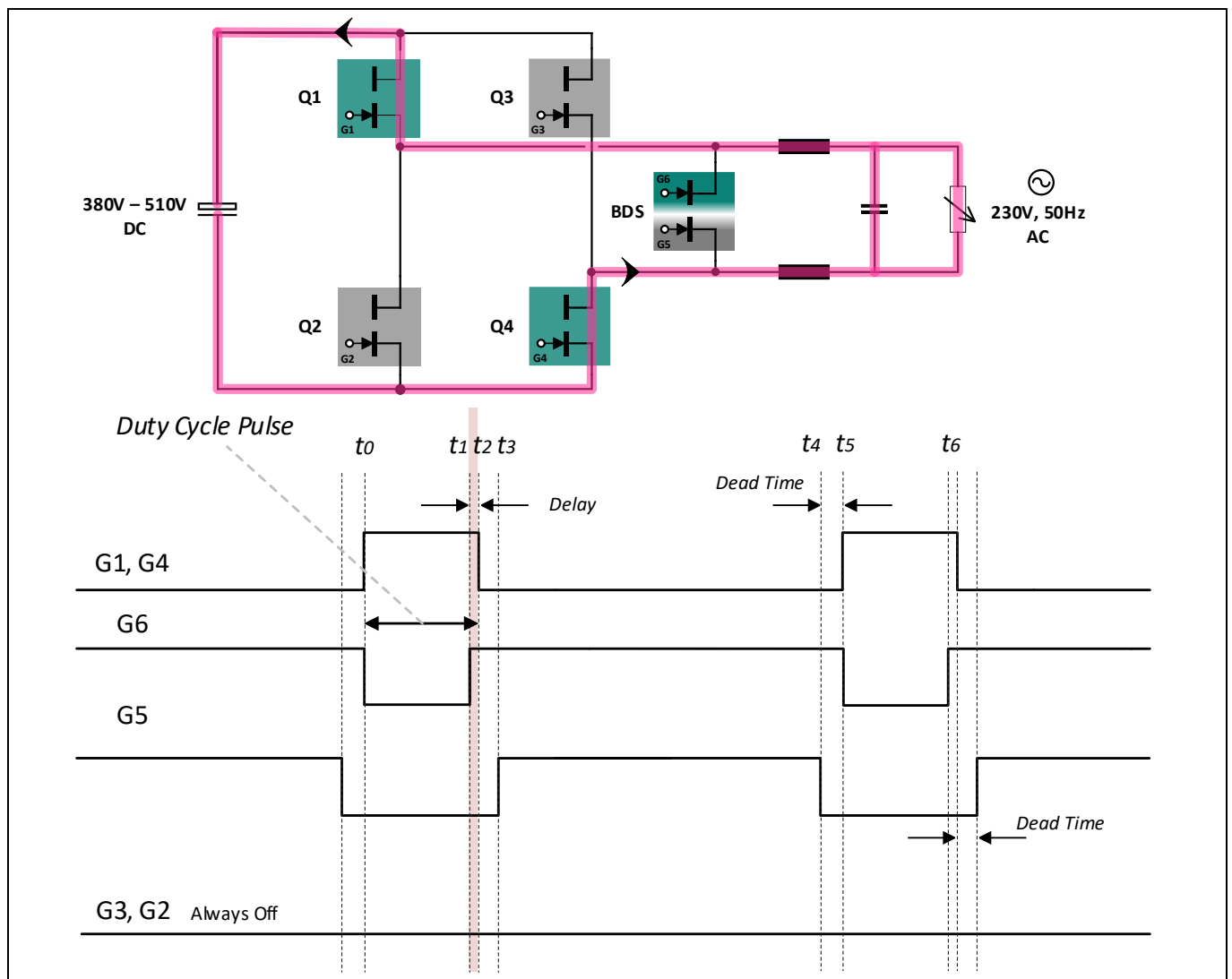


Figure 35 State 2 (Time t_1 to t_2)

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4 All-GaN HERIC switching states

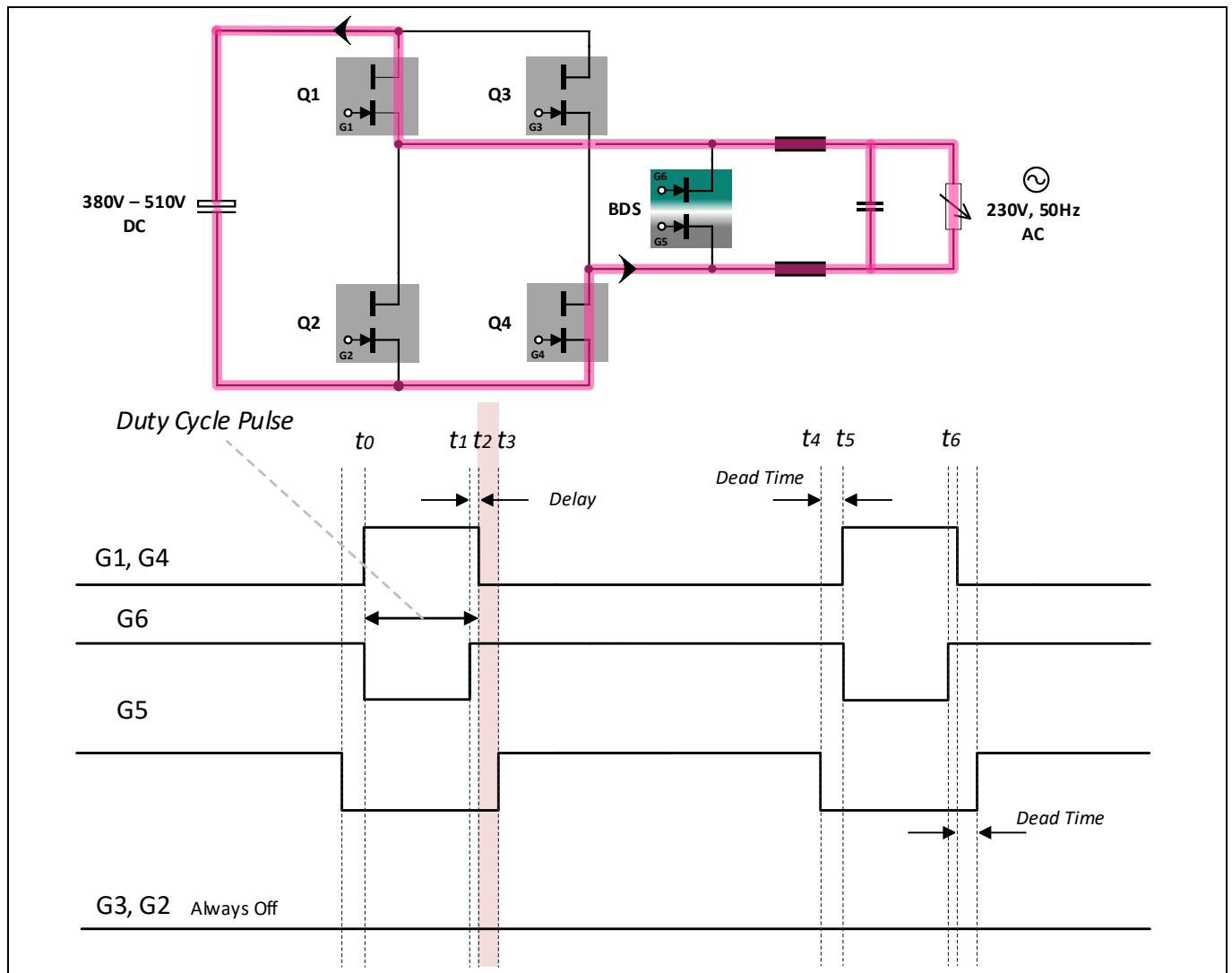


Figure 36 State 3 (Time t_2 to t_3)

4 All-GaN HERIC switching states

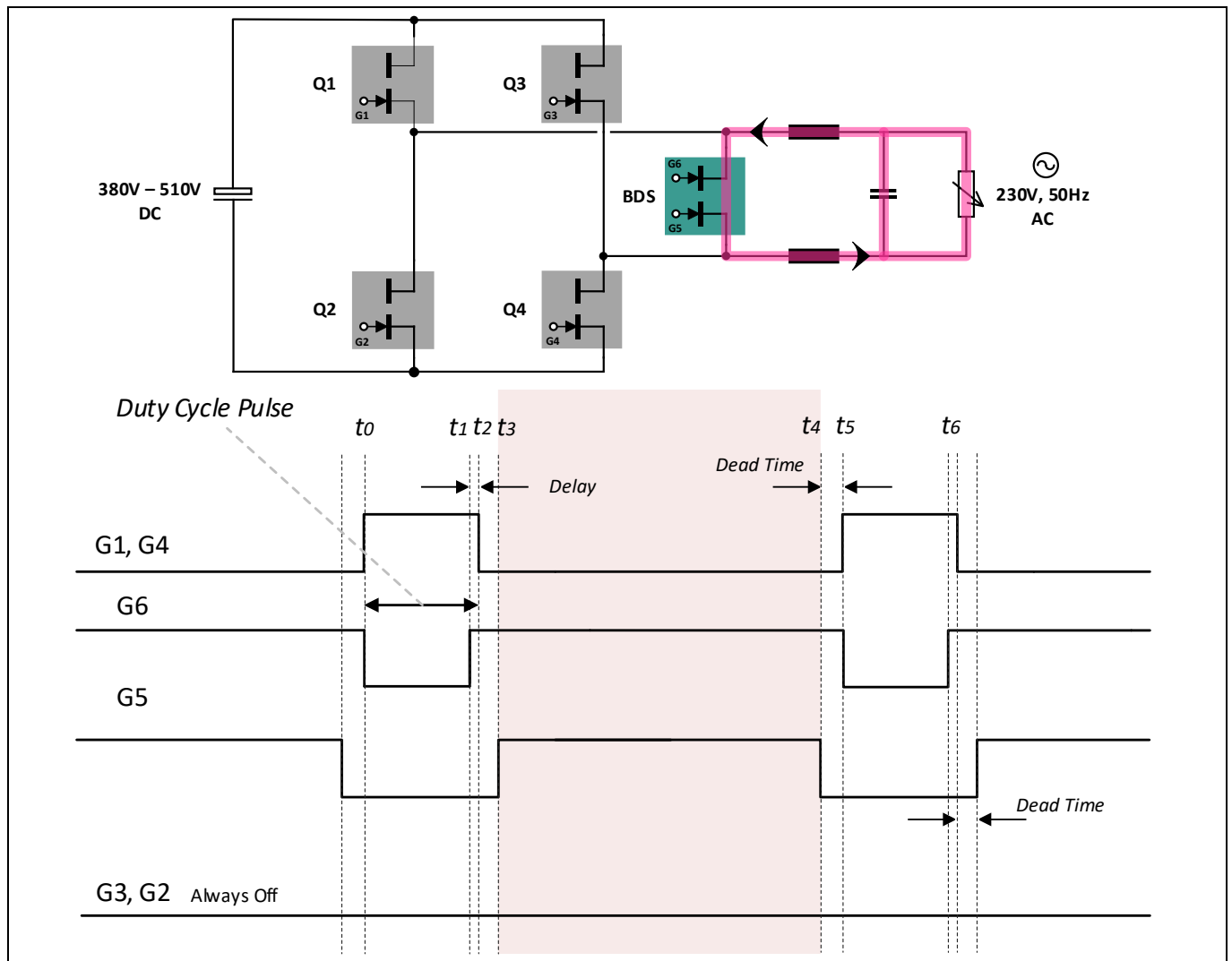


Figure 37 State 4 (Time t_3 to t_4)

4 All-GaN HERIC switching states

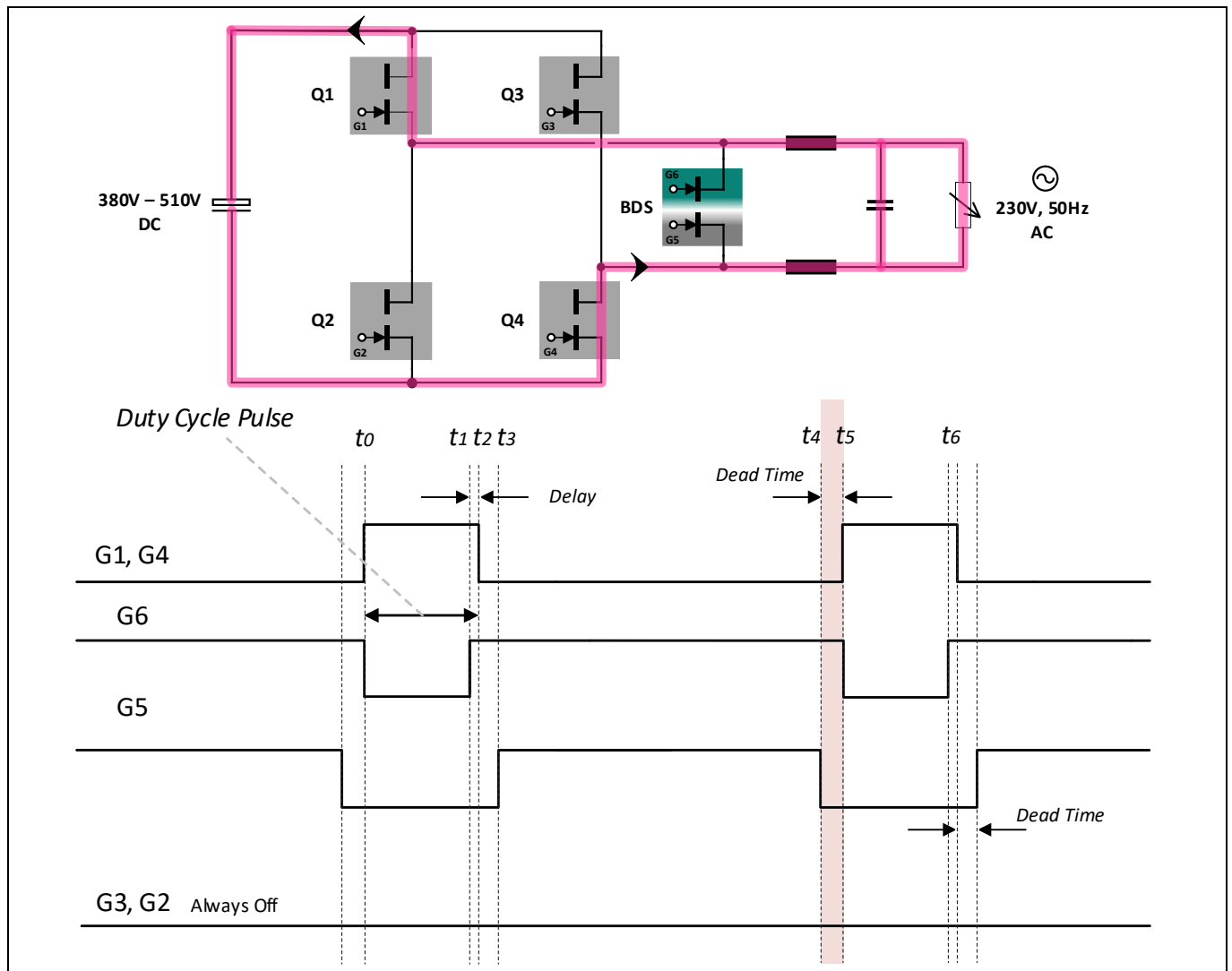


Figure 38 State 5 (Time t_4 to t_5)

Similarly, during negative half line cycle operation, switches Q1 and Q4 remains off while Q3, Q2, and BDS are switched at high frequency. Overall switching scheme for all-GaN HERIC is shown in [Figure 39](#).

4 All-GaN HERIC switching states

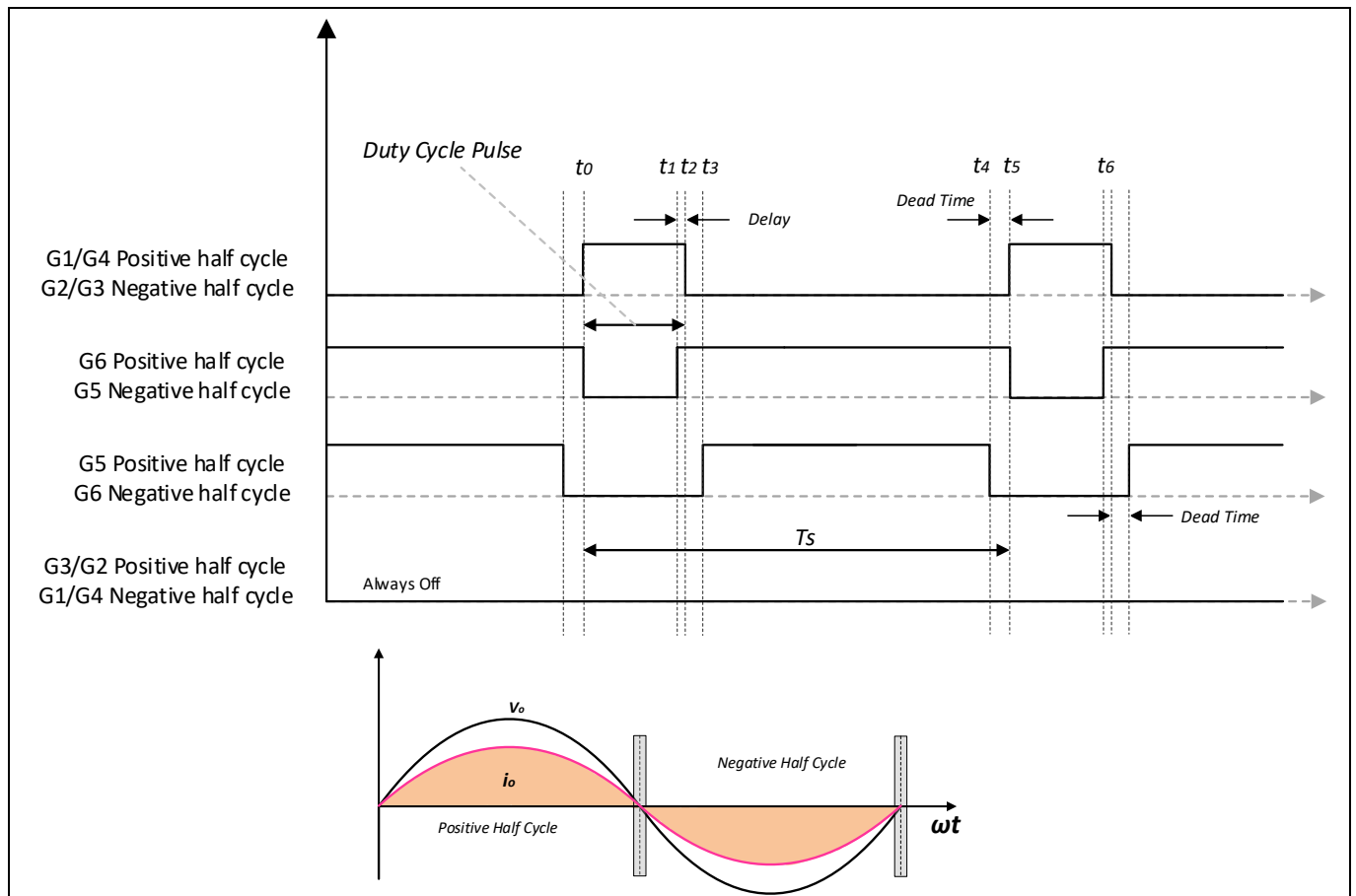


Figure 39 Switching scheme for all-GaN HERIC

5 Testing the design

5 Testing the design

The EVAL_3kW_GaN_HERIC evaluation board is tested using the XMC7200-based power control board reference design REF-CLBXMC7PEC that can be purchased separately. It is operated in an off-grid mode and tested using a resistive and reactive load.

5.1 Control

The firmware allows you to operate the HERIC in an open/close loop using the SPWM scheme. The firmware also allows you to change the modulation index.

5.2 HERIC Debugger graphical user interface

The HERIC Debugger provides a GUI which can control and monitor the application in run-time (Figure 40).

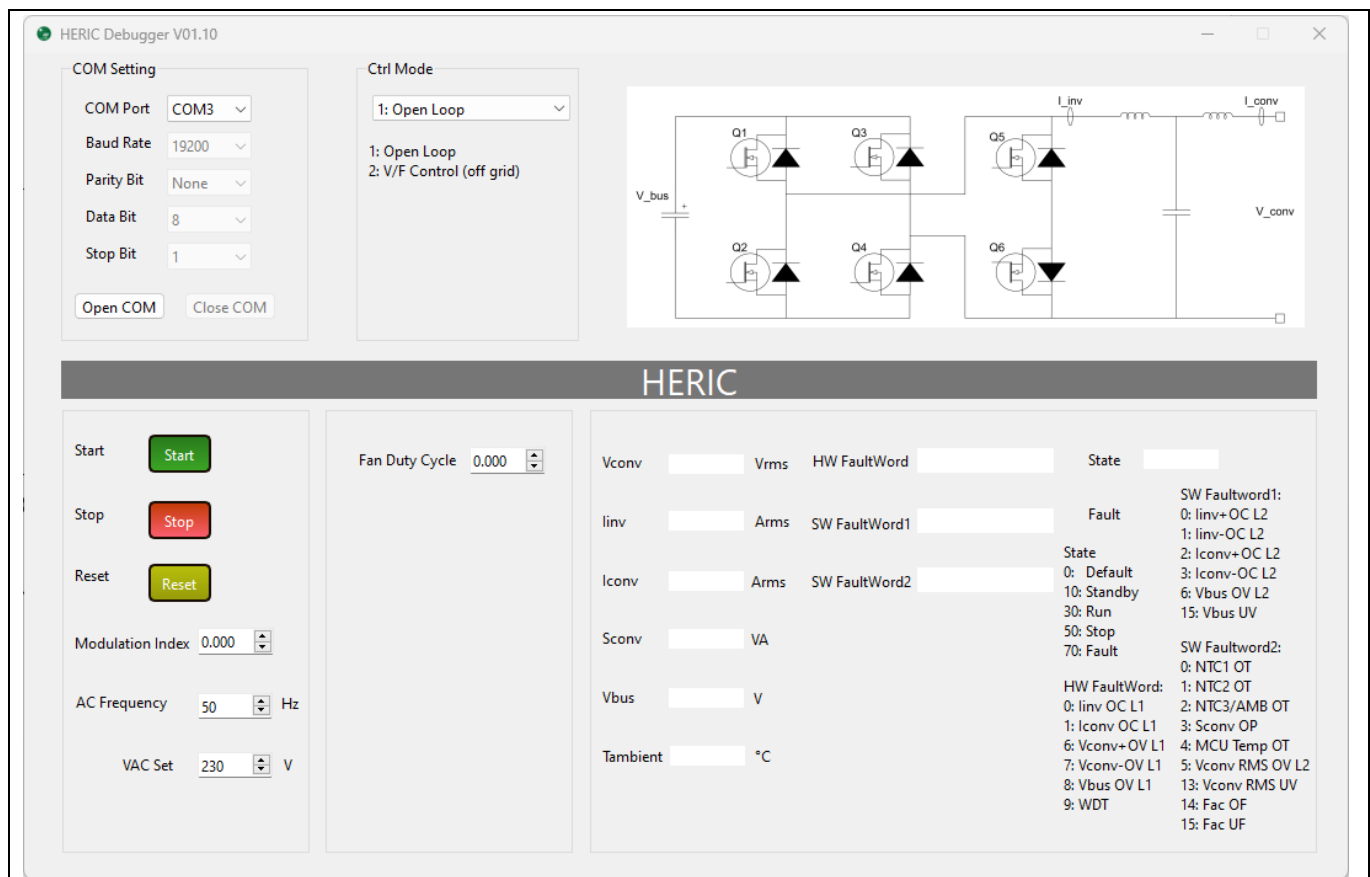


Figure 40 HERIC Debugger GUI

5 Testing the design

5.2.1 GUI parameters

Table 8 describes the list of parameters within the HERIC Debugger GUI.

Table 8 GUI parameters

Parameter	Type	Description	Unit	Min. value	Max. value
COM Port	COM Port settings	COM port number for the commissioning port	N/A	N/A	NA
Baud Rate	COM Port settings	The data transfer rate (only 19200 supported)	baud	19200	NA
Parity Bit	COM Port settings	Error checking bit (only 'None' supported)	NA	None	NA
Data Bit	COM Port settings	Number of bits in data packet (only 8-bits supported)	bit	8	NA
Stop Bit	COM Port settings	Number of stop bits in transfer packet (only 1 stop bit supported)	bit	1	NA
Open COM	Control Button	To connect GUI to COM port	N/A	N/A	NA
Close COM	Control Button	To disconnect GUI from COM port	N/A	N/A	NA
Ctrl Mode	Configurable Input	Converter control mode: Detail is given on UI	N/A	1: Open loop 2: V/F control (off grid)	
Modulation Index	Configurable Input	Modulation index for Open Loop and V/F Control modes	N/A	0.000	1.000
AC Frequency	Configurable Input	AC frequency	Hz	45	65
Fan Duty Cycle	Configurable Input	Fan speed	NA	0.000	1.000
VAC Set	Configurable Input	AC voltage	V	185	240
Vconv	Application output	Converter RMS voltage	Vrms	NA	–
Iinv	Application output	Inverter current	Arms	NA	–
Iconv	Application output	Converter current	Arms	NA	–
Sconv	Application output	Converter power	VA	NA	–
Vbus	Application output	Bus voltage	V	NA	–
Tambient	Application output	Ambient temperature	°C	NA	–

5 Testing the design

Parameter	Type	Description	Unit	Min. value	Max. value
HW FaultWord	Application output	HW fault representation	NA	Bit 0: I _{inv} overcurrent Bit 1: I _{conv} overcurrent Bit 6: V _{conv} overvoltage Bit 7: V _{conv} undervoltage Bit 8: V _{bus} overvoltage Bit 9: Watchdog timer no service	–
SW FaultWord1	Application output	SW fault representation (level 1)	NA	Bit 0: I _{inv} overcurrent Bit 1: I _{inv} undercurrent Bit 2: I _{conv} overcurrent Bit 3: I _{conv} undercurrent Bit 6: V _{BUS} overvoltage Bit 15: V _{BUS} undervoltage	–
SW Faultword2	Application output	SW fault representation (Level 2)	NA	Bit 14: AC over- frequency Bit 15 over- frequency	–
State	Application output	HERIC application state representation	NA	0: Default 10: Standby 30: Run 50: Stop 70: Fault	–
Fault	Application output	Fault state indication	NA	Green: No fault Red: Fault	–

5 Testing the design

5.2.2 Connecting to the board with the GUI

1. Connect the HERIC board and control board as described in Section 5.3.1

Note: The signal cables from the power board provide the necessary power to the control board. No external power supply is required for the control board.

2. Connect an external 24 V power supply to the HERIC board via X23 (Figure 41)

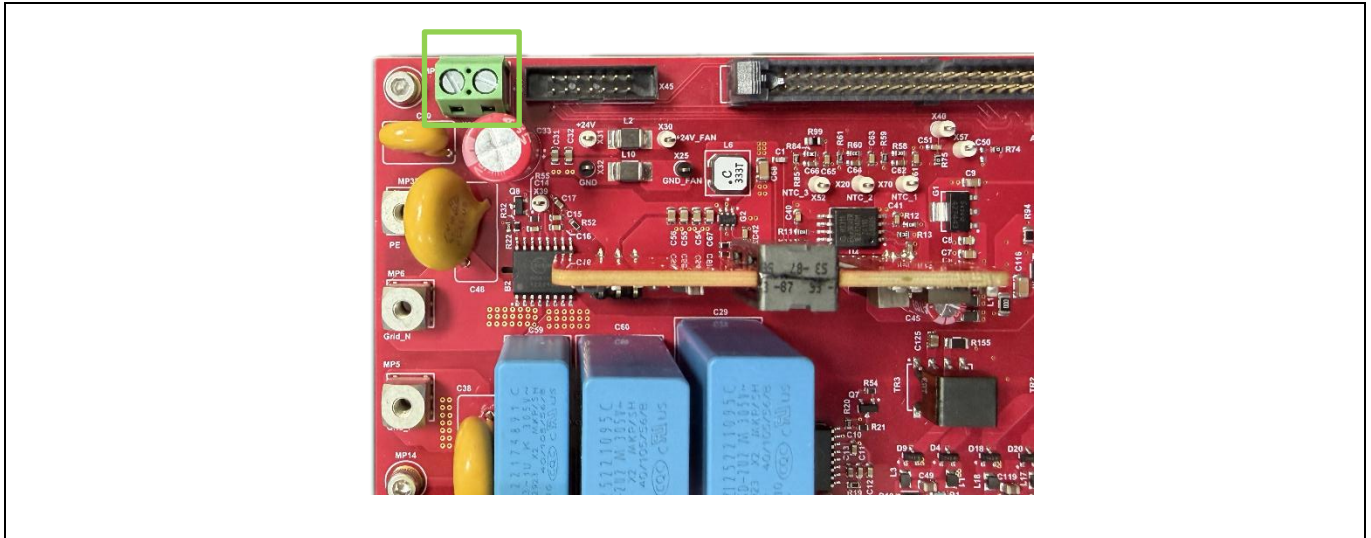


Figure 41 X31 and X32 for connection to external 24 V

3. Connect a USB cable via the commissioning port of the control board to the PC (Figure 42)

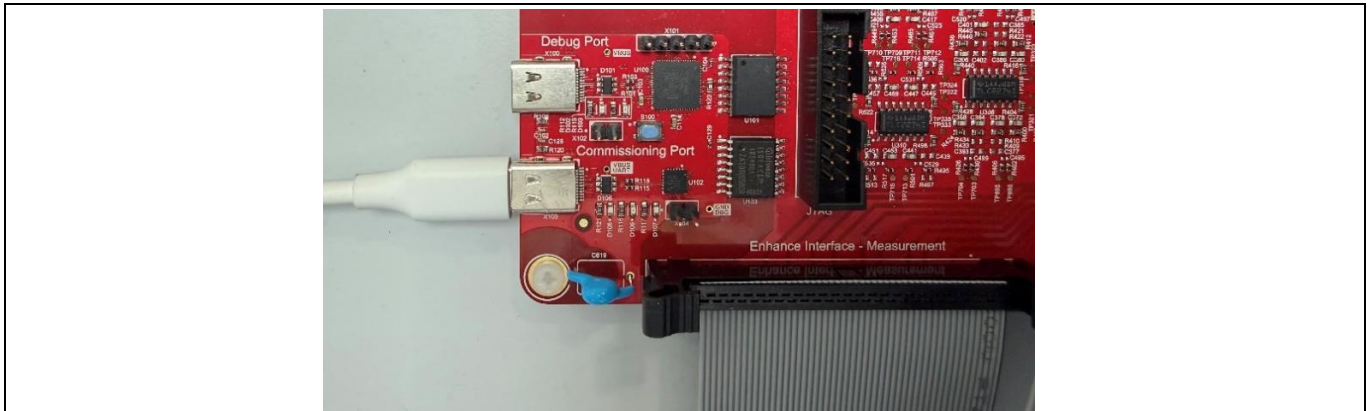


Figure 42 Commissioning port on Control board

4. Launch the HERIC Debugger GUI on PC. A login window will appear (Figure 43). Select **Normal** and key in 123456 as the password

5 Testing the design

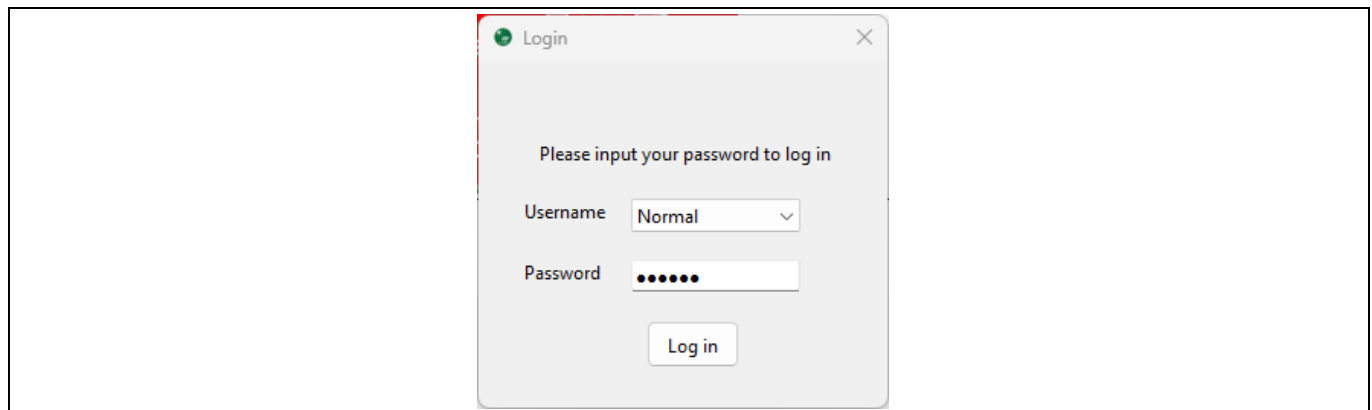


Figure 43 Login window for HERIC Debugger GUI

5. In the COM port setting in the GUI, select the **COM Port** number for the control board. If unsure about the number, check in the PC's **Device Manager** (Figure 44). Then, click **Open COM**

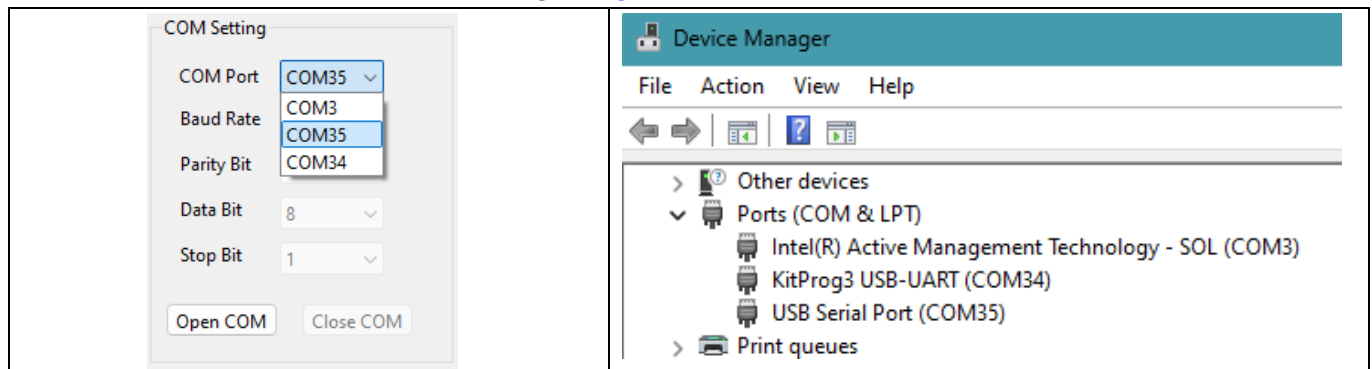


Figure 44 COM Port number selection

6. Switch on the input **Vbus** supply. The Vbus value should be reflected on the GUI (Figure 45) to show that the connection is successful.

5 Testing the design



Figure 45 GUI connection successful

5.2.3 Using the converter in Open Loop mode

Prerequisite

The setup is successfully up and running and the GUI shows the connection to the board as per the guide in [Section 5.2.2 Connecting to the board with the GUI](#).

1. Select **Open Loop** from the dropdown options under **Ctrl Mode**
2. Set the **Modulation Index** value
3. Set the **AC Frequency** value
4. Click **Start**

5 Testing the design



Figure 46 Using the converter in Open Loop mode

Note: The modified parameters in the GUI (e.g., Modulation Index, AC Frequency) take effect only after the Start button is pressed.

5.2.4 Using the converter in V/F Control mode

Once the setup is successfully up and running per Chapter 5.2.2 Connecting to the board with the GUI, follow the steps below to start the converter in V/F Control mode (Figure 47):

1. Select **V/F Control** from the dropdown options under **Ctrl Mode**
2. Set the **VAC Set** value
3. Set the **AC Frequency** value and click **Start**

5 Testing the design

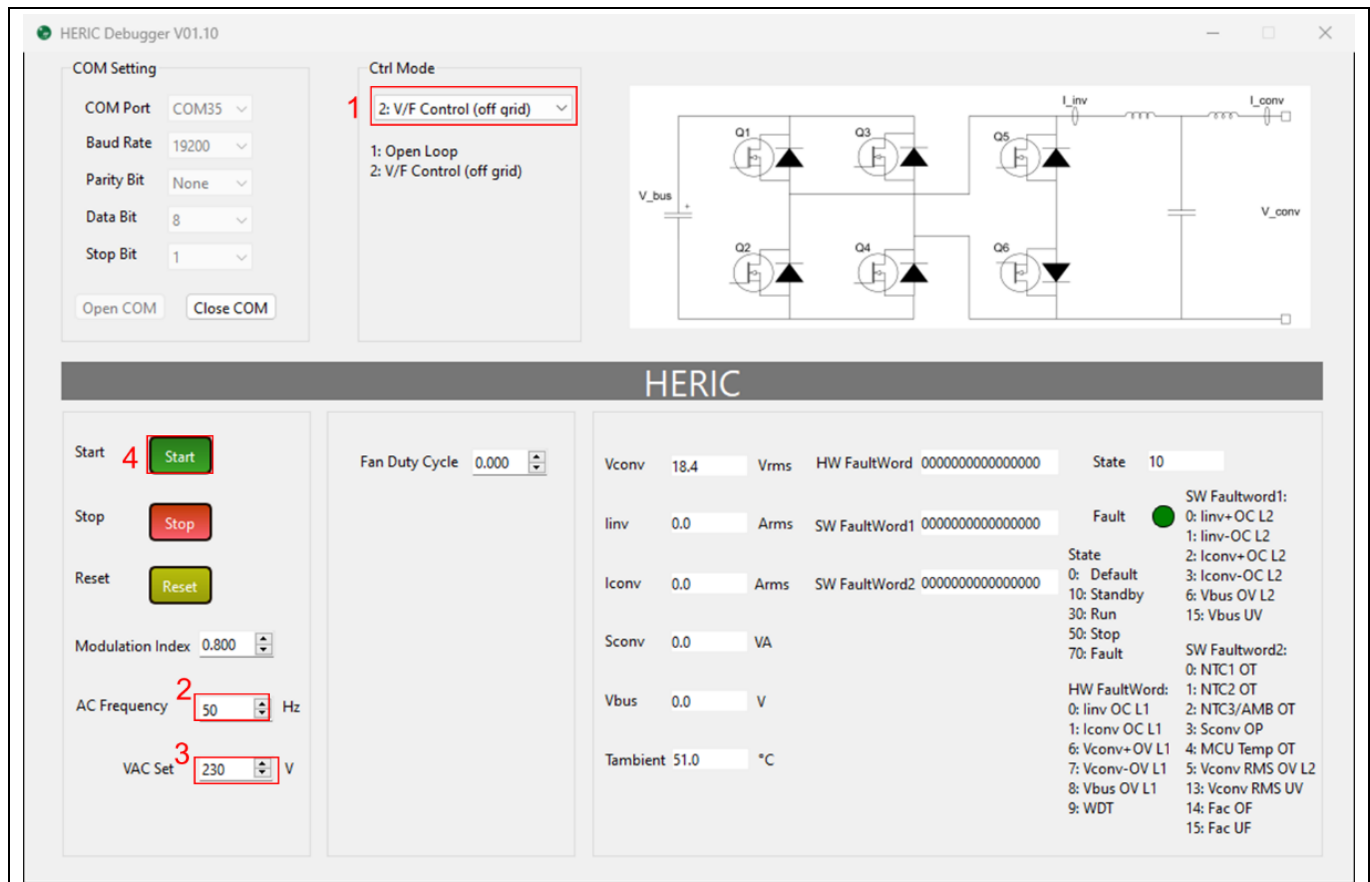


Figure 47 Using the converter in V/F Control mode

Note: The modified parameters in the GUI (for example, AC Frequency, VAC Set) will take effect only after the Start button is pressed.

5.2.5 Rectifying a fault

If there are any faults, the **State** field indicates 70 and the **Fault** indicator will turn red (Figure 48). The fault can then be checked from the fault words (i.e., HW FaultWord, SW FaultWord1, and SW FaultWord2). The fault word bit representation is given in Figure 48.

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5 Testing the design



Figure 48 Fault indication in the GUI

Once the fault is investigated and alleviated, you can reset the application. To reset the application, click **Reset**.

5 Testing the design

5.2.6 Stopping the converter

To stop the converter, click **Stop** on the GUI as shown in the following figure.

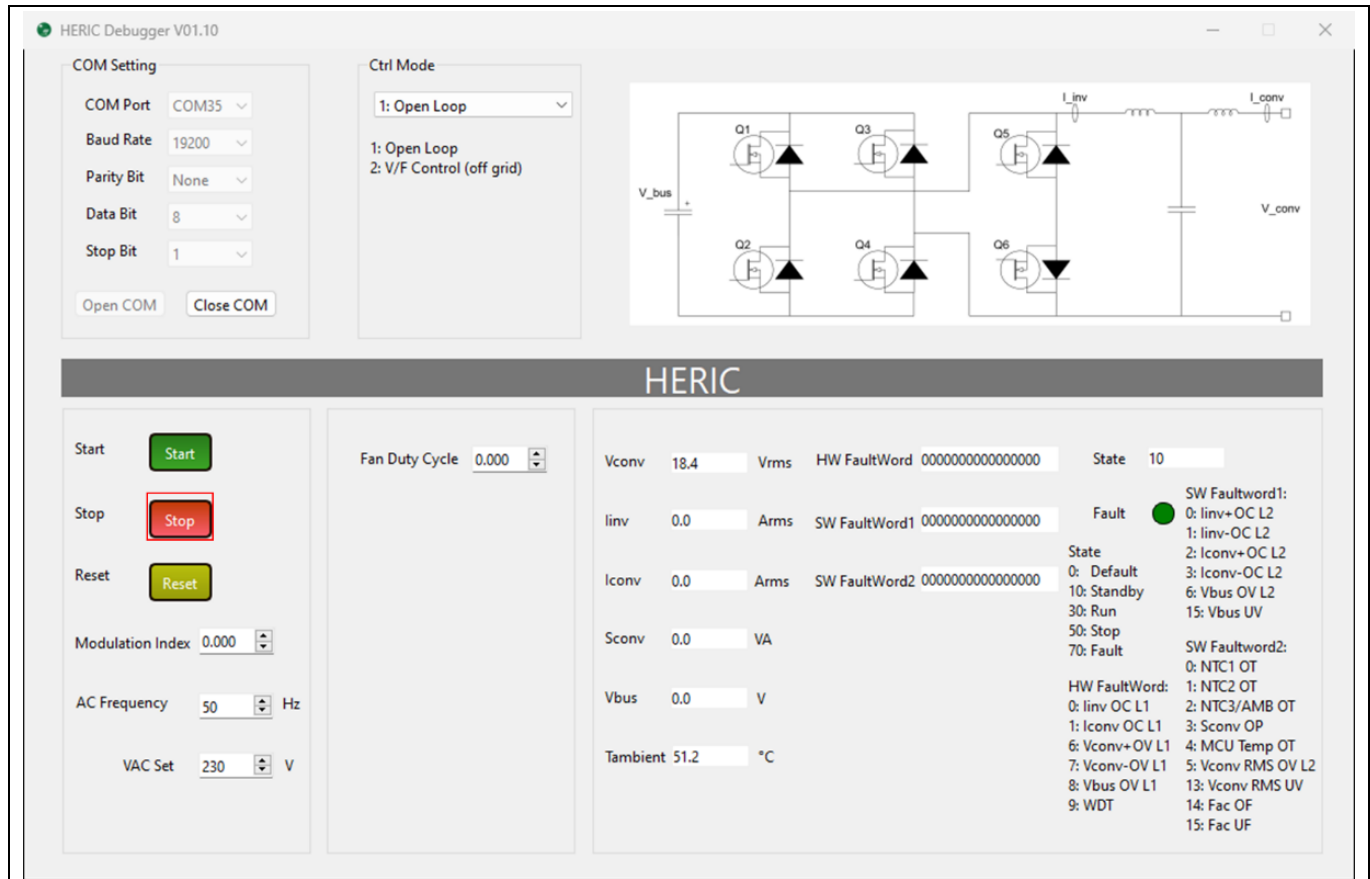


Figure 49 Stopping the converter

5.3 Test results

5.3.1 Bench setup

The inverter is operated in a closed-loop, off-grid mode where the output voltage is regulated.

Note: Do not operate the inverter outside the voltages, currents, and frequencies specified.

The inverter was tested only for the specifications shown in [Table 8](#) with an AC load in the Constant Power mode. Performance is not guaranteed if the inverter is operated outside these specifications.

The following equipment is needed to start testing:

- HERIC power board
- REF-CLBXM7PEC kit with the HERIC firmware
- GUI
- AC load with constant power mode capability (Resistive load could be used alternatively but some results may vary)
- DC power source

5 Testing the design

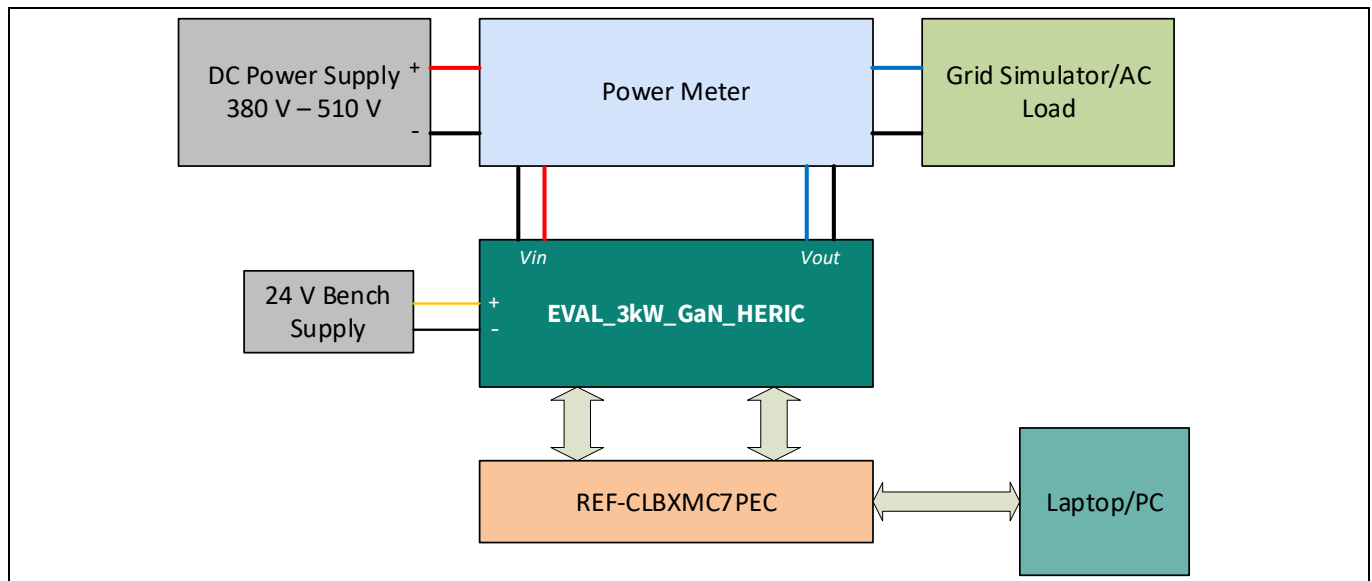


Figure 50 Test setup

5.3.2 Output AC voltage against different DC input voltages

The design was tested with input DC voltages 380 V, 445 V, and 510 V. The output RMS voltage was regulated close to 230 V at a power of 3 kW.

Table 9 DC input voltage range

Input voltages	380 V DC, 445 V DC, and 510 V DC
PWM	50 kHz
Output power	3 kW, $V_{out}=230$ V RMS/50 Hz

Table 10 Test data

Input voltage (V DC)	Output voltage (V_{L-rms})	Output power (kW)	Output current (A_{rms})	PF	iTHD	Efficiency
380	230	3.0	13.18	0.99	1.1	99.14
445	230	3.0	13.18	0.99	1.12	99.00
510	230	3.0	13.18	0.99	1.35	98.83

Note: Efficiency results are inclusive of auxiliary power supply losses also.

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions

5 Testing the design

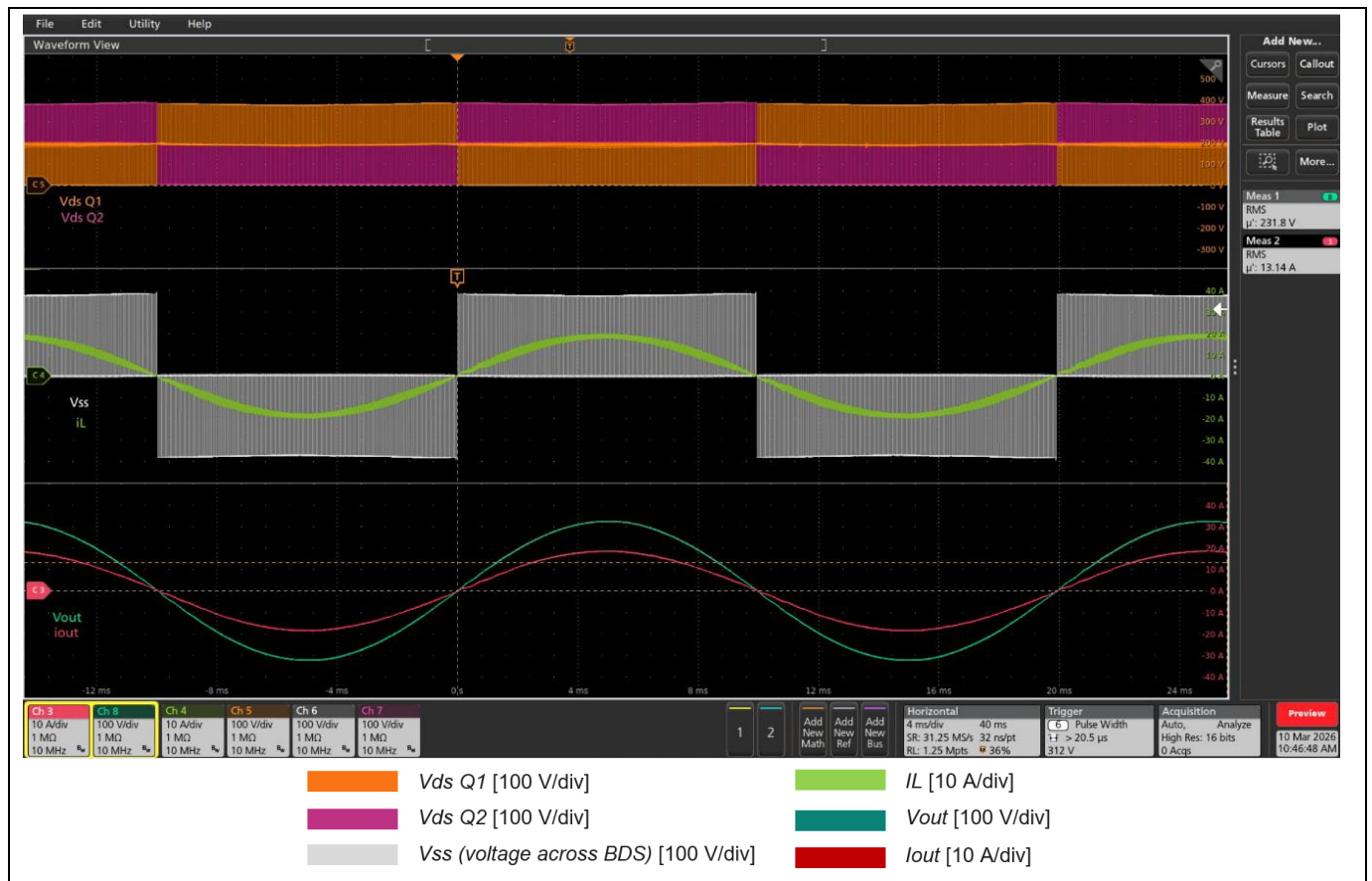


Figure 51 Typical system waveforms: Input DC voltage = 380 V at 3 kW

3 kW all-GaN HERIC evaluation board

CoolGaNTM BDS-based HERIC for solar photovoltaic solutions

5 Testing the design

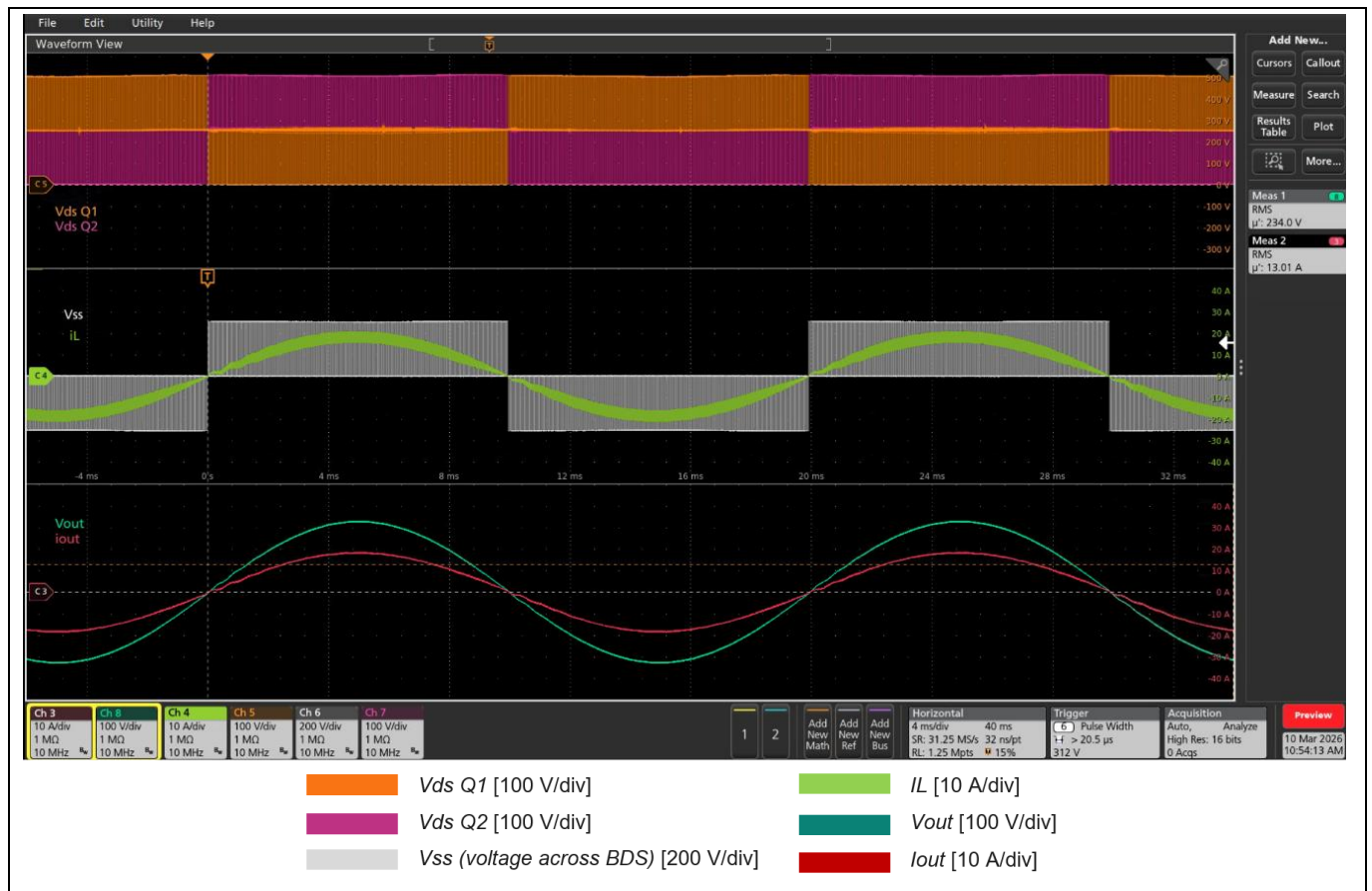


Figure 52 Typical system waveforms: Input DC voltage = 510 V at 3 kW

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions

5 Testing the design

5.3.3 Reactive load testing

The inverter is tested with reactive loads at 0.8 leading and lagging power factors. It can be seen from the following images that this inverter can support this wide range of power factors.

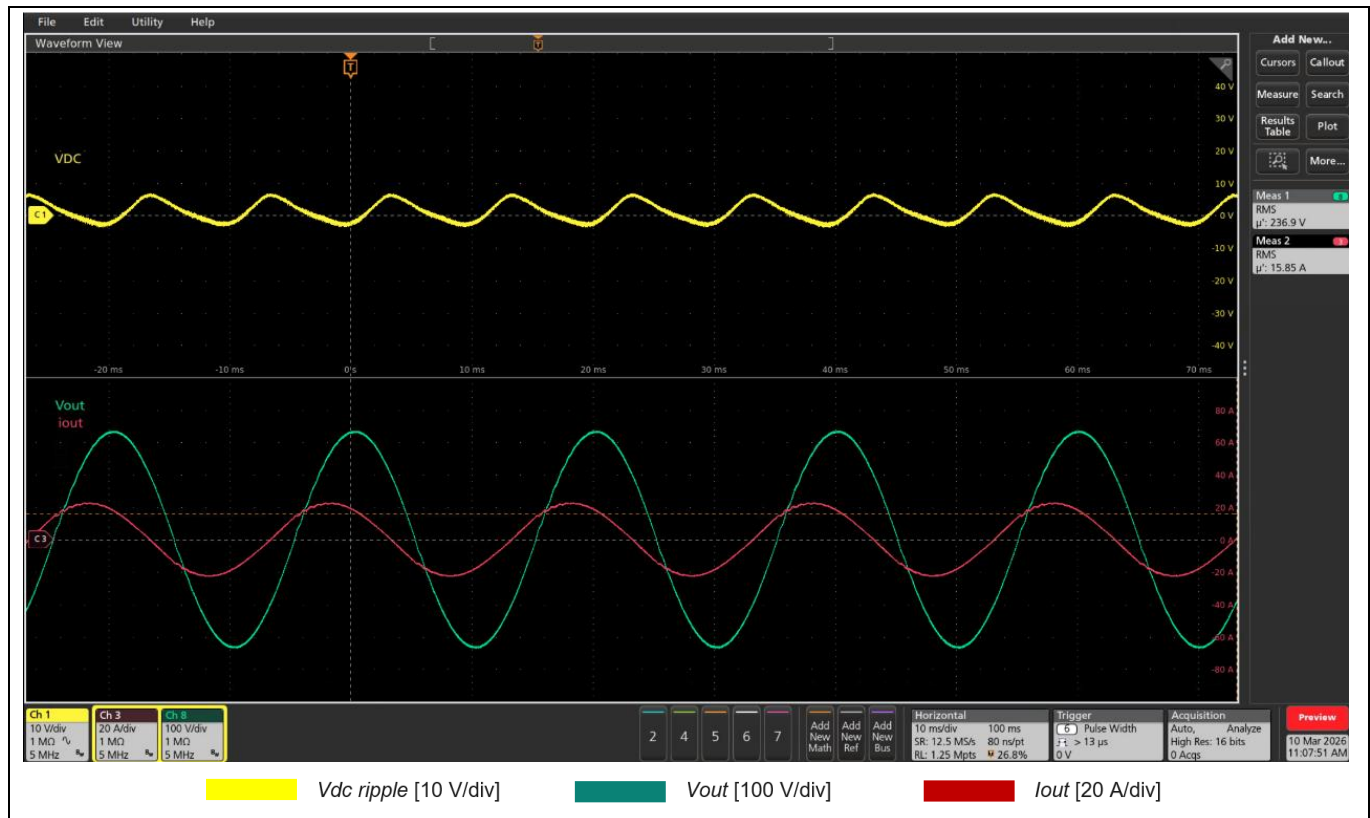


Figure 53 Typical system waveforms: Input DC voltage = 510 V, Pout = 3.75 kVA at 0.8 leading PF

5 Testing the design

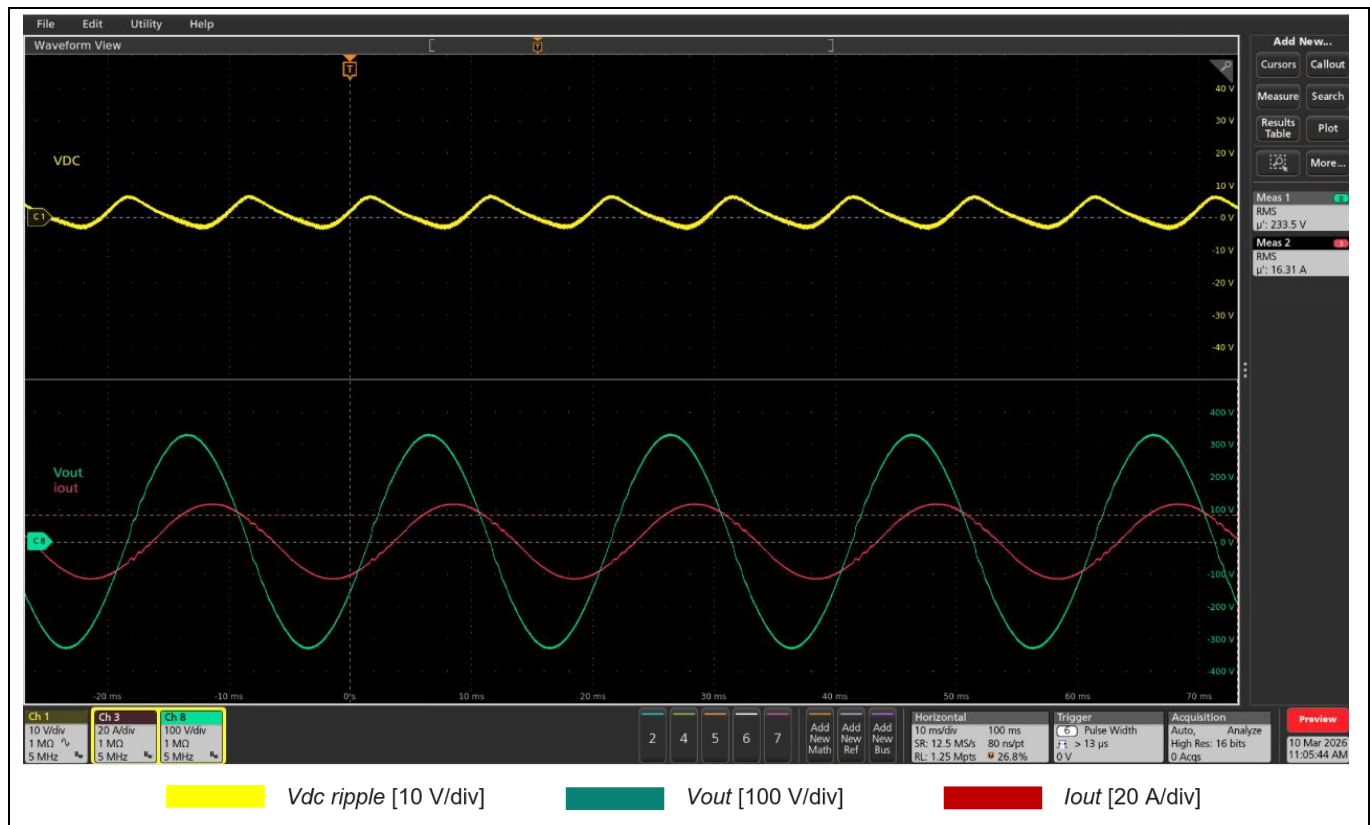


Figure 54 Typical system waveforms: Input DC voltage = 510 V, Pout = 3.75 kVA at 0.8 lagging PF

5.3.4 Closed-loop testing

Figure 51 shows the output waveforms of the inverter captured during step load change. To test the step load response, the inverter is operated in closed-loop, no-load condition and then step load is applied at the output (13 A). Also, the load has been changed from 13 A to 0 A to check the inverter response when there is a sudden removal of load at the output. As can be seen from the waveforms in Figure 55, there is no abnormal fluctuations in the output voltage waveform during step load change.

5 Testing the design

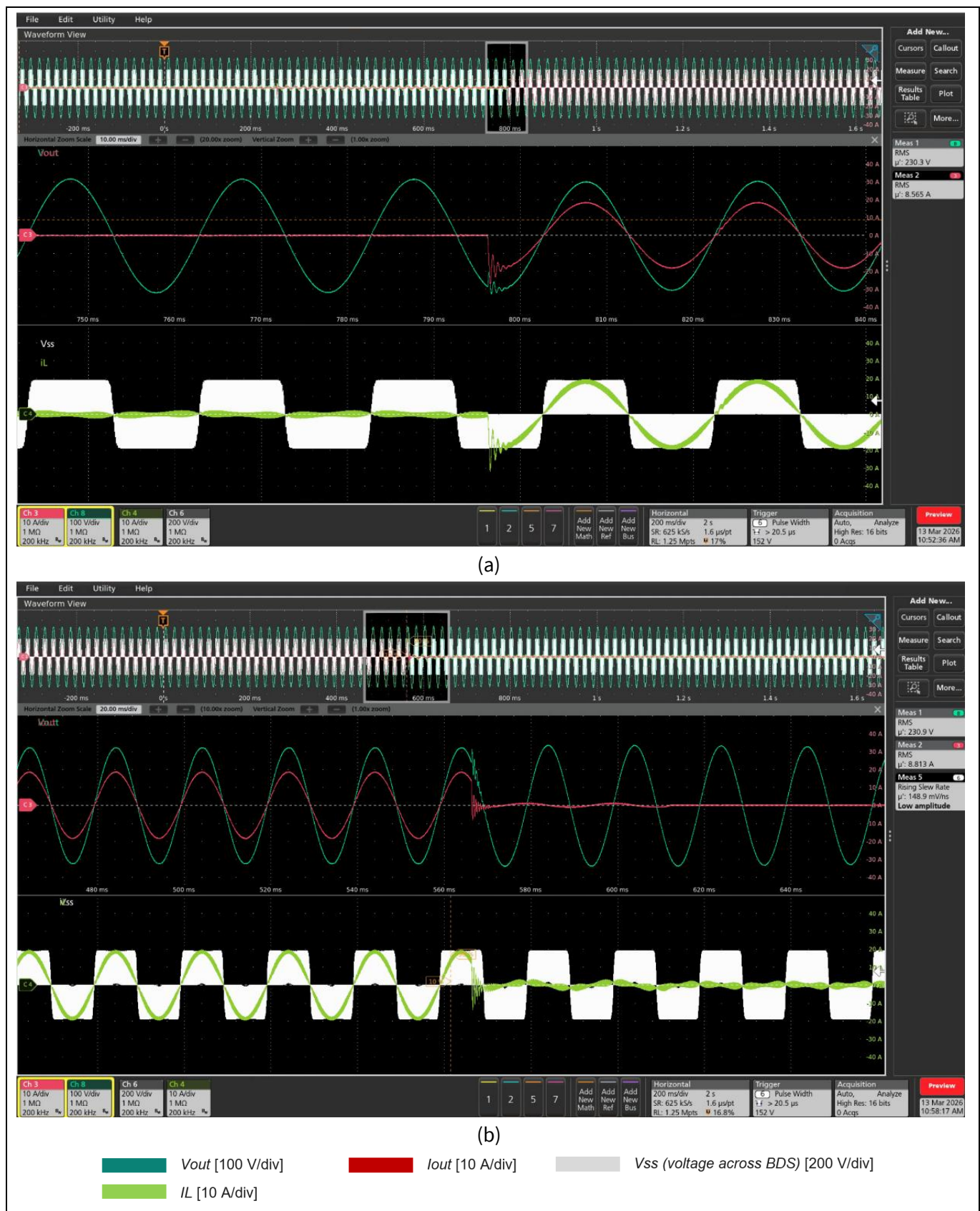


Figure 55 Closed-loop testing: Step load response (a) Step load applied (0 A to 13 A) (b) Load off (13 A to 0 A)

3 kW all-GaN HERIC evaluation board

CoolGaN™ BDS-based HERIC for solar photovoltaic solutions

5 Testing the design

5.3.5 Output short-circuit protection test

The output of the inverter is shorted with the help of circuit breaker during no-load operation condition.

Figure 56 shows the waveforms captured during output short circuit condition.

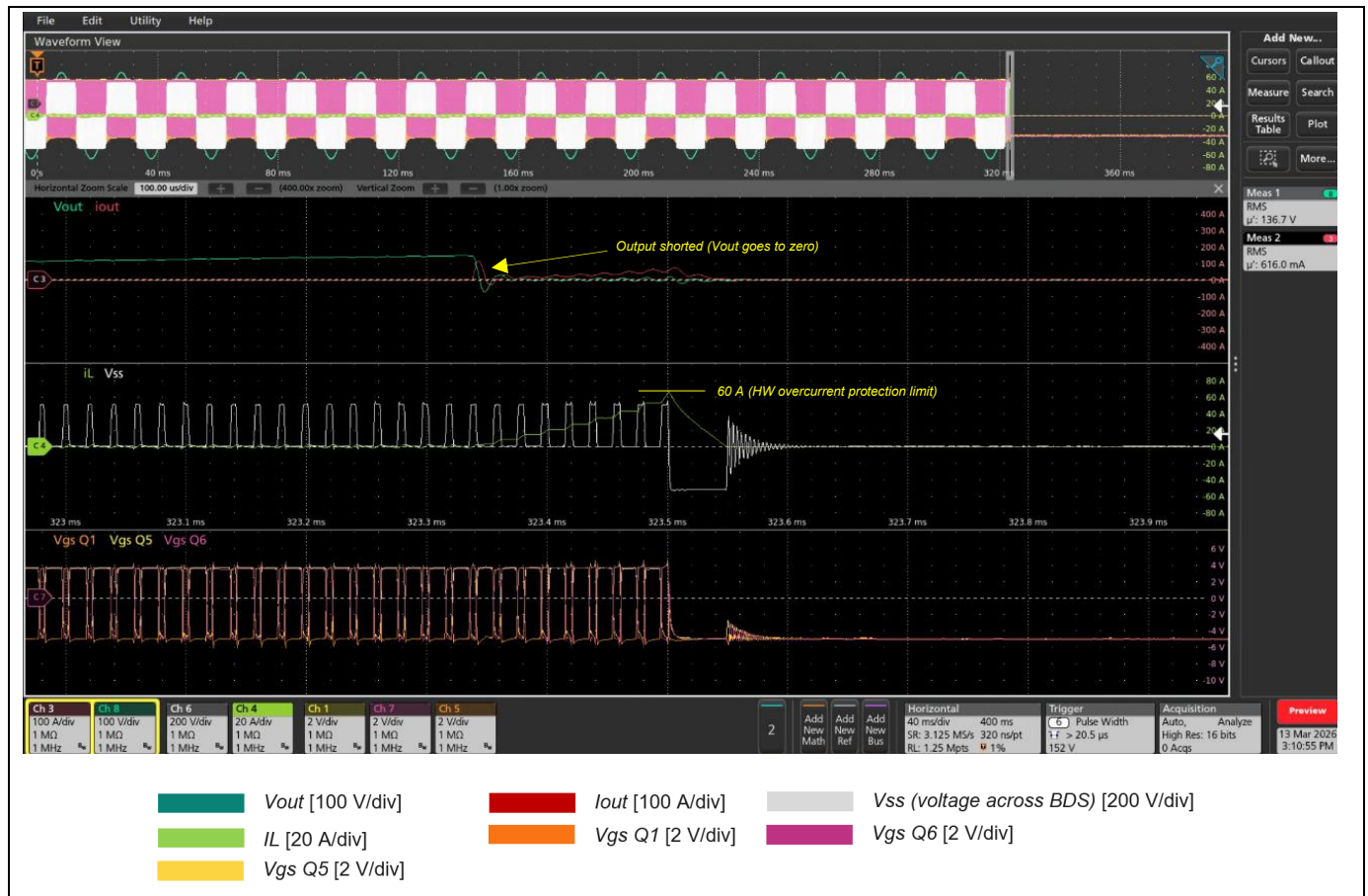


Figure 56 Output short-circuit protection test: Input DC voltage = 510 V, V_{out} = 230 V, 50 Hz

5 Testing the design

5.3.6 Efficiency and temperature measurements

Table 11 Power semiconductors efficiency measurement

Specification	Efficiency measurement using Yokogawa WT330 power meter		
Condition	$V_{in} = 380\text{ V}$, $V_{rms} = 230\text{ V}$, Loading = 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% HERIC power stage efficiency only to demonstrate high efficiency benefits of CoolGaN™ Transistor		
Operation	Efficiency at $V_{in} = 380\text{ V}$	Efficiency at $V_{in} = 445\text{ V}$	Efficiency at $V_{in} = 510\text{ V}$
5% load	95.50	93.98	92.13
10% load	96.58	95.75	94.96
20% load	98.01	97.44	96.83
30% load	98.55	98.13	97.69
40% load	98.82	98.50	98.15
50% load	98.97	98.71	98.42
60% load	99.06	98.83	98.59
70% load	99.10	98.92	98.70
80% load	99.13	98.96	98.76
90% load	99.13	98.99	98.80
100% load	99.14	99.00	98.83
CEC efficiency	98.87	98.61	98.32

Note: Efficiency results includes auxiliary power supply losses as well.

Efficiency at 380 V is highest because the switching loss is low. At 380 V, full load 99.14% efficiency is achieved (max. efficiency). At 510 V, efficiency is the least due to the higher switching losses.

5 Testing the design

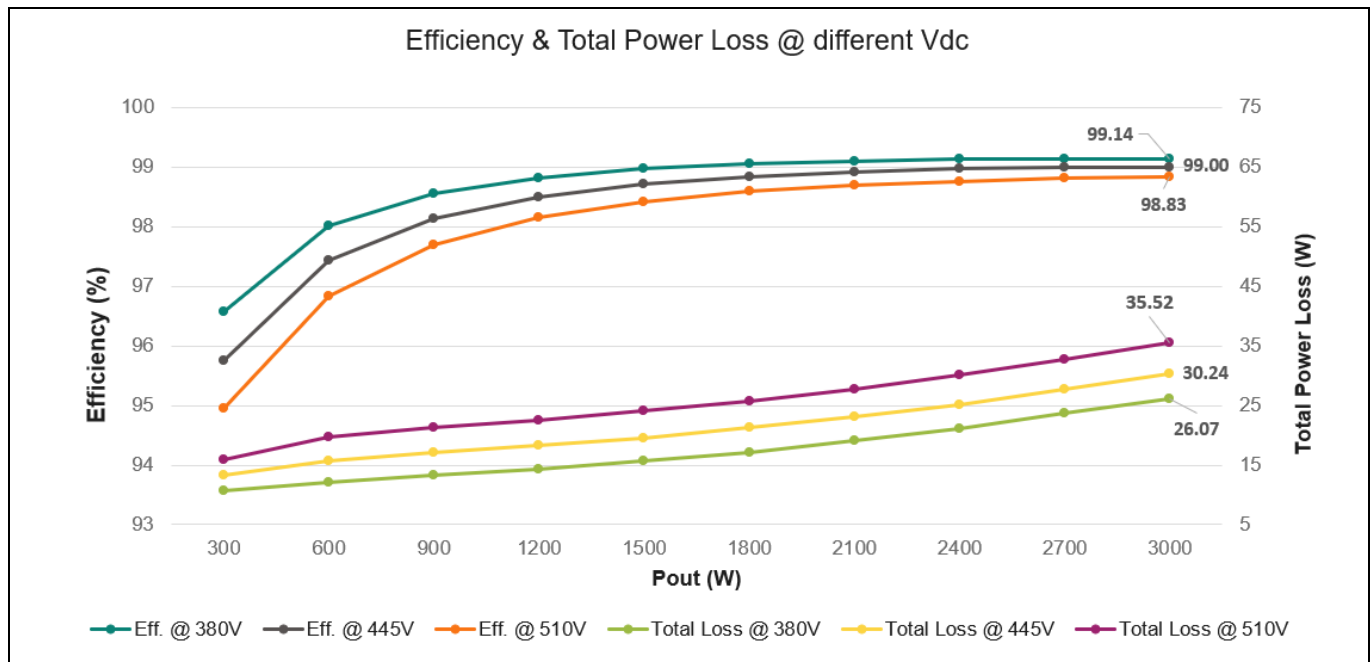


Figure 57 Efficiency and total power loss of the inverter power stage

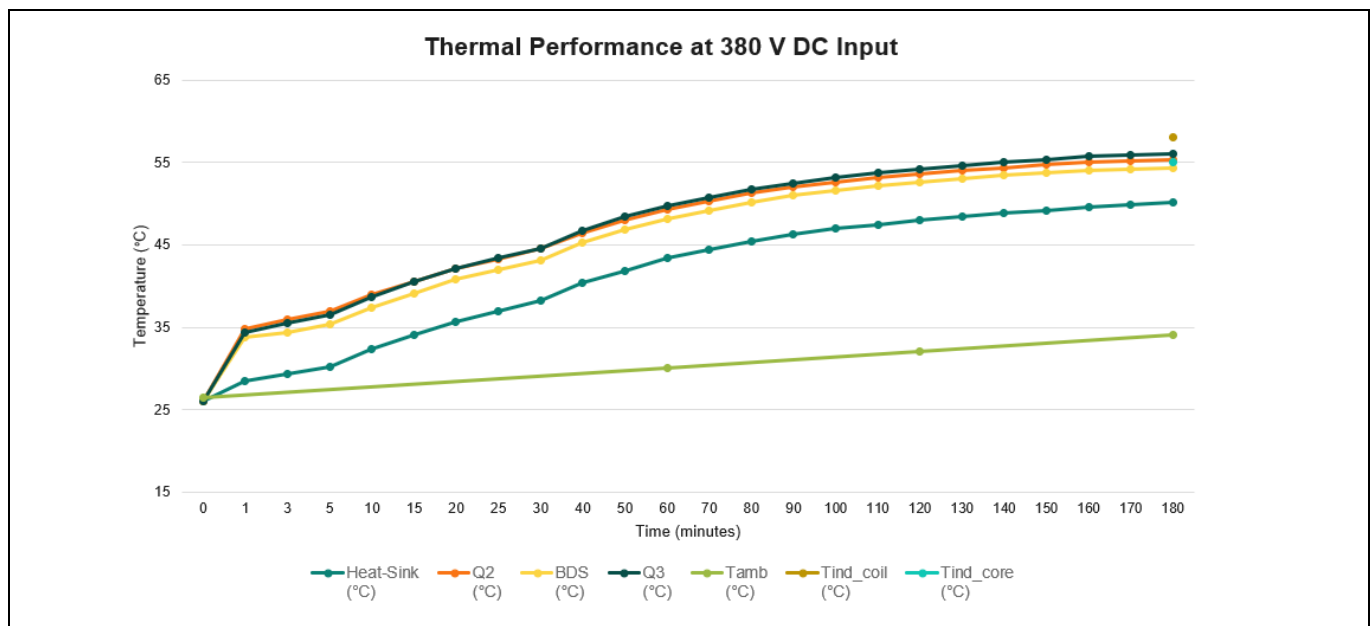


Figure 58 Temperature curves at 380 V DC input, 3 kW load, PF = 1

The power device's temperature increases slowly but stabilizes after an hour. While BDS (freewheeling FET) conducts for longer, the temperature of the full-bridge FETs and BDS is almost the same. Power loss in BDS is mainly due to the conduction loss during the complete-line cycle operation, while Q2 and Q3 only operate in the negative half-line cycle and are hard-switched, contributing to switching losses as well.

5 Testing the design

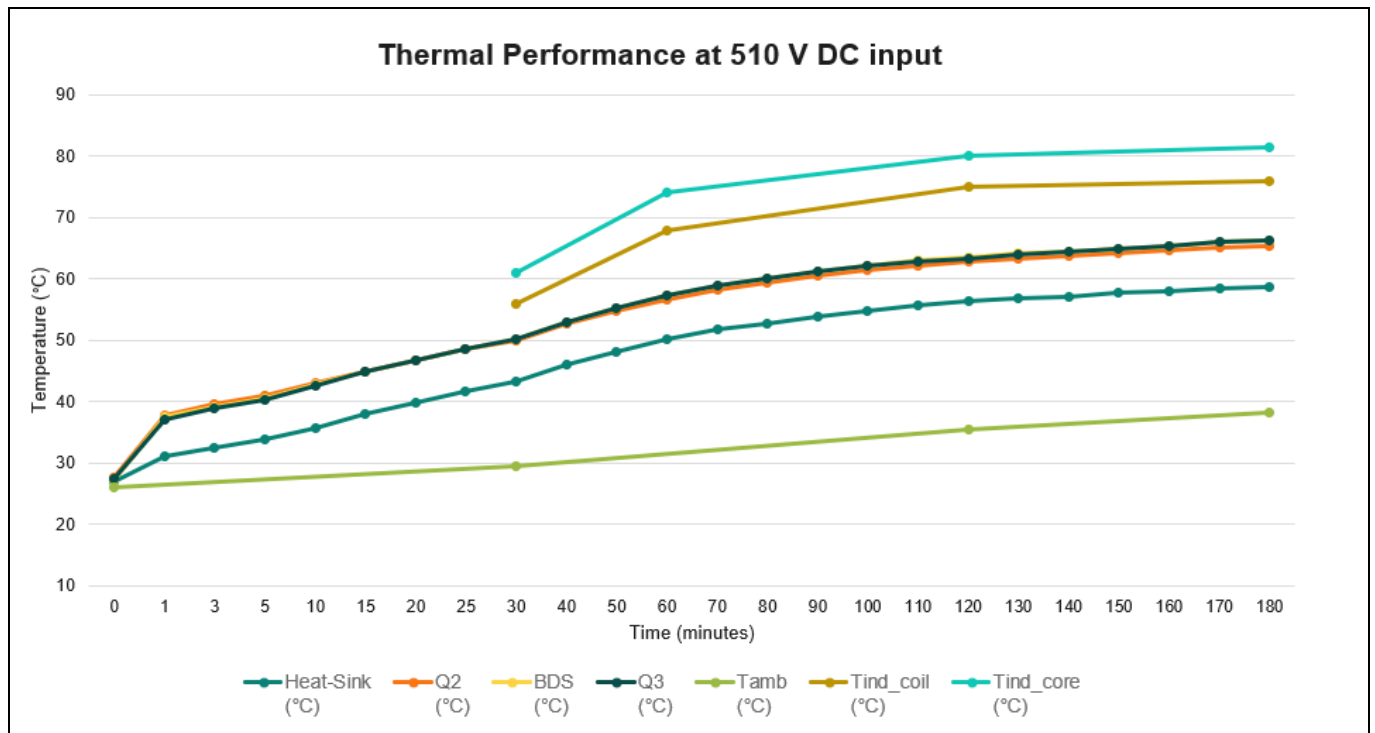


Figure 59 Temperature curves at 380 V DC input, 3 kW load, PF = 1

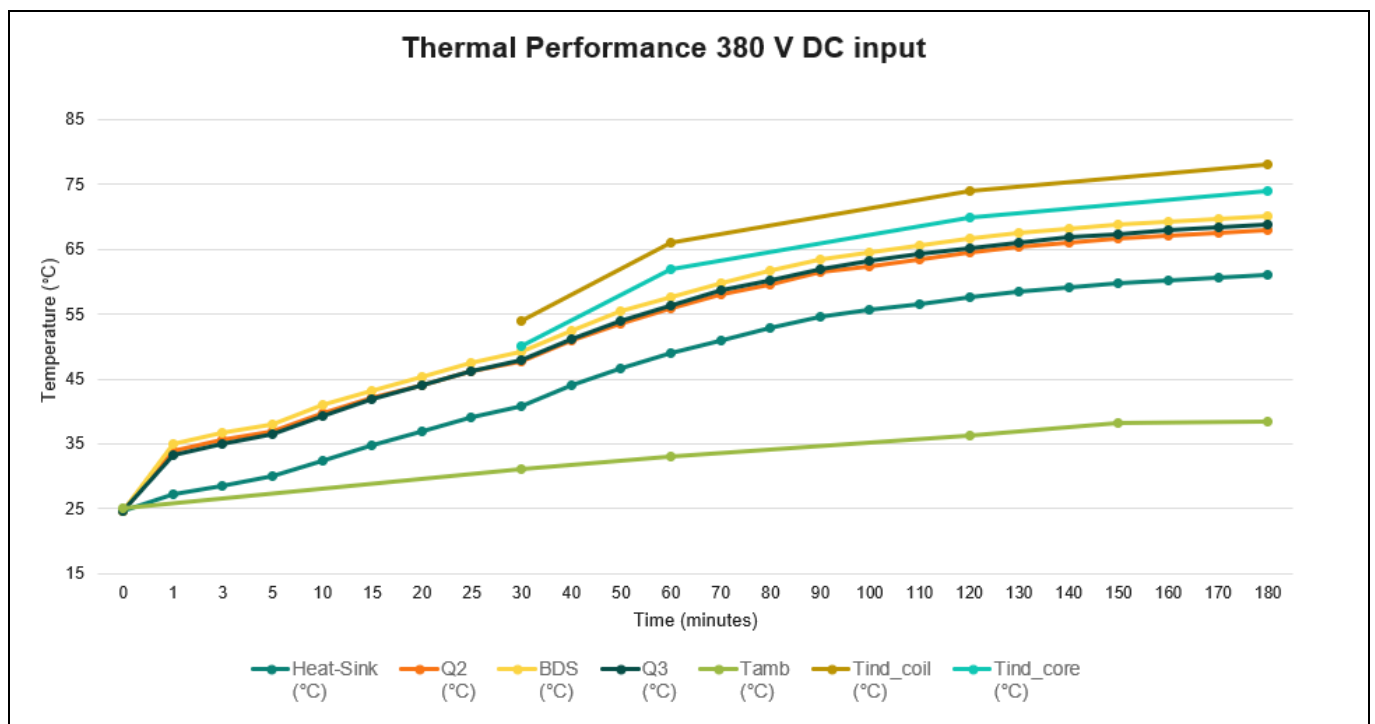


Figure 60 Temperature curves at 380 V DC input, 3.75 kVA load, 0.8 lagging PF

5 Testing the design

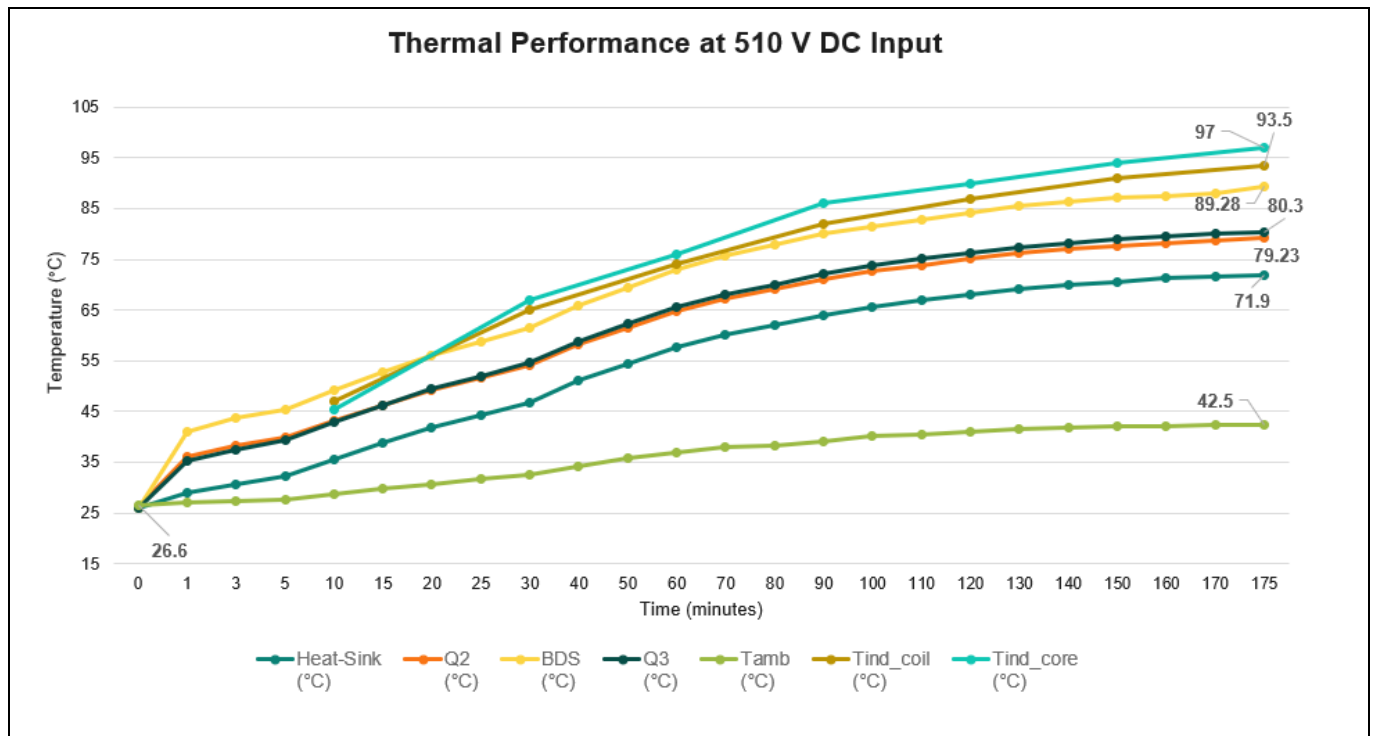


Figure 61 Temperature curves at 510 V DC input, 3.75 kVA load, 0.8 lagging PF

At 510 V input, 3.75 kVA output power, the output RMS current reaches 16.3 A at 0.8 power factor. This is the peak operating power rating for all-GaN HERIC board. As can be seen in the results shown in [Figure 61](#), the temperature of the power devices remains well below 100°C after almost three hours of operation at this load. Also, the heatsink temperature reaches 71.9°C and ambient temperature of the DUT reaches 42.5°C.

6 Board layout

6 Board layout

6.1 All-GaN HERIC evaluation board

Table 12 Mechanical data

Dimensions	250 mm x 155 mm
No. of layers	6
Copper thickness	77.36 mil
Weight	~3 kg

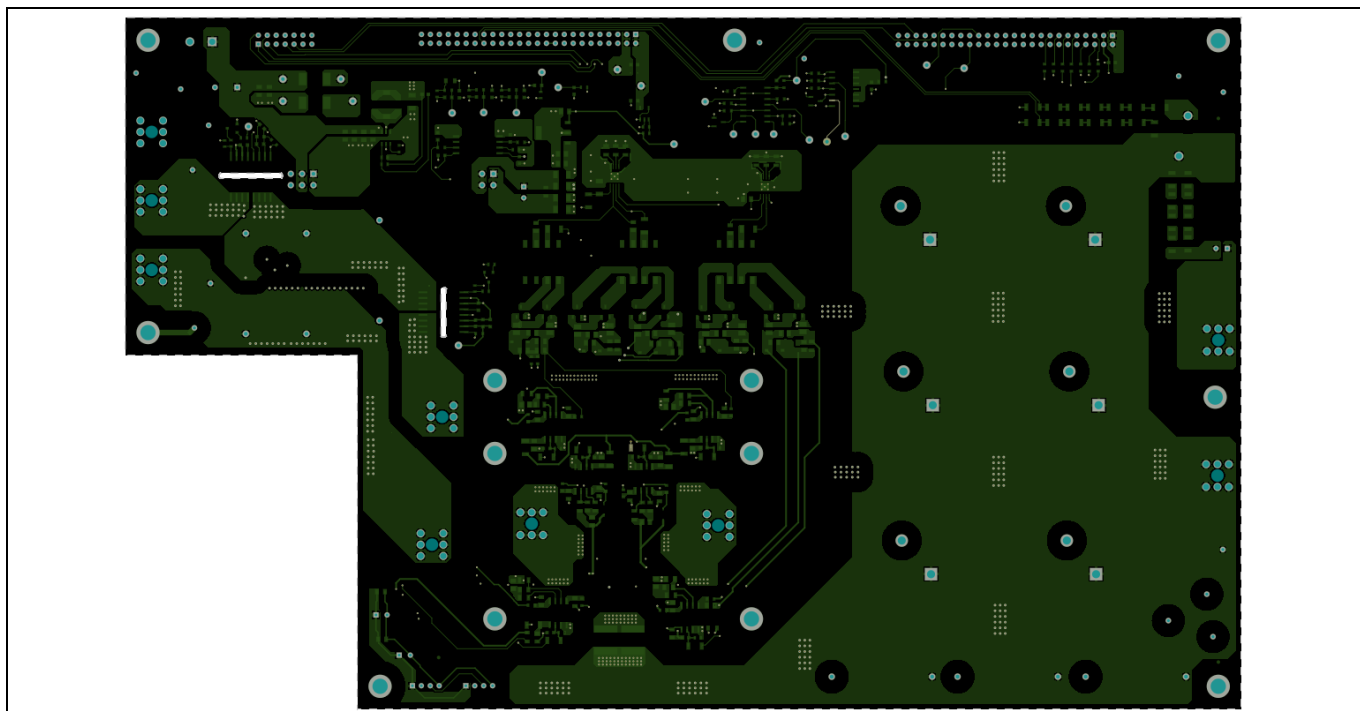


Figure 62 Layer 1 top layer

The top layer contains the traces for high current including MOSFETs current, input BUS_DC+, and AC output. Also, some thin traces have been used for control-related task on the low-voltage side.

6 Board layout

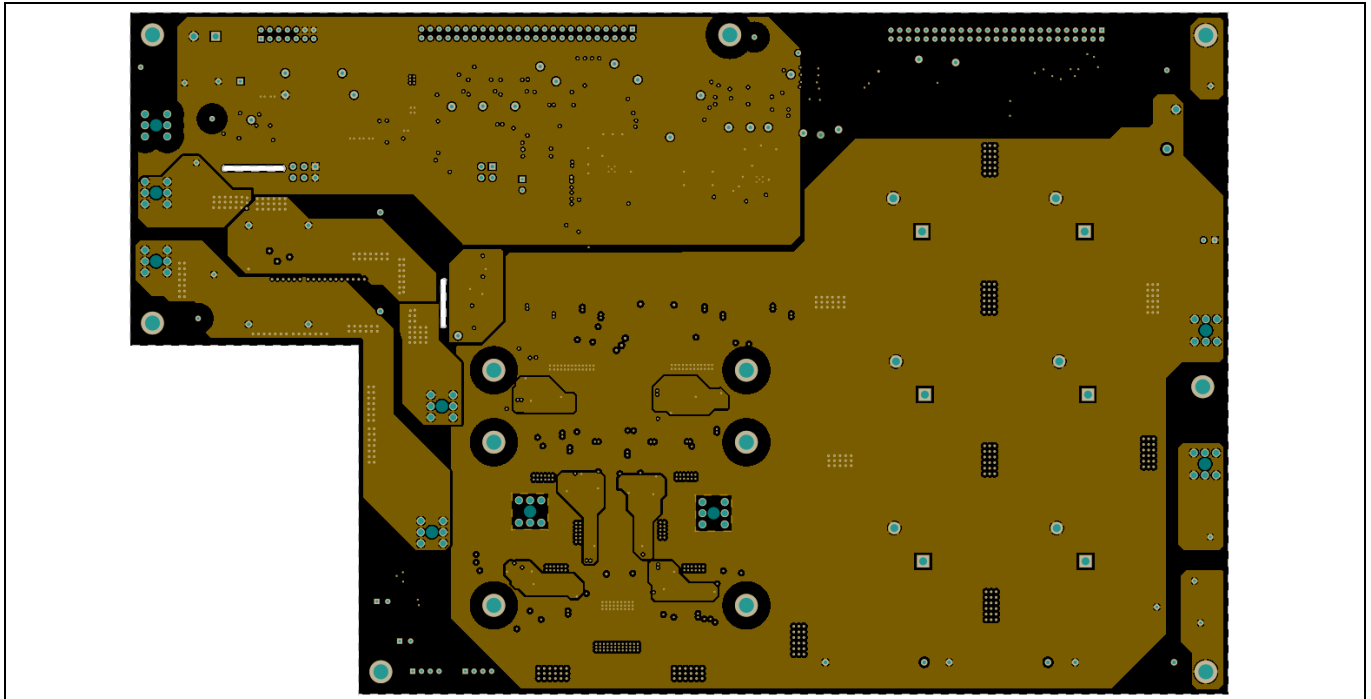


Figure 63 Layer 2 inner layer 1

The second layer has been dedicated to different ground layers including negative DC bus and low-voltage ground.

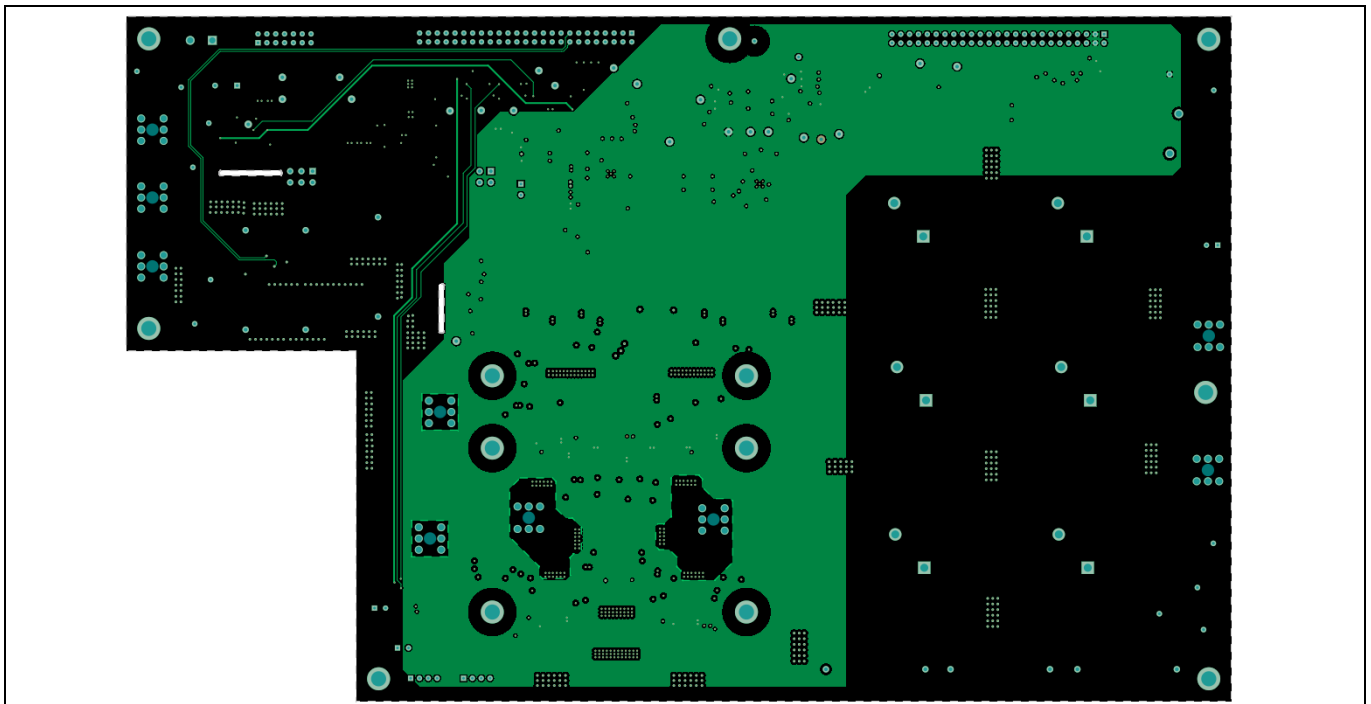


Figure 64 Layer 3 inner layer 2

The third layer is dedicated to the low-voltage ground digital section. This is to cover the PWM signals that go to the gate drivers.

6 Board layout

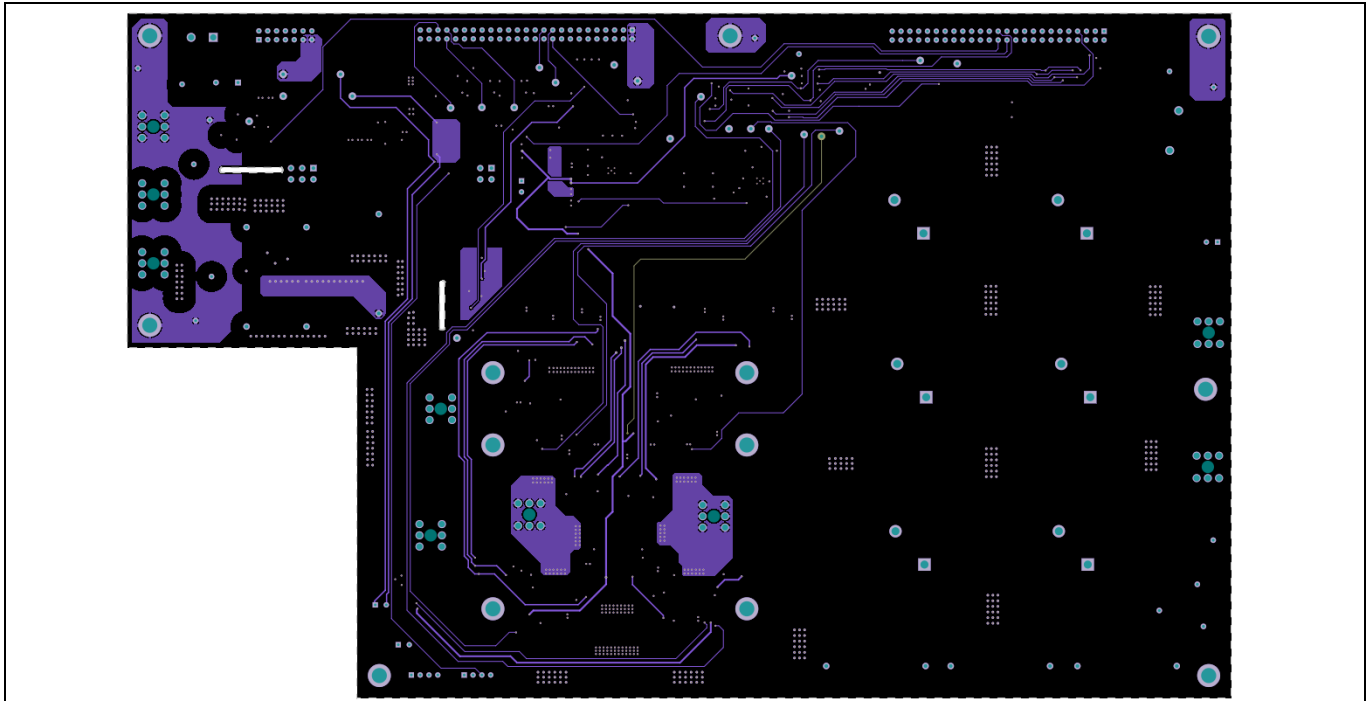


Figure 65 Layer 4 inner layer 3

The fourth layer is mainly dedicated to PWM traces and is also used to add copper and improve current conduction around the switching node.

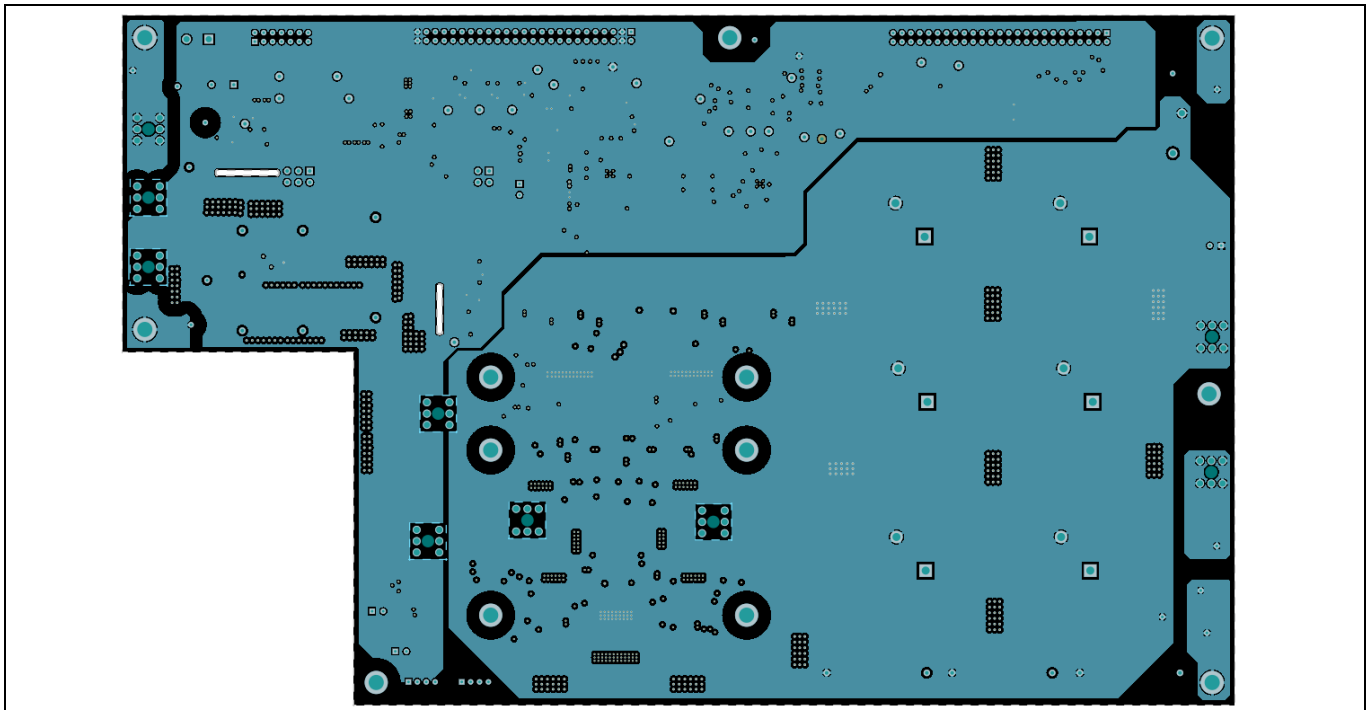


Figure 66 Layer 5 inner layer 4

The fifth layer has been dedicated to different ground layers including negative DC bus and low-voltage ground.

6 Board layout

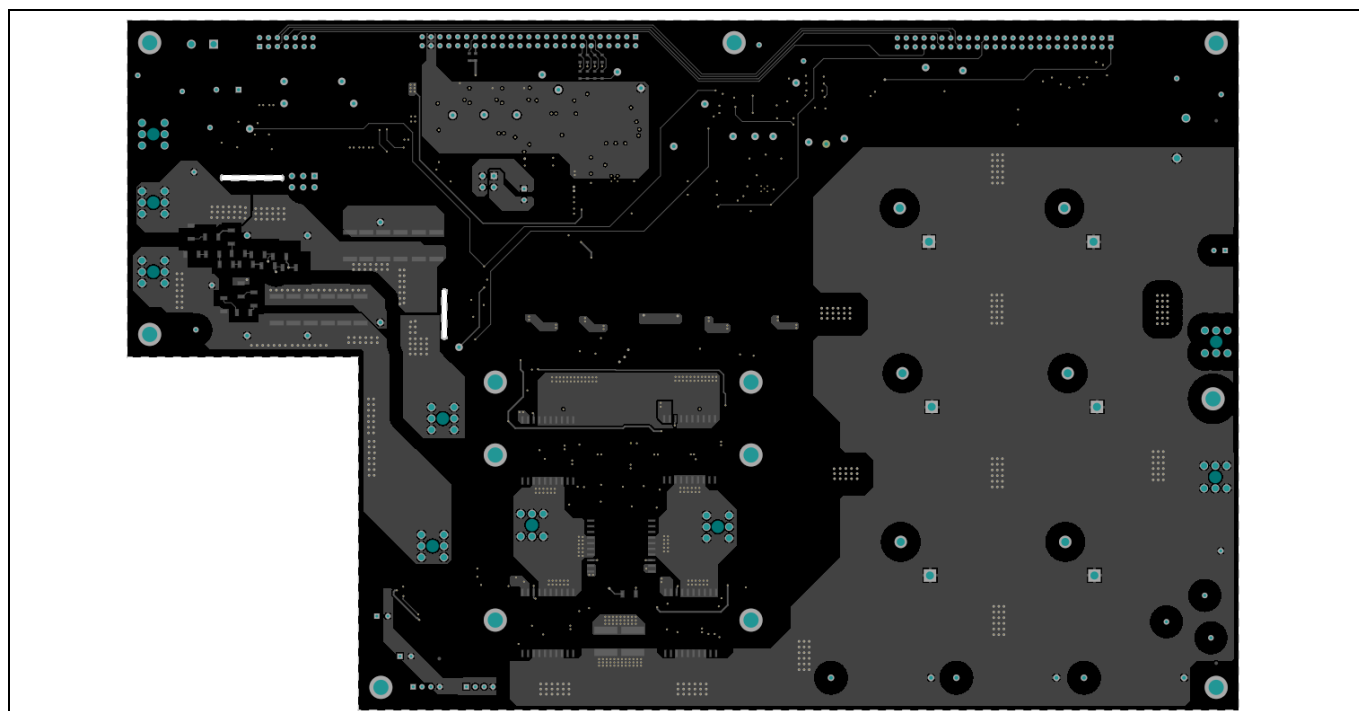


Figure 67 Layer 6 – Bottom layer

The bottom layer contains the traces for high current including MOSFETs current, input BUS_DC+, and AC output. Also, some thin traces have been used for control-related task on the low-voltage side.

6.2 PB-APS-24V-5V ISO

Table 13 Mechanical data

Dimensions	57.1 mm x 27.1 mm
No. of layers	8
Copper thickness	4.13 mil

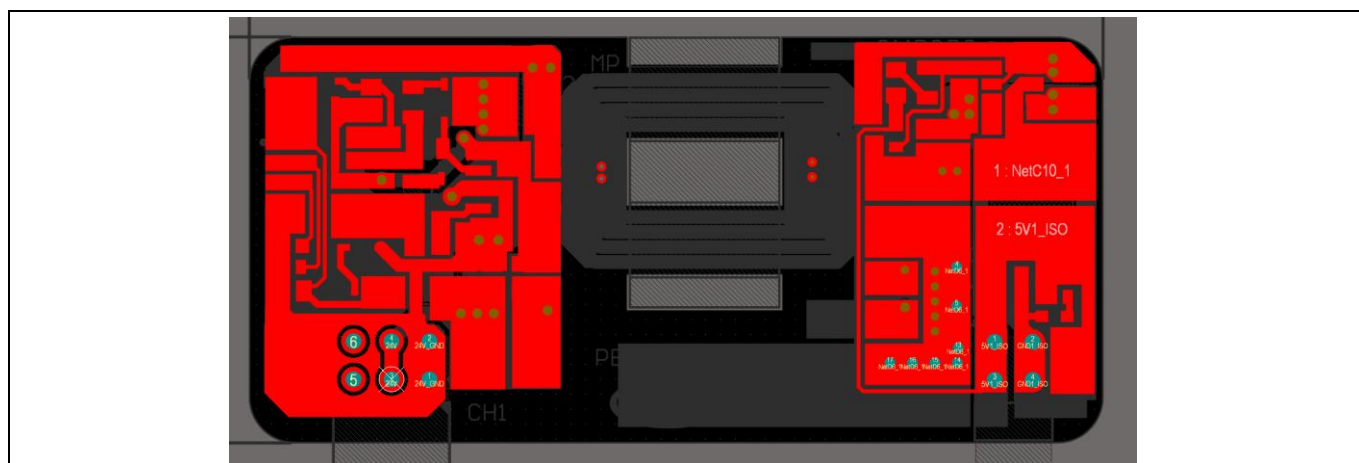


Figure 68 Layer 1

6 Board layout

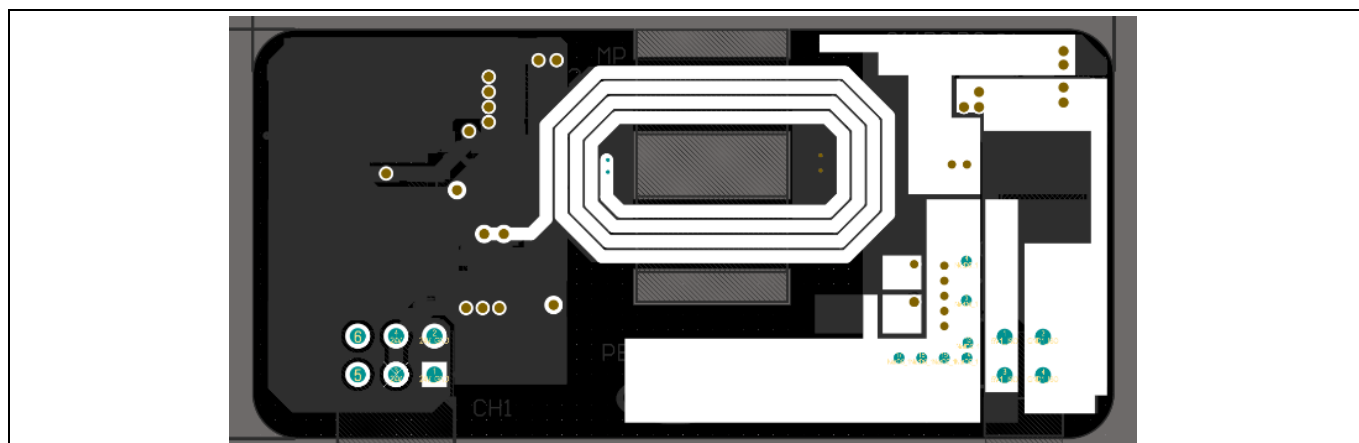


Figure 69 Layer 2

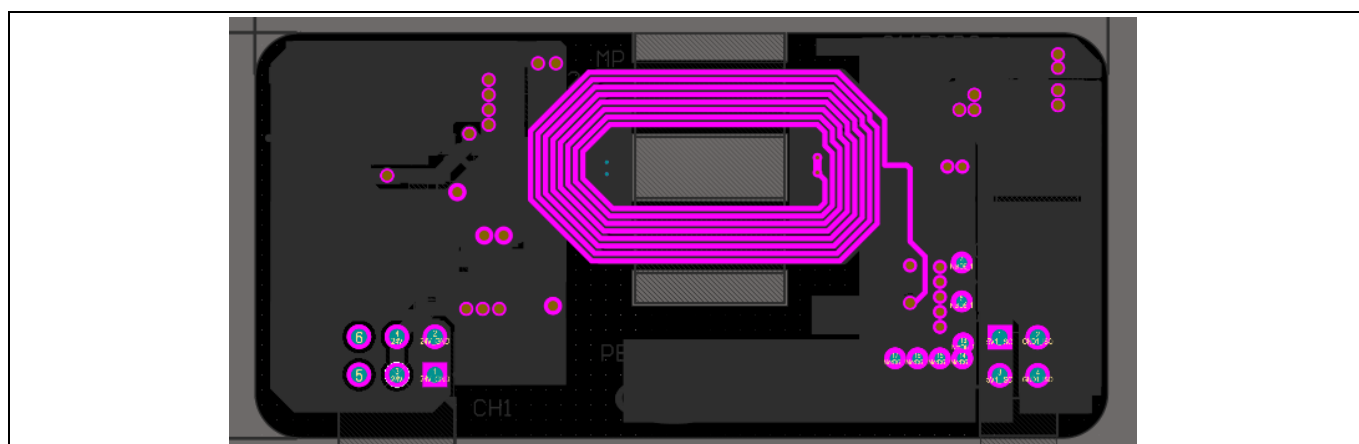


Figure 70 Layer 3

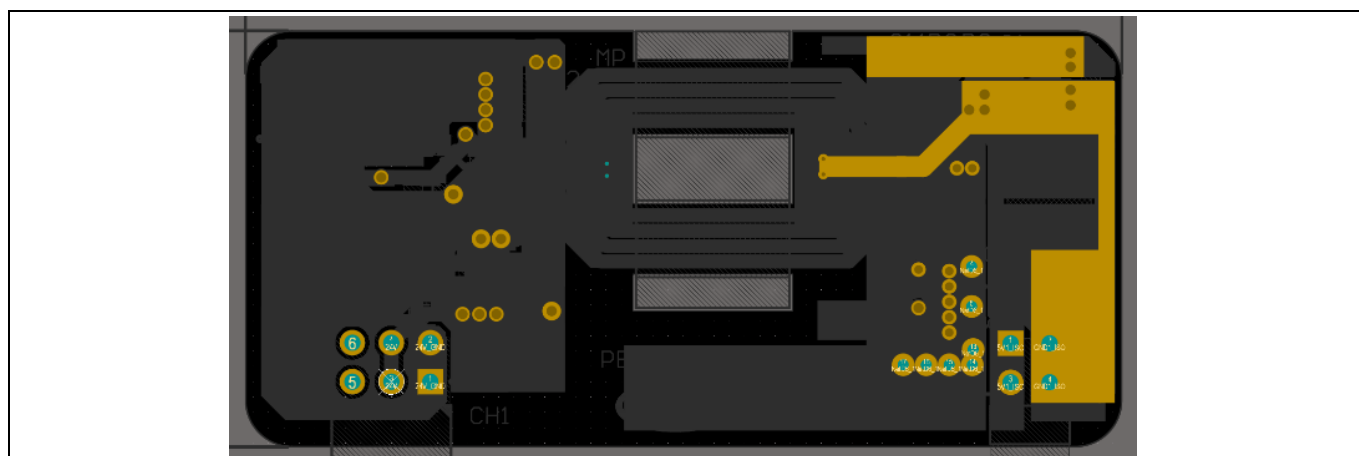


Figure 71 Layer 4

6 Board layout

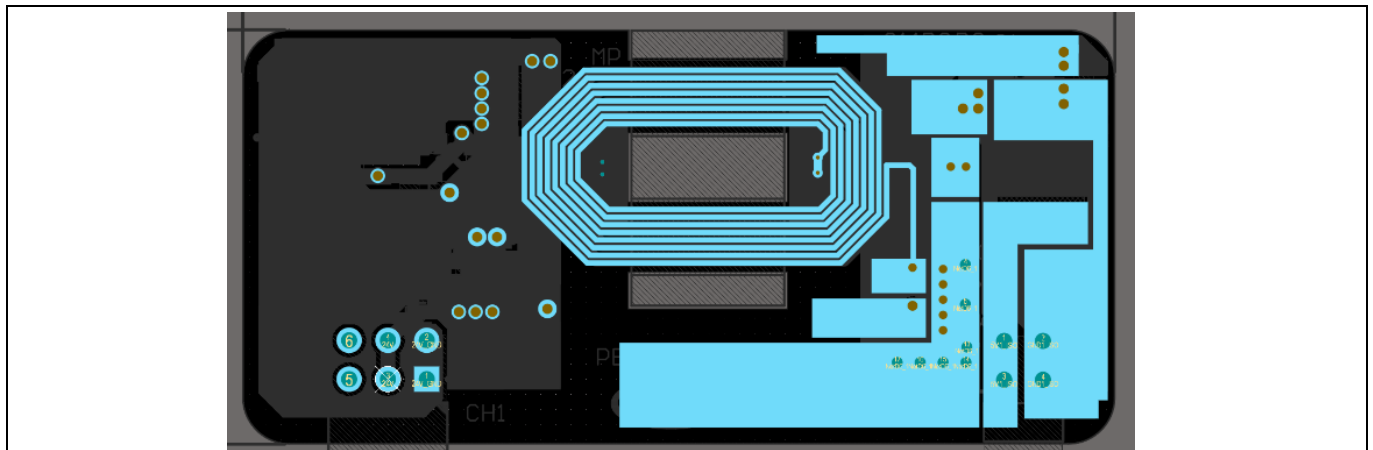


Figure 72 Layer 5

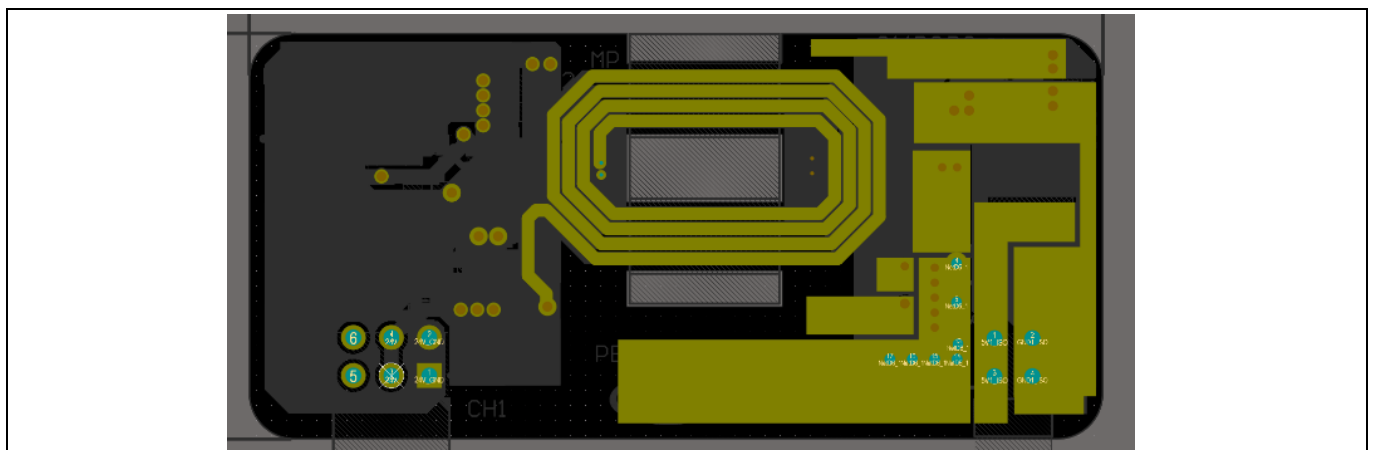


Figure 73 Layer 6

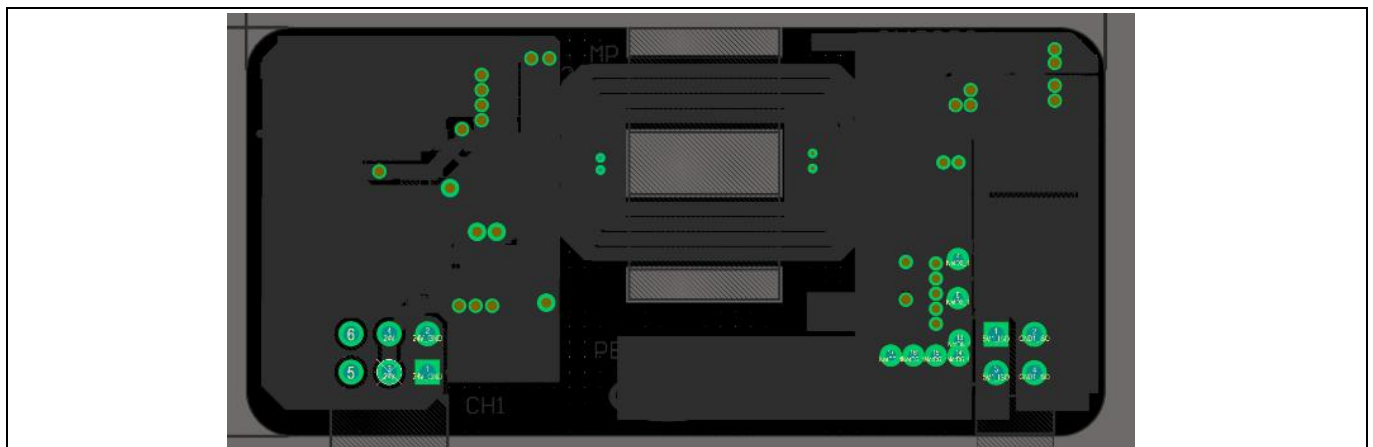


Figure 74 Layer 7

6 Board layout

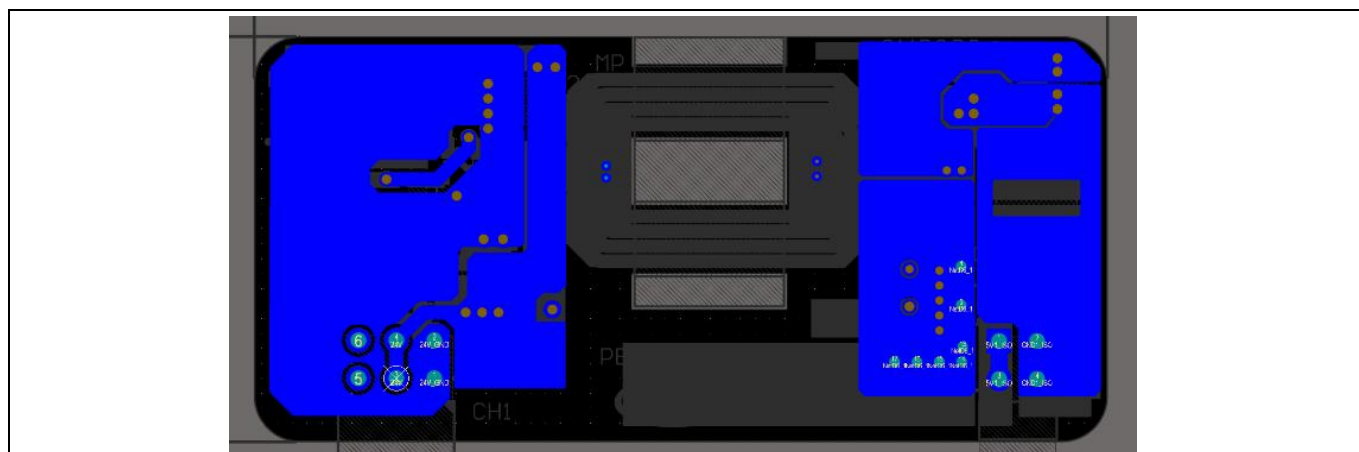


Figure 75 **Layer 8**

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- [3] Infineon Technologies: *CoolGaN™ BDS 650 V G5 datasheet*; [Available online](#)
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- [6] H. Schmidt, C. Siedle, and J. Ketterer; *DC/AC converter to convert direct electric voltage into alternating voltage or into alternating current*, U.S. Patent 7 046 534, May 16, 2006

Revision history

Revision history

Document revision	Date	Description of changes
V 1.0	2026-09-10	Initial release

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The electrical installation must be completed in accordance with the appropriate safety requirements.