# CoolGaN™ bidirectional switch 650 V G5 demo board user guide

## DEMO_AC_ZVS_HVBDS

## About this document

### Scope and purpose

This user guide describes the operation and use of the DEMO_AC_ZVS_HVBDS demonstration board. The guide also contains the schematic and bill of materials. For more information on CoolGaN™ BDS 650 V G5 IGLT65R055B2, see the datasheet [1].

### Intended audience

This document is intended as a guide for design engineers demonstrating the performance of CoolGaN™ BDS 650 V G5 IGLT65R055B2 with the DEMO_AC_ZVS_HVBDS demonstration board.

### Demonstration board

This board is to be used during the design-in process for demonstrating and measuring the soft switching behavior and performance of the BDS under AC conditions.

This board is not intended for hard switching conditions.

*Note: PCB and auxiliary circuits are NOT optimized for final customer design.*

### CoolGaN™

Infineon's CoolGaN™ solutions offer unmatched quality and operate at higher switching speeds resulting in lower power losses, higher efficiency, paving the way for smaller and lighter power supplies with the same size but increased power capability.

CoolGaN™ target applications include:

- 1-phase string inverter solutions
- 3-phase string inverter solutions
- Microinverter solutions
- Motor Control
- Server power supply units (PSU)

## Important notice

“Demonstration Boards and Reference Boards” shall mean products embedded on a printed circuit board (PCB) for demonstration and/or demonstration purposes, which include, without limitation, demonstration, reference and demonstration boards, kits and design (collectively referred to as “Reference Board”).

Environmental conditions have been considered in the design of the Demonstration Boards and Reference Boards provided by Infineon Technologies. The design of the Demonstration Boards and Reference Boards has been tested by Infineon Technologies only as described in this document. The design is not qualified in terms of safety requirements, manufacturing, and operation over the entire operating temperature range or lifetime.

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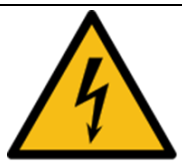
## Safety precautions

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

**Table 1 Safety precautions**

| | |
|---|---|
|  | **Warning:** *The AC potential of this board is up to 240 VAC. 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 demonstration or reference board contains capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait 5 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 demonstration or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by an 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 demonstration 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 demonstration 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 demonstration 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

The CoolGaN™ bidirectional switch 650 V G5 IGLT65R055B2 is the first of its kind monolithic GaN switch, capable of actively blocking voltage and current in both directions. It has a quasi-common drain design with a double gate structure using the Infineon gate injection transistor (GIT) technology. The CoolGaN™ BDS is fundamentally a five terminal device, two gates, two sources and substrate. It has four modes of operations: the traditional on/off modes and two diode modes where the switch can be actively controlled to behave like a diode that can block voltages in both directions.

The CoolGaN™ bidirectional switch (BDS) targets multiple applications:

- Replacing back-to-back discrete switches in existing applications that employ BDS such as Vienna rectifiers, T-type converters, HERIC, etc.,
- Other applications such as solar micro-inverters employing single stage DC-AC conversion

The DEMO_AC_ZVS_HVBDS demonstration board aims to demonstrate the AC soft-switching capability of the BDS in typical 50/60 Hz AC grid conditions with symmetrical triangular current mode (TCM) operations. The board also features a load-less setup and can test the BDS in a range of voltage, current, and switching frequency conditions, all under a simple open loop control.

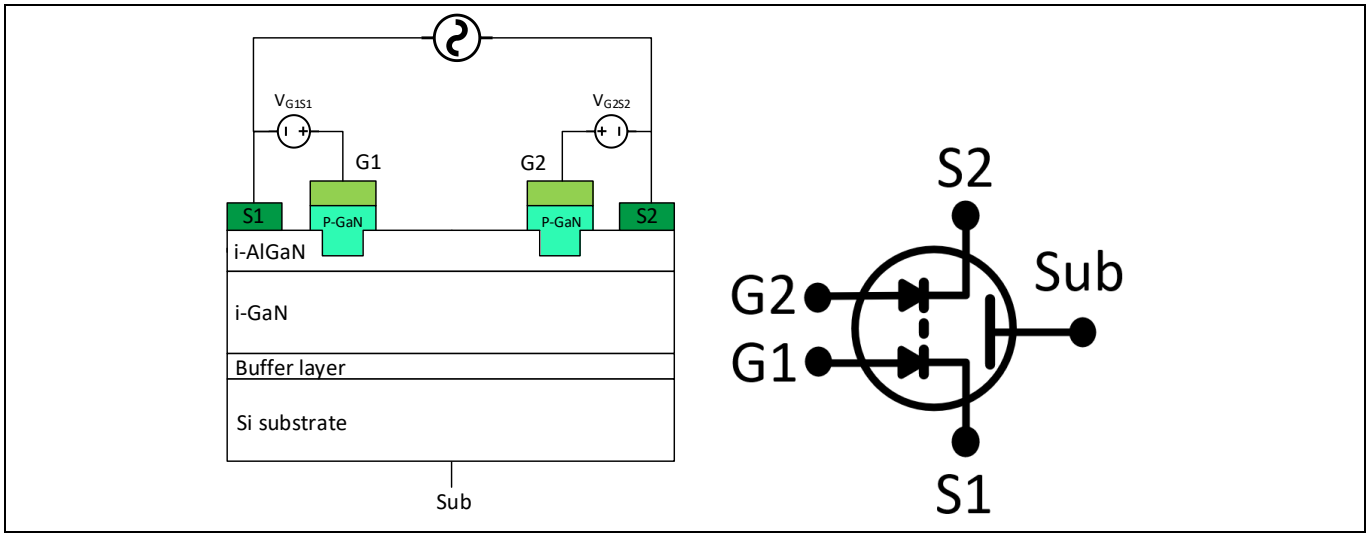



**Figure 1 BDS with double gate structure using GIT technology (left) and the basic device symbol (right)**

# 2 AC-ZVS BDS board

## 2.1 Board features

- $V_{ACin}$ = ± 90–240 $V_{AC}$, grid voltages
- $F_{grid}$ = 50–60 Hz, grid frequency
- D = 48–49%, duty cycle
- $F_{SW}$ = 100–400 kHz, switching frequency
- $L_B$ = 20–300 µH, external inductor (tested using an air-core from Johann Lasslop GmbH)
- $V_{DD}$ = 8–12 V, aux. supply
- +5 = 5 V supply

## 2.2 Connections and operating instructions

The DEMO_AC_ZVS_HVBDS demo board requires a 5 V supply as well as a $V_{DD}$ between 8–12 V for the auxiliary supplies.

**Table 2 Connections**

| Label | | | Descriptions |
|---|---|---|---|
| Input | VACin | VAC+ | Connect the input AC grid voltage to this pin |
| | | VAC- | Return of input power |
| Inductor | L_B | VSW1 | Connect the external inductor to this pin, also the switch node of the two BDS |
| | | VSW2 | Return of the external inductor, midpoint of the capacitor leg |
| VDC | 9 | VDD | Connect the auxiliary power (+9 V) to this pin |
| | 5 | +5 | Connect the input power (+5 V) to this pin |
| | G | GND | Ground pins for supply return path, shared between VDD and +5 |
| Signal inputs | PWM_G1 | PWM1 | Connect a PWM signal to this pin for the gates |
| | PWM_G2 | PWM2 | Connect an inverse PWM signal to this pin for the gates |
| Ground | GND | Gnd_ | Sense pins for the ground reference |
| Gate signals | G1A | G1A | Connect a differential scope probe to this pin to monitor G1A gate signal |
| | G1B | G1B | Connect a differential scope probe to this pin to monitor G1B gate signal |
| | G2A | G2A | Connect a differential scope probe to this pin to monitor G2A gate signal |
| | G2B | G2B | Connect a differential scope probe to this pin to monitor G2B gate signal |
| VSS | Vin+ | FVAC+ | Sense pins for Vin+ |
| | SW | VSW1 | Sense pins for switch node |
| | Vin- | FVAC- | Sense pins for Vin- |
| AC/DC mode | W1 | W1 | Alternative DC switching operation, de-solder AC from mid-point and connect mid-point to DC node |
| | W2 | W2 | Alternative DC switching operation, de-solder AC from mid-point and connect mid-point to DC node |

## 2.3 Power-on procedure

**Table 3 Power-on steps for AC-ZVS BDS board**

| Board config | Description |
|---|---|
| PWM_G1 and PWM_G2 | Connect to the signal generator with correct complementary gate signals |
| VDC | Apply 5 and VDD (9) VDC supplies |
| L_B | Connect external inductor within the stated value range |
| VACin | Connect AC power supply to VAC+, VAC- |

*Note: Make sure that the gate signal is on before turning on supplies.*

*Note: All boards will come pre-selected to AC mode. For both AC and DC mode, follow the power-on procedure.*

## 2.4 AC-ZVS BDS board

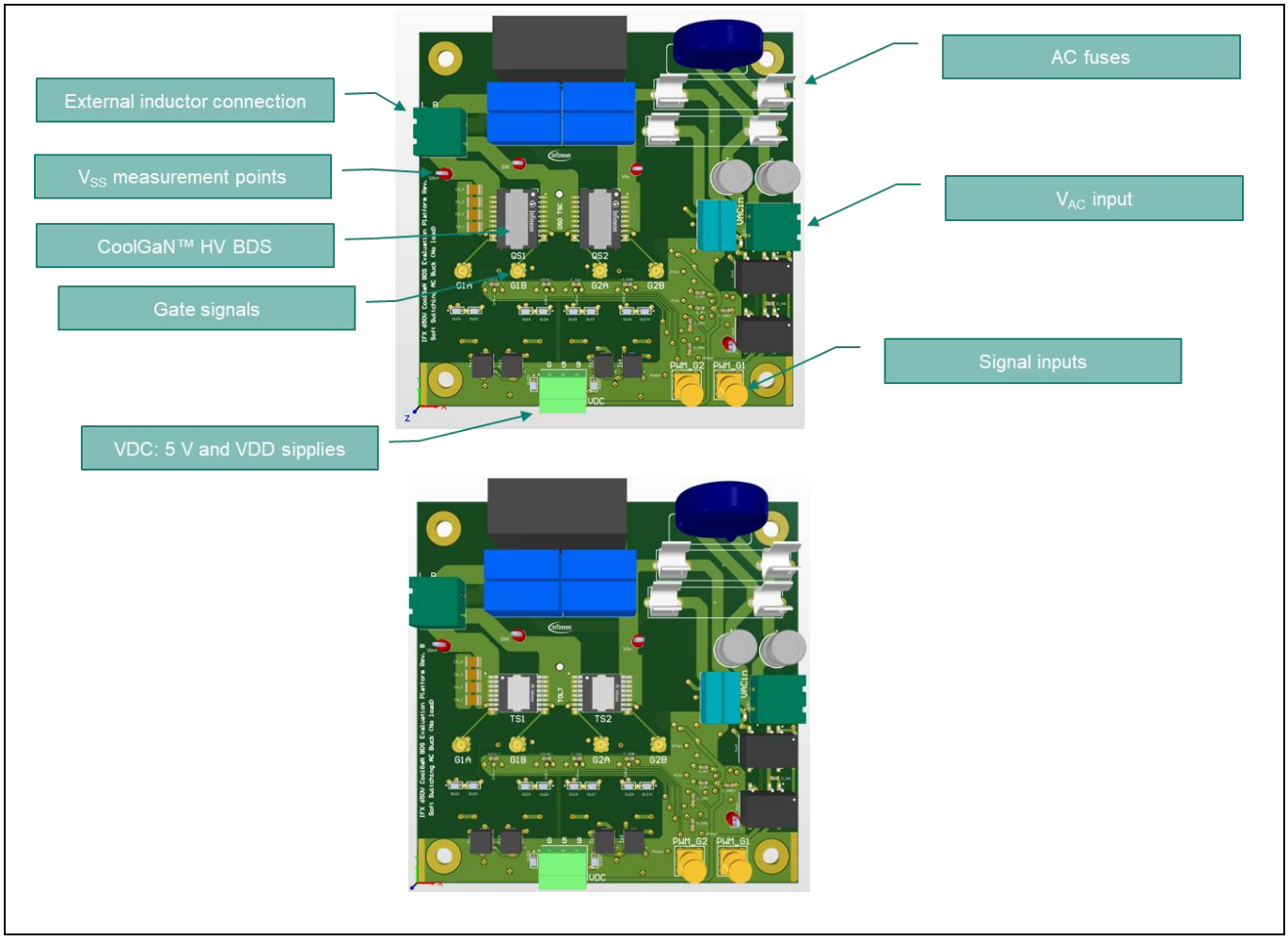



**Figure 2 DEMO_AC_ZVS_HVBDS demonstration board (top), DSO TSC and TOLT versions**

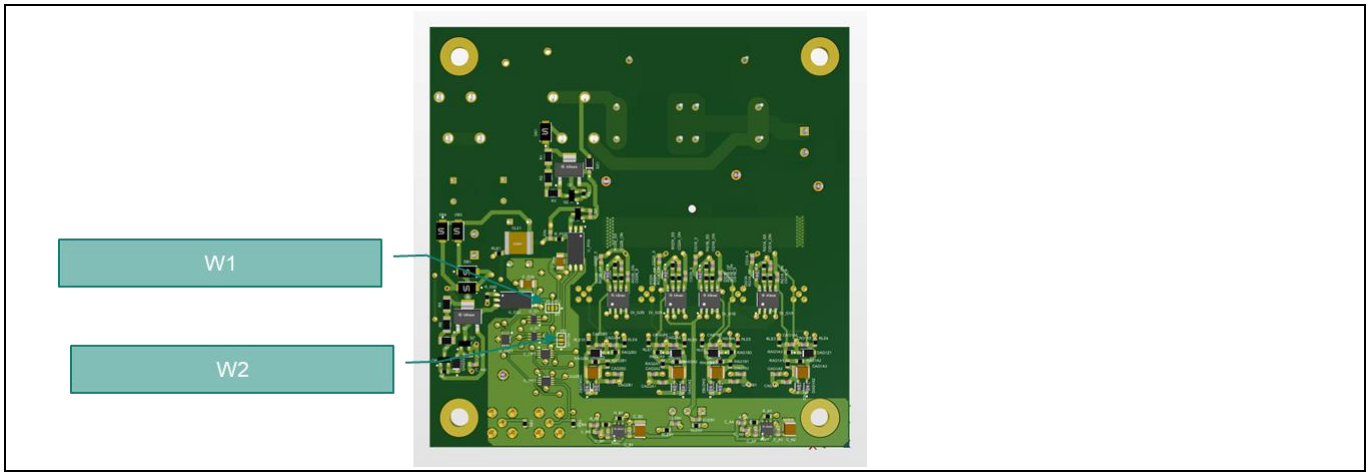



**Figure 3 DEMO_AC_ZVS_HVBDS demonstration board (bottom), DSO TSC version**

## 2.5 PCB layout

The following figures illustrate the PCB layout design of the DEMO_AC_ZVS_HVBDS demo board, FR4 material, four layers, 10 x 10 $cm^2$.

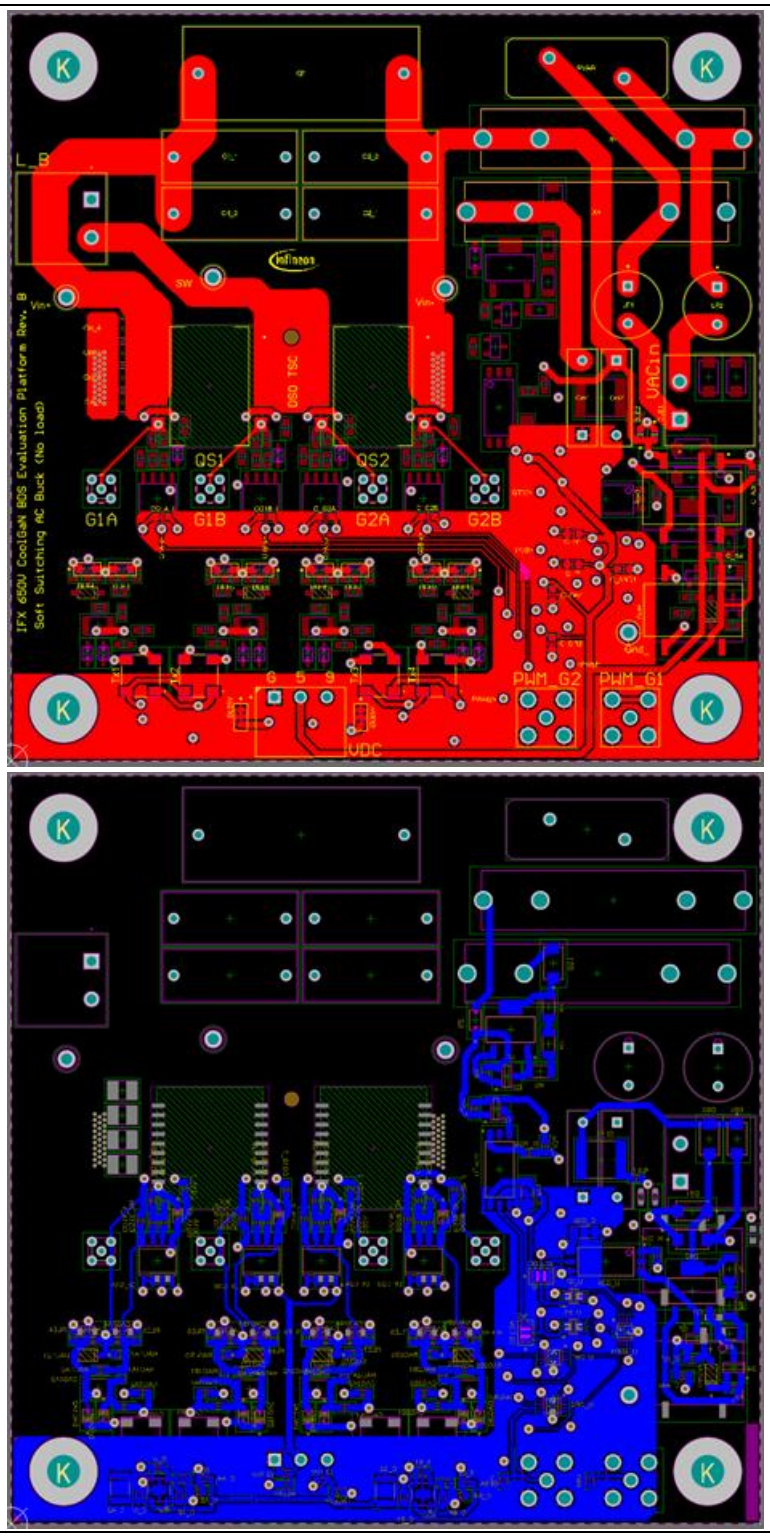



**Figure 4 DEMO_AC_ZVS_HVBDS demo board – Top layer (layer 1), bottom layer (layer 4)**

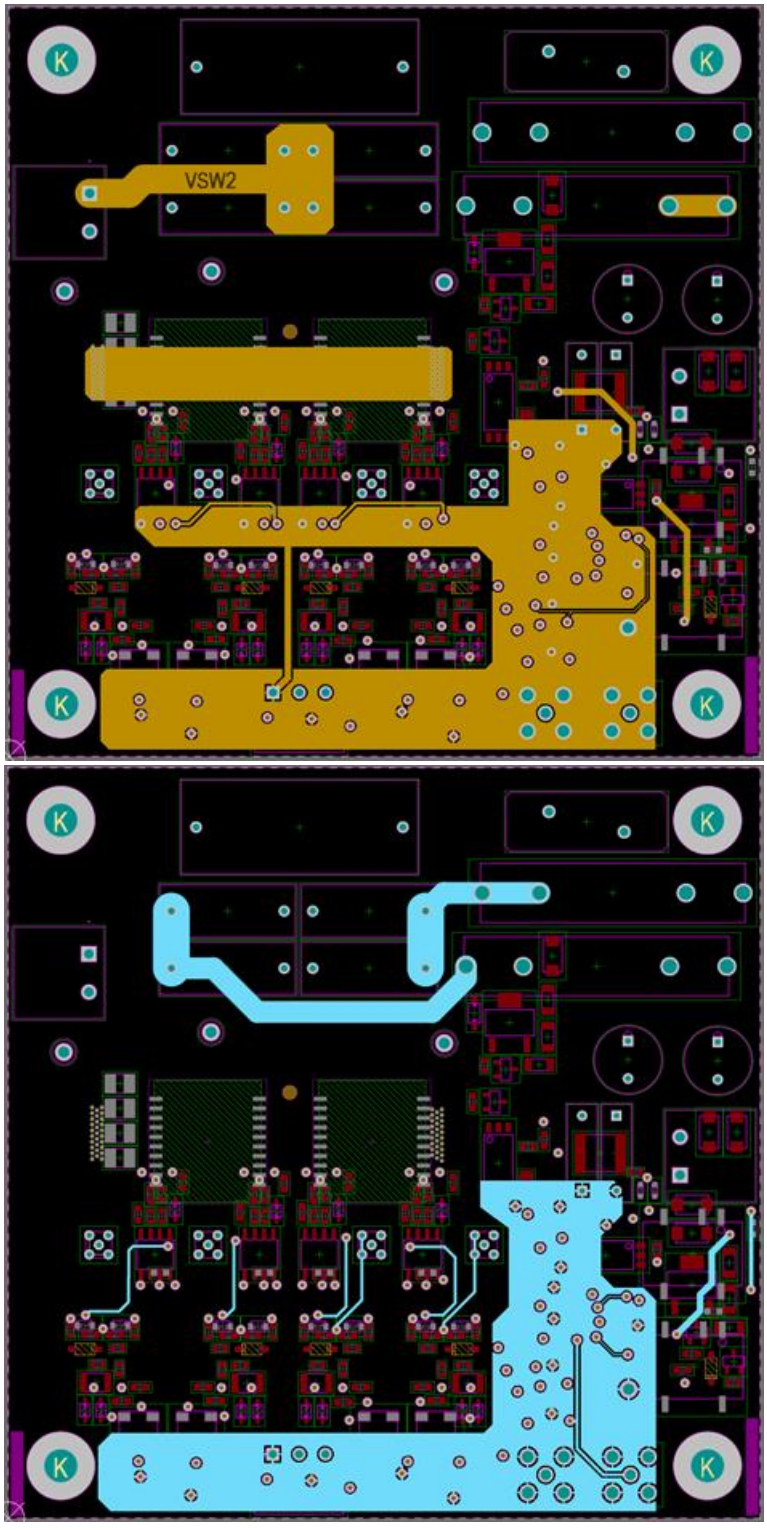



**Figure 5 DEMO_AC_ZVS_HVBDS demo board – Layer 2 (layer 2), Layer 3 (layer 3)**

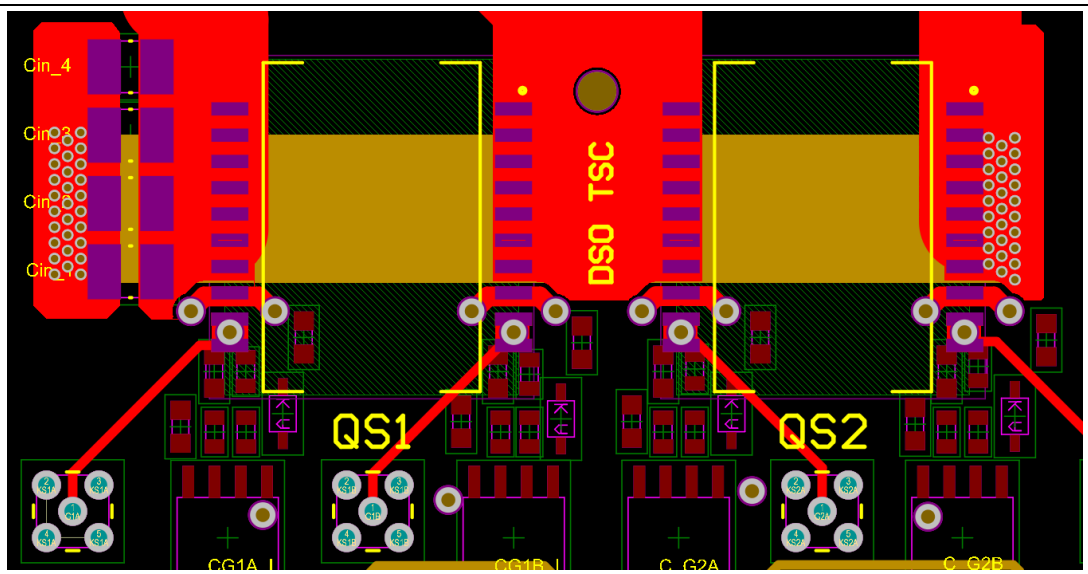



**Figure 6** **Commutation path of the two BDS (half bridge) between top layer and layer 2**

## 2.6 Simplified block diagram for the AC-ZVS BDS board

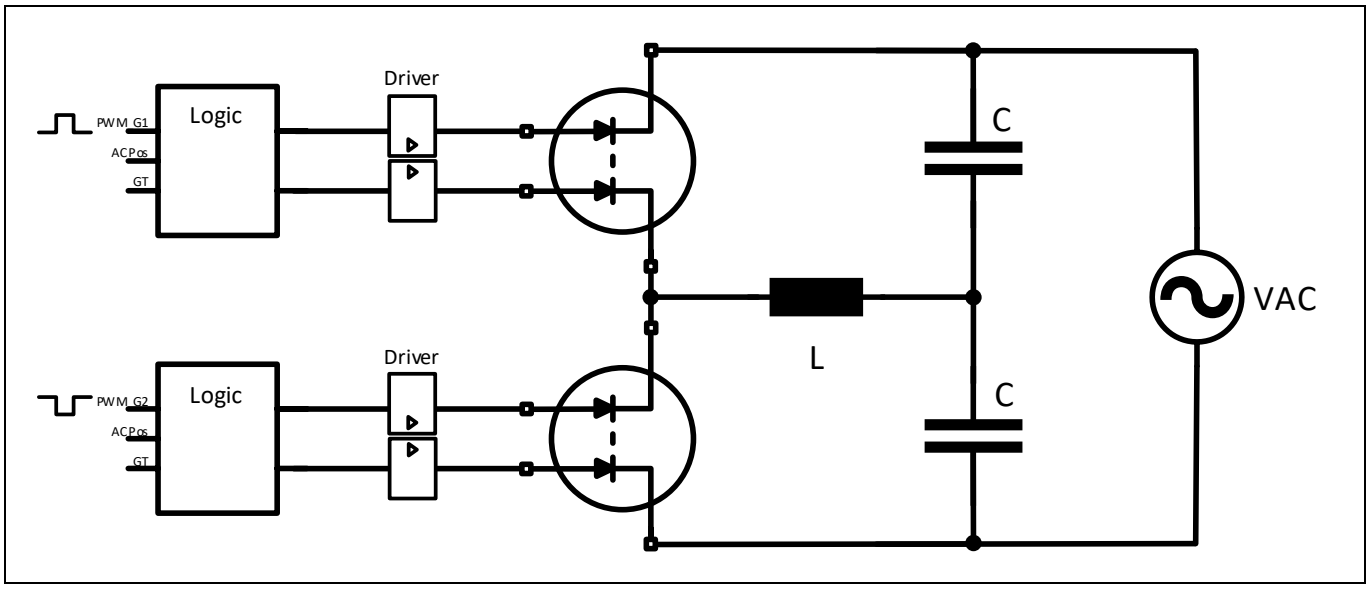



**Figure 7** **Simplified block diagram of the DEMO_AC_ZVS_HVBDS demonstration board, inductor is external**

## 2.7 Schematics

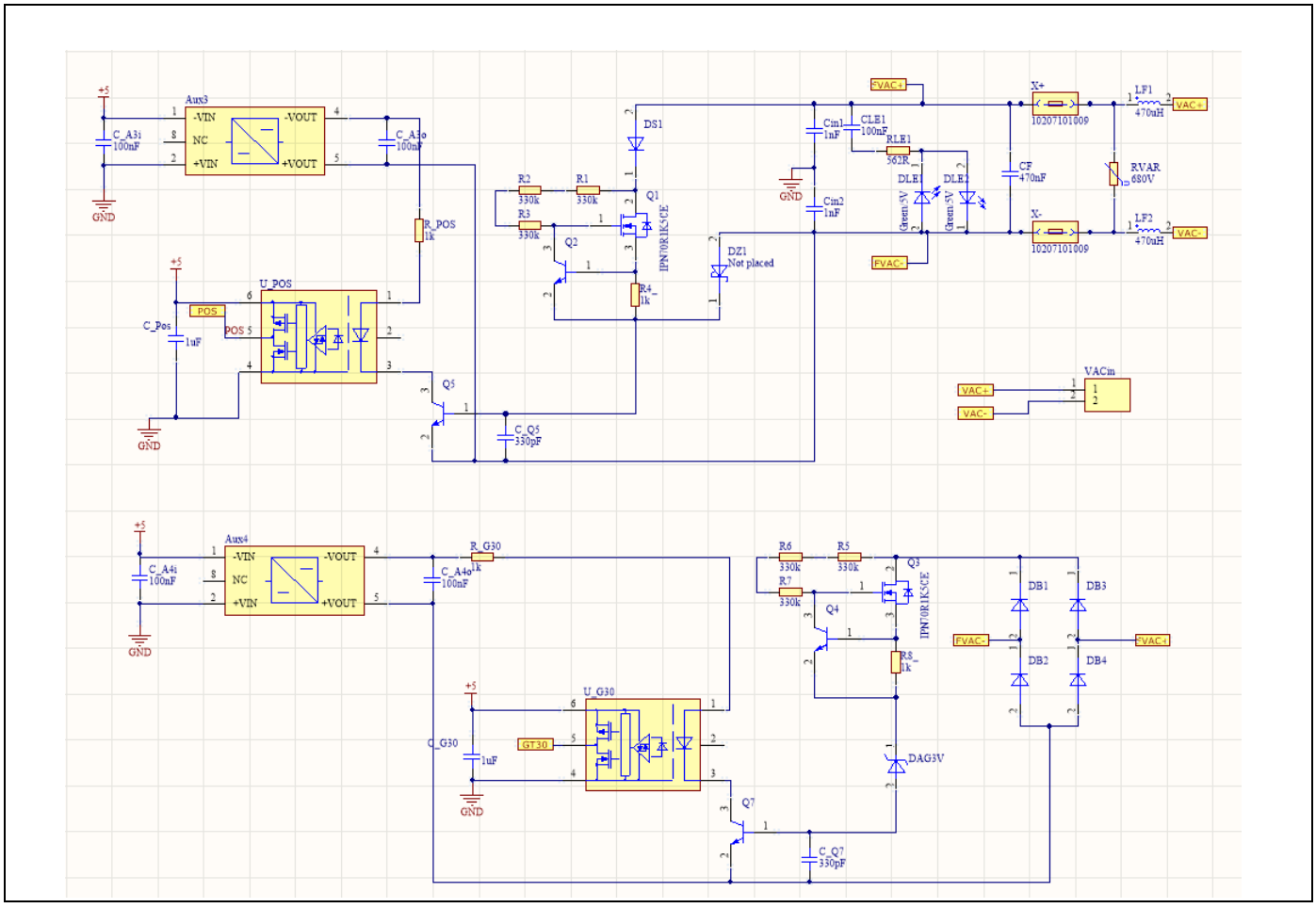



**Figure 8 Schematic of the VAC input and POS and GT sensing**

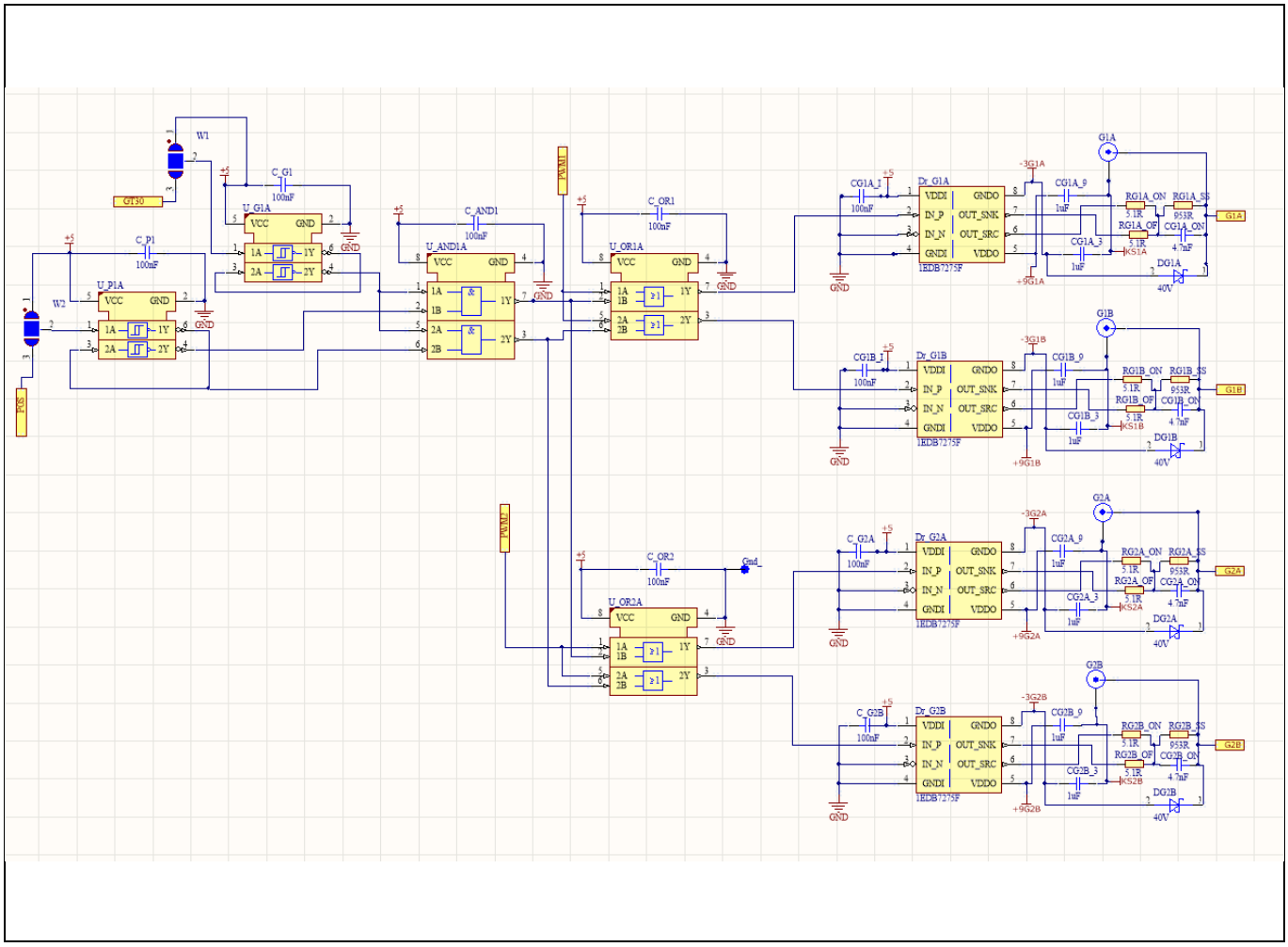



**Figure 9 Schematic of the logic circuits, PWM inputs, and gate drivers**

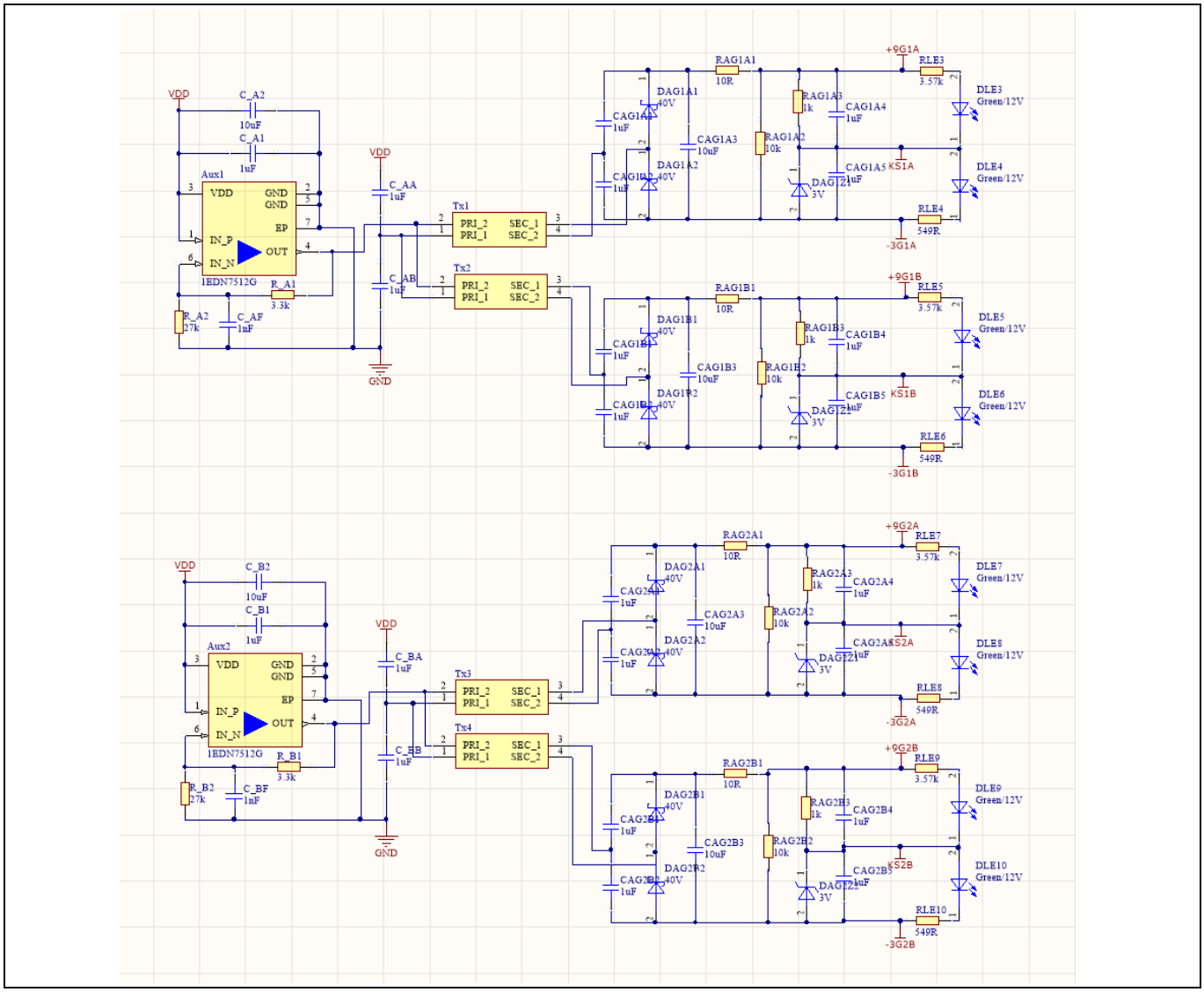



**Figure 10 Schematic of the auxiliary supplies for the floating gate drivers**

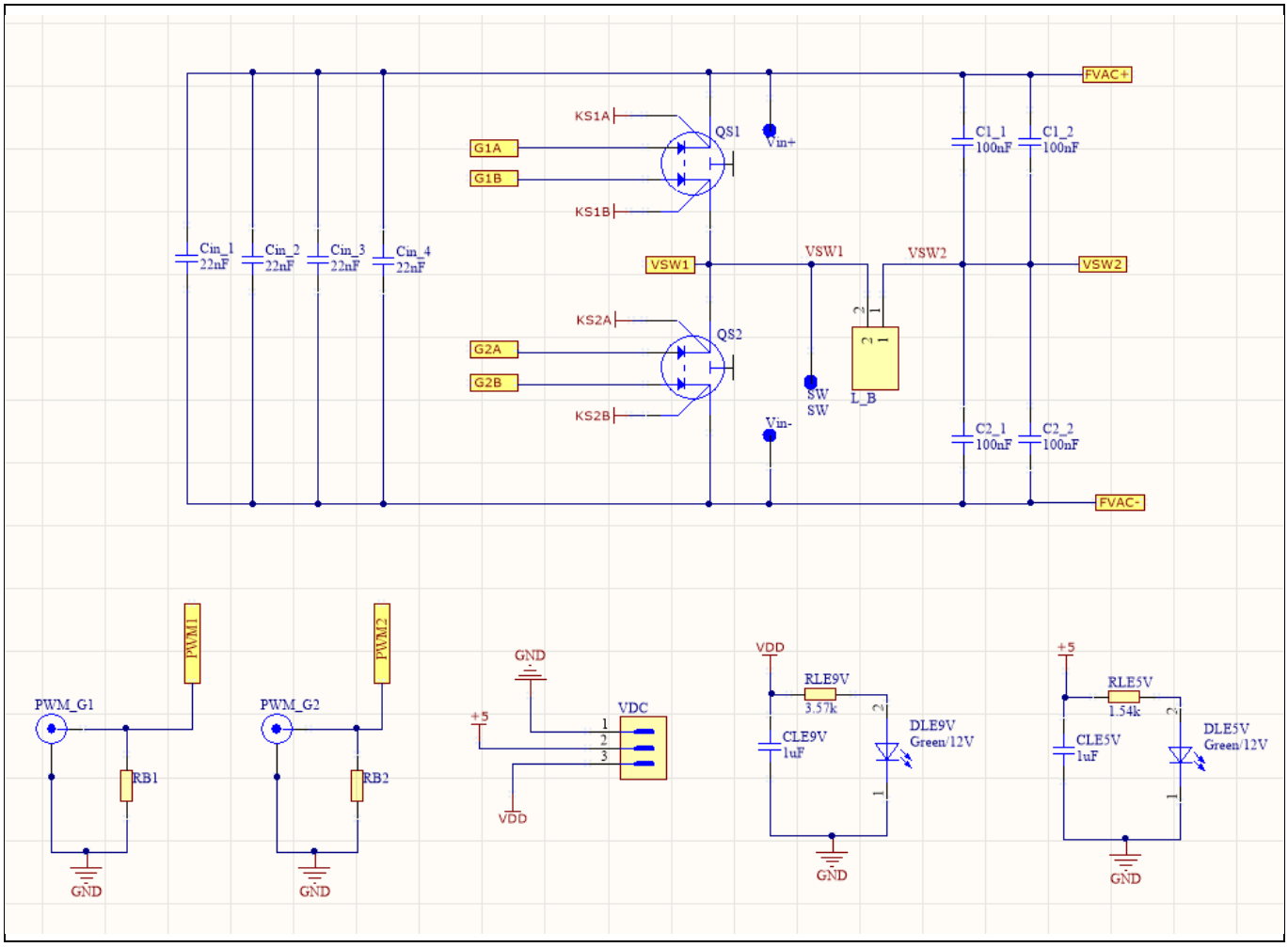



**Figure 11 Schematic of the BDS half bridge switching against a capacitor divider leg**

## 2.8 Bill of materials

**Table 4 DEMO_AC_ZVS_HVBDS - Bill of materials**

| Qty | Reference | Value | Manufacturer | Part number | Description |
|---|---|---|---|---|---|
| 2 | Aux1, Aux2 | 1EDN7512G | Infineon Technologies | 1EDN7512G | Driver for Aux. power |
| 2 | Aux3, Aux4 | IES0105S09 | XP Power | IES0105S09 | Aux. supply |
| 4 | C1_1, C1_2, C2_1, C2_2 | 100 nF | Epcos | B32652A6104J000 | Film Caps |
| 34 | C_A1, C_AA, C_AB, C_B1, C_BA, C_BB, C_Q5, C_Q7, CAG1A1, CAG1A2, CAG1A4, CAG1A5, CAG1B1, CAG1B2, CAG1B4, CAG1B5, CAG2A1, CAG2A2, CAG2A4, CAG2A5, CAG2B1, CAG2B2, CAG2B4, CAG2B5, CG1A_3, CG1A_9, CG1B_3, CG1B_9, CG2A_3, CG2A_9, CG2B_3, CG2B_9, CLE5V, CLE9V | 1 uF | Murata | GCM188R71E105KA64D | ceramic caps |
| 6 | C_A2, C_B2, CAG1A3, CAG1B3, CAG2A3, CAG2B3 | 10 uF | Murata | GRM32DR71E106KA12L | ceramic caps |
| 13 | C_A3i, C_A3o, C_A4i, C_A4o, C_AND1, C_G1, C_G2A, | 100 nF | Murata | GCM188R71E104KA57D | ceramic caps |

| Qty | Reference | Value | Manufacturer | Part number | Description |
|---|---|---|---|---|---|
| | C_G2B, C_OR1, C_OR2, C_P1, CG1A_I, CG1B_I | | | | |
| 2 | C_AF, C_BF | 1 nF | Murata | GCM188R71H102KA37J | ceramic caps |
| 2 | C_G30, C_Pos | 1 uF | Murata | C1206X105J5RACTU | ceramic caps |
| 1 | CF | 470 nF | TDK Corporation | B32914A5474M000 | Film Caps |
| 4 | CG1A_ON, CG1B_ON, CG2A_ON, CG2B_ON | 4.7 nF | Murata | GCM188R71H472KA37J | ceramic caps |
| 2 | Cin1, Cin2 | 1 nF | TDK Corporation | B32021A3102K000 | Film Caps |
| 4 | Cin_1, Cin_2, Cin_3, Cin_4 | 22 nF | Wurth Elektronik | 885342209007 | ceramic caps |
| 1 | CLE1 | 100 nF | Kemet | C2220C104KDRAC7800 | ceramic caps |
| 12 | DAG1A1, DAG1A2, DAG1B1, DAG1B2, DAG2A1, DAG2A2, DAG2B1, DAG2B2, DG1A, DG1B, DG2A, DG2B | 40 V | Infineon Technologies | BAT165 | Schottky Diode. |
| 5 | DAG1Z1, DAG1Z2, DAG2Z1, DAG2Z2, DAG3V | 3 V | Diodes | MMSZ5225BT1G | Zener diode |
| 5 | DB1, DB2, DB3, DB4, DS1 | S1M-T R3G | Taiwan Semiconductor | S1M-13-F | Diode |
| 2 | DLE1, DLE2 | Green/5 V | Wurth Elektronik | 150060GS75000 | LED |
| 10 | DLE3, DLE4, DLE5, DLE5V, DLE6, DLE7, DLE8, DLE9, DLE9V, DLE10 | Green/12 V | OSRAM | LG M67K-H1J2-24-Z | LED |
| 4 | Dr_G1A, Dr_G1B, | 1EDB7275F | Infineon Technologies | 1EDB7275F | Gate Driver |

| Qty | Reference | Value | Manufacturer | Part number | Description |
|---|---|---|---|---|---|
| | Dr_G2A, Dr_G2B | | | | |
| 4 | G1A, G1B, G2A, G2B | MMCX-J-P-H-ST-TH1 | Samtec | MMCX-J-P-H-ST-TH1 | MMCX connector |
| 4 | Gnd_, SW, Vin-, Vin+ | | Keystone Electronics | 5010 | Test points |
| 2 | L_B, VACin | MSTBA 2,5/ 2-G-5,08 | Phoenix | 1757242 | PCB header, pair with 1757019 |
| 2 | LF1, LF2 | 470 uH | Bourns | RLB9012-471KL | Inductor |
| 2 | PWM_G1, PWM_G2 | SMACONNECTOR | Low Power Radio Solutions | SMACONNECTOR | SMA connector |
| 2 | Q1, Q3 | IPN70R1K5CE | Infineon Technologies | IPN70R1K5CE | 700V CoolMOS |
| 4 | Q2, Q4, Q5, Q7 | MMBT4401LT1G | ON Semiconductor | MMBT4401LT1G | 40V BJT |
| 2 | QS1, QS2 | 650 V, 70 mOhm Max. | Infineon Technologies | IGLT65R055B2 | BDS |
| 6 | R1, R2, R3, R5, R6, R7 | 330k | Vishay | CRCW1206330KFK | Resistors |
| 8 | R4_, R8_, R_G30, R_POS, RAG1A3, RAG1B3, RAG2A3, RAG2B3 | 1k | Vishay | CRCW06031K00FK | Resistors |
| 2 | R_A1, R_B1 | 3.3k | Vishay | CRCW06033K30FK | Resistors |
| 2 | R_A2, R_B2 | 27k | Vishay | CRCW060327K0FK | Resistors |
| 4 | RAG1A1, RAG1B1, RAG2A1, RAG2B1 | 10R | Vishay | CRCW060310R0FKEA | Resistors |
| 4 | RAG1A2, RAG1B2, RAG2A2, RAG2B2 | 10k | Vishay | CRCW060310K0FKEA | Resistors |
| 2 | RB1, RB2 | 49.9R | Vishay | CRCW060349R9FK | Resistors |
| 8 | RG1A_OF, RG1A_ON, RG1B_OF, RG1B_ON, RG2A_OF, RG2A_ON, | 5.1R | Vishay | CRCW06035R10FK | Resistors |

## AC-ZVS BDS board

| Qty | Reference | Value | Manufacturer | Part number | Description |
|---|---|---|---|---|---|
| | RG2B_OF, RG2B_ON | | | | |
| 4 | RG1A_SS, RG1B_SS, RG2A_SS, RG2B_SS | 953R | Vishay | CRCW0603953RFK | Resistors |
| 1 | RLE1 | 562R | Vishay | CRCW0603562RFK | Resistors |
| 5 | RLE3, RLE5, RLE7, RLE9, RLE9V | 3.57k | Vishay | CRCW06033K57FK | Resistors |
| 4 | RLE4, RLE6, RLE8, RLE10 | 549R | Vishay | CRCW0603549RFK | Resistors |
| 1 | RLE5V | 1.54k | Vishay | CRCW06031K54FK | Resistors |

# 3 Typical operating waveforms

## 3.1 100 kHz, 50 ms

AC-ZVS BDS demonstration board configuration:

- $V_{ACin}$ = 230 $V_{AC}$
- $F_{grid}$ = 50 Hz
- D = 48.5%
- $F_{sw}$ = 100 kHz
- $L_B$ = 300 µH

**Operating conditions**: Room temperature, no airflow, no heatsink

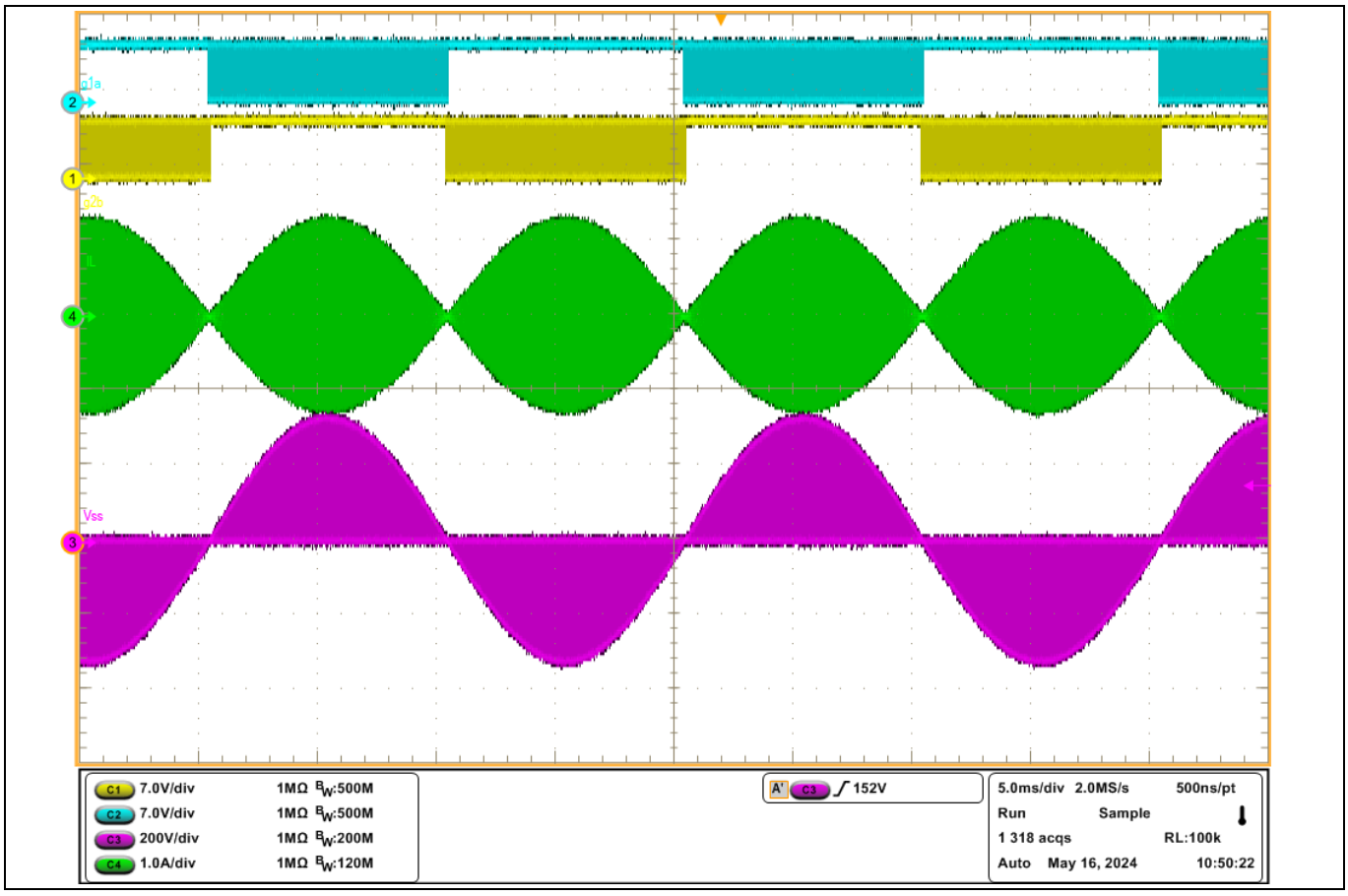



**Figure 12 Typical operating waveforms at 100 kHz (Ch1: G2B, Ch2: G1A, Ch3: VSS, Ch4: IL)**

## 3.2 100 kHz, 100 µs, positive Vss

AC-ZVS BDS demonstration board configuration:

- $V_{ACin}$ = 230 $V_{AC}$
- $F_{grid}$ = 50 Hz
- D = 48.5%
- $F_{sw}$ = 100 kHz
- $L_B$ = 300 µH

**Operating conditions**: Room temperature, no airflow, no heatsink

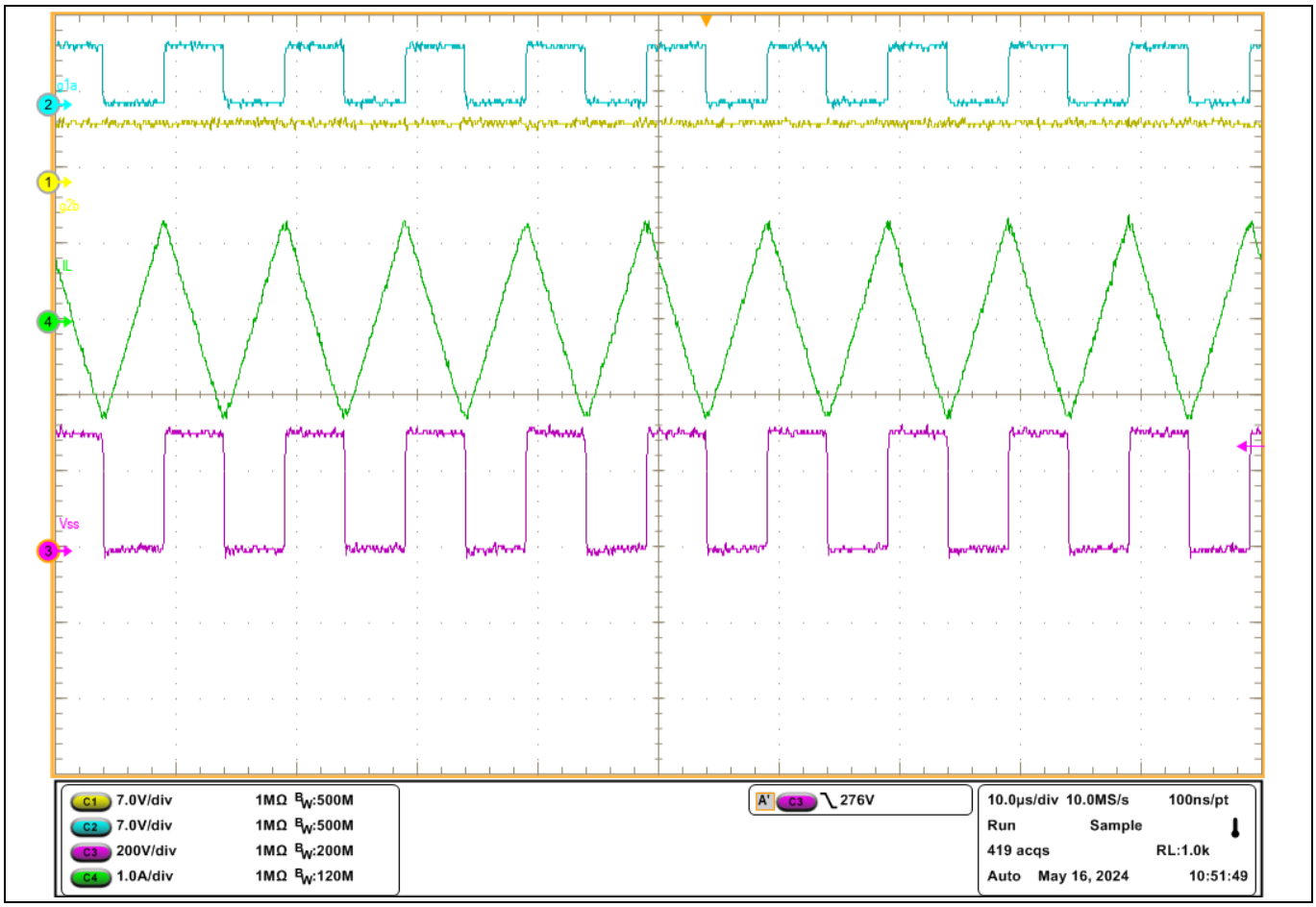



**Figure 13 Typical operating waveforms at 100 kHz (Ch1: G2B, Ch2: G1A, Ch3: VSS, Ch4: IL)**

## 3.3 100 kHz, 100 µs, negative Vss

AC-ZVS BDS demonstration board configuration:

- $V_{ACin}$ = 230 $V_{AC}$
- $F_{grid}$ = 50 Hz
- D = 48.5%
- $F_{sw}$ = 100 kHz
- $L_B$ = 300 µH

**Operating conditions**: Room temperature, no airflow, no heatsink

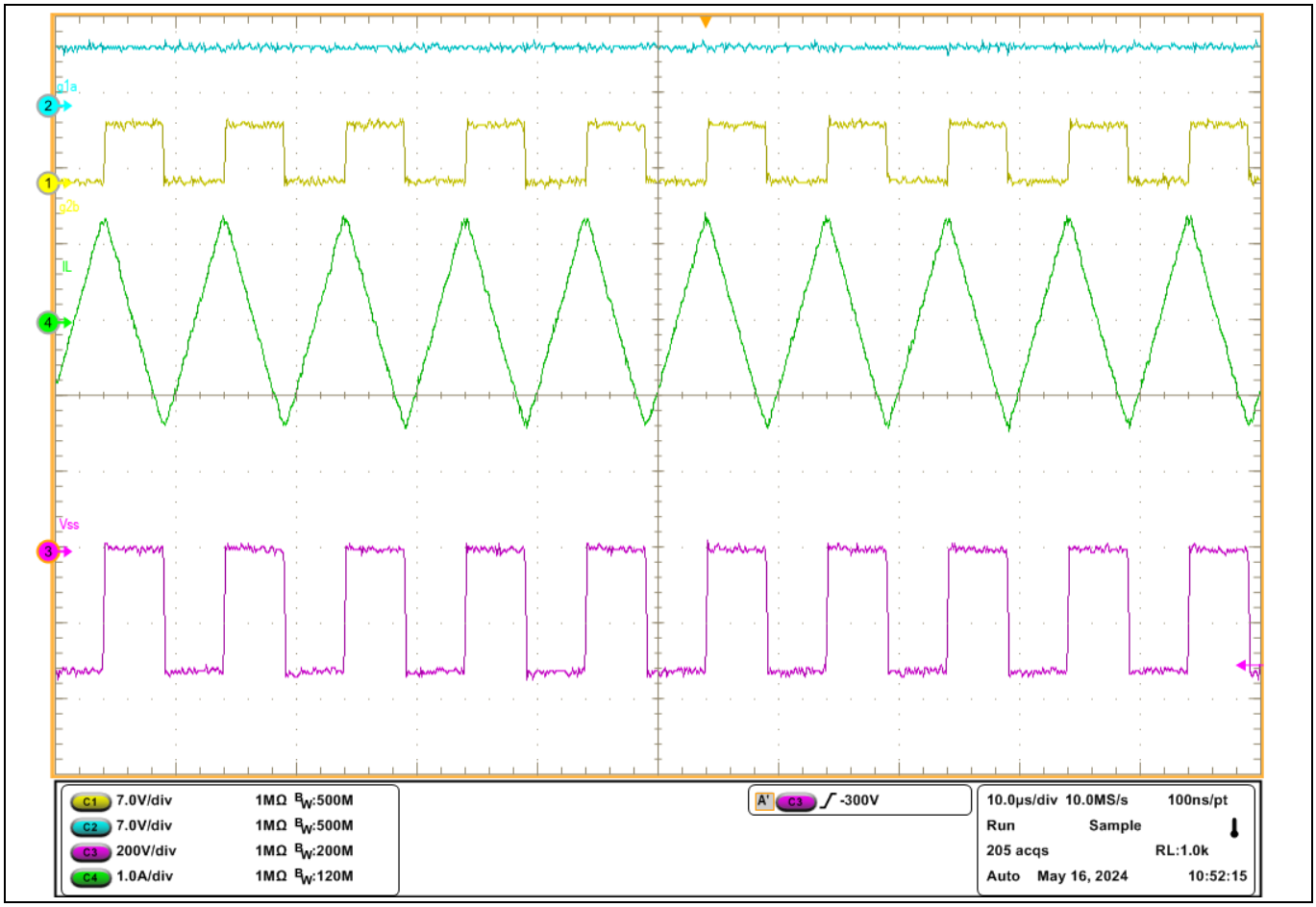



**Figure 14 Typical operating waveforms at 100 kHz (Ch1: G2B, Ch2: G1A, Ch3: VSS, Ch4: IL)**

## 3.4 400 kHz, 100 ms

AC-ZVS BDS demonstration board configuration:

- $V_{ACin}$ = 240 $V_{AC}$
- $F_{grid}$ = 50 Hz
- D = 48%
- $F_{sw}$ = 400 kHz
- $L_B$ = 20 µH
- $T_{case}$ = 46.3°C

**Operating conditions**: Room temperature, no airflow, no heatsink

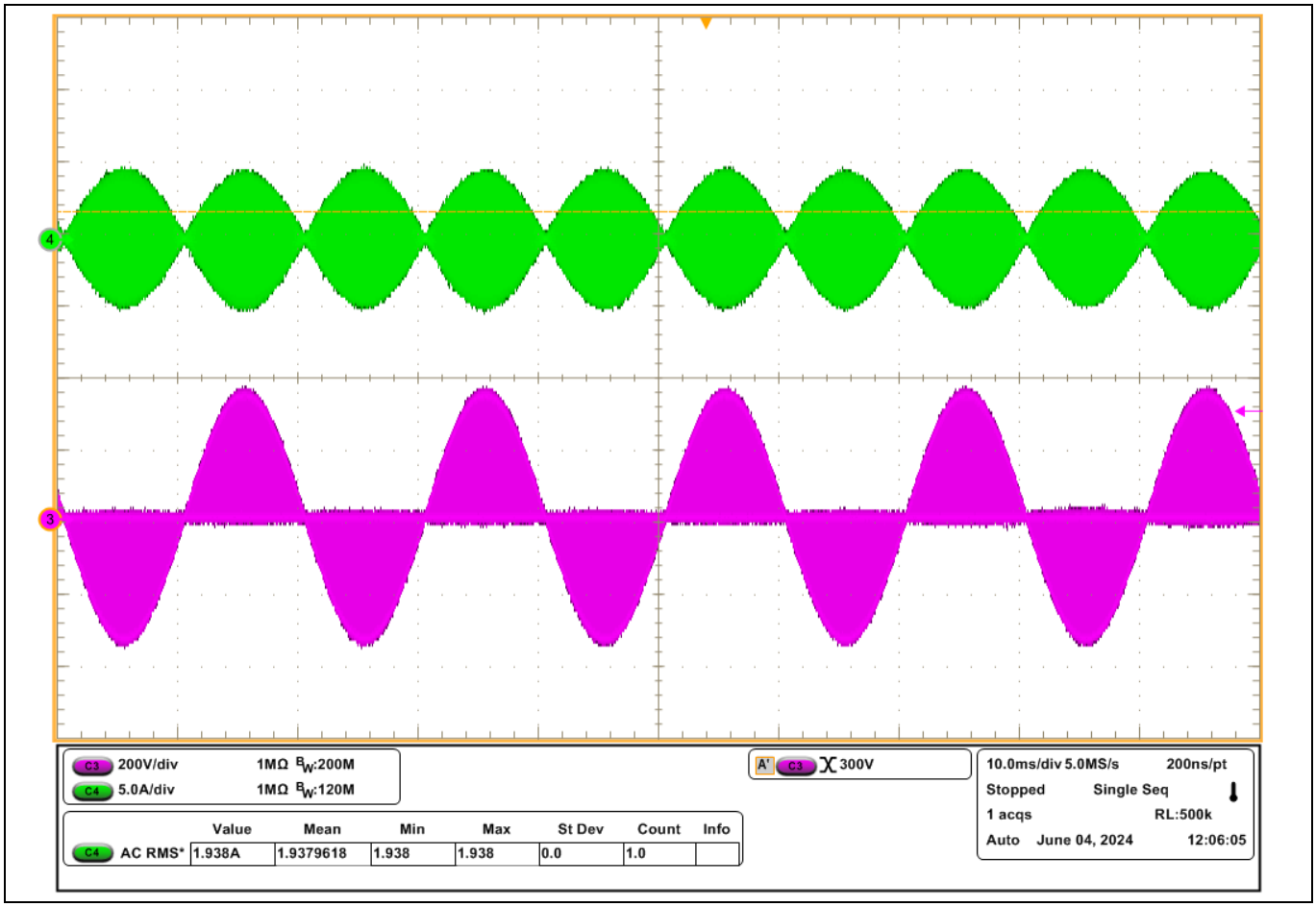



**Figure 15 Typical operating waveforms at 400 kHz (Ch3: VSS, Ch4: IL)**

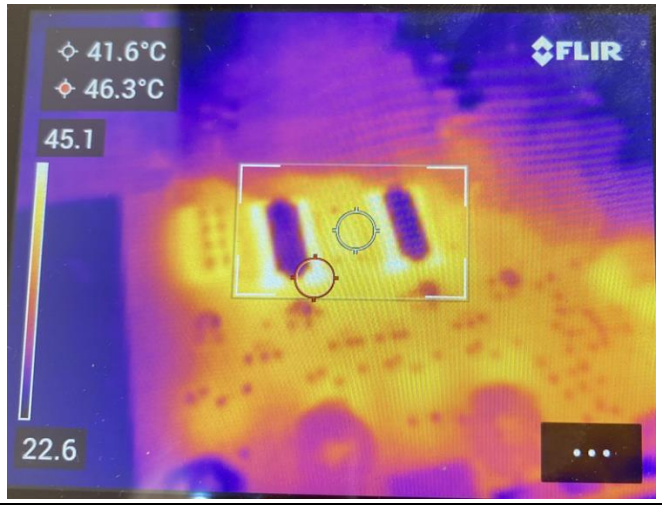



**Figure 16 Thermal image of the BDS**

# 4 Module performance

## 4.1 Total power consumption curves

Dual-phase power module demonstration board:

- $F_{grid}$ = 50 Hz
- D = 48.5%
- $T_c$ = <40°C

**Operating conditions**: Room temperature, no airflow, no heatsink

*Note: The power consumption curves include the losses of BDS, the inductor losses, the losses of the capacitors, and PCB trace losses. Measured at the input of the terminals*

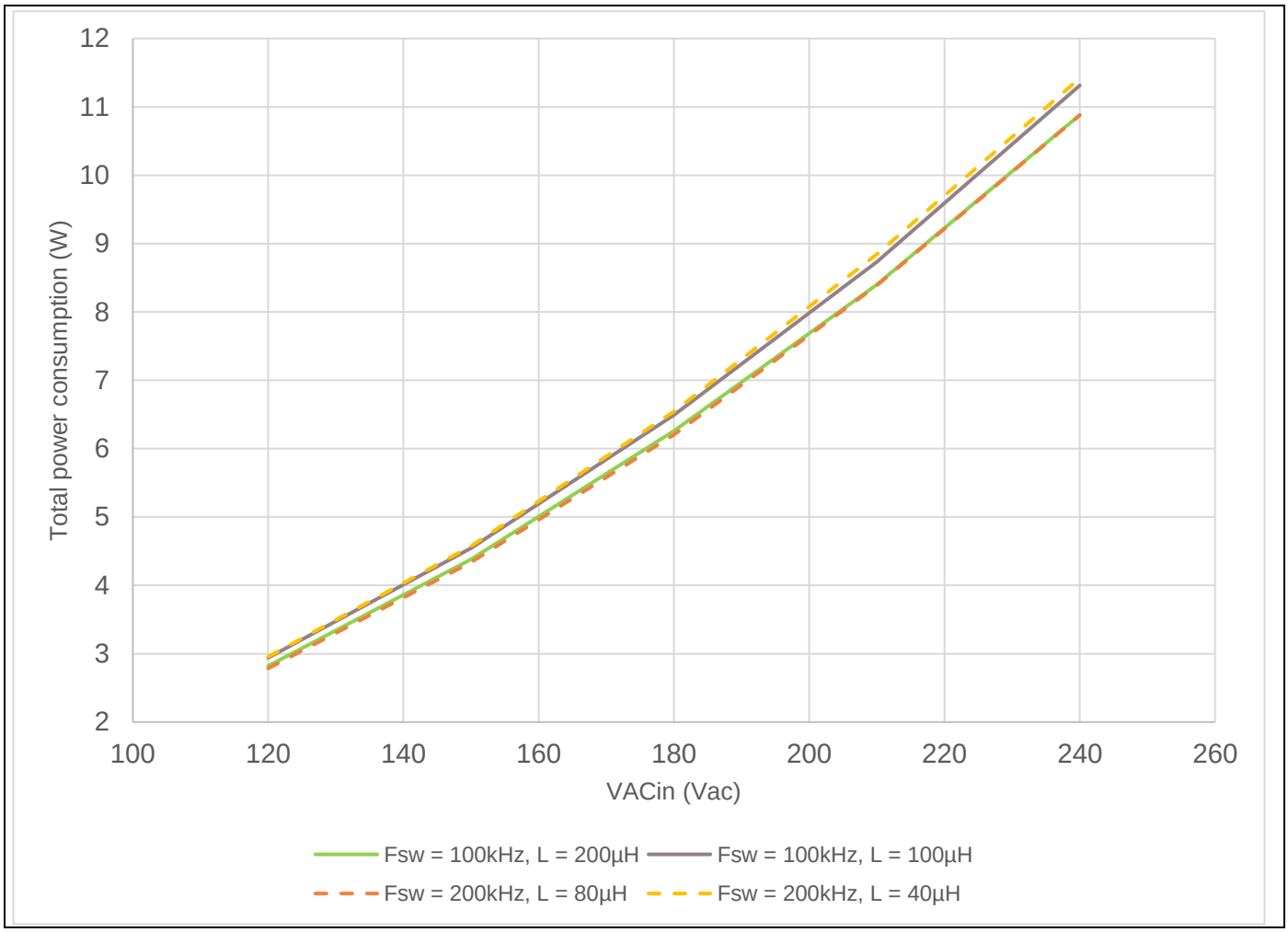



**Figure 17 Total power consumption vs. VACin at different switching frequencies and inductor values.**

## References

[1] Infineon Technologies: *CoolGaN™ BDS 650 V G5 IGLT65R055B2 Bi-directional enhancement-mode power transistor datasheet.* Available online

## Revision history

| Document revision | Date | Description of changes |
|---|---|---|
| V1.0 | 2024-06-07 | First draft |
| V1.1 | 2024-10-22 | The statement: “This board is not intended for hard switching conditions” added. |
| V1.2 | 2025-04-24 | BDS symbol |

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