5kW Interleaved Totem Pole PFC with 1ED2127 and 650V CoolSiC™

About this document

Scope and purpose

This document presents EVAL-1EDSIC-PFC-5KW evaluation board, which is an Infineon's complete system solution for a 5kW interleaved totem pole PFC (Power Factor Correction).

The EVAL-1EDSIC-PFC-5KW has been designed to address the growing need for enhanced efficiency in power supply units for home appliances: Heating ventilation and air conditioning (HVAC), GPD (general purpose driver). Those applications require the highest efficiency (>98.7% at 230VAC half load) and high demanding features. The overall board's dimensions are 218mm x 170mm x 60mm with a power density of (36 W/in3).

The system solution is based on Infineon SOI level-shifter drivers with integrated overcurrent protection for high side switch, wide bandgap CoolSiC™ and CoolMOS™ power switch, SOI drivers and microcontroller. The interleaved totem pole implemented in the EVAL-1EDSIC-PFC-5KW board operates in Continuous Conduction Mode (CCM) with full digital control implementation on the Infineon XMC™ 4200 series microcontroller.

This document describes the converter system architecture and hardware, with a summary of the experimental results. This board is intended to be used during the design-in process for evaluating and measuring characteristic curves, and for checking datasheet specifications.

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

Note: *Boards do not necessarily meet safety, EMI, quality standards (for example UL, CE) requirements*

Important notice

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

Environmental conditions have been considered in the design of the Evaluation Boards and Reference Boards provided by Infineon Technologies. The design of the Evaluation 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.

The Evaluation Boards and Reference Boards provided by Infineon Technologies are subject to functional testing only under typical load conditions. Evaluation Boards and Reference Boards are not subject to the same procedures as regular products regarding returned material analysis (RMA), process change notification (PCN) and product discontinuation (PD).

Evaluation Boards and Reference Boards are not commercialized products, and are solely intended for evaluation and testing purposes. In particular, they shall not be used for reliability testing or production. The Evaluation Boards and Reference Boards may therefore not comply with CE or similar standards (including but not limited to the EMC Directive 2004/EC/108 and the EMC Act) and may not fulfill other requirements of the country in which they are operated by the customer. The customer shall ensure that all Evaluation Boards and Reference Boards will be handled in a way which is compliant with the relevant requirements and standards of the country in which they are operated.

The Evaluation Boards and Reference Boards as well as the information provided in this document are addressed only to qualified and skilled technical staff, for laboratory usage, and shall be used and managed according to the terms and conditions set forth in this document and in other related documentation supplied with the respective Evaluation Board or Reference Board.

It is the responsibility of the customer’s technical departments to evaluate the suitability of the Evaluation Boards and Reference Boards for the intended application, and to evaluate the completeness and correctness of the information provided in this document with respect to such application.

The customer is obliged to ensure that the use of the Evaluation Boards and Reference Boards does not cause any harm to persons or third party property.
The Evaluation Boards and Reference Boards and any information in this document is provided "as is" and Infineon Technologies disclaims any warranties, express or implied, including but not limited to warranties of non-infringement of third-party rights and implied warranties of fitness for any purpose, or for merchantability.

Infineon Technologies shall not be responsible for any damages resulting from the use of the Evaluation Boards and Reference Boards and/or from any information provided in this document. The customer is obliged to defend, indemnify and hold Infineon Technologies harmless from and against any claims or damages arising out of or resulting from any use thereof.

Infineon Technologies reserves the right to modify this document and/or any information provided herein at any time without further notice.

Safety precautions

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

Table 1 Safety precautions

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

Table of contents

About this document ... **1**
Important notice ... **2**
Safety precautions ... **3**
Table of contents ... **4**
1 Introduction ... **5**
1.1 The Importance of Interleaving in PFC Designs ... 5
1.1 The Value of 1ED2127 Gate Driver OCP protection in Interleaved Totem Pole ... 7
1.2 EVAL-1EDSIC-PFC-5KW board description ... 8
1.3 Board parameters and technical data ... 12
2 System and functional description ... **13**
2.1 Overview of Block Diagram ... 13
2.2 Summary of firmware controls and protections ... 14
2.3 1ED2127 Over-Current Protection ... 15
2.1 Supplies Description ... 17
2.2 Inrush current circuit ... 20
3 Digital control implementation ... **22**
3.1 Signal conditioning for digital control of totem-pole CCM PFC ... 22
4 System design ... **24**
4.1 Schematics ... 24
4.2 Layout ... 34
4.3 Bill of material ... 41
4.4 Connector details ... 48
5 System performance ... **49**
5.1 Test results ... 49
5.2 Thermal Measurement ... 53
Appendices ... **55**
5.3 Application example: Heat Pumps as Key Technology for Decarbonization ... 55
References ... **56**
Revision history ... **57**
Disclaimer ... **58**

1 Introduction

As the world transitions to a low-carbon economy, the increasing adoption of electrically powered devices is putting a strain on the electrical distribution network. The spread of devices such as electric vehicles, renewable energy systems, and energy-efficient appliances is leading to a significant increase in the distortion of the electric grid. This distortion can cause problems in the electrical distribution network, including voltage drops, overheating, and even blackouts.

To mitigate these issues, power supply designs require advanced power factor correction (PFC) circuitry to meet strict power factor (PF) standards. PFC is a critical component in power conversion systems, as it ensures that the input current waveform is sinusoidal and in phase with the input voltage waveform, resulting in a high-power factor. A high PF is essential to reduce the distortion of the grid and ensure a stable and efficient power supply.

The advent of wide-bandgap (WBG) semiconductors, such as GaN and SiC, has revolutionized the field of power electronics. These semiconductors have enabled the implementation of advanced PFC topologies, such as bridgeless totem-pole PFC and interleaved totem-pole PFC. These topologies offer improved performance, efficiency, and reliability compared to traditional boost PFC topologies.

1.1 The Importance of Interleaving in PFC Designs

Interleaving plays a crucial role in PFC totem pole designs, as it allows for the effective reduction of input and output ripple currents by distributing them across multiple interleaved stages. By interleaving multiple totem pole stages with a phase shift between them, the total ripple in the input and output currents is significantly reduced, leading to improved performance and efficiency of the PFC system.

The benefits of interleaved PFC designs are numerous, including:

- Improved power factor, resulting in reduced distortion of the grid
- Reduced input and output ripple currents, leading to improved system reliability and efficiency
- Increased power density, making it suitable for high-power applications
- Improved thermal performance, resulting in reduced cooling requirements

In conclusion, the PFC stage is becoming an indispensable component in power conversion systems as the world transitions to a low-carbon economy. The advent of WBG semiconductors and advanced PFC topologies, such as interleaved totem-pole PFC, are critical in ensuring a stable and efficient power supply.

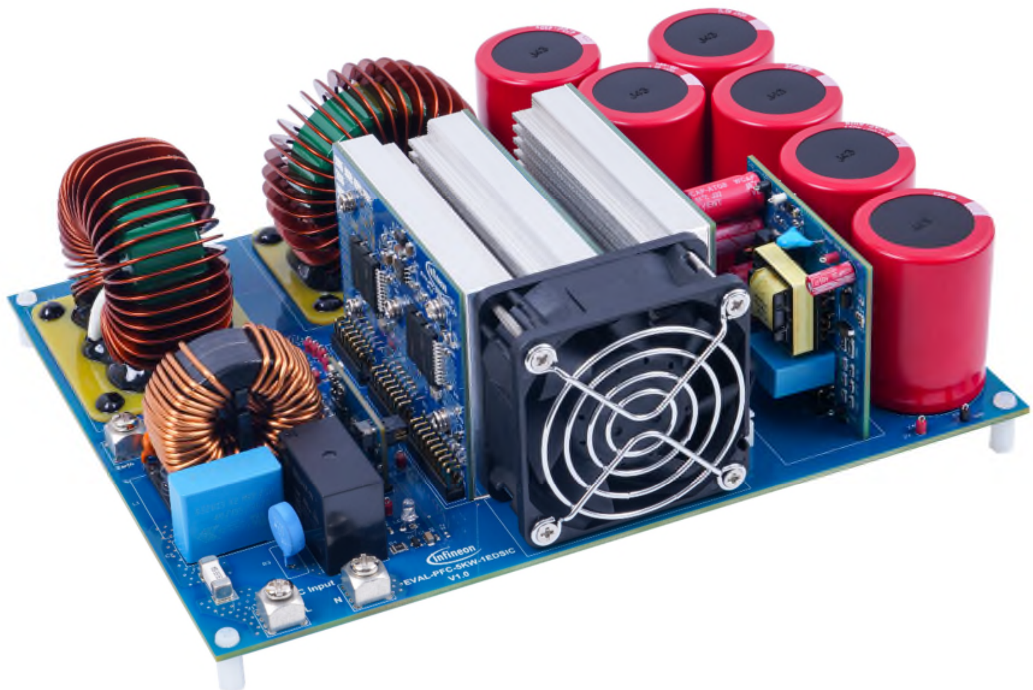

Figure 1 EVAL-1EDSIC-PFC-5KW: 5kW interleave totem pole PFC

1.1 The Value of 1ED2127 Gate Driver OCP protection in Interleaved Totem Pole

The EVAL-1EDSIC-PFC-5KW board includes hardware over current protection feature that does not depend exclusively on the MCU. This hardware protection is an essential safety measure that prevents damage to the system in the event of a shoot-through, ensuring the overall reliability and integrity of the interleaved totem pole topology.

The hardware implementation of OCP feature is indispensable in an interleaved totem pole Power Factor Correction (PFC) system, particularly when compared to other PFC topologies.

In interleaved Boost PFC configuration, left side of Figure 2, only low-side switches are employed (Q1 and Q2), while a diode serves as the high-side component (D5 and D6). Protection of these topologies is relatively straightforward, as the power switch's source is not floating.

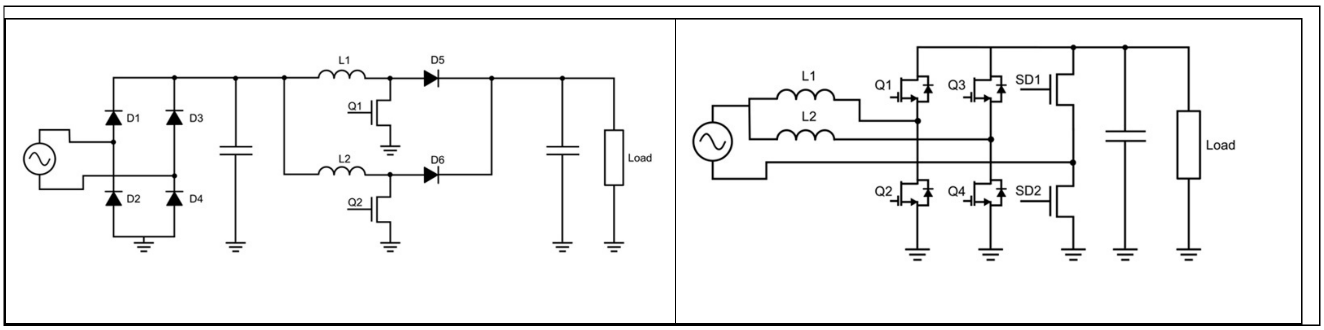

Figure 2 Interleaved Boost Totem Pole on the left and Interleaved Totem-Pole on the right

In contrast, the interleaved totem pole PFC topology, right side of Figure 2, offers superior performance and efficiency due to the substitution of a high-side switch for the diode (Q1 and Q3 in the place of D5 and D6). This design enhancement enables the system to achieve higher levels of performance and efficiency.

However, it is important to note that this topology also increases the system's complexity, as it necessitates the additional requirement to drive the high-side switch and protect it from short-circuit events.

Indeed, single channel 650V SOI driver 1ED21271S65F guarantees a protection independent from the gate driver’s GND reference. Make it able to trigger an output reset of the high side switch in case of shorts that could happen in the bridge. More details are given in 2.3 1ED2127 Over-Current Protection.

1.2 EVAL-1EDSIC-PFC-5KW board description

Figure 1 and Figure 3 illustrates the EVAL-1EDSIC-PFC-5KW interleaved totem-pole board,

The design has been developed to meet the demand for high efficiency in power supply unit for modern application. Test results show 98.7% at 230VAC half load.

The overall dimensions are 218mm x 170mm x 60mm and yielding a power density of 36 W/in3.

The main components used in EVAL-1EDSIC-PFC-5KW interleaved totem-pole board are as follows:

- single channel drive 1ED21271S65F for driving PFC high and low side CoolSiC™ power switch,
- high side and low side driver 2ED2182S06F for driving PFC high and low side CoolMOS™ power switch
- CoolSiC™ MOSFET 650V IMBG65R022M1H,
- CoolMOS™ S7 SJ MOSFET 600V IPQC60R010S7,
- Controller: XMC™ 4200 Arm® Cortex®-M4 processor core for PFC control
- ICE2QR2280G for the bias supply implementation

The EVAL-1EDSIC-PFC-5KW board consists of multiple daughter boards vertically inserted into the motherboard. The motherboard features bus capacitors, an AC EMI filter, current sensors, and two load inductors.

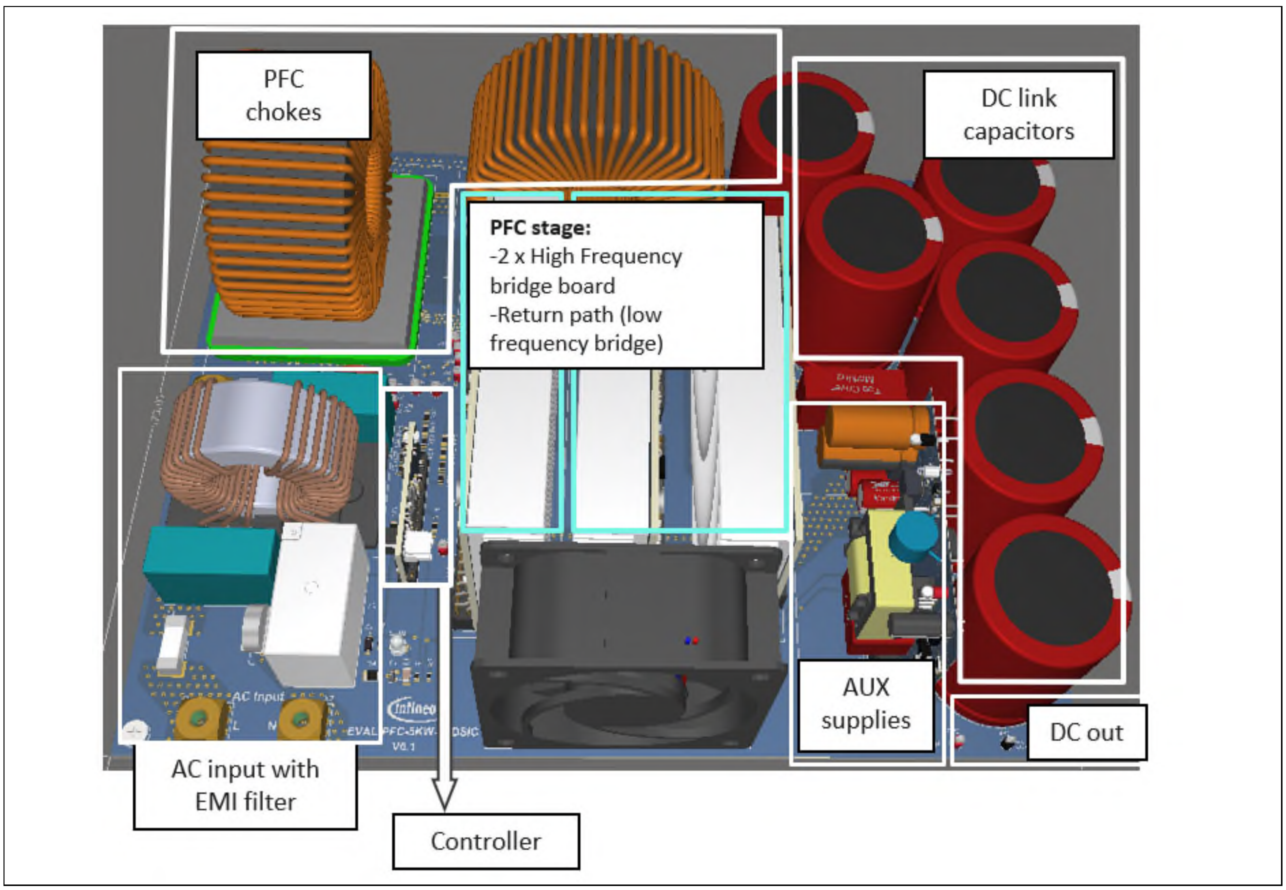

Figure 3 Board description

As depicted in the Figure 3, PFC stage is situated on the central part of the board, with the AC connector located at the far left. Adjacent to the AC connector there is a single-stage EMI filter, followed by two PFC chokes, one for each high-frequency bridge. A dedicated controller board, which drives the interleaved totem-pole AC-DC converter, is located to the right of the AC input.

The middle section of the board features three main daughter boards, perpendicular to the fan flow, which implement the interleaved totem pole PFC stage. This design ensures optimal performance and minimizes thermal issues by strategically placing critical components. Additionally, the AUX supplies daughterboard is located on the right side of the fan, followed from a series of DCBUS capacitors.

In total, the motherboard features five daughter boards:

- AUX power supply, which converts AC voltage to 18V using a QR CoolSET™ controller and 950V P7 CoolMOS™ ICE2QR2280G switch to generate the required voltages for the control card, driving, relay, and fan supply.
- Digital control implemented using the Infineon XMC™ 4200 microcontroller, which ensures proper operation of the interleaved totem-pole topology.
- Two high-frequency bridge (65KHz), each featuring a 22 mΩ 650 V CoolSiC™ (IMBG65R022M1H) in a PG-TO263-7 pin package, driven by a 1ED21271S65F gate driver, Figure 5.
- Return path board (low-frequency bridge) (50/60Hz), featuring a 10 mΩ 600 V CoolMOS™ S7 (IPQC60R010S7) in a PG-HDSOP-22 package, driven by a 2ED2182S06F gate driver, Figure 6.

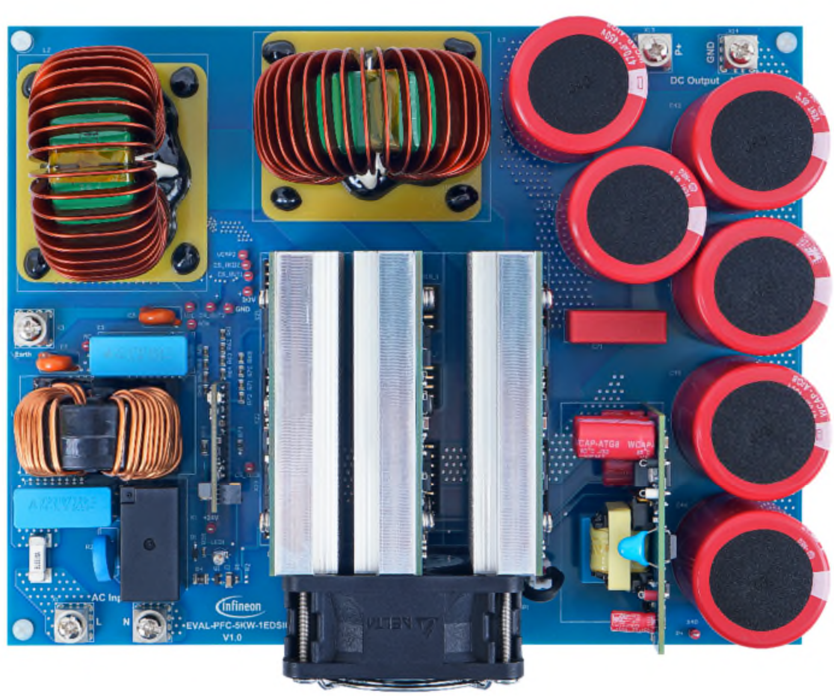

Figure 4 Motherboard Top view

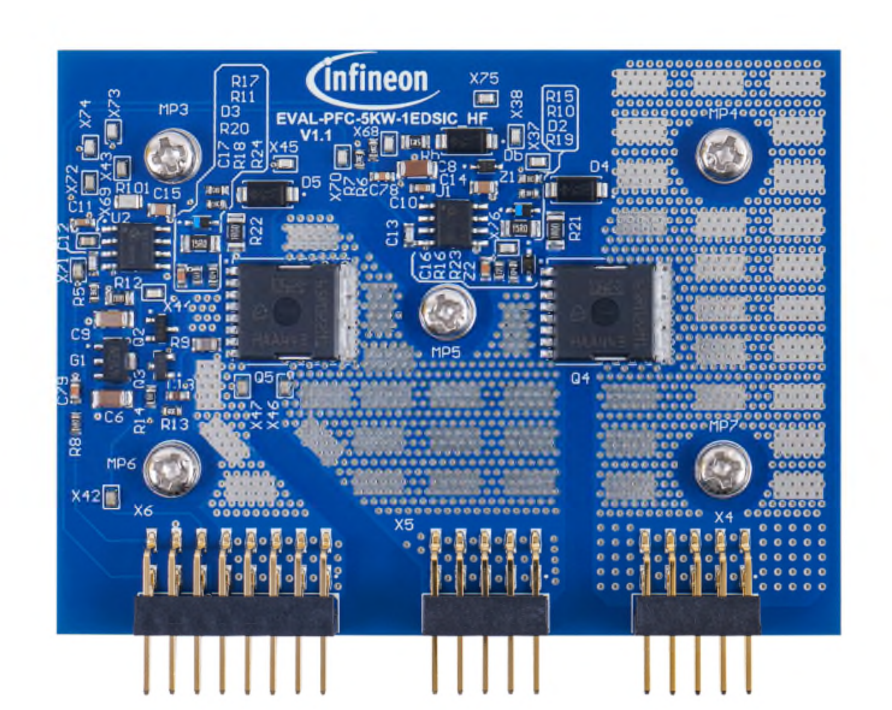

Figure 5 high-frequency 22mΩ 650 V CoolSiC™ (IMBG65R022M1H) in a PG-TO263-7 pin package, with 1ED21271S65F

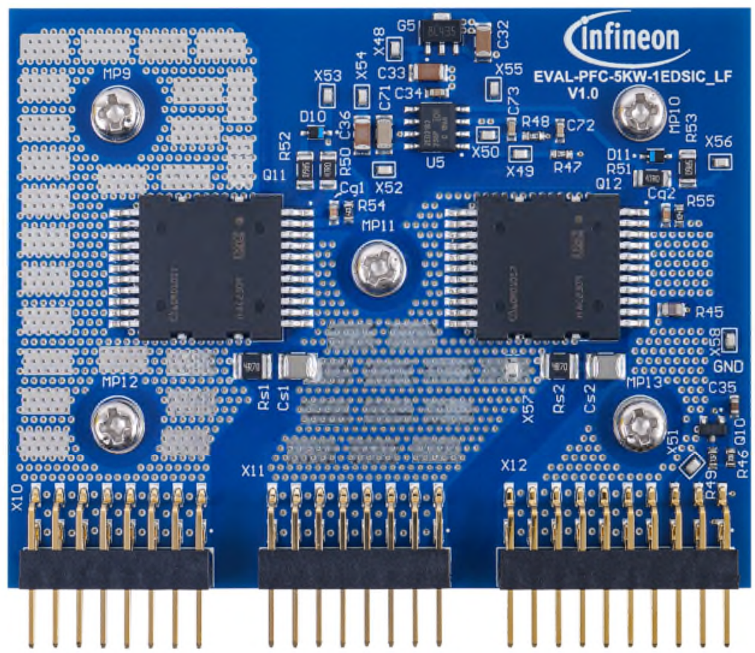

Figure 6 Return path board (low-frequency bridge) (50/60Hz), 10mΩ 600 V CoolMOS™ S7 (IPQC60R010S7) in a PG-HDSOP-22 package, with 2ED2182S06F gate driver

1.3 Board parameters and technical data

This paragraph presents the specifications, performance and behavior of the EVAL-1EDSIC-PFC-5KW with average current mode control in CCM for PFC operation. Table 1 shows the demonstrator performance and specifications under several steady-state and dynamic conditions.

Parameter	Specification
Vin	75 to 264VAC
POUT	<5 kW
Efficiency test	η_{pk} = 98.7 percent at 2500 W (50 percent load)
THD	THD less than 10 percent from 10 percent load
Power factor (PF)	PF more than 0.95 from 20 percent load
Output DC voltage	400 V
Steady-state Vout ripple	|ΔVout| less than 30 Vpk-pk at 100 percent load
In-rush current	Iin_peak less than 35 A, measured on the first AC cycle
Power line disturbance	Vout_min = 300 V (UVP) No damage: * PFC soft start if bulk voltage under 300 V * PFC soft start if AC out of range for certain time
Load transient	Vout_max = 450 V (OVP) 90% load at 10%, 0.2A/µs
OCP	Peak current limit 50 A

Table 1 Board Specification at Tvj=25°C, 230 Vrms, 50 Hz/60 Hz

2 System and functional description

2.1 Overview of Block Diagram

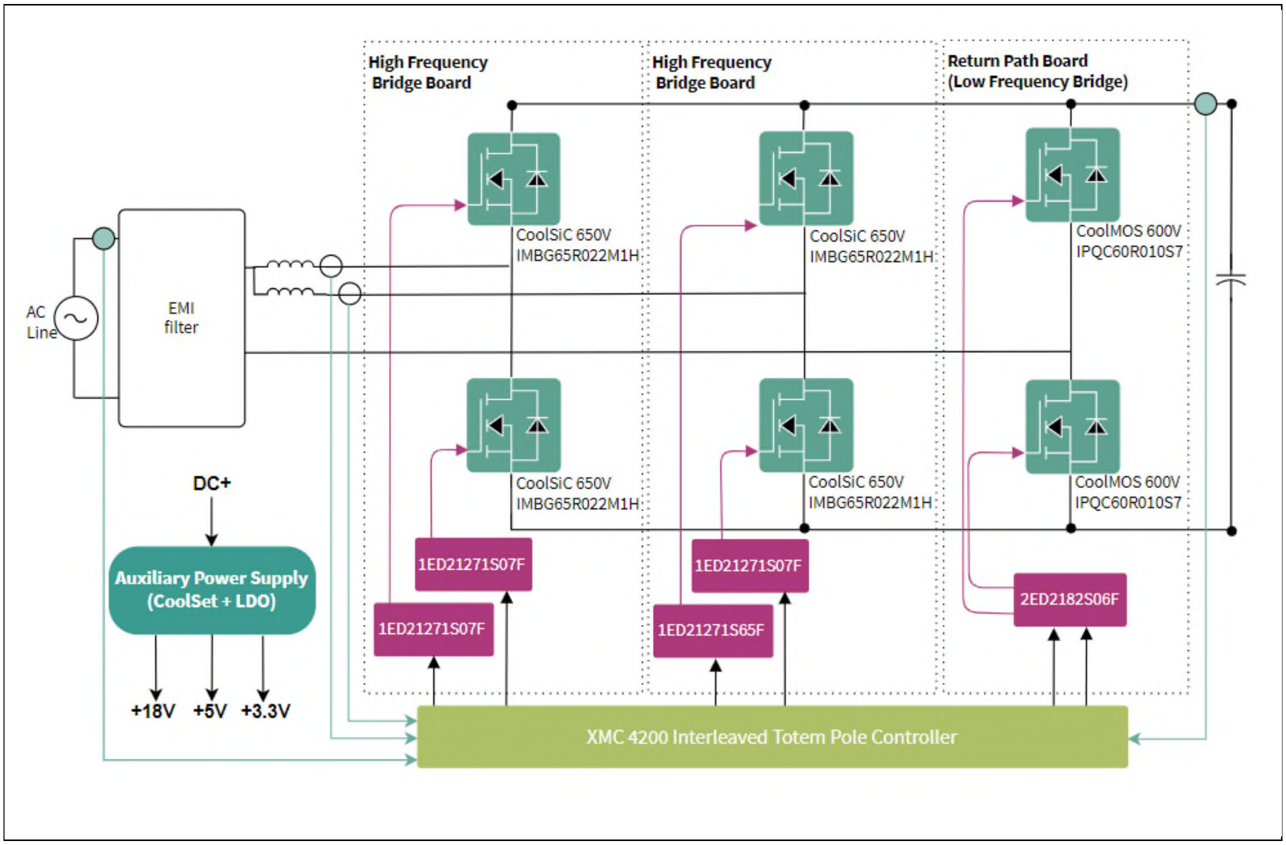

Figure 7 Functional block

Figure 7 shows the simplified circuit diagram of the EVAL-1EDSIC-PFC-5KW demo board. The PFC stage consist of two high frequency bridge and one return path board. All Infineon devices used in the implementation of the EVAL-1EDSIC-PFC-5KW board are listed below:

- In the two high frequency bridge (65KHz):
  - 22 mΩ 650 V CoolSiC™ (IMBG65R022M1H) in PG-TO263-7 pin package
  - gate driver: single channel 650V 4A 1ED21271S65F
- In the Return Path board (low frequency bridge) (50/60Hz)
  - 10 mΩ 600 V CoolMOS™ S7 (IPQC60R010S7) in PG-HDSOP-22 package
  - high side and low side driver 600V 2.5A 2ED2182S06F
- XMC™ 4200 microcontroller for PFC control implementation
- ICE2QR2280G quasi-resonant CoolSET™ with integrated 800V CoolMOS™ SJ MOSFET for auxiliary power supply

The EVAL-1EDSIC-PFC-5KW can be operated with an AC voltage input from 74V AC to 264V AC in continuous conduction mode (CCM) with 65 kHz of switching frequency. The bulk capacitance is designed to comply with 10ms hold-up time at full load condition

The high frequency bridge uses the 650V CoolSiC™ M1 SiC IMBG65R022M1H, a Silicon Carbide (SiC) device. This choice is justified by the need to minimize switching losses, which are a critical concern at high frequencies. SiC devices are known for their fast-switching capabilities and low switching losses, making them well-suited for high-frequency applications.

The 1ED21271S65F gate driver features overcurrent protection, which enables it to detect and quickly prevent various types of short circuits. This is a crucial feature, especially in Power Factor Correction (PFC) systems, as it helps to ensure safe and reliable operation.

One of the significant advantages of this gate driver is that it eliminates the need for a shunt resistor, which is typically required for overcurrent protection. The integrated overcurrent protection feature in the 1ED21271S65F simplifies the design and reduces the overall component count, making it an attractive solution for PFC systems.

On the other hand, the low-frequency bridge (return path board) employs the 600 V CoolMOS™ S7 (IPQC60R010S7), a MOSFET device. The primary reason for this selection is the low on-resistance (Rds(on)) of 10 milliohms, which results in low conduction losses. This is a key consideration for low-frequency bridge, where conduction losses can dominate

The controller board is based on the XMC™ 4200 Infineon microcontroller, which provides advanced features such as PFC, THD, voltage regulation, input overcurrent protection (OCP), overvoltage protection (OVP), undervoltage protection (UVP), and start-up. More details in [2] and [3]

2.2 Summary of firmware controls and protections

In this paragraph there is a summary of control and protections managed from MCU:

- **Current Loop Protection or Over Current Protection (OCP)**: it's a first level of overcurrent protection. it is implemented via firmware and is set at 40A. This protection is specifically designed to safeguard the control current loop, which is responsible for regulating the flow of electrical current within the system. This firmware-based protection ensures that the control loop operates within a safe and stable range, preventing any potential damage or malfunction. Current reading is performed by hall sensor placed on the motherboard.
- **Undervoltage protection (UVP)**, set at 300V, in case of power line disturbances, if DCBUS goes below this value, MCU will put the system in a safe condition,
- **Overvoltage protection (OVP)** or Output Voltage control loop: set at 450V,
- **Fault management,** MCU is responsible to handle the following hardware protections**:**
    - **Temperature Protection**, Figure 13, in each bridge there is a PTC resistor, that will activate the switch IRLML2030, and will pull down RFE signal that immediately disable the output. In the meanwhile, the same RFE signal is shared with MCU that will manage the fault.
    - **OCP**: 1ED2127 provides a second level of overcurrent protection, it is a hardware-based mechanism set at 50A. This protection is designed to intervene in the event of an effective shoot-through in the bridge, which can occur when there is an unintended flow of current between the high-side and low-side switches.
    - **UVLO (Under Voltage Lockout):** 1ED2127 provides undervoltage lockout protection on both the VCC (logic and low-side circuitry) power supply and the VBS (high-side circuitry) power supply**.**

      Once 1ED2127 senses the fault condition that occurred for OCP or UVLO , the RFE pin(pin 3 in Figure 8) is internally pulled to COM and the fault clear timer is activated, RFE signal is sent to MCU and MCU will proceed to put the system in a safe condition. RFE output stays in the low state until the fault condition has been removed, plus 10us ($t_{FLTC,INT}$), After this, the voltage on RFE pin will start to rise, dictated by external pull-up voltage and R_{FLTC} / C_{FLTC} network.

2.3 1ED2127 Over-Current Protection

Each high frequency bridge is driven from a single channel driver 1ED21271S65F which is equipped with an over-current protection feature (CS input pin). Once the driver detects an over-current event with de-sat detection circuit as shown in Figure 8, the output will be shut down, and RFE is pulled to COM. So, the CoolSiC™ switch can be promptly protected during different kind of short circuit event.

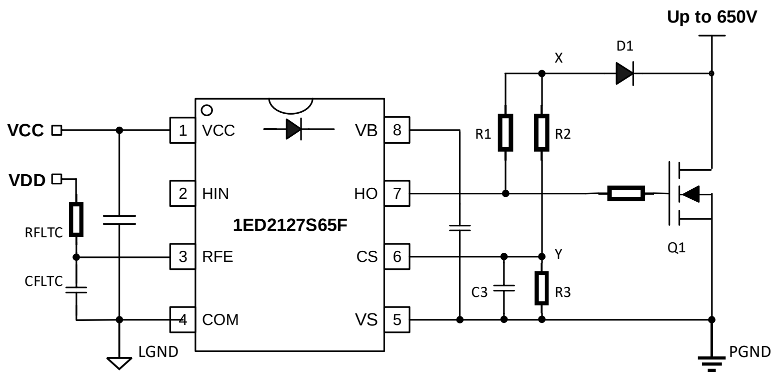

Figure 8 Over-current protection with de-sat detection circuit

Thanks to an external resistor circuitry between CS pin and power switch drain, it's possible to indirectly sense the power switch saturation status. When the power switch bridge is in saturation region, the CS threshold will be reached, the 1ED21271S65F will turn off the output and then trigger a FLT signal to the microcontroller that will put the system in a safe condition.

For EVAL-1EDSIC-PFC-5KW it has been chosen 1ED21271S65F because of the 1.8V CS threshold.

CS pin voltage, V_y in Figure 8, has to reach the threshold V_{th} to trigger the OCP protection.

V_y in normal operation is set by the voltage divider of R2 and R3, which should be less than 1.8 V threshold. In this condition when Q1 current rise gradually, the voltage at Y will slowly rise to 1.8 V when CS will be triggered Figure 9 (a).

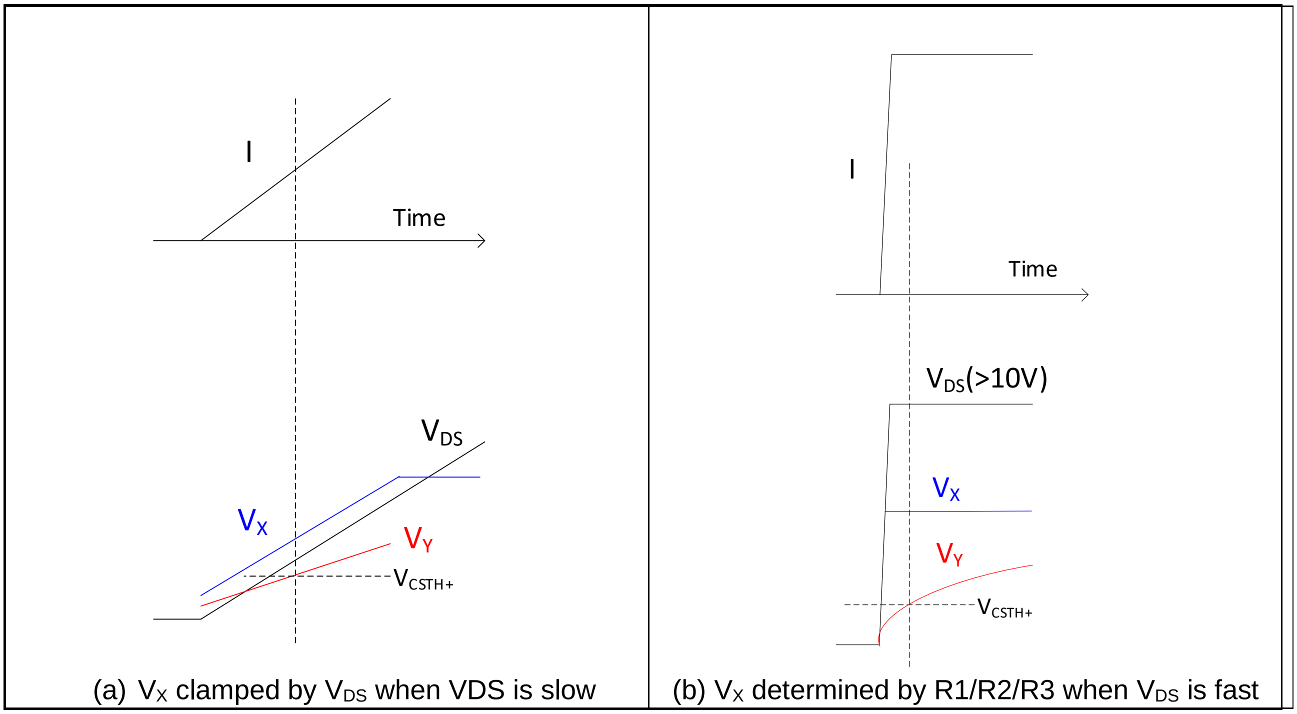

Figure 9 1ED2127 de-sat circuit

By comparison in the short circuit condition, both current and V_{DS} voltage rise rapidly, as shown in Figure 9 (b). In this case, the voltage at X will no longer be clamped by V_{DS} of Q1 due to the de-sat diode D1. Instead, it will be determined by voltage divider R1 / R2 / R3 of HO. In order to rapidly drive V_Y in this condition, it is import to set voltage divider of R1+R2 and R3 to more than 1.8 V. Otherwise, it will take **a very long time** to charge C3 to reach 1.8 V even though the VDS of Q1 is already at >100 V. The suggested overdrive voltage is 2x V_{CSTH+} = 3.6 V, which will result in 0.5 * R3 * C3 filter time to reach V_{CSTH}.

therefore we need to assure this equation is satisfied:

$$\frac{V_{HO} * (R_3 + R_2)}{(R_1 + R_3 + R_2)} \geq V_{DS,Q1}^{ocp} + V_{F,D1}$$

That can be rearranged as:

$$\frac{R_2 + R_3}{R_1} \geq \frac{V_{DS,Q1}^{ocp} + V_{F,D1}}{V_{HO} - (V_{DS,Q1}^{ocp} + V_{F,D1})}$$

The power switch chosen for this application is the 22mΩ CoolSiC™.

Setting OCP at 50A. we will expect a saturation voltage on Q1 about:

$$V_{DS,Q1}^{ocp} \geq 50A * 22\text{m}\Omega = 1.1\text{V}$$

In this condition voltage at point X will be,

$$V_x \geq V_{DS,Q1}^{ocp} + V_{F,D1} = 1.1V + 1.7V = 2.8V$$

- To calculate R2 and R3, let's consider the voltage divider

$$V_y \equiv \frac{V_x * R_3}{R_3 + R_2}$$

Putting together the above equations, we obtain

$$\frac{R_3}{R_2} \geq \frac{V_{th}}{V_{DS,Q1}^{ocp} + V_{F,D1} - V_{th}}$$

R2 and R3 selected are 1kohm and 12kohm.

- R1 is chosen to minimize the increased miller capacitance effect from diode D1 and makes sure there is not significant current (V_{HO} - V_X) / R1 being drawn from the HO output. Assuming we want to limit the current to be less than 1.2 mA, R1 will be 15kohm for V_{CC} = 18 V.
- C3 requires particular attention, it needs to be selected big enough to successfully filter and avoid spurious OCP event, but if chosen too big, CS will reach the threshold in a really long time. For this application, C3 equals 330pF.

More details about how the protection circuit works, and other design tips are explained in the following Application Note [1]

2.1 Supplies Description

The AUX power supply daughter board, placed between the bus capacitor and the HF frequency bridge, is designated to perform AC-DC conversion, generating 24V, 5V. The flyback circuit incorporates the ICE2QR2280G quasi-resonant CoolSET™, which features an integrated 800V CoolMOS™ SJ MOSFET, as shown in Figure 10

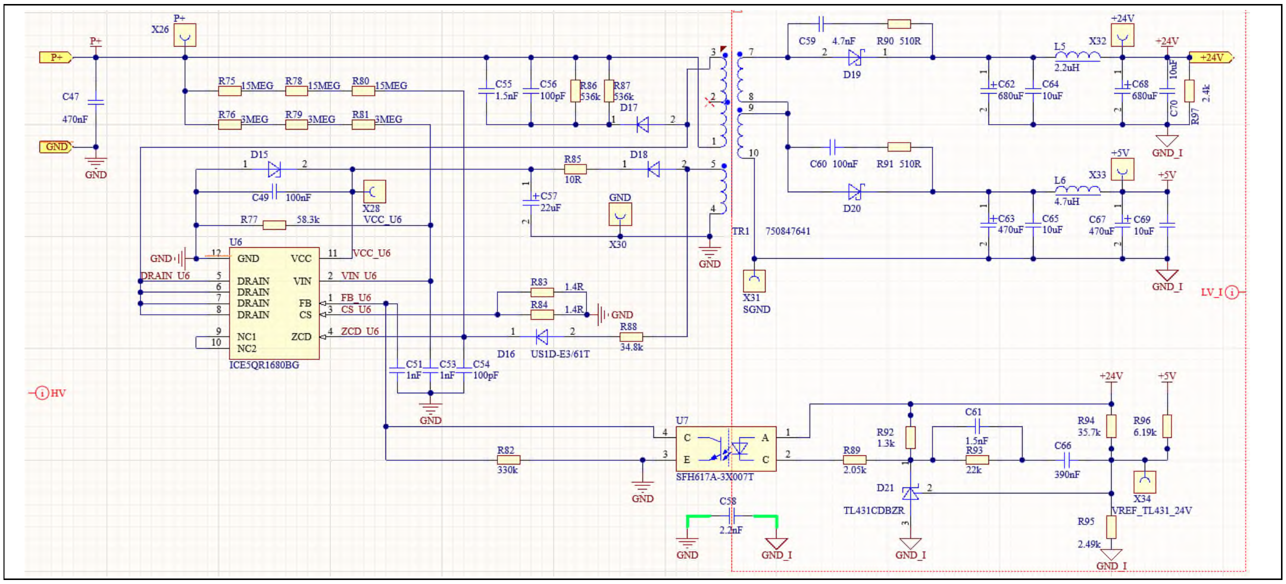

Figure 10 Aux Power Supply Board

In each High Frequency bridge board the 24V supply is converted to 18V to provide a suitable voltage for the single-channel gate driver 1ED21271S65F, which drives the CoolSiC™ (IMBG65R022M1H). Notably, CoolSiC™ device exhibit lower channel resistance and require higher VGS compared to other technologies. The two high-side supplies are generated through bootstrapping, with Db and Rb, while the low-side is obtained short-circuiting the primary supply, VCC 18 V to VB thru R101, see Figure 11.

This selected approach is both uncomplicated and cost-efficient, making it an excellent solution for implementation. By utilizing the bootstrap method, the high-side gate driver voltage supply can be obtained with minimal components, requiring only a high-voltage diode and a resistor.

For instance, Figure 11 shows the bootstrap circuit utilized in the interleaved totem-PFC with CoolSiC™ from Infineon and level shifter gate driver.

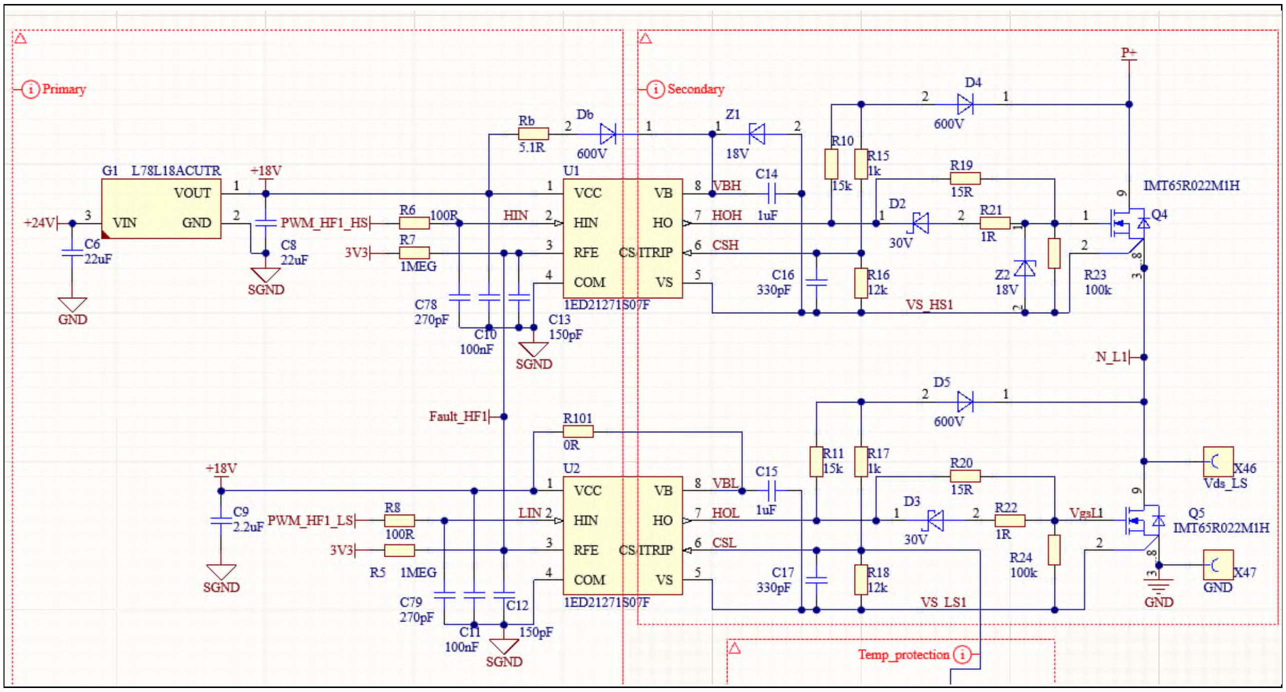

Figure 11 High frequency bridge

In the Return Path board, or low frequency bridge, the 24V output, coming from the flyback in the Aux power supply daughter, is converted to 15V to supply the half bridge driver 2ED2182S06F that drive the CoolMOS™ IPQC60R010S7.

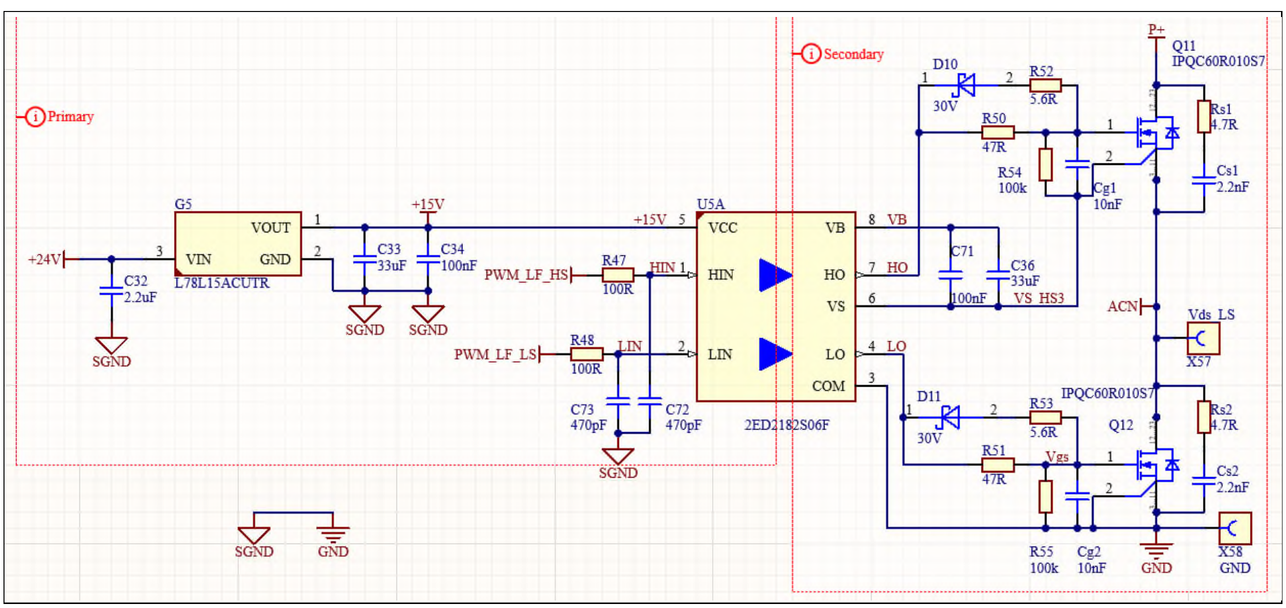

Figure 12 Return Path board

The Aux power supply daughter board also provides the 3.3V to pull up FLT signal of 1ED21271S65F and to supply the temperature protection circuit available on each switching leg.

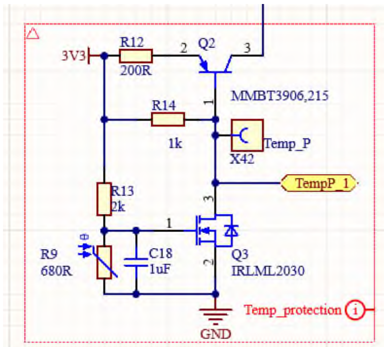

Figure 13 Temperature Protection circuit

2.2 Inrush current circuit

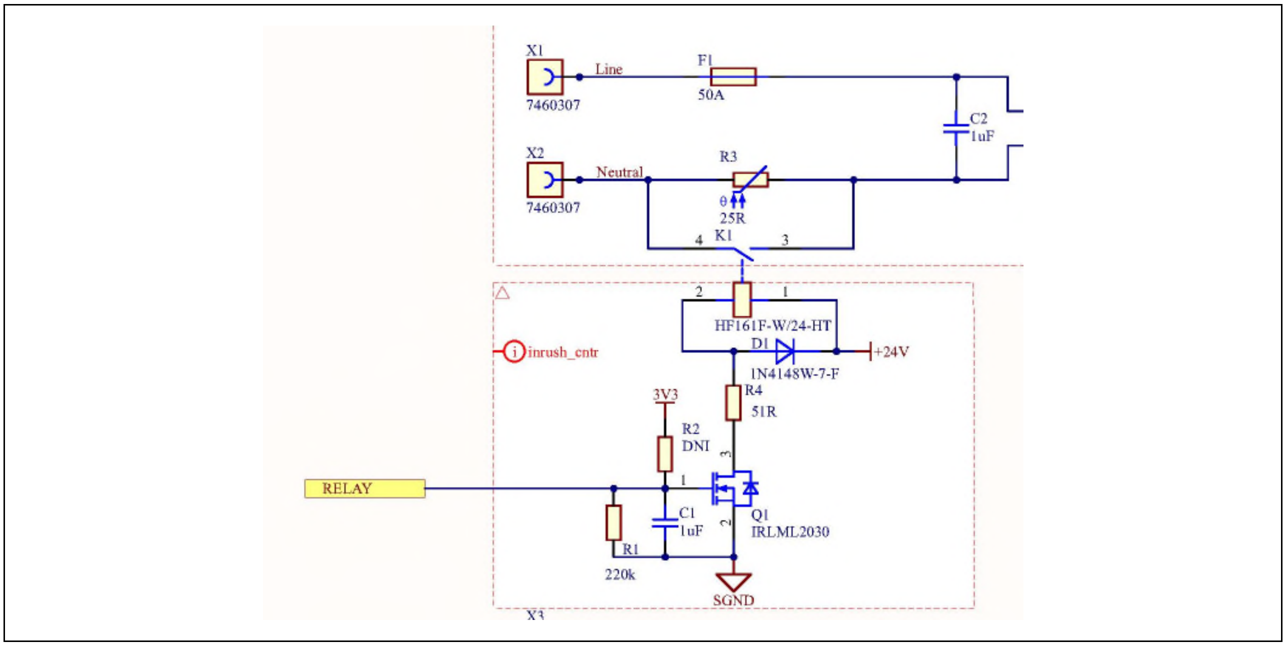

Figure 14 Inrush circuit

Inrush current circuits are essential in such systems to prevent damage to components and ensure reliable operation, as they limit the high initial current surge that occurs when a device is first powered on. Without inrush current protection, the sudden surge can cause overheating, voltage drops, and even complete system failure, making it a critical component in many applications, and for this reason, a soft start is often advised to gradually ramp up the voltage and current, reducing the stress on the system and ensuring a safe and reliable startup.

In this paragraph it is explained how soft start work in EVAL PFC 5KW 1EDSIC.

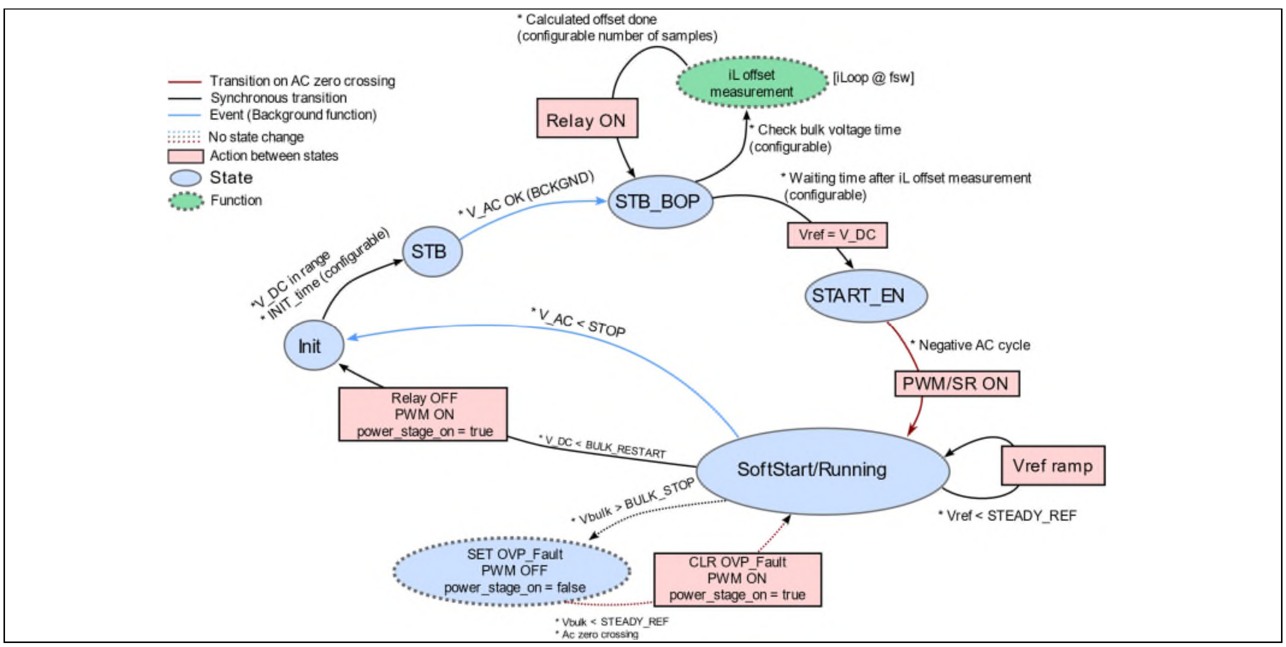

Figure 15 Totempole state machine for the interleaved 5kW PFC operation

In Figure 14 25ohm PTC(R3) and a relay(K1) are the key element for inrush circuit, the soft-start is working as illustrated in the state machine depicted in the Figure 15

In the *Init* state MCU monitors the DC bus voltage, when it's larger than 129V for a certain period of time, it will go to STB state, then it will check if VAC is larger than the threshold (~74V), it will go to STB_BOP state and consequently it will switch on the relay (K1) and bypass the PTC (R3).

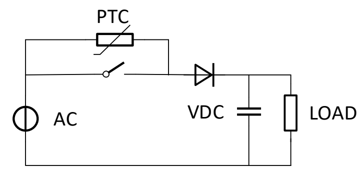

Figure 16 Equivalent circuit of Figure 11

Note: Note that not to have the heavy load connected before soft-start, otherwise it may have startup fail. heavy load means low resistance, so that the voltage on VDC will be too low for the startup threshold in the code, since VDC equal to the voltage divider of PTC and LOAD for VAC peak, as shown in Figure 16.

3 Digital control implementation

3.1 Signal conditioning for digital control of totem-pole CCM PFC

The interleaved PFC of EVAL-1EDSIC-PFC-5KW implements CCM average current mode control with duty feed-forward (DFF). Unlike the classic PFC in which the AC voltage is rectified by the diode bridge, in the bridgeless totem-pole PFC converter the inductor current is both positive and negative. In addition, isolation or common mode rejection is required to measure the inductor current if the control ground in place in the negative rail of the bulk voltage, as it has been traditionally done in classic PFC. A hall-effect sensor is therefore a good solution for this kind of system.

The output of the hall-effect sensor matches very well the ADC inputs when supplied with the same voltage: positive and negative current are measured with the span of the ADC and a shift if zero current to half of the ADC range. If a sensor with proper BW is selected, also the high frequency ripple can be sensed, and the signal can be used for peak current limitation as well. In case of lower BW, the hall-effect sensor typically offers an over-current detection signal which could be used for the same purpose.

Due to the control reference location, the bulk voltage sense is as simple as a resistive partition as shown in Figure 17. In the case of the of AC voltage sense, in order to avoid issues during AC zero crossing if no current is flowing into the PFC, both lines are sensed against ground and then added. Since the total AC sensing signal is rectified, a comparison of both line and neutral sensing voltages provides the polarity signal.

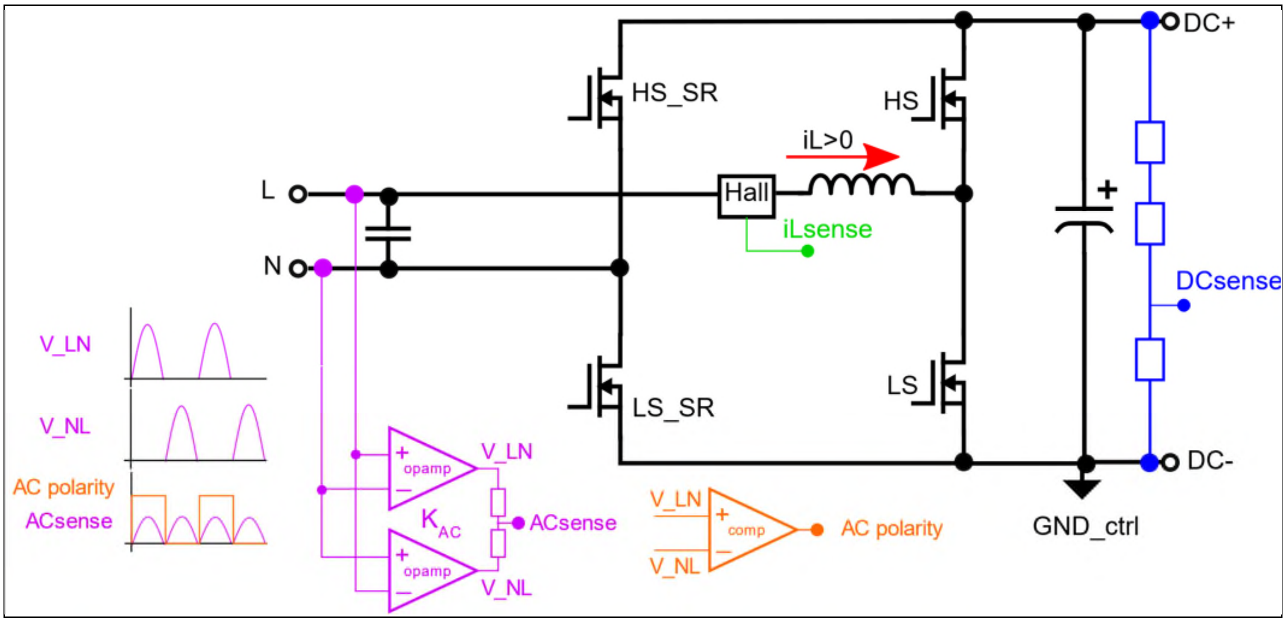

Figure 17 Block diagram of the sensing circuitry required for bidirectional totem-pole control with XMC™ and control reference in the AC rail in series with the PFC choke

Since the AC voltage is used for the current reference generation in the selected average current mode structure, the current reference is a full wave rectified sinusoidal sequence. However, the current sense after the ADC is a sinusoidal sequence with offset at half of the ADC spam. Therefore, the ADC result from the current sense requires first the offset to be removed and then rectified according to the AC polarity signal. These two steps, together with extra gain, are implemented by software in the XMC™ controller.

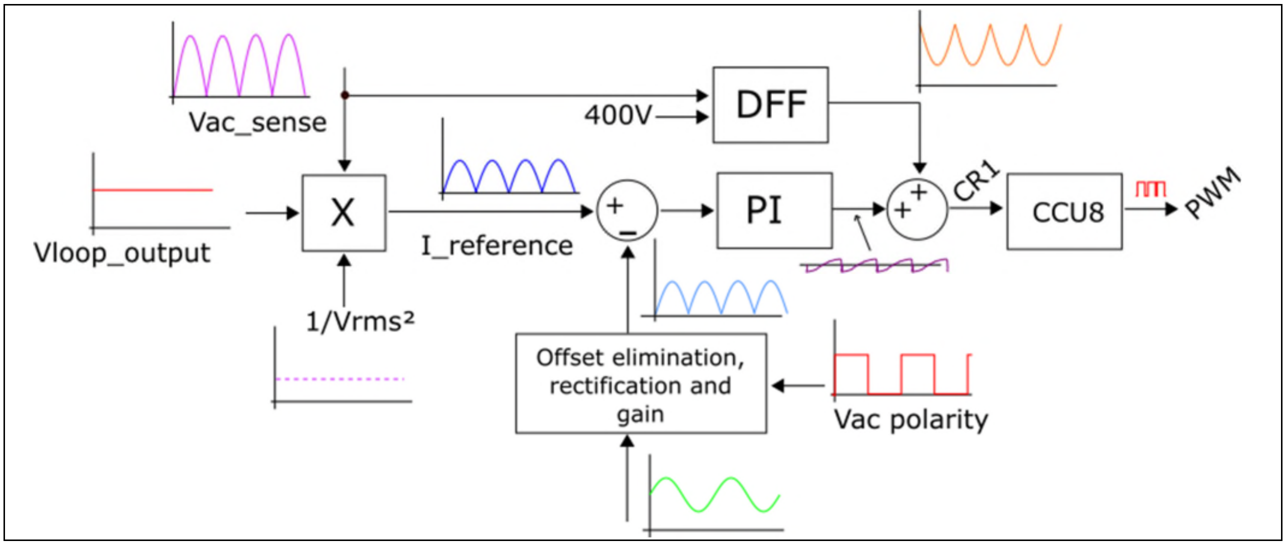

Figure 18 Current loop structure with duty cycle feed-forward and the required current manipulation

4 System design

4.1 Schematics

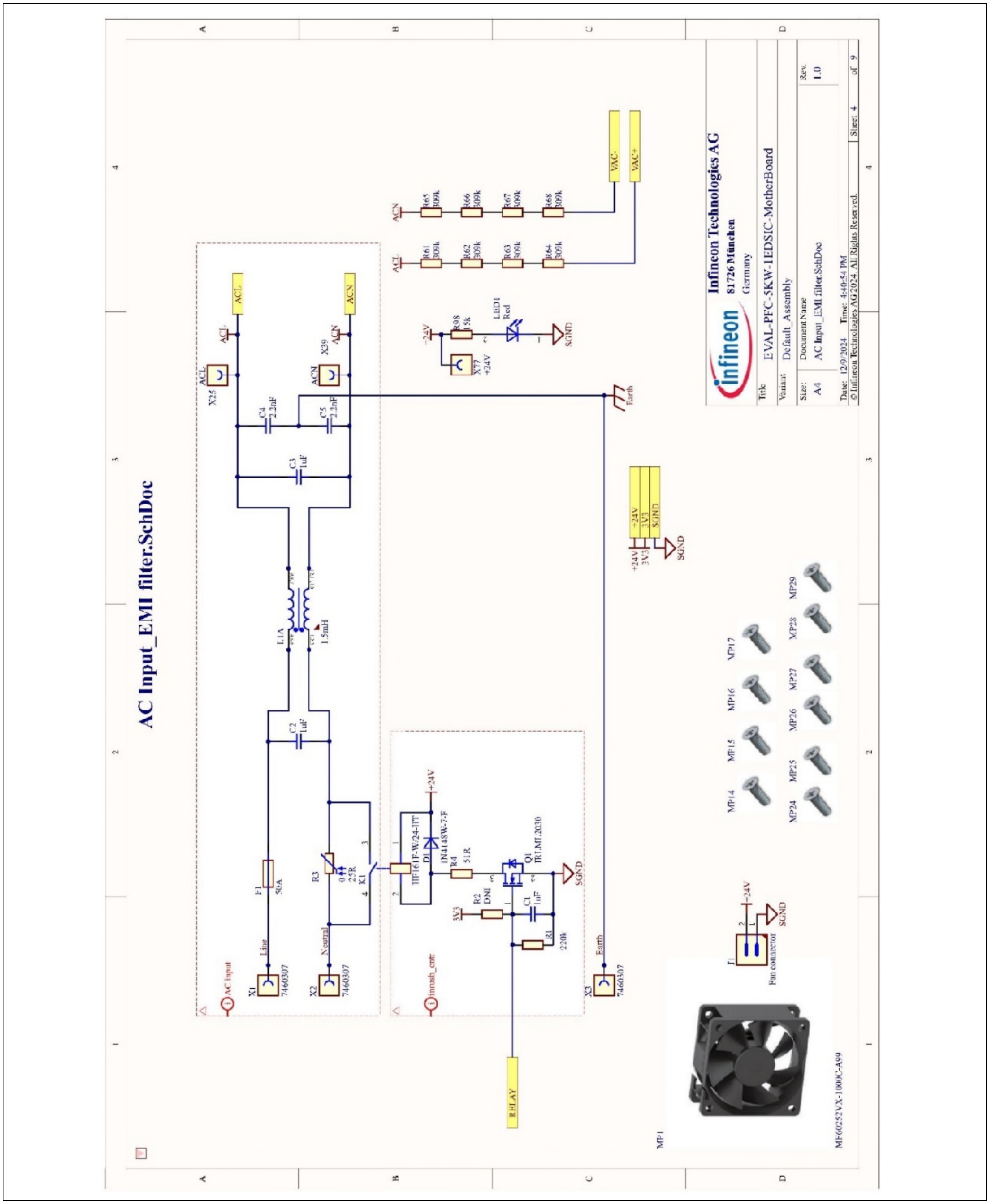

Figure 19 Motherboard Schematic: AC input EMI filter

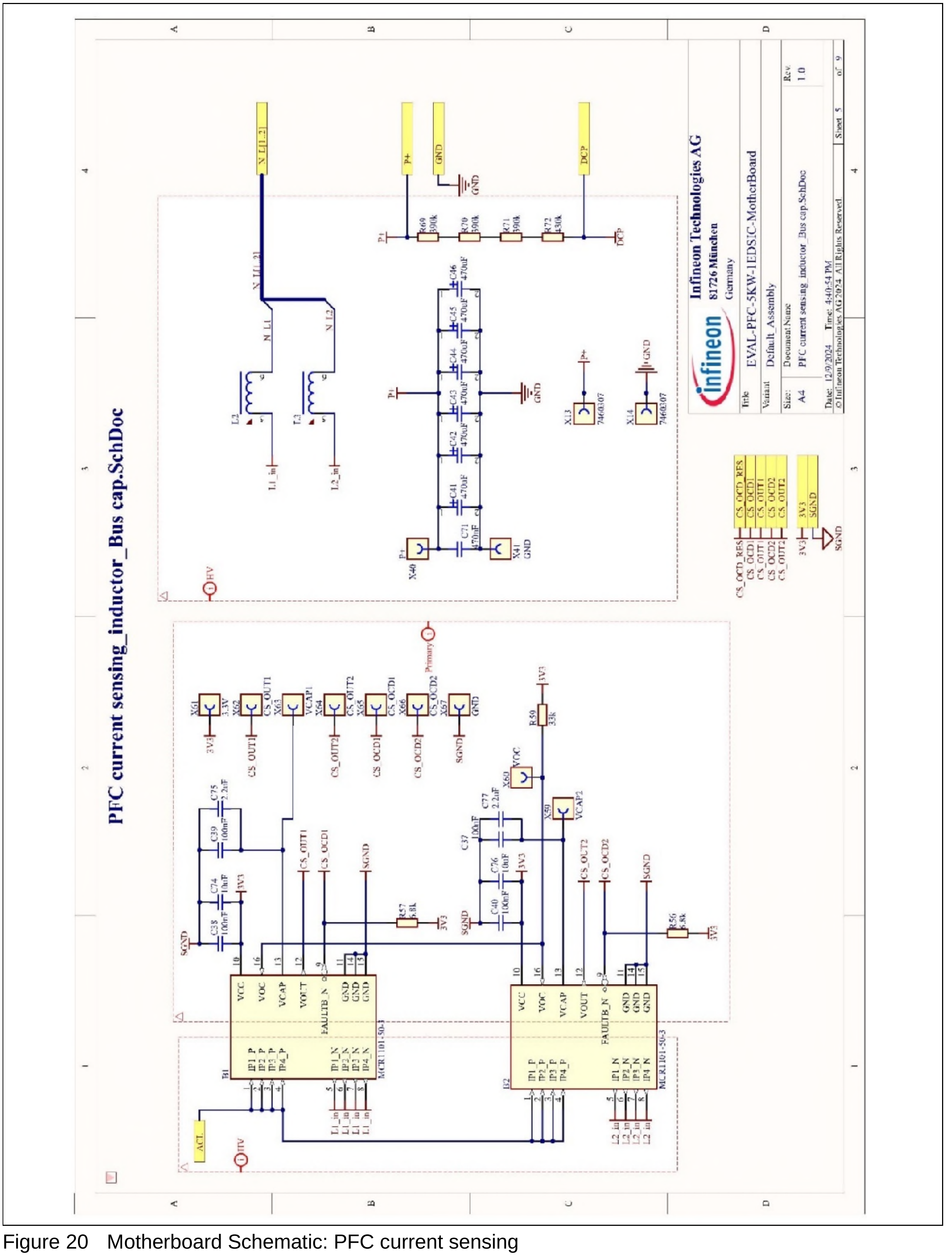

Figure 20 Motherboard Schematic: PFC current sensing

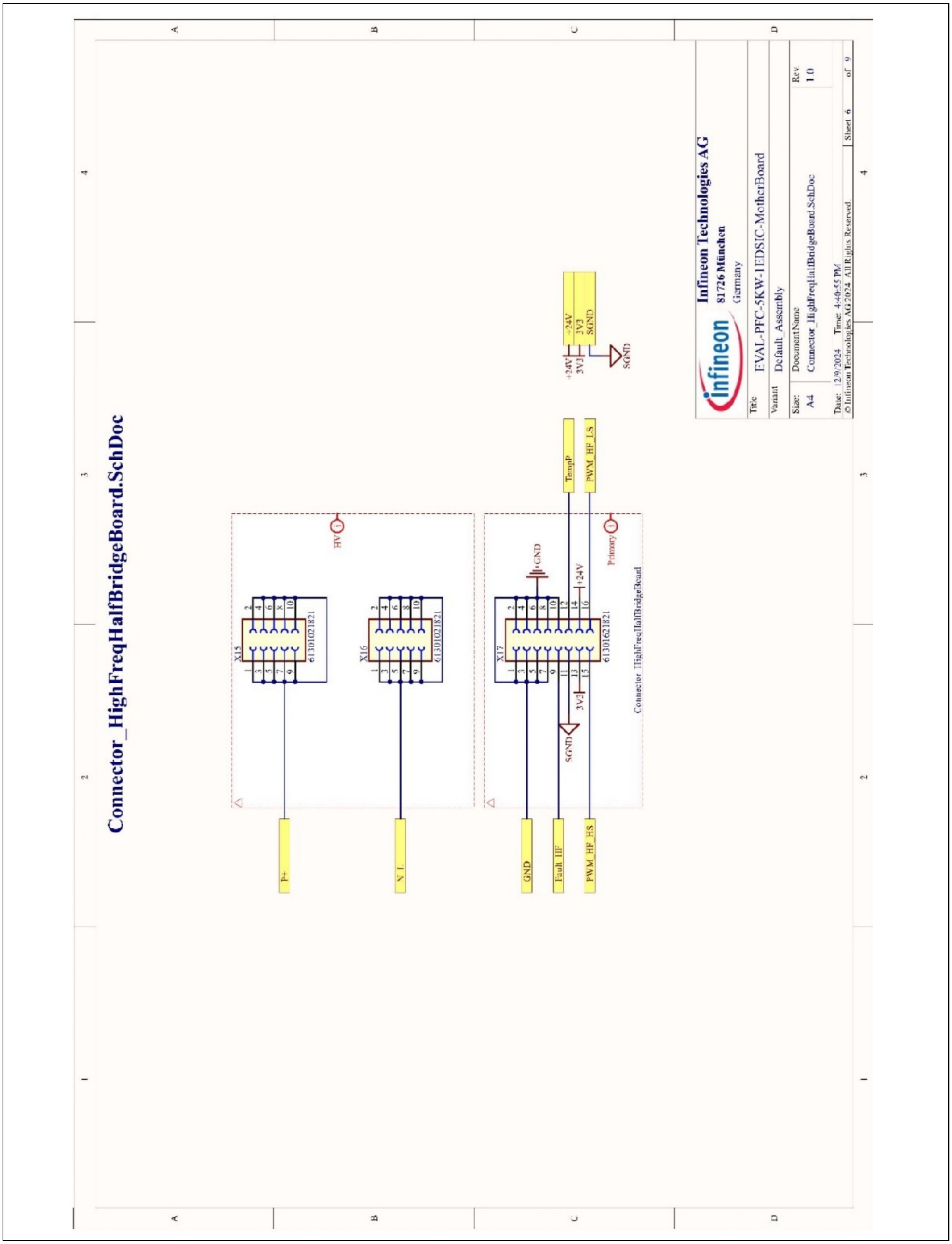

Figure 21 Motherboard Schematic: Connector HighFreqHalfBridgeBoard

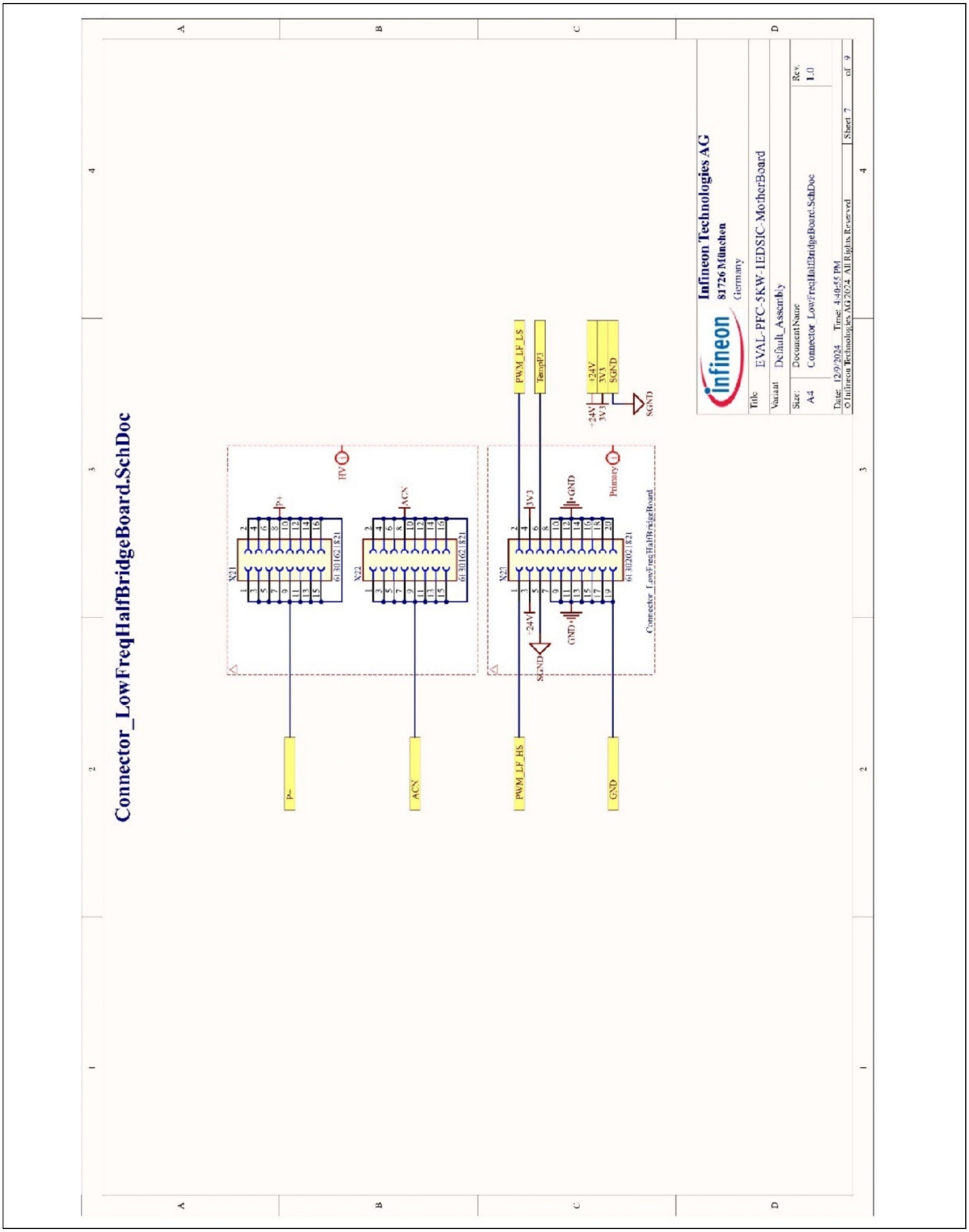

Figure 22 Motherboard Schematic: Connector LowFreqHalfBridgeBoard

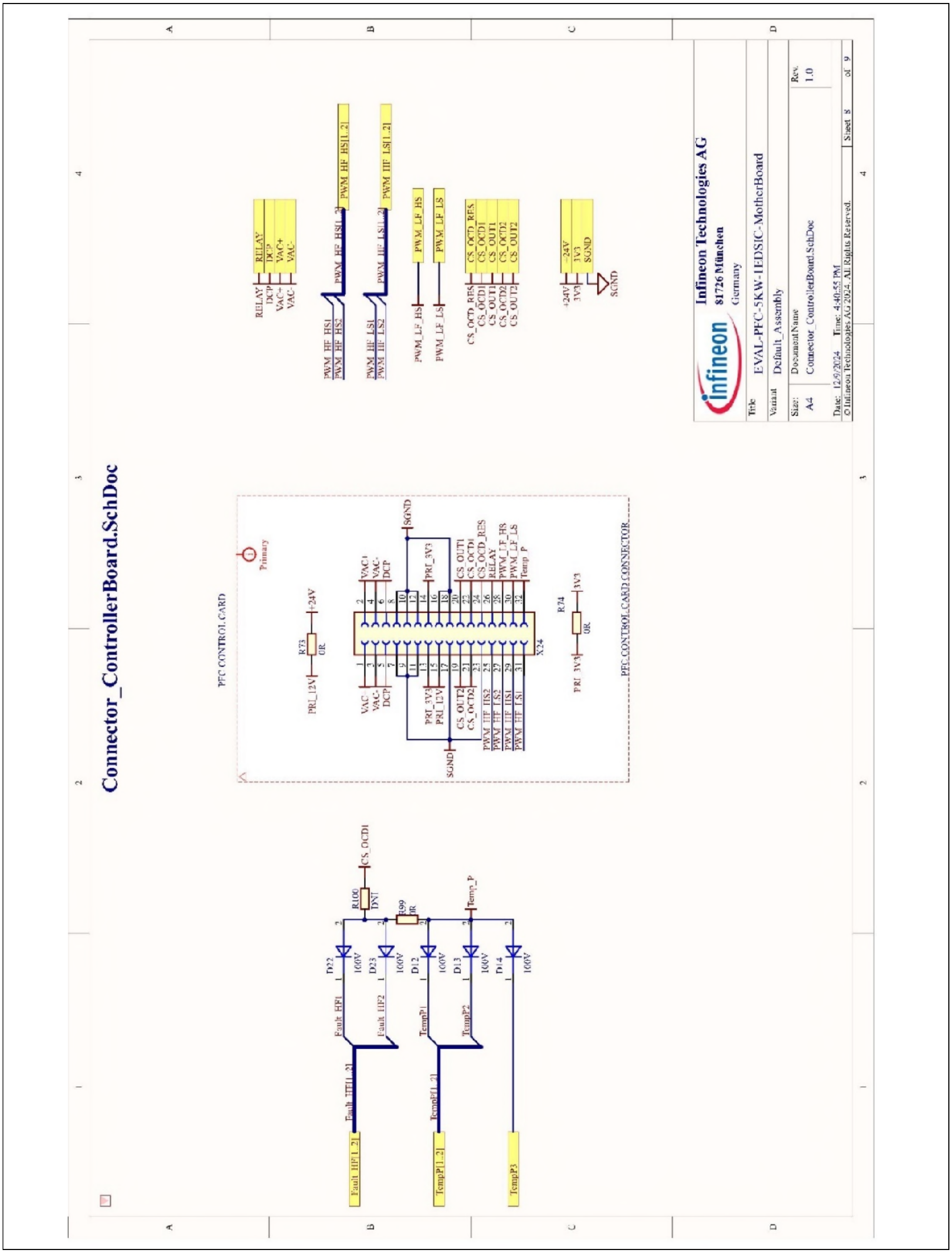

Figure 23 Motherboard Schematic: Connector Controller Board

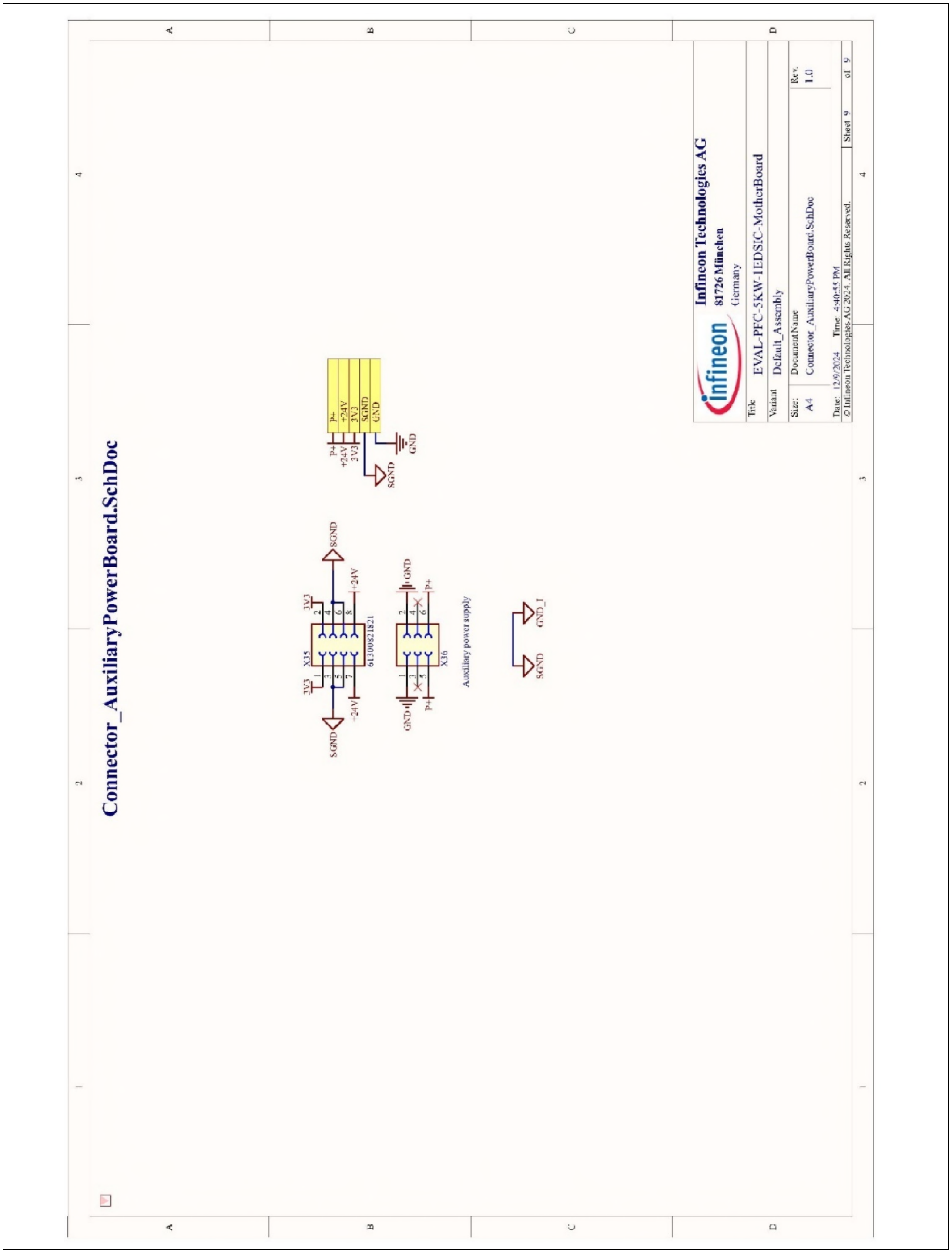

Figure 24 Motherboard Schematic: Connector AUX Board

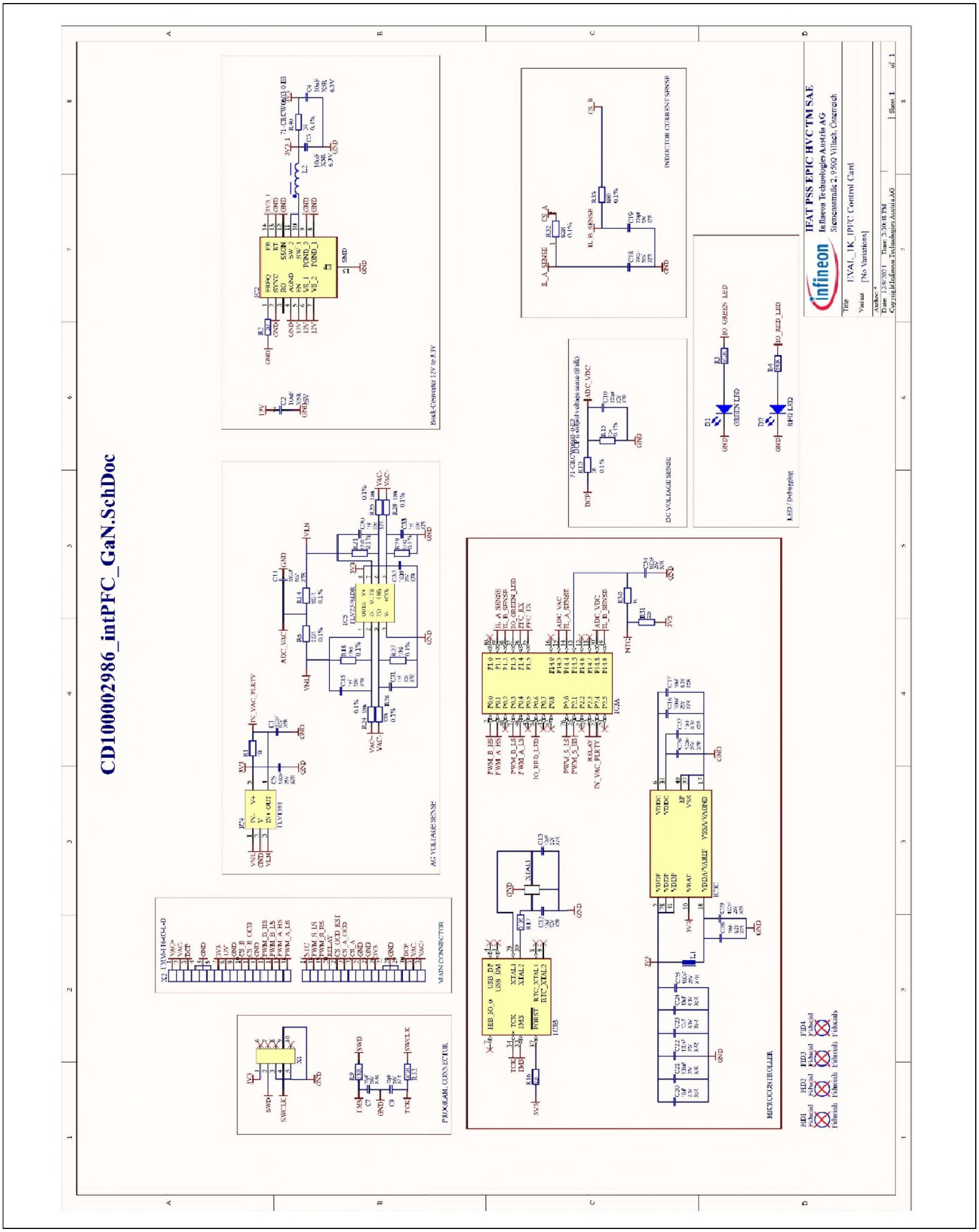

Figure 25 Controller Card Schematic

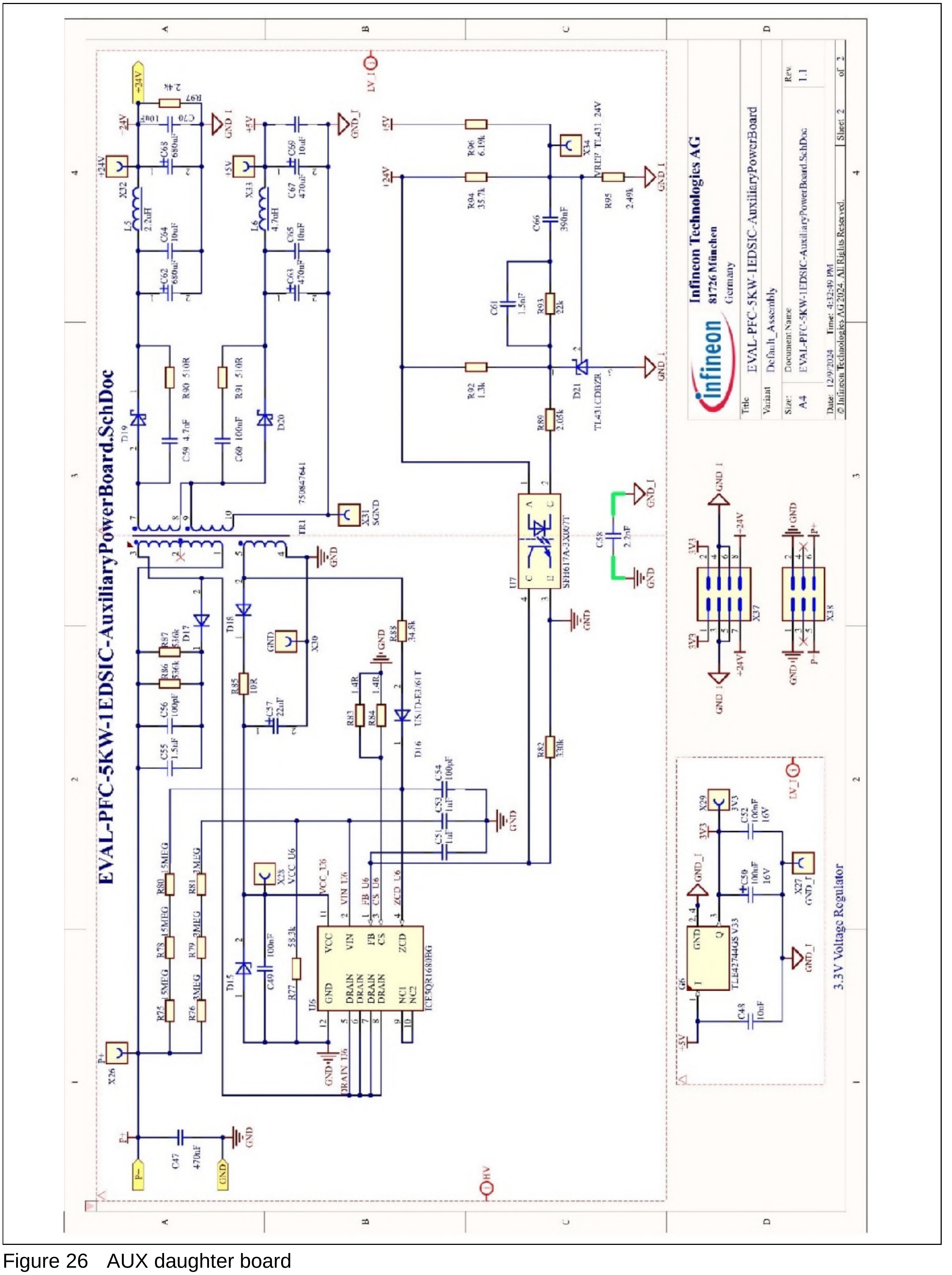

Figure 26 AUX daughter board

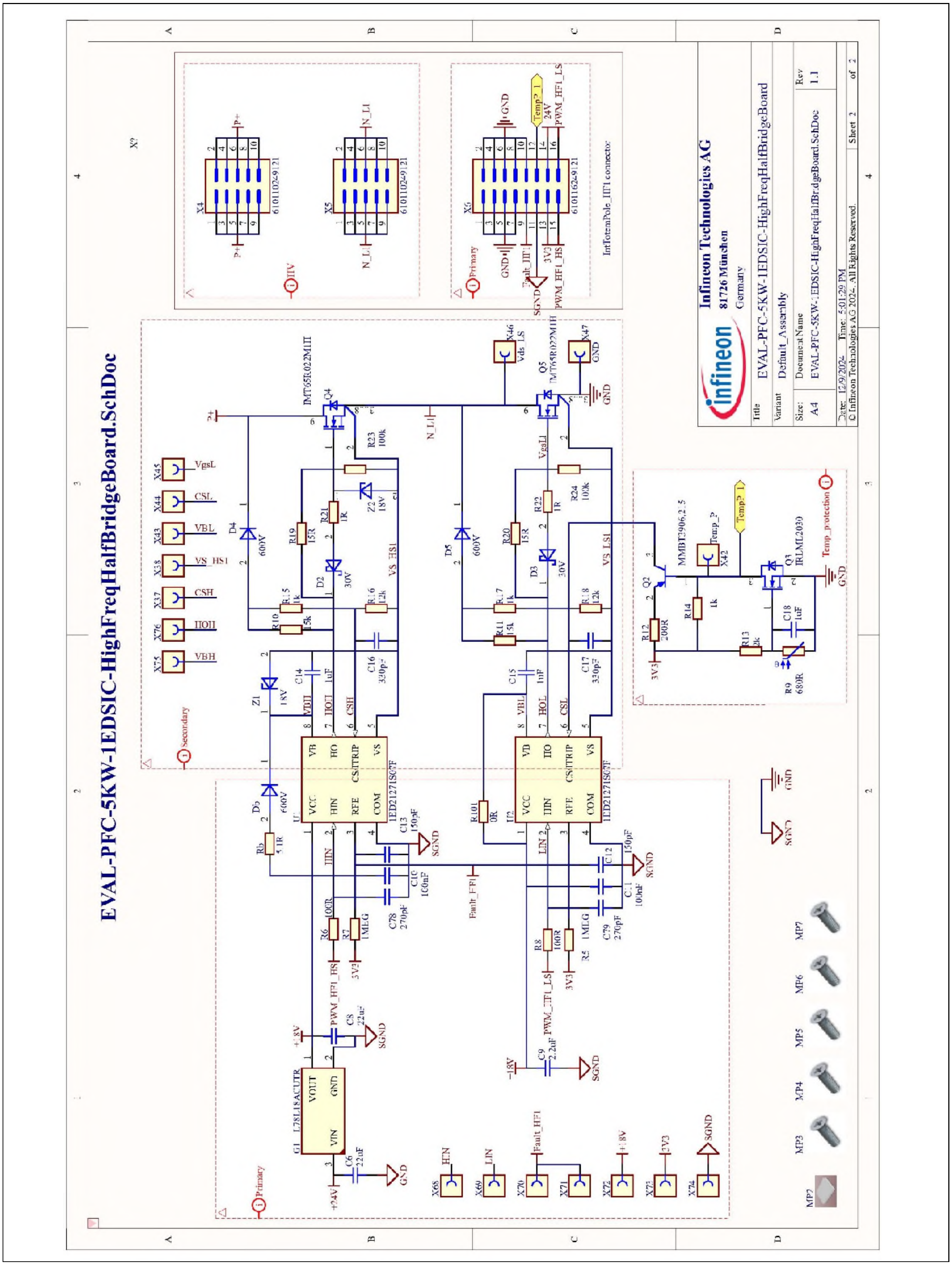

Figure 27 High Frequency bridge schematic

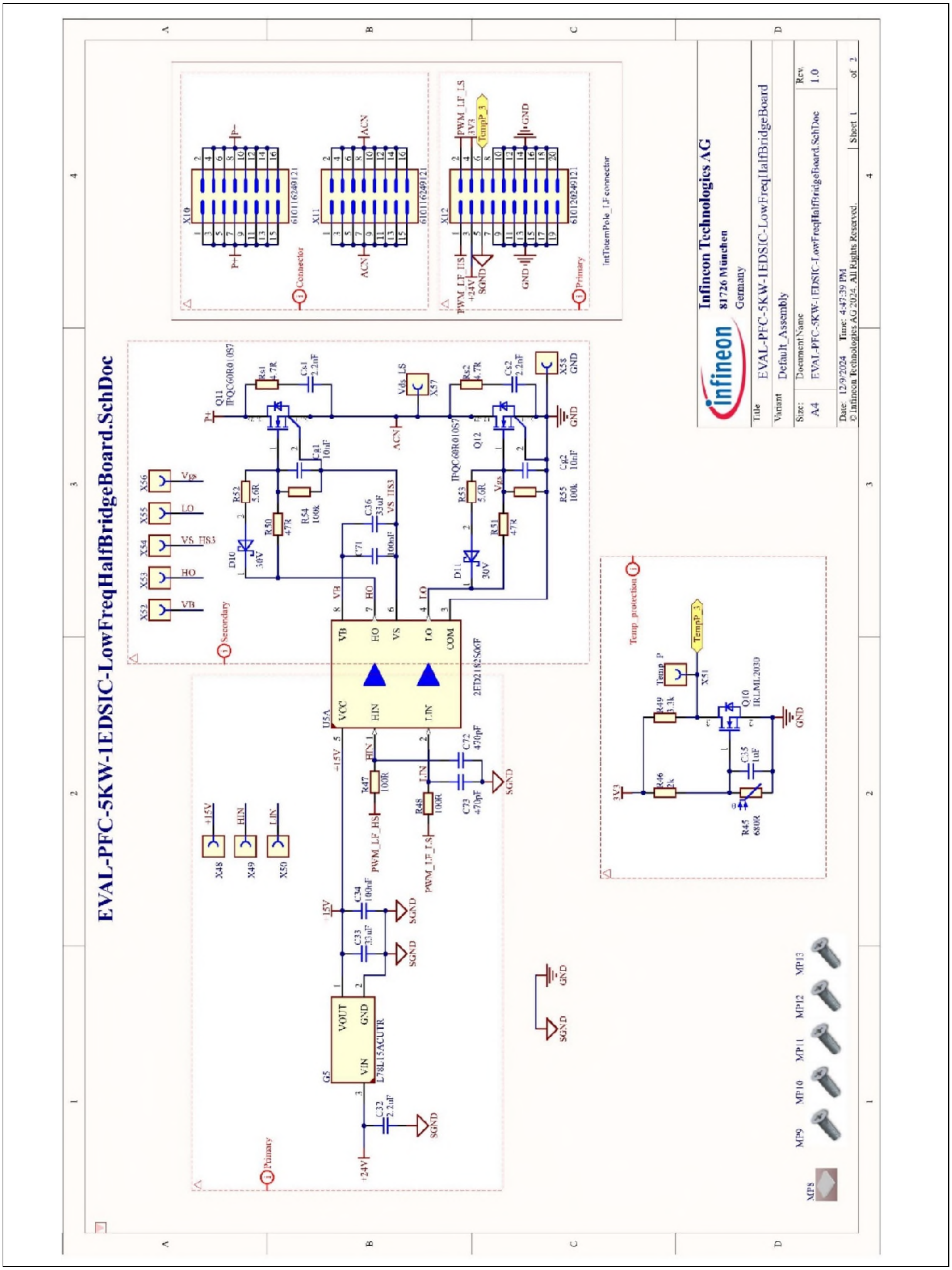

Figure 28 Return Path: Low Frequency Half Bridge Board

4.2 Layout

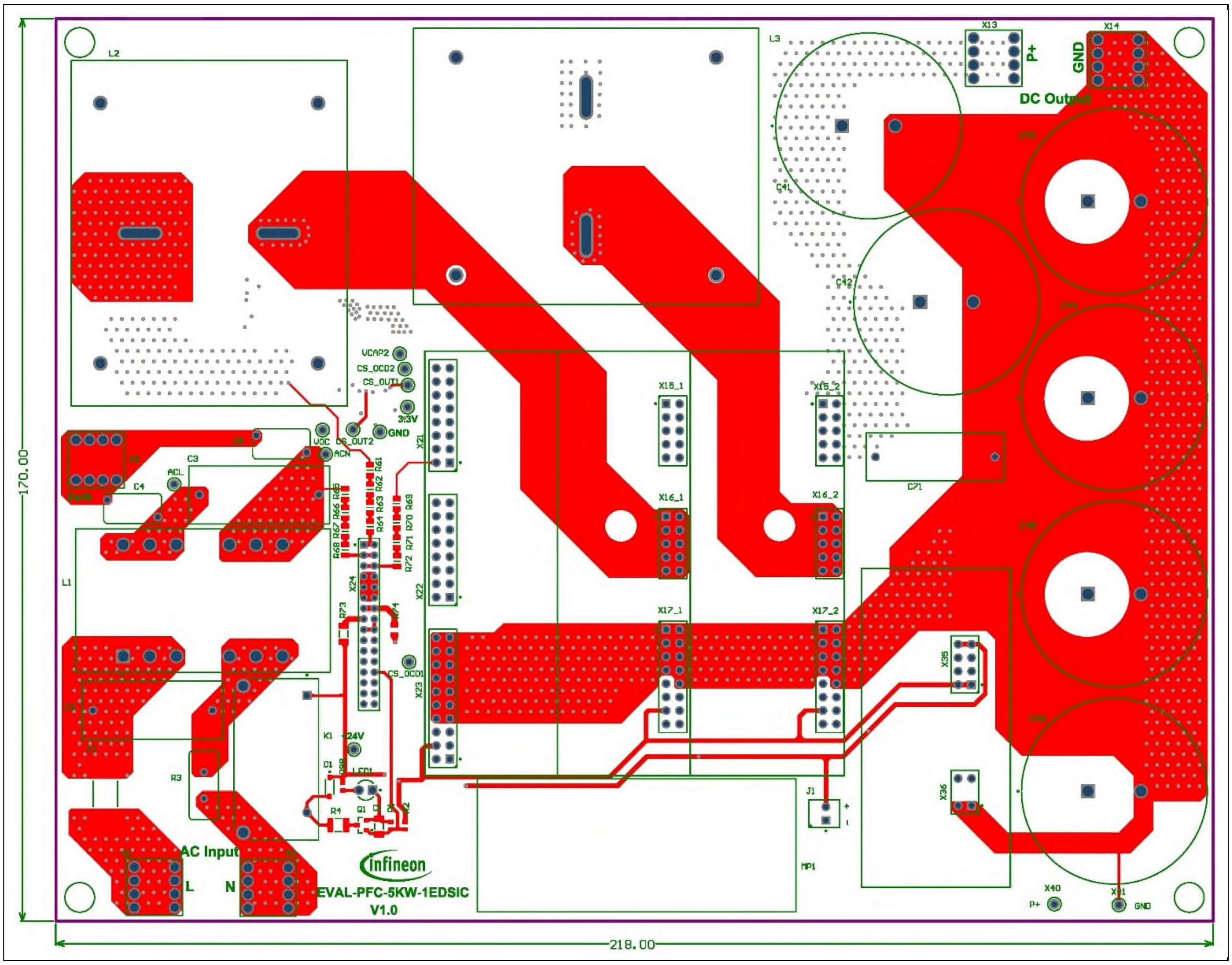

Figure 29 Motherboard TOP PCB

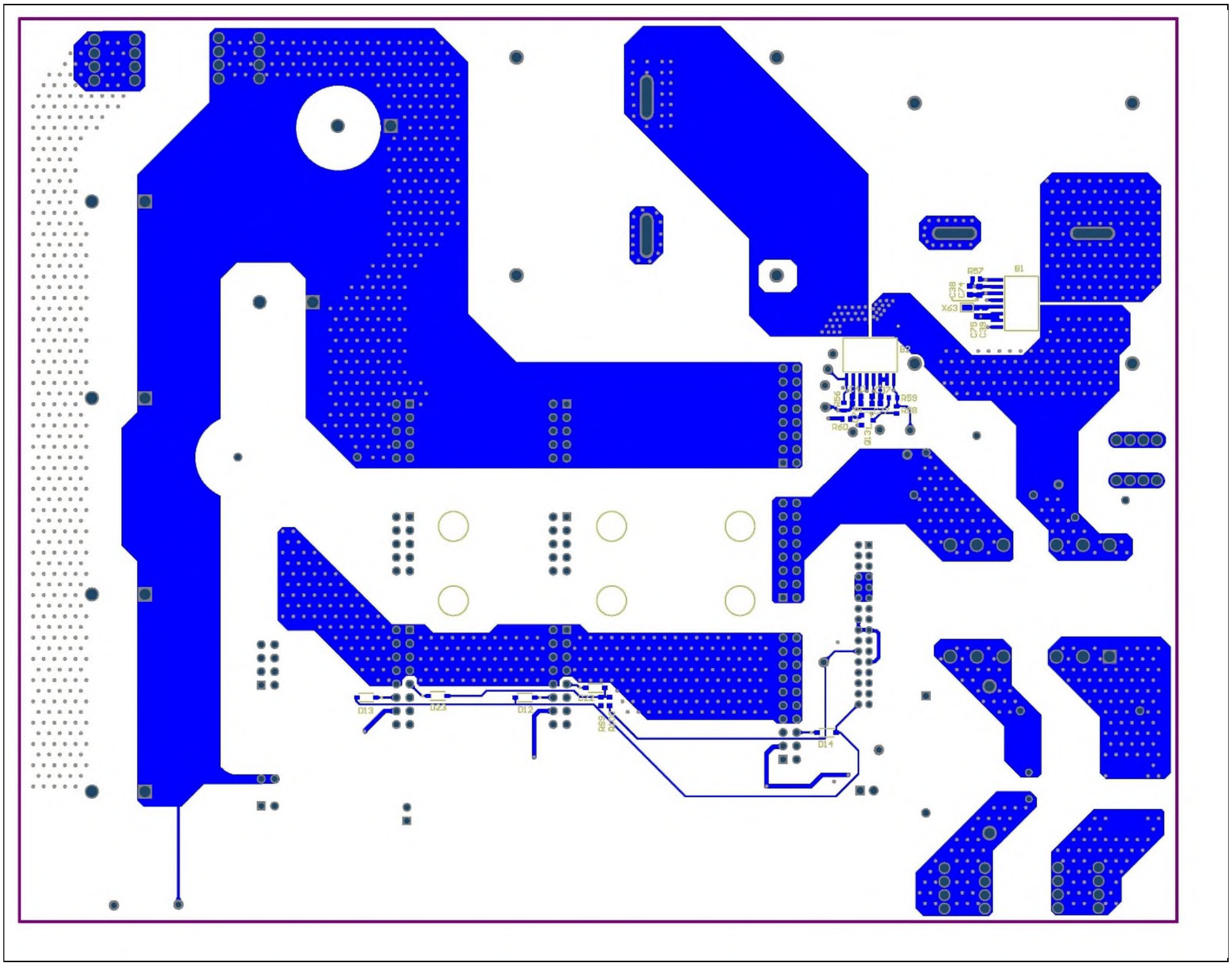

Figure 30 Motherboard Bottom PCB

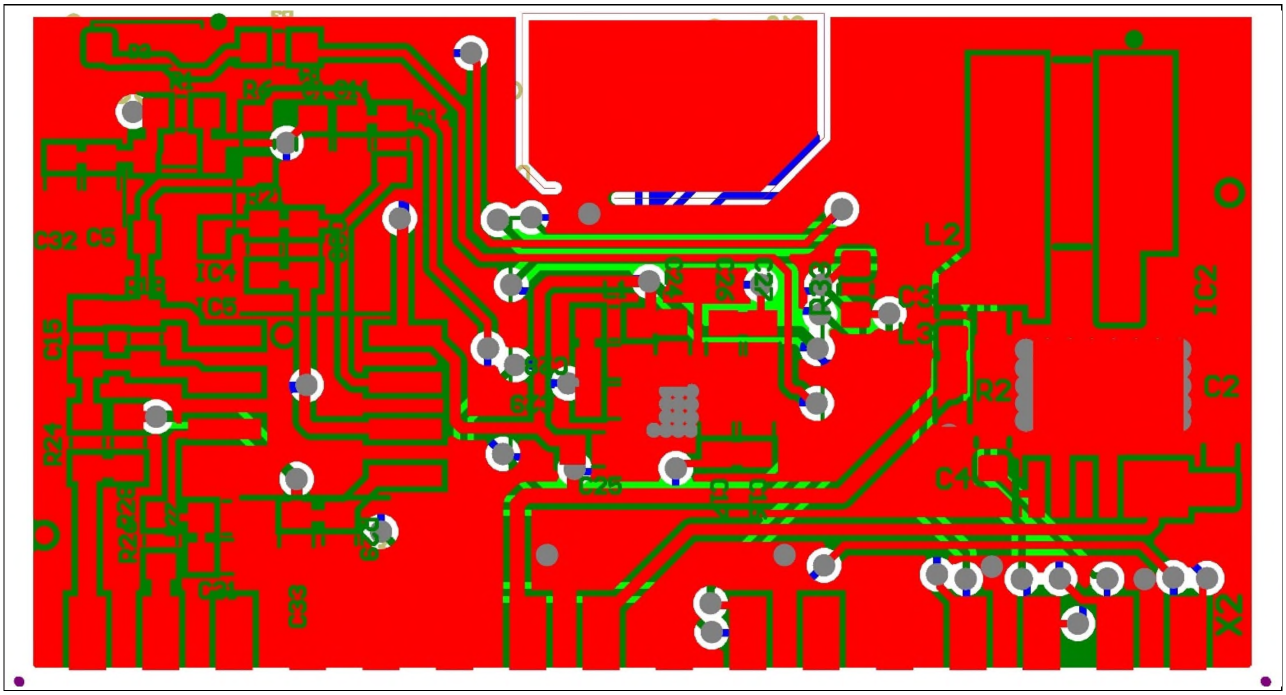

Figure 31 Controller Card TOP

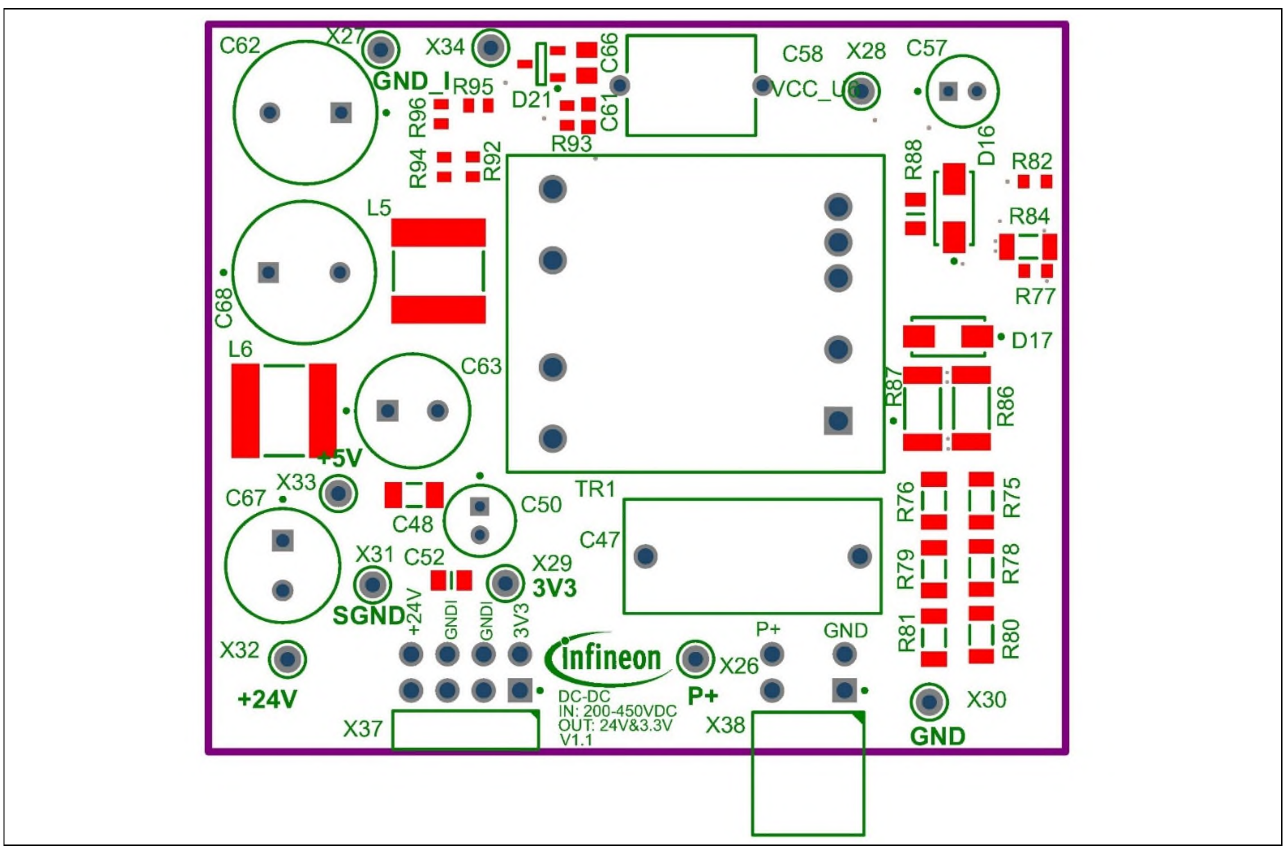

Figure 32 AUX daughter board TOP

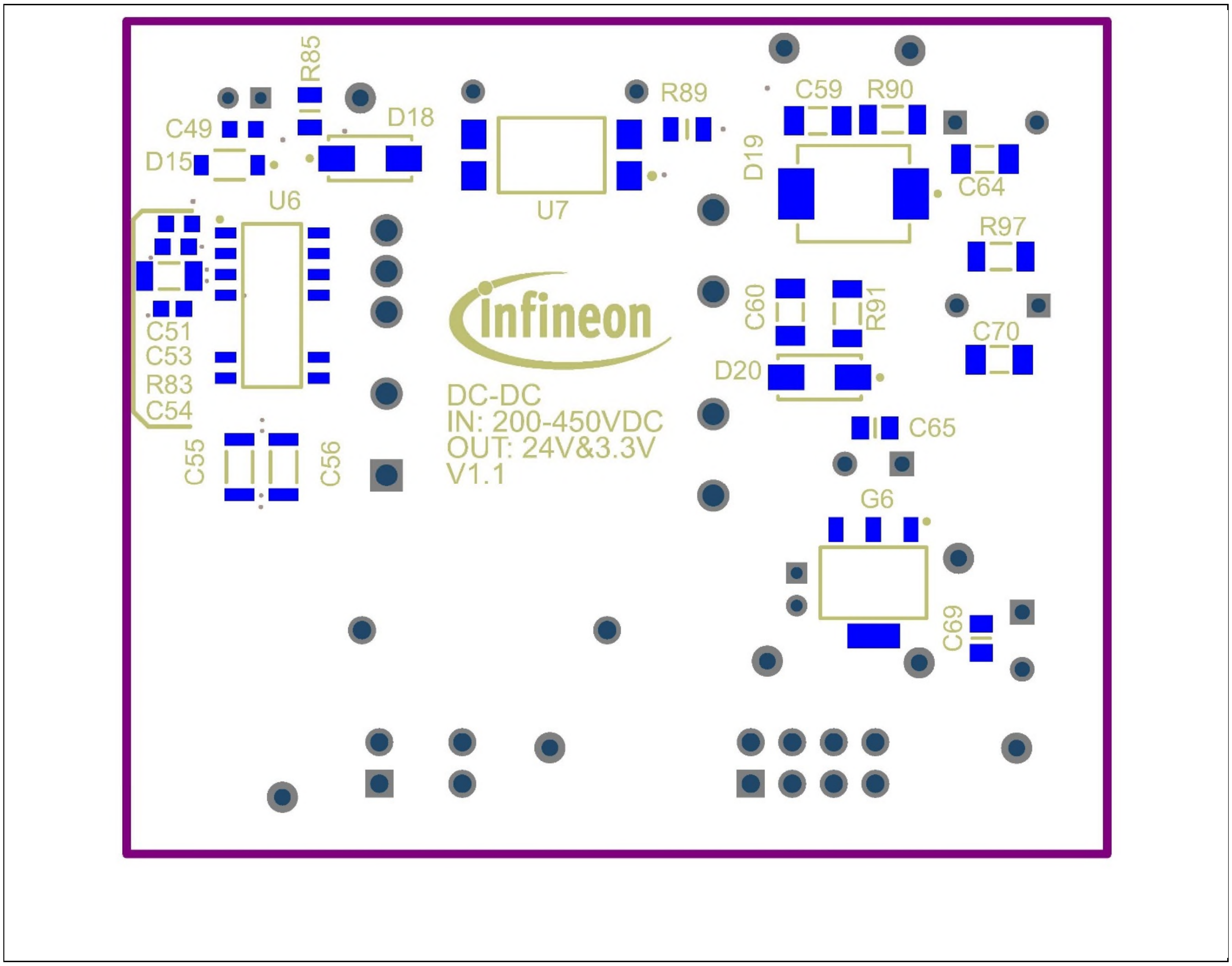

Figure 33 AUX daughter board BOTTOM

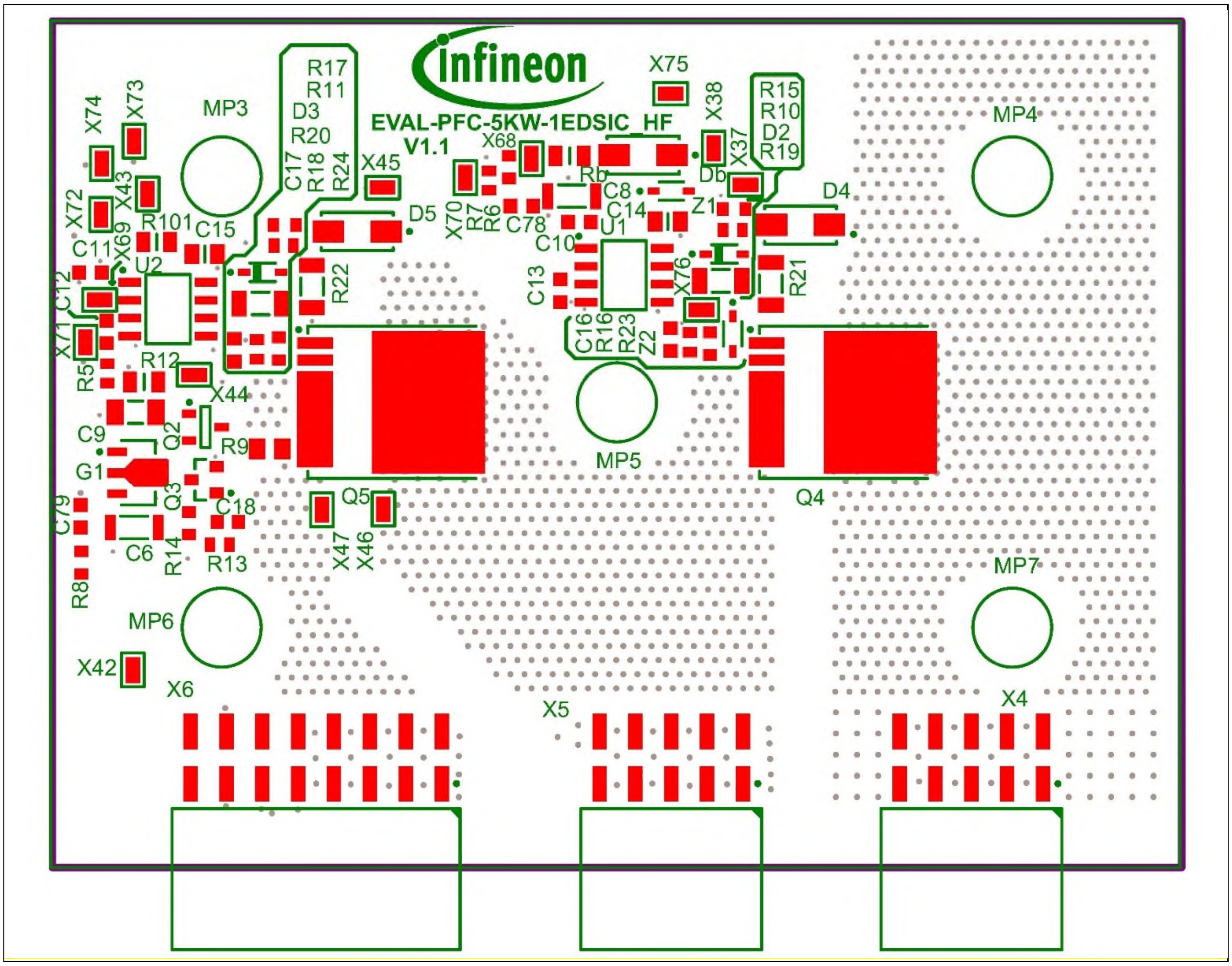

Figure 34 High Frequency bridge TOP

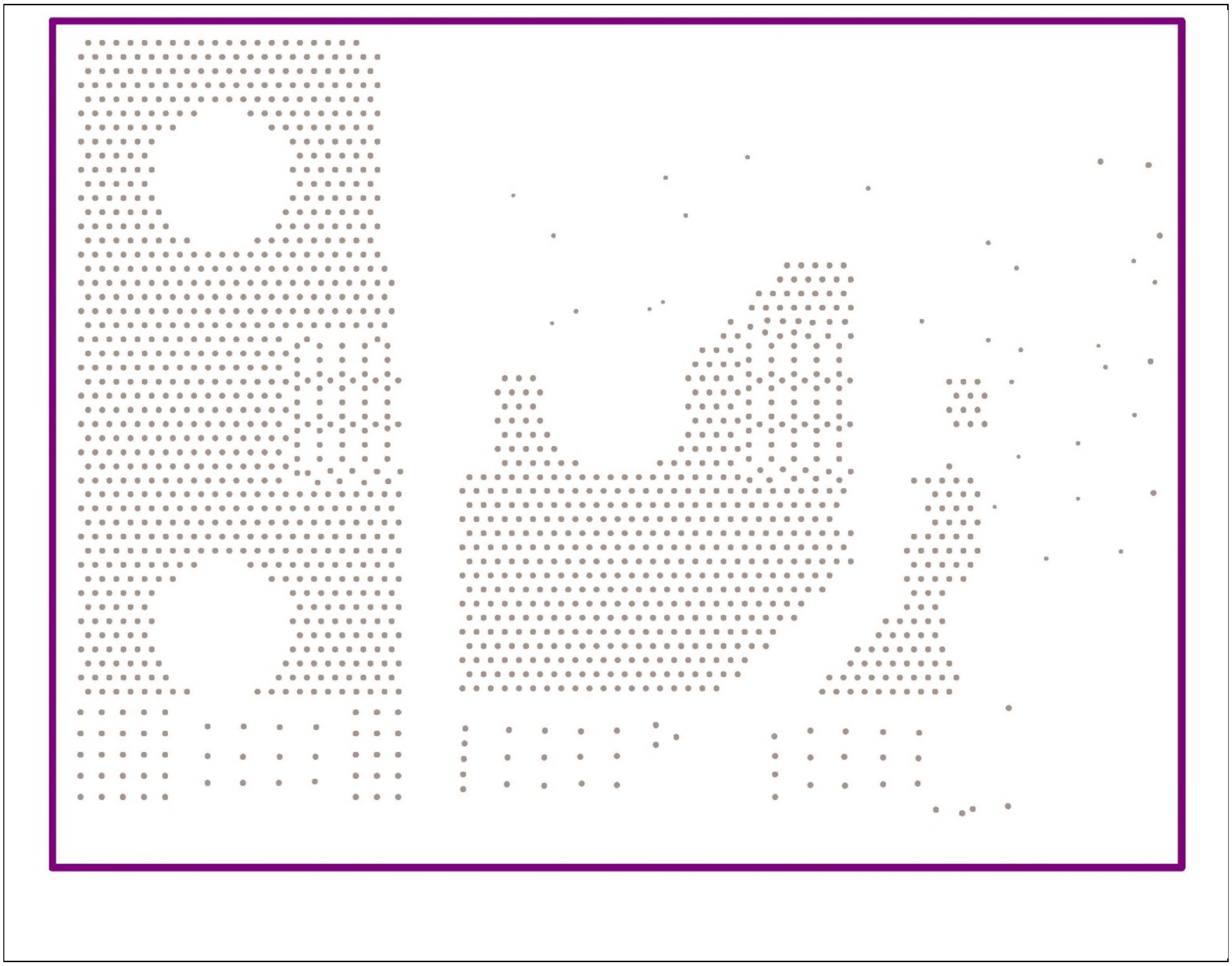

Figure 35 High Frequency bridge BOTTOM

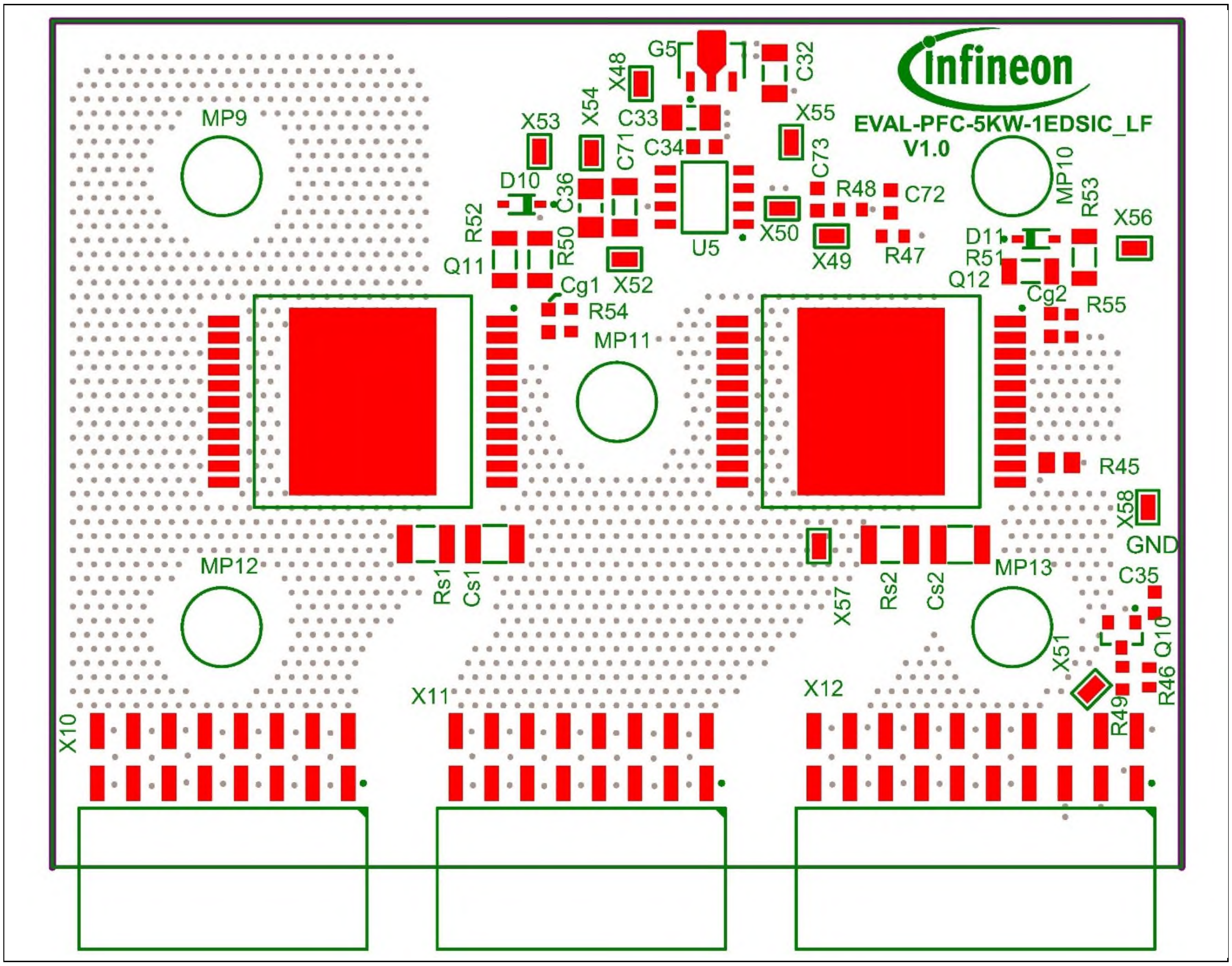

Figure 36 Return Path: Low Frequency Half Bridge Board TOP

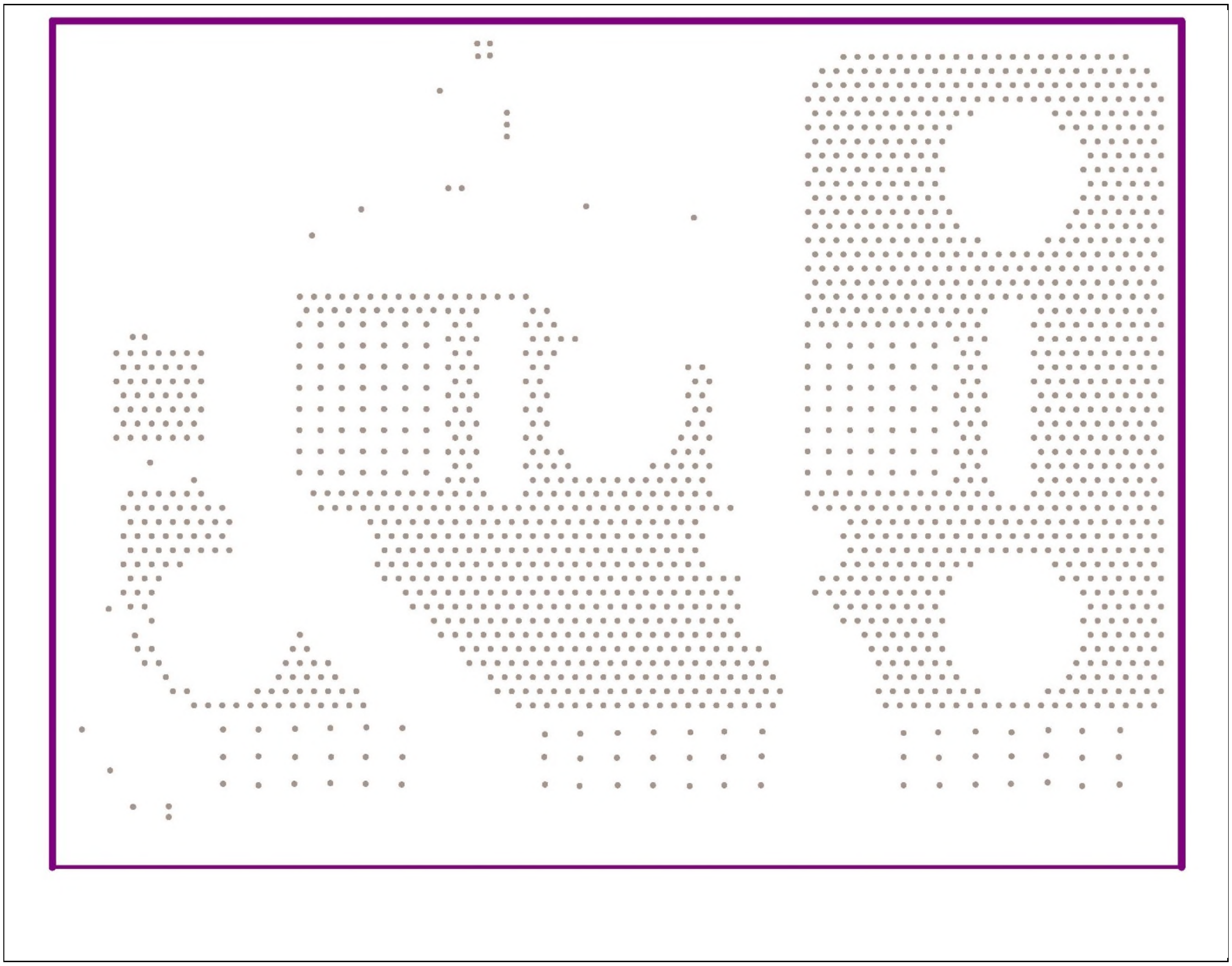

Figure 37 Return Path: Low Frequency Half Bridge Board BOTTOM

4.3 Bill of material

The complete bill of material is available on the download section of the Infineon homepage. A log-in is required to download this material.

Table 2 Motherboard BOM

Quantity	Designator	Value	Manufacturer
2	B1, B2	MCR1101-50-3	ACEINNA
1	C1	1uF	MuRata
2	C2, C3	1uF	TDK Corporation
2	C4, C5	2.2nF	Vishay
4	C37, C38, C39, C40	100nF	MuRata
6	C41, C42, C43, C44, C45, C46	470uF	Wurth Elektronik
1	C71	470nF	Wurth Elektronik
2	C74, C76	10uF	MuRata
2	C75, C77	2.2uF	MuRata

1	D1	1N4148W-7-F	Diodes Incorporated
5	D12, D13, D14, D22, D23	100V	Diodes Incorporated
1	F1	50A	Cooper Bussmann
1	J1	61900211121	Wurth Elektronik
1	K1	HF161F-W/24-HT	HONGFA
1	L1	1.5mH	Wurth Elektronik
2	L2, L3		POCO Holding Co., Ltd
1	LED1	Red	LiteOn Optoelectronics
1	MP1	MF60252VX-1000C-A99	-
10	MP14, MP15, MP16, MP17, MP24, MP25, MP26, MP27, MP28, MP29	M310 KRSTMCZ100-	Duratool
1	Q1	IRLML2030	Infineon Technologies
1	Q13	BSS306N	Infineon Technologies
1	R1	220k	Vishay
1	R2	47k	Vishay
1	R3	25R	TDK Corporation
1	R4	51R	Vishay
2	R56, R57	6.8k	Vishay
1	R58	6.8k	Vishay
1	R59	33k	Yageo
1	R60	1.4k	Vishay
8	R61, R62, R63, R64, R65, R66, R67, R68	309k	Vishay
3	R69, R70, R71	390k	Vishay
1	R72	430k	Vishay
1	R73	0R	Vishay
1	R74	0R	Yageo
1	R98	15k	TE Connectivity
1	R99	0R	Yageo
1	R100	0R	Yageo
5	X1, X2, X3, X13, X14	7460307	Wurth Elektronik
4	X15_1, X15_2, X16_1, X16_2	61301021821	Wurth Elektronik
4	X17_1, X17_2, X21, X22	61301621821	Wurth Elektronik
1	X23	61302021821	Wurth Elektronik
1	X24	62003221821	Wurth Elektronik
1	X25	ACL	Keystone Electronics Corp.
1	X35	61300821821	Wurth Elektronik
1	X36	61300621821	Wurth Elektronik
1	X39	Test Point THT	Keystone Electronics Corp.
1	X40	Test Point THT	Keystone Electronics Corp.

1	X41	Test Point THT	Keystone Electronics Corp.
1	X59	Test Point THT	Keystone Electronics Corp.
1	X60	Test Point THT	Keystone Electronics Corp.
1	X61	Test Point THT	Keystone Electronics Corp.
1	X62	Test Point THT	Keystone Electronics Corp.
1	X63	Test Point THT	Harwin
1	X64	Test Point THT	Keystone Electronics Corp.
1	X65	Test Point THT	Keystone Electronics Corp.
1	X66	Test Point THT	Keystone Electronics Corp.
1	X67	Test Point THT	Keystone Electronics Corp.
1	X77	Test Point THT	Keystone Electronics Corp.

Table 3 AUX supplies BOM

Quantity	Designator	Value	Manufacturer
1	C47	470nF	TDK Corporation
1	C48	10uF	MuRata
1	C49	100nF	AVX
1	C50	100uF	Wurth Elektronik
2	C51, C53	1nF	MuRata
1	C52	100nF	MuRata
1	C54	100pF	TDK Corporation
1	C55	1.5nF	MuRata
1	C56	100pF	MuRata
1	C57	22uF	Wurth Elektronik
1	C58	2.2nF	MuRata
1	C59	4.7nF	MuRata
1	C60	100nF	MuRata
1	C61	1.5nF	MuRata
2	C62, C68	680uF	Wurth Elektronik
2	C63, C67	470uF	Wurth Elektronik
2	C64, C70	10uF	MuRata
2	C65, C69	10uF	MuRata
1	C66	390nF	MuRata
1	D15	22V	Vishay
2	D16, D18	US1D-E3/61T	Vishay
1	D17	US1M-E3/61T	Vishay
1	D19	B3100-13-F	Diodes Incorporated
1	D20	SS14HE3_B/H	Vishay
1	D21	TL431CDBZR	Texas Instruments
1	G6	TLE42744GS V33	Infineon Technologies
1	L5	2.2uH	MuRata
1	L6	4.7uH	MuRata
3	R75, R78, R80	15MEG	Yageo
3	R76, R79, R81	3MEG	Vishay
1	R77	58.3k	Yageo

1	R82	330k	Yageo
2	R83, R84	1.4R	Vishay
1	R85	10R	Vishay
2	R86, R87	536k	Vishay
1	R88	34.8k	Vishay
1	R89	2.05k	Vishay
2	R90, R91	510R	Vishay
1	R92	1.3k	Vishay
1	R93	22k	Vishay
1	R94	35.7k	Vishay
1	R95	2.49k	Vishay
1	R96	6.19k	Vishay
1	R97	2.4k	Vishay
1	TR1	750847641	Wurth Elektronik
1	U6	ICE5QR1680BG	Infineon Technologies
1	U7	SFH617A-3X007T	Vishay
1	X26	Test Point THT, Red	Keystone Electronics Corp.
1	X27	Test Point THT, Black	Keystone Electronics Corp.
1	X28	Test Point THT, Red	Keystone Electronics Corp.
1	X29	Test Point THT, Red	Keystone Electronics Corp.
1	X30	Test Point THT, Black	Keystone Electronics Corp.
1	X31	Test Point THT, Black	Keystone Electronics Corp.
1	X32	Test Point THT, Red	Keystone Electronics Corp.
1	X33	Test Point THT, Red	Keystone Electronics Corp.
1	X34	VREF_TL431_24V	Keystone Electronics Corp.
1	X37	6.13E+10	Wurth Elektronik
1	X38	6.13E+10	Wurth Elektronik

Table 4 Controller Card BOM

Quantity	Designator	Value	Manufacturer
1	C1	100pF	
3	C2, C3, C4	10uF	
9	C5, C16, C21, C22, C25, C26, C29, C32, C34	100nF	
2	C7, C9	15pF	
4	C10, C11, C18, C19	330pF	
2	C12, C13	10pF	
4	C15, C30, C31, C33	1nF	
6	C17, C20, C23, C24, C27, C28	10uF	
1	D1	GREEN LED	Digi-Key
1	D2	RED LED	Digi-Key
1	IC2	TLS4120D0EPV33XUMA1	Infineon

1	IC3	XMC4200Q48K256BAXUMA 1	IFX
1	IC4	TLV1391IDBVT	Digi-Key
1	IC5	TLV2376IDR	Farnell
1	L1	742792602	Digikey
1	L2	100µH	Mouser
1	R1	10k	
1	R2	2k7	
5	R3, R4, R9, R12, R17	510R	
2	R6, R14	680R	
2	R13, R40	0R	Mouser
1	R15	10k	Digikey
2	R16, R31	22k	
4	R18, R21, R27, R29	17k8	Digikey
4	R24, R25, R26, R28	309k	Digikey
1	R30	1k	
2	R32, R33	806R	
1	X1		Digi-Key
1	X2	TMM-116-03-L-D	Farnell
1	XTAL1	QT325S-12.000MEEQ-T	Digikey

Table 5 High Frequency Bridge BOM

Quantity	Designator	Value	Manufacturer
2	C6, C8	22uF	TDK Corporation
1	C9	2.2uF	MuRata
2	C10, C11	100nF	MuRata
2	C12, C13	150pF	MuRata
2	C14, C15	1uF	MuRata
2	C16, C17	330pF	MuRata
1	C18	1uF	MuRata
2	C78, C79	270pF	MuRata
2	D2, D3	30V	Infineon Technologies
3	D4, D5, Db	600V	Vishay
1	G1	L78L18ACUTR	STMicroelectronics
1	MP2	AL-Heatsink-L80XW60XH15	-
5	MP3, MP4, MP5, MP6, MP7	M310 KRSTMCZ100-	Duratool
1	Q2	MMBT3906,215	Nexperia
1	Q3	IRLML2030	Infineon Technologies
2	Q4, Q5	IMT65R022M1H	Infineon Technologies
2	R5, R7	1MEG	Vishay

2	R6, R8	100R	Yageo
1	R9	680R	TDK Corporation
2	R10, R11	15k	Vishay
1	R12	200R	Vishay
1	R13	2k	Vishay
3	R14, R15, R17	1k	Yageo
2	R16, R18	12k	Vishay
2	R19, R20	15R	Vishay
2	R21, R22	1R	Vishay
2	R23, R24	100k	Yageo
1	R101	0R	Keystone Electronics Corp.
1	Rb	5.1R	Vishay
2	U1, U2	1ED21271S65F	Infineon Technologies
2	X4, X5	WR PHD SMT Angled Dual Pin Header, 10 Pin, 2.54 mm Pitch, 250V, 3A	Wurth Elektronik
1	X6	WR PHD SMT Angled Dual Pin Header, 16 Pin, 2.54 mm Pitch, 250V, 3A	Wurth Elektronik
14	X37, X38, X43, X44, X45, X68, X69, X70, X71, X72, X73, X74, X75, X76	Test Point, Surface Mount, 3.5A	Harwin
1	X42	Test Point, Surface Mount, 3.5A	Harwin
1	X46	Test Point, Surface Mount, 3.5A	Harwin
1	X47	Test Point, Surface Mount, 3.5A	Harwin
2	Z1, Z2	20V	ON Semiconductor

Table 6 Return Path Board BOM

Quantity	Designator	Comment	Manufacturer
1	C32	2.2uF	MuRata
2	C33, C36	33uF	TDK Corporation
1	C34	100nF	AVX
1	C35	1uF	MuRata
1	C71	100nF	MuRata
2	C72, C73	470pF	MuRata
2	Cg1, Cg2	10nF	AVX
2	Cs1, Cs2	2.2nF	MuRata
2	D10, D11	30V	Infineon Technologies
1	G5	L78L15ACUTR	STMicroelectronics
1	MP8	AL-Heatsink-L80XW60XH15	-
5	MP9, MP10, MP11, MP12, MP13	M310 KRSTMCZ100-	Duratool
1	Q10	IRLML2030	Infineon Technologies
2	Q11, Q12	IPQC60R010S7	Infineon Technologies
1	R45	680R	TDK Corporation

1	R46	2k	Vishay
2	R47, R48	100R	Yageo
1	R49	3.3k	Yageo
2	R50, R51	47R	Vishay
2	R52, R53	5.6R	Vishay
2	R54, R55	100k	Yageo
2	Rs1, Rs2	4.7R	Vishay
1	U5	2ED2182S06F	Infineon Technologies
2	X10, X11	610116249121	Wurth Elektronik
1	X12	610120249121	Wurth Elektronik
8	X48, X49, X50, X52, X53, X54, X55, X56	S2761-46R	Harwin
1	X51	Temp_P	Harwin
1	X57	Vds_LS	Harwin
1	X58	GND	Harwin

4.4 Connector details

Table 7 Connectors

PIN	Label	Function
	X35, X36	Connector Aux
	X24	Connector Controller
	X21, X22, X23	Connector High Frquency Bridge
	X15, X16, X17	Connector Return Board

5 System performance

5.1 Test results

Note: *Due to production variations and measurement set-up, efficiency variations up to ±0.2 percent can be seen in the result shown.*

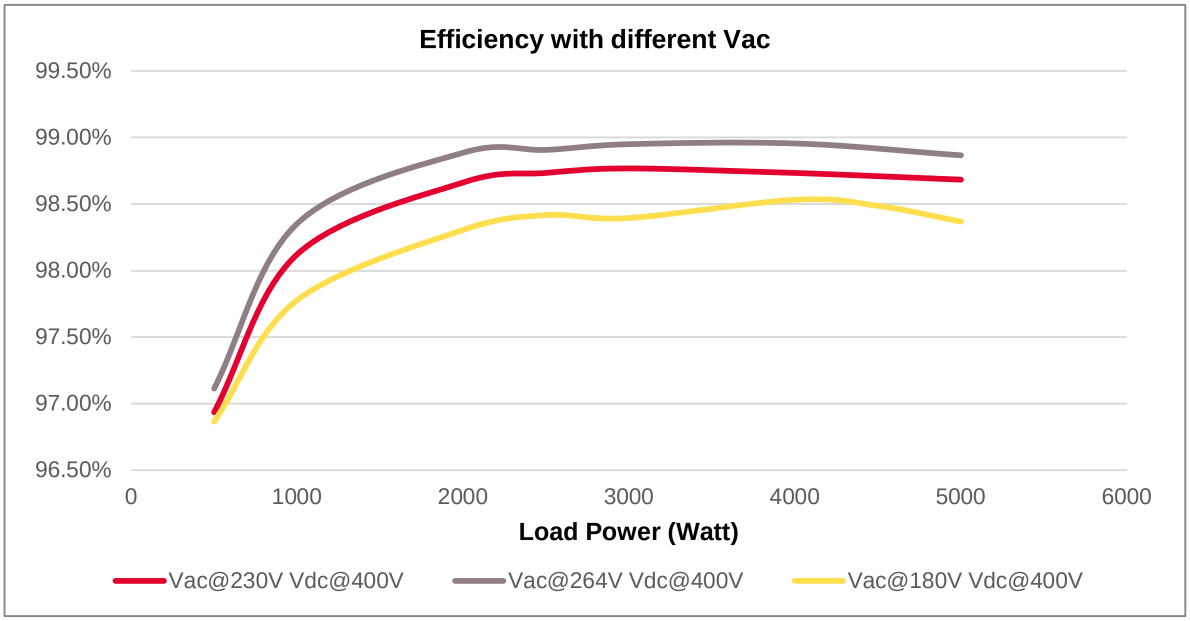

Figure 38 **Efficiency at different AC voltage**

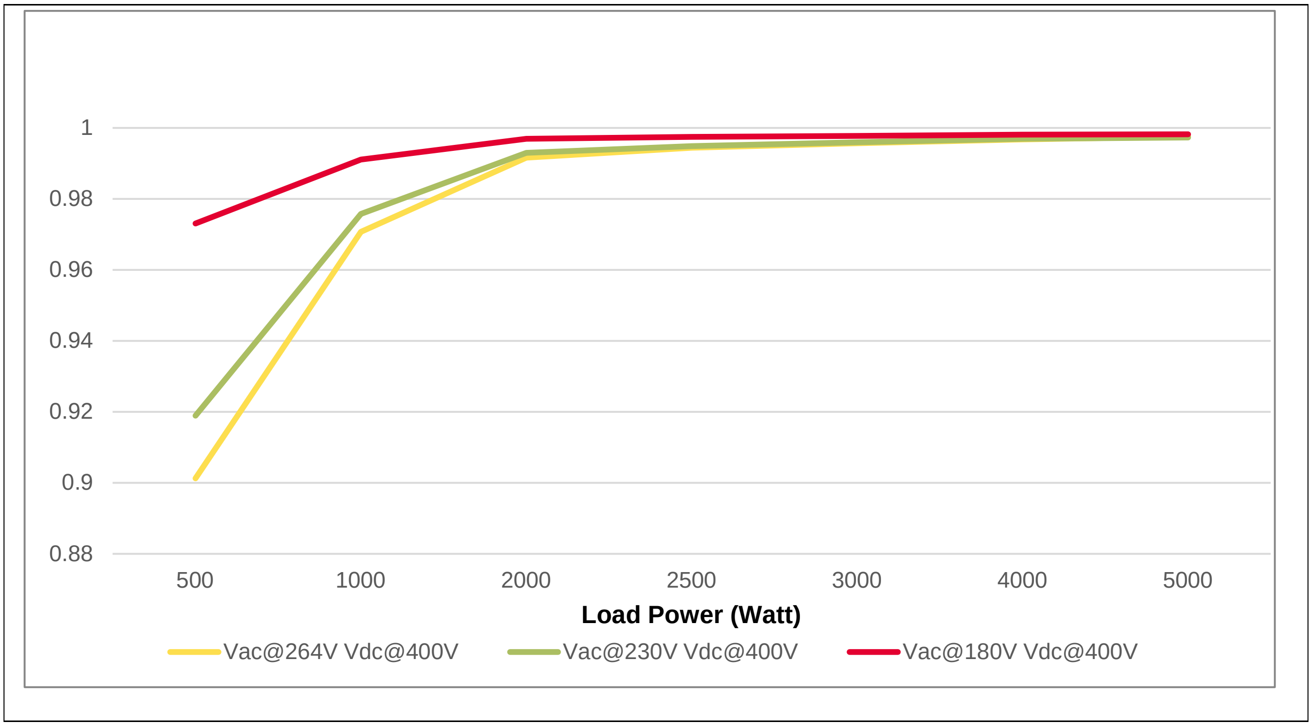

Figure 39 Power factor at different AC voltage

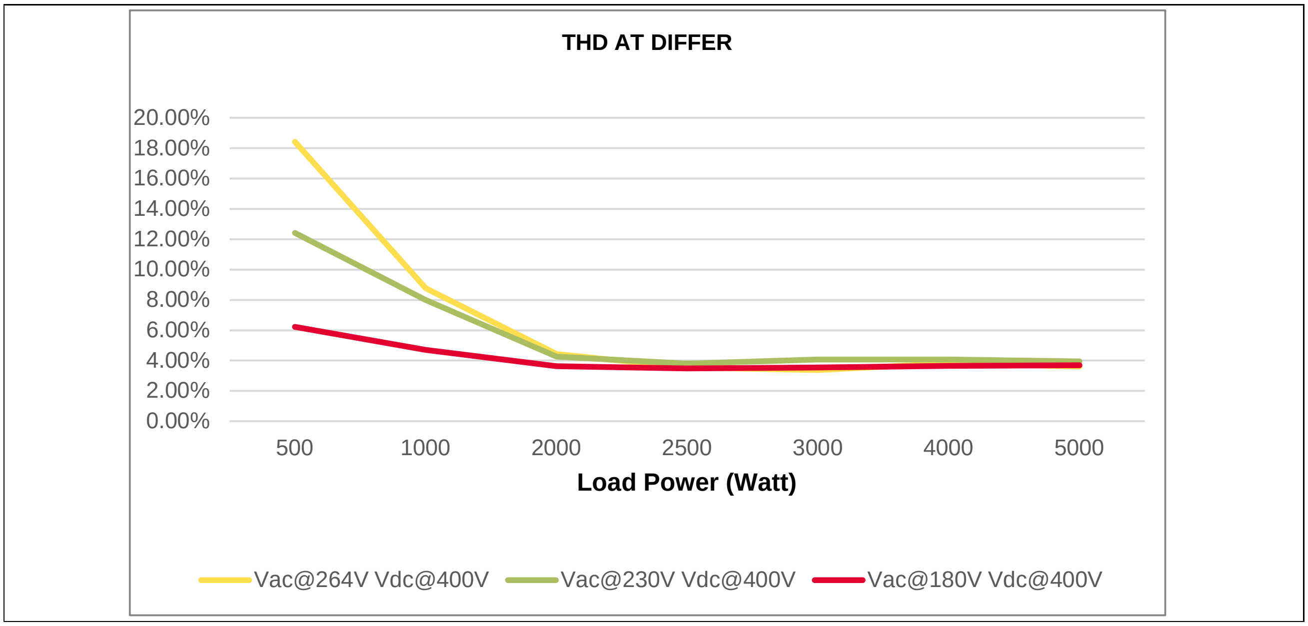

Figure 40 THD at different AC voltage

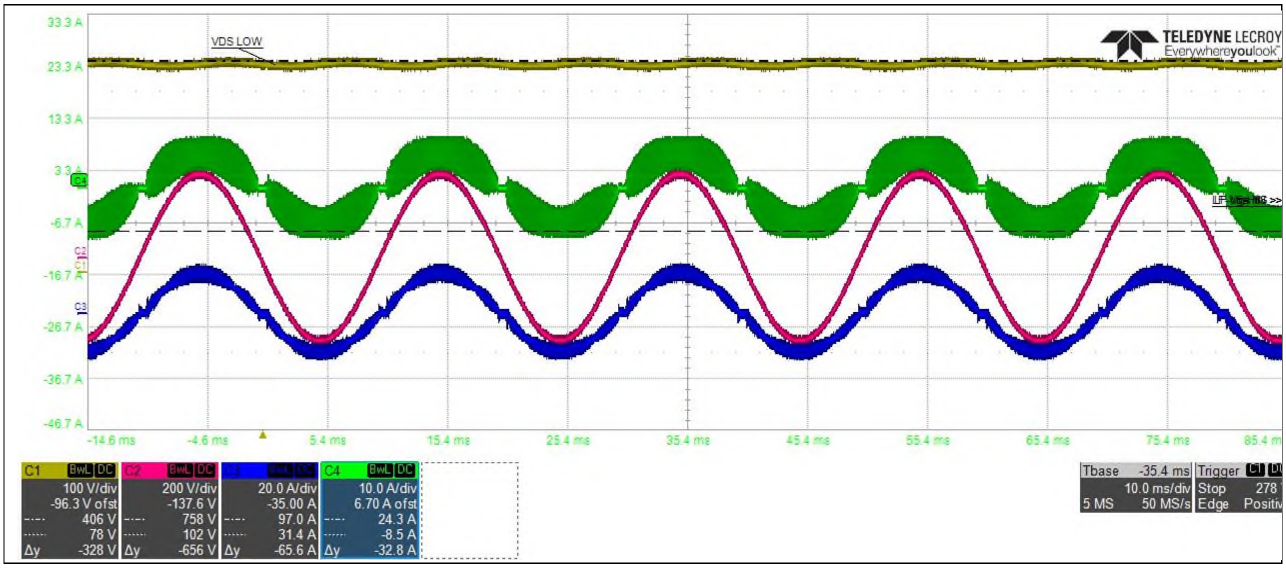

Figure 41 Steady-state waveforms at 230 V, 50 Hz AC voltage, 50 percent load

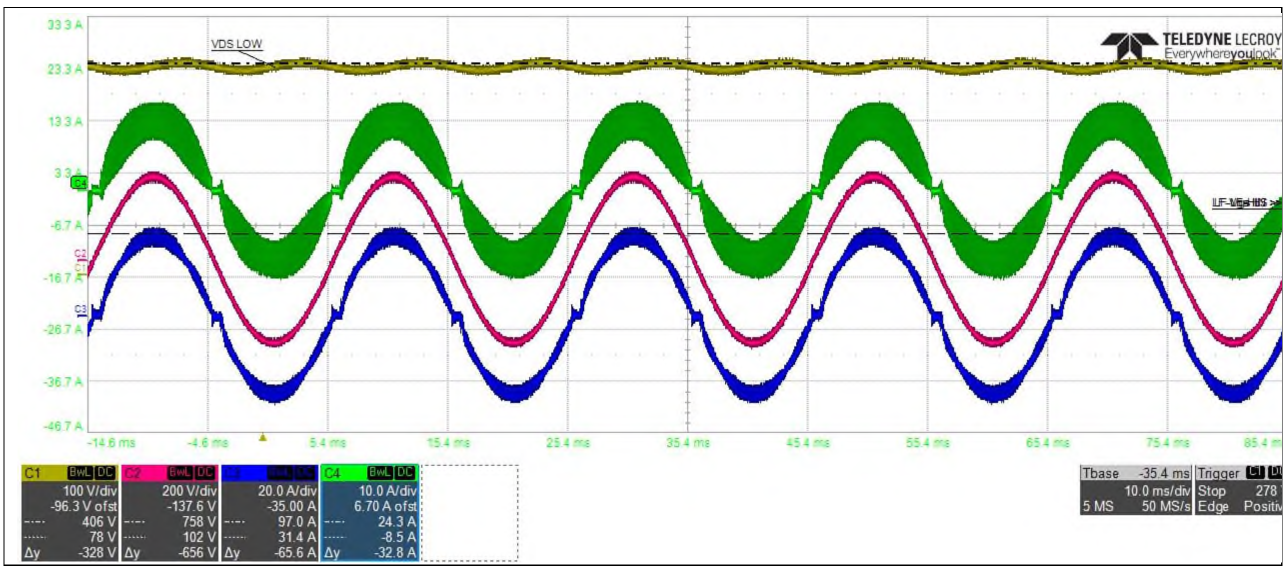

Figure 42 Steady-state waveforms at 230 V 50Hz AC voltage and 100 percent load

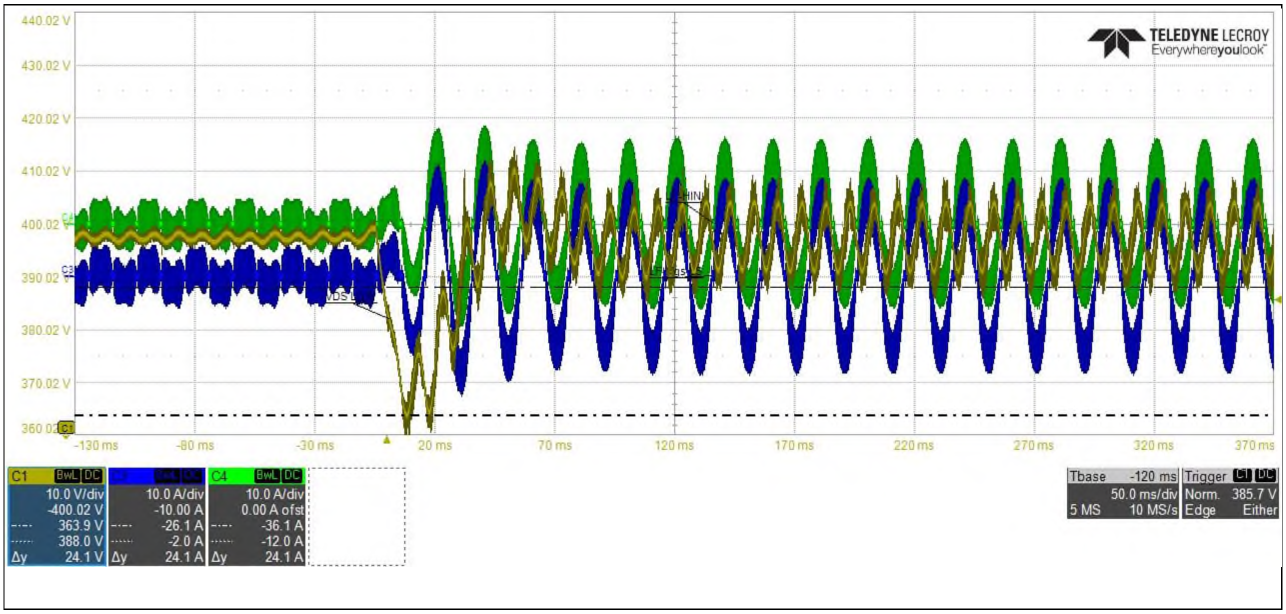

Figure 43 Load from 50 to 100 Vac@220V Vdc@400V

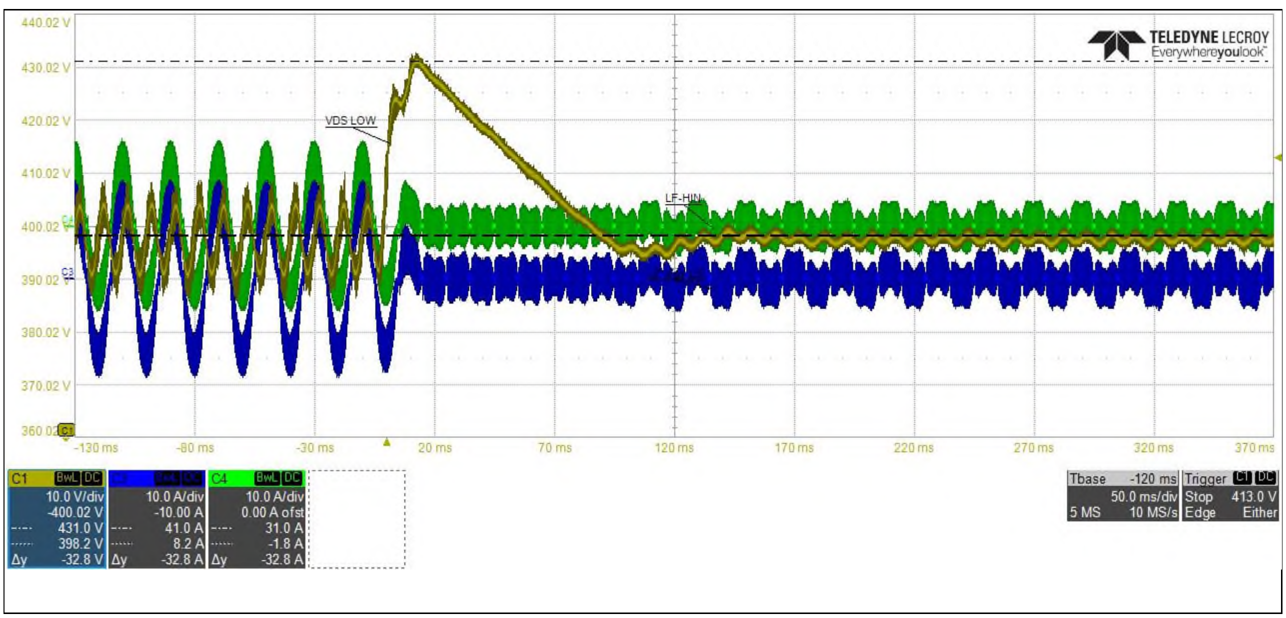

Figure 44 **Load from 100 to 50 Vac@220V Vdc@400V**

5.2 Thermal Measurement

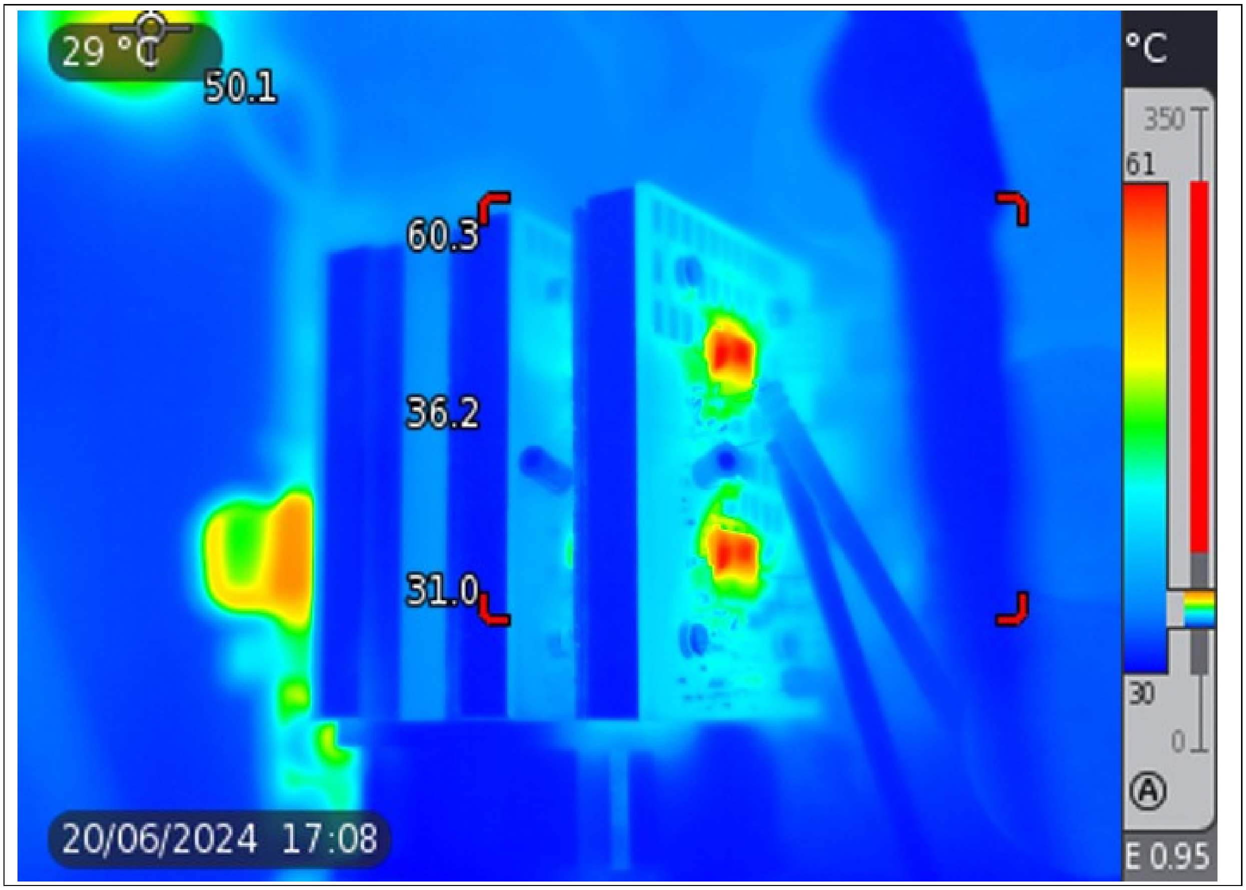

Figure 45 Board thermal characterization at Vac 180V and Vdc 400V, full load

The thermal behavior of the interleaved PFC totem-pole after a warm-up period of 30 minutes at 100% load and with an input voltage of 180 V is analyzed and is shown in Figure 45. For test purpose, the inductor is displaced from the board to easily probe current.

With a ambient temperature of 29degC, chokes reaches 50degC and CoolSiC™ 60.3degC during working condition with full load of 5kW.

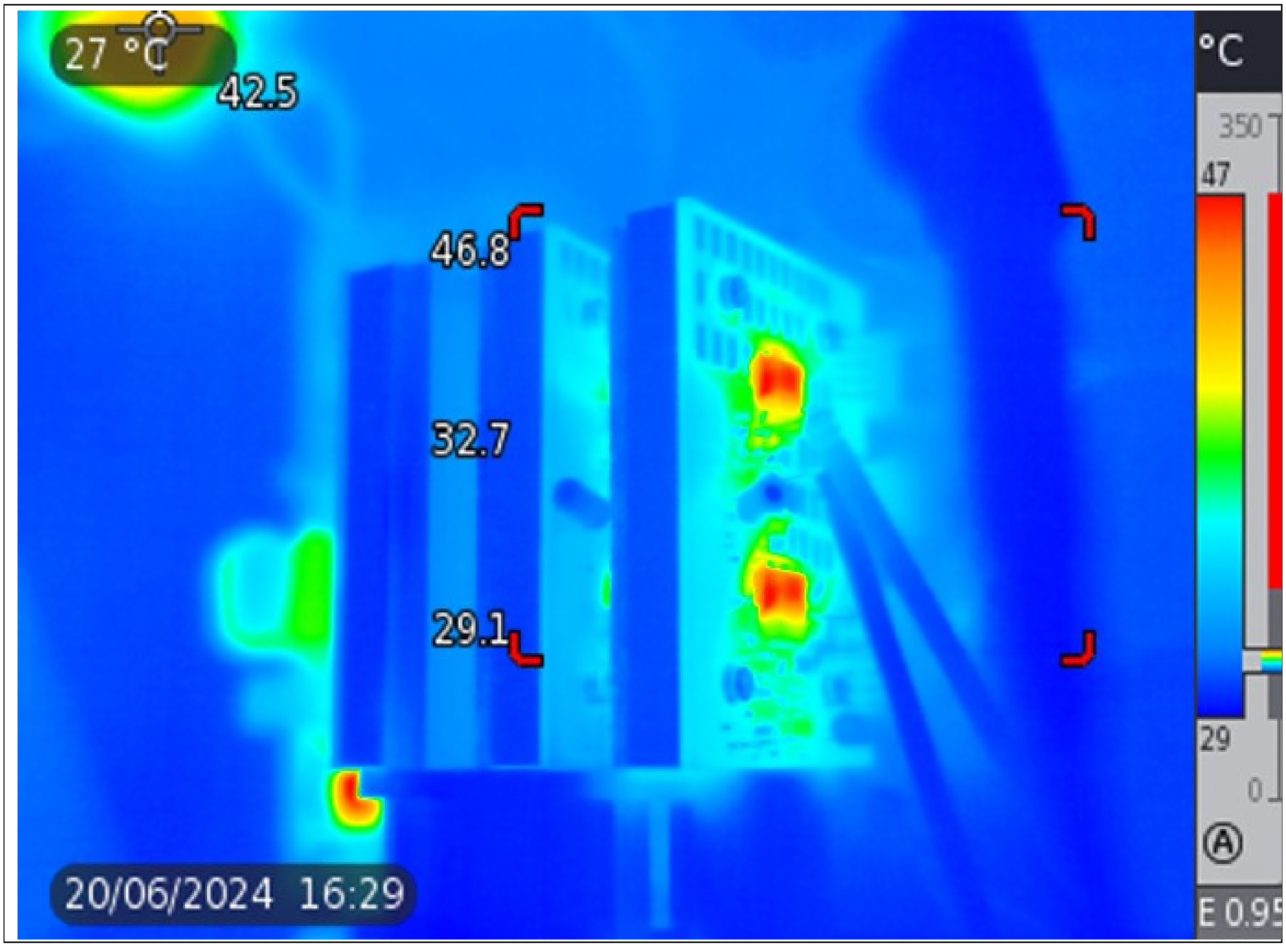

Figure 46 Board thermal characterization at Vac 180V and Vdc 400V, 60% load

With an ambient temperature of 27degC at 60% load (3kW), chokes reaches 42.5degC and CoolSiC™ 46.8degC.

Appendices

5.3 Application example: Heat Pumps as Key Technology for Decarbonization

One of the key technologies driving decarbonization is the heat pump, which can provide both heating and cooling without burning fossil fuels. Heat pumps are becoming increasingly popular as a replacement for traditional fossil fuel-based heating systems, such as carbon fossil boilers. By using heat pumps, we can reduce our reliance on fossil fuels and decrease greenhouse gas emissions.

The connection between PFC and heat pumps lies in the power supply requirements of heat pumps. Heat pumps require a stable and efficient power supply to operate effectively, which is where PFC comes in. PFC ensures that the power supply to the heat pump is efficient and reliable, which is critical for maintaining a stable and efficient grid.

The EVAL-1EDSIC-PFC-5KW board is a system solution enabled by Infineon Technologies power semiconductors as well as drivers and microcontroller. The evaluation board consists of an AC-DC bridgeless interleaved totem-pole topology, and it is intended for application where highest efficiency is required. Furthermore, the totem-pole topology is simple and offers a reduced part count and full utilization of the PFC inductor and switches.

References

[1] Infineon Technologies AG: Application Note 1ED21271S65F; Available online

[2] Infineon Technologies AG: 1000 W telecom power supply for 5G edge computing and small cells using CoolSIC™ 650 V and CoolMOS™ 600 V CDF7 in TOLL package, AN_085359_PL52_025, May 2024; Available online

[3] Infineon Technologies AG: High efficiency 3 kW bridgeless dual-boost PFC demo board, AN_201708_PL52_025, September 2017; Available online

Revision history

Document revision	Date	Description of changes
V 1.0	12/20/2024	Initial Release

Trademarks

All referenced product or service names and trademarks are the property of their respective owners.

Edition 2024-12-19

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

UG xxx (user guide number)