REF_ESC_48V_80A_FOC user manual

Three-phase power inverter board for drones using OptiMOS™ 8 100 V power MOSFETs and XENSIV™ TMR current sensing

About this document

Scope and purpose

This user guide helps to get started with the REF_ESC_48V_80A_ESC reference board for battery-powered drone applications. This document provides information on the hardware, test setup as well as firmware information.

Intended audience

This user guide is intended for system application engineers who seek inspiration for their next motor drive designs.

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Safety precautions

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

Table 1 Safety precautions

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

Table of contents

1 Introduction

1.1 Overview

REF_ESC_48V_80A_FOC is a reference design equipped with the latest generation of Infineon's OptiMOS™ 8 100 V power MOSFETs in combination with XENSIV™ TMR current sensors and Infineons PSOC™ Control C3 microcontroller to perform field-oriented control (FOC) in battery-powered drone applications using Infineons's latest motor control library and GUI support. The board is designed as an out-of-the-box solution to target the application of Electronic Speed Controllers (ESC) of drones.

The reference design consists of two boards, a logic board and a power board, as shown in Figure 1 . The power board mainly consists of the power MOSFETs, bulk capacitances and the current sensors whereas the logic board contains the microcontroller unit, auxiliary power supply units as well as gate driving circuitry. The logic board generates on-board 3.3 V as well as 15 V rails to power current sensors, temperature sensor as well as microcontroller and gate driver ICs, respectively. Since the main control scheme in drones is FOC, the board is equipped with 3 current sensors to measure phase currents as feedback for the current controller.

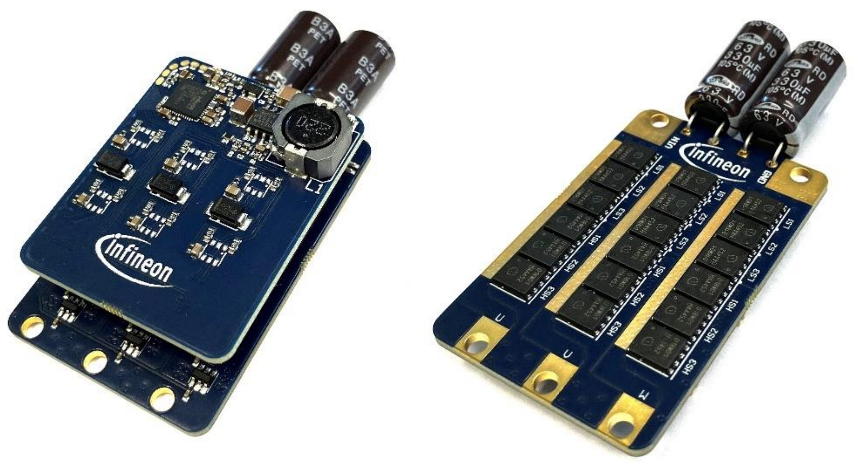

Figure 1 Reference design REF_ESC_48V_80A_FOC. Left image shows fully assembled board and right image shows the power board.

Main components of the design:

- **OptiMOS™ 8 100 V power MOSFETS** ISC019N10NM08, 1.9 mΩ (max) in a 3 x 5 mm PQFN package as a best-in-class solution; alternatively board can be equipped with ISC040N10NM08
- XENSIV™ TLE5572 TMR-based magnetic current sensors for AC and DC current measurement in a SOT32-6 package
- **EiceDRIVER™ 1EDN7550B** TDI gate driver with 4 A source and 8 A sink capability
- **PSOC™ Control C3 32-bit ARM Cortex M33** industrial microcontroller in a 48-pin QFN package
- **fully open-source motor control firmware**

The reference design characteristics are:

- 48 V nominal input voltage for 12S battery configurations

- High power density design; small-scale, modular design comprising of a power PCB with 6 layers 2 oz. copper and a logic PCB with 4 layers 1 oz. copper
- 15 V and 3.3 V auxiliary power supplies
- Non-invasive, shunt-less current sensing using TMR-based current sensors

1.2 Board parameters and technical data

Table 1 REF_ESC_48V_80A_FOC board specifications

Parameter	Value	Unit	Comment
Input			
Nominal input voltage	48	V	DC voltage from battery or power supply
Maximum input voltage	60	V	DC voltage from battery or power supply
Maximum input current	45	A	DC current
Output			
Maximum three-phase power	2000	W	tested with forced air-flow in lab condition
Maximum continuous current per phase	60	A	phase RMS current measured with current probe
Maximum peak current per phase	80	A	phase RMS current measued for 3 seconds with current probe until thermal limit of MOSFET package
Switching Parameters			
Switching frequency	20	kHz	configurable in firmware
Deadtime	500	ns	configurable in firmware
dV/dt	1 V	V/ns	set by external gate resistor
Onboard supply			
	15	V	used for gate driving and input supply for 3.3 V regulator
	3.3	V	used for MCU, current sensor and temperature sensor
PCB characteristics			
Material power board	-	-	FR4 material, 2 oz. copper each layer, six layers
Material logic board	-	-	FR4, 1 oz. copper each layer, four layers
Dimensions	52 x 34 x 10	mm	Board dimensions without electrolytic capacitor

1.3 Block diagram

A block diagram of the reference design is shown in Figure 2. A buck converter is used to convert the input DC voltage to 15 V for gate driver ICs. The 15 V rail is converted to 3.3 V by a linear drop-out (LDO) regulator to provide power to the microcontroller on the logic board, and power to the current sensors and temperature sensor on the power board. A simple resistor divider network is used to sense the bus voltage for the motor controller. Gate resistors on the power board are used to control dV/dt of the power MOSFET. The current sensors are non-invasive, so no direct electrical connection to the switch node is needed. All electrical connections from logic board to power board are realized by the use of 1.27 mm pin header connectors.

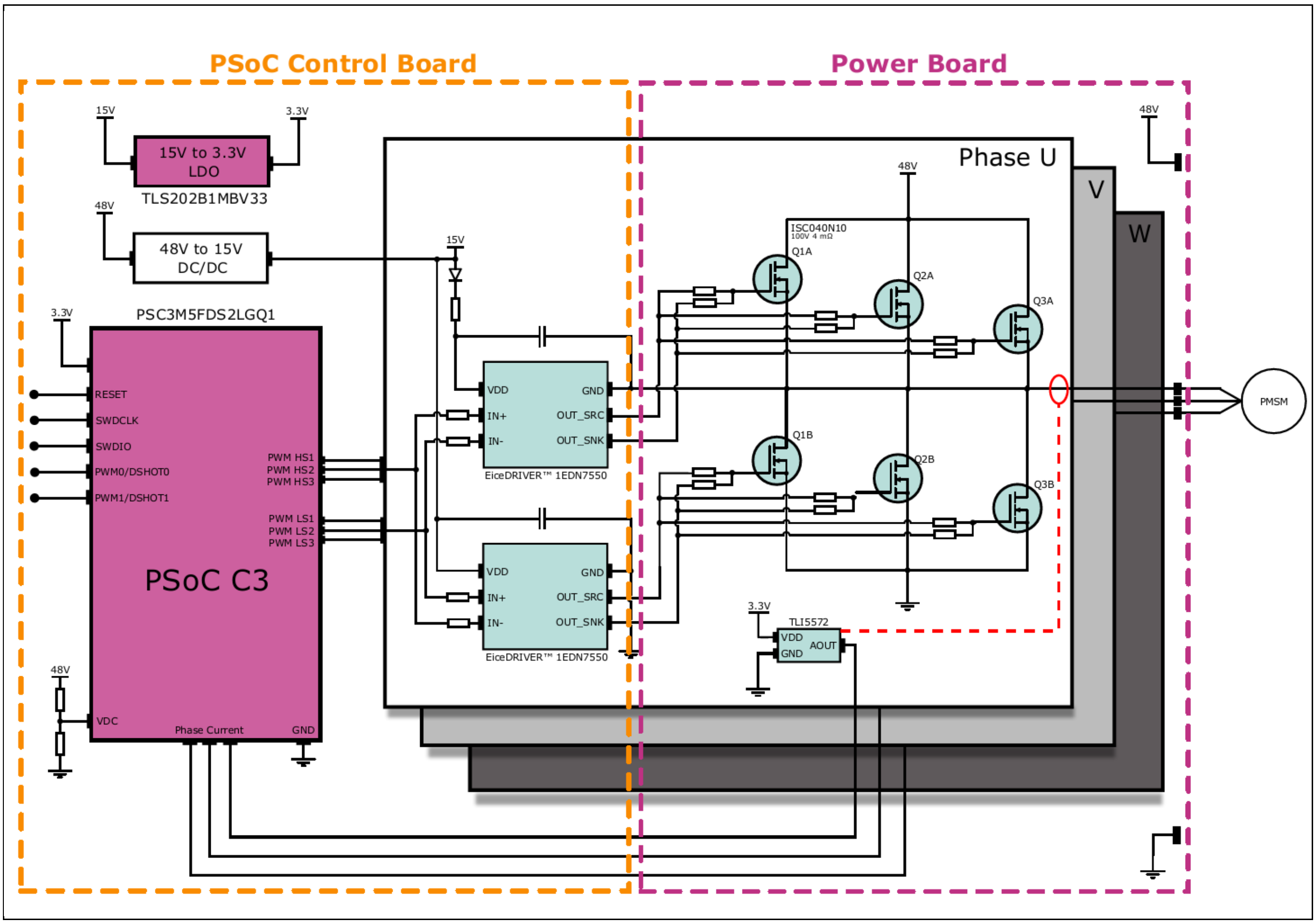

Figure 2 **Block diagram of reference design REF_ESC_48V_80A_FOC.**

2 Hardware Description

2.1 Logic Board

Figure 3 highlights the main sections of the logic board, namely DC-DC conversion stage, microcontroller and gate driving circuitry. Battery supply potential as well as GND potential are connected through pin headers with the power board. The bottom layer consists solely of connectors to the power board.

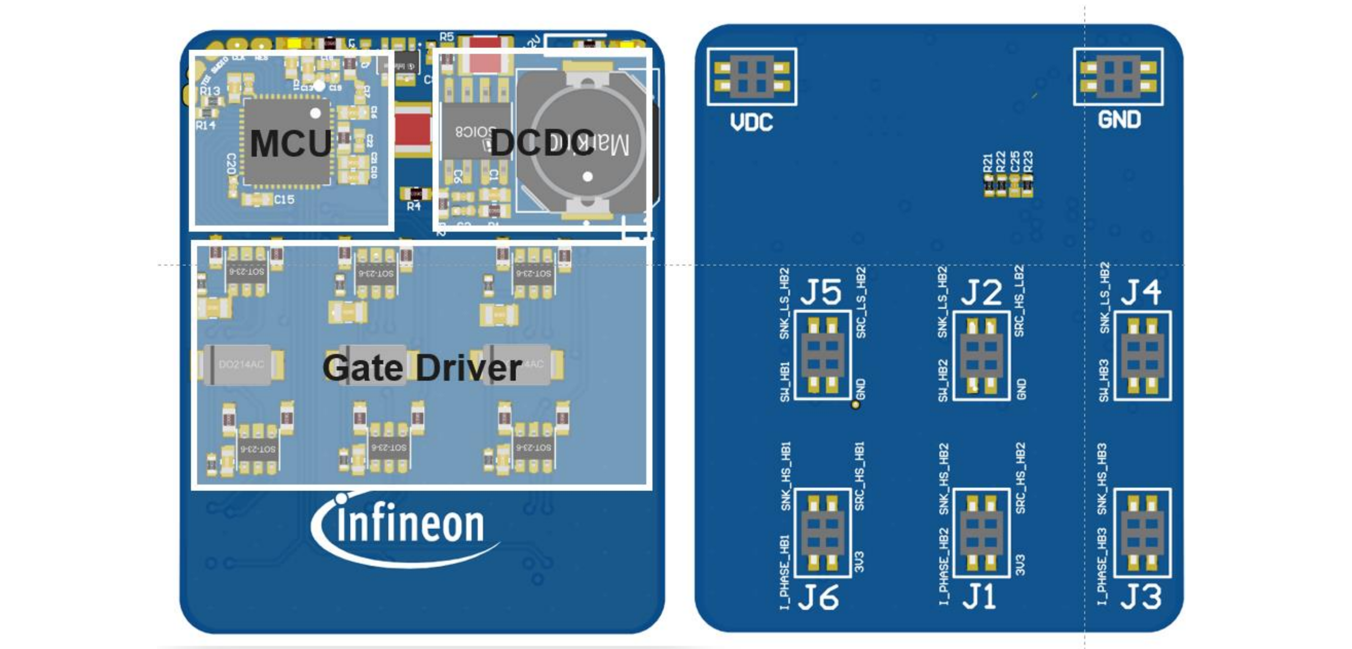

Figure 3 **Left: Top side of the logic board highlighting the most important sections of the board. Right: Bottom side of the logic board.**

A schematic overview of the power board is shown in Figure 4. The schematic can be divided into three core elements

- **Microcontroller**: This block contains the PSOC Control C3 microcontroller circuitry including routing to the current sensors and gate drivers as well as connector circuitry to physically connect the logic board to the power board.
- **Gate driver**: This block contains the EiceDRIVER™ 1EDN7550B gate driver circuitry used to drive the power MOSFETs.
- **Auxiliary Power**: This block contains the circuitries to obtain auxiliary 15 V supply for gate driving as well as 3.3 V for microcontroller and current sensor supply.

In addition, a voltage divider circuit provides a voltage measurement of the bus voltage routed to an analog pin on the microcontroller.

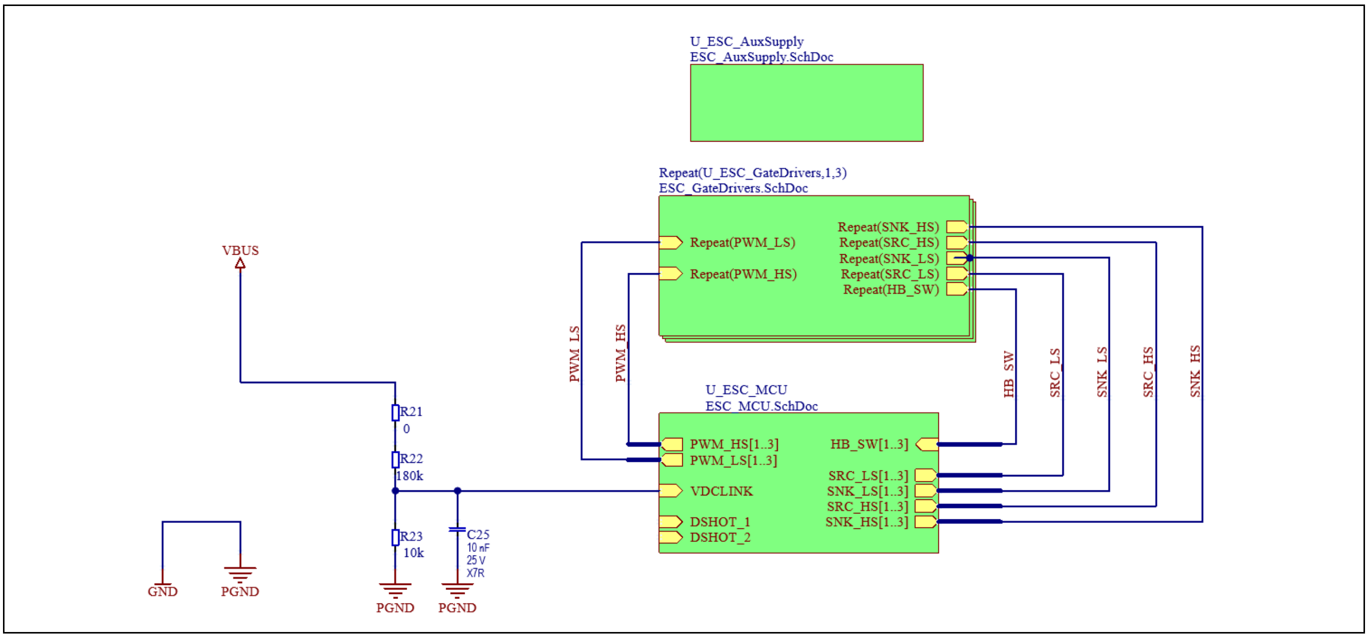

Figure 4 **Schematic overview of the logic board.**

2.2 Power board

Figure 5 highlights the main sections of the power board, the power MOSFET stage with three MOSFETs parallel per leg as well as the current sensing. Battery supply potential as well as GND potential are connected through solder pads with the power board. The power board is a 6 layer PCB with 2 oz. copper on all layers.

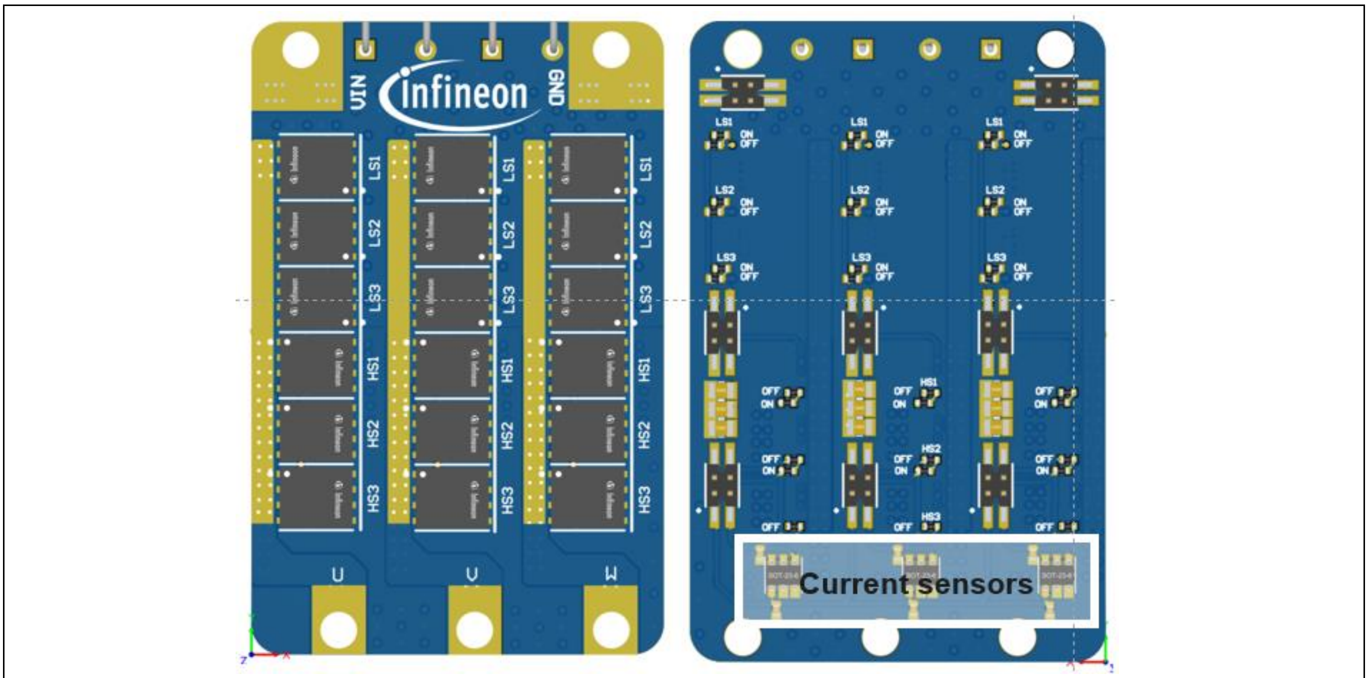

Figure 5 **Left: Top side of the power board with paralleled power MOSFETs. Right: Bottom side, showing current sensors, gate resistors and bypass capacitors.**

2.2.1 Current Sensing

2.2.1.1 Layout

Current sensing is implemented as true phase current sensing using XENSIV™ TMR-based current sensors. These sensors allow to measure currents in a non-invasive scheme. Thanks to this technology, potential shunt replacement in motor control applications can be conducted, since the sensor operates fully loss-less, comes in a compact SOT23-6 package, operates truly linear over the full-scale range and achieves same bandwidth as shunt resistors. Nevertheless, careful layouting the current path underneath the sensor as well as sensor placement is crucial. Figure 6 shows the implemented layout of the current rail and the sensor placement. It is important to add a keep-out layer on the bottom layer, otherwise the magnetic field will be affected by the current return path (GND layer) and the sensor readings will not reflect the real current in the rail. Also, symmetric placement of the rail as well as narrowing the polygon is important such that the current flow is concentrated underneath the sensing element to obtain highest sensitivity readings.

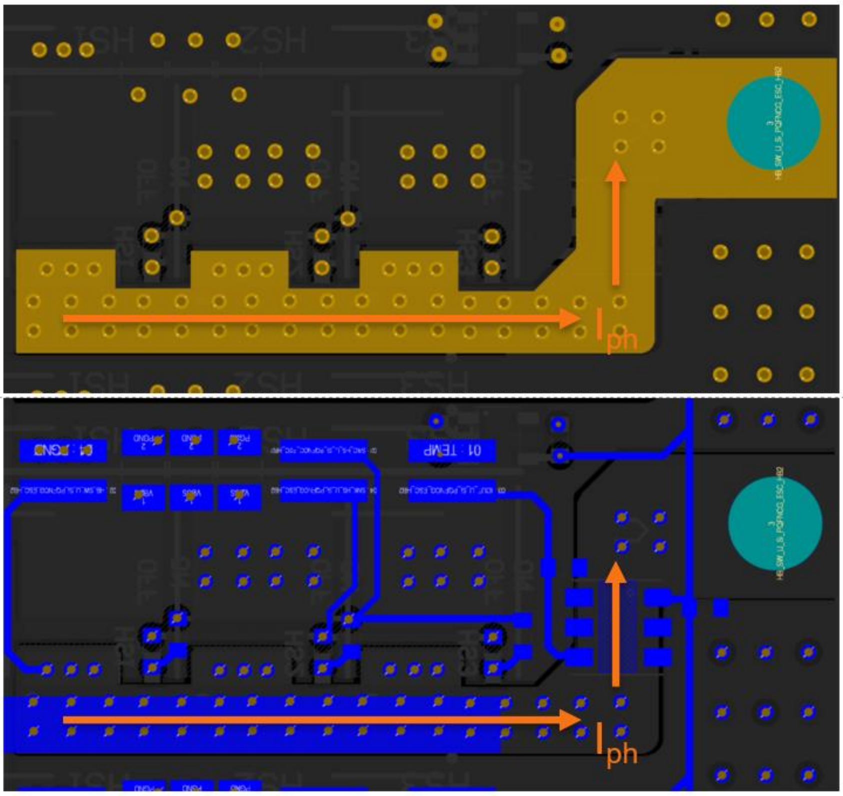

Figure 6 Layout technique used for current sensing. Current-carrying layers overlap with sensor area to achieve highest sensitivity. Bottom layer consists of keep-out at the sensor location.

Figure 7 shows the implemented sensor placement using vertical current rails to minimize almost all crosstalk between individual phase current sensors. Since the sensor has highest sensitivity in y-direction, it is important to reduce unwanted magnetic field contributions from the other rails in that direction. This is achieved by placing the sensors in a vertical manner, as shown in Figure 7. A current flowing through the sensing element in x-direction produces its main magnetic field in y-direction, hence crosstalk is kept at a minimum.

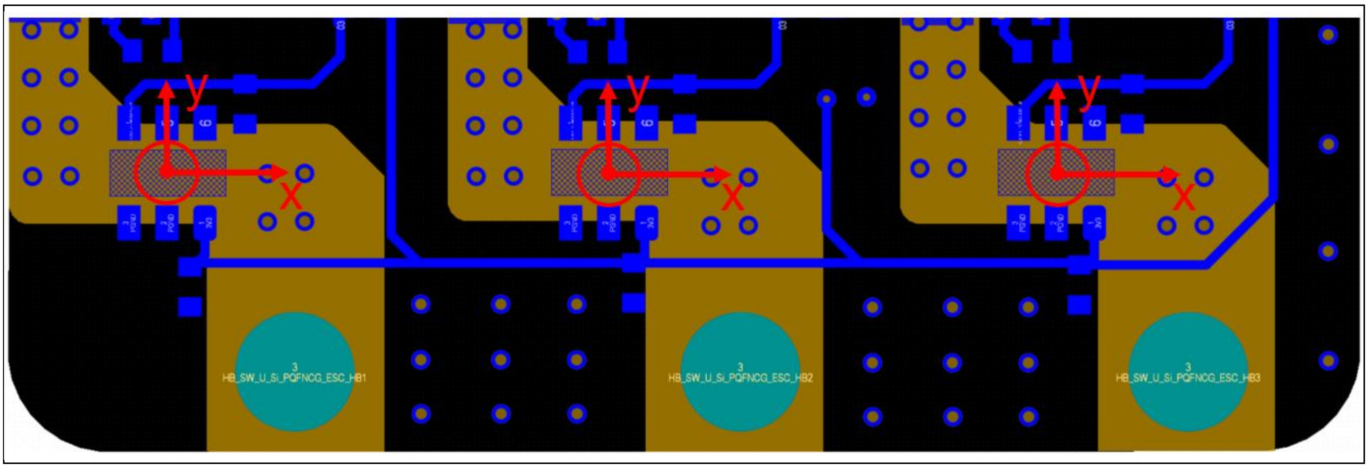

Figure 7 Sensor placement for lowest crosstalk. Direction of highest sensor sensivity is in y-direction.

2.2.1.2 Sensitivity Measurement

The sensitivity of the current readout depends on multiple factors due to the magnetic nature of the sensor. The easiest method to evaluate sensitivity of the individual sensors on the board is to inject a known DC current and read the differential voltage change. Based on this method, a matrix with individual sensitivies as well as cross-sensitivites can be evaluated and used as a calibration routine at startup. For evaluation, a DC current of $I_{DC} =$ was chosen and the voltage readout recorded with a 7.5 digit DMM. Based on these measurements, the following sensitivity matrix was found, using TLE5572-AE08E1-R-E0001

$$S_{TMR}\begin{bmatrix}21.2 & 0.04 & 0.03\\ 0.03 & 21.2 & 0.03\\ 0.04 & 0.05 & 21.2\end{bmatrix}\frac{mV}{A}$$

As can be seen from the above matrix, crosstalk is kept at a minimum. In the motor control firmware, these values are directly used to conduct offset-gain calibration of the ADC readings. A typical sensor signal reading as obtained after ADC conversion is shown in Figure 8.

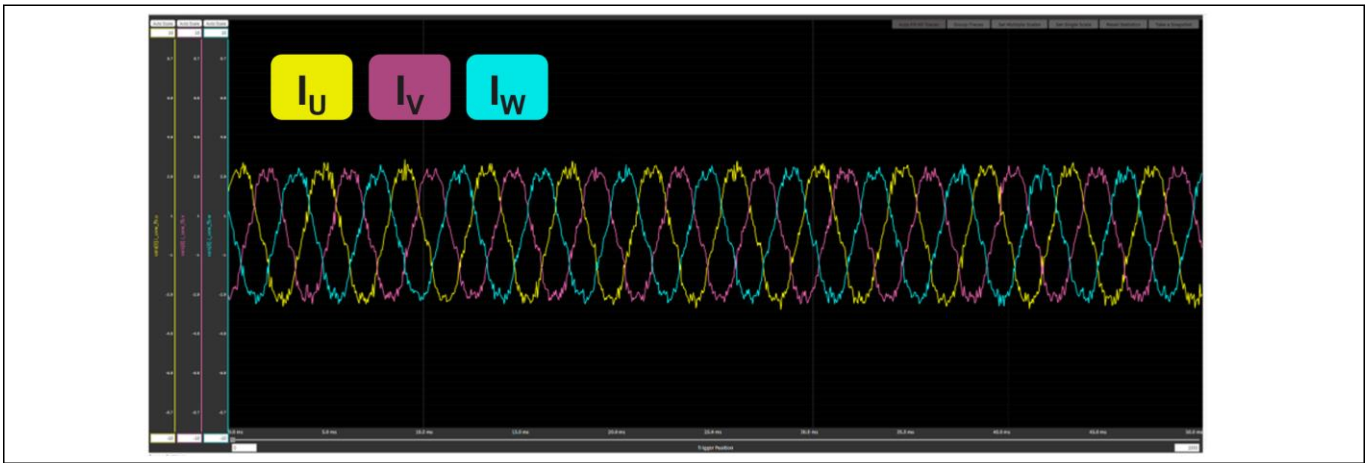

Figure 8 Three-phase current sensor signals after ADC conversion at low-load condition.

3 System Operation

3.1 Startup and debugger connection

Before powering up the board, make sure the logic board is properly attached to the power board via the pin header connectors, shown in Figure 9. Board startup is obtained by connecting the battery supply voltage via cables to the solder pads on the power board. On the logic board, two LEDs will flash up, indicating active 15 V as well as 3.3 V supply rails, highlighted in Figure 10.

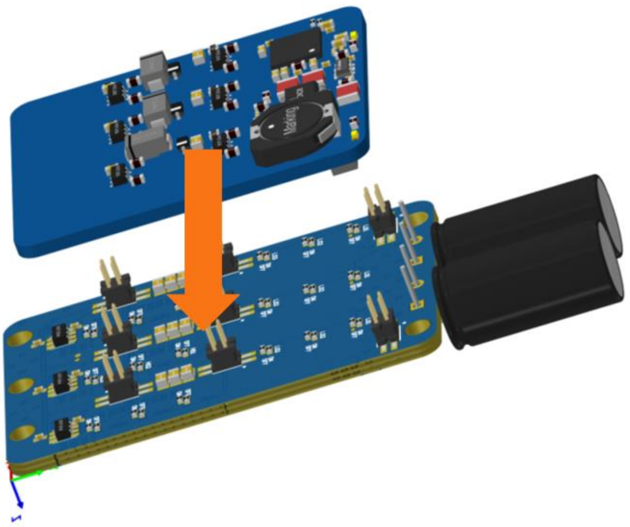

Figure 9 Connecting logic board to power board via pin headers.

In order to communicate to the board, a debugger such as XMC™ Link which supports SEGGER JLink is required. The debugger connection to the board is done via direct wire soldering to the according solder pads, shown in Figure 10. For SWD interface, SWDIO, SWDCLK as well as RESET and the 3.3 V supply rail must be connected to the debugger. Please note, that the board must be powered on such that the connection to the MCU is established.

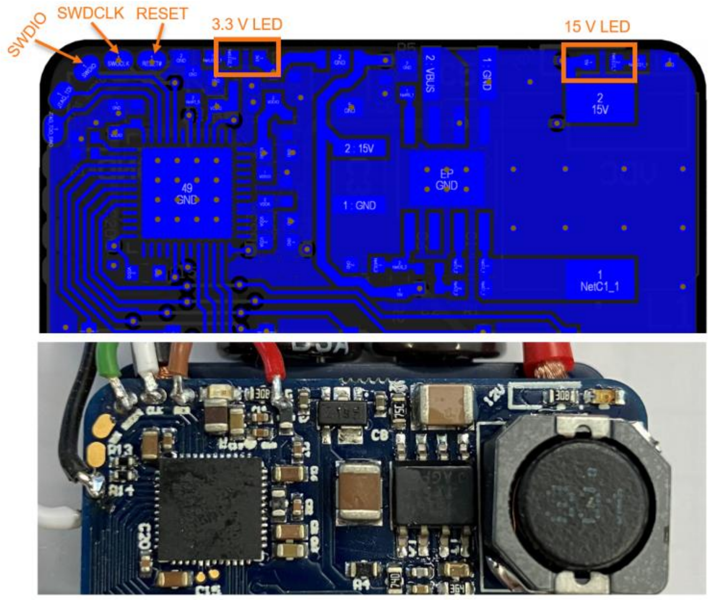

Figure 10 Hardware wiring for debugger connection.

Once the board is powered on and the debugger connected, the board is ready to be used and the MCU can be flashed with motor control firmware if used for the first time. Connection to external servo controllers, such as flight controller units is established by soldering wires to the DSHOT solder pads on the logic board. The firmware allows configuration of either PWM oder DSHOT interface for throttle commands.

3.2 Control and firmware

The reference design uses the newest release version of the Infineon motor control library (IMCL) v3.0.0. IMCL is a set of motor control algorithms for general-purpose motor control including more then 25 permutations of control type, control entity, feedback type and startup methods. The most important control strategy for drones is sensorless FOC, which is commonly used in drones. RFO control decomposes the phase currents into d-axis and q-axis currents using Clarke-Park transformation and comprises of modules for speed control, current control as well as observer feedback. Thus, RFO operates in the rotor frame of the PMSM, which is the commonly used control strategy for sensorless FOC. A block diagram of RFO is shown in Figure 11. In addition to the standard blocks, filter blocks are added to further improve control performance.

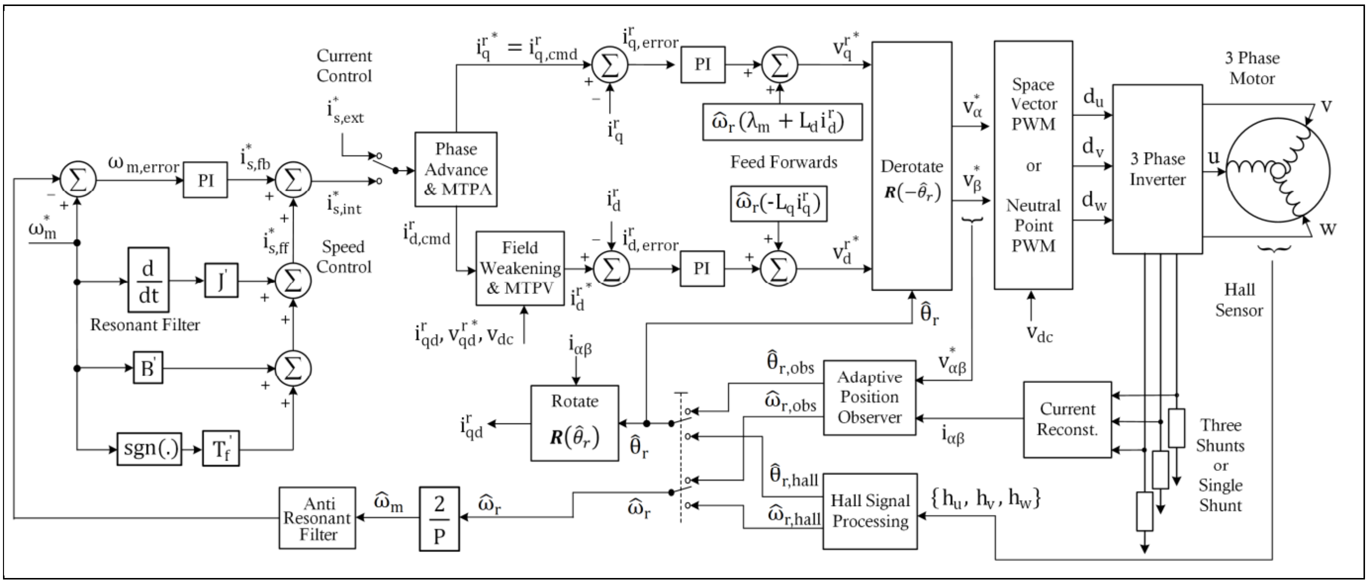

Figure 11 Block diagram of RFO implemented in IMCL.

3.3 Firmware upload and GUI usage

For a detailed instruction on firmware usage, upload and GUI usage, please follow the instructions on the board's **GitHub repository**.

4 Experimental Results and Measurements

4.1 Lab and Measurement Setup

4.1.1 RL load

All tests and results in the following subsections are performed using OptiMOS™ 8 100 V power MOSFET with part number ISC040N10NM8 if not stated otherwise.

A block diagram of the lab setup for is shown in Figure 12. For so-called static tests, an RL load with known values ($R_L =$) is used, which can be understood as a certain operating point of a real PMSM. In order to evaluate the system losses, current and voltage measurements at the inverter input and output are necessary. At the input, the DC current is measured as a voltage drop at a known shunt resistance and both current and voltage are logged with a datalogger. At the output, a power analyzer in 3P4W configuration is used to measure active and reactive power in the system. Since the star point of the PMSM is not accessible, a star point adapter is used to measure the phase voltages. The phase currents are meaused using fluxgate-type current sensors. For thermal measurements, a thermal camera is used to monitor onboard temperature distribution.

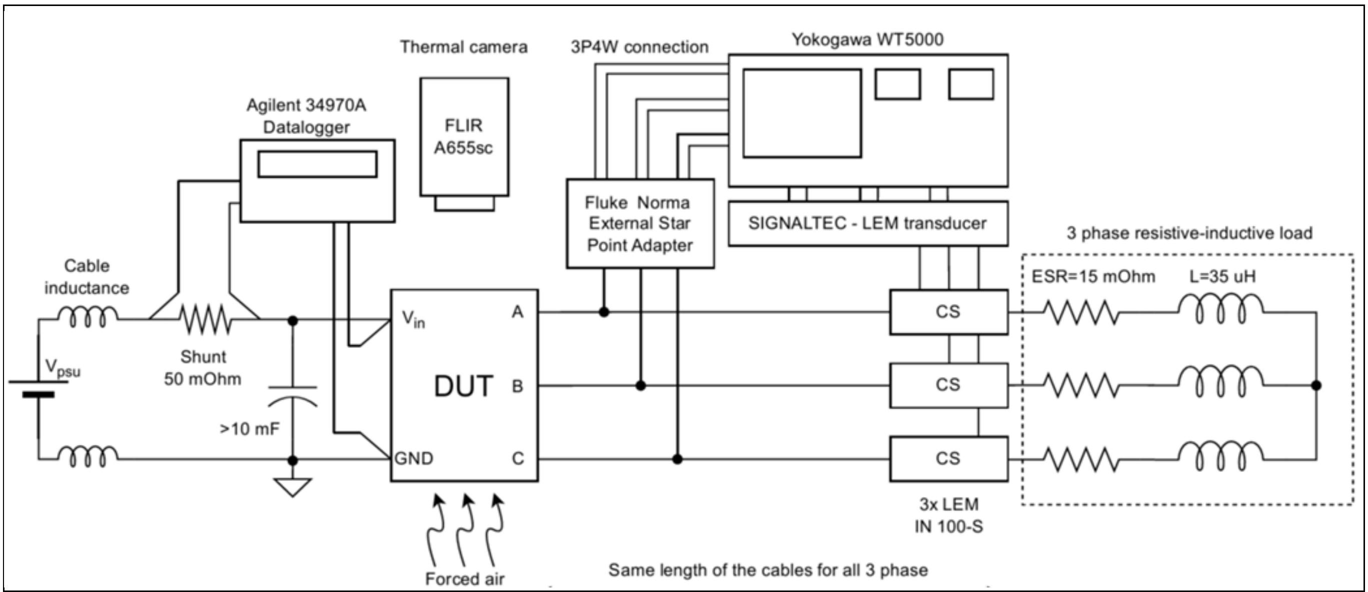

Figure 12 Block diagram of the lab setup.

4.1.2 Motor load

To test the board as close as possible to real conditions, a target drone motor was chosen for load tests. The target motor is the T-Motor U15II KV80 heavy lift drone motor which can run up to 4000 rpm and 8 Nm load torque. The load torque is applied using a so-called motor-generator setup (MGS) where the motor is mechanically coupled to a second motor of same type which acts as a generator. Due to the rotational movement, a back-EMF voltage will be induced in the generator windings, which can be rectified to obtain DC voltage and fed into an electronic load to control the load current on the motor. A torque/speed meter is used to obtain mechanical information which is further used to compute mechanical power to obtain total system power. A block diagram of this setup is shown in Figure 13.

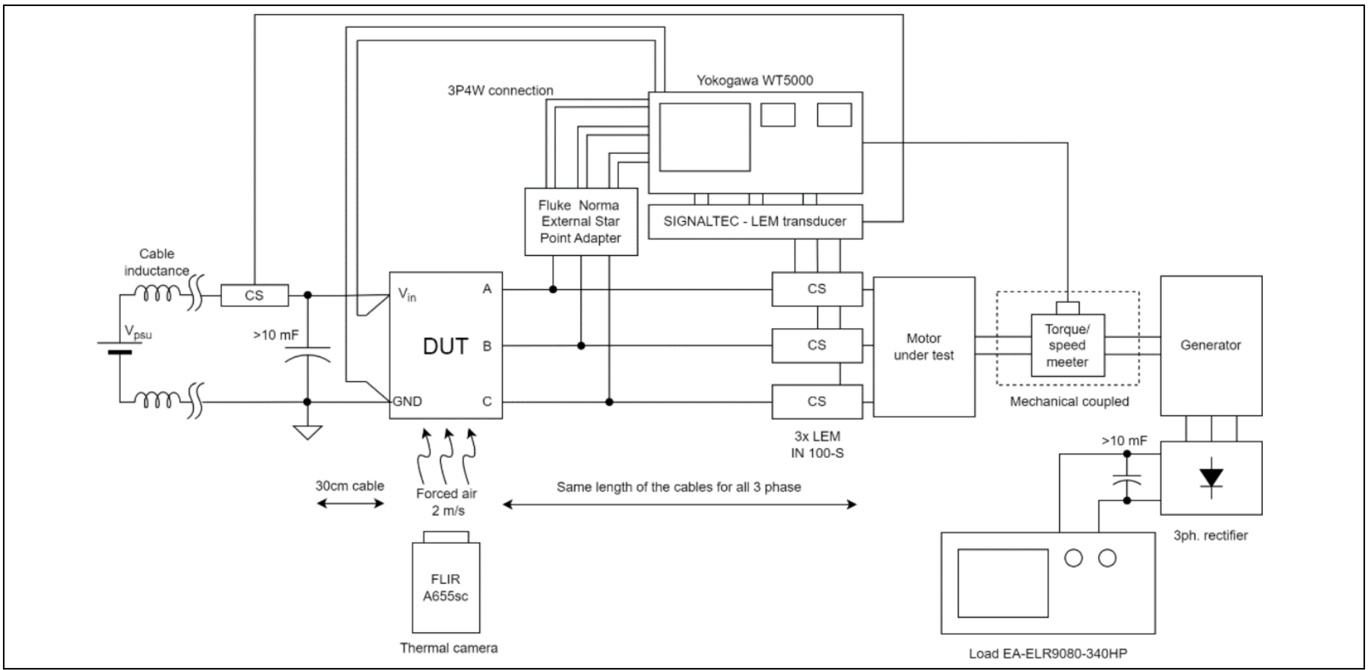

Figure 13 **Block diagram of the motor load setup.**

4.2 Thermal measurements

Thermal measurements were performed using the RL load shown in Figure 12 under different airflow conditions as well as motor load in a motor-generator setup. The board was exposed to airflow from a given direction and the measurements were performed until reaching steady-state. Figure 14 shows thermal camera images after 5 minutes steady-state condition at 48 V input voltage and 60 ARMS phase current using the RL load.

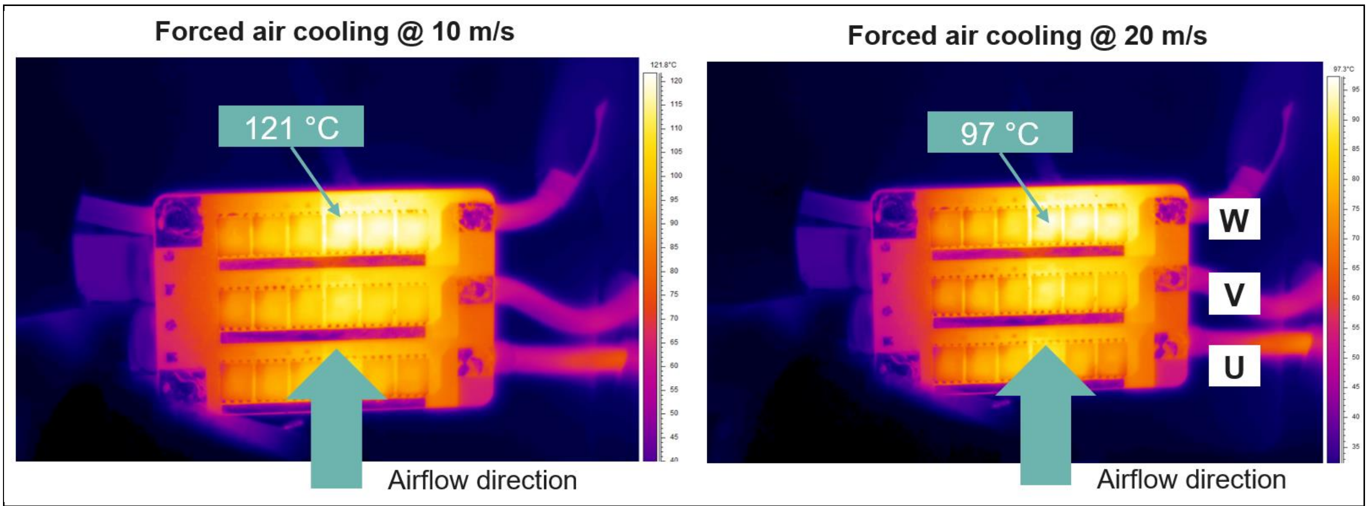

Figure 14 **PCB temperatures during steady-state thermal tests with RL load for different cooling scenarios at 60 A_{RMS} phase current.**

The same test was repeated with the motor-generator setup at different motor speeds with load torques up to 5 Nm. All the measurements are done in steady-state and thermal equilibrium of the board. Results of the motor test are shown in Figure 15.

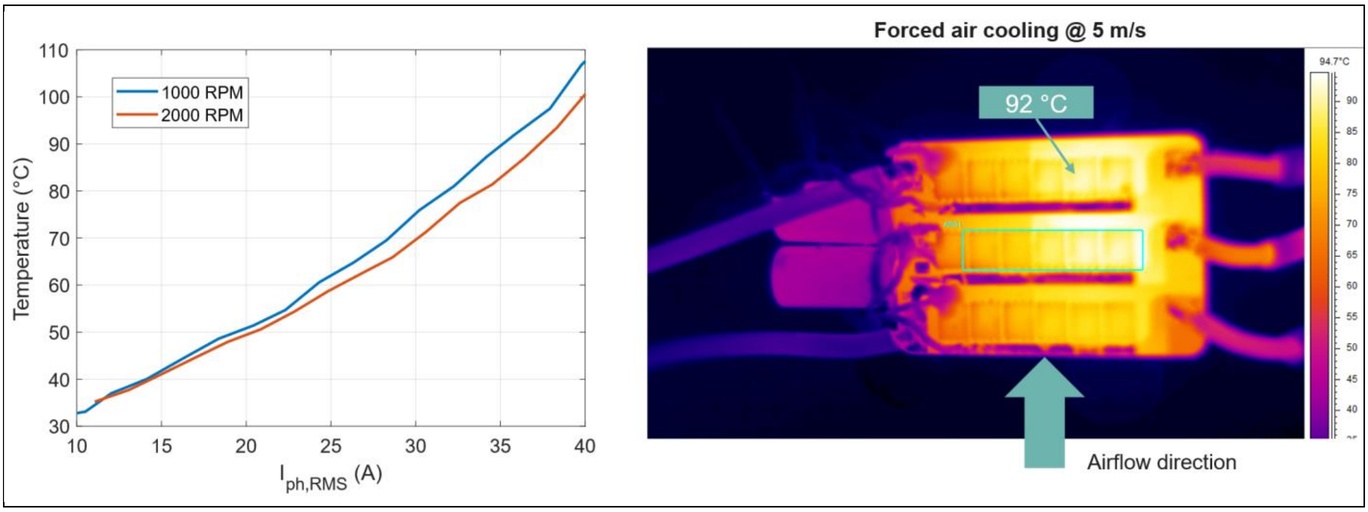

Figure 15 **PCB temperatures during steady-state thermal tests with motor load for different cooling scenarios at 60 A_{RMS} phase current.**

4.3 Loss evaluation with target motor

Losses are evaluated for the target motor at different speeds and results are shown in Figure 16.

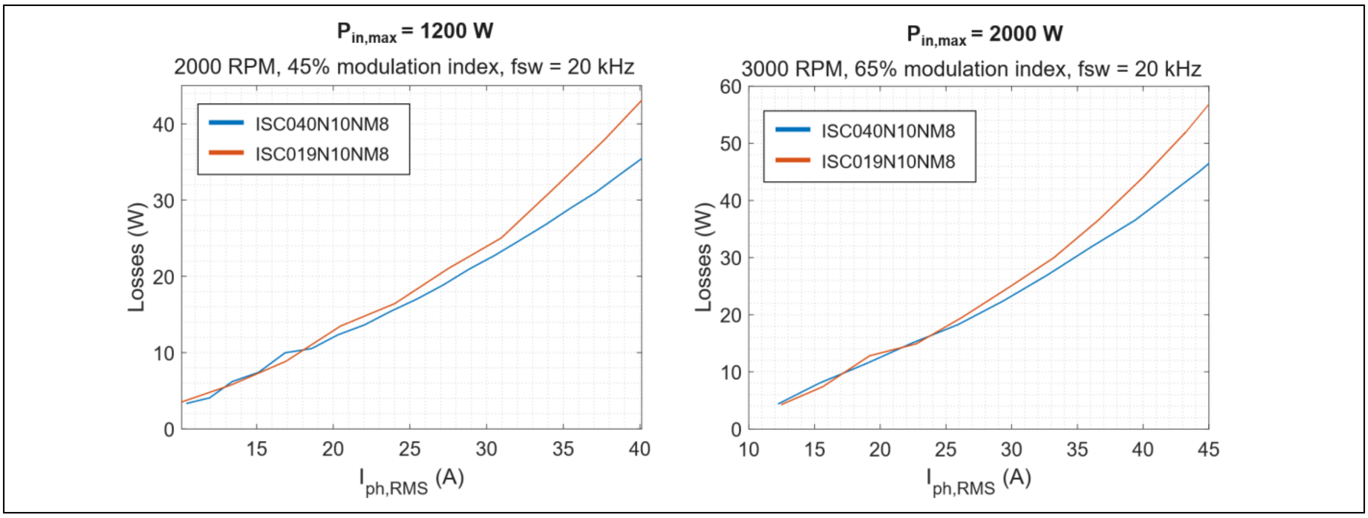

Figure 16 **Obtained inverter losses using the target motor at two different operating points.**

5 Schematics and Layout

5.1 Schematics

5.1.1 Auxiliary power circuitry

The buck converter reduces the battery voltage (voltage range 36 V ~ 52 V) to a regulated value of 15 V to supply the gate driver ICs. For powering the PSOC™ C3 microcontroller and other circuitry, the 15 V rail is further reduced to 3.3 V by Infineon's TLS202B1MBV33 LDO regulator. On-board LED indicators are used to provide feedback of onboard power. The onboard power supply architecture is shown in Figure 17.

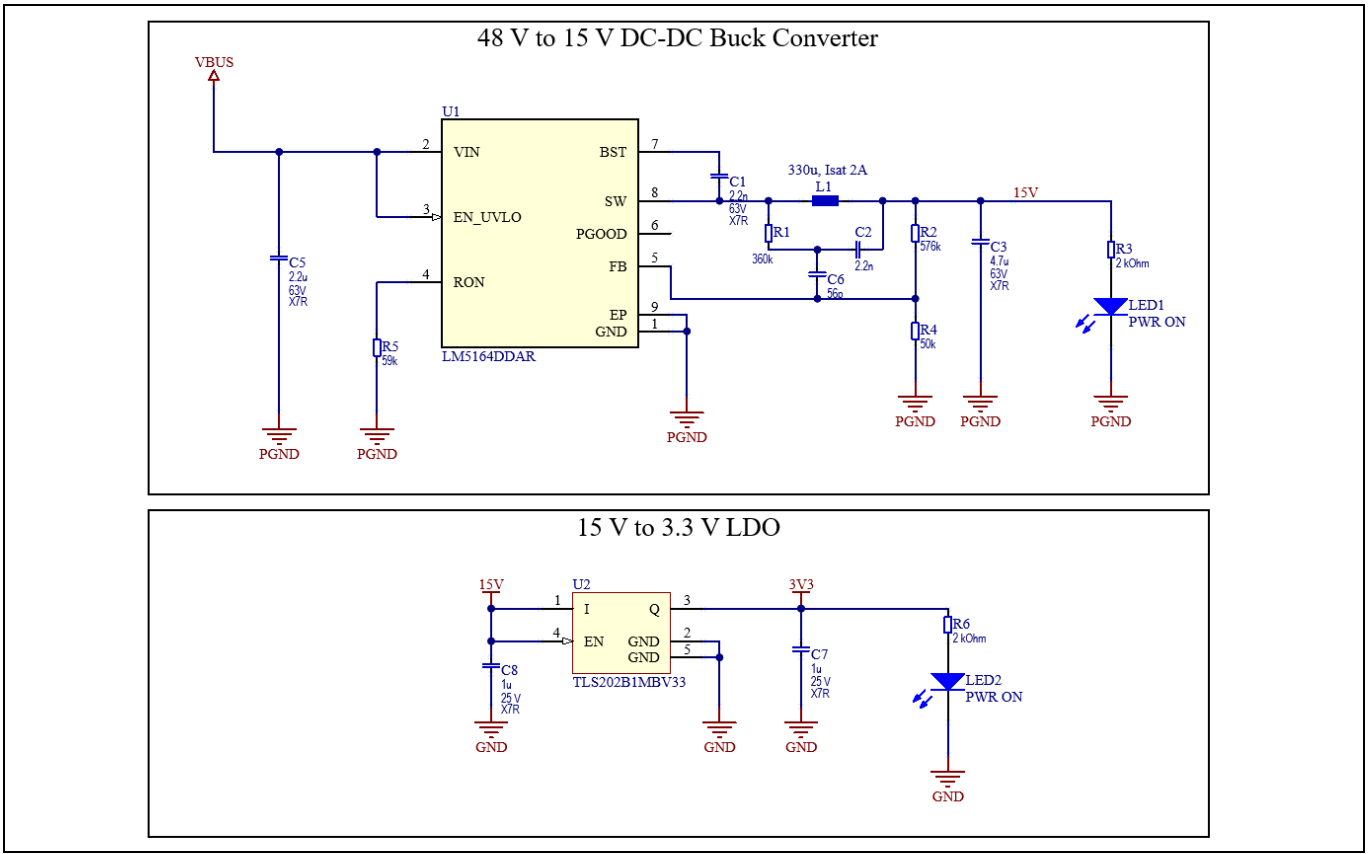

Figure 17 Buck converter and LDO regulator used in the logic board.

5.1.2 Microcontroller circuitry

Infineon's PSOC™ C3 Control microcontroller IC has been implemented as the main microcontroller for motor control. The microcontroller is implemented with interfaces for debugging and user can chose to either use JTAG or SWD debugging interface routed to solder pads on the top side of the logic board, see Figure 18. Additionally, to communicate with drone flightcontrollers, two digital lines are routed to solder pads which can either be configured to standard PWM interface or DShot600 interface. In total 5 analog inputs are used for the internal ADC, the 3 phase current readings from TLE5572 as well as DC bus voltage sensing and temperature sensing. The overall circuitry is comprised of standard passive components (ferrite beads and bypass caps) and two 1 kΩ pull-down resistors on P2.2 and P2.3 are added to ensure correct boot-up procedure of the microcontroller.

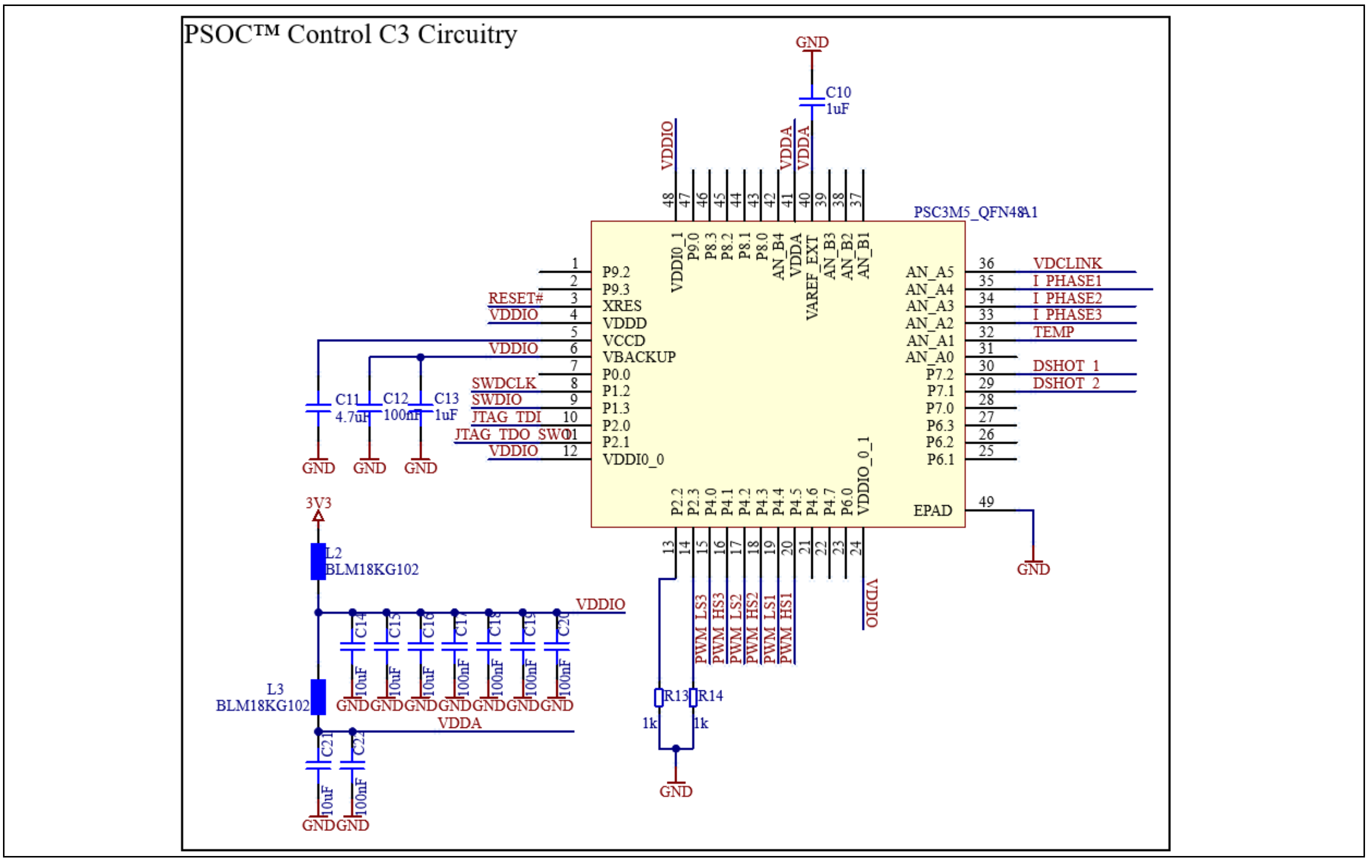

Figure 18 Microcontroller circuitry used in the logic board.

5.1.3 Gate driver circuitry

Infineon's 1EDN7550B gate driver IC has been implemented for both low-side and high-side driving of the inverter MOSFETs. The schematic of the circuitry is shown in Figure 19. The 1EDN7550B is a true differential input (TDI) gate driver IC with enhanced common-mode robustness and eliminates risks of false triggering. Also, 1EDN7550B comes in small package footprints, allowing for compact designs with limited space. The driver has strong source (4 A) and sink (8 A) capabilities, making it very robust against issues such as ground bounce. Two input resistors for both positive as well as negative input terminal are mandatory for correct operation of 1EDN7550B. Based on datasheet recommendation, the value for 3.3 V logic supply of these resistors is 33kΩ in 0402 SMD package.

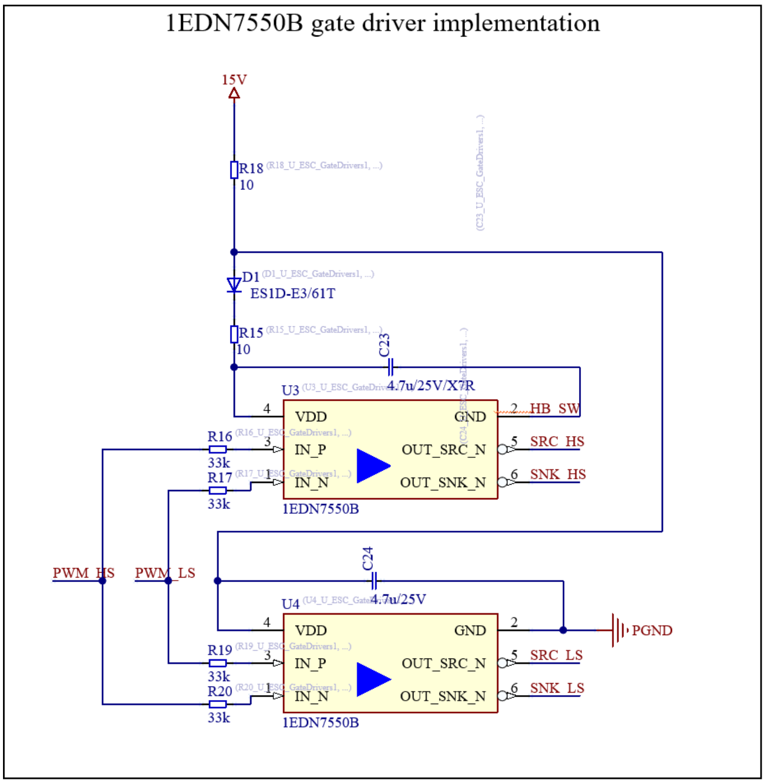

Figure 19 Gate driver circuitry used in the logic board.

5.2 Layout

The power board consists of a 6 layer PCB with 2 oz. copper on all layers, prepreg thickness of 100 µm and core material layer thickness of 500 µm. The logic board consists of a 4 layer PCB with 1 oz. copper manufactured in a standard 1.6 mm PCB fabrication process.

5.2.1 Logic Board

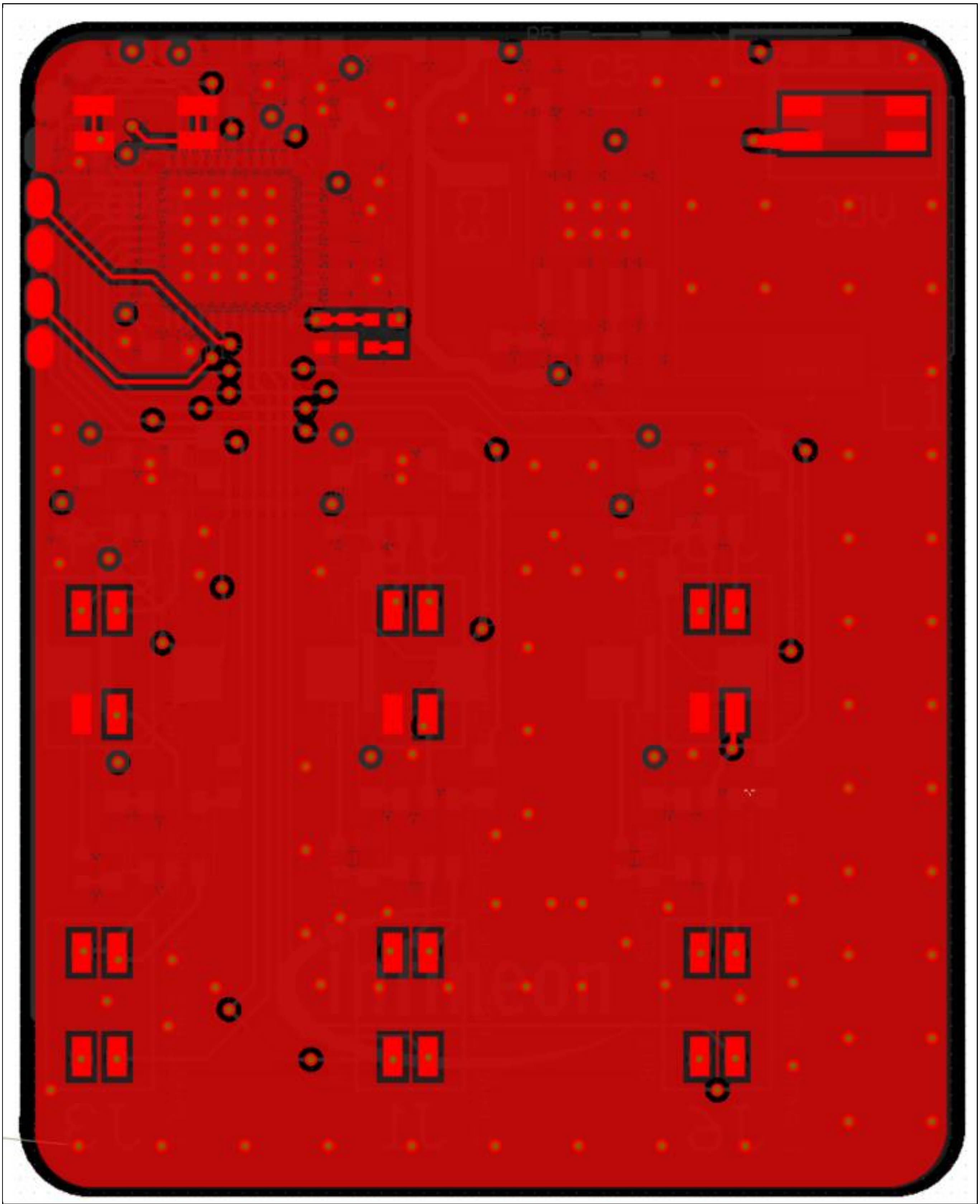

Figure 20 **Logic board top layer.**

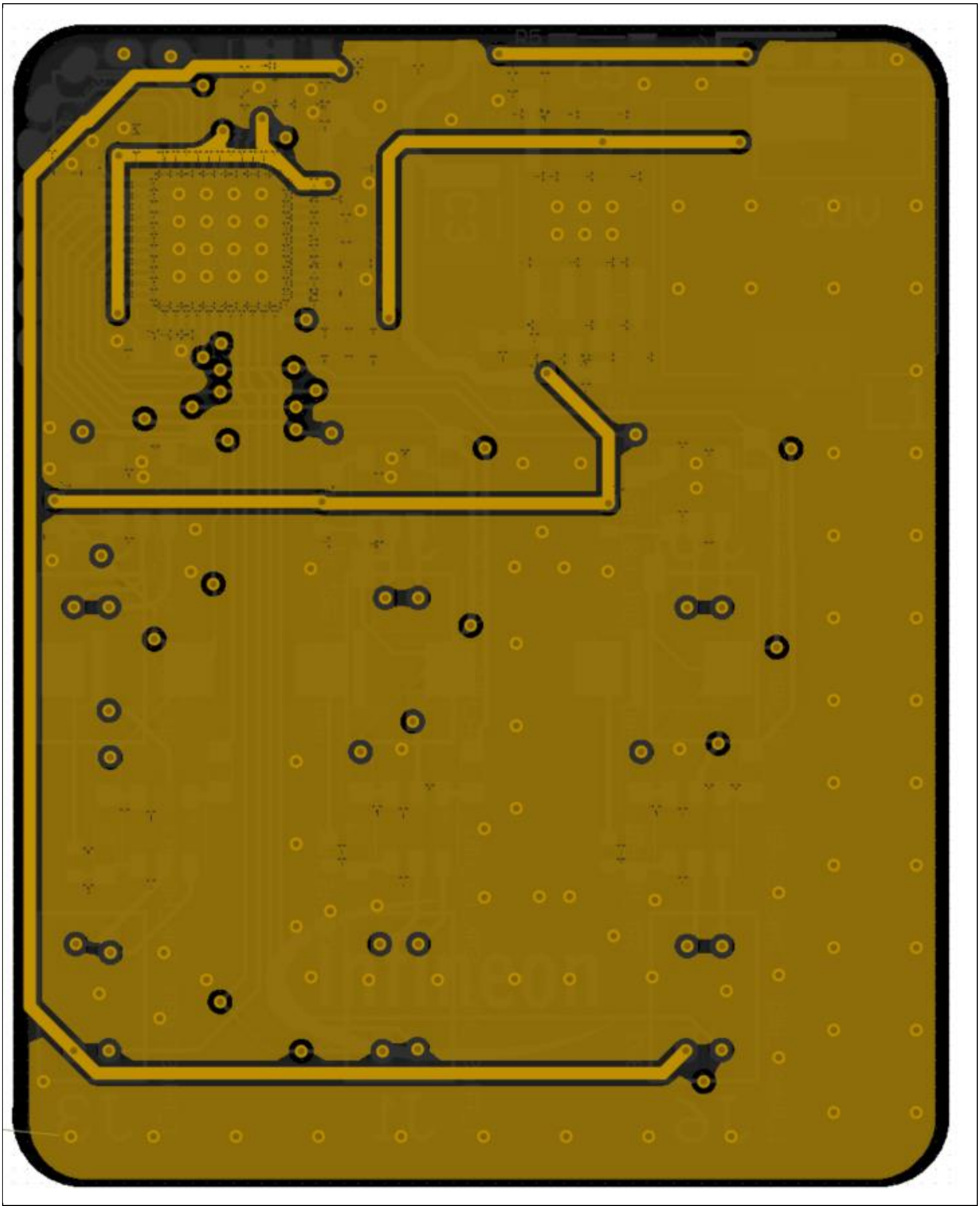

Figure 21 **Logic board first inner layer.**

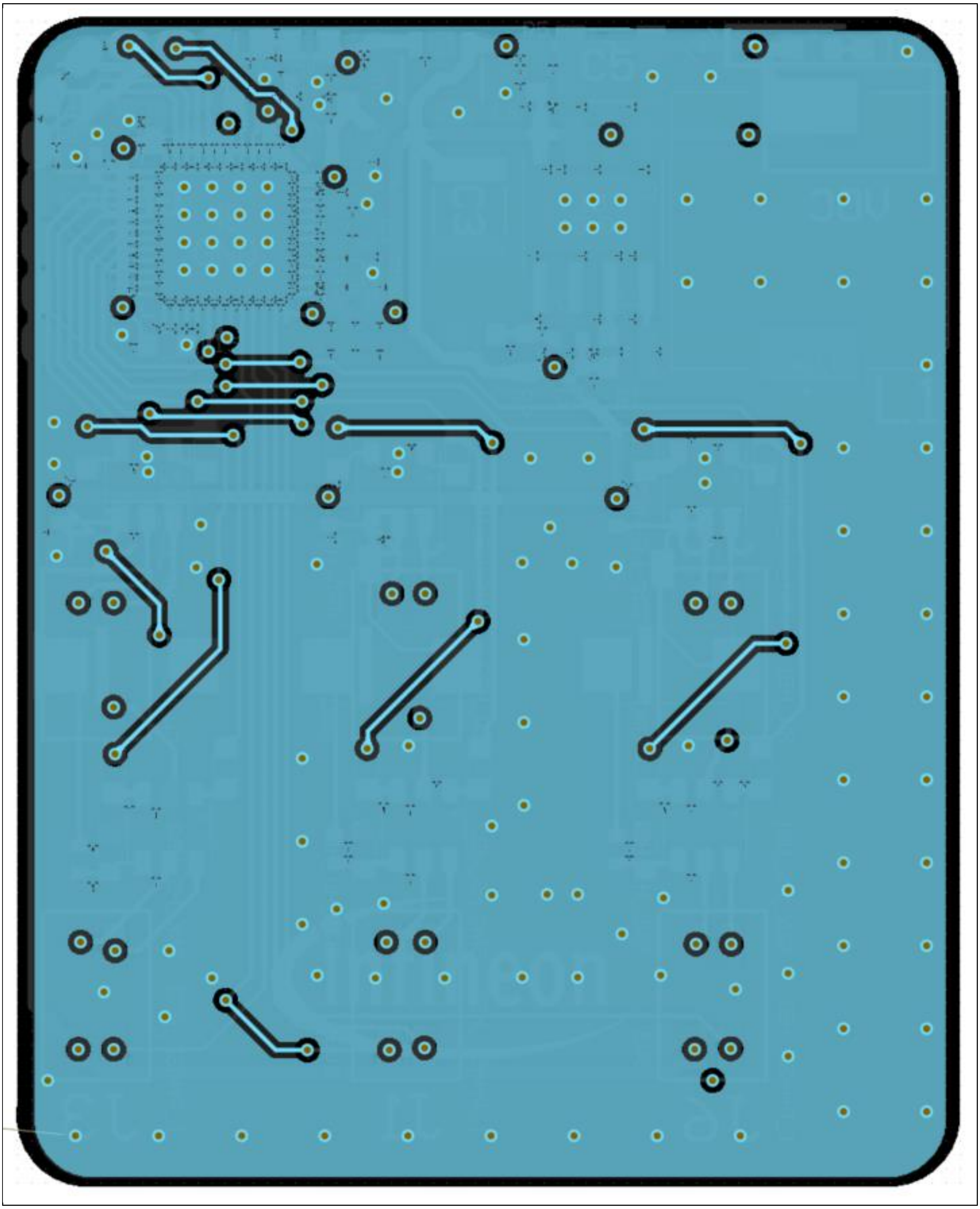

Figure 22 Logic board second inner layer.

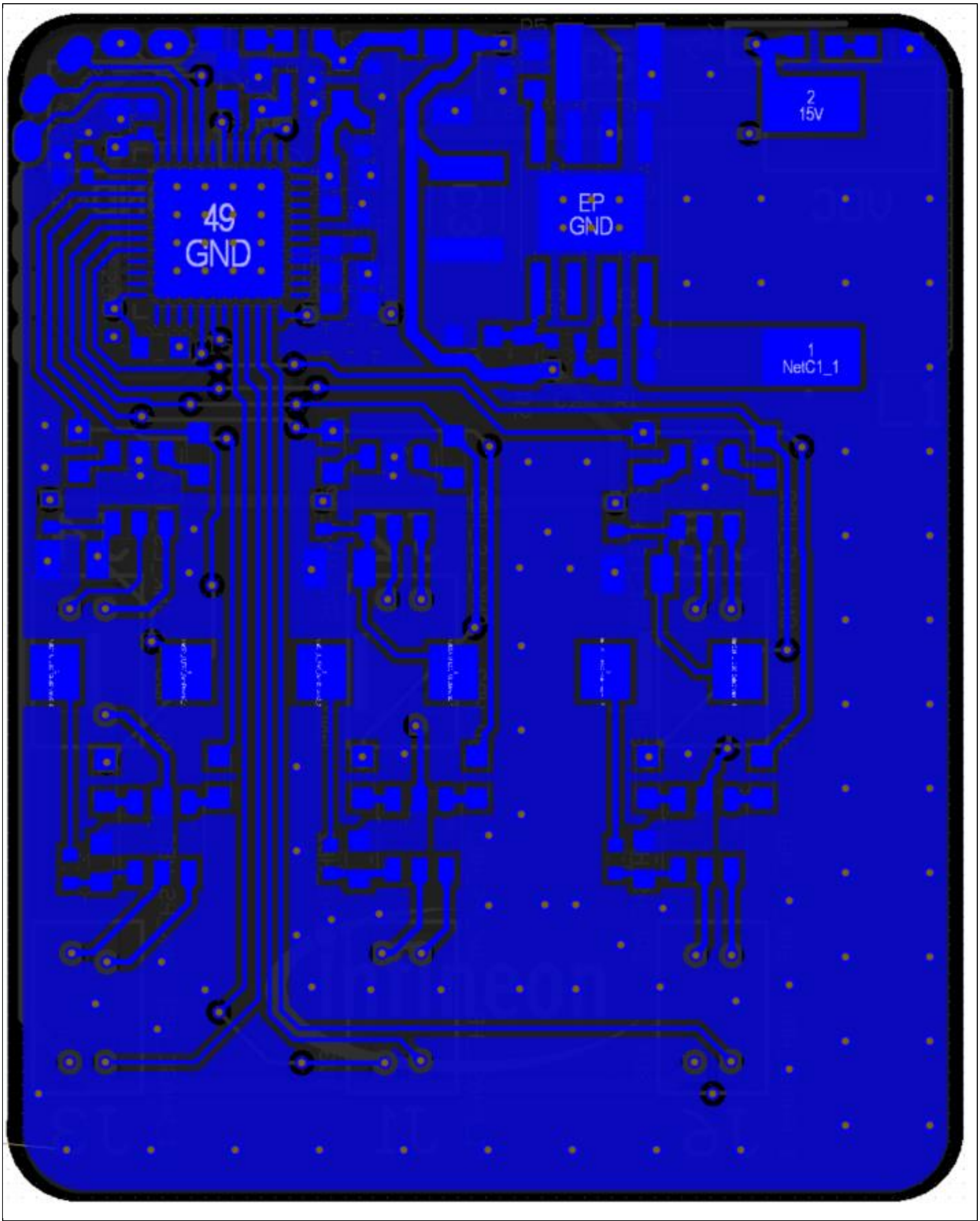

Figure 23 Logic board bottom layer.

5.2.2 Power Board

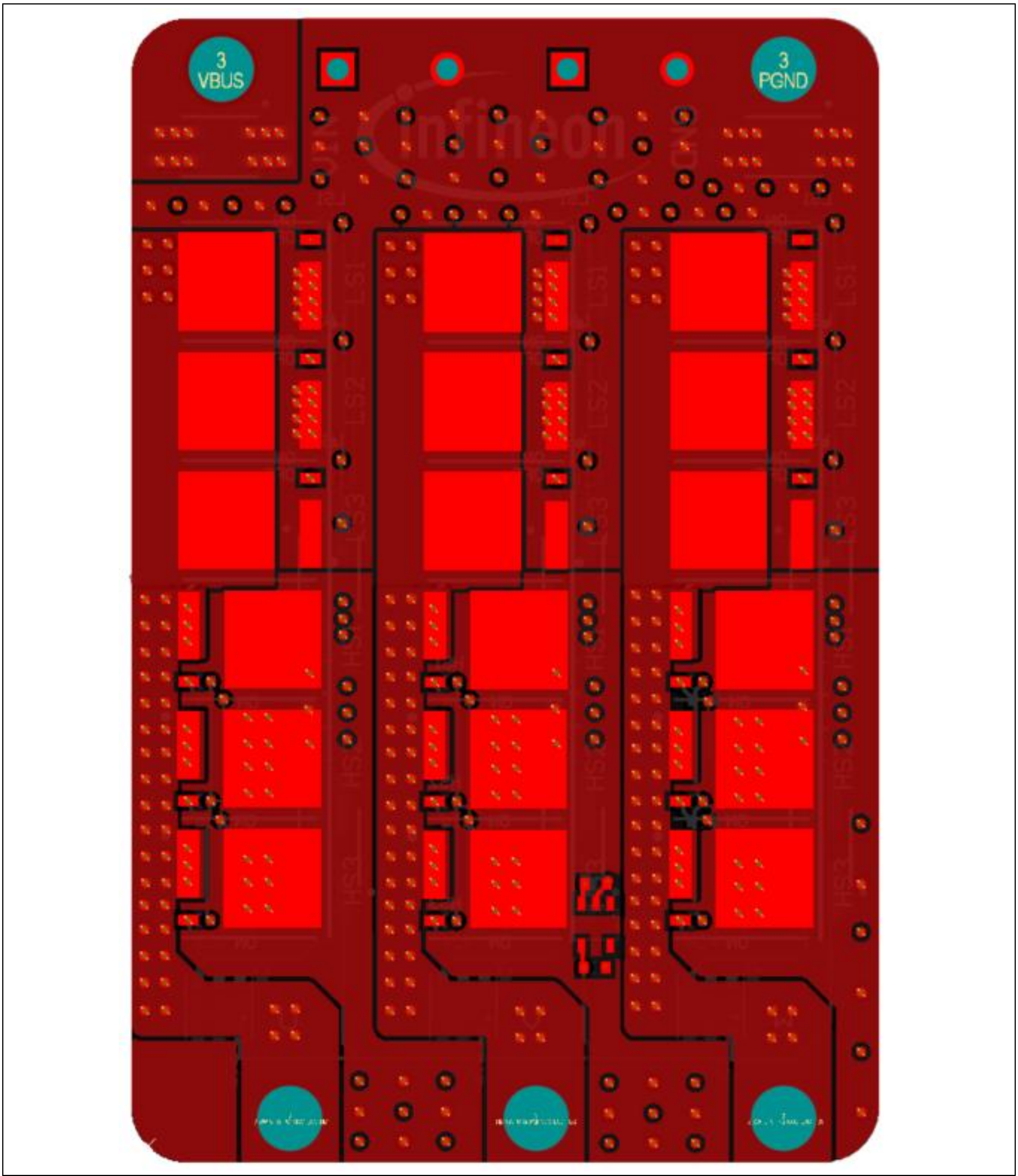

Figure 24 **Power board top layer.**

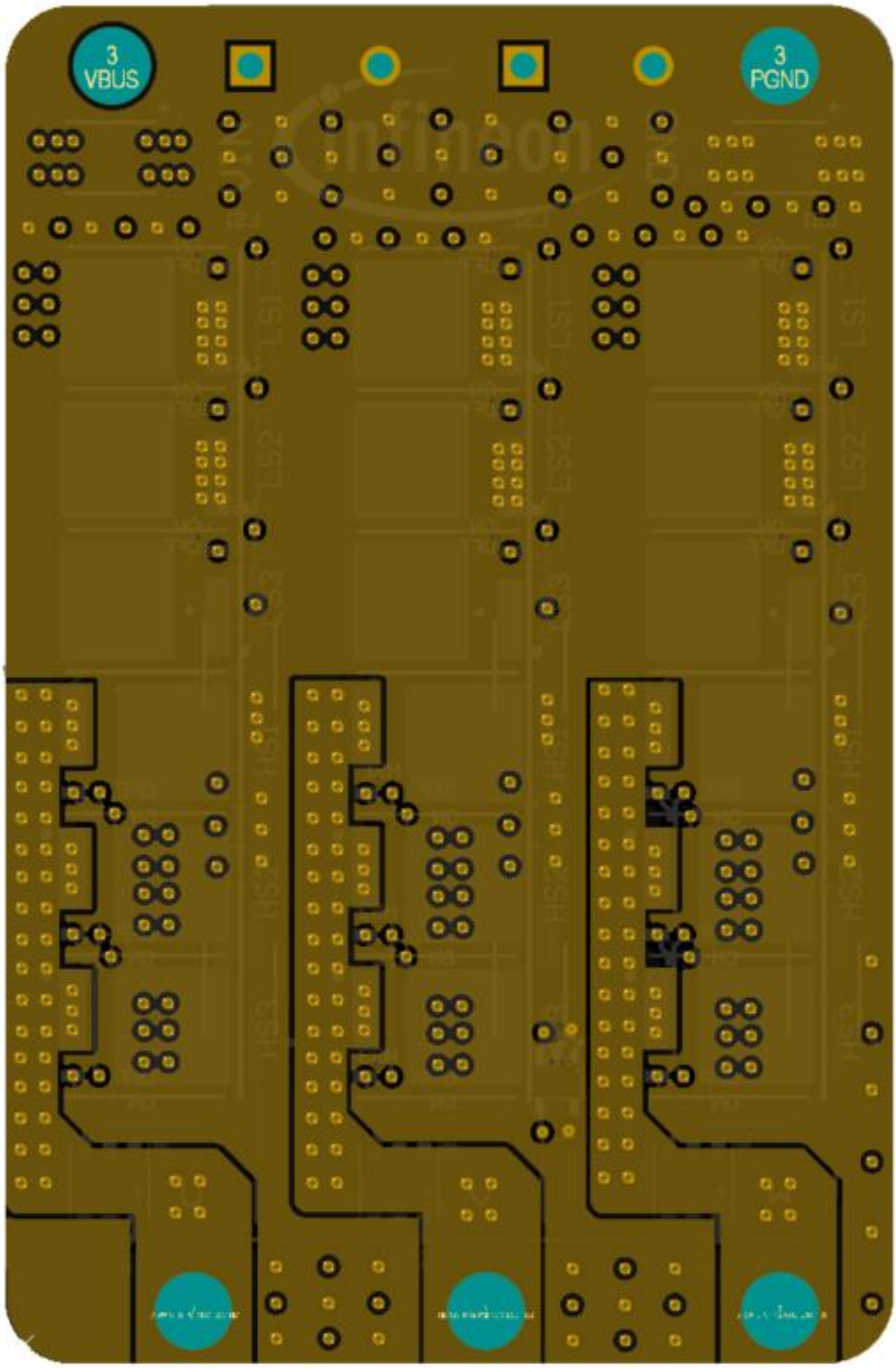

Figure 25 **Power board first inner layer.**

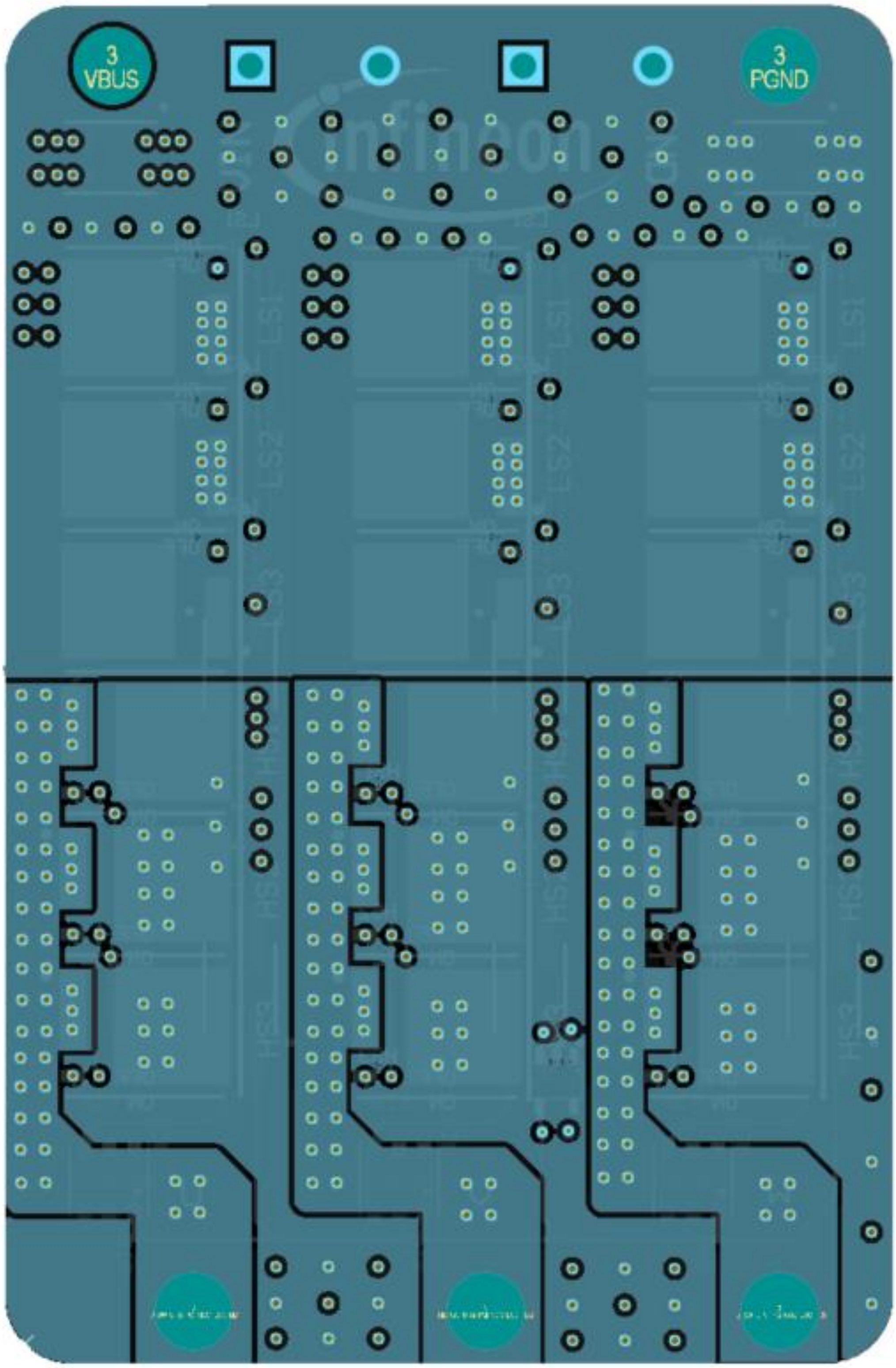

Figure 26 Power board second inner layer.

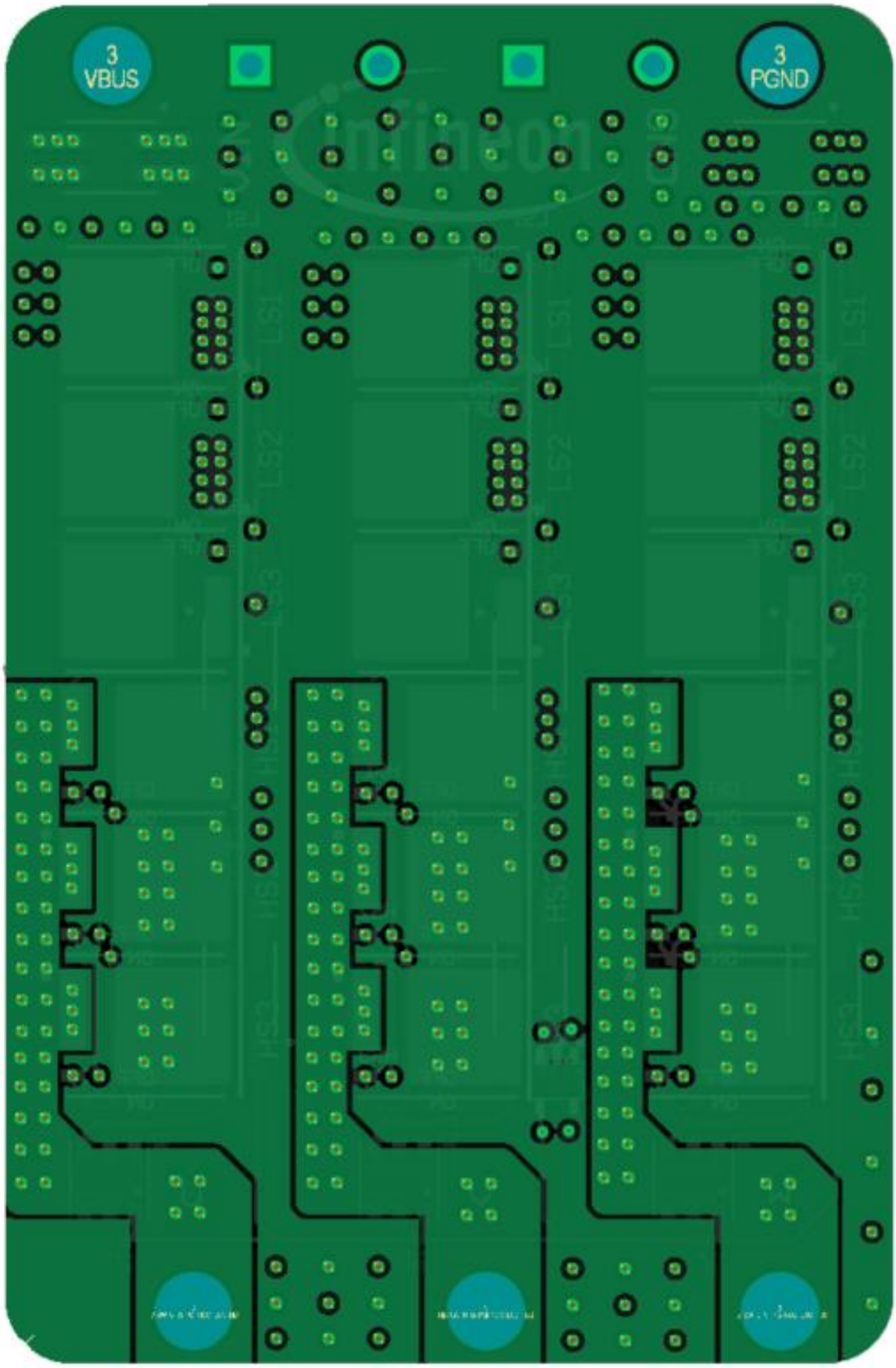

Figure 27 Power board third inner layer.

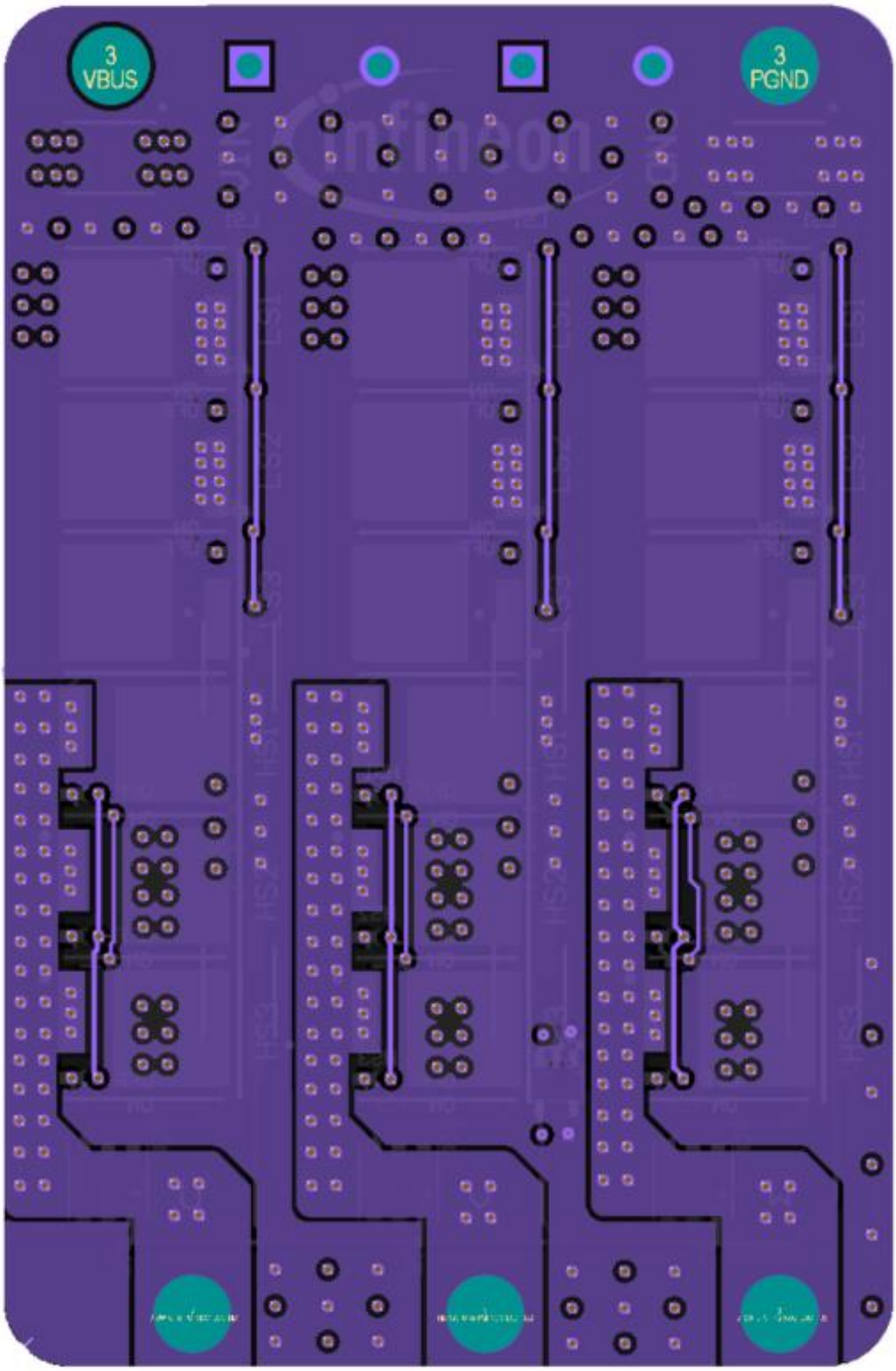

Figure 28 Power board fourth inner layer.

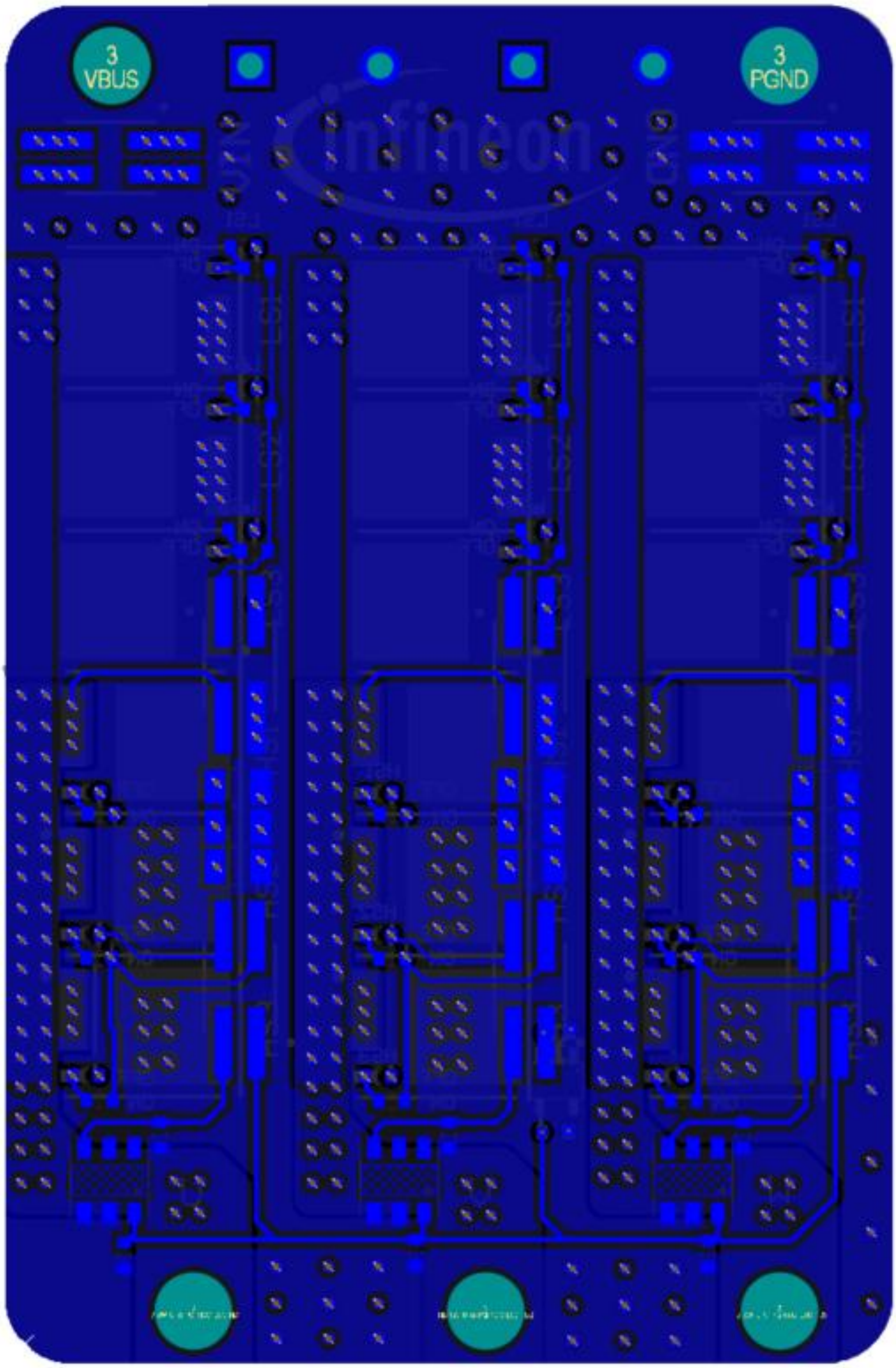

Figure 29 Power board bottom layer.

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Glossary

ESC
Electronic speed controller

FOC
field-oriented control

IC
integrated circuit

LDO
low drop-out

MCU

Microcontroller unit

PCB
printed circuit board

RMS
root mean square

TMR
tunnel magneto-resitive

Revision history

Document revision	Date	Description of changes
Version 1.0	02/2026	Preliminary version

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Edition yyyy-mm-dd

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document Reference Number