EVAL_6EDL7141_FOC_3SH 1 kW user manual

Three-phase motor inverter board using MOTIX™ 6EDL7141

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About this document

Scope and purpose

This user manual presents a detailed description of the functionalities of the Infineon EVAL_6EDL7141_FOC_3SH evaluation power board for battery-powered brushless direct current (BLDC) motor drives. This board is used to drive three-phase BLDC motors using field-oriented control (FOC) with sensorless feedback on an XMC™ series microcontroller. The inverter portion uses an OptiMOS™ 5 power MOSFET 60 V technology (sTOLL) 7 x 8 mm^2 power MOS package for each phase of the three-phase inverter. An onboard XMC™ microcontroller provides easy-to-use control firmware, and an onboard debugger (OBD) using **SEGGER J-Link** technology provides an easy-to-use interface from PC to board with Infineon motor control GUI.

Intended audience

This document is intended for manufacturers of battery-powered power tools, engineers familiar with three-phase motor drive systems and motor controls, and users wanting three-phase motor control with FOC.

Infineon components featured

- **MOTIX™ 6EDL7141** – three-phase motor control gate driver IC for battery-supplied BLDC motor control
- **XMC1404-Q064X0064** – 32-bit microcontrollers with Arm® Cortex®-M0 with 64 kB Flash
- **IST011N06NM5** – 60 V, 1.1 mΩ sTOLL N-channel power MOSFET
- **XMC4200-Q48K256** – 32-bit microcontrollers with Arm® Cortex®-M4 with 256 kB Flash
- **IFX54441LD V33** – micropower, low-noise, 3.3 V fixed low-dropout voltage regulator
- **ESD5V3U2U-03F**, ultralow capacitance ESD diode array

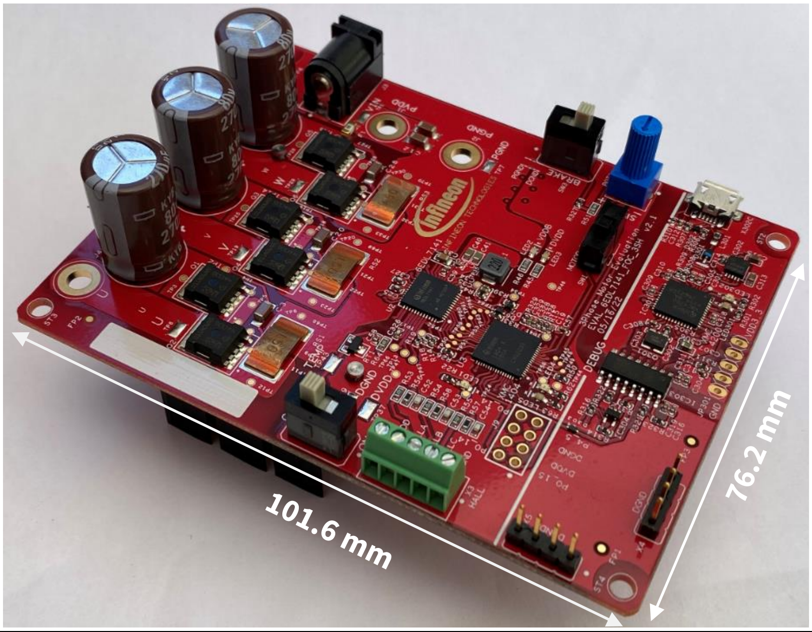

Figure 1 Isometric image of evaluation power board (EVAL_6EDL7141_FOC_3SH)

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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 DC-link potential of this board is up to 100 V DC. Ensure the polarity is correct, otherwise the board will be damaged!* *When measuring voltage waveforms by oscilloscope, high-voltage differential probes are required. Failure to use correct probes may result in damage, personal injury or death.*
	Warning: *The evaluation or reference board contains DC bus capacitors, which take time to discharge after removal of the main supply. Before working on the drive system, wait five minutes for capacitors to discharge to safe voltage levels. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *The evaluation or reference board is connected to the grid input during testing. Hence, high-voltage differential probes must be used when measuring voltage waveforms by oscilloscope. Failure to do so may result in personal injury or death. Darkened display LEDs are not an indication that capacitors have discharged to safe voltage levels.*
	Warning: *Remove or disconnect power from the drive before you disconnect or reconnect wires, or perform maintenance work. Wait five minutes after removing power to discharge the bus capacitors. Do not attempt to service the drive until the bus capacitors have discharged to zero. Failure to do so may result in personal injury or death.*
	Caution: *The heatsink 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

The EVAL_6EDL7141_FOC_3SH evaluation board is powered with a **MOTIX™** 6EDL7141 **three-phase motor control gate driver IC** for BLDC motor control with onboard XMC™, OBD and **IST011N06NM5** OptiMOS™ 5 60 V power MOSFET for battery-powered applications. The **MOTIX™** 6EDL7141 has an integrated buck converter to supply 3.3 V or 5 V for digital logic. The evaluation board is populated with a low-side 0.5 mΩ shunt resistor for each bridge inverter section for sensorless FOC operation. The board has also a Hall sensor connection for customers who will develop their own motor control code using the Hall sensor for FOC-sensored applications. The evaluation board is a full system solution board ready to be plugged in to the motor. The only items needed are the motor, power supply and PC for GUI control. The board is populated with a fuse for inverter overcurrent protection (OCP) and also has reverse polarity protection components. The leg overcurrent sensing using **MOTIX™** 6EDL7141 could be configured using Infineon motor control GUI. The board is also populated with a temperature sensor, and user LEDs to extend the functionality of the board. A picture of the board is shown in **Figure 2**.

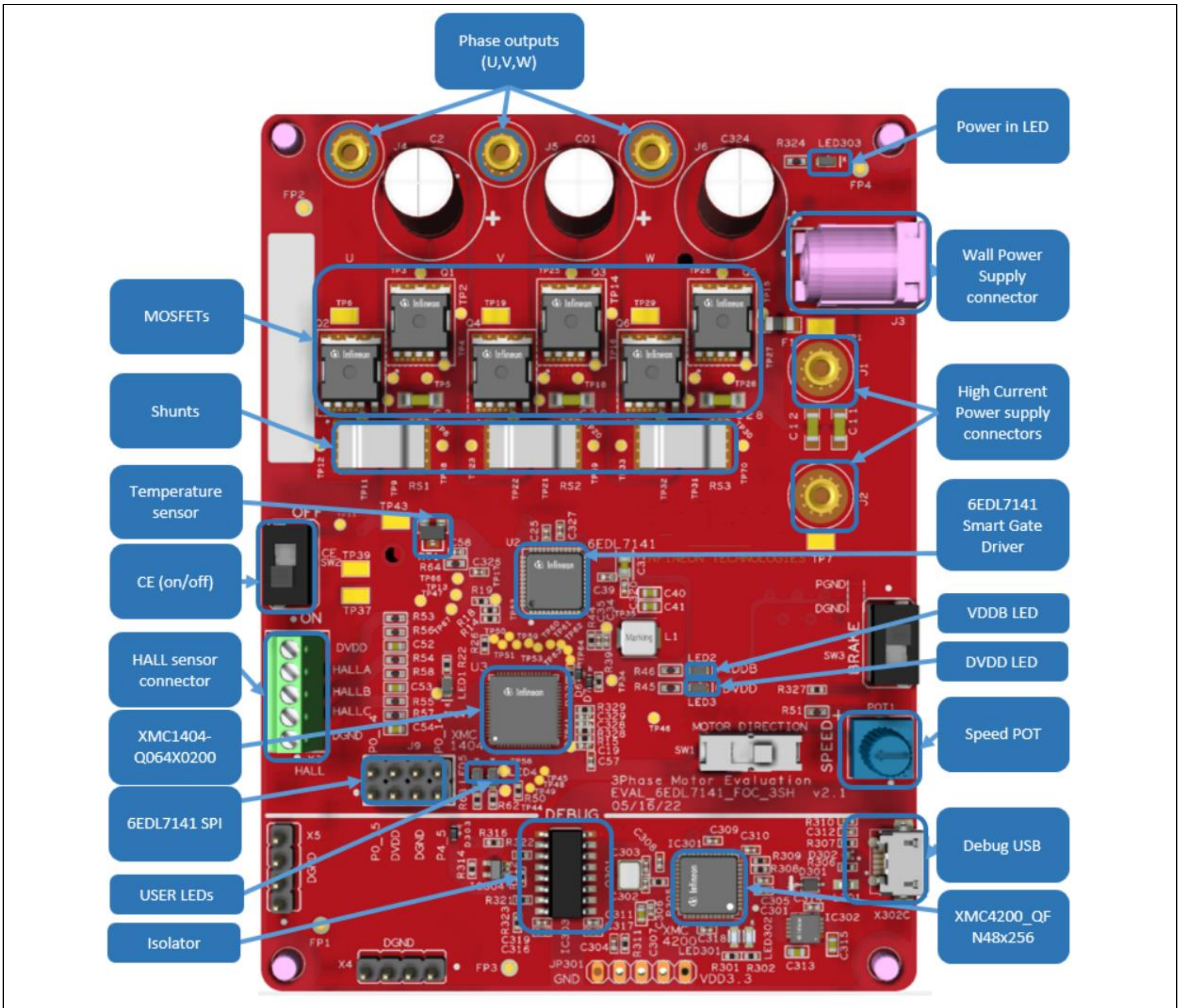

Figure 2 **Evaluation board (EVAL_6EDL7141_FOC_3SH)**

1.2 Board parameters and technical data

Table 2 shows the evaluation board parameters and technical details.

Table 2 Parameters

Parameter	Symbol	Conditions	Value	Unit
Input DC voltage	V_{IN}	DC voltage input	36~42	V
Buck output 12 V	+12 V	Maximum 1 A output current	12 ±5%	V
LDO output 5 V	+5 V	Maximum 300 mA output current	5 ±5%	V
Maximum inverter switching frequency	f_{SW}	V_{CC} = 12 V	20	kHz
Maximum output phase current	I_{phase_peak}	T_A = 25°C, T_C = 100°C, air cooling, f_{SW} = 20 kHz	282	A_{peak}
Maximum output power	P_{OUT}	Sufficient cooling applied to maintain MOSFET temperature below 125°C	1000[1]	W
Maximum output power with heatsink	P_{OUT}	With supplied heatsink as tested	1000	W
Peak output power with heatsink	P_{OUT}	Peak power for 2 minutes with heatsink, or maintain MOSFET temperature below 125°C with forced air cooling	1500	W
PCB characteristics				
Material		1.6 mm thickness, 2 oz. copper each layer, six layers	FR4	
Dimensions		Length x width	76.2 x 101.6	mm

1.3 Main features

The main features of the EVAL_6EDL7141_FOC_3SH evaluation board using **MOTIX™** 6EDL7141 **three-phase motor control gate driver IC** for products using BLDC or PMSM motors are:

- Single sTOLL power MOSFET at each bridge of the three-phase inverter
- 36 V nominal input and 42 V maximum input voltage
- 1000 W continuous power
- 1.5 kW maximum peak power for 2 minutes
- Fuse for OCP
- Reverse polarity protection
- 3.3 or 5.0 V onboard generation for compatible digital interface
- Onboard debugger powered by **SEGGER J-Link** technology
- Hardware supports both block commutation control and FOC using Hall sensors or back EMF

[1] Continuous operation at full load may require forced air cooling.

1.4 Block diagram

A block diagram of the three-phase inverter board is shown in **Figure 3**. In this design, the **MOTIX™** 6EDL7141 was programmed to produce 12 V gate drive voltage and an integrated buck converter creates 8 V output with 500 kHz switching frequency. The buck converter output is fed to an integrated linear regulator, which is set to output 5 V DVDD to power up the onboard XMC1404 and digital control signals. Alternatively, it is also possible to set 3.3 V output by GUI configuration or by changing external resistor R44. OCP is configured by GUI to sense low-shunt voltage drop for each leg. Hall sensor inputs are populated on this design for future development of sensored FOC control by the customer. They are not currently used in the FOC FW provided, and therefore motor Hall sensors do not need to be connected to this board when using Infineon FOC using GUI.

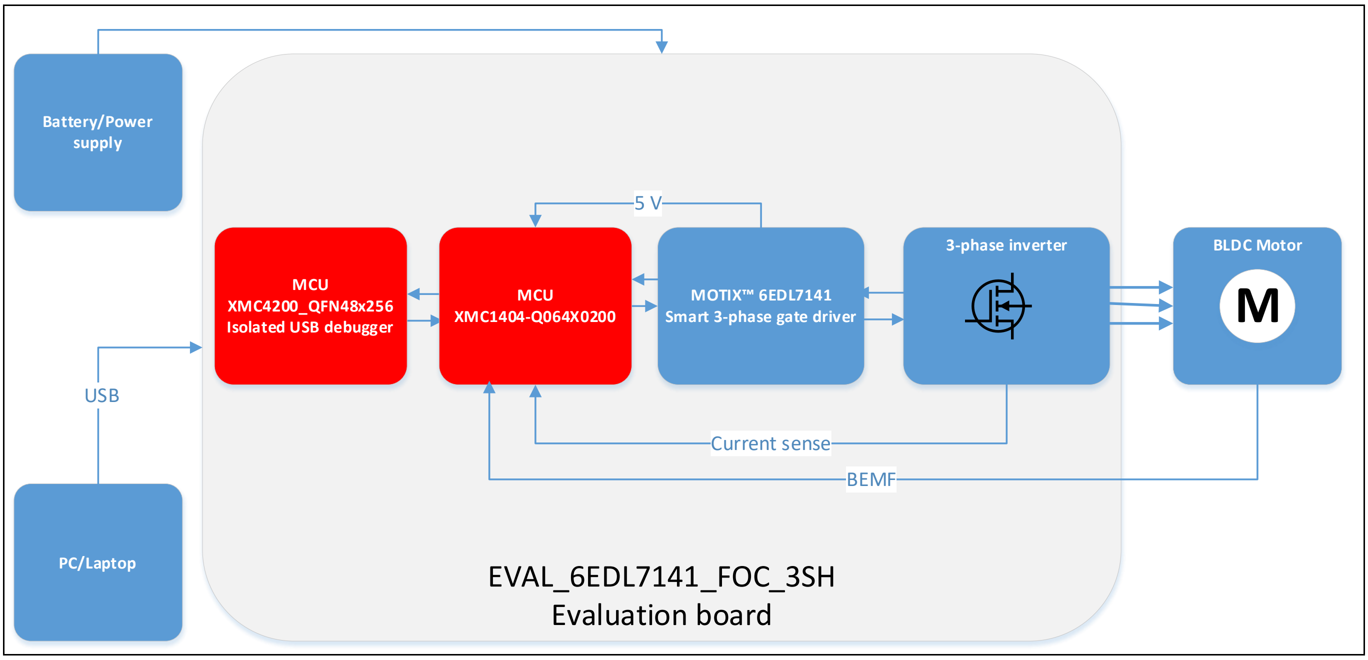

Figure 3 EVAL_6EDL7141_FOC_3SH block diagram

2 Hardware description

The evaluation board PCB top and bottom 3D views are shown in **Figure 4**. The evaluation board has all the necessary functional blocks to drive a three-phase BLDC motor. The board is divided into three logical sections – section 1: OBD, section 2: digital control, section 3: power inverter. An aluminum heatsink is attached to the bottom side of the PCB under the inverter section. An insulator made of thermal insulating material (TIM) is placed between the heatsink and the MOSFETs to eliminate any potential short-circuit caused by the heatsink and to provide a flat, smooth surface to transfer heat. The heatsink is designed to use with a Z-clip and two-pin configuration, which reduces the need for screwing and drilling of the heatsink.

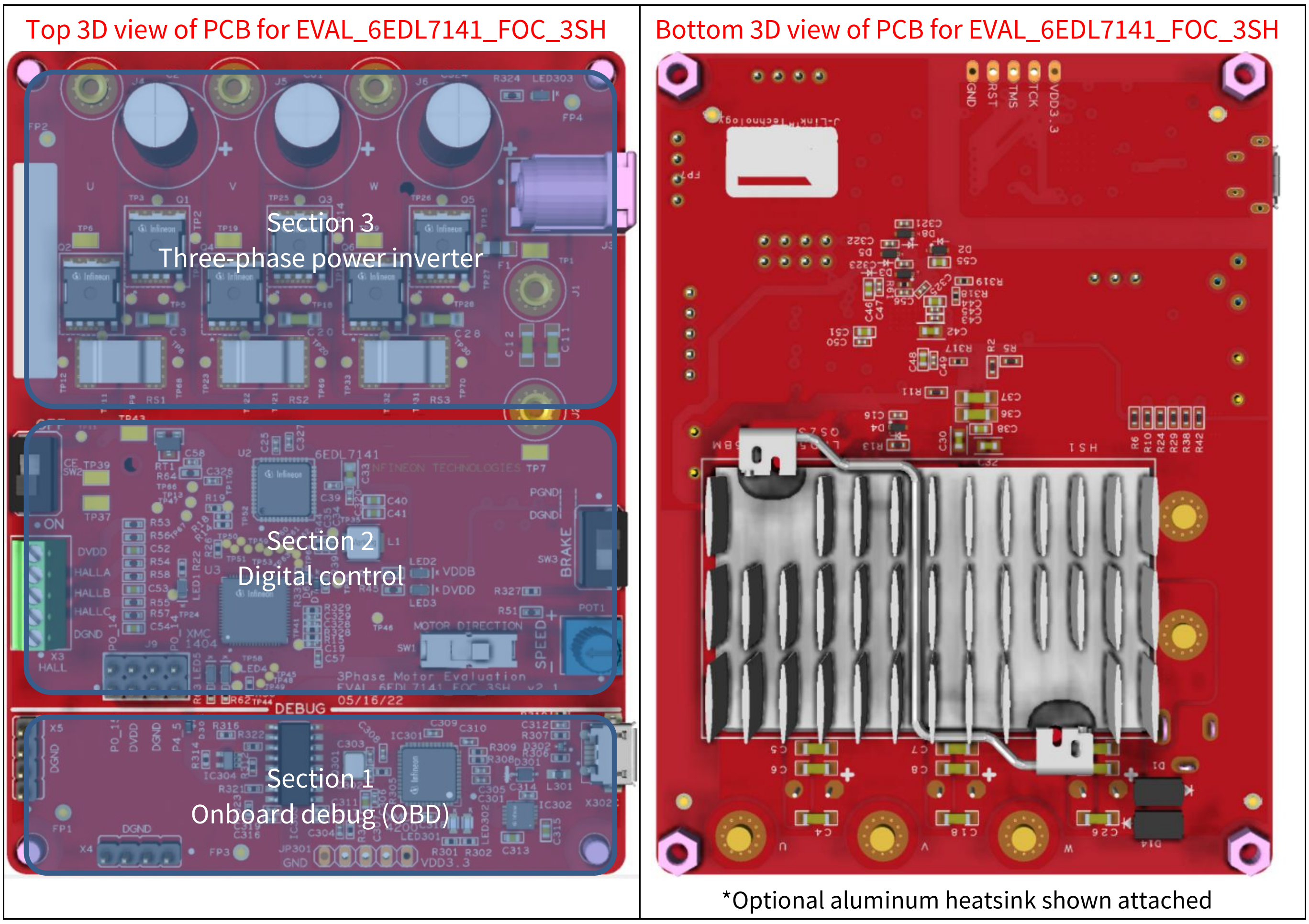

Figure 4 PCB top and bottom view of the evaluation board

2.1 Power supplies

The integrated sink-buck converter is configurable to set 7, 10, 12 or 15 V to drive the charge pump and internal integrated LDO. Buck could be configured to 500 kHz or 1 MHz. On this board 12 V output at 500 kHz frequency is configured. LDO is configurable to deliver 5 or 3.3 V to supply external digital components with maximum 300 mA. To power the XMC1404 microcontroller on this board LDO is set for 5 V settings, which could be changed to 3.3 V by hardware resistor R44 or GUI settings. The onboard power supply architecture is shown in **Figure 5**. Gate driver architecture of the MOTIX™ 6EDL7141 is shown in **Figure 6.**

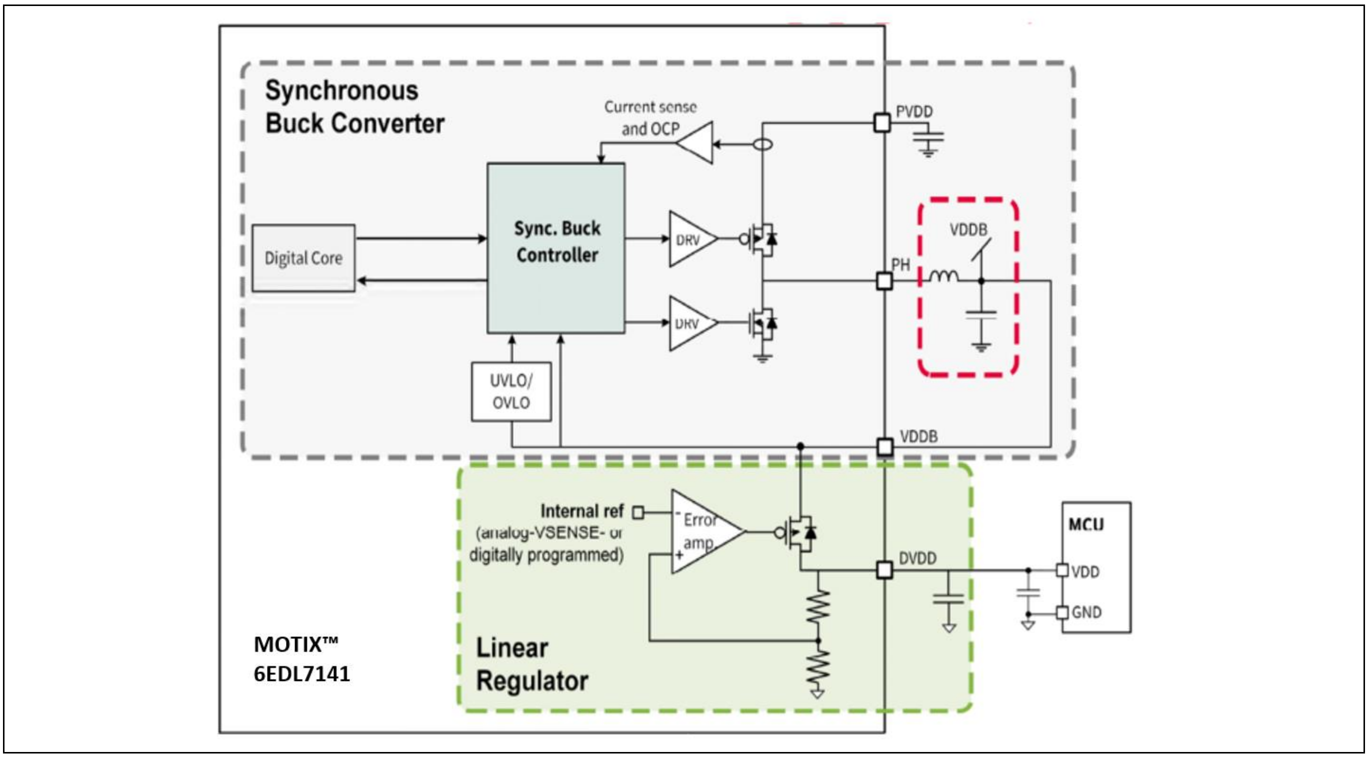

Figure 5 **Integrated buck and LDO regulators – block diagram of the MOTIX™ 6EDL7141**

2.2 Gate drivers

Infineon's MOTIX™ 6EDL7141 smart gate driver IC has been implemented in this design for driving the three-phase inverter MOSFETs.

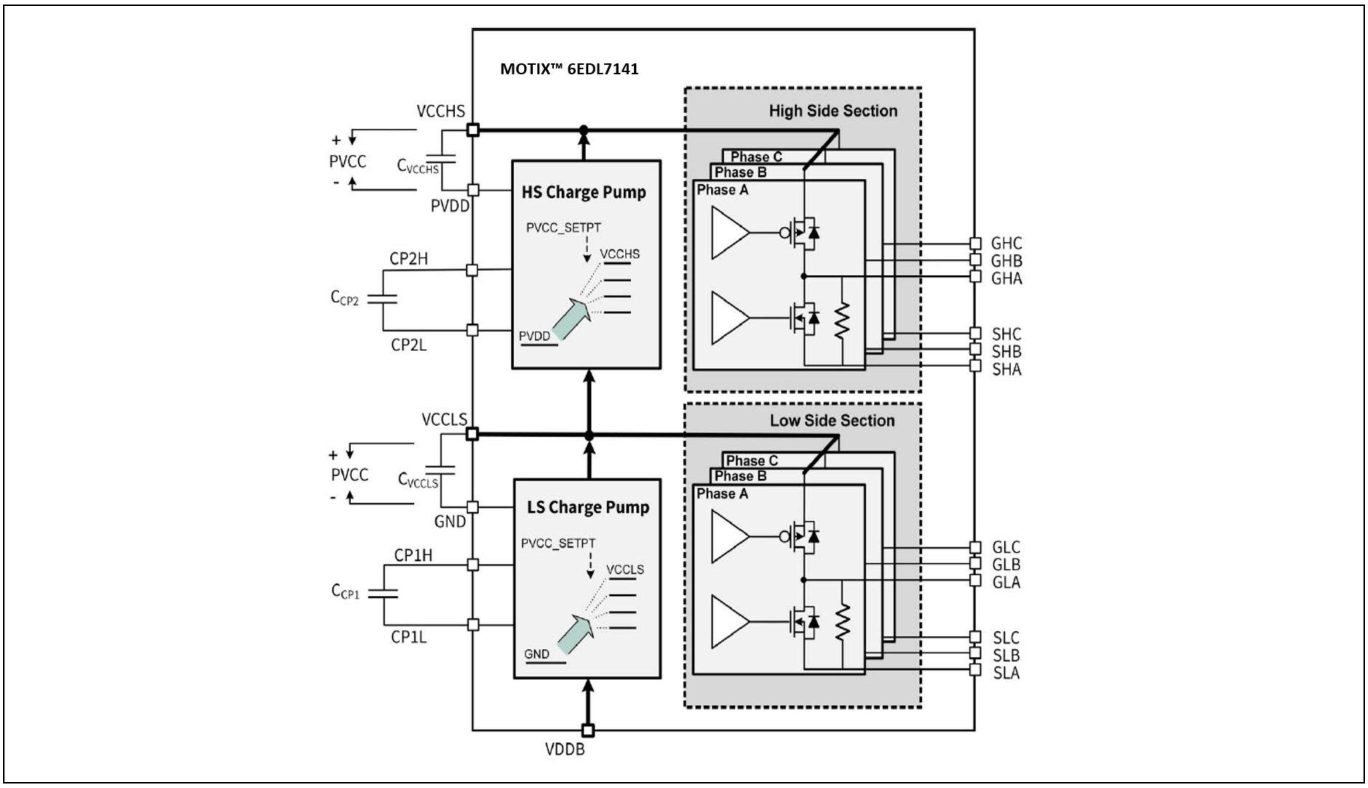

Figure 6 **Gate driver architecture overview of MOTIX™ 6EDL7141**

3 Control and firmware

3.1 Field-oriented control

FOC, also known as vector control, is implemented on this board. FOC is a control method to generate a three-phase sinusoidal signal to maximize the efficiency of the inverter when targeting high-power applications. Infineon's FOC algorithm requires real-time feedback of the current and rotor position. Phase-current feedback is provided by using a single shunt on each leg of the inverter. It is also possible to develop a Hall sensor feedback reading with a FOC-sensored algorithm using this board, because the board is also populated with Hall sensor inputs. Infineon's proprietary FOC algorithm parameters can be adjusted to enable a smooth transition from V/F open-loop to closed-loop FOC. The block diagram of a typical FOC block commutation system with Hall sensors is shown in **Figure 7**.

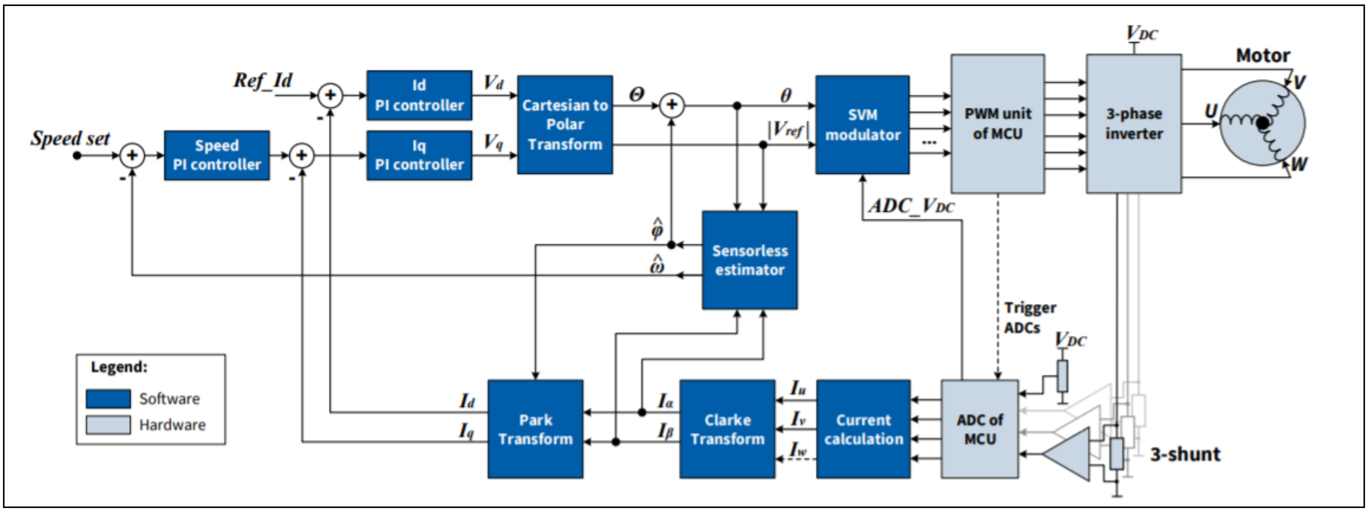

Figure 7 Block diagram of FOC commutation algorithm

3.2 PID tuning

Infineon's motor control GUI has a PID tuning option to fine-tune the control and feedback loop.

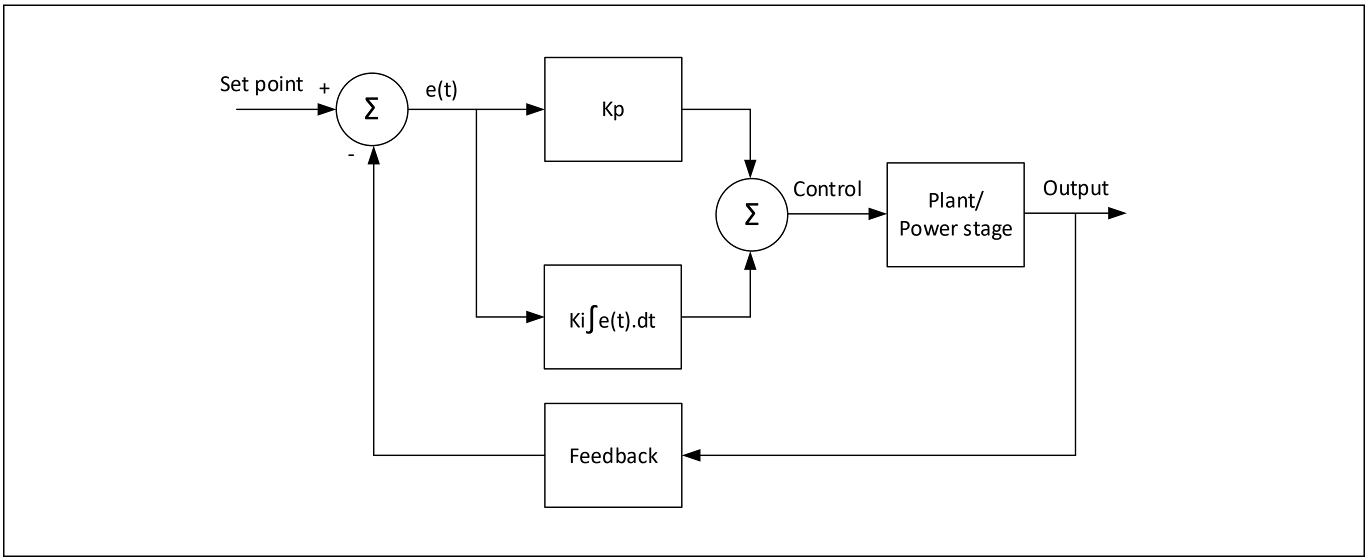

Figure 8 P-I control block diagram

The P-I controller is a widely used feedback control mechanism, which continuously calculates an error value e(t) that is the difference between the set-point of the measured output quantity (here, speed in RPM) and the actual measured value. In this case the speed is derived by the firmware from the Hall sensor input signals. The error value is fed to the proportional calculator, where it is multiplied by K_P, and to the integral calculator, where it is integrated with respect to time and the result multiplied by K_I. These two results are then added together to provide a control value, which is applied to the power stage to provide a correction that will adjust the output to match the set-point. The goal is to optimize the values of K_P and K_I for the specific system (inverter and motor) to achieve minimal delay and overshoot when changes are made to the commanded speed.

4 System operation

4.1 System start-up

To power up the board only one power supply, V_{IN} 36 to 42 V, is needed as the **MOTIX™** 6EDL7141 internal integrated buck and LDO will provide MOSFET gate voltage and digital logic voltage. The motor speed is set by adjusting hardware POT1 or by GUI software control. Parameters of the gate drivers are programmed and modified using BPA motor control GUI. The GUI provides an easy-to-use interface to modify and monitor parameters and provide motor status.

4.1.1 Operating waveforms

Figure 9 and **Figure 10** give an overview of the inverter switching waveforms FOC method at 3700 RPM with an input power of 1000 W at 36 V input voltage. **Figure 12** and **Figure 13** show detailed switching waveforms of gate-source and drain-source voltages of both high-side and low-side MOSFETs for phase V, and also the phase V current.

At start-up the GUI is configured to start with open-loop with transition to closed-loop once the initial user-configured motor speed is reached. **Figure 11** shows the three-step start-up process with maximum efficiency tracking (MET) current waveform for phase V. The MET is a transition from open-loop to closed-loop. This is an important stage to provide a smooth transition from open-loop to closed-loop FOC and ensure the stator flux is perpendicular to the rotor flux. It is also possible to configure the start-up method using GUI to direct FOC, which with start with direct FOC control.

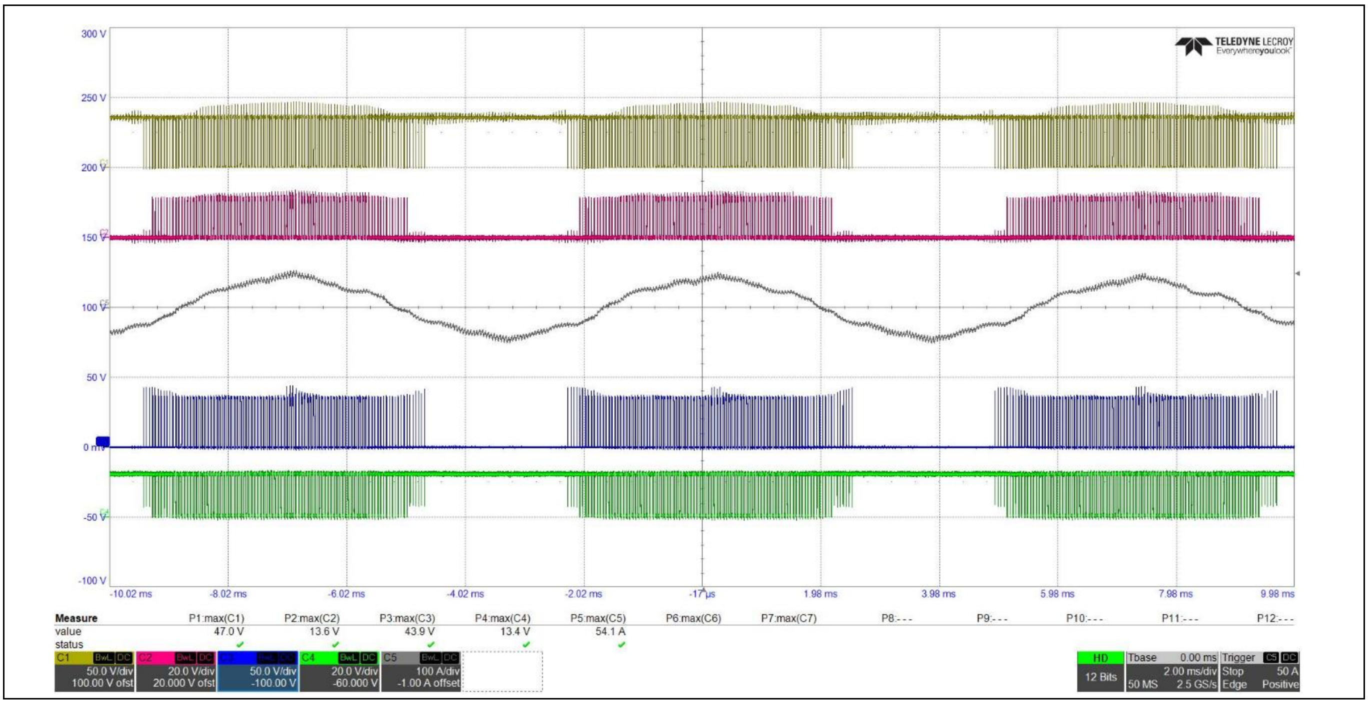

Figure 9 High-side and low-side MOSFET voltages and current for phase V (2 ms/div); V_{DS_HS} (yellow), V_{GS_HS} (pink), V_{DS_LS} (blue), V_{GS_LS} (green), I_{PHASE_V} (gray)

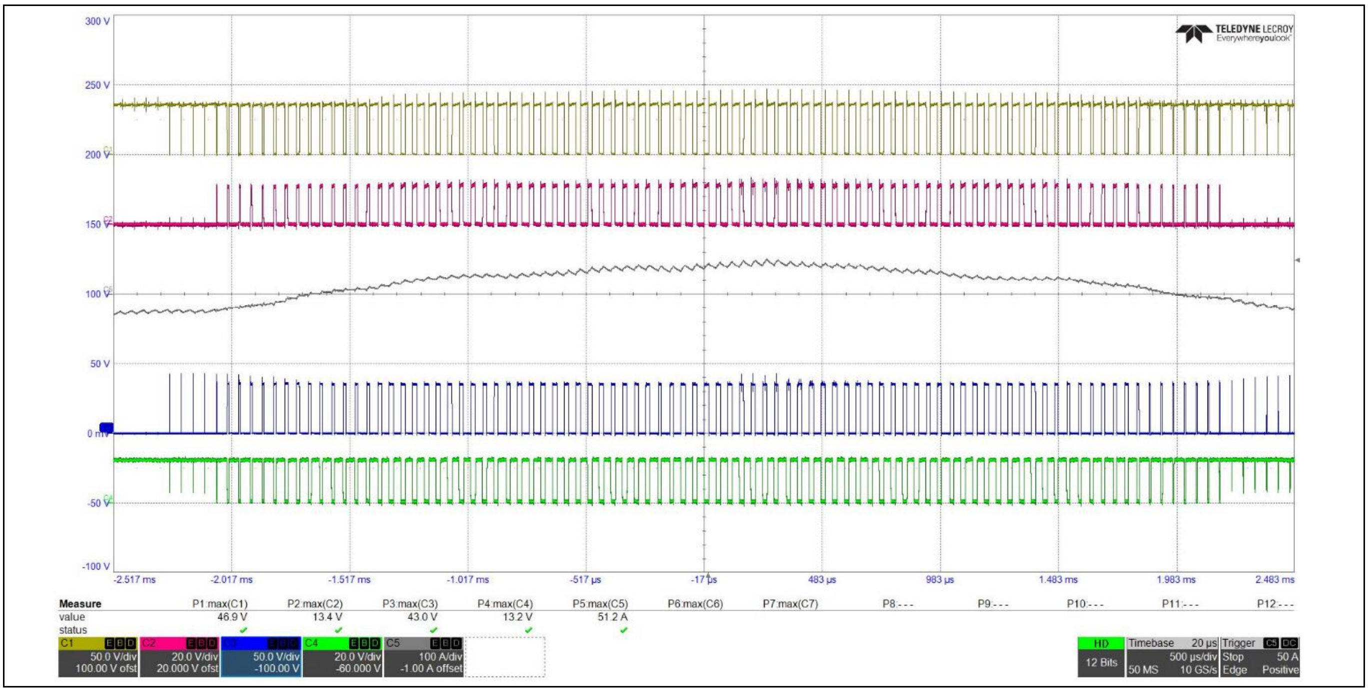

Figure 10 High-side and low-side MOSFET voltages and current for phase V (500 µs/div); V_{DS_HS} (yellow), V_{GS_HS} (pink), V_{DS_LS} (blue), V_{GS_LS} (green), I_{PHASE_V} (gray)

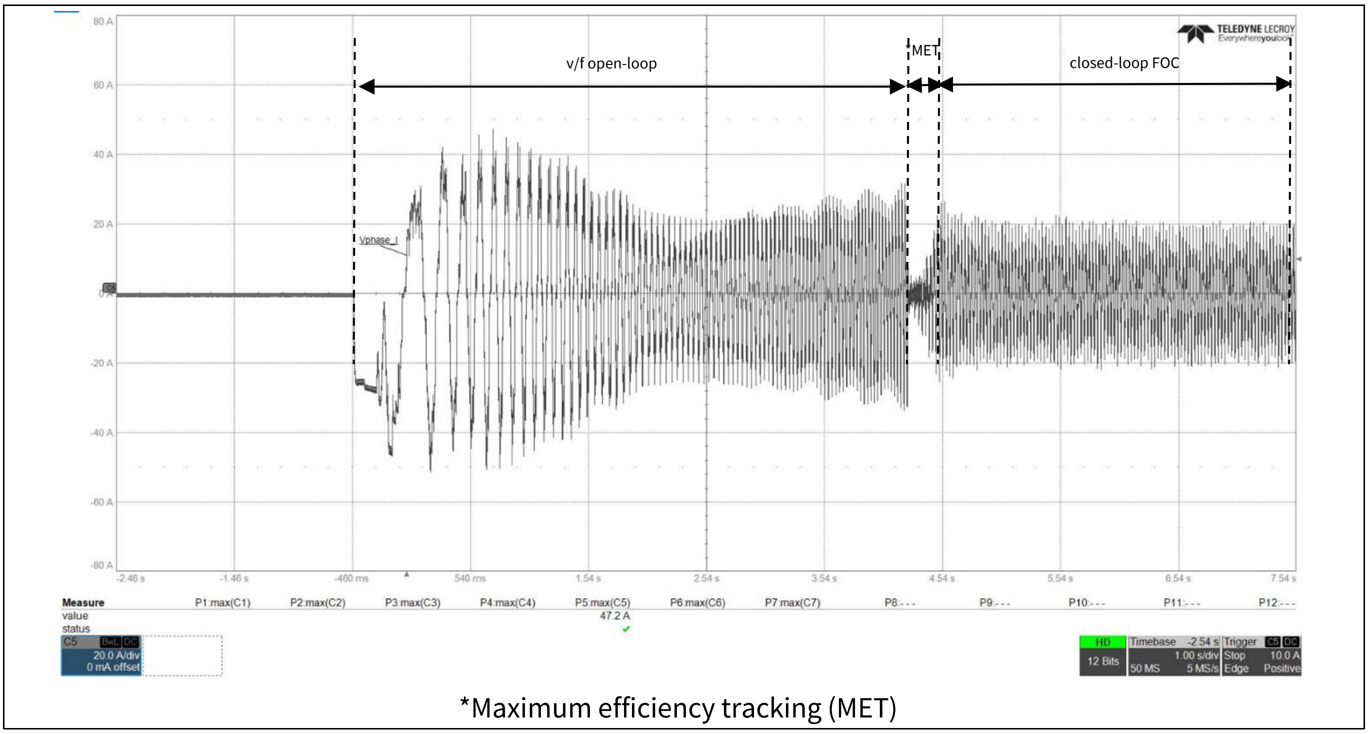

Figure 11 Phase V FOC start-up current (1 s/div); I_{PHASE_V} (gray)

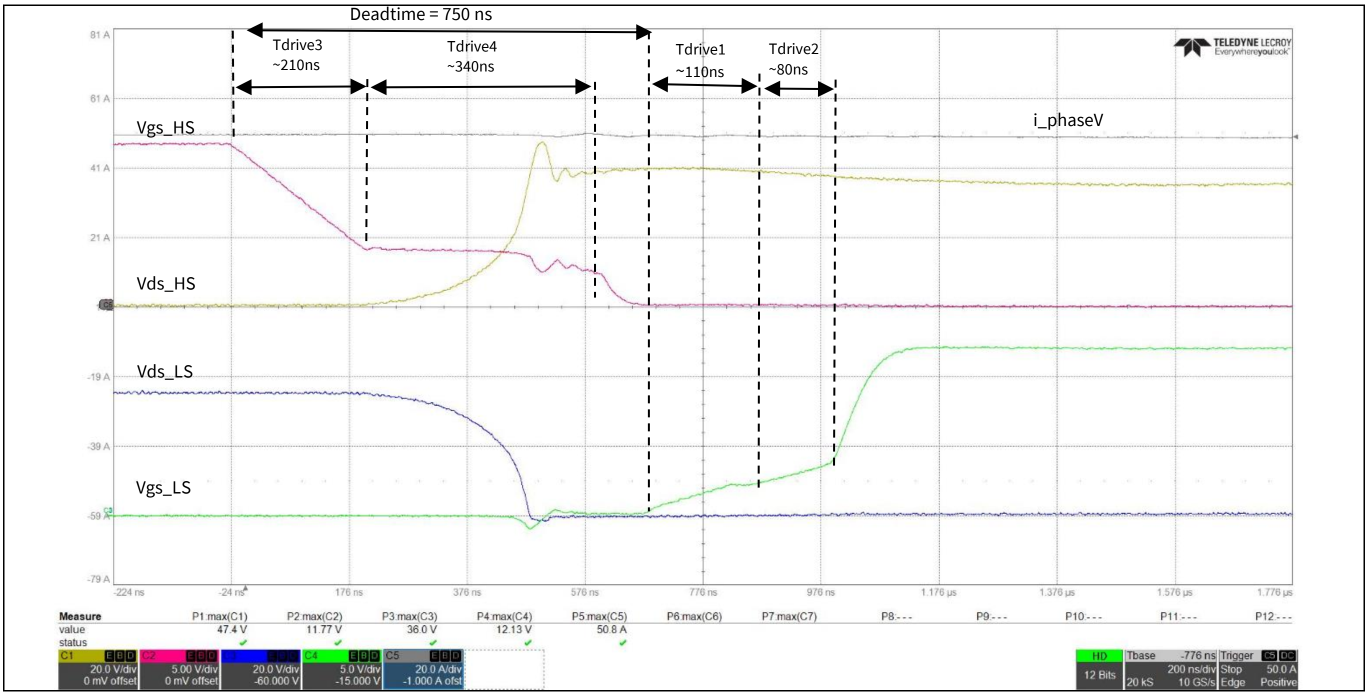

Figure 12 **High-side and low-side MOSFET gate-source and drain-source voltages for phase V during high-side MOSFET turn-off and low-side MOSFET turn-on (100 ns/div); V_{GS_HS} (blue), V_{DS_LS} (green), V_{GS_HS} (yellow), V_{DS_LS} (pink)**

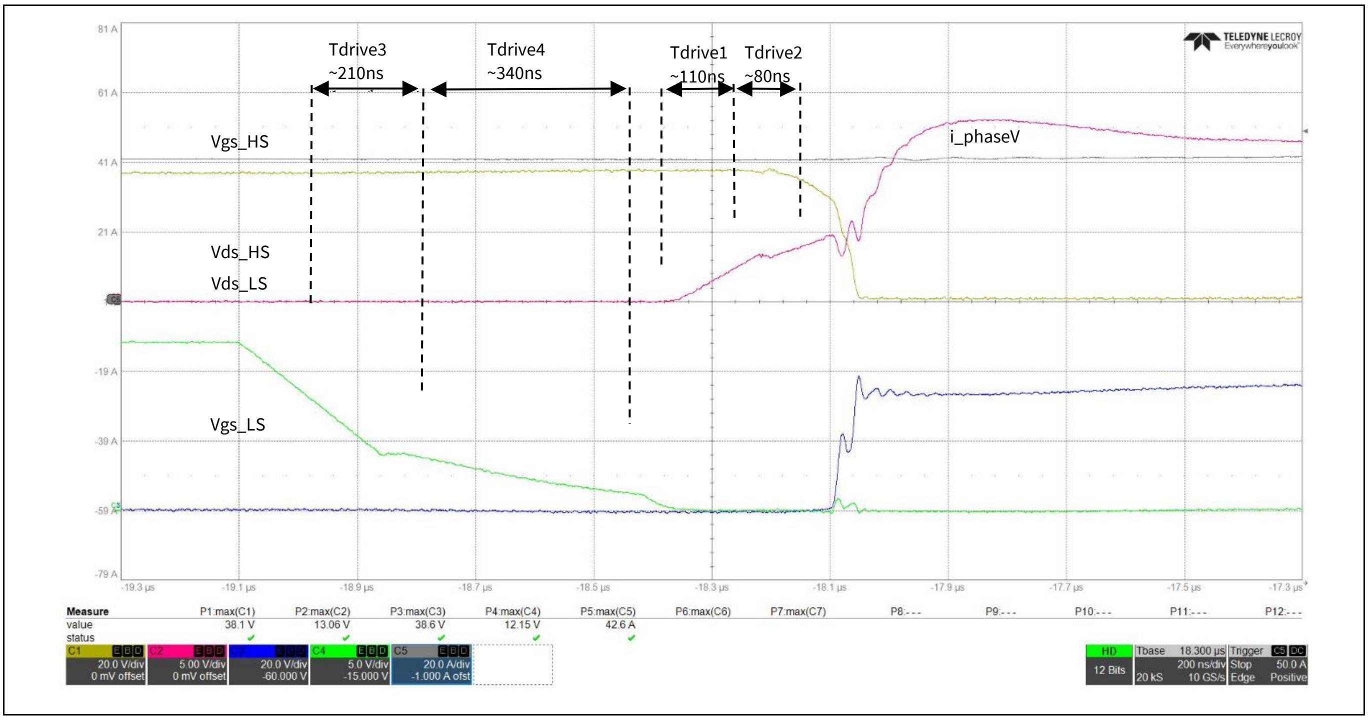

Figure 13 **High-side and low-side MOSFET gate-source and drain-source voltages for phase V (1 ms/div) for high-side MOSFET turn-on and low-side MOSFET turn-off (200 ns/div); V_{GS_HS} (blue), V_{GS_LS} (yellow), V_{DS_HS} (green), V_{DS_LS} (pink)**

4.1.2 Power measurements

		Element 1	Element 2	Element 3	Element 4
Urms	[V]	36.59	15.34	15.15	15.14
Irms	[A]	29.76	35.3	36.6	34.0
P	[W]	1071.19	348.50	364.80	337.20

Figure 14 Input and output measurements with an input power of 500 W at 36 V input voltage

In **Figure 14**, the results for Element 1 represent the DC input to the inverter. Elements 2, 3 and 4 are connected to the output phases U, V and W, respectively.

The total input power is 1071.19 W. Total output power is equal to 348.5 W + 364.8 W + 337.2 W = 487.5 W for an input power of 1050.5 W.

This gives an efficiency of $\frac{1050.5}{1071.19} * 100 = 98\%$ with losses of 20.7 W.

4.1.3 Thermal measurements

Thermal images were taken after 12 minutes of operation to allow the components to rise and reach steady-state at an input power of 1000 W at 36 V input voltage, as shown in **Figure 15**. No forced air cooling was used.

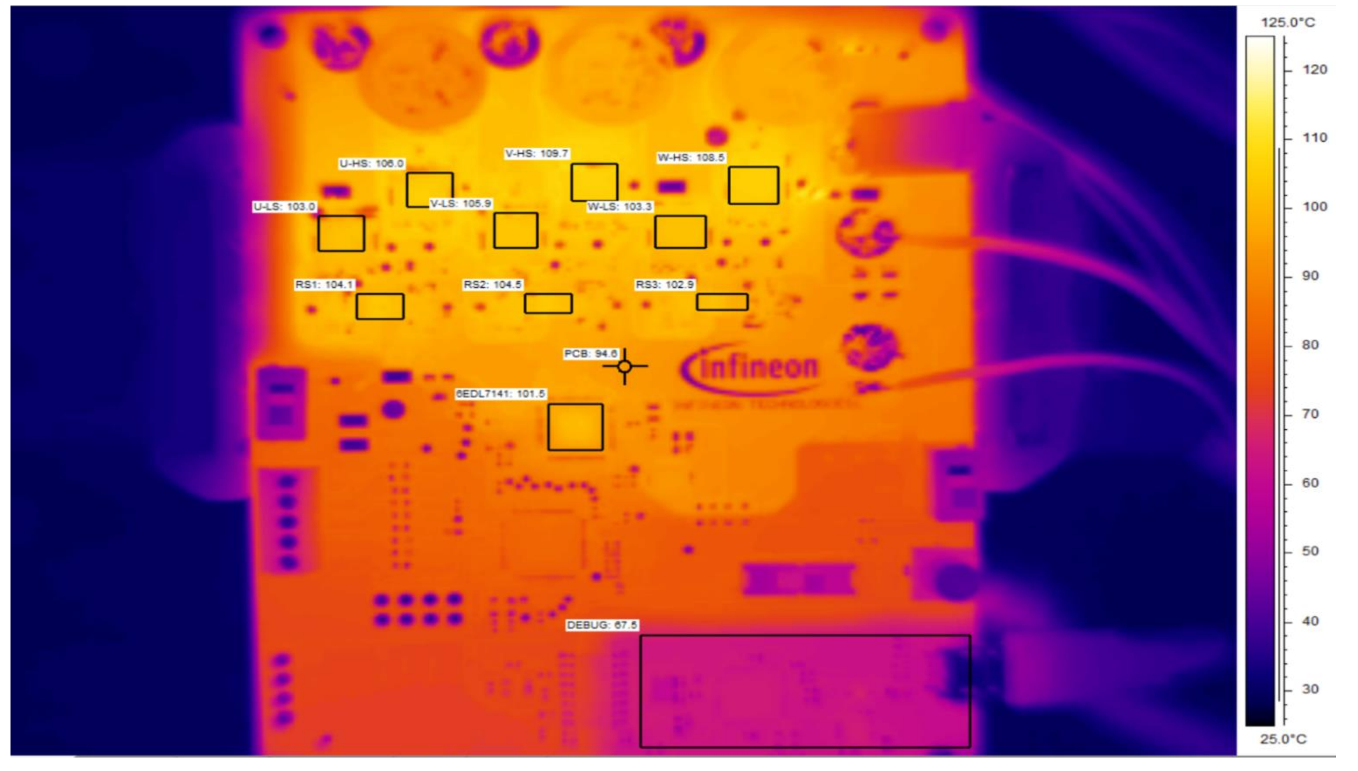

Figure 15 Thermal measurements at 36 V input, 1000 W load at 3700 RPM 20 in-lb (2.25 N-m) torque

The temperature above shows the system at equilibrium after running for 12 minutes with 1000 W input power. **Table 3** summarizes the measurements.

Table 3 Temperature of the components

Point of interest	°C
Phase U high-side MOSFET	106
Phase U low-side MOSFET	103
Phase U shunt	104.1
Phase V high-side MOSFET	109.7
Phase V low-side MOSFET	105.9
Phase V shunt	104.5
Phase W high-side MOSFET	108.5
Phase W low-side MOSFET	103.3
Phase V shunt	102.9
6EDL7141	101.5
PCB	94.6

5 Schematics and PCB layout

5.1 EVAL_6EDL7141_FOC_3SH schematic

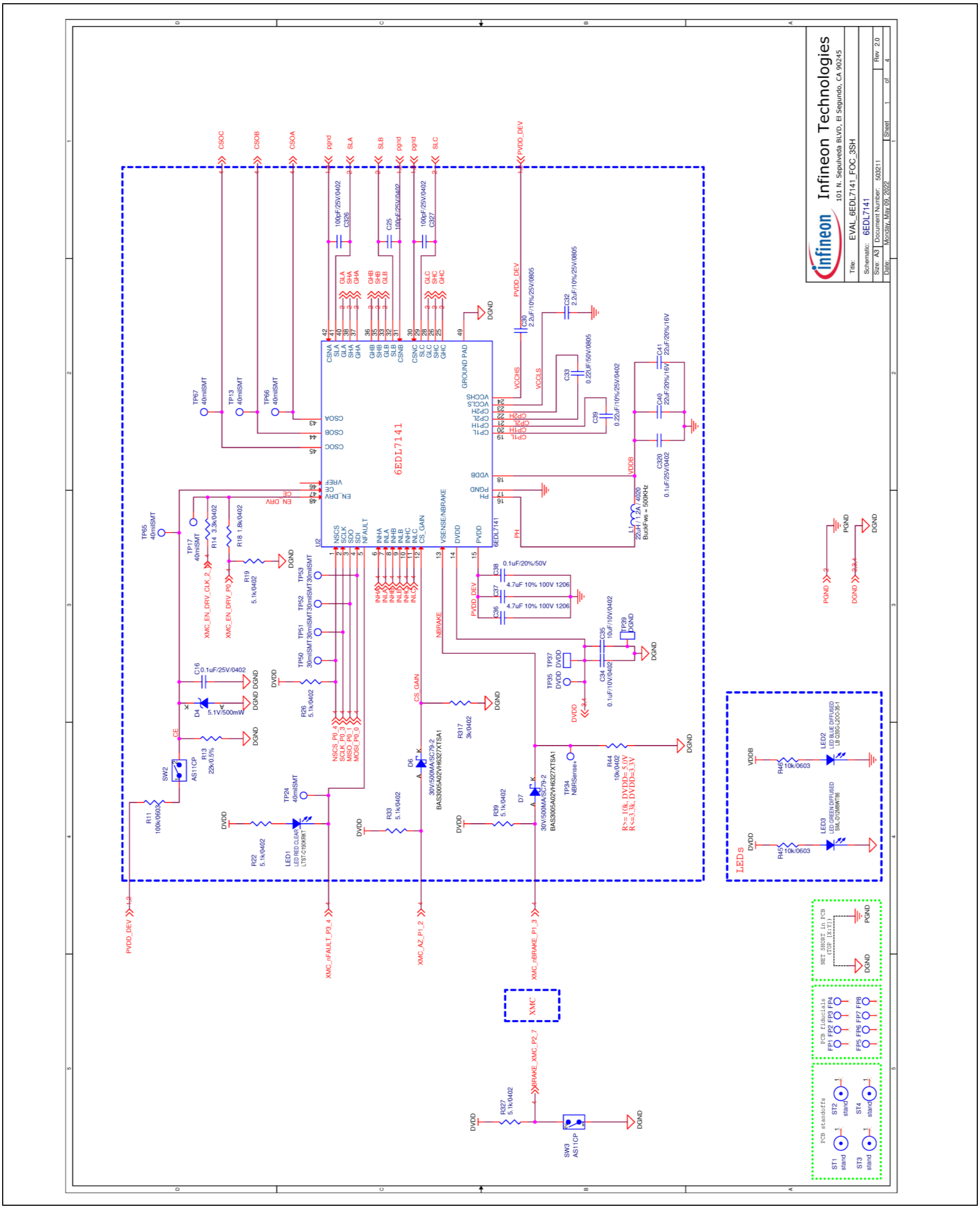

Figure 16 MOTIX™ 6EDL7141 schematic

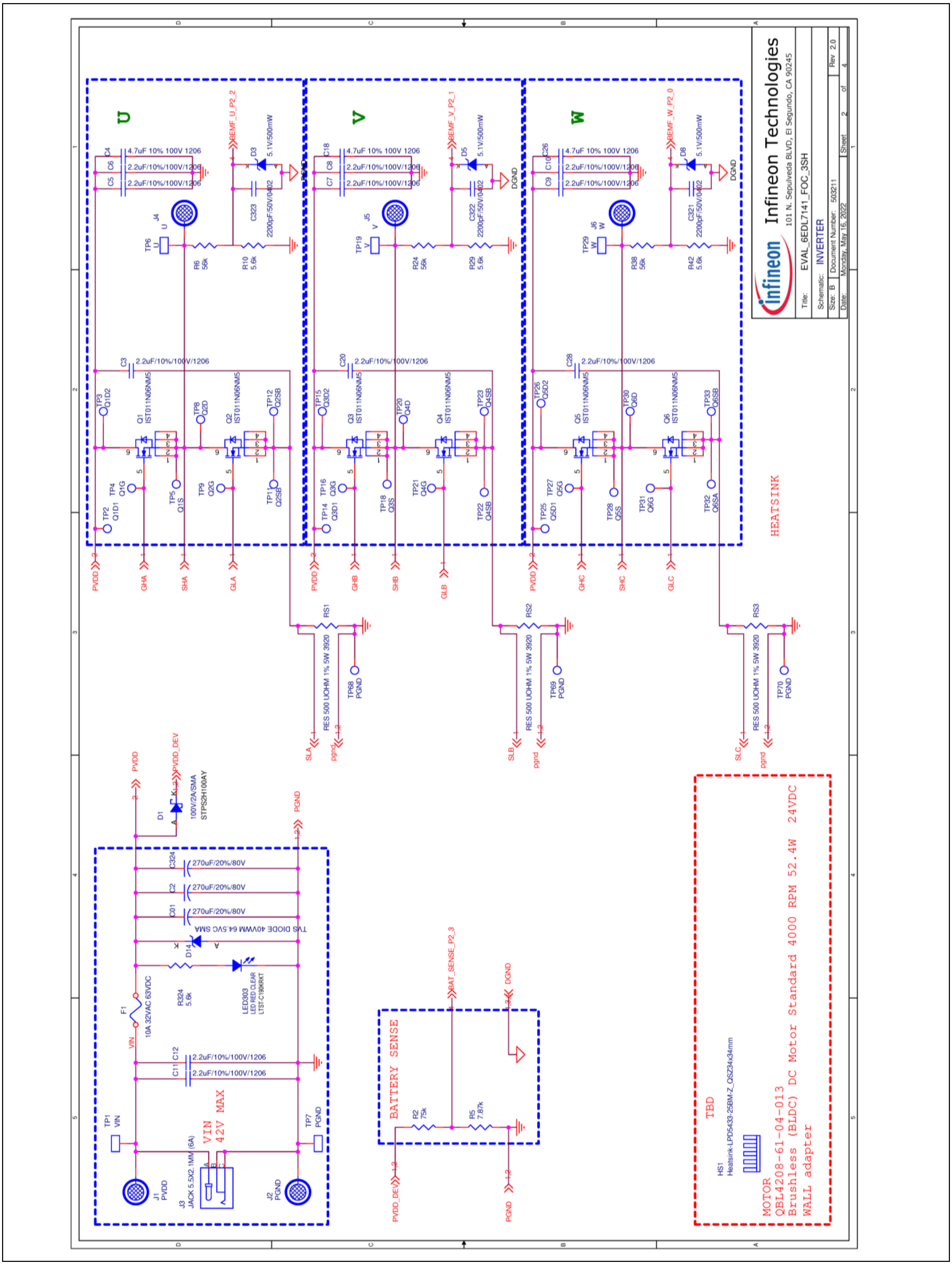

Figure 17 **Battery input and inverter schematic**

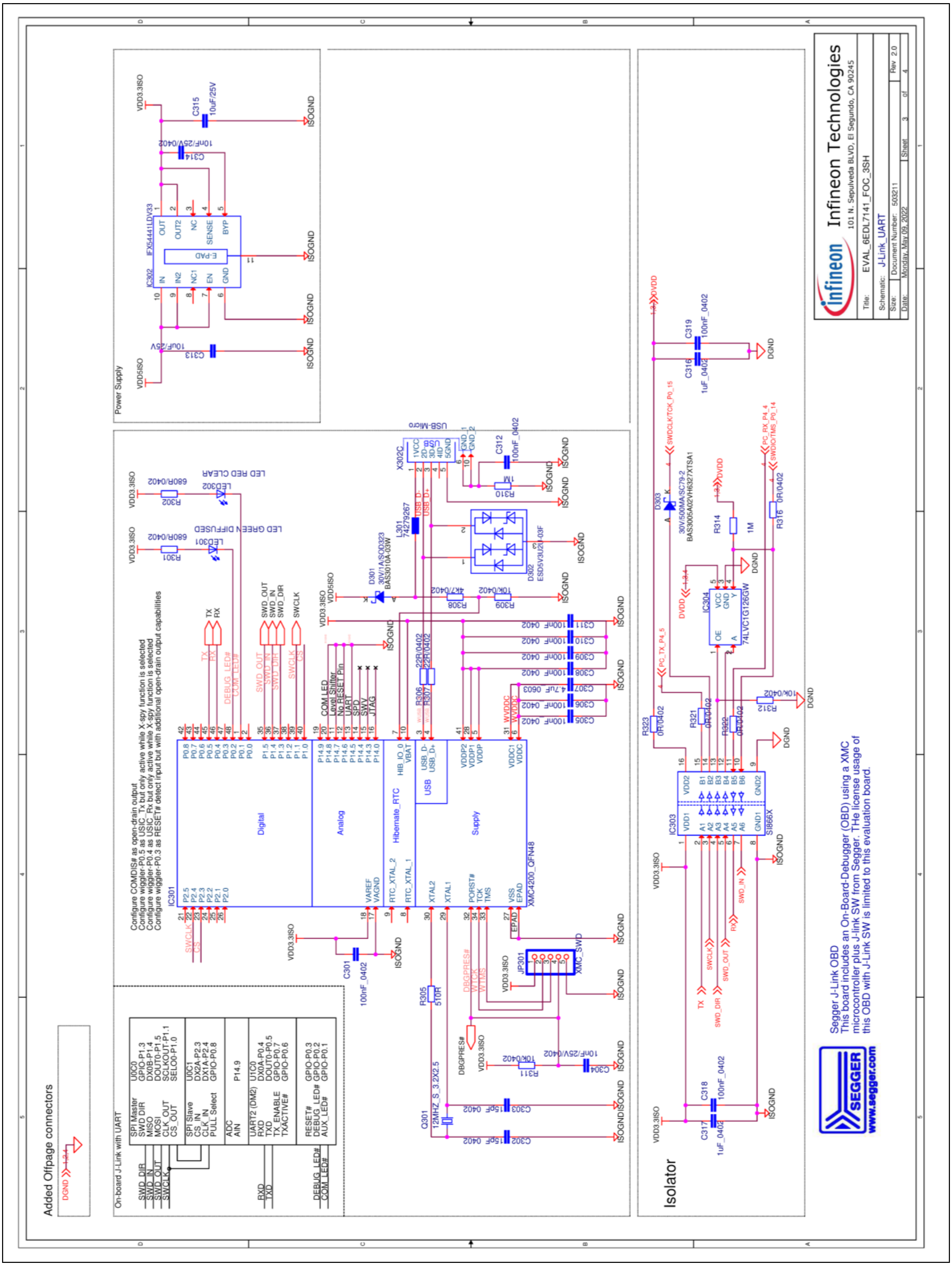

Figure 18 Onboard debugger schematic

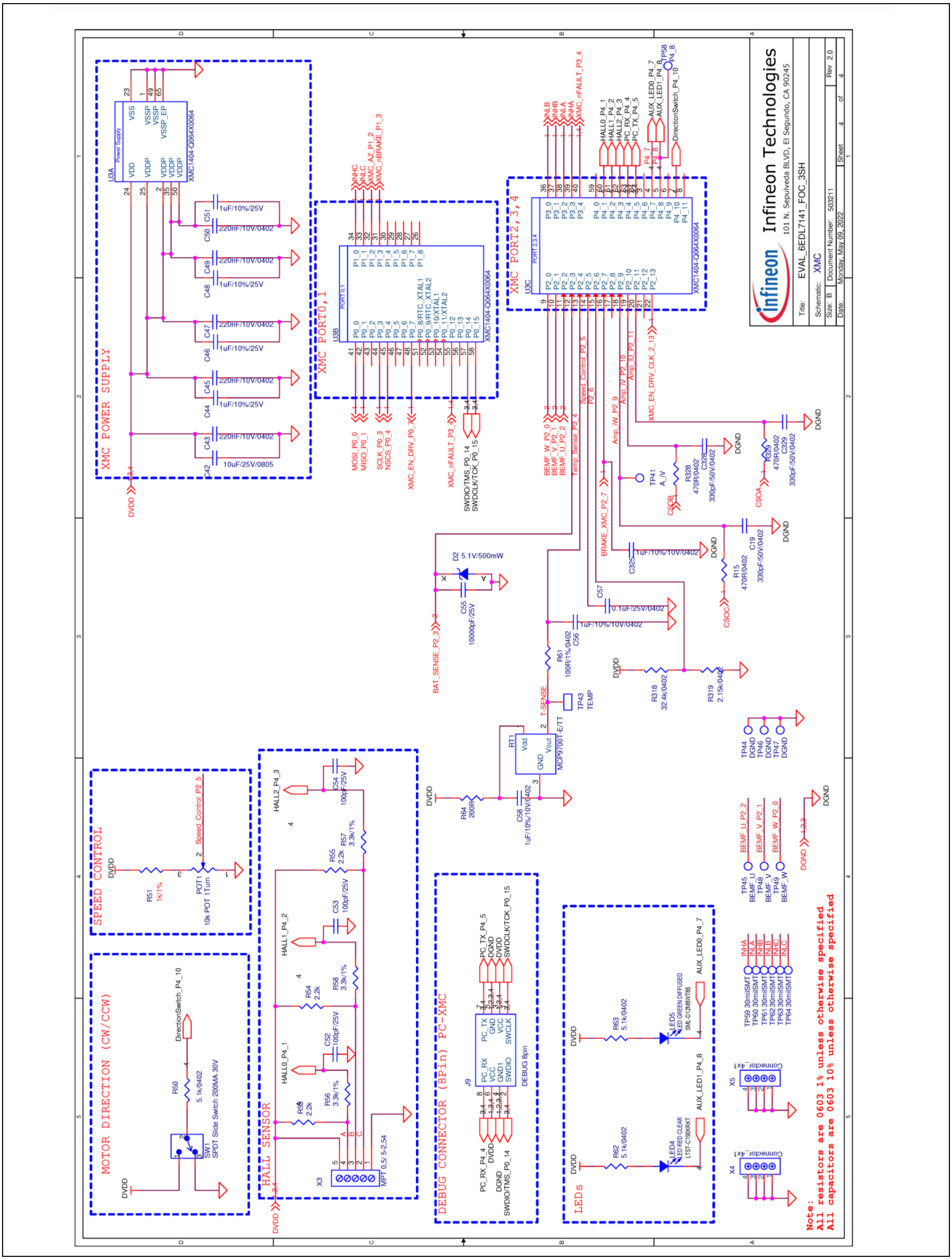

Figure 19 XMC1404 schematic

5.2 Layout

The EVAL_6EDL7141_FOC_3SH board consists of six copper PCB layers. All the layers have 2 oz. copper and the board size is 3.0 x 4.0 inches (76.2 x 101.6 mm). The board material is FR4 grade with 1.6 mm thickness. The Gerber files are available from the downloads section of the **Infineon website**. A login is required to download this material.

The PCB was logically divided into three areas to provide better routing for each section, as well as solid signal separation and shielding.

- Section 1 is the digital debugger section, which consists of all the logic components required to communicate with a PC via USB connection.

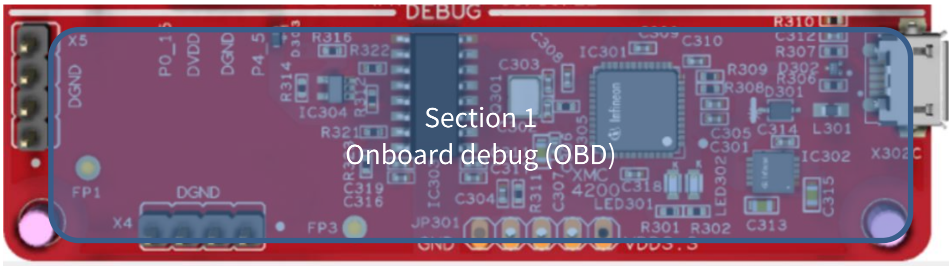

Figure 20 PCB layout section 1 – OBD

- Section 2 is the digital controller section, which includes Infineon's **XMC1404-Q064X0064** 32-bit microcontroller and MOTIX™ 6EDL7141 three-phase gate driver. This is a mostly low-digital logic-level section, except for the path to the power gate driver, which is based on the board input voltage (36 to 42 V). XMC1404 holds firmware for motor control, sets communication with the gate driver and processes all digital logic.

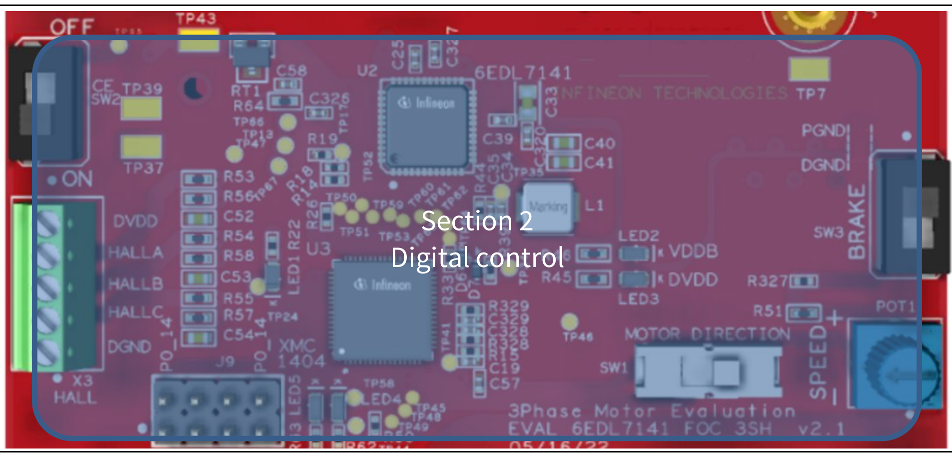

Figure 21 PCB layout section 2 – digital control

- Section 3 is the three-phase inverter section, which holds six Infineon **IST011N06NM5** MOSFETs, 60 V, 1.1 mΩ sTOLL input bypass capacitor, and low-side shunt resistors for current sense (CS). The low-side CS resistors must be positioned as close as possible to the inverter to minimize parasitic inductance and provide a shared ground loop for the inverter.

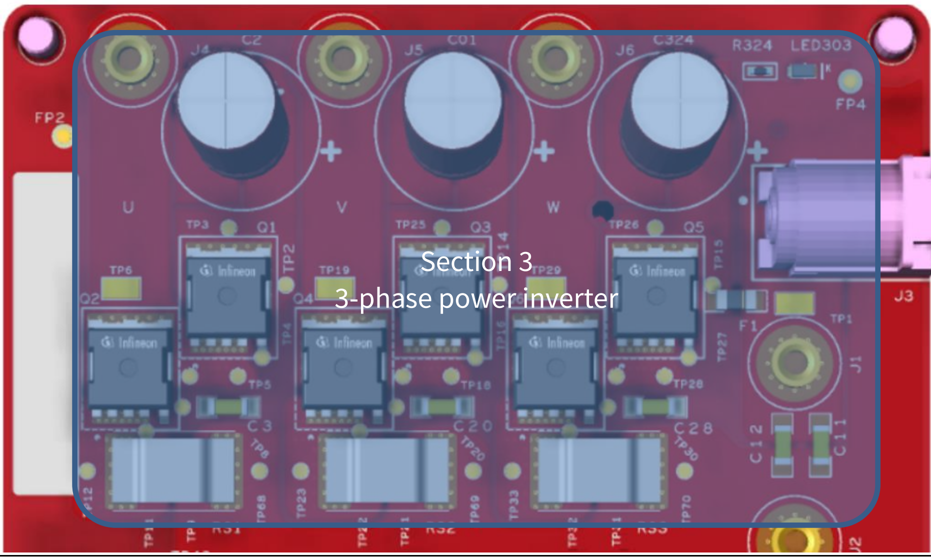

Figure 22 **PCB layout section 3 – three-phase power inverter**

Layout was optimized for FOC current sensing by routing the CS path to the controller in the mid 2 layer with the ground layer to the adjacent layer. When routing noise sensitive signals the designer must also consider the impact of electrical noise, especially when the current is low, as any nearby high dv/dt signal can compromise the integrity of the CS signal.

The design incorporates via in-pad plated-over (VIPPO) technology to increase vertical heat spread and provide high power dissipation for the inverter section, shunts and IC, as well as other devices that require heat spread.

The top layer, mid 1 layer, mid 2 layer, mid 3 layer, mid 4 layer and bottom layer PCB layouts are shown in **Figure 23** to **Figure 28**.

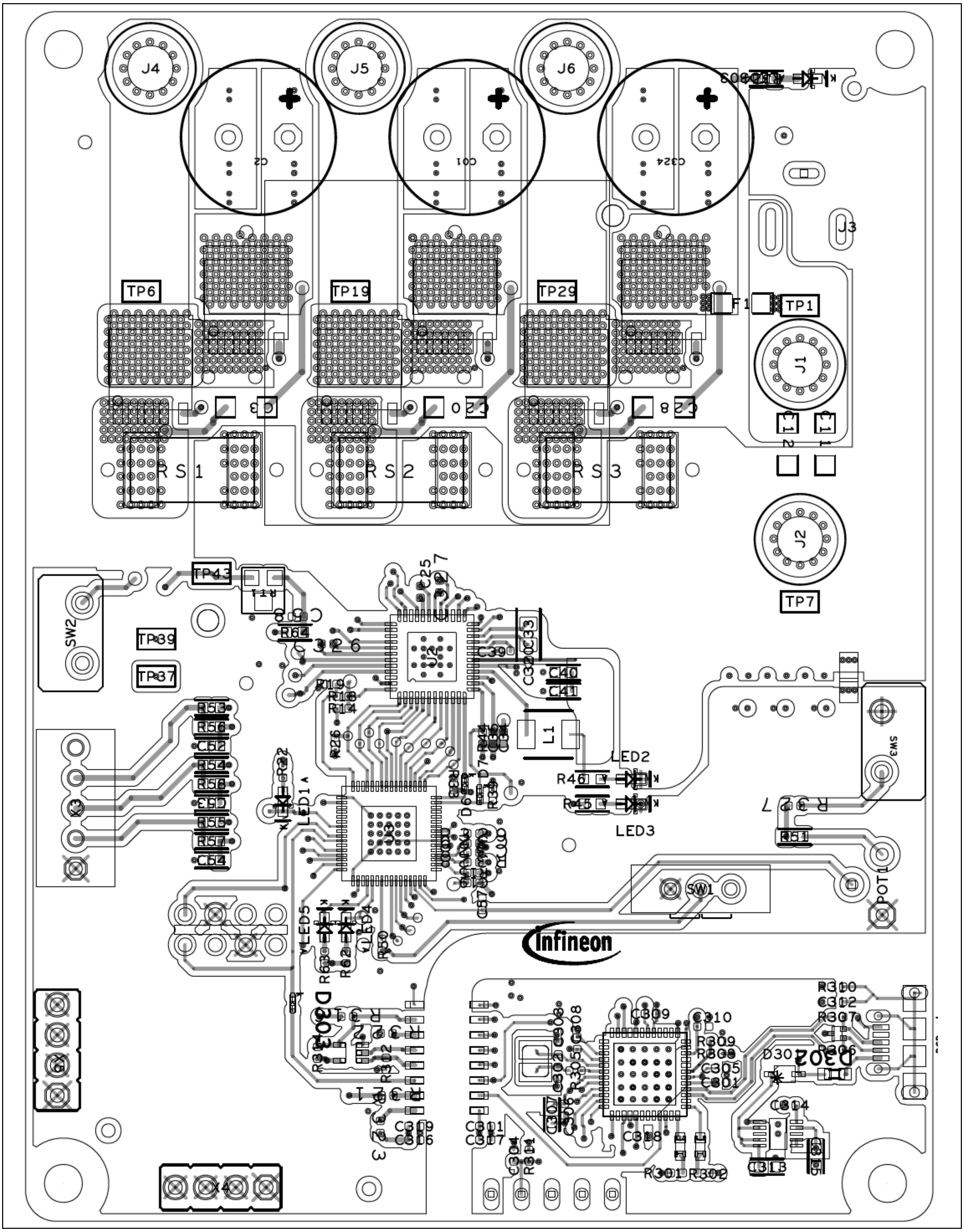

Figure 23 Top layer

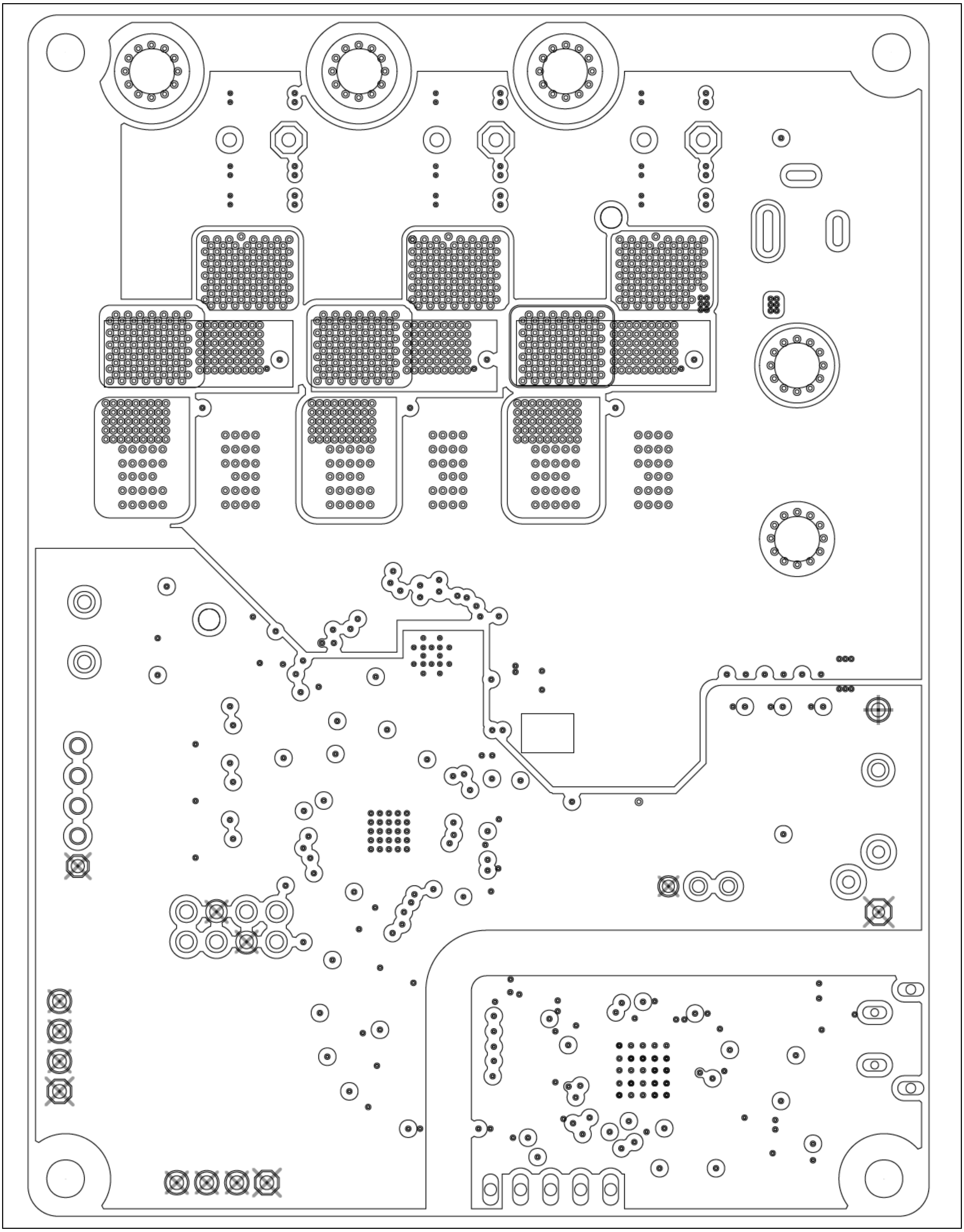

Figure 24 **Mid 1 layer**

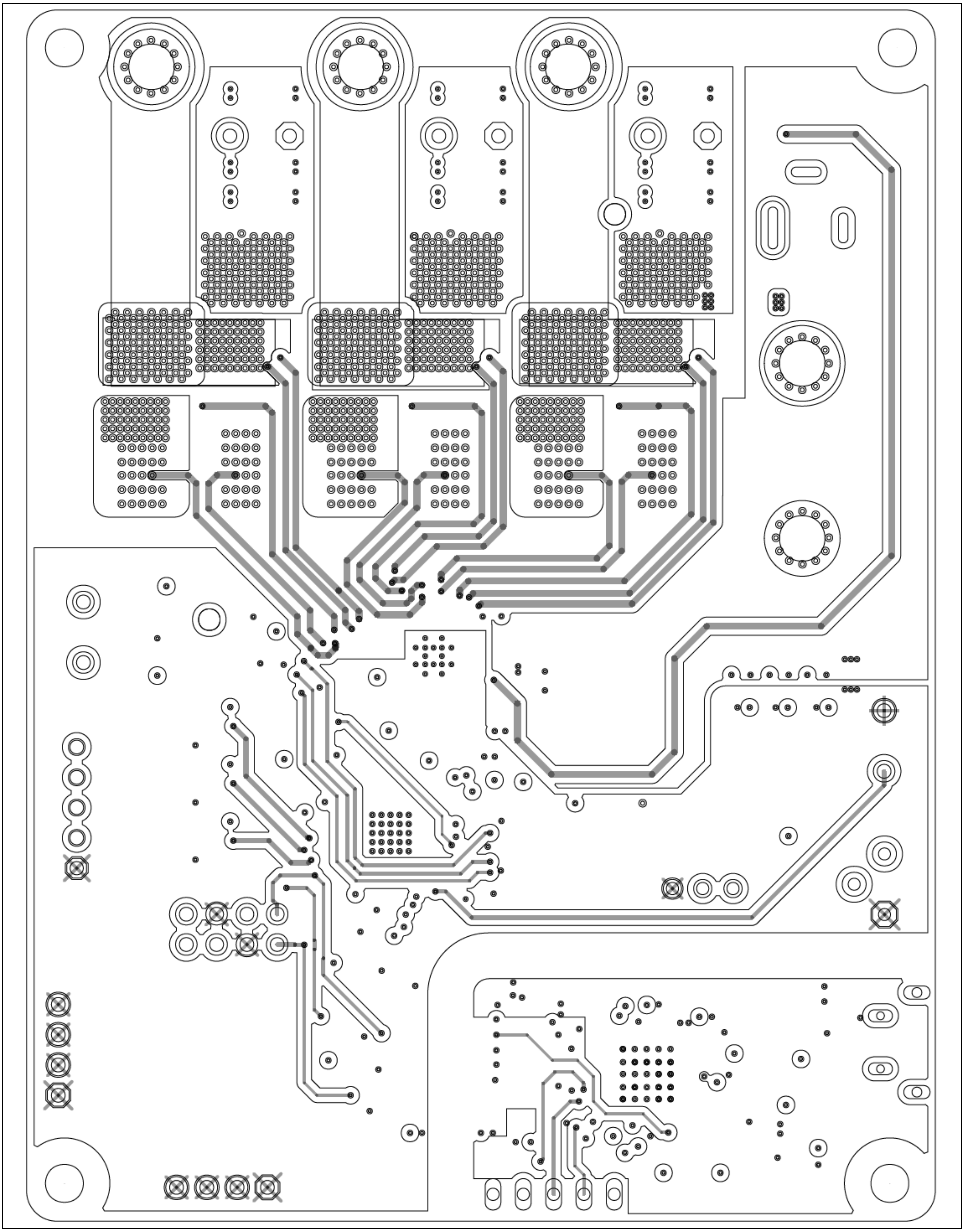

Figure 25 **Mid 2 layer**

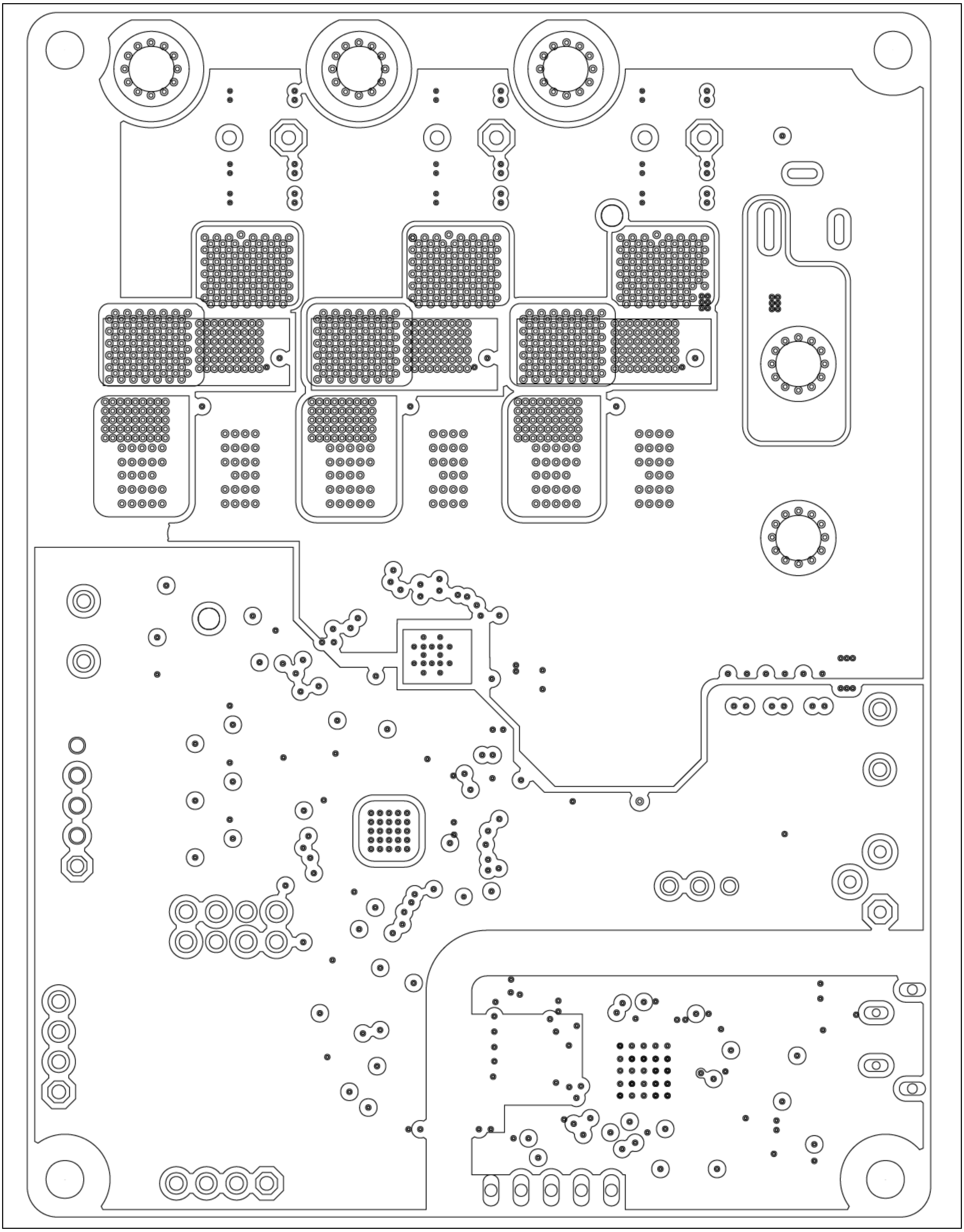

Figure 26 Mid 3 layer

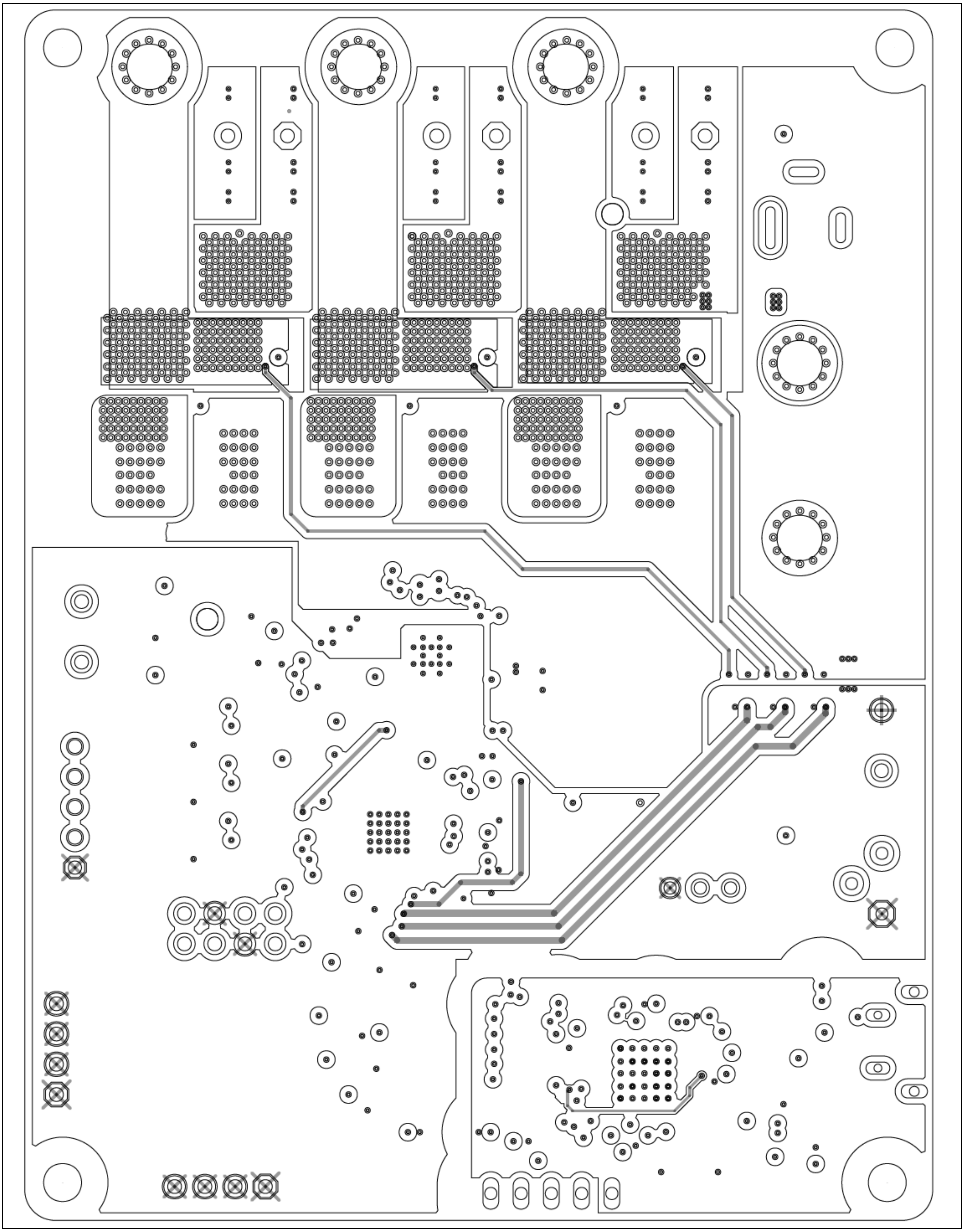

Figure 27 Mid 4 layer

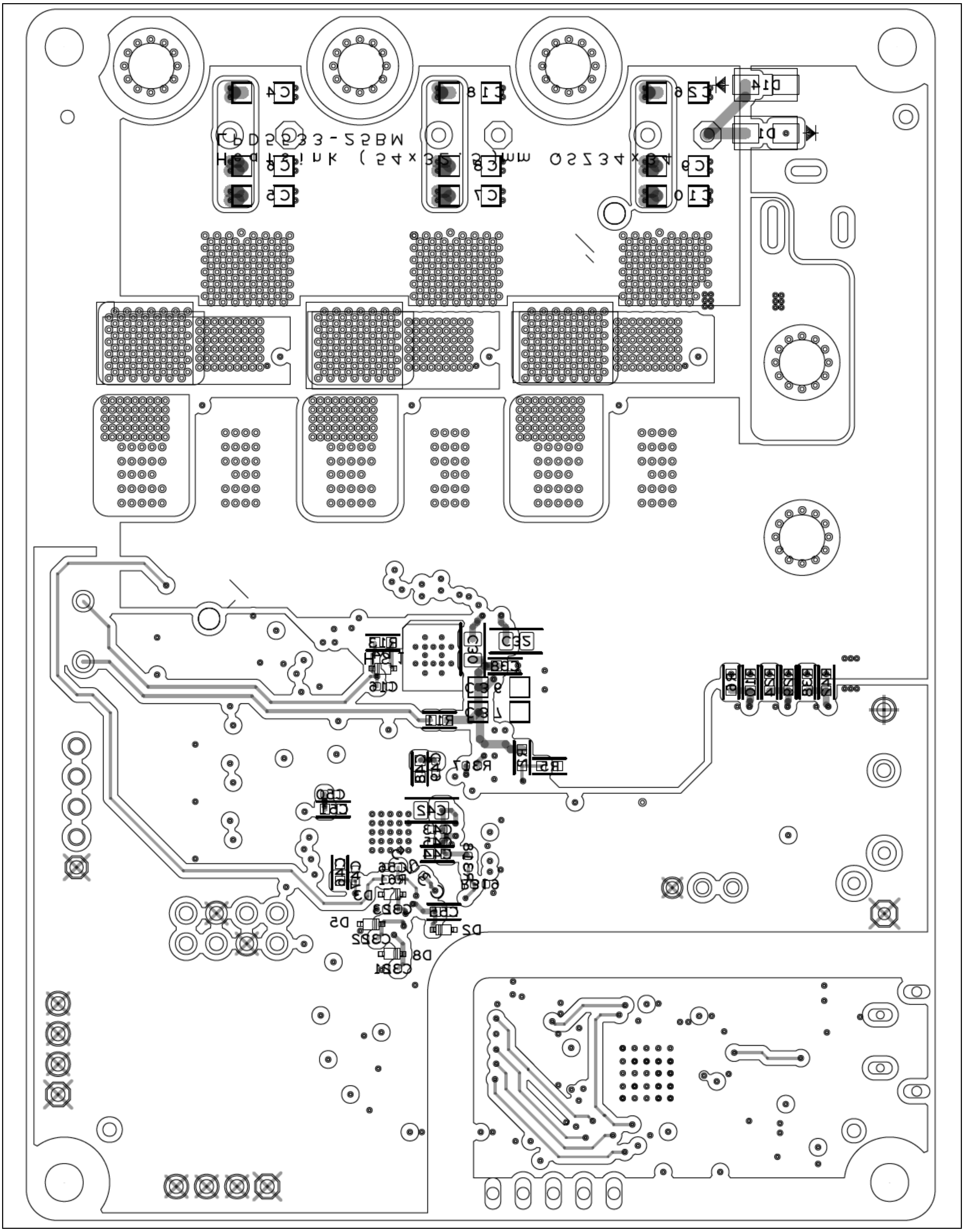

Figure 28 **Bottom layer**

5.3 Bill of materials

The complete bill of materials (BOM) is available from the downloads section of the **Infineon website**. A login and product registration might be required to download this material.

Table 4 BOM of the evaluation board EVAL_6EDL7141_FOC_3SH

Item	Qty.	Description	References	Manufacturer	Part number
1	3	270 µF, 80 V, 20%, radial	C01, C2, C324	United Chemi-Con	EKYB800ELL271MK20S
2	11	2.2 µF, 100 V, 10%, 1206	C3, C5, C6, C7, C8, C9, C10, C11, C12, C20, C28	TDK Corporation	C3216X7S2A225K160AB
3	5	4.7 µF, 100 V, 10%, 1206	C4, C18, C26, C36, C37	Murata	GRM31CC72A475KE11L
4	3	0.1 µF, 25 V, 10%, 0402	C16, C57, C320	Samsung	CL05A104KA5NNNC
5	3	330 pF, 50 V, 10%, 0402	C19, C328, C329	Murata	GCM155R71H331KA37D
6	3	100 pF, 25 V, 5%, 0402	C25, C326, C327	Kemet	C0402C101J3GACTU
7	2	2.2 µF, 25 V, 10%, 0805	C30, C32	Samsung	CL21A225KAFNNNG
8	1	0.22 µF, 50 V, 10%, 0805	C33	Kemet	C0805C224K5RACAUTO
9	1	0.1 µF, 10 V, 10%, 0402	C34	Samsung	CL05A104KP5NNNC
10	1	10 µF, 10 V, 20%, 0402	C35	Samsung	CL05A106MP5NUNC
11	1	0.1 µF, 100 V, 10%, 0603	C38	Yageo	CC0603KRX7R0BB104
12	1	0.22 µF, 25 V, 10%, 0402	C39	Murata	GRT155R61E224ME01D
13	2	22 µF, 16 V, 20%, 0603	C40, C41	Samsung	CL10A226MO7JZNC
14	1	10 µF, 25 V, 10%, 0805	C42	Samsung	CL21A106KAFN3NE
15	5	220 nF, 10 V, 10%, 0402	C43, C45, C47, C49, C50	TDK	GRM155R61A224KE19J
16	4	1 µF, 25 V, 10%, 0603	C44, C46, C48, C51	Samsung	CL10A105KA8NNNC
17	3	100 pF, 25 V, 5%, 0603	C52, C53, C54	AVX	06033A101JAT2A
18	1	10000 pF, 25 V, 10%, 0603	C55	AVX	06033D103KAT2A
19	3	1 µF, 10 V, 10%, 0402	C56, C58, C325	Murata	GRM155C81A105KA12D
20	10	100 nF, 25 V, 10%, 0402	C301, C305, C306, C308, C309, C310, C311, C312, C318, C319	Vishay	VJ0402Y104KXXCW1BC
21	2	15 pF, 25 V, 5%, 0402	C302, C303	Walsin Technology Corporation	0402N150J250CT
22	2	10 nF, 25 V, 5%, 0402	C304, C314	Kemet	C0402C103J3RACTU
23	1	4.7 µF, 25 V, 20%, 0603	C307	Taiyo Yuden	TMK107BBJ475MA-T
24	2	10 µF, 25 V, 20%, 0603	C313, C315	Murata	GRM188R61E106MA73J
25	2	1 µF, 6.3 V, 10%, 0402	C316, C317	Taiyo Yuden	JMK105BJ105KV-F

Item	Qty.	Description	References	Manufacturer	Part number
26	3	2200 pF, 50 V, 10%, 0402	C321, C322, C323	TDK Corporation	C1005X5R1H222K050BA
27	1	100 V, 2 A, SMA	D1	STMicroelectronics	STPS2H100AY
28	5	5.1 V, 500 mW	D2, D3, D4, D5, D8	On-Semi	MM5Z5V1T1G
29	3	30 V, 500 mA, SC79-2	D6, D7, D303	Infineon Technologies	BAS3005A02VH6327XTSA1
30	1	TVS, 40 V_{WM}, 64.5 V C, SMA	D14	Eaton – Electronics Division	SMAJE40A
31	1	30 V, 1 A, SOD-323	D301	Infineon Technologies	BAS3010A-03W
32	1	TVS, 5.3 V_{WM}, 15 V C, TSFP-3	D302	Infineon	ESD5V3U2U03FH6327XTSA1
33	1	10 A, 32 V AC, 63 V DC	F1	Littelfuse Inc.	0458010.DR
35	1	Heatsink-LPD5433-25BM-Z_QSZ, 34 x 34 mm	hs1	AlphaNovatech	LPD52x27-25-QSZ34x34
36	1	IC MCU 32-bit 256 kB Flash 48 V_{QFN}	IC301	Infineon	XMC4200Q48K256BAXUMA1
37	1	IC linear regulator, 3.3 V, 300 mA, TSON-10	IC302	Infineon	IFX54441LDV33XUMA1
38	1	Digital ISO, 2500 V_{RMS}, 6-ch GP 16-SOIC	IC303	Silicon Labs	634-SI8662BB-B-IS1
39	1	IC non-inverter buffer 5.5 V 5TSSOP	IC304	Nexperia	74LVC1G126GW,125
42	1	Jack 5.5 x 2.1 mm (6 A)	J3	Tensility International Corp	-
46	1	Vertical header connector 8-position 2.54 mm	J9	Adam Tech	PH2-08-UA
47	1	Vertical header connector 5-position 2.54 mm	JP301	Harwin	PINHD-1X5
48	1	22 µH, 1.2 A, 4020	L1	Bourns	SRP4020TA-220M
49	1	74279267	L301	Würth Elektronik	74279267
50	3	Clear red LED	LED1, LED4, LED303	Lite-On Inc.	LTST-C190KRKT
51	1	Blue diffused LED	LED2	OSRAM	LB Q39G-L2OO-35-1
52	2	Green diffused LED	LED3, LED5	Rohm Semiconductor	SML-D12M8WT86
53	1	Green diffused LED	LED301	Rohm Semiconductor	SML-D12M8WT86
54	1	Clear red LED	LED302	Lite-On Inc.	LTST-C190KRKT
55	1	Potentiometer, 10 k, 1 turn	POT1	Bourns Inc.	3362P-1-103TLF
56	6	N-channel, 60 V, 38 A, 3.8 W, PG-HSOF-5-1	Q1, Q2, Q3, Q4, Q5, Q6	Infineon Technologies	IST011N06NM5AUMA1
57	1	Crystal, 120000 MHz, 8 pF, SMD	Q301	Kyocera	CX3225GA12000D0PTVCC
58	1	75 k, 0.1 W, 1%, 0603	R2	Panasonic	ERJ-3EKF7502V
59	1	7.87 k, 0.1 W, 1%, 0603	R5	Yageo	RC0603FR-077K87L
60	3	56 k, 0.1 W, 1%, 0603	R6, R24, R38	Yageo	RC0603FR-0756KL
61	4	5.6 k, 0.1 W, 1%, 0603	R10, R29, R42, R324	Stackpole	RMCF0603FT5K60
62	1	100 k, 0.1 W, 1%, 0603	R11	Yageo	RC0603FR-07100KL
63	1	22 k, 0.1 W, 1%, 0603	R13	Yageo	RC0603FR-0722KL
64	1	3.3 k, 0.1 W, 1%, 0402	R14	KOA	RK73H1ETTP3301F

Item	Qty.	Description	References	Manufacturer	Part number
65	3	470 R, 0.1 W, 1%, 0402	R15, R328, R329	Panasonic	ERJ-2RKF4700X
66	1	1.8 k, 0.063 W, 0.1%, 0402	R18	Panasonic	ERA-2AEB182X
67	9	5.1 k, 0.1 W, 5%, 0402	R19, R22, R26, R33, R39, R50, R62, R63, R327	Panasonic	ERJ-2GEJ512X
68	4	10 k, 0.063 W, 5%, 0402	R44, R309, R311, R312	Yageo	RC0402JR-0710KL
69	2	10 k, 0.1 W, 5%, 0603	R45, R46	Yageo	RC0603JR-0710KL
70	1	1 k, 0.1 W, 1%, 0603	R51	Yageo	RC0603FR-071KL
71	3	2.2 k, 0.1 W, 1%, 0603	R53, R54, R55	Yageo	RC0603FR-072K2L
72	3	3.3 k, 0.1 W, 1%, 0603	R56, R57, R58	Yageo	RT0603FRE073K3L
73	1	100 R, 0.063 W, 1%, 0402	R61	Yageo	RC0402FR-07100RL
74	1	200 R, 0.1 W, 1%, 0603	R64	KOA	AC0603FR-07200RL
75	2	680 R, 0.063 W, 1%, 0402	R301, R302	Vishay	CRCW0402680RFKEDC
76	1	510 R, 0.1 W, 1%, 0402	R305	Panasonic Electronic Components	ERJ-2RKF5100X
77	2	22 R, 0.1 W, 5%, 0402	R306, R307	Panasonic	ERJ-2GEJ220X
78	1	4k7, 0.1 W, 1%, 0402	R308	Panasonic	ERJ-2RKF4701X
79	2	1 M, 0.063 W, 1%, 0402	R310, R314	Yageo	RC0402FR-071ML
80	4	0 R, 0.1 W, 0402	R316, R321, R322, R323	Panasonic	ERJ-2GE0R00X
81	1	3 k, 0.063 W, 1%, 0402	R317	Panasonic	RMCF0402FT3K00
82	1	32.4 k, 0.063 W, 1%, 0402	R318	Bourns	CR0402-FX-3242GLF
83	1	2.15 k, 0.063 W, 1%, 0402	R319	Vishay	RC0402FR-072K15L
84	3	0.5 m, 5 W, 1%, 3920	RS1, RS2, RS3	Stackpole Electronics Inc.	HCS3920FT1L00
85	1	Analog sensor, -40°C to 125°C, SOT-23-3	RT1	Microchip	MCP9700T-E/TT
86	4	Standoff hex, #4-40, aluminum, 3/8 in.	ST1, ST2, ST3, ST4	Keystone	8400
87	1	SPDT slide switch, 200 mA, 30 V	SW1	E-Switch	EG1218
88	2	SPST slide switch, 0.4 V_A, 28 V	SW2, SW3	NKK Switches	AS11CP
89	1	3-phase smart gate drive control	U2	Infineon	6EDL7141
90	1	MCU, 32-bit, 64 kB Flash, 64 V_{QFN}	U3A	Infineon	XMC1404Q064X0064AAXUMA1
91	1	Block terminator, 5-pin, side entry, 2.54 mm PCB	X3	PHOENIX CONTACT	1725685
92	2	Vertical 4-position header, 2.54 mm	X4, X5	Any	PH1-04-UA
93	1	Receptor, USB 2.0, Micro AB, SMD, RA	X302C	Würth Elektronik	629105150921

References

[1] Infineon Technologies AG: MOTIX™ 6EDL7141, Datasheet (Rev. 1.06); 2022-03-08; **MOTIX™ 6EDL7141**

[2] Infineon Technologies AG: EVAL_6EDL7141_TRAP_1SH 18 V brushless DC motor drive board, Application note (V 1.1); 2021-11-15; **EVAL_6EDL7141_TRAP_1SH 18 V brushless DC motor drive board**

[3] Infineon Technologies AG: EVAL_IMD700A_FOC_3SH 18 V brushless DC motor drive board, Application note (V 1.0); 2022-03-15; **EVAL_IMD700A_FOC_3SH 18 V brushless DC motor drive board**

[4] SEGGER: SEGGER Software Licensing. **Available online**

[5] Infineon Technologies AG: PMSM FOC motor control software using XMC™, Application note (V 1.0); **PMSM FOC motor control software using XMC™**

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