REF_2200W_DRHSC_XDP user guide

54 V to 12 V 2200 W dual-stage hybrid switching capacitor (DR-HSC) converter

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About this document

Scope and purpose

This document is to show the performance of the 2200 W dual-stage hybrid switched capacitor (DR-HSC) DC-DC converter design and to highlight design tips and considerations from the hardware and firmware perspective. This user guide details the reference board of a novel two-stage approach proposed by Infineon that addresses 48 V to 12 V non-isolated conversion for datacenters, cloud computing, and AI applications.

Intended audience

Power supply design engineers, system engineers, and embedded power designers.

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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 assembly's sensitive to electrostatic discharge (ESD). Electrostatic control precautions are required when installing, testing, servicing or repairing the assembly. Component damage may result if ESD control procedures are not followed. If you are not familiar with electrostatic control procedures, refer to the applicable ESD protection handbooks and guidelines.*
	Caution: *A drive that is incorrectly applied or installed can lead to component damage or reduction in product lifetime. Wiring or application errors such as undersizing the motor, supplying an incorrect or inadequate AC supply, or excessive ambient temperatures may result in system malfunction.*
	Caution: *The evaluation or reference board is shipped with packing materials that need to be removed prior to installation. Failure to remove all packing materials that are unnecessary for system installation may result in overheating or abnormal operating conditions.*

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1 Introduction

1.1 Overview

REF_2200W_DRHSC_XDP is a 2200 W non-isolated DC-DC converter aimed at emerging 48 V power structures in datacenters, cloud computing, and AI applications. As these applications demand increasingly more power, high-power non-isolated DC-DC converters are expected to become more popular and relevant. This reference board supports a 40 V–60 V input range and a regulated 12 V output. A two-stage approach is adopted in this reference design; the first stage is a 2:1 zero-voltage switching (ZVS) switched-capacitor converter (SCC)or ZSC to reduce the input by half, followed by a 3LFC-DP converter, which converts the mid voltage to a regulated 12 V output.

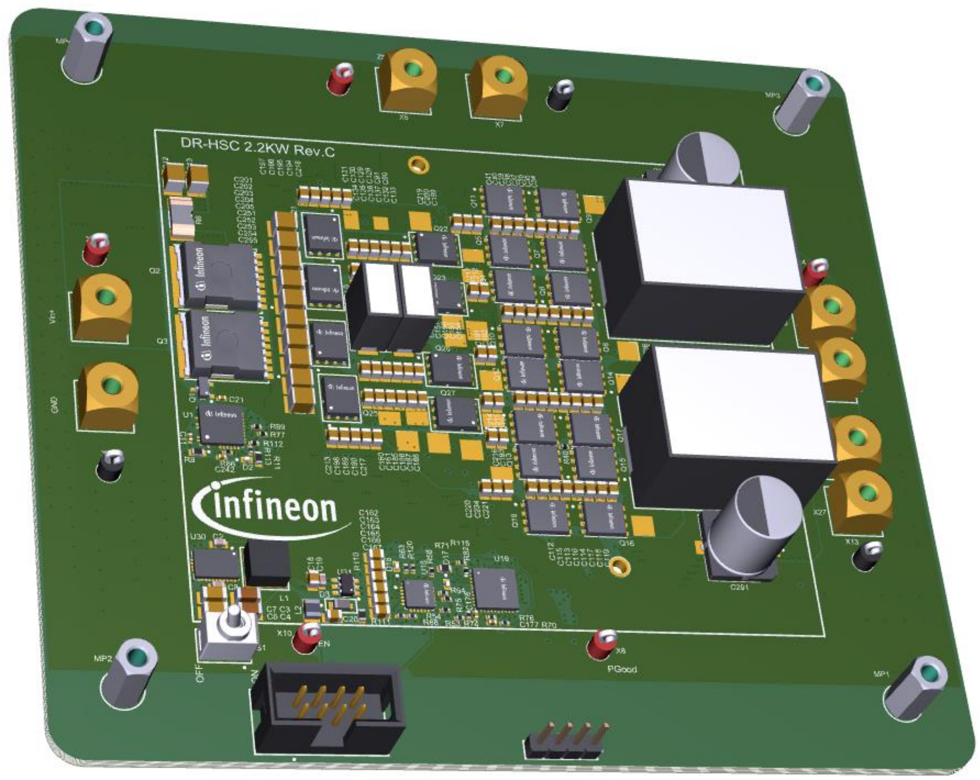

Figure 1 Isometric image of reference board (REF_2200W_DRHSC_XDP)

The main Infineon components used in the 2200 W digital DR-HSC are:

- OptiMOS™ 5 IPT010N08NM5, 80 V N-channel FET 1 mΩ, TOLL (HSOF-8), eFuse
- OptiMOS™ 6 BSC007N04LS6, 40 V 0.7 mΩ, ZSC FETs
- OptiMOS™ 5 BSC005N03LS5I, 30 V 0.5 mΩ, 3LFC-DP FETs
- 1EDN7550B Infineon's single-channel non-isolated gate-driver
- XDP™ XDP710 Infineon's intelligent hot-swap controller and protection IC
- XDP™ XDPP1100 The smallest digital power controller with PMBus interface
- XMC™ XMC1302 32-bit microcontroller with Arm® Cortex®-M0

Figure 2 REF_2200W_DRHSC_XDP board top view

1.2 Technical specifications

Table 2 Specifications

	Min.	Typ.	Max.	Unit
Input voltage range	40	54	60	V
Maximum input current (100 percent load, 54 V_{IN})	–	–	43	A
Output voltage (at V_{IN} = 42 V to 72 V)	–	12	–	V
Output current (at V_{IN} = 54 V, 235 m^3/h air flow or better forced air cooling, 25°C room temperature)	–	–	184	A
Output current (at V_{IN} = 48 V, 60 V, 235 m^3/h air flow (or better) forced air cooling, 25°C room temperature)	–	–	170	A
Output voltage regulation (V_{IN} = 54 V, load 0 A to 184 A)	–	±100	–	mV
Output voltage ripple (peak-to-peak at full load) With 990 µF output capacitor	–	–	300	mV

1.3 Layout

REF_2200W_DRHSC_XDP board consists of eight copper PCB layers. All the layers have 2 oz. copper, and the board size is 130 mm x 118 mm. The board material is FR4 grade with 1.6 mm thickness. PCB layouts are shown in the following figures.

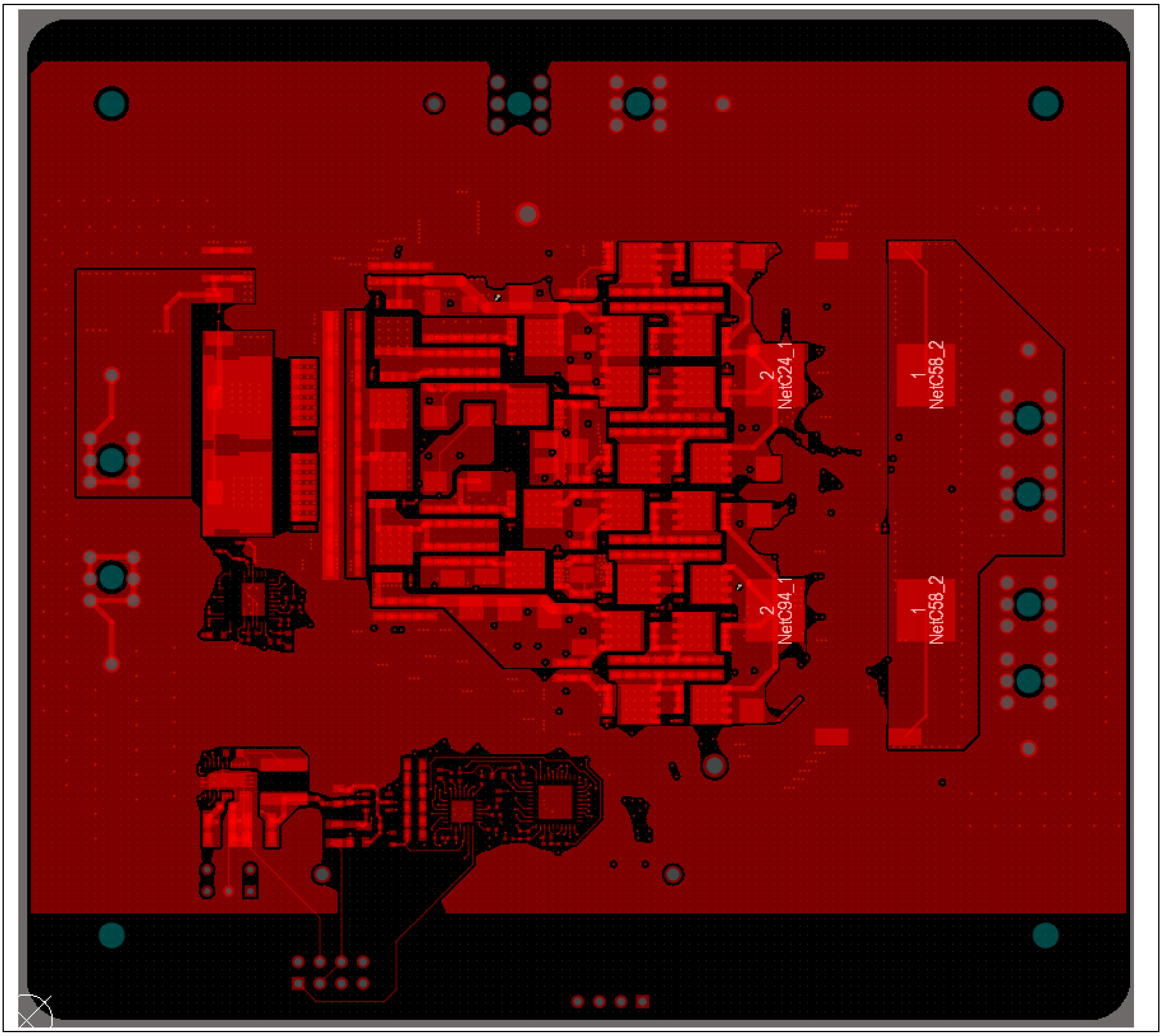

Figure 3 Top layer

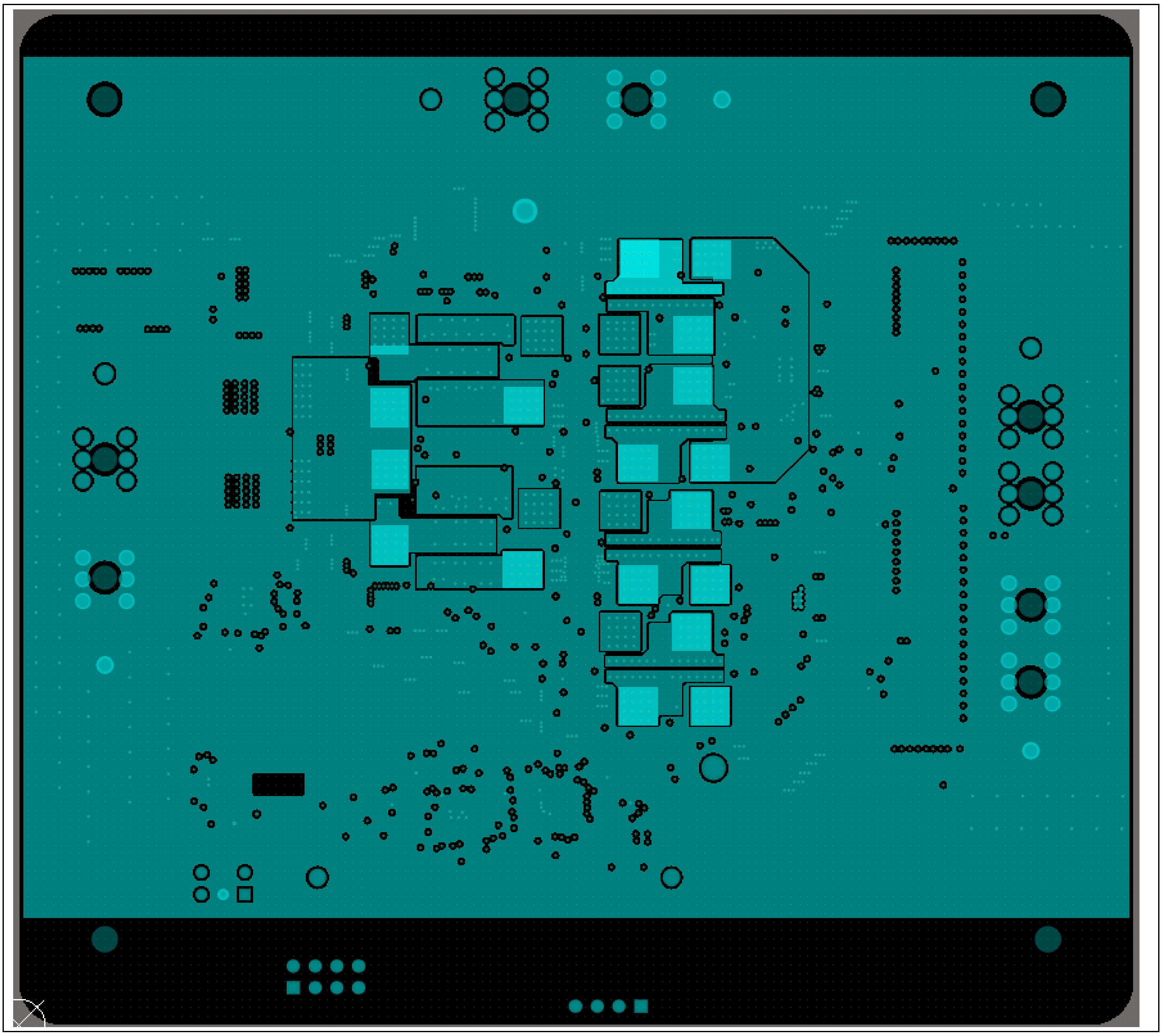

Figure 4 **Inner layer 1**

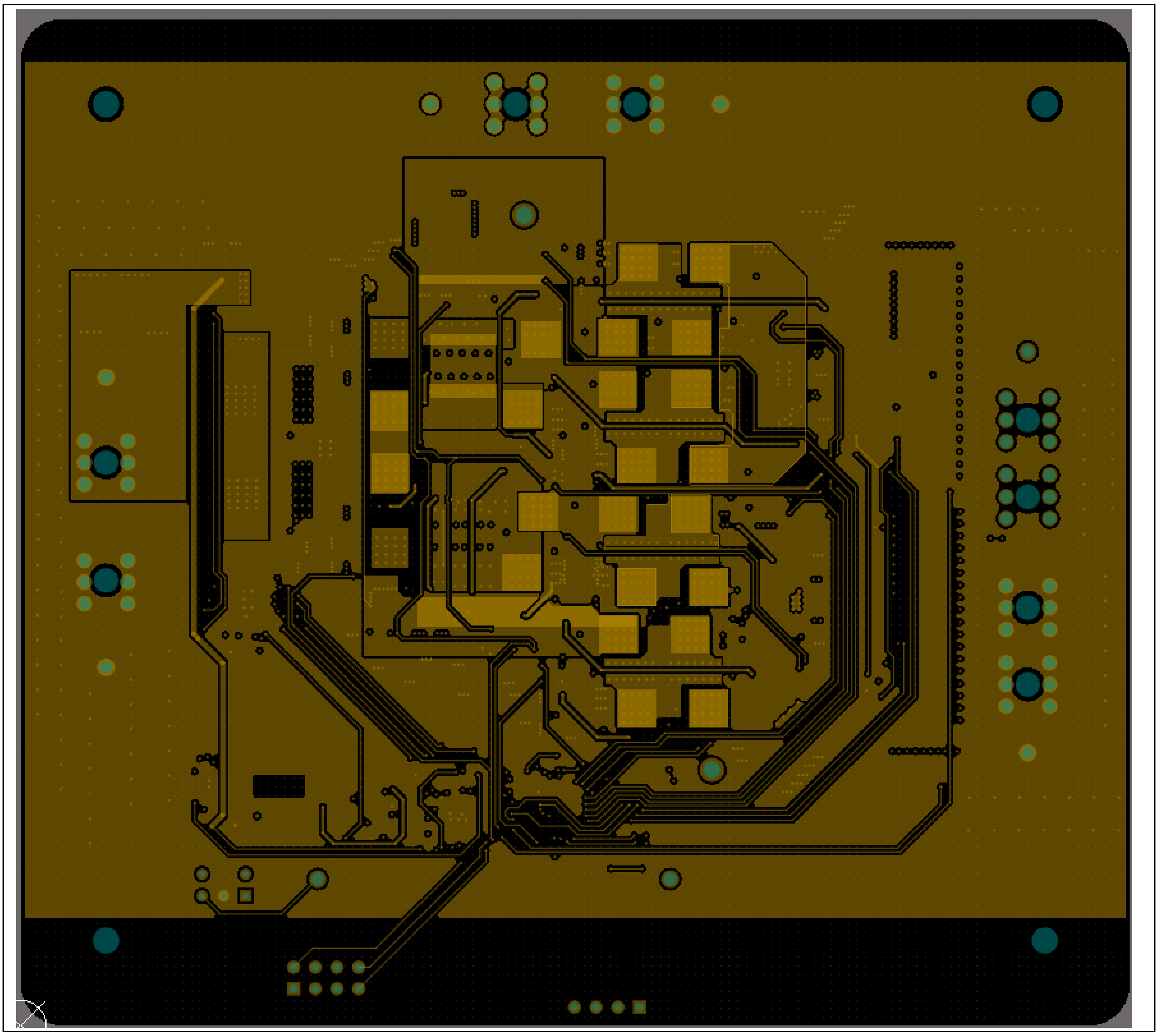

Figure 5 **Inner layer 2**

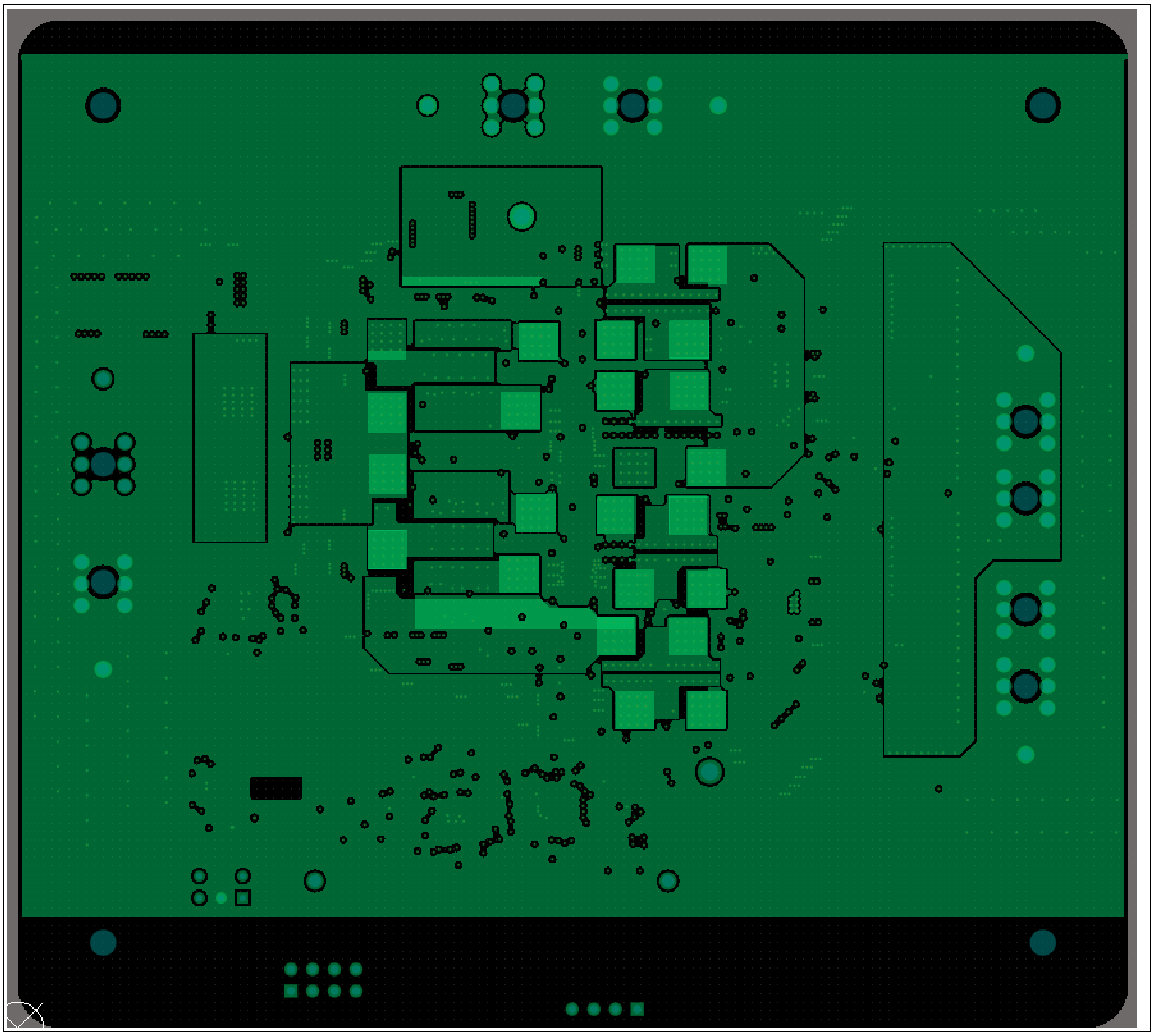

Figure 6 Inner layer 3

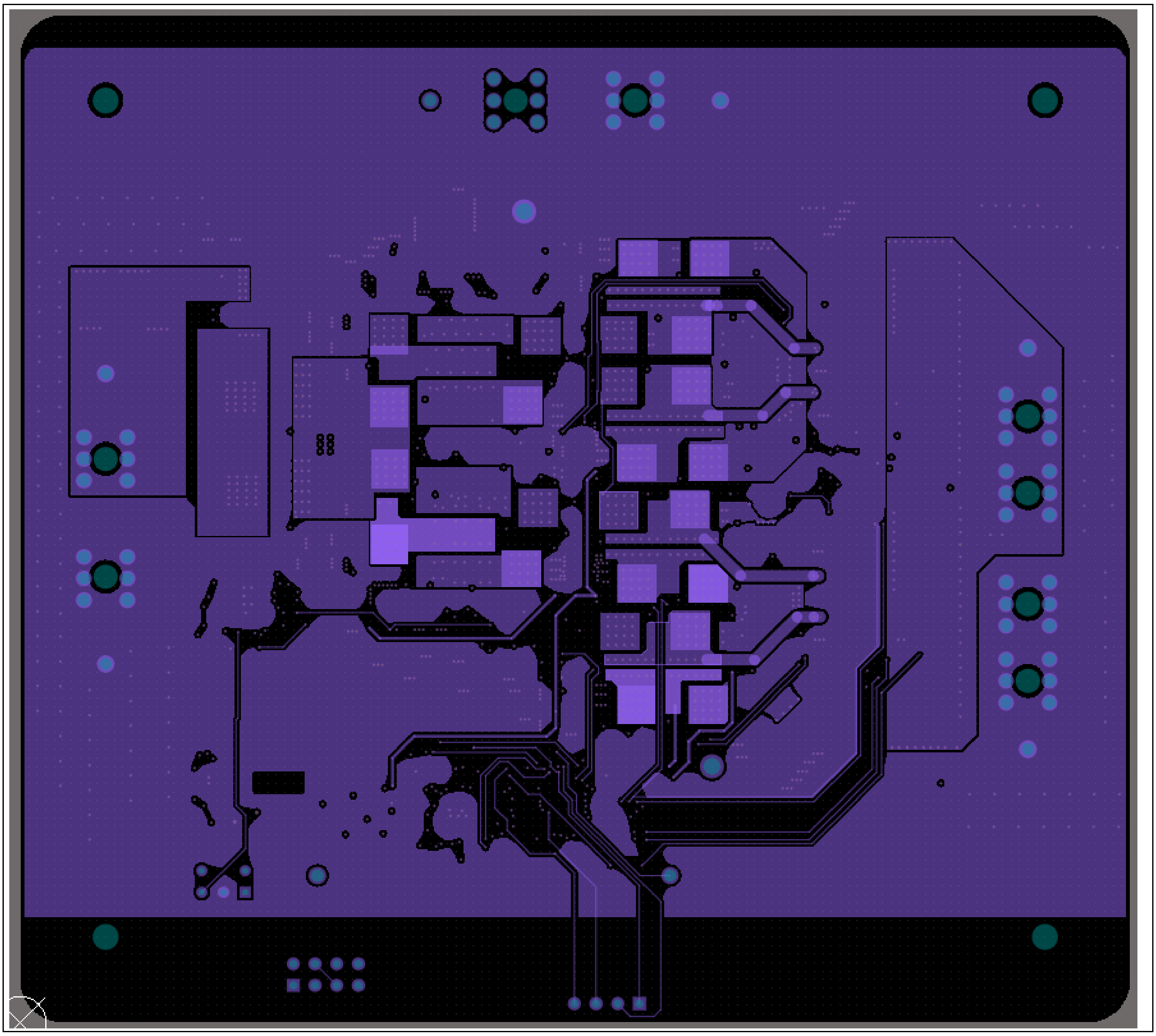

Figure 7 Inner layer 4

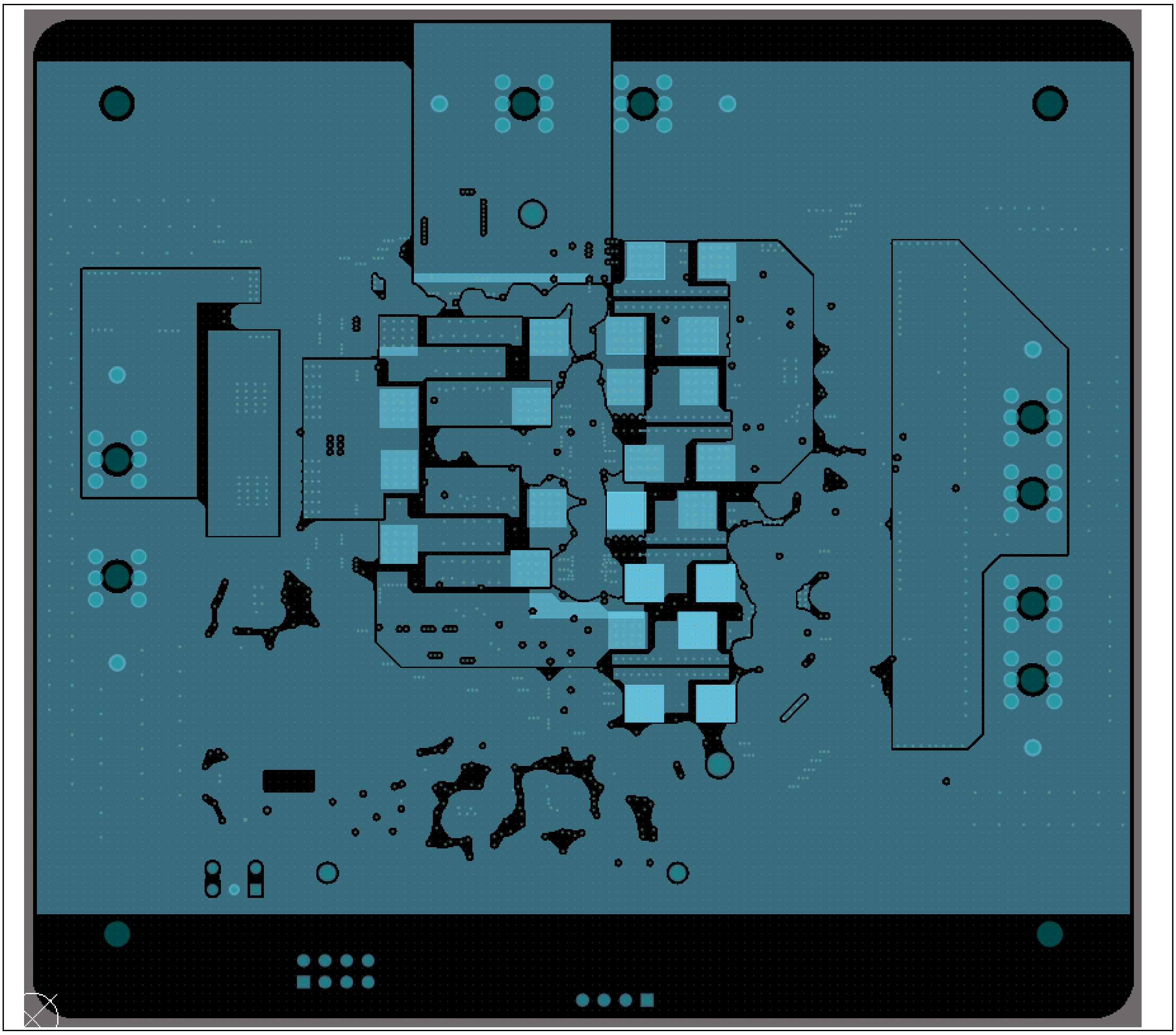

Figure 8 **Inner layer 5**

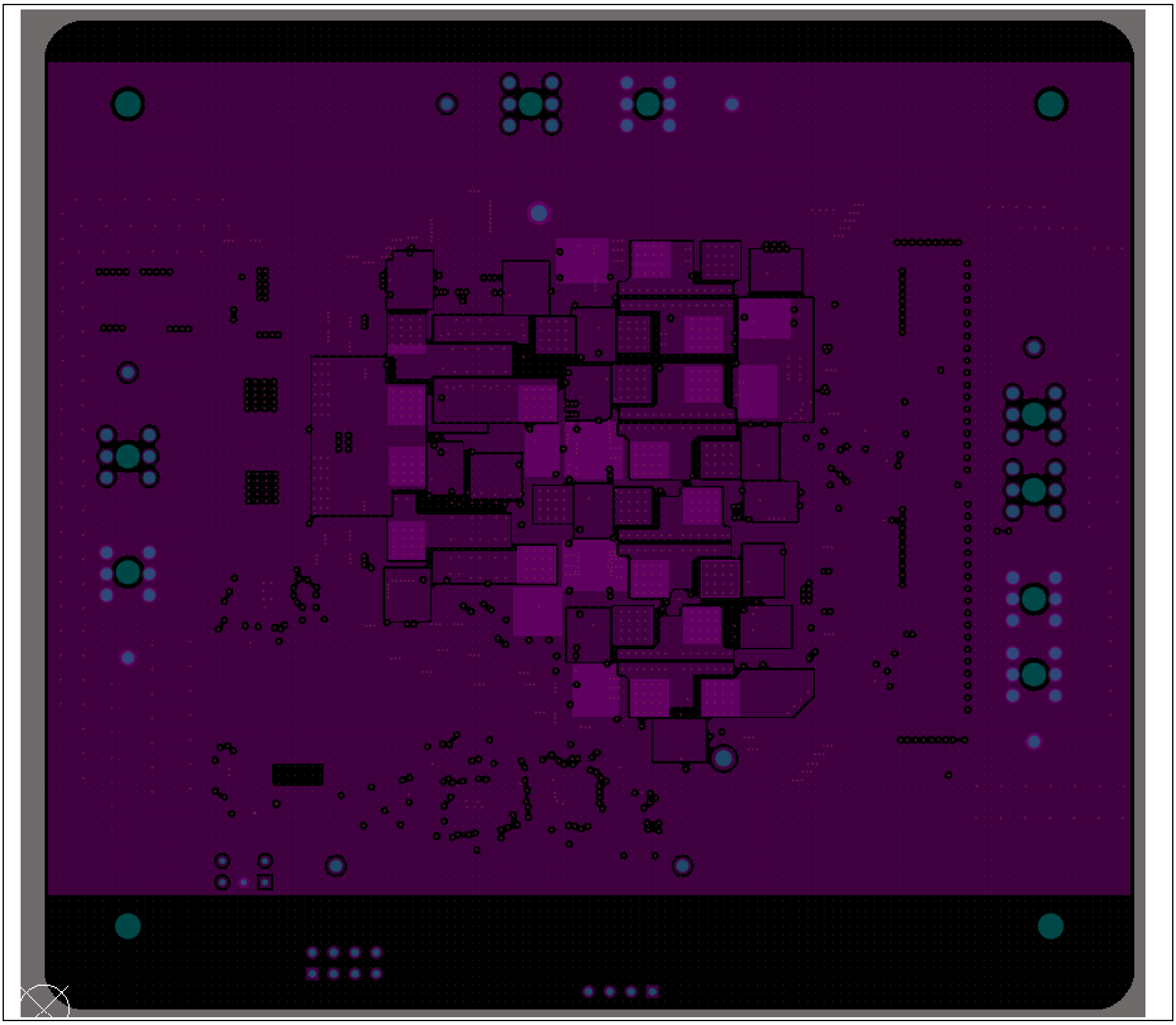

Figure 9 **Inner layer 6**

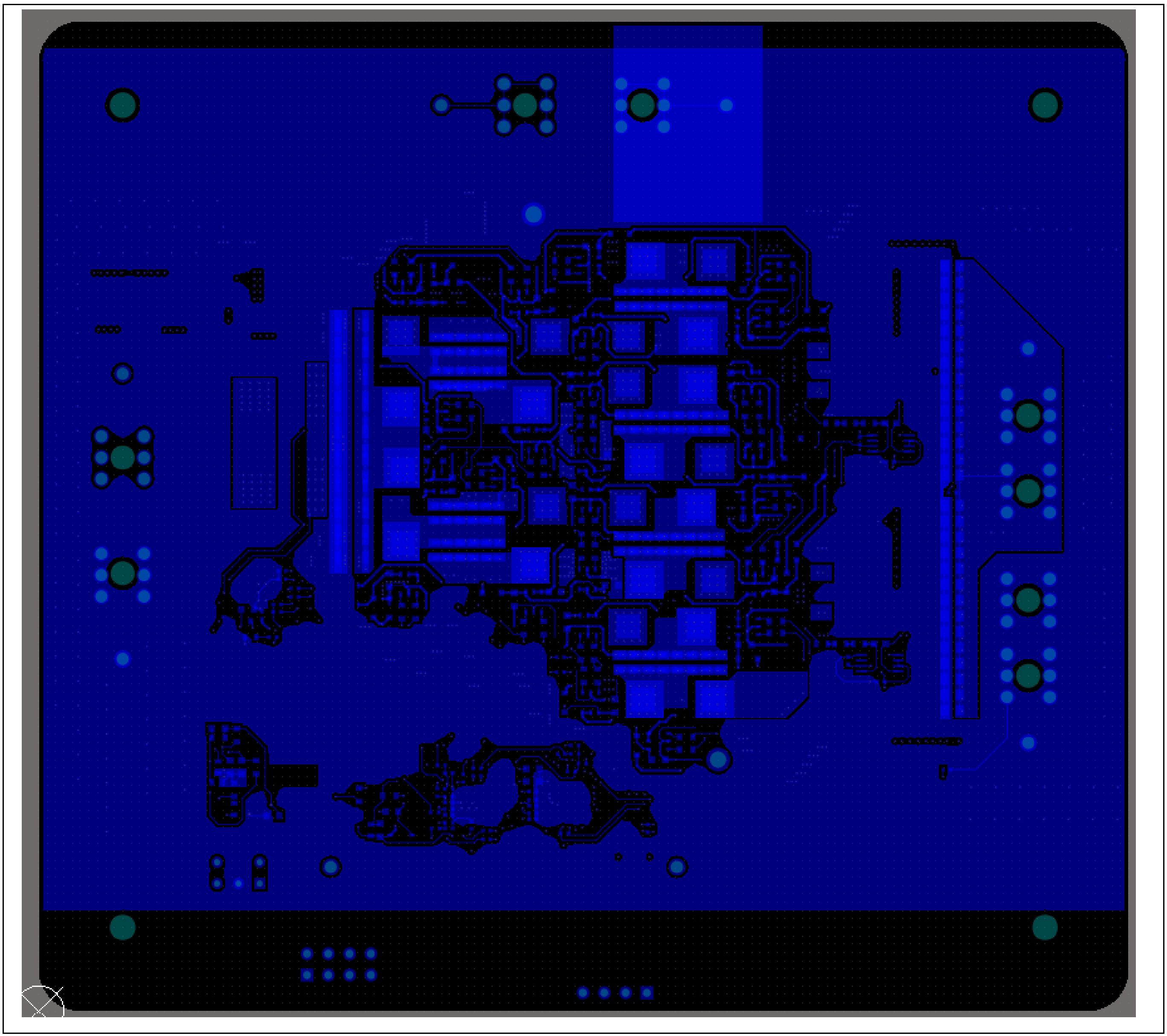

Figure 10 **Bottom layer**

1.4 Schematics

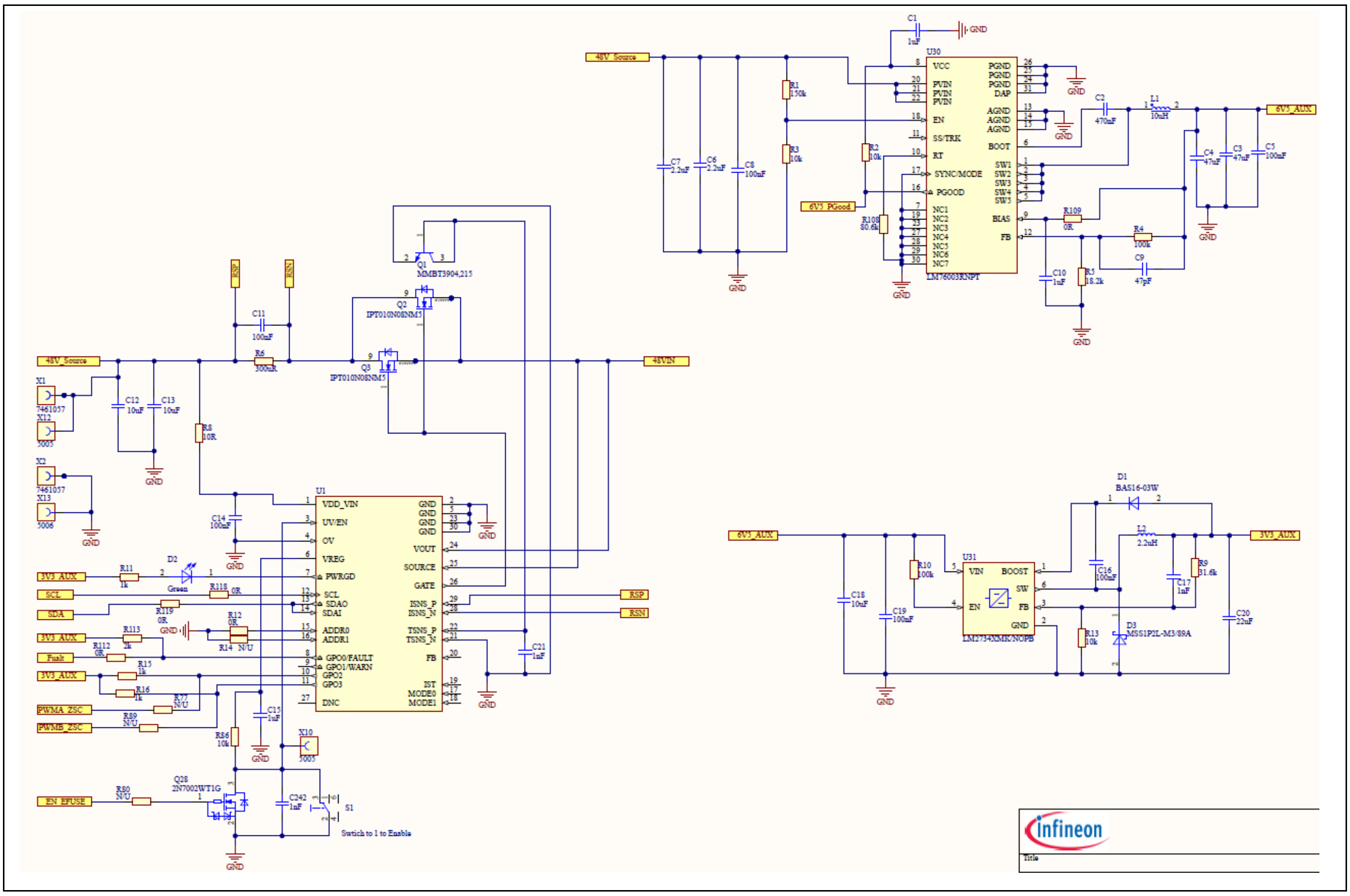

Figure 11 Hot-swap and auxiliary converter

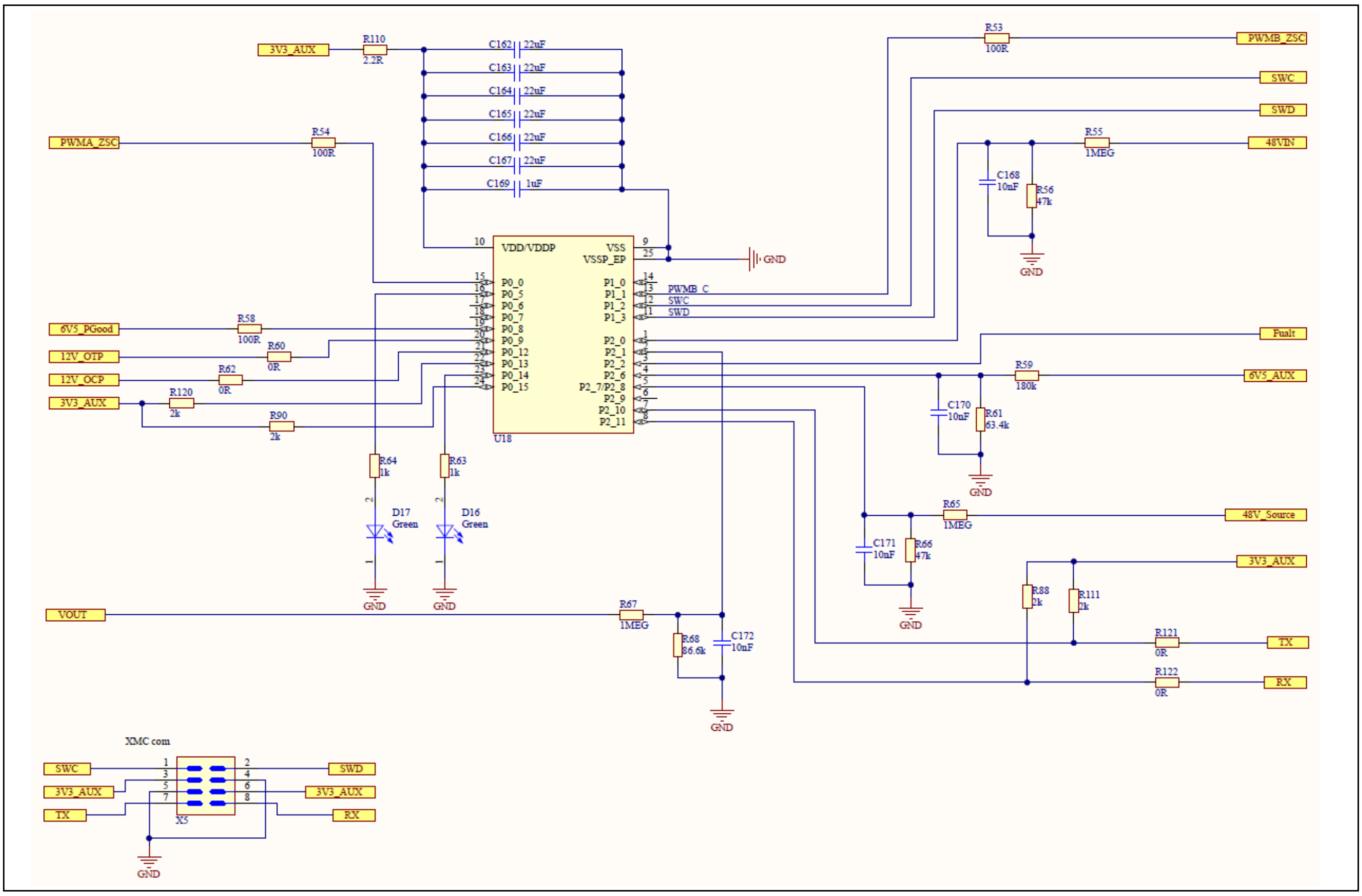

Figure 12 XMC1302 circuit

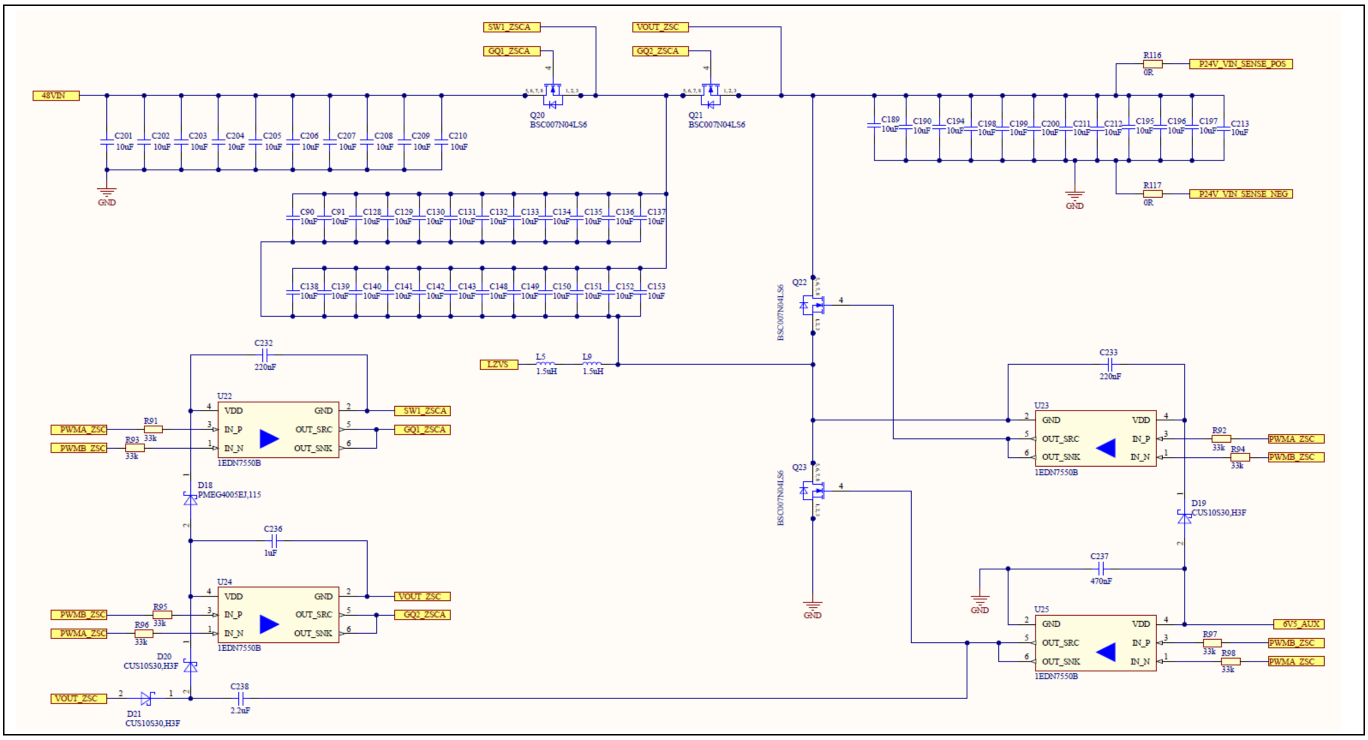

Figure 13 ZSC_A phase

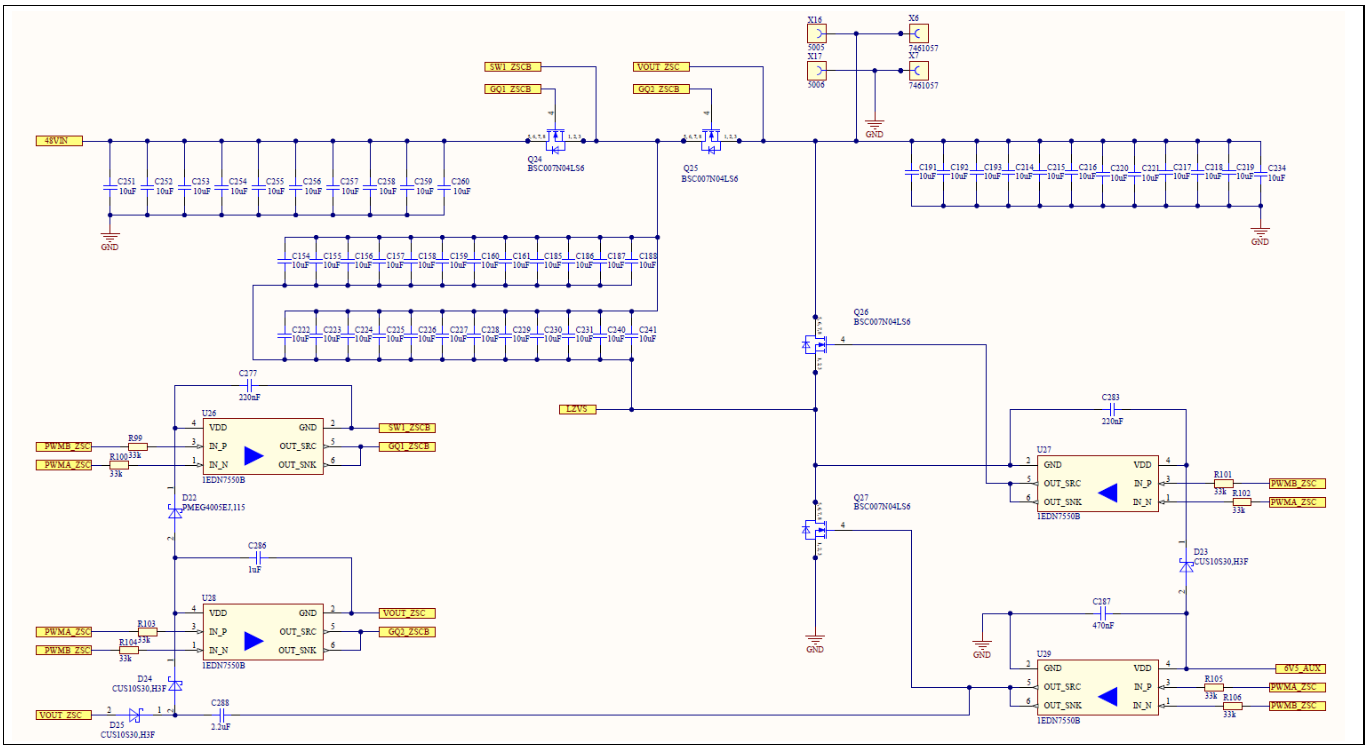

Figure 14 ZSC_B phase

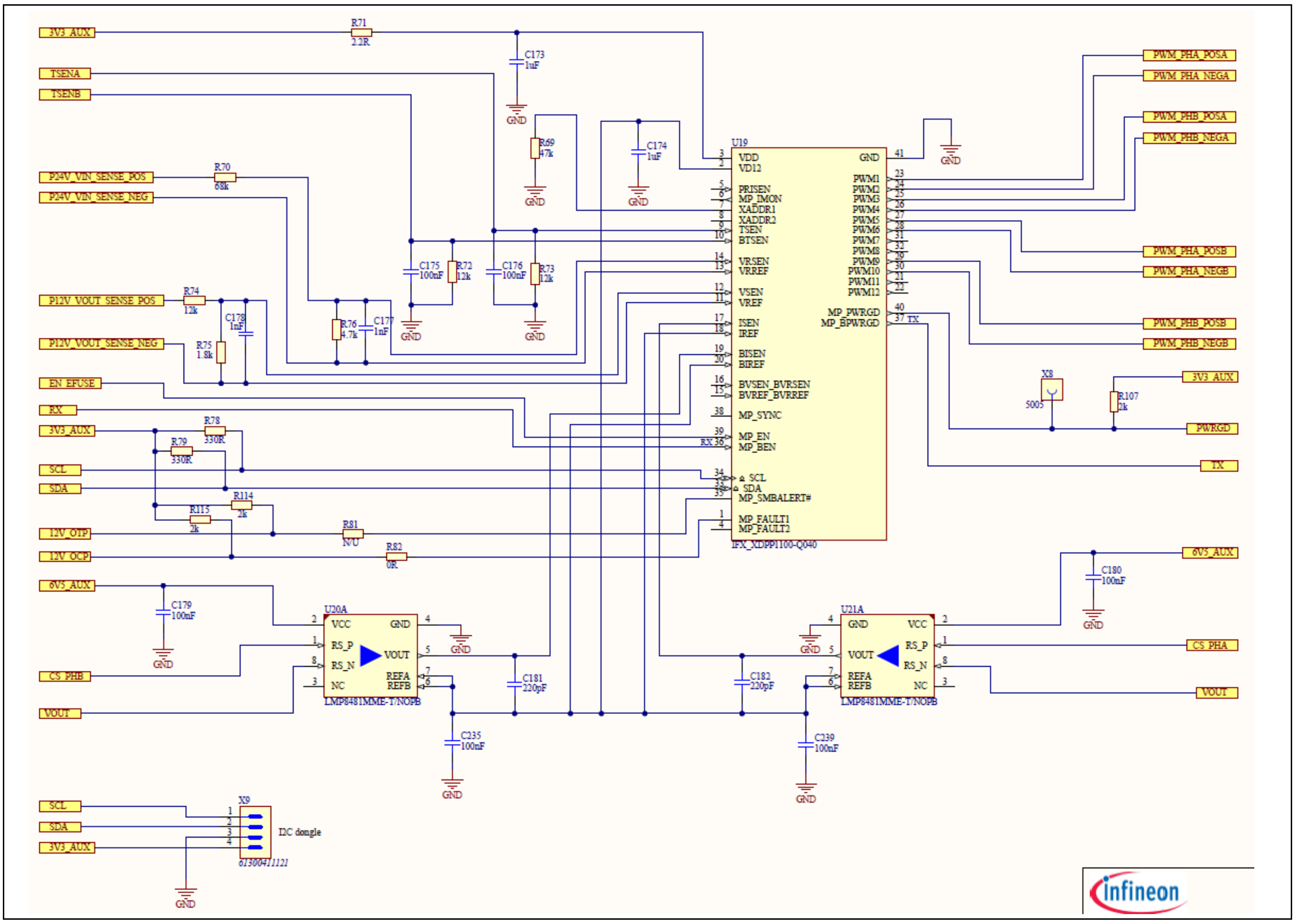

Figure 15 XDPP1100 circuit schematic

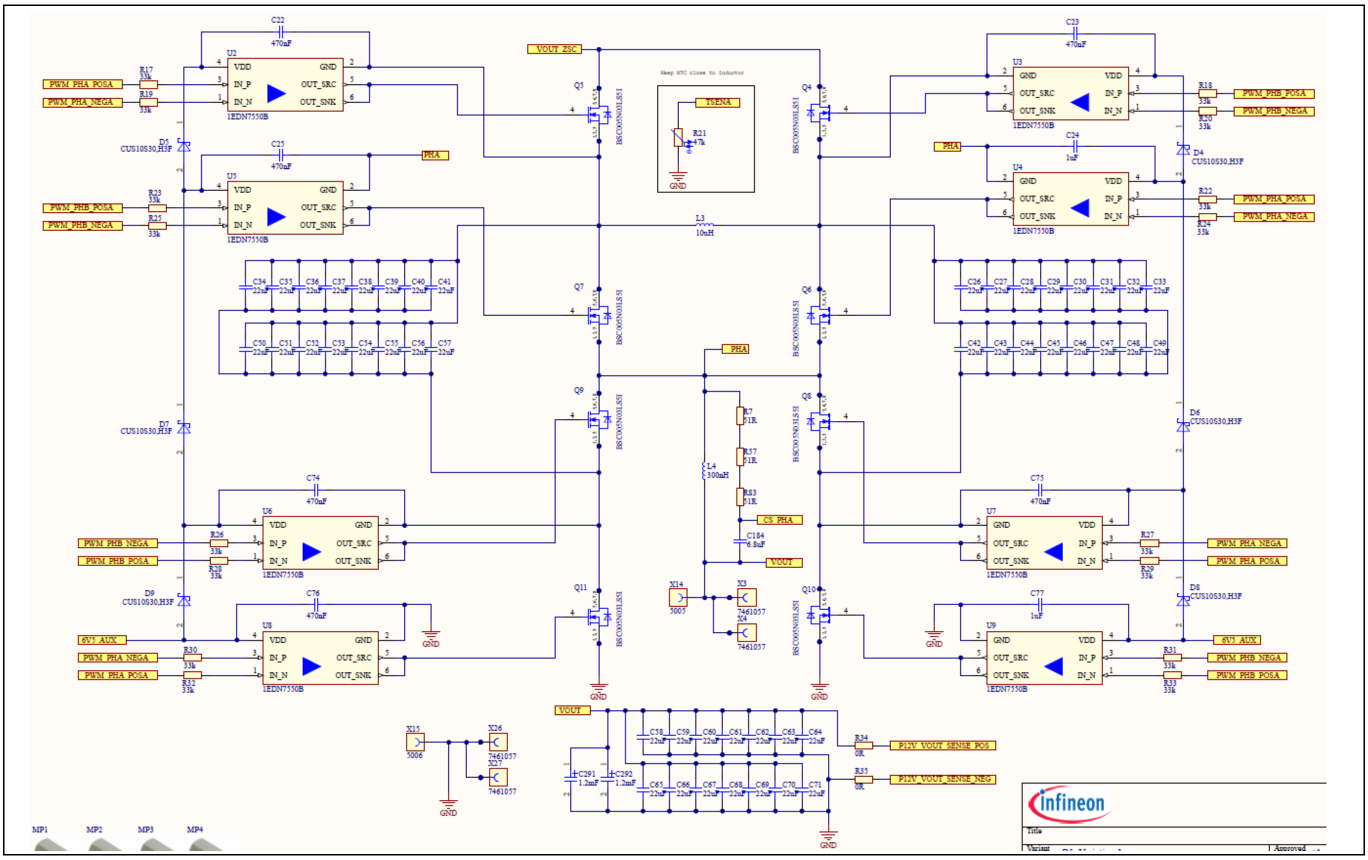

Figure 16 3LFC-DP_A phase

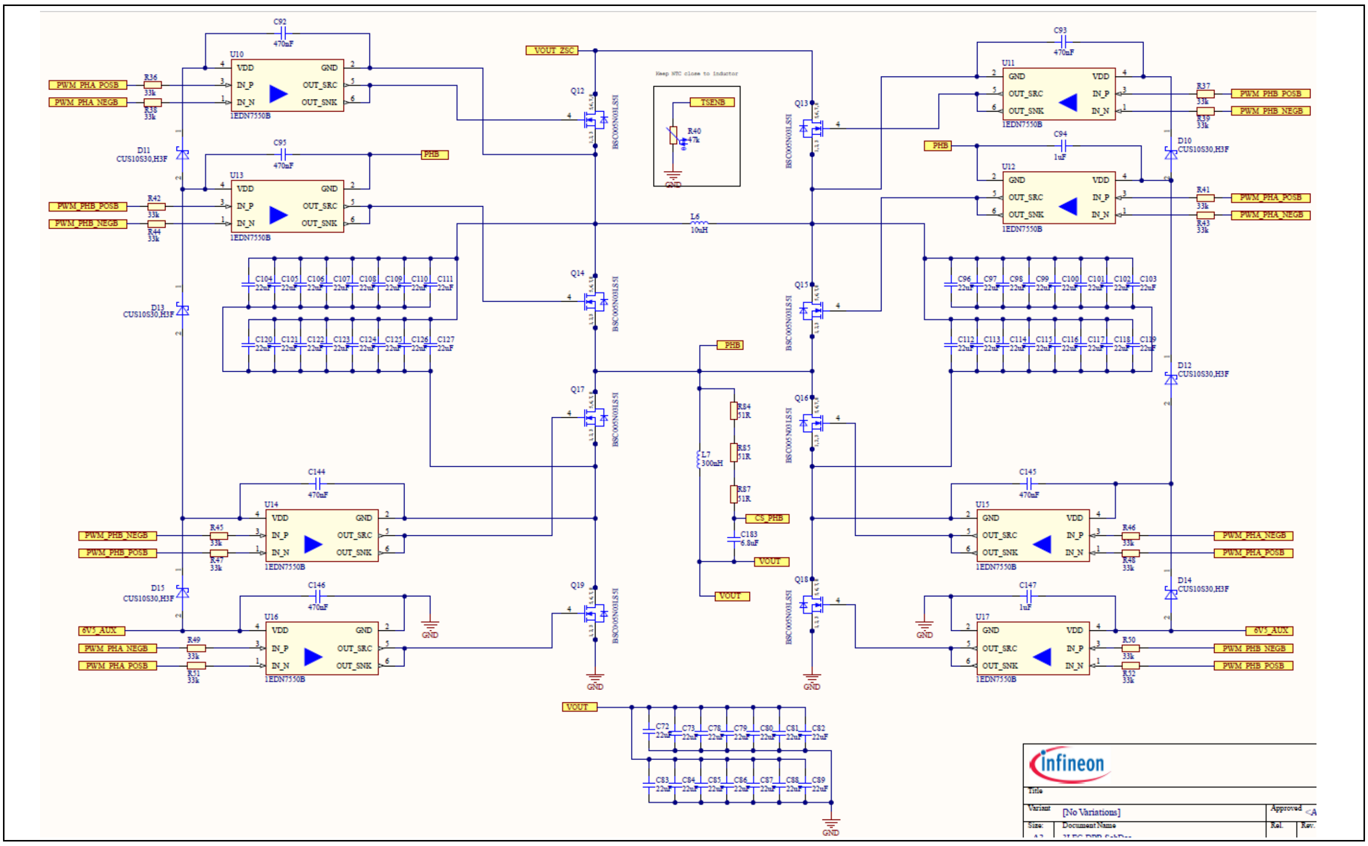

Figure 17 3LFC-DP_B phase

1.5 Block diagram

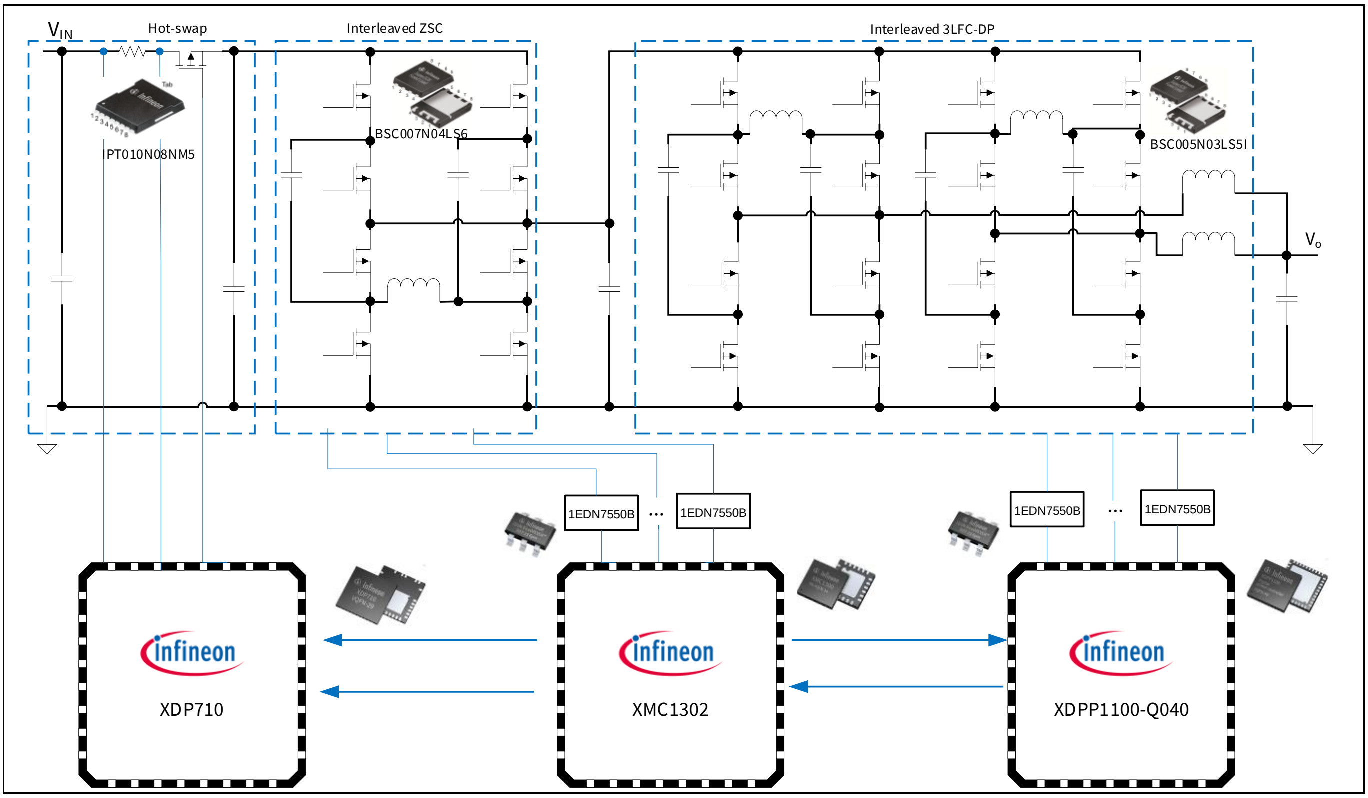

Figure 18 Block diagram

Figure 18 shows the block diagram of the REF_2200W_DRHSC_XDP board.

In the design, a XDP710-002-based hot-swap circuit is used for input-protection and limiting the inrush-current. XDP710 is the first product from Infineon's intelligent hot-swap controller and protection IC family. This device has a 5.5 V to 80 V input voltage range with a transient up to 100 V for 500 ms that drives single or multiple parallel N-channel MOSFETs. Two IPT010N08NM5 80 V MOSFETs in parallel are used to reduce conduction losses.

Following the hot-swap circuit is a 2:1 ZSC converter, which reduces the input voltage by half. Two phases with a 180-degree phase shift are used to support the high-power requirement. The ZSC is open-loop controlled and has two complementary pulse-width modulators (PWMs) from XMC1302 and 1EDN7550B to drive the MOSFET.

The final stage is a 3LFC-DP converter (dual-phase three-level buck converter).

There are eight MOSFETs in total for each phase, and two phases with 90-degree phase shift are employed. XDPP1100-Q040 is used as a controller for this 3LFC-DP stage and 1EDN7550B is used to drive the MOSFETs.

The auxiliary supply circuit (not shown in Figure 18) has an HV converter, which converts the 40 V–60 V input to a 6.5 V supply for the driver IC 1EDN7550B that in turn drives the MOSFETs. Finally, an op-amp for inductor-current sensing is also supplied by 6.5 V. Another converter, which converts 6.5 V to 3.3 V, powers XDPP1100-Q040 and XMC1302.

1.6 Bill of materials

Table 3 BOM of REF_2200W_DRHSC_XDP

Part references	Qty	Type	Value/rating/tolerance/package/other	Manufacturer	Part number
C1, C10, C24, C77, C94, C147, C173, C174, C236, C286	10	Capacitor	Ceramic capacitor / 1 µF / 25 V / 20% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GRM188R71E105MA12
C2, C22, C23, C25, C74, C75, C76, C92, C93, C95, C144, C145, C146, C237, C287	15	Capacitor	Ceramic capacitor / 470 nF / 25 V / 10% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GCM188R71E474KA64
C3, C4	2	Capacitor	Ceramic capacitor / 47 µF / 16 V / 20% / X5R (EIA) / -55°C to 85°C / 1206(3216) / SMD / -	Murata	GRM31CR61C476ME44L
C5, C8, C14, C16, C19	5	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM188R72A104KA35D
C6, C7	2	Capacitor	Monolithic chip ceramic capacitor / 2.2 µF / 100 V / 10% / X7R (EIA) / -55°C to 125°C / 1206(3216) / SMD / -	Murata	GRM31CR72A225KA73
C9	1	Capacitor	Ceramic capacitor / 47 pF / 50 V / 5% / C0G (EIA) / NP0 / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GCM1885C1H470JA16
C11, C175, C176, C179, C180, C235, C239	7	Capacitor	Ceramic capacitor / 100 nF / 25 V / 20% / X7R (EIA) / -55°C to 125°C / 0402(1005) / SMD / - Ceramic capacitor / 100 nF / 25 V / 20% / X7R (EIA) / -55°C to 125°C / 0402(1005) / SMD / -	Murata	GRM155R71E104ME14
C12, C13, C201, C202, C203, C204, C205, C206, C207, C208, C209, C210, C251, C252, C253, C254, C255, C256, C257, C258, C259, C260	22	Capacitor	Ceramic capacitor / 10 µF / 100 V / 10% / X7S (EIA) / -55°C to 125°C / 1210(3225) / SMD / -	Murata	GRM32EC72A106KE05L
C15	1	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM155R6YA105ME11
C17	1	Capacitor	Monolithic chip ceramic capacitor	Murata	GCM188R71H102JA37

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
C18	1	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM21BR61C106KE15
C20	1	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM21BR60J226ME39
C21, C177, C178, C242	4	Capacitor	Monolithic chip ceramic capacitor / 1 nF / 100 V / 10% / X7R (EIA) / -55°C to 125°C / 0402(1005) / SMD /	Murata	GRM155R72A102KA01
C26, C27, C28, C29, C30, C31, C32, C33, C34, C35, C36, C37, C38, C39, C40, C41, C42, C43, C44, C45, C46, C47, C48, C49, C50, C51, C52, C53, C54, C55, C56, C57, C58, C59, C60, C61, C62, C63, C64, C65, C66, C67, C68, C69, C70, C71, C72, C73, C78, C79, C80, C81, C82, C83, C84, C85, C86, C87, C88, C89, C96, C97, C98, C99, C100, C101, C102, C103, C104, C105, C106, C107, C108, C109, C110, C111, C112, C113, C114, C115, C116, C117, C118, C119, C120, C121, C122, C123, C124, C125, C126, C127, C162, C163, C164, C165, C166, C167	98	Capacitor	Ceramic capacitor / 22 µF / 25 V / 20% / X5R (EIA) / -55°C to 85°C / 805(2012) / SMD	Murata	GRM21BR61E226ME44L
C90, C91, C128, C129, C130, C131, C132, C133, C134, C135, C136, C137, C138, C139, C140, C141, C142, C143, C148, C149, C150, C151, C152, C153, C154, C155, C156, C157, C158, C159, C160, C161, C185, C186, C187, C188, C189, C190, C191, C192, C193, C194, C195, C196, C197, C198, C199, C200, C211, C212, C213, C214, C215, C216, C217, C218, C219, C220, C221, C222, C223, C224, C225, C226, C227, C228, C229, C230, C231, C234, C240, C241	72	Capacitor	Ceramic capacitor / 10 µF / 50 V / 10% / X5R (EIA) / -55°C to 85°C / 805(2012) / SMD / -	Murata	GRM21BR61H106KE43L
C168, C170, C171, C172	4	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM155R71H103MA88

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
C169	1	Capacitor	Monolithic chip ceramic capacitor	Murata	GRM155C71A105KE11D
C181, C182	2	Capacitor	Ceramic capacitor / 220 pF / 50 V / 10% / X8R (EIA) / -55°C to 150°C / 402(1005) / SMD / -	TDK Corporation	CGA2B2X8R1H221K050BD
C183, C184	2	Capacitor	Ceramic capacitor / 6.8 µF / 6.3 V / 10% / X7S (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	TDK Corporation	C1608X7S0J685K080AC
C232, C233, C277, C283	4	Capacitor	Ceramic capacitor / 220 nF / 25 V / 5% / X7R (EIA) / -55°C to 125°C / 0603(1608) / SMD / -	Murata	GRM188R71E224JA88
C238, C288	2	Capacitor	Ceramic capacitor / 2.2 µF / 25 V / 10% / X5R (EIA) / -55°C to 85°C / 0603(1608) / SMD / -	Murata	GRM188R61E225KA12D
C291, C292	2	Capacitor	Capacitor / ELCO / 1.2 mF / 16 V / 20% / aluminum electrolytic / -55°C to 105°C / 10.30 mm L x 10.30 mm W x 12.70 mm H / - / -	Panasonic	16SVPG1200M
D1	1	Diode	Silicon switching diode	Infineon Technologies	BAS16-03W
D2, D16, D17	3	LED	LED / GBD-C281TGKT-5A / green	GBG	GBD-C281TGKT-5A
D3	1	Schottky diode	Surface-mount Schottky Barrier rectifier 1 A / 20 V	Vishay	MSS1P2L-M3/89A
D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14, D15, D19, D20, D21, D23, D24, D25	18	Schottky diode	Schottky barrier diode, 30 V / 1 A	Toshiba	CUS10S30, H3F
D18, D22	2	Diode	Schottky barrier rectifiers	Nexperia	PMEG4005EJ,115
L1	1	Inductor	Inductor / STD / 10 µH / 4.8 A / 20% / -40°C to 125°C / 70.2 mR / 5.4 x 5.4 x 3.1 mm / inductor, SMD, 3.90 mm pitch, 2 pin, 5.40 mm L x 5.40 mm W x 3.10 mm H body / - / -	Würth Elektronik	78438367100

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
L2	1	Inductor	Inductor / STD / 2.2 µH / 970 mA / 20% / -55°C to 125°C / 100 mR / 1008(2520) / inductor, chip, 2.50 mm L x 2.00 mm W x 1.00 mm H / SMD / -	Murata	LQM2HPN2R2MG0
L3, L6	2	Inductor	Inductor / STD / 10 µH / 2 A / 20% / -55°C to 125°C / 182.8 mR / SMD / molded inductor, two leads, body 5.49 x 5.18 mm, IPC medium density / SMD / -	Vishay	IHLP2020BZER100M11
L4, L7	2	Inductor	Inductor / STD / 300 nH / 185 A / 15% / -55°C to 130°C / - / 18 x 25 x 15 mm / inductor, SMD, 17.75 mm pitch, 2 pin, 25.00 mm L x 18.00 mm W x 15.00 mm H body / - / -	ITG Electronics	SLA1006018A-300L
L5, L9	2	Inductor	Inductor / STD / 1.5 µH / 25 A / 15% / -55°C to 130°C / 1.1 R / SMD / inductor, SMD, 7.70 mm pitch, 2-pin, 9.00 mm L x 5.00 mm W x 9.50 mm H body / SMD / -	ITG Electronics	SLQ36385A-1R5L
Q1	1	Transistor	NPN switching transistor	Nexperia	MMBT3904,215
Q2, Q3	2	MOSFET	Single N-channel OptiMOS™ 5 power MOSFET, 80 V	Infineon Technologies	IPT010N08NM5
Q4, Q5, Q6, Q7, Q8, Q9, Q10, Q11, Q12, Q13, Q14, Q15, Q16, Q17, Q18, Q19	16	MOSFET	OptiMOS™ 5 power-transistor, 30 V	Infineon Technologies	BSC005N03LS5I
Q20, Q21, Q22, Q23, Q24, Q25, Q26, Q27	8	MOSFET	N-channel 40 V 100 A 188 W surface-mount PG-TDSON-8-6	Infineon Technologies	BSC007N04LS6
Q28	1	MOSFET	Insulated-gate field-effect transistor (IGFET), N-channel, enhancement, body diode, resistor gate, ESD diode gate/source, pin 1 gate, 2 source, 3 drain, 3 pins	ON Semiconductor	2N7002WT1G

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
R1	1	Resistor	Resistor / STD / 150 k / 100 mW / 1% / 100 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW0603150KFK
R2, R3, R13	3	Resistor	10 k / 75 V / 5%	Yageo	RC0603JR-0710KL
R4, R10	2	Resistor	General-purpose chip resistor	Yageo	RC0603FR-07100KL
R5	1	Resistor	Resistor / STD / 18.2 k / 100 mW / 1% / 100 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060318K2FK
R6	1	Resistor	Resistor / STD / 300 µR / 6 W / 1% / 200 ppm/K / -65°C to 170°C / 2512(6332) / SMD / -	Yageo	PU2512FKGP60U3L
R7, R57, R83, R84, R85, R87	6	Resistor	Resistor / STD / 51 R / 100 mW / 1% / 100 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060351R0FK
R8	1	Resistor	General-purpose chip resistor	Yageo	RC0603FR-0710RL
R9	1	Resistor	Standard thick-film chip resistor	Vishay	CRCW060331K6FK
R11	1	Resistor	Automotive-grade thick-film chip resistor	Yageo	AC0603JR-071KL
R12, R34, R35, R60, R62, R82, R112, R116, R117, R118, R119, R121, R122	13	Resistor	General-purpose chip resistor / STD / 0 R / 63 mW / 0 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Yageo	RC0402JR-070RL
R15, R16	2	Resistor	1 k / 50 V / 5%	Yageo	RC0402JR-131KL
R17, R18, R19, R20, R22, R23, R24, R25, R26, R27, R28, R29, R30, R31, R32, R33, R36, R37, R38, R39, R41, R42, R43, R44, R45, R46, R47, R48, R49, R50, R51, R52, R91, R92, R93, R94, R95, R96, R97, R98, R99, R100, R101, R102, R103, R104, R105, R106	48	Resistor	Resistor / STD / 33 k / 100 mW / 0.1% / 25 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo	RT0603BRD0733KL
R21, R40	2	Resistor	Resistor / NTC / 47 k / - / 1% / - / -40°C to 125°C / 0402(1005) / SMD / -	Murata	NCP15WB473F03RC

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
R53, R54, R58	3	Resistor	Resistor / STD / 100 R / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Yageo	RC0402FR-07100RL
R55, R65, R67	3	Resistor	Standard thick-film chip resistor	Vishay	CRCW04021M00FK
R56, R66, R69	3	Resistor	Standard thick-film chip resistor / STD / 47 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW040247K0FK
R59	1	Resistor	Standard thick-film chip resistor	Vishay	CRCW0402180KFK
R61	1	Resistor	Standard thick-film chip resistor	Vishay	CRCW040263K4FK
R63, R64	2	Resistor	Automotive-grade thick-film chip resistor	Yageo	AC0603JR-071KL
R68	1	Resistor	Standard thick-film chip resistor	Vishay	CRCW040286K6FK
R70	1	Resistor	Resistor / STD / 68 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW040268K0FK
R71, R110	2	Resistor	Resistor / STD / 2.2 R / 100 mW / 1% / 100 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW06032R20FK
R72, R73, R74	3	Resistor	Resistor / STD / 12 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW040212K0FK
R75	1	Resistor	Resistor / STD / 1.8 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW04021K80FK
R76	1	Resistor	Resistor / STD / 4.7 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW04024K70FK

Part references	Qty	Type	Value/rating/tolerance/package/other	Manufacturer	Part number
R78, R79	2	Resistor	Resistor / STD / 330 R / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -	Vishay	CRCW0402330RFK
R86	1	Resistor	10 k / 75 V / 5%	Yageo	RC0603JR-0710KL
R88, R90, R107, R111, R113, R114, R115, R120	8	Resistor	Resistor / STD / 2 k / 63 mW / 1% / 100 ppm/K / -55°C to 155°C / 0402(1005) / SMD / -,	Vishay	CRCW04022K00FK
R108	1	Resistor	Resistor / STD / 80.6 k / 100 mW / 1% / 100 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Vishay	CRCW060380K6FK
R109	1	Resistor	Resistor / STD / 0 R / 100 mW / 0 ppm/K / -55°C to 155°C / 0603(1608) / SMD / -	Yageo	AC0603JR-070RL
S1	1	Switch	Sealed ultraminiature toggle switches	C&K	GT11MCBE
U1	1	IC	Hot-swap controller	Infineon Technologies	XDP710-002
U2, U3, U4, U5, U6, U7, U8, U9, U10, U11, U12, U13, U14, U15, U16, U17, U22, U23, U24, U25, U26, U27, U28, U29	24	IC	EiceDRIVER™, single-channel low-side gate driver IC for MOSFET and IGBT, 4.2 V UVLO	Infineon Technologies	1EDN7550B
U18	1	IC	XMC1000 industrial microcontrollers Arm® Cortex®-M0 32-bit processor core	Infineon Technologies	XMC1302-Q024X0064
U19	1	IC	Digital power controller with PMBus interface and Arm® Cortex®-M0	Infineon Technologies	XDPP1100-Q040
U20, U21	2	IC	High-side current sense amplifier	Texas Instruments	LMP8481MME-T/NOPB
U30	1	IC	Synchronous step-down voltage regulator	Texas Instruments	LM76003RNPT
U31	1	IC	1 A load step-down DC-DC regulator	Texas Instruments	LM2734XMK/NOPB
X1, X2, X3, X4, X6, X7, X26, X27	8	Connector	WP-BUTR Redcube press-fit, 100 A	Würth Elektronik	7461057
X5	1	Connector	WR-BHD male box header 8 pins, 2.54 mm pitch, dual-row, 3 A, 250 V AC	Würth Elektronik	61200821621

Part references	Qty	Type	Value/rating/tolerance/ package/other	Manufacturer	Part number
X8, X10, X12, X14, X16	5	Connector	PC test point, compact, silver plate, red	Keystone Electronics Corp.	5005
X9	1	Connector	Headers and wire housings WR-PHD 2.54 mm header 4-pin single str. gold	Würth Elektronik	61300411121
X13, X15, X17	3	Connector	PC test point, compact, silver plate	Keystone Electronics Corp.	5006

2 Design considerations and tips

2.1 Auxiliary power supplies

Figure 19 shows an HV buck converter as an auxiliary power source, which converts input (40 V–60 V) to 6.5 V to supply the driver IC, current sensing op-amp, and downstream auxiliary power. It is suggested to add a 22 µF 100 V or equivalent e-capacitor at the input for damping to suppress the oscillation at the DC input side. Such an oscillation is usually the result of placing the ESL input cable and ceramic capacitors at the input of the regulator, and may damage the regulator IC if there is a significant voltage peak.

Another way to prevent regulator damage due to oscillation is to place the regulator after the hot-swap circuit, which means to use the output of the hot-swap as the input source for this auxiliary converter.

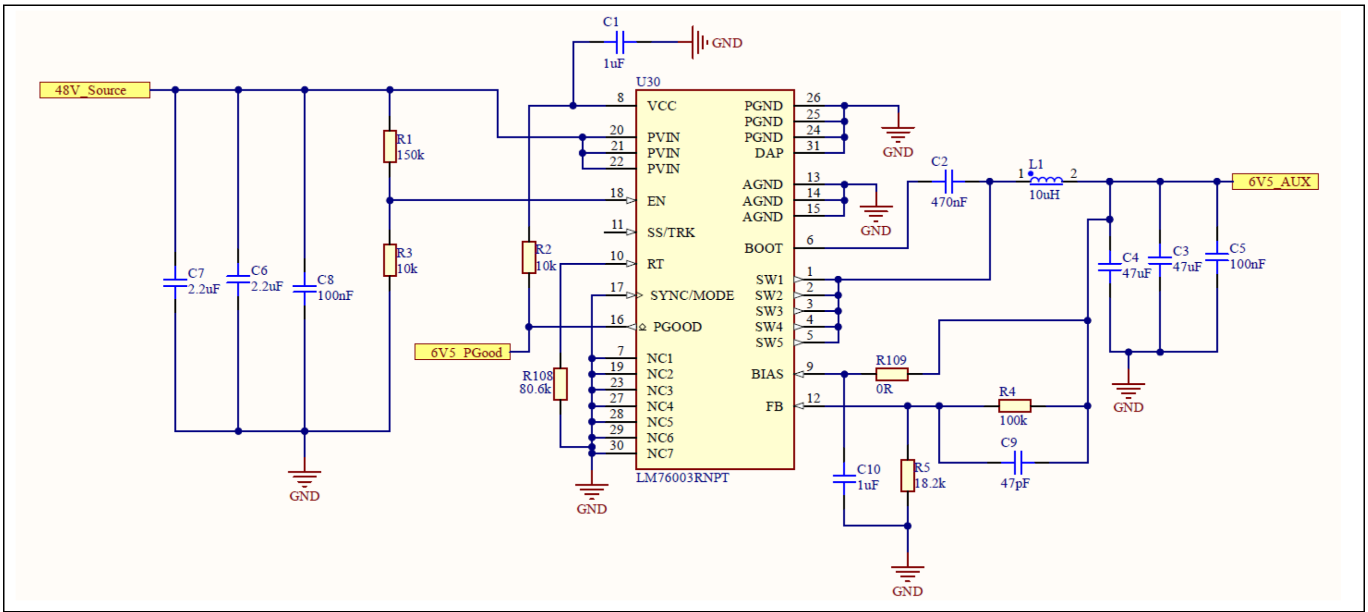

Figure 19 HV buck regulators used in the demo board

Figure 20 shows the second auxiliary power supply, which converts 6.5 V to 3.3 V to power the XMC1302 MCU and the digital controller XDPP1100.

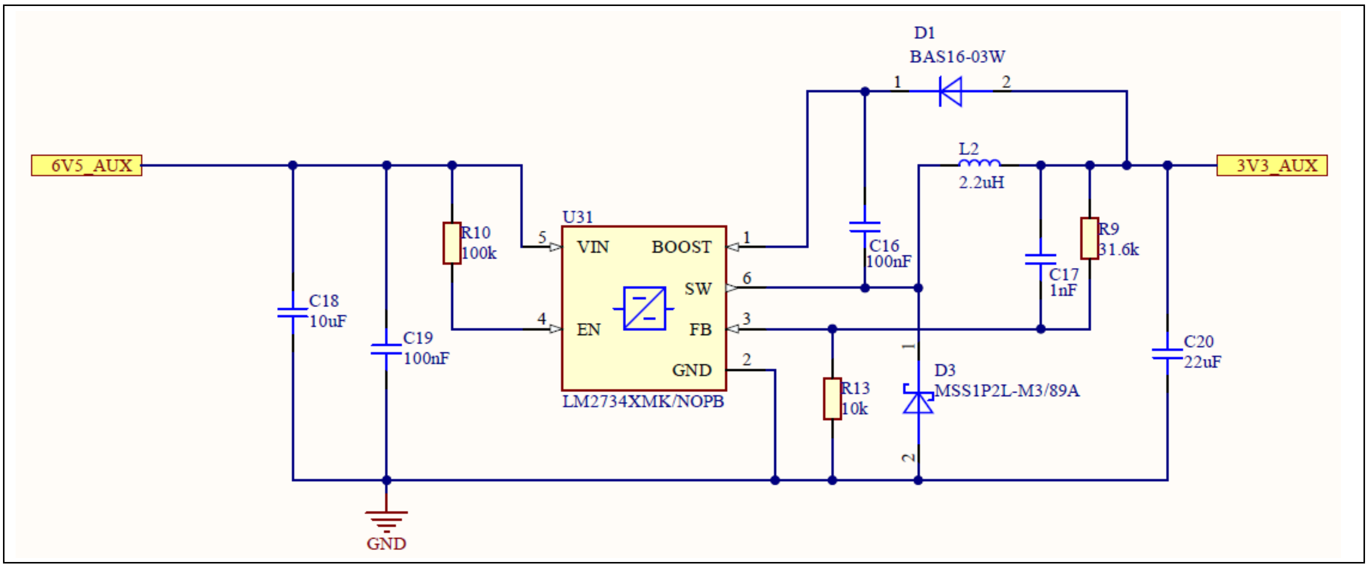

Figure 20 6.5 to 3.3 V regulators used in the demo board

2.2 Gate drivers

Figure 21 is the gate driver circuit for the low-side MOSFETs of a 3LFC-DP converter; this is a typical circuit for driving MOSFETs in both ZSC and 3LFC-DP converters of this reference design board. EiceDRIVER™ 1EDNx550 is a part of the truly differential inputs (TDI) family of single-channel, high-side, and low-side gate driver ICs. The TDI family has a fully differential input circuitry. The TDIs provide excellent common-mode robustness (CMR) and eliminate the risk of false triggering. The small package footprints enable versatile layouts in both low-side and high-side driving.

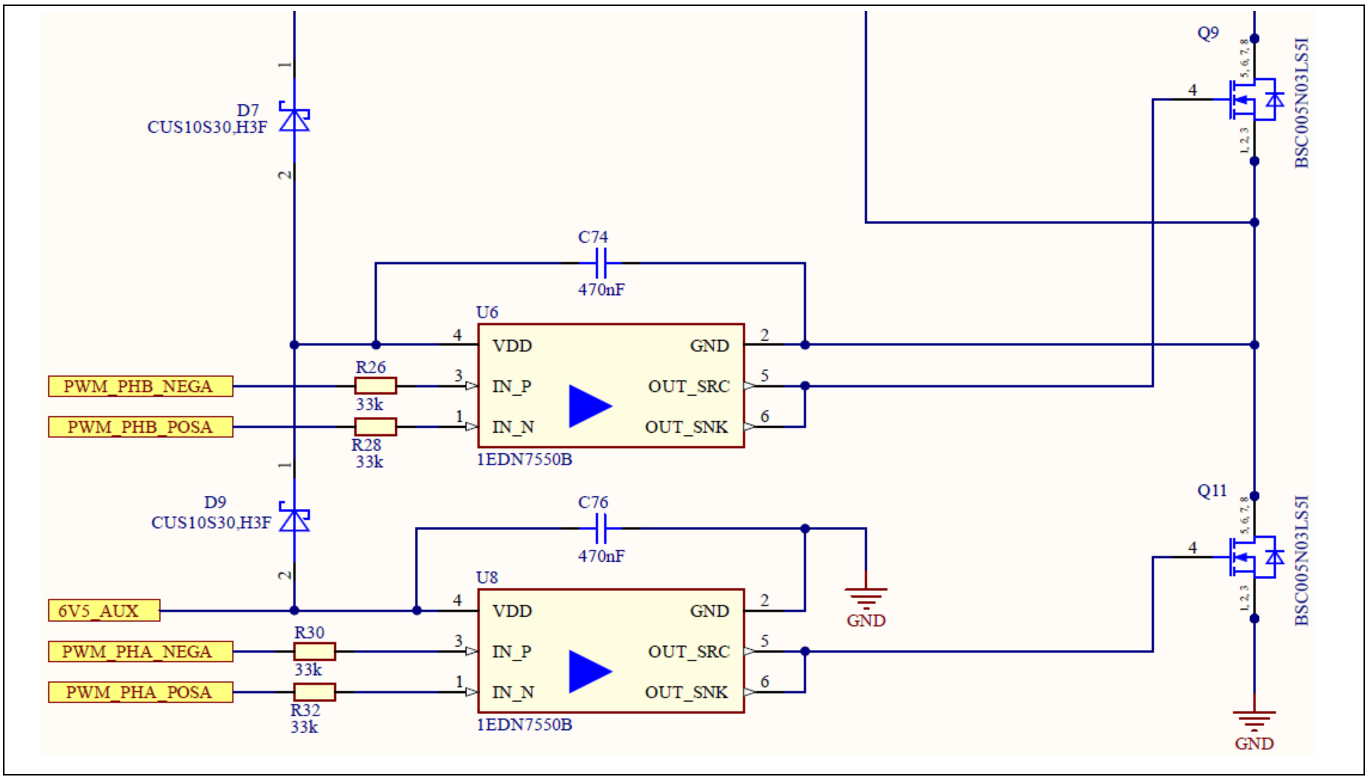

Figure 21 Gate driver circuit

Figure 22 is an input-resistor configuration-lookup table for 1EDNx550. The input resistor should be selected depending on the maximum common-mode voltage in the circuit. In this reference design, the maximum common-mode static voltage is 60 V without considering potential voltage spikes, which may be seen in the ZSC converter, but less in the 3LFC-DP converter. So 33 kΩ, 0.1 percent input resistors are used for compatibility with all circuits in the board.

Controller PWM output voltage	Input resistor configuration			Ground shift robustness	
	Value	Tolerance	Form factor[19]	CMR static [20]	CMR dynamic
2.5 V	24 kΩ	1%	≥0402	-30 V/+30 V	±150 V
		0.1%	≥0603	-54 V/+63 V	±150 V
3.3 V	33 kΩ	1%	≥0402	-40 V/+40 V	±150 V
		0.1%	≥0603	-72 V/+84 V	±150 V
5 V	51 kΩ	1%	≥0603	-60 V/+60 V	±150 V
		0.1%	≥0805	-108 V/+126 V	±200 V
12 V	127 kΩ	1%	≥0805	-140 V/+140 V	±200 V
		1%	≥1206	-140 V/+140 V	±400 V
		0.1%	≥1206	-200 V/+200 V	±400 V
15 V	160 kΩ	1%	≥0805	-150V/+150 V	±200 V
		1%	≥1206	-175 V/+175 V	±400 V
		0.1%	≥1206	-200 V/+200 V	±400 V

Figure 22 Input-resistor configuration-lookup table for 1EDNx550, source from the datasheet [3]

PCB layout is also important. Figure 23 shows one example of the board; input resistors should be placed symmetrically close to the driver and the traces connecting the resistors to the driver should be as short as possible to avoid coupling to another signal or power plane. In this design, the circuit is placed on the bottom side, while the plane underneath the bottom layer is the ground of the driver, so all traces and input resistors couple to the same plane on the ground. Additionally, a ground trace is routed as a shield surrounding the circuit to prevent coupling from other circuits.

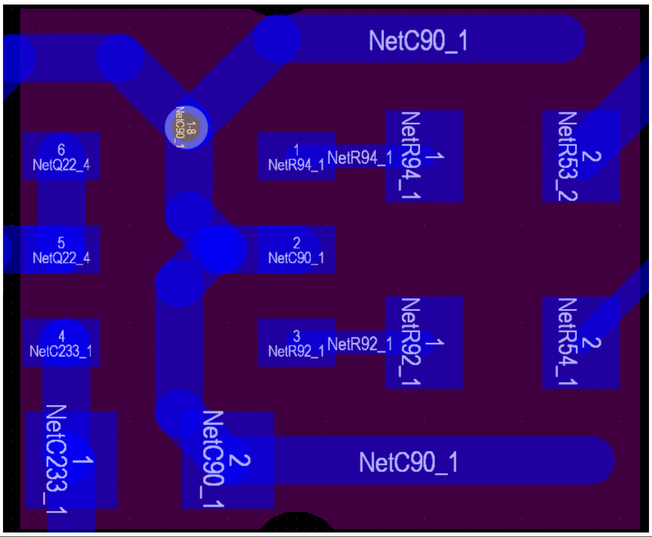

Figure 23 PCB layout of 1EDNx550

2.3 Output current sensing circuit

Figure 24 is the output current sensing circuit. This is to monitor the output load current by sensing the current through the DCR of the inductor. The RC across the inductor should be fine-tuned to get accurate current-sensing. At no-load or light-load, there is a reverse current through the inductor in a buck-derived topology. In this case, an op-amp with bidirectional sensing capability is recommended, otherwise the light-load current will not be measured accurately. The DCR of the inductor has a positive temperature coefficient, which means its resistance increases as the temperature rises. Temperature compensation should be considered to achieve accurate output current sensing, which can be achieved easily with XDPP1100. To sense the temperature of the inductor accurately and achieve good temperature compensation, NTC R21 is placed close to inductor L7. In this design, the light-load output current reading is accurate, as shown in Figure 37. Mid to full-load output is shown in Figure 38.

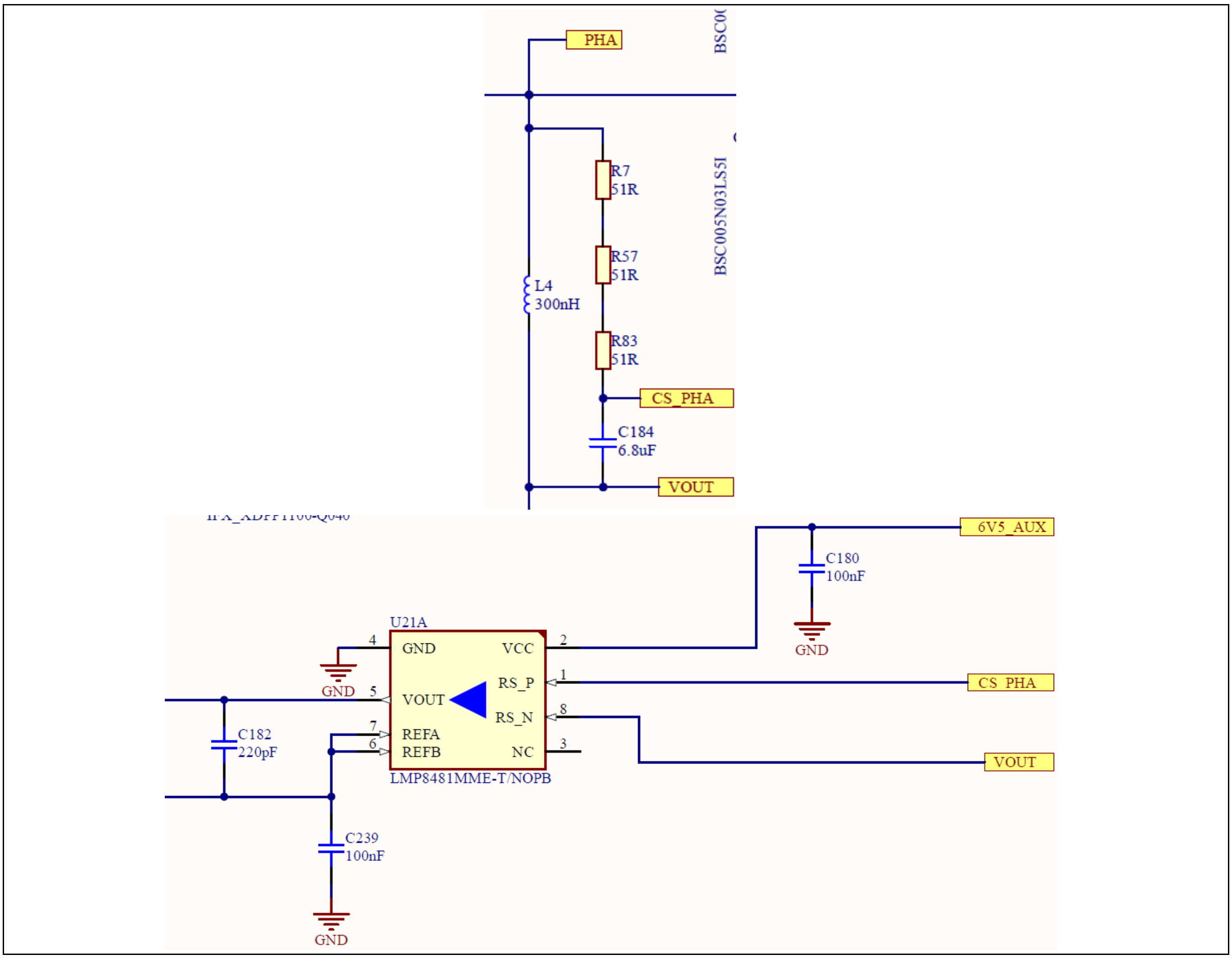

Figure 24 Output current sensing circuit

2.4 Hot-swap circuit

Figure 25 is the hot-swap circuit, which is usually needed in the PSU of datacenters to limit the inrush current when the module is plugged into the system rack. For this design, XDP710-configured mode is a fully digital mode (FDM), so most parameters are configured by a PMBus command and a few components are present around XDP710. Two IPT010N08NM5 in parallel reduce conduction loss and control the temperature. Q1 should be placed close to Q2 and Q3 to monitor temperature, provide temperature protection, and allow accurate control of the safe operating area (SOA). S1 is used for on/off control of this hot-swap circuit.

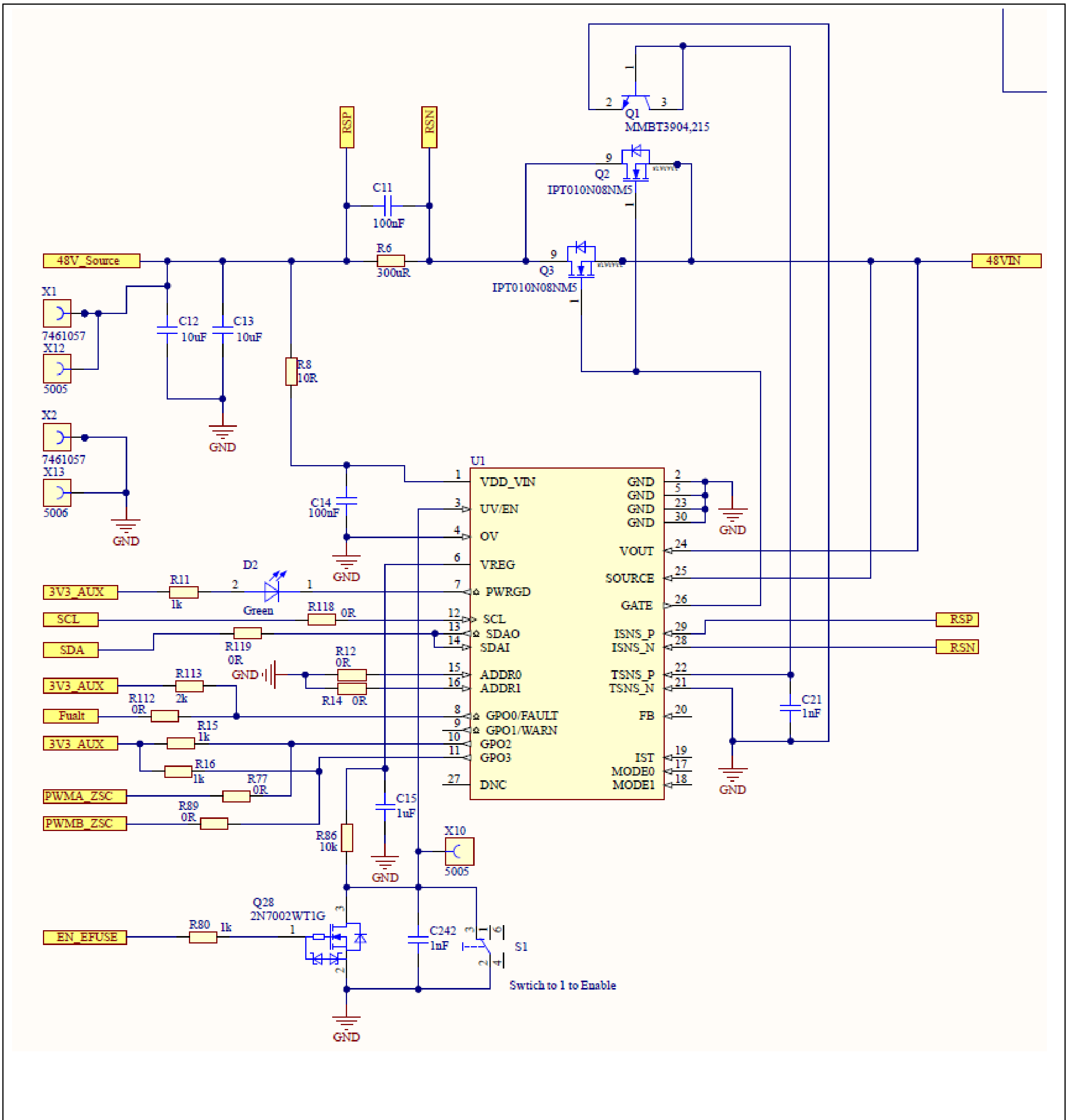

Figure 25 Hot-swap circuit

2.5 ZSC converter

Figure 26 shows one phase of the ZSC converter. In the design, there are two phases at a 180-degree phase shift to each other. Proposed by Infineon, the ZSC topology is a 2:1 converter, which reduces the input by half. The switching frequency of this design is 460 kHz, which is close to the resonant frequency comprised of ESL (dominated by MOSFETs' lead inductance, plus PCB trace inductance) and flying capacitors. The X5R-type ceramic capacitor is used as a flying capacitor in this design to achieve high capacitance with a small footprint due to size limitations. In general, X7R-type or better is suggested for ZSC for better performance. L5 and L9 are the ZVS inductors and can be merged to a single inductor of a customized size. They do not handle the load DC current and so their conduction loss is not critical, but their magnetic loss is dominant as a result of the high switching frequency. There is a heatsink to help the inductor dissipate heat.

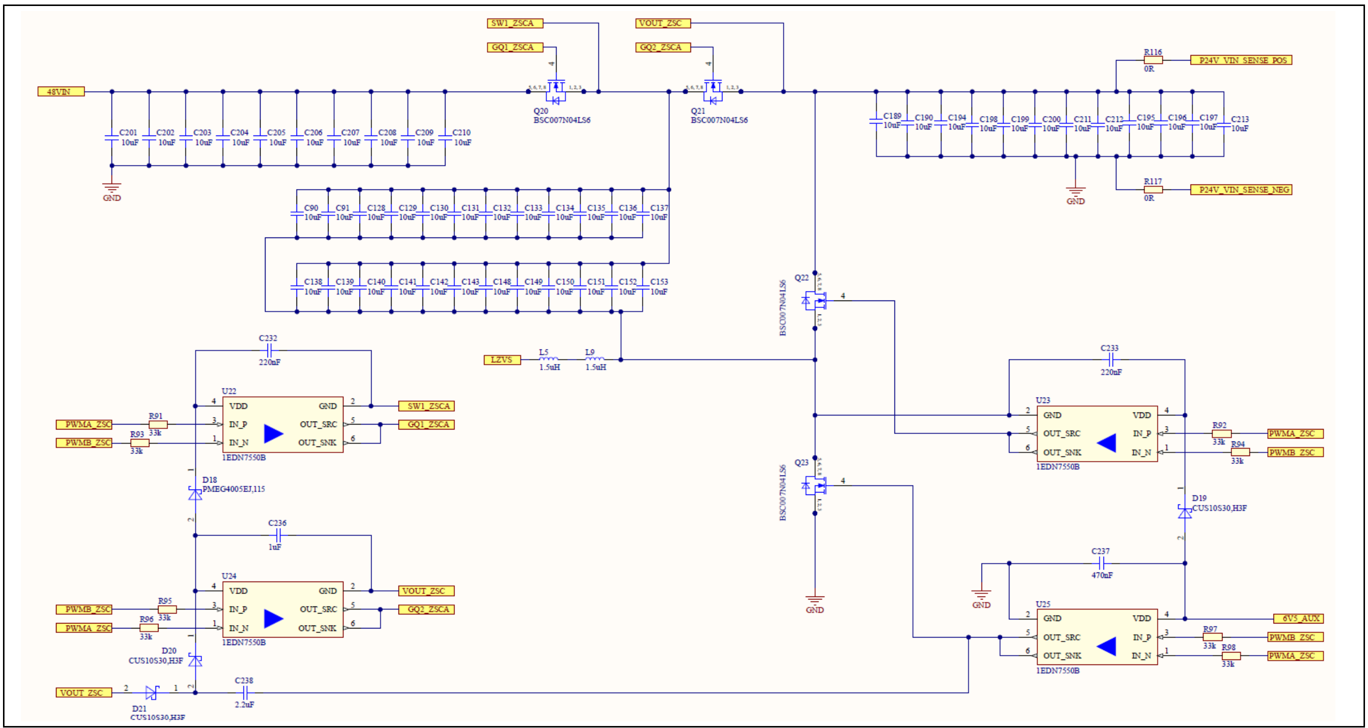

Figure 26 ZSC converter schematic

2.6 3LFC-DP converter

Figure 27 shows one phase of an interleaved 3LFC-DP converter with a phase shift of 90 degrees. In this design, the switching frequency is 150 kHz. Compared to a conventional three-level buck converter, 3LFC-DP has two phases with 180-degree shift; that is why it has eight MOSFETs here, while a conventional three-level buck has four MOSFETs. L6 is a balancing inductor to ensure that the phases share the loading well.

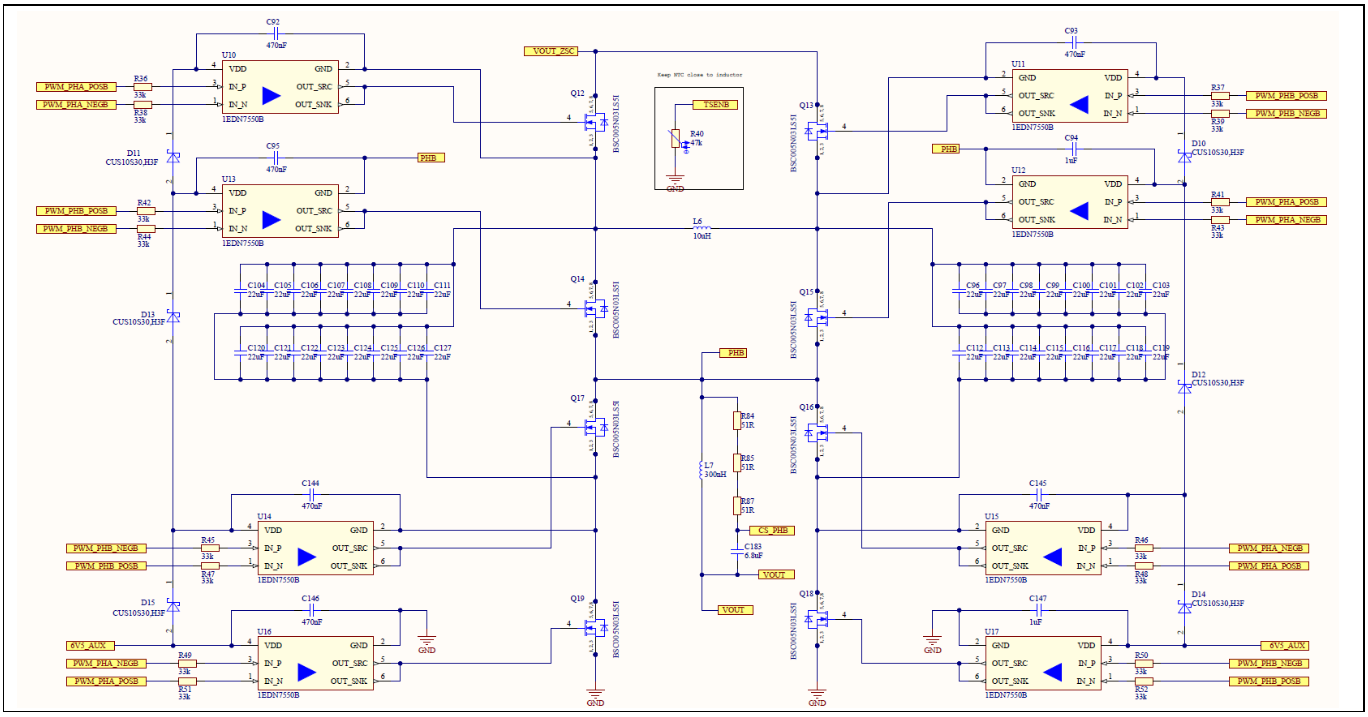

Figure 27 3FLC-DP converter schematic

2.7 XMC1302 and the surrounding circuit

Figure 28 shows XMC1302 and the surrounding circuit. XMC1302 is used to control the ZSC stage and deliver its PWMs as well. XMC1302 also monitors the status of both the output and the input. The fault status of this PSU is stored in XMC1302's memory so that the logs about the fault information can be read anytime.

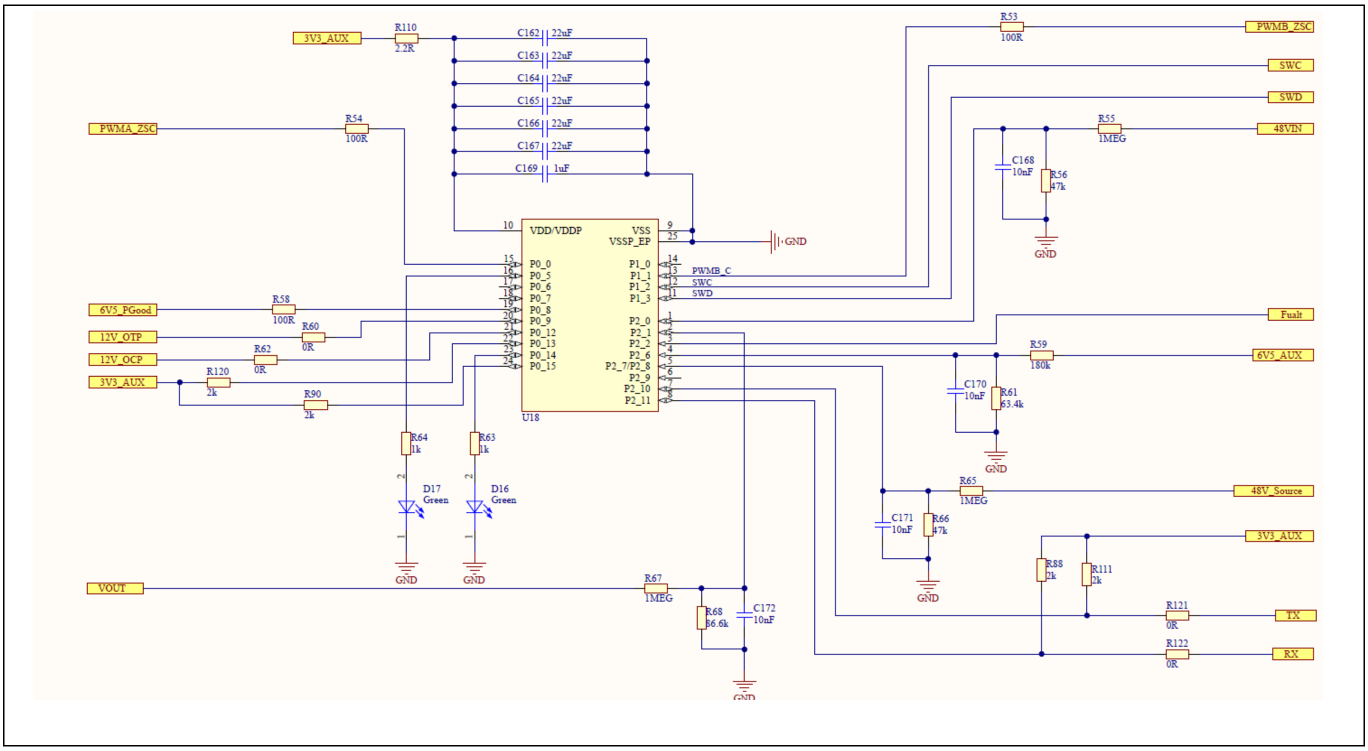

Figure 28 Schematic of XMC1302 and the surrounding circuit

2.8 XDPP1100 and the surrounding circuit

Figure 29 shows the digital controller XDPP1100 and the surrounding circuit to control the interleaved 3LFC-DP. The opamp for sensing the output current is capable of sensing the reverse current, which appears at no-load or light-load in the buck-derivate topology, ensuring an accurate current reading at light load. At this circuit, VD12 of XDPP1100 is connected to REF of the opamp as the reference input.

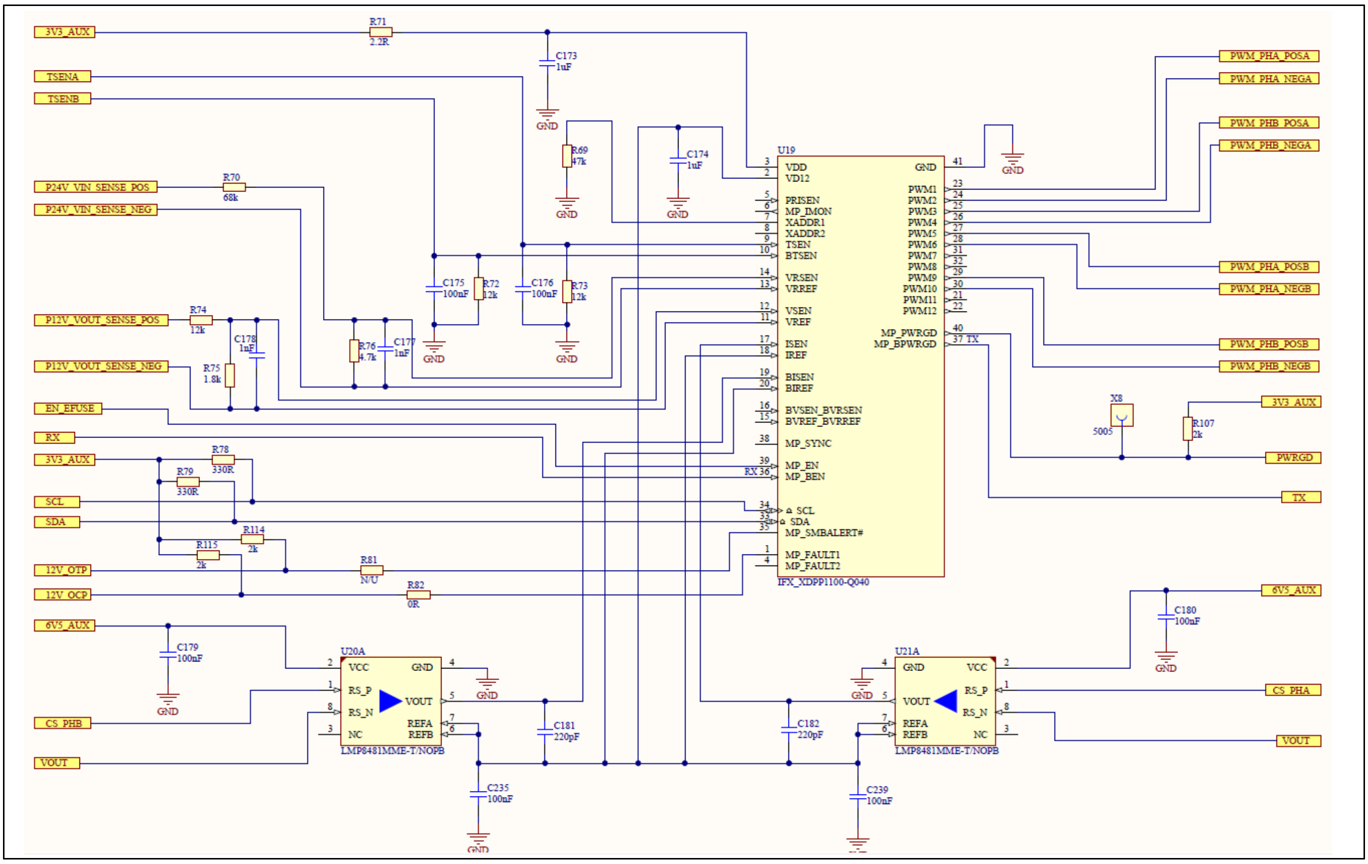

Figure 29 Schematic of XDPP1100 and the surrounding circuit

3 Board operation

3.1 Board setup

As Figure 30 shows, the left side cables are input, the right side are output. X6 and X7 are the output connectors of the ZSC converter where the load should be connected for a dedicated evaluation of the ZSC converter. X9 is the connector for I^{2}C communication and programming of both the hot-swap controller XDP710 and the digital controller XDPP1100. X15 is for programming XMC1302. A heatsink is glued onto the section of the board that tends to generate more heat, to improve heat dissipation and prevent overheating. Parts labelled L5, L9, Q22, Q23, Q26, and Q27 of the ZSC converter, and also MOSFETs of the 3LFC-DP converter generate the most heat. On the bottom of the board a heatsink is used as the base plate to assist with heat dissipation. A fan with an air flow of 235 m^3/h or better should be used for forced air cooling to ensure the maximum power output of 2200 W.

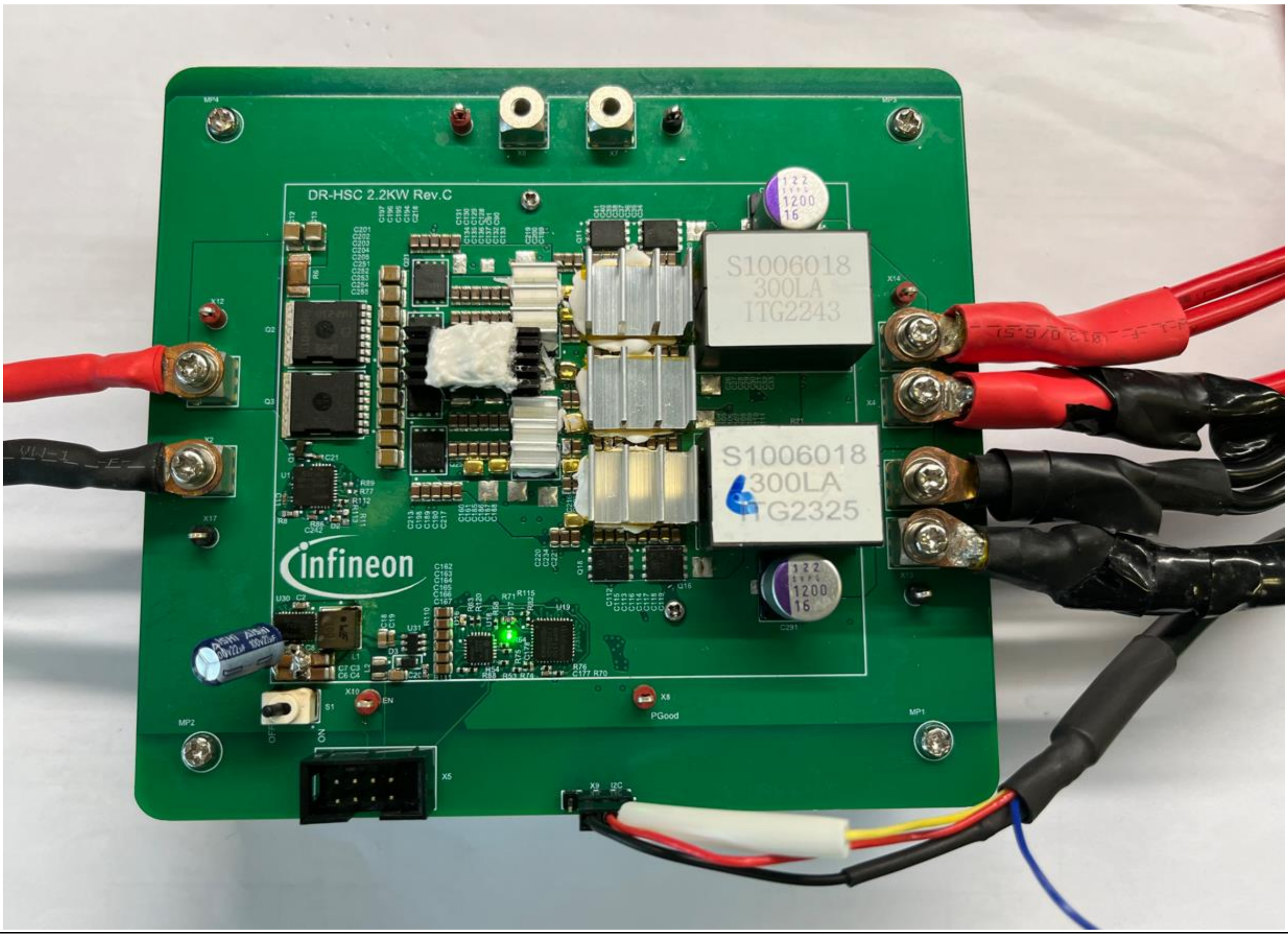

Figure 30 **Board setup**

3.2 Startup and shutdown

Push switch S1 to the ON position to power on the converters. In the start-up waveform shown in Figure 31, **CH1** is EN, **CH2** is P_{GOOD}, **CH3** is 12 V output, and the turn-on delay is ~150 ms.

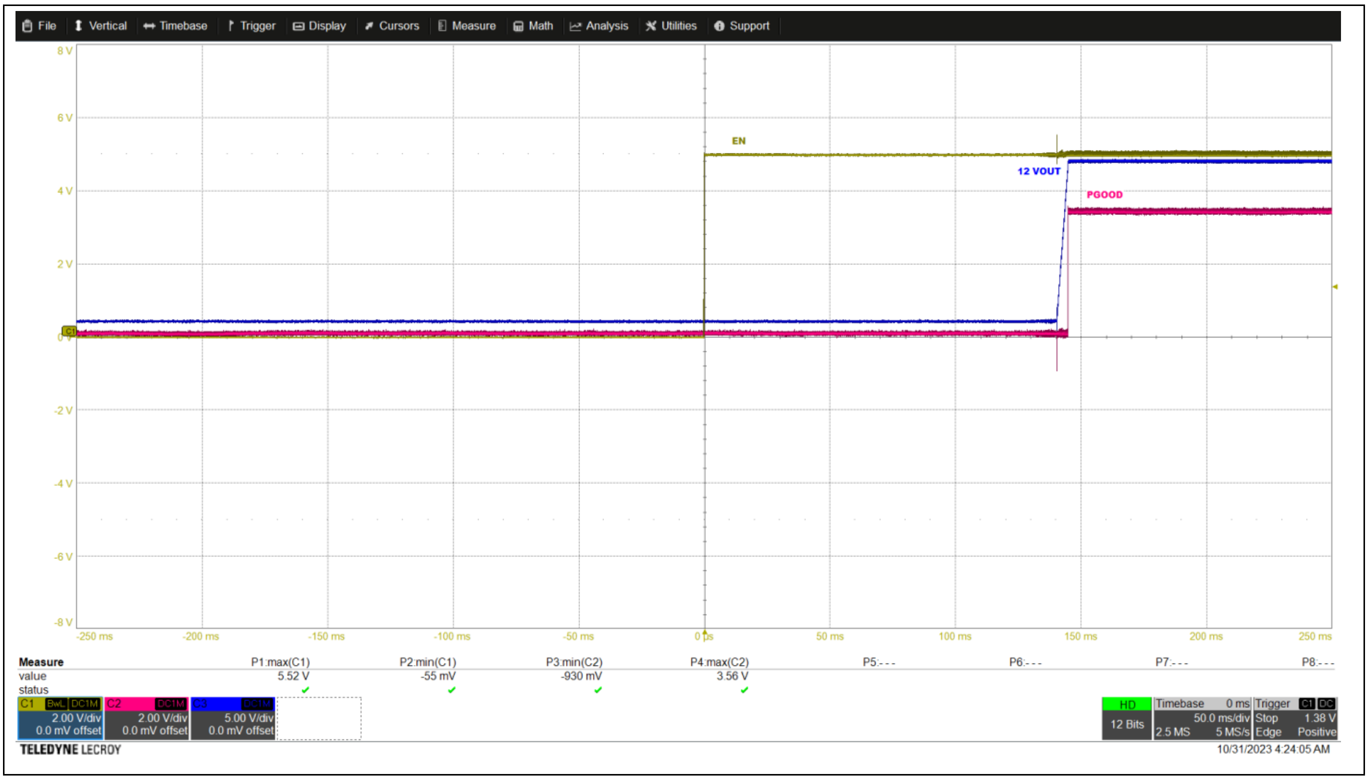

Figure 31 Startup waveform. CH1: EN, CH2: P_{GOOD}, CH3: 12 V output, turn-on delay: ~150 ms

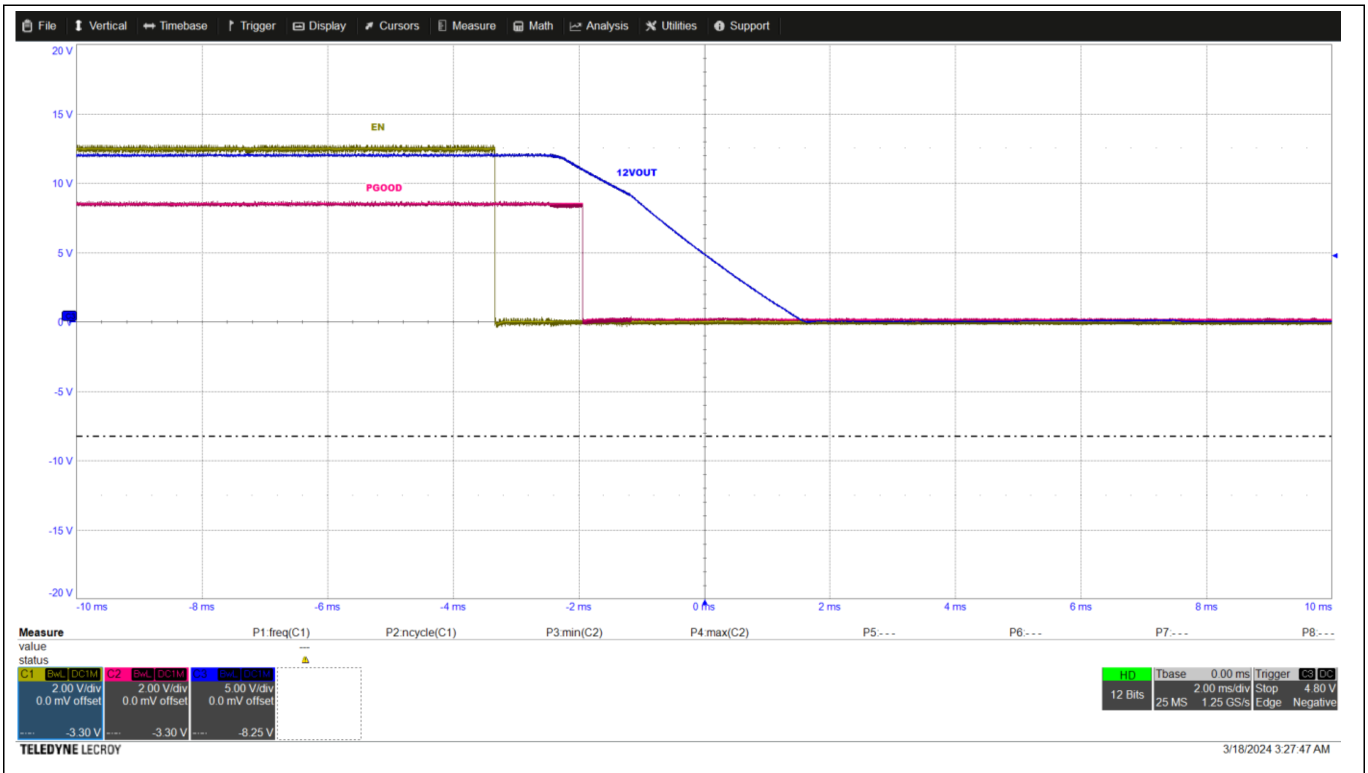

Figure 32 Shutdown waveform. CH1: EN, CH2: P_{GOOD}, CH3: 12 V output

3.3 Switching waveforms

ZSC converter – **CH1** Q23, **CH2** Q27 switching V_{DS} waveform, as shown in Figure 33.

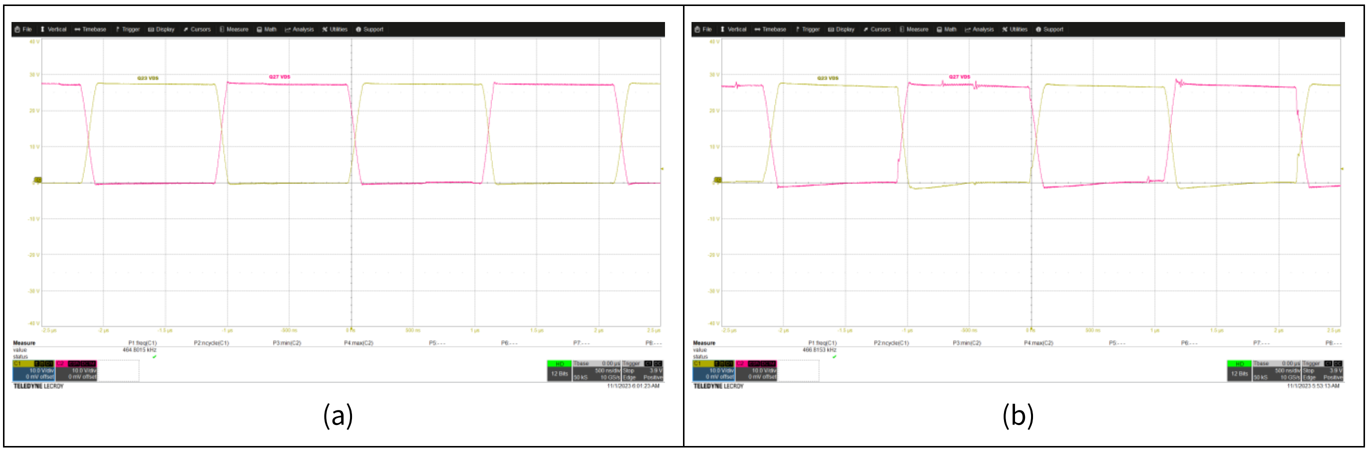

Figure 33 ZSC MOSFETs switching waveform – (a) 54 V, no load; (b) 54 V, 184 A full load

Figure 34 shows 3LFC-DP converter – **CH1** Q11, **CH2** Q18 switching V_{DS} waveform.

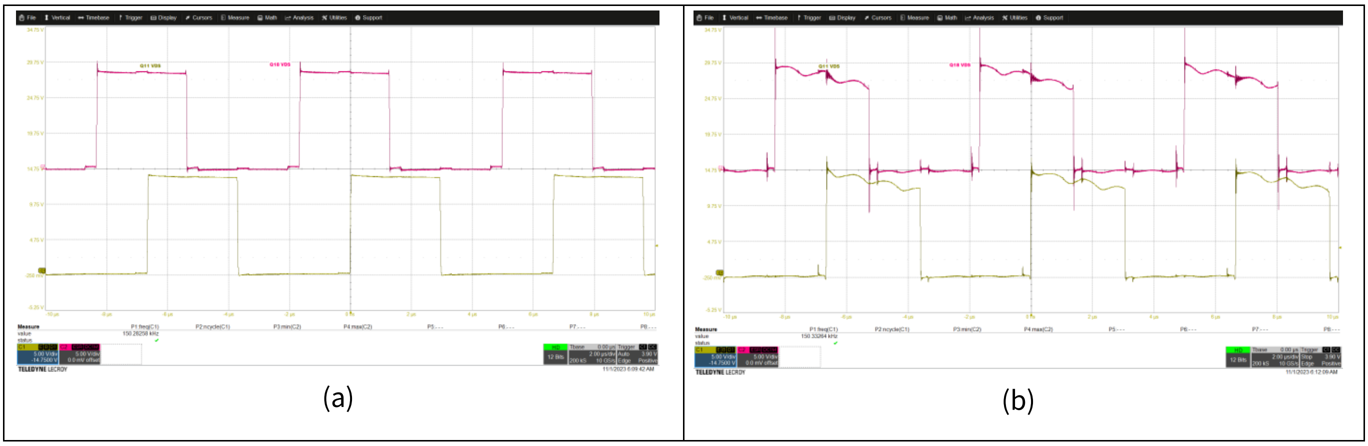

Figure 34 3LFC-DP MOSFETs switching waveform – (a) 54 V, no load; (b) 54 V, 184 A full load

3.4 Output regulation over input

Figure 35 shows output voltage regulation over input. At inputs lower than 44 V, the output is not regulated due to the limitation of the maximum attainable duty cycle of XDPP1100 for such topologies. The output is regulated once the input exceeds 44 V.

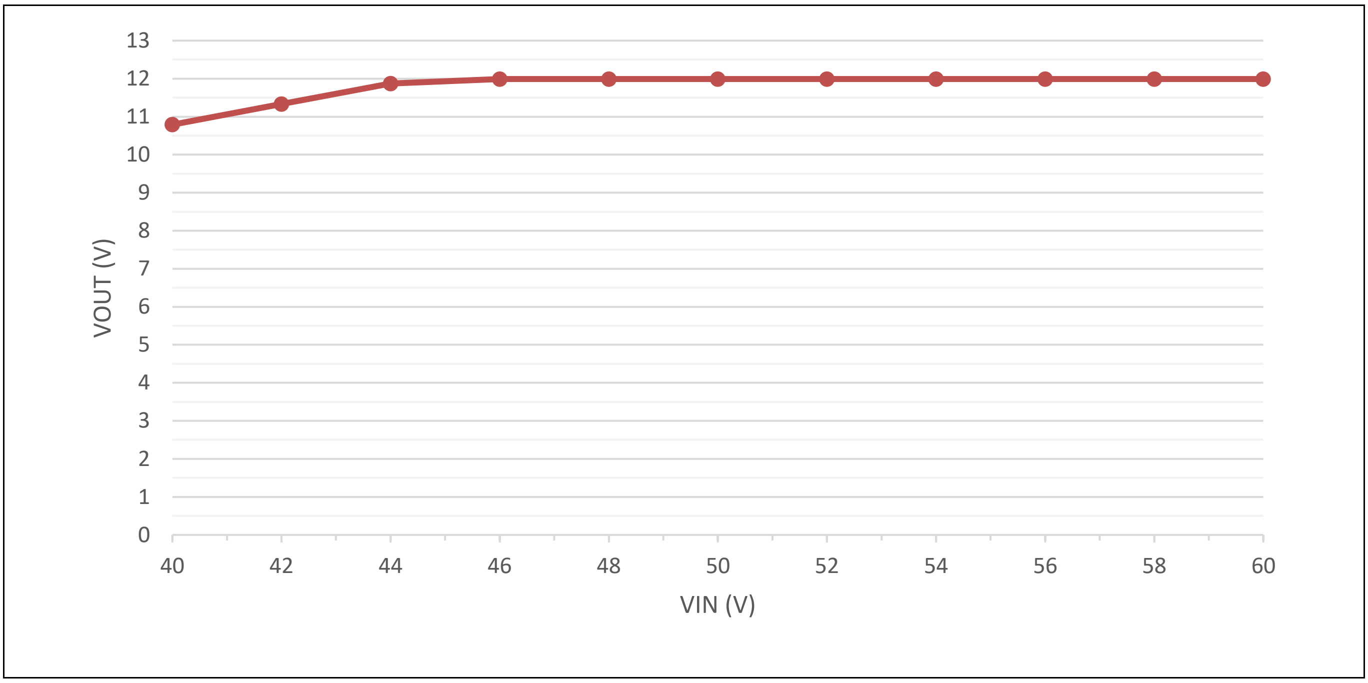

Figure 35 Output regulation over input

3.5 Measured efficiency

In Figure 36, at 48 V DC input the maximum allowed output power is limited to 2000 W to prevent overheating of components.

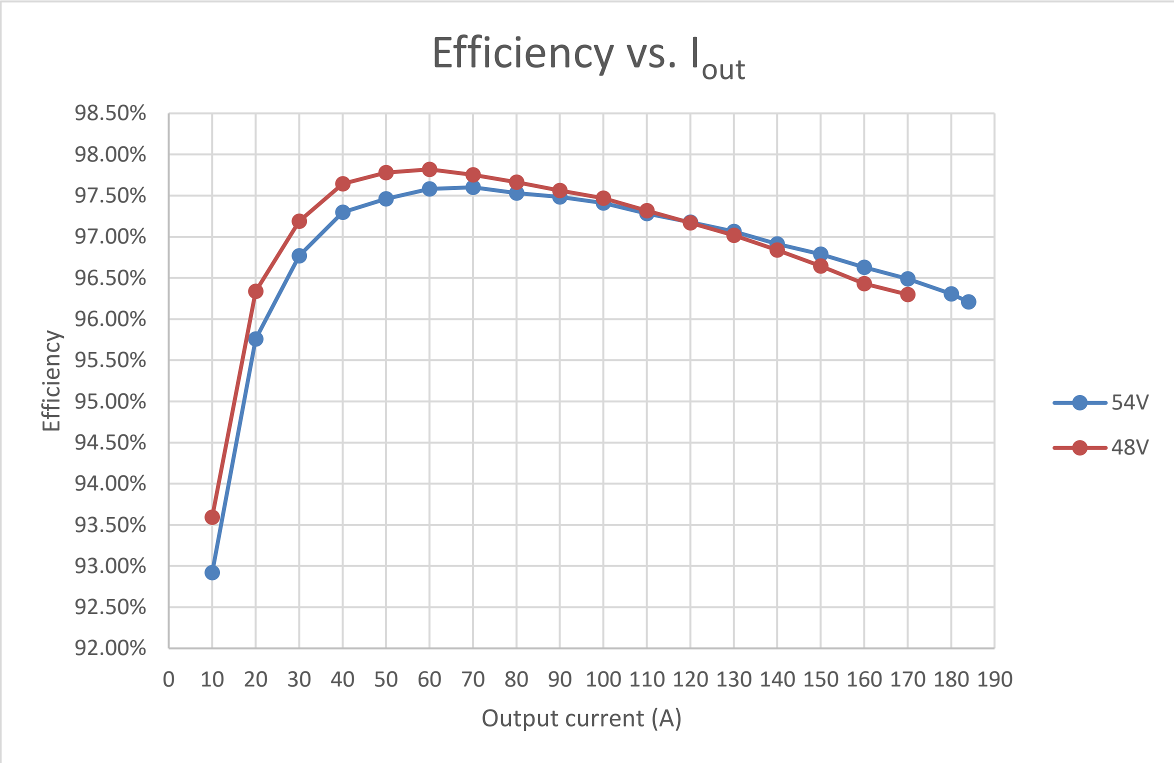

Figure 36 Measured efficiency results at 48 V DC, 54 V DC

3.6 Output current telemetry

Figure 37 shows the light load 0 A–10 A output current telemetry result. At 48 V DC input, the error is -2 A, while at 54 V DC input, the error is +1 A. The error is caused by the RC capacitor across the output inductor in the circuit, and can be improved by fine-tuning the capacitor. However, it is not easy to get a perfect value due to the tolerance of the component. Despite this, both telemetry results with 54 V and 48 V DC input respectively show good accuracy over the entire load.

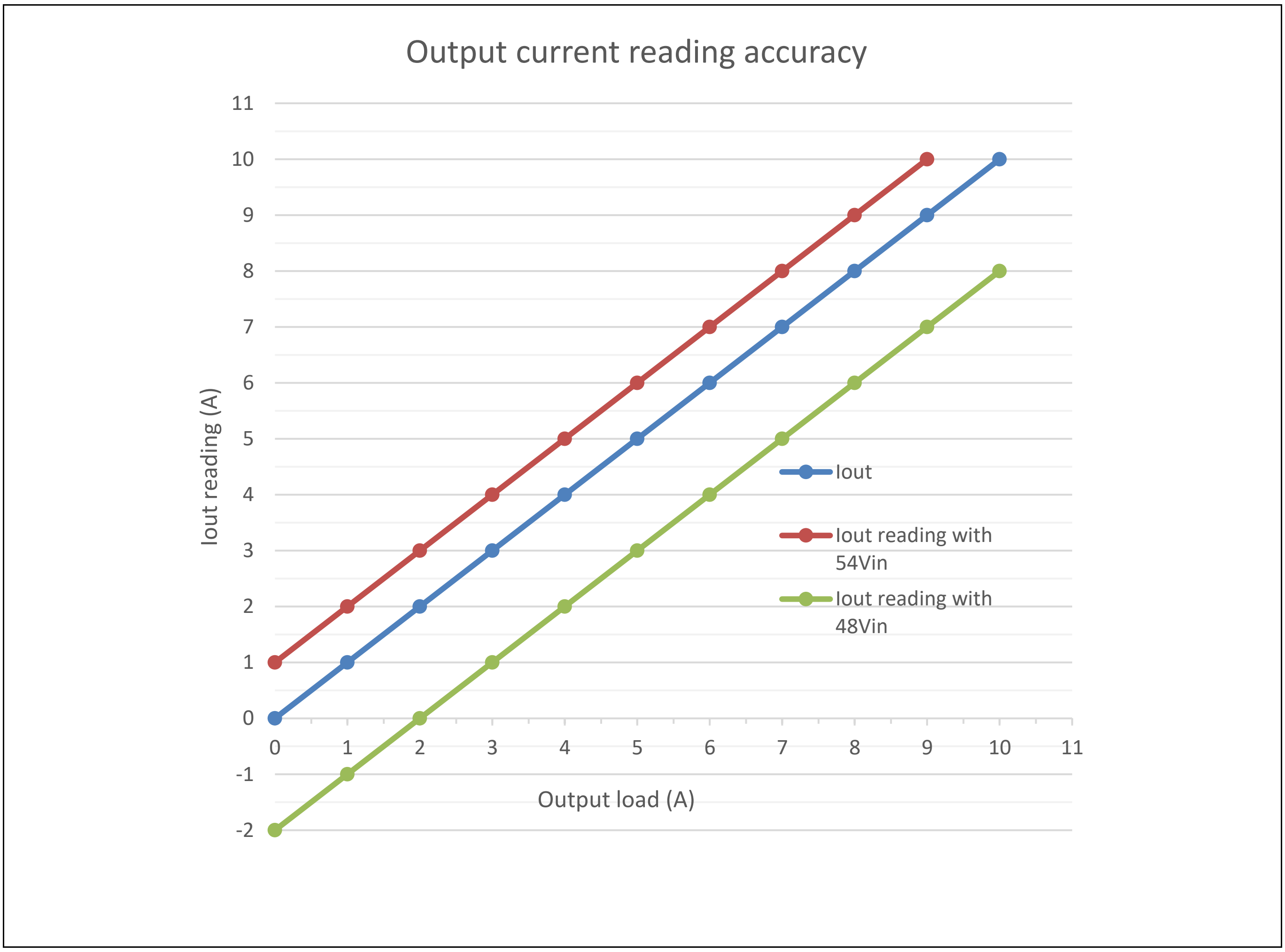

Figure 37 Light-load output current telemetry 0 A–10 A at 48 V DC and 54 V DC

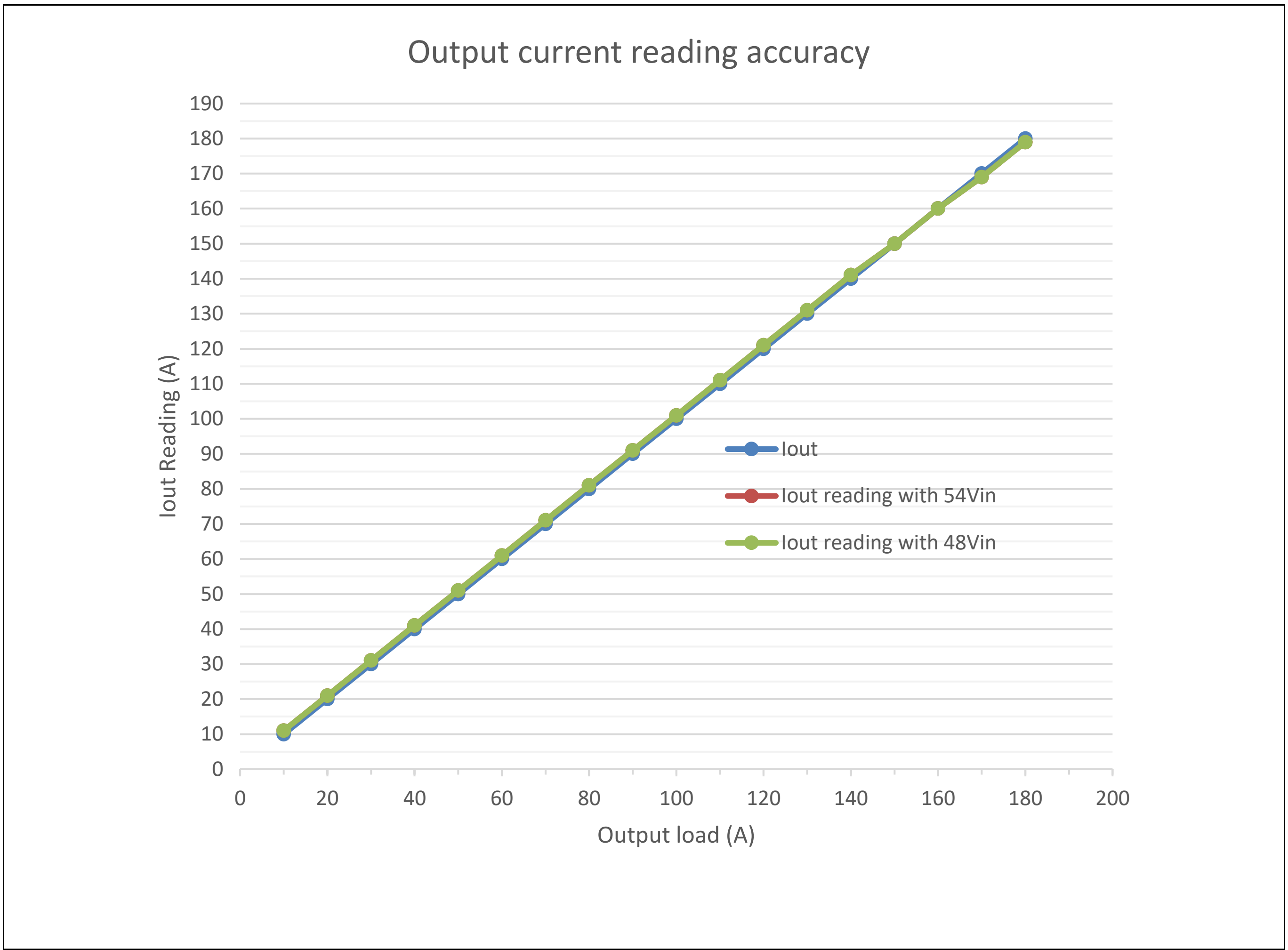

Figure 38 **Mid- to full-load output current telemetry 10 A–180 A at 48 V DC and 54 V DC**

3.7 Output ripple

As shown in Figure 39, the no-load output ripple is 54 mV at 54 V input and the full-load ripple is 103 mV.

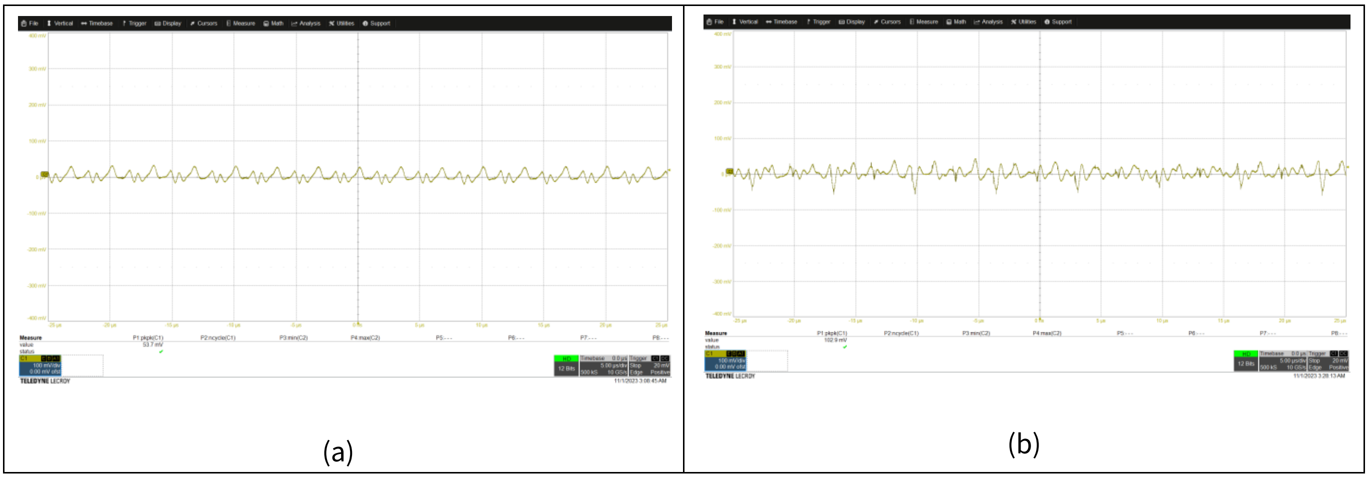

Figure 39 **Output voltage ripple (AC-coupled mode) – (a) V_{IN} = 54 V, I_{OUT} = 0 A; (b) V_{IN} = 54 V, I_{OUT} = 184 A**

3.8 Dynamic load response

As shown in Figure 40, the overshoot and undershoot is lower than 200 mV for dynamic load response.

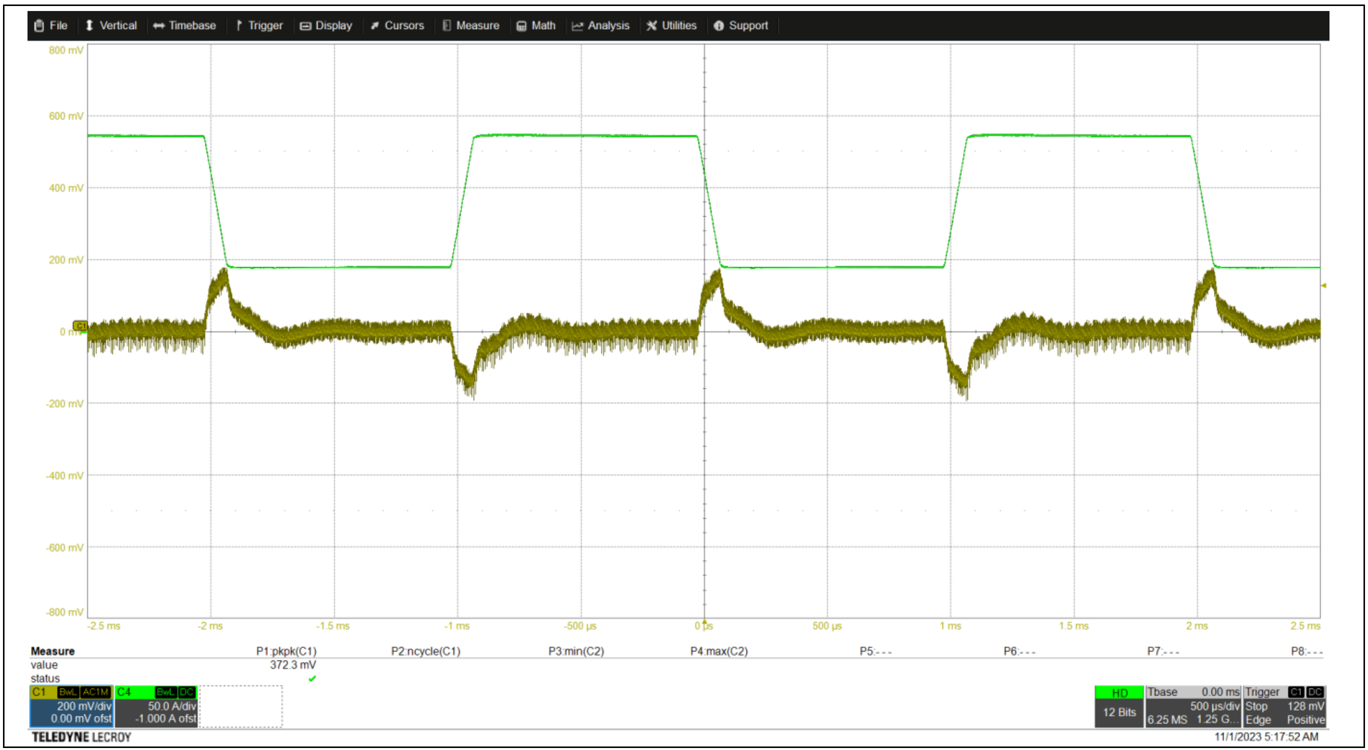

Figure 40 Dynamic load response V_{IN} = 54 V, I_{OUT} = 46 A–138 A, 25 percent–75 percent, 1 A/µS, 1 ms

3.9 Thermal measurements

Thermal images were taken after 45 minutes of operation to allow the components to reach steady-state at an output power of 2200 W at 54 V input voltage, as shown in Figure 41. Forced cooling with 235 m^3/h air flow was used for this testing. The hottest spot is 88.1°C. ZSC MOSFETs Q26, Q27, Q22, Q23, and 3LFC MOSFETs Q4, Q5, Q12, and Q13 are hot spots. For 48 V or 60 V input, the maximum allowed output power should be reduced to 2000 W.

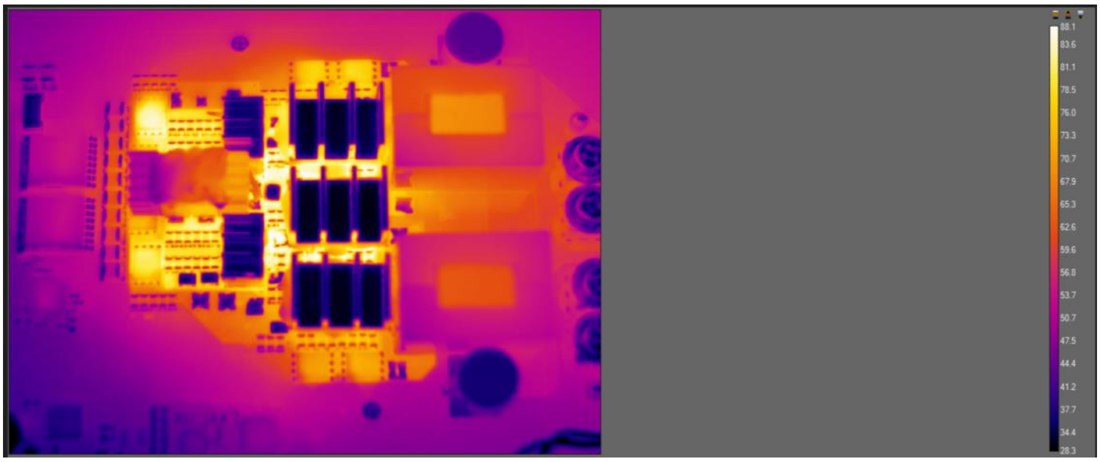

Figure 41 Thermal measurements at 54 V input and 2200 W load

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[1] Infineon Technologies AG: *XDPP1100 datasheet*; Available online

[2] Infineon Technologies AG: *XDP710 Hot-swap Controller datasheet*; Available online

[3] Infineon Technologies AG: *EiceDRIVER™ 1EDNx550 datasheet*; Available online

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[5] Infineon Technologies AG: *OptiMOS™ 5 Power-Transistor 80 V datasheet*; Available online

[6] Infineon Technologies AG: *OptiMOS™ 6 Power-Transistor 40 V datasheet*; Available online

[7] Infineon Technologies AG: *OptiMOS™ 5 Power-Transistor 30 V datasheet*; Available online

Glossary

3LFC-DP converter
Three-level, flying capacitor, dual phase buck converter

CMR
Common-mode robustness

TDI
Truly differential inputs

ZSC
Zero-voltage switching (ZVS), switched-capacitor converter (SCC)

Revision history

Document revision	Date	Description of changes
1.0	2024-05-30	Initial release

Edition 2024-05-30

Published by

Infineon Technologies AG

81726 Munich, Germany

Do you have a question about this document?

Email: erratum@infineon.com

Document reference

UG054206