High efficiency 170 W AC-DC reference design with XDP™ digital power XDPS2201 hybrid-flyback controller

For eBike charger with constant current and constant voltage mode

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Scope and purpose

This document is an engineering report for a 170 W AC-DC converter reference design which uses Infineon's XDP™ digital power XDPS2201 hybrid-flyback controller and a CoolSET™ daughterboard with Infineons's ICE5AR4770AG quasi-resonant (QR) flyback controller.

The converter has an extraordinarily high peak efficiency of **95 percent** and two control inputs that define the setpoints for the constant current (CC) and constant voltage (CV) regulation loops. Thus, it is ready to be used together with a safety switch and charging controller in battery charging applications. It can nevertheless be used in standard power supply applications as well.

The hybrid-flyback topology enables an extraordinarily small transformer size, comparable to resonant half-bridge and much smaller than standard flyback. Unlike resonant topologies the transformer construction is as simple as that of a standard flyback, without the need to minimize leakage inductance. This leads to very competitive system cost of the presented solution.

This document contains design features, board specfactions, performance data and a bill of materials (BOM) including transformer specifications.

Intended audience

Design engineers, technicians, and developers of electronic systems.

Table of contents

1 Test setup and safety instructions

This engineering report describes the board specifications, schematics and layout, BOM, and performance data.

This AC-DC reference design consists of a main board and a CoolSET™ daughterboard. The main board includes the hybrid-flyback (HFB) stage with Infineon's XDP™ digital power XDPS2201 hybrid-flyback controller and the output regulation circuit (CC-control and CV-control feature). The hybrid-flyback stage can be disabled via the disable button. A programming interface gives access to the XDPS2201 for parameter configuration and failure mode reporting.

The CoolSET™ daughterboard includes a QR flyback stage with Infineon's ICE5AR4770AG flyback controller and provides an independent constant 5 V auxiliary supply for the secondary side.

To implement a battery charger with this reference design, a battery safety switch must be connected in order to guarantee safe operation.

Attention: ***For safety reasons, it is prohibited to connect this reference design board to any battery without adding the battery safety switch externally.***

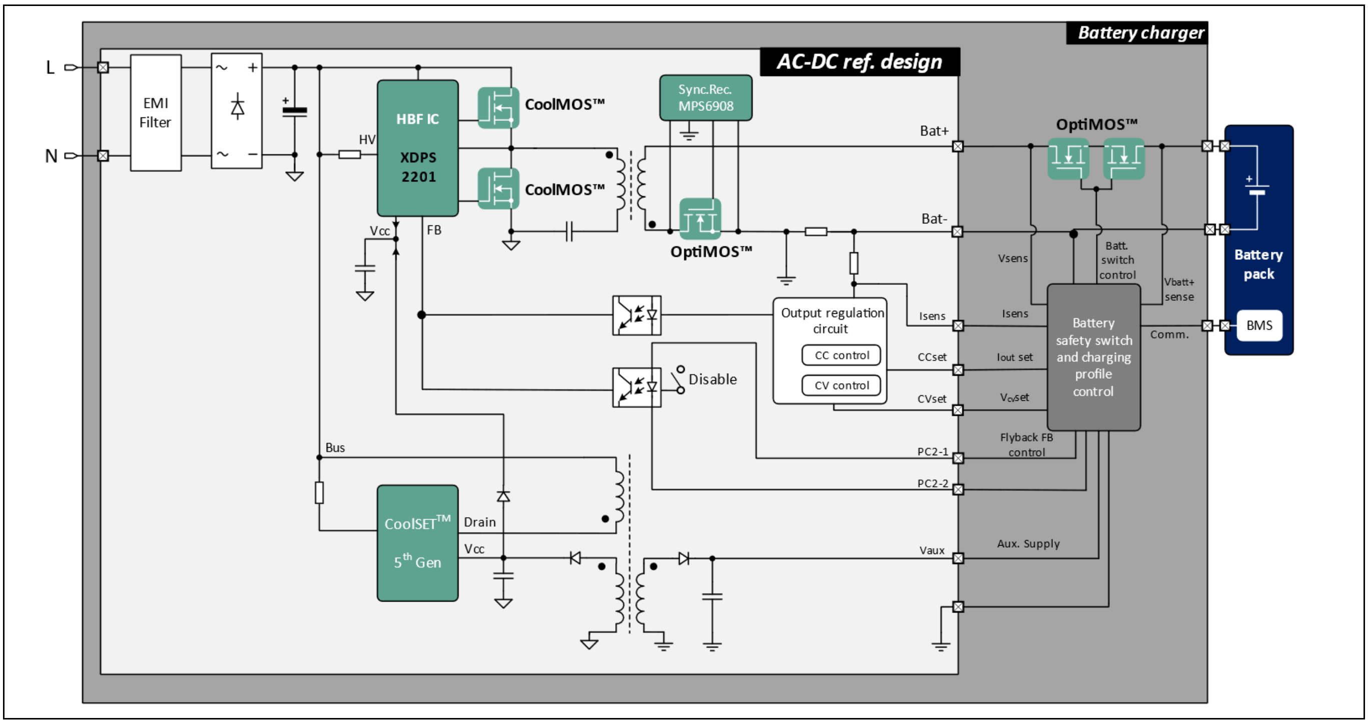


Figure 1 **Test setup of AC-DC reference design with external battery**

All mentioned measurements in the engineering report have been performed with the two following test setups. An AC source is used to power the reference board.

1.1 CC test setup

To set the desired charging current the CC_{set} value is controlled via an external DC source, according to **Figure 4**. The constant output voltage is used as default (CV_{set} = 3.0 V, V_{CV} = 42 V DC). An electronic load in CV mode is used to simulate a charging battery.

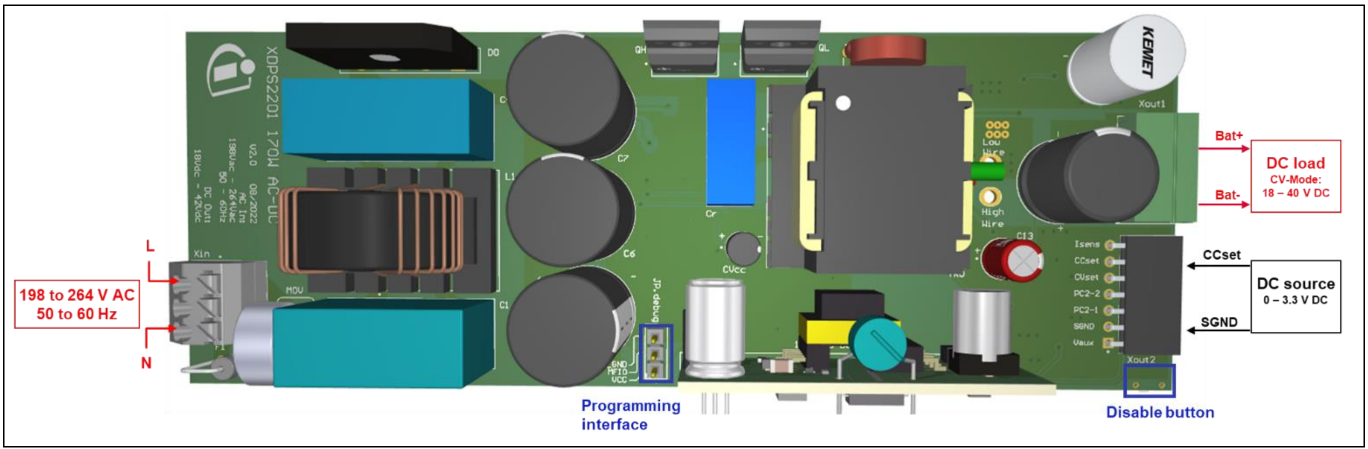


Figure 2 CC test setup with electronic load and setting CCset via DC source

1.2 CV test setup

To set the desired constant output voltage the CV_{set} value is controlled via an external DC source, according to **Figure 5**. The charging current is set to high (CC_{set} =3.0 V) via another external DC source. An electronic load in CC mode is used to simulate a charging battery.

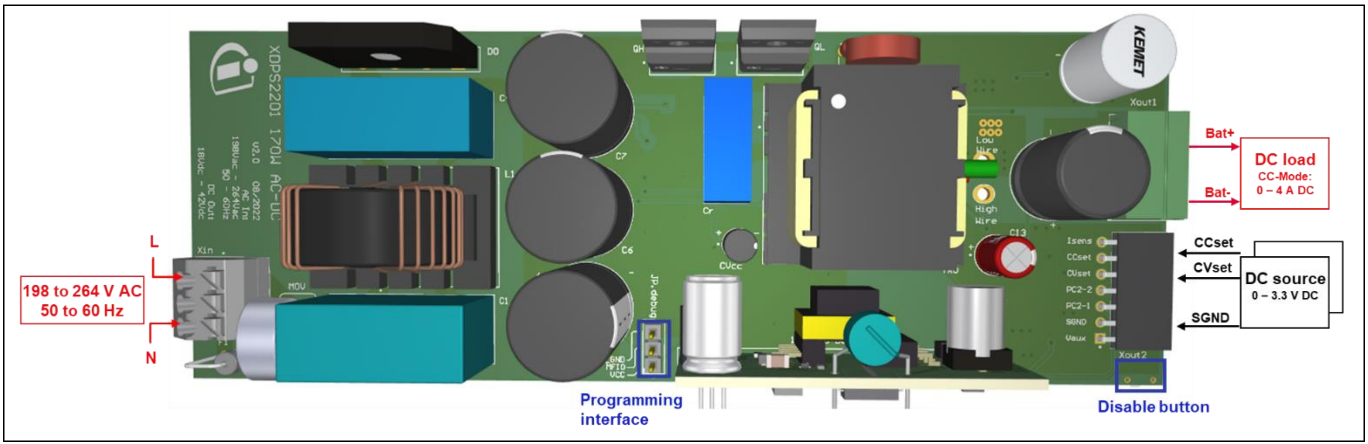


Figure 3 CV test setup with electronic load and setting CCset via DC source

Attention: ***Lethal voltages are present on this reference design. Do not operate the board unless you are trained to handle high-voltage circuits. Do not leave this board unattended when it is powered up.***

2 Board specifications

Table 1 Input and output specifications

Description	Symbol	Value	Unit
Input voltage range	V_{in}	198 to 264	V AC
Input frequency	f_{in}	50 to 60	Hz
CC_{set} range (see **Figure 4**)	CC_{set}	0 to 3.3	V DC
CV_{set} range (default CV_{set} = 0 V, V_{CV} = 42 V DC, see **Figure 5**)	CV_{set}	0 to 3.3	V DC
Output voltage range	V_{out}	18 to 42	V DC
Nominal output current	I_{outnom}	4.0	A
Max. output current	I_{outmax}	4.22	A
Efficiency at full output power (V_{in} = 230 V AC; output load = 40 V; I_{outmax} = 4.22 A)	η	More than 95	%
Average efficiency (V_{in} = 230 V AC)	η_{avg}	94.7	%

The following table highlights the key components and board dimensions of the main board.

Table 2 Key components and board dimensions – main board

Item	Specification
HFB controller IC	XDPS2201
MOSFETs	2x IPA60R280P7S, BSC160N15NS5, BSS169
PCB dimensions (L x W x H)	155 mm x 55.5 mm x 27 mm

The following table highlights the key components and board dimensions of the CoolSET™ daughterboard.

Table 3 Key components and board dimensions – CoolSET™ daughterboard

Item	Specification
Controller IC + integrated CoolMOS™	ICE5AR4770AG
PCB dimensions (L x W x H)	50 mm x 25 mm x 14 mm

Set the CC_{set} value via control interface connector Xout2, Pin 6 according to the desired charging current, as described in **Figure 4**. By default, the CC_{set} is not set internally and needs to be set from external DC supply.

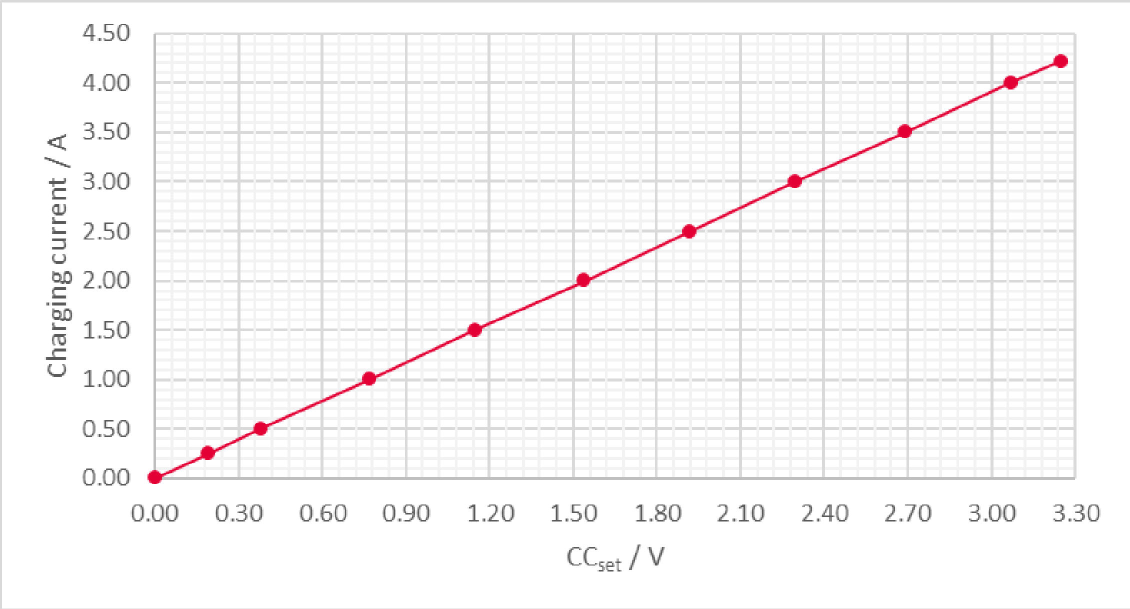


Figure 4 CCset values for desired charging current

Set the CV_{set} value via control interface connector Xout2, Pin5 according to the desired CV voltage, as described in **Figure 5**. By default, the CV_{set} value is set to 3.00 V via a resistor network, so CV voltage V_{CV} = 42 V.

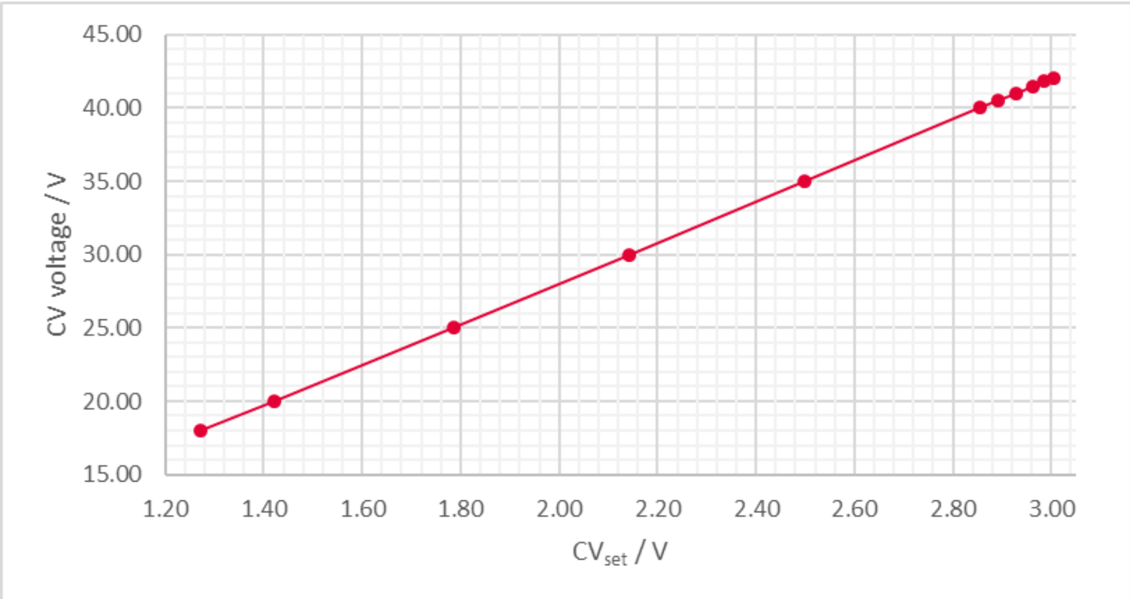


Figure 5 CVset values for desired CV voltage

3 Schematic and layout

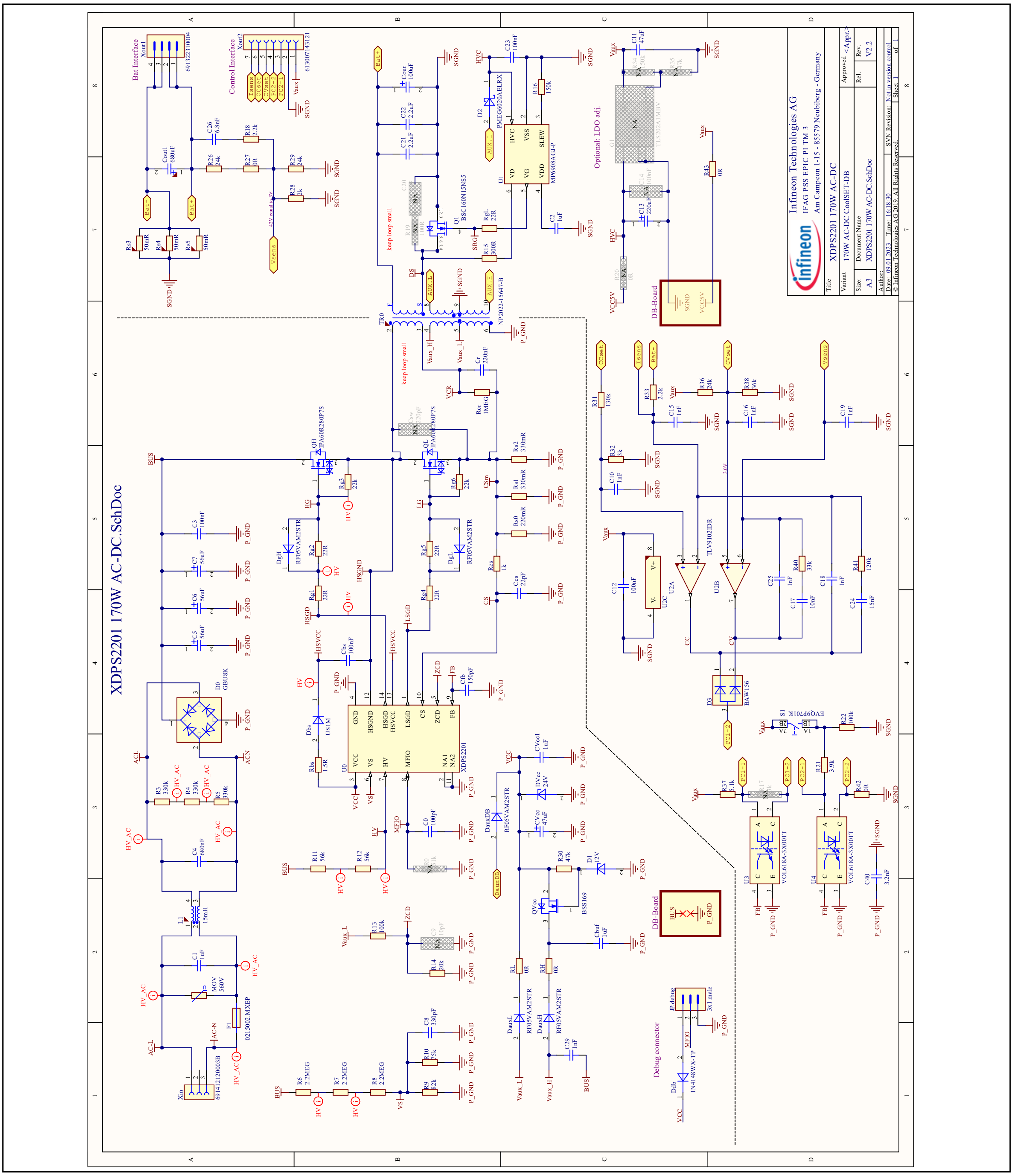


Figure 6 Main board schematic

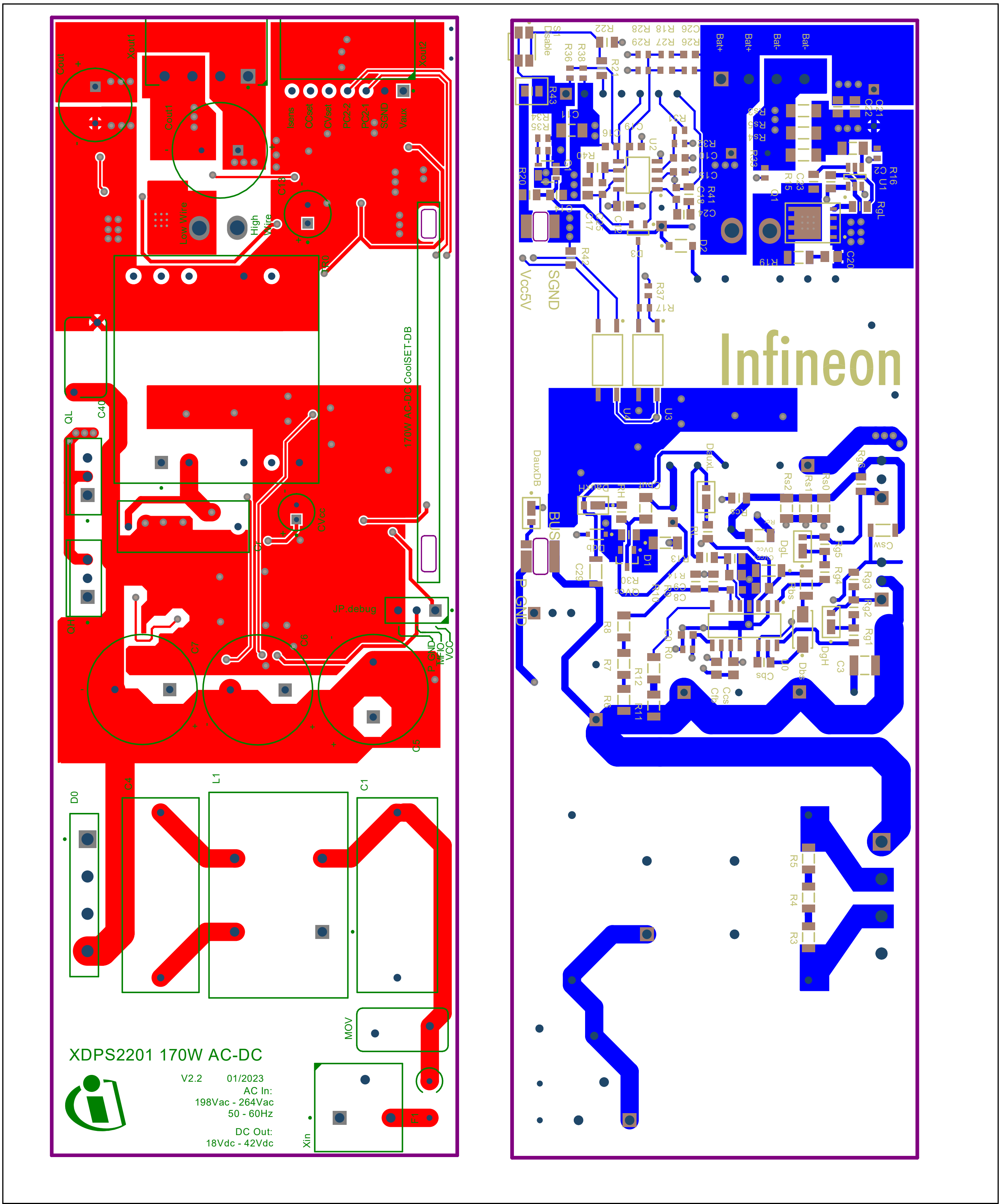


Figure 7 Main board PCB top (left) and bottom (right)

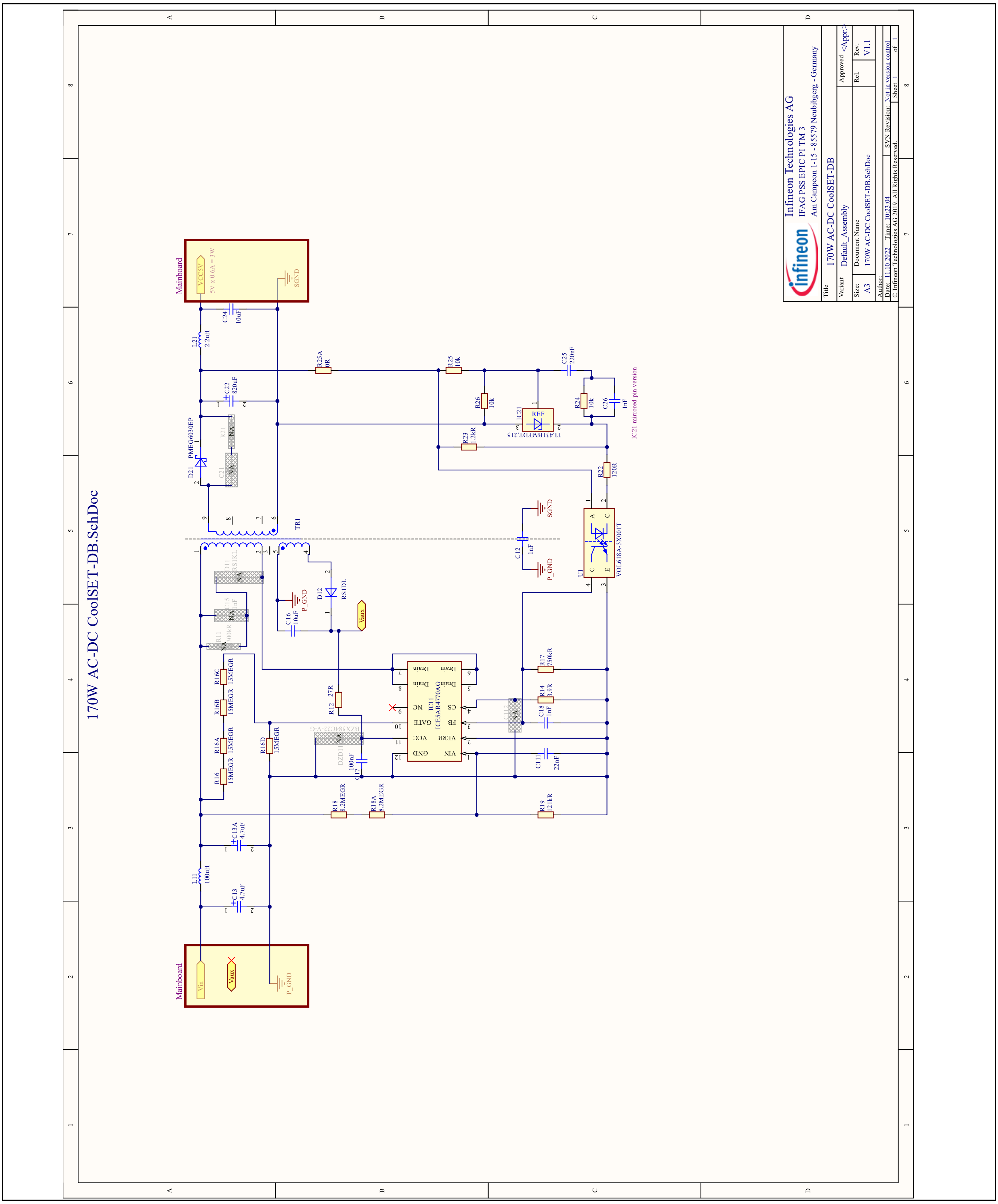


Figure 8 CoolSET™ daughterboard schematic

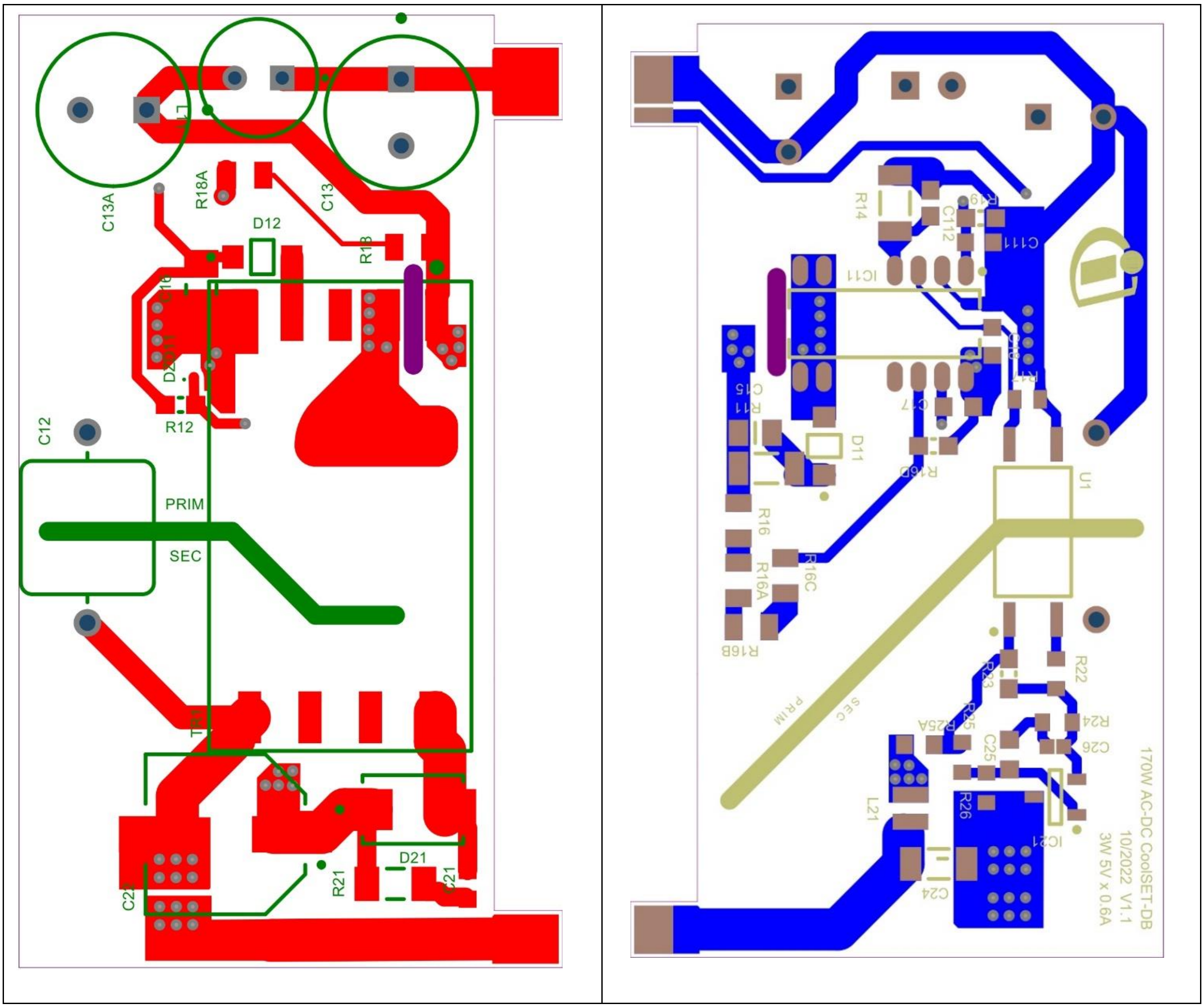


Figure 9 CoolSET™ daughterboard PCB top (left) and bottom (right)

4 Performance data

The performance data have been measured with the CC test setup described in **Figure 2**.

4.1 Efficiency

The efficiency was measured with different input voltage V_{in}. The battery load was simulated via an electronic load in CV mode. The board was lying on a laboratory desk under free air convection.

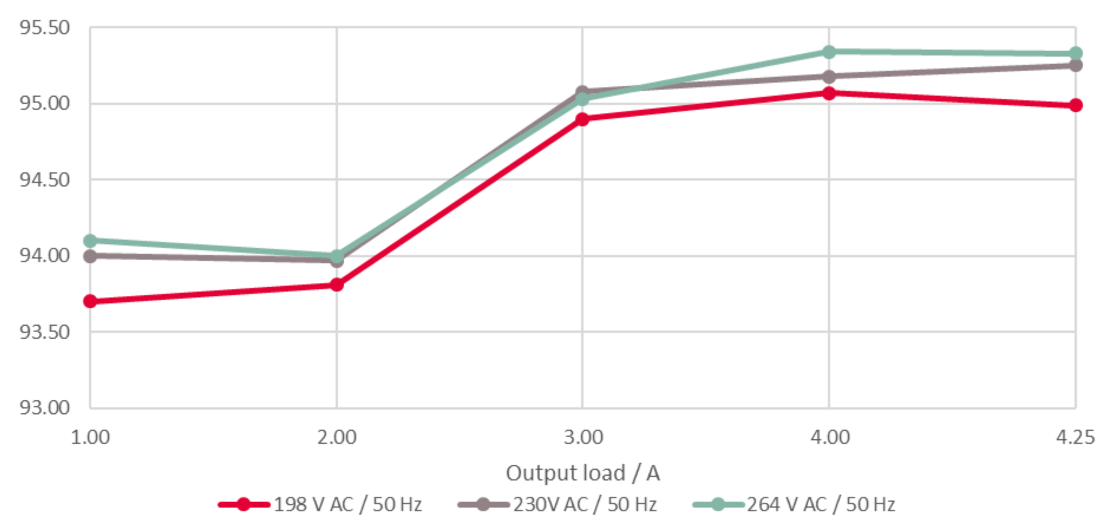


Figure 10 Efficiency at different input voltages

The average efficiency was measured at different input voltages at full output power – refer to **Table 4**.

Table 4 Average efficiency

V AC (V_{RMS})	Output load (V)	I_{out} (A)	I_{outnom} (%)	Efficiency	Average efficiency
198	40	1.00	25	93.7	94.5
		2.00	50	93.8	
		3.00	75	94.9	
		4.00	100	95.1	
		4.25	125	95.0	
230	40	1.00	25	94.0	94.7
		2.00	50	94.0	
		3.00	75	95.1	
		4.00	100	95.2	
		4.25	125	95.3	
264	40	1.00	25	94.1	94.8
		2.00	50	94.0	
		3.00	75	95.0	
		4.00	100	95.3	
		4.25	125	95.3	

4.1 Charging behavior

Figure 11 shows the implemented CC-CV charging method with default CV setting (CV_{set} = 3.0 V) and external CC setting to 0.5 A (CC_{set} = 0.42 V) for pre-charging current in the range of 18 V to 27 V battery voltage and to 4 A for nominal charging current (CC_{set} = 3.05 V) up to 42 V battery voltage. At 42 V battery voltage, CV control takes over and limits the battery voltage accordingly. Accuracy will depend on the tolerance of the resistor network of voltage sensing and the accuracy of the reference voltage.

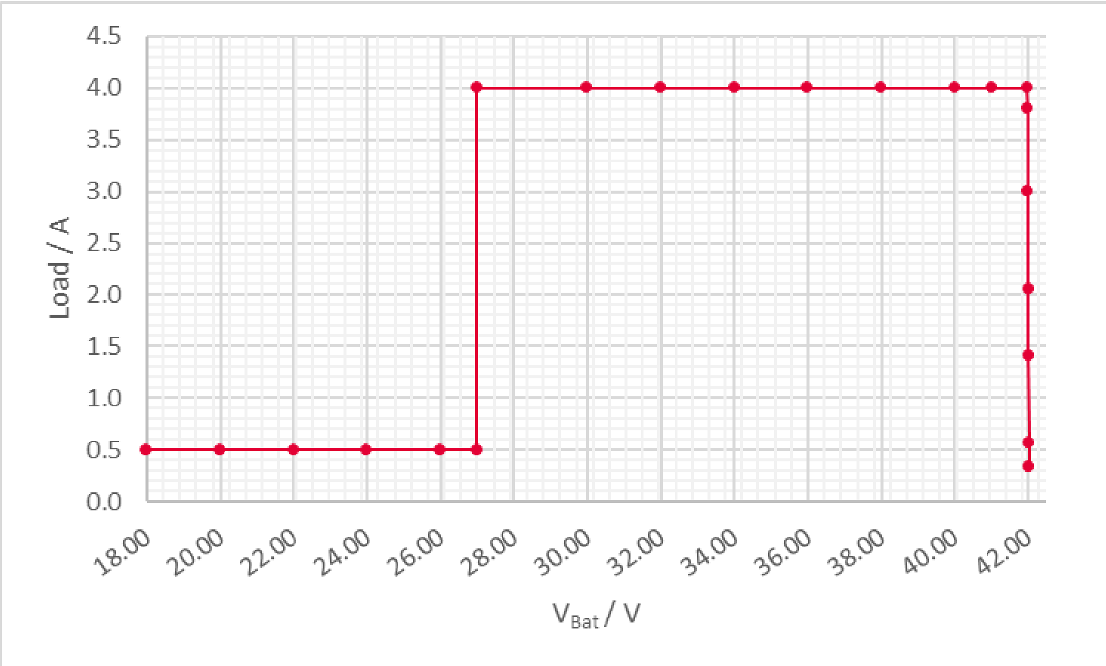


Figure 11 CC-CV charging behavior, Iload = 0.5 A and 4 A, CCset = 0.42 V and 3.05 V, CVset = 3.0 V

4.2 Standby power

The HFB under no output load is operating in CV mode, while the XDP™ digital power XDPS2201 controller is powered via the CoolSET™ daughterboard. **Figure 12** shows the input power consumption under no-load condition.

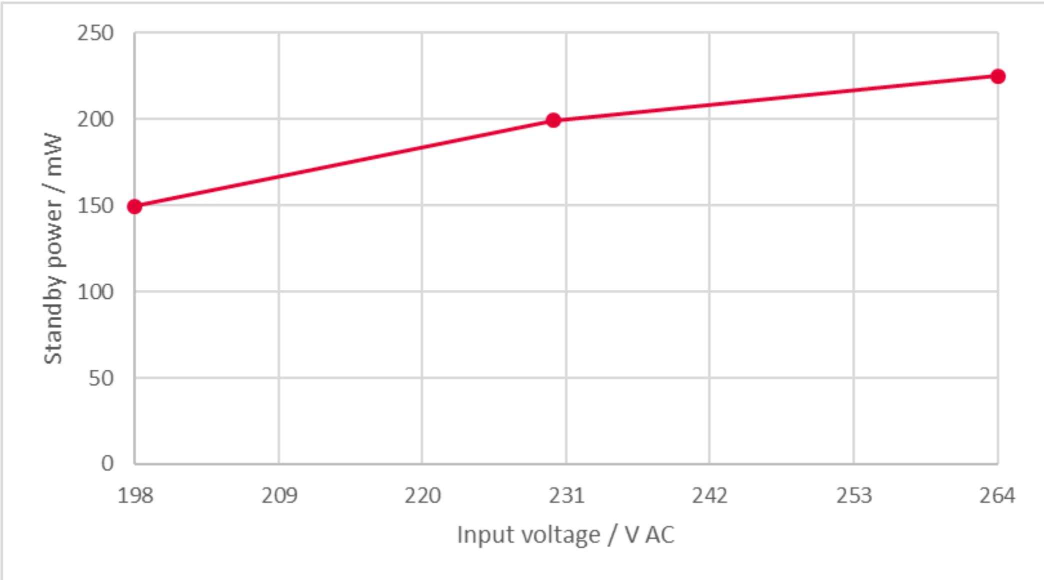
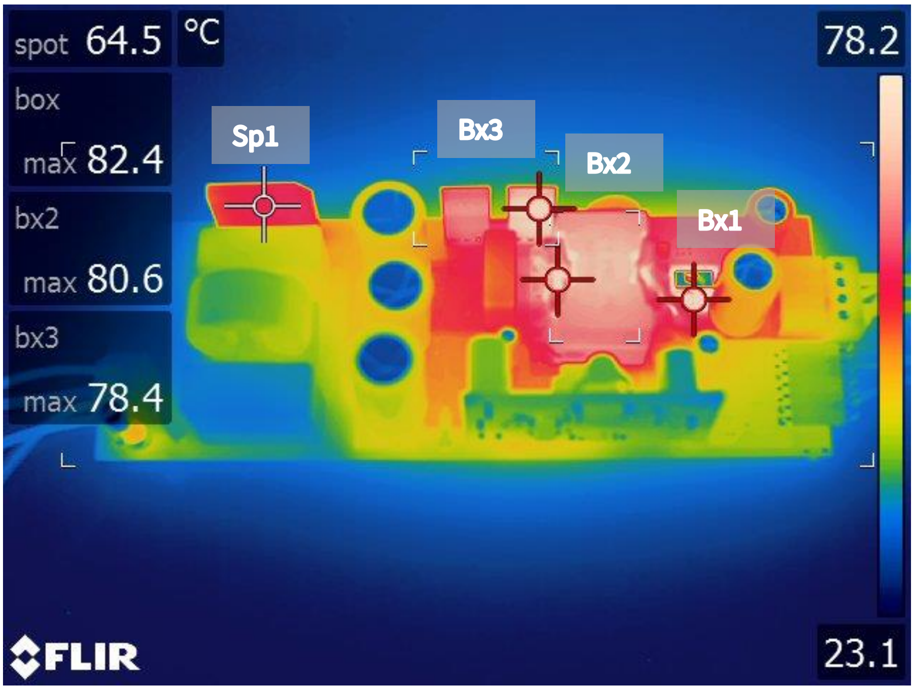


Figure 12 Standby power consumption

4.3 Thermal measurement

The open-frame thermal measurement was done after one hour of operation at nominal output load, using an infrared thermography camera. The ambient temperature was approximately 20°C.

V_{in} = 230 V AC, P_{out} = 170 W



Parameters

Emissivity	0.95
Reflected temp.	22.0°C
Atmospheric temp.	20.0°C
Relative humidity	50.0%

Camera information

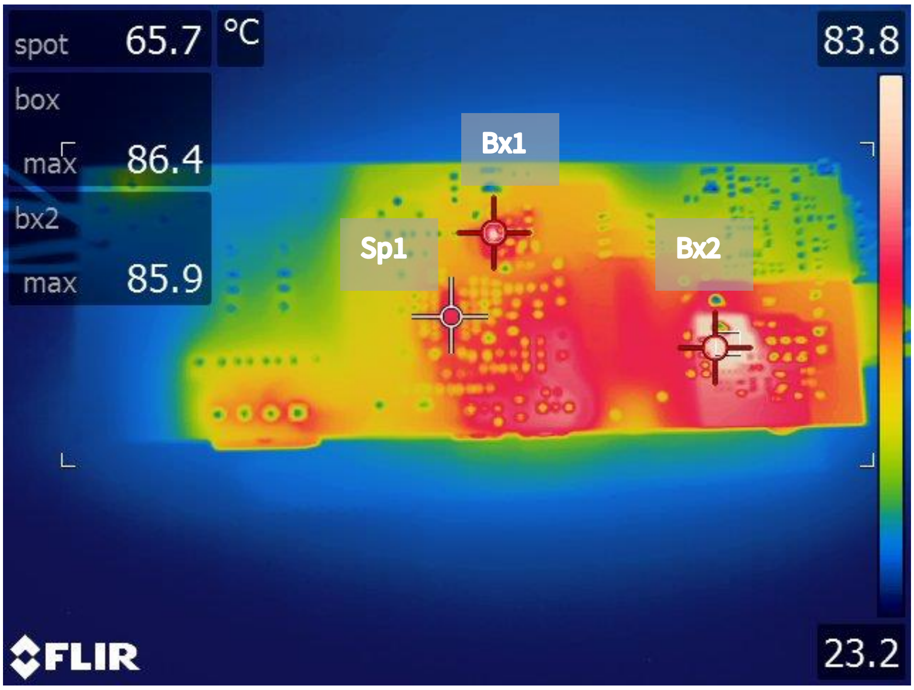
Camera model	FLIR T600
Lens	FOL13
Camera serial	55905689
Field of view	45.01

Figure 13 Infrared thermal image of PCB top side

Table 5 Temperature spots of PCB top side

No.	Designator	Function	Component	Temperature
Bx1 max	Q1	SR MOSFET OptiMOS™	BSC160N15NS5	82.4°C
Bx2 max	TR0	Transformer	NP2022-15647-B	80.6°C
Bx3 max	QH, QL	Half-bridge CoolMOS™	IPA60R280P7S	78.4°C
Sp1	D0	Bridge rectifier	GBU8K	64.5°C

V_{in} = 230 V AC, P_{out} = 170 W



Parameters

Emissivity	0.95
Reflected temp.	22.0°C
Atmospheric temp.	20.0°C
Relative humidity	50.0%

Camera information

Camera model	FLIR T600
Lens	FOL13
Camera serial	55905689
Field of view	45.01

Figure 14 **Infrared thermal image of PCB bottom side**

Table 6 **Temperature spots of PCB bottom side**

No.	Designator	Function	Component	Temperature
Bx1 max	QV_{CC}	Linear regulator transistor	BSS169	86.4°C
Bx2 max	Q1	SR MOSFET OptiMOS™	BSC160N15NS5	85.9°C
Sp1	U0	Hybrid-flyback controller	XDPS2201	65.7°C

4.4 Conducted emissions

The conducted emissions test was performed at full output power according to EN 55014 for battery chargers. The measurement was performed in phase and neutral configuration with a rated voltage of 230 V AC/50 Hz and with a sufficient margin to the limit of 6 dB, except spot #1.

The measurement equipment used for this emissions test was Rohde & Schwarz HM6050-2 and Tektronix RSA503A. The setup was based on EN 55022 standard class B limits. A variable wire resistor adjusted to 9.5 Ω was used as a dummy load.

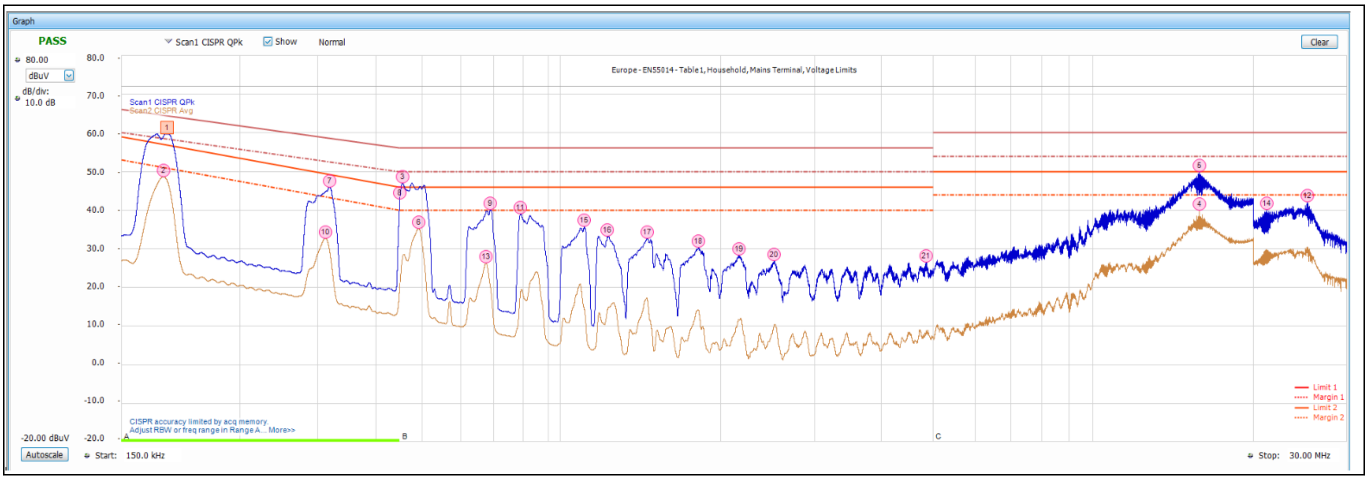


Figure 15 Conducted emissions – phase line

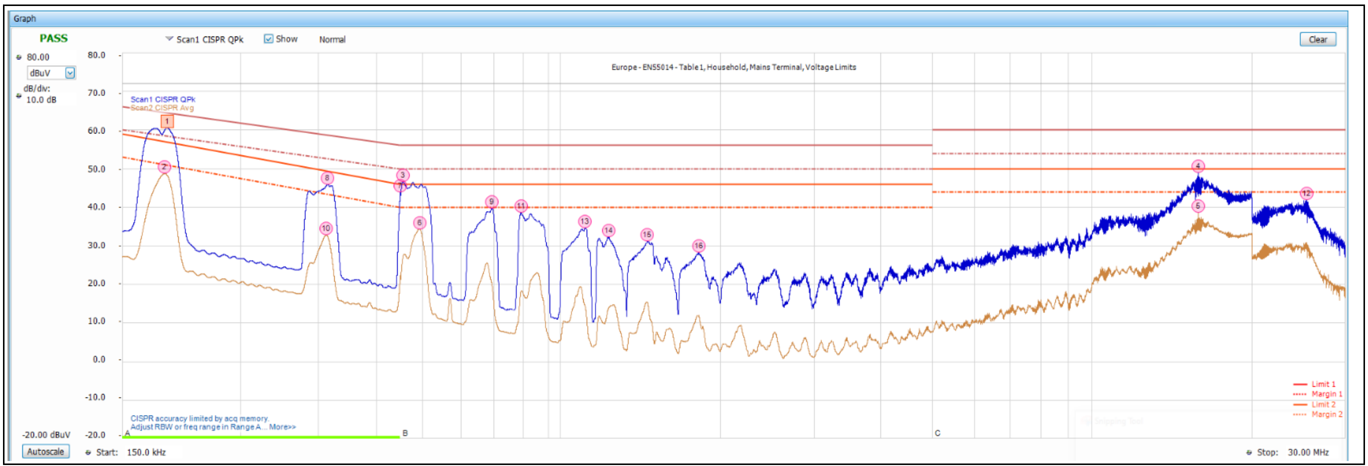


Figure 16 Conducted emissions – neutral line

5 Switching waveforms

This chapter contains switching waveforms for start-up, operation mode, and protection features.

5.1 Start-up

Start-up behavior was measured at full-load condition. The HFB operates in continuous resonant mode (CRM) – see **Figure 17**. At no-load condition, the HFB remains in burst mode (BM) mode, as shown in **Figure 18**.

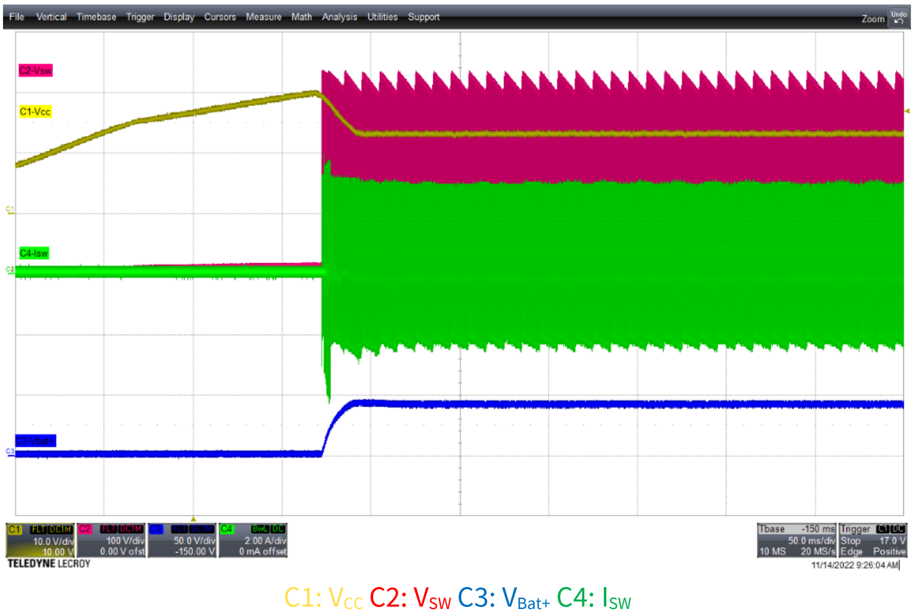


Figure 17 Start-up at full load, 230 V AC input

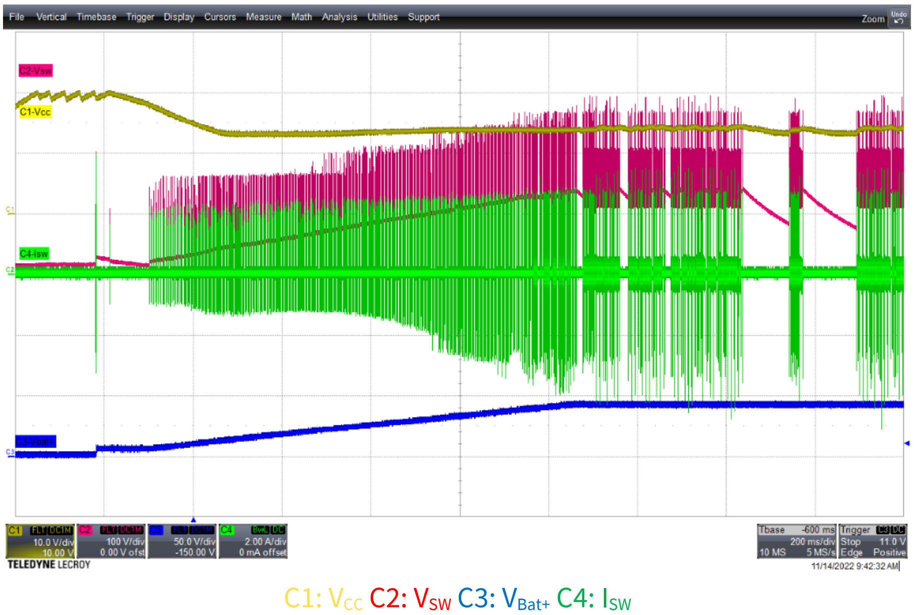


Figure 18 Start-up at no load, 230 V AC input

5.2 Operation mode

Modes during steady-state operation

The HFB has multiple operation modes to optimize efficiency over the line, load current, and output voltage ranges. **Figure 19** shows CRM operation at full-load condition in steady-state. For medium-load condition, the HFB operates in the zero-voltage resonant valley switching (ZV-RVS) mode (see **Figure 20**) while BM mode covers the light-load and no-load range, as shown in **Figure 21**. For a more detailed description of multiple operation mode please refer to the design guide **[1]**.

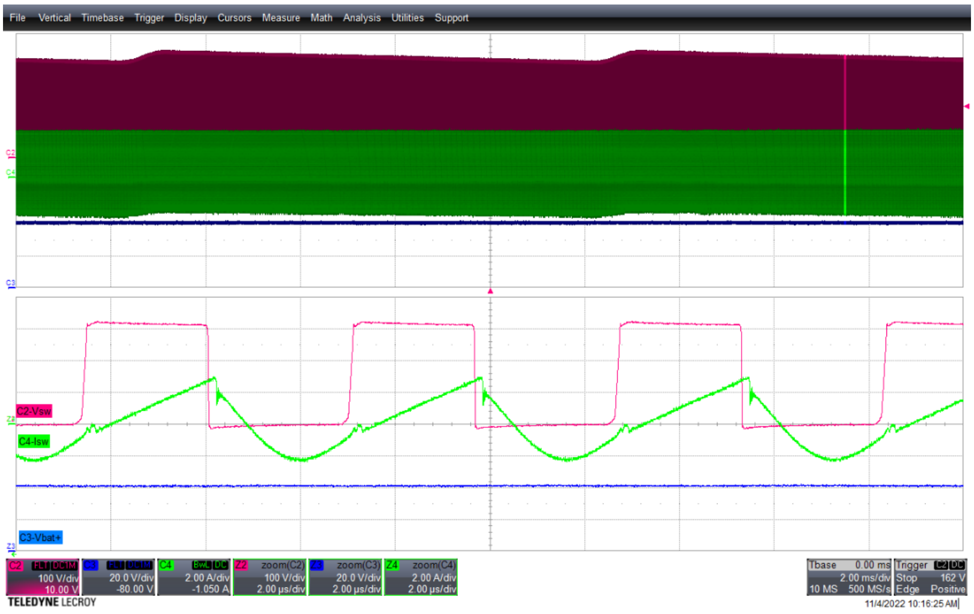


Figure 19 CRM mode at VBat+ = 40 V, load = 4 A, CCset: 3.07 V

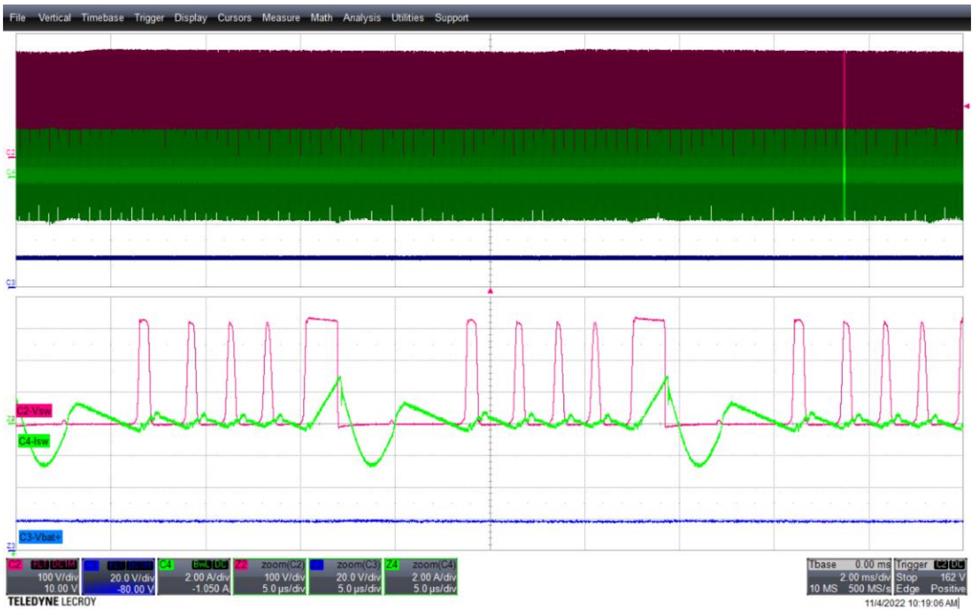


Figure 20 ZV-RVS mode at VBat+ = 18 V, load = 2 A, CCset: 1.54 V

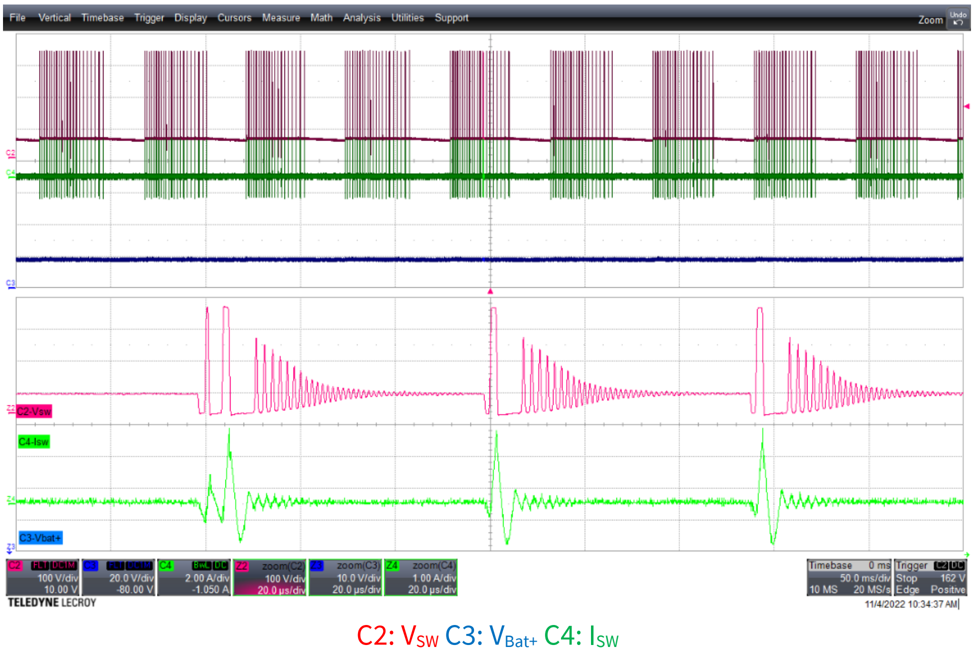


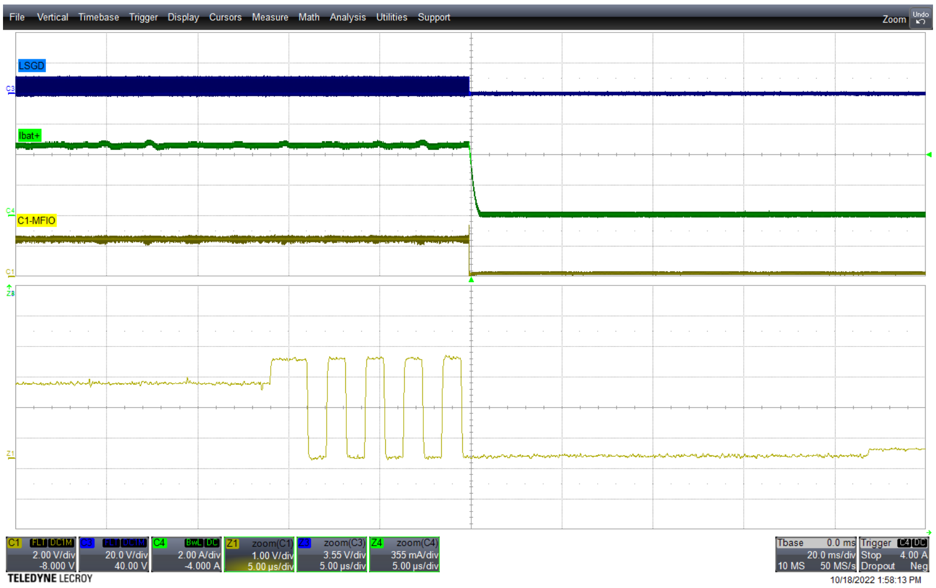
Figure 21 **Burst mode at VBat+ = 40 V, load = 0 A, CCset: 0 V**

5.3 Protection

The XDP™ digital power XDPS2201 has various protection features during normal operation. This chapter shows the overcurrent protection (OCP) with different levels, input overvoltage protection (V_{in_OVP}), and output undervoltage protection V_{in_UVP}). Once protection is triggered, the correspondending error code is sent out from the MFIO pin, see [1]. For a detailed description of all protection features, refer to the datasheet [2].

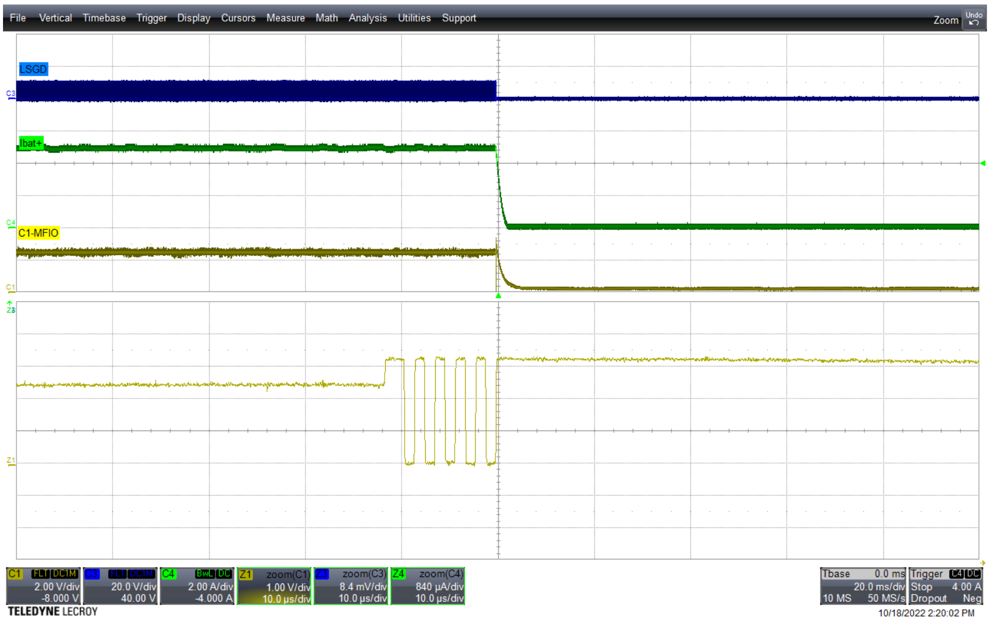
Overcurrent protection

The following figures show overcurrent protection level 1 (OCP1lev1) and level 2 (OCP1lev2) at different output loads.



C1: MFIO C3: LSGD C4: I_{Bat+}

Figure 22 OCP1lev1 triggering at output load of 4.4 A

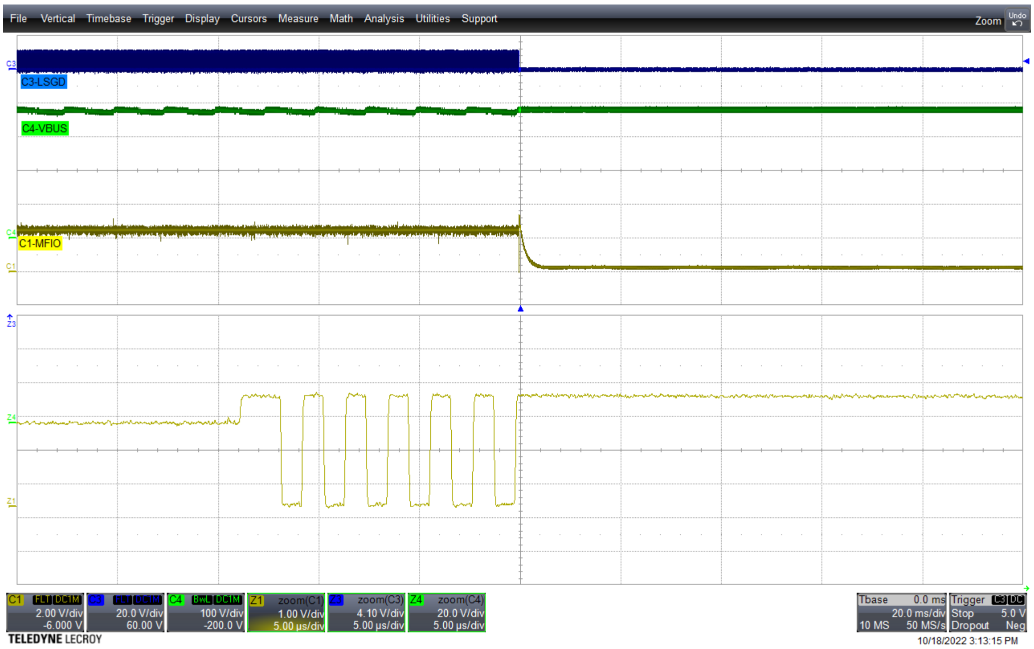


C1: MFIO C3: LSGD C4: I_{Bat+}

Figure 23 OCP1lev2 triggering at output load of 4.7 A

Input overvoltage protection

In case of overvoltage at the input, the HFB controller stops switching for certain time and enters auto-restart mode.



C1: MFIO C3: LSGD C4: V_{BUS}

Figure 24 Vin_OVP triggering at input voltage of 268 V AC

Output undervoltage protection

In case of an overload event at the output the HFB controller stops switching and enters auto-restart mode immediately.

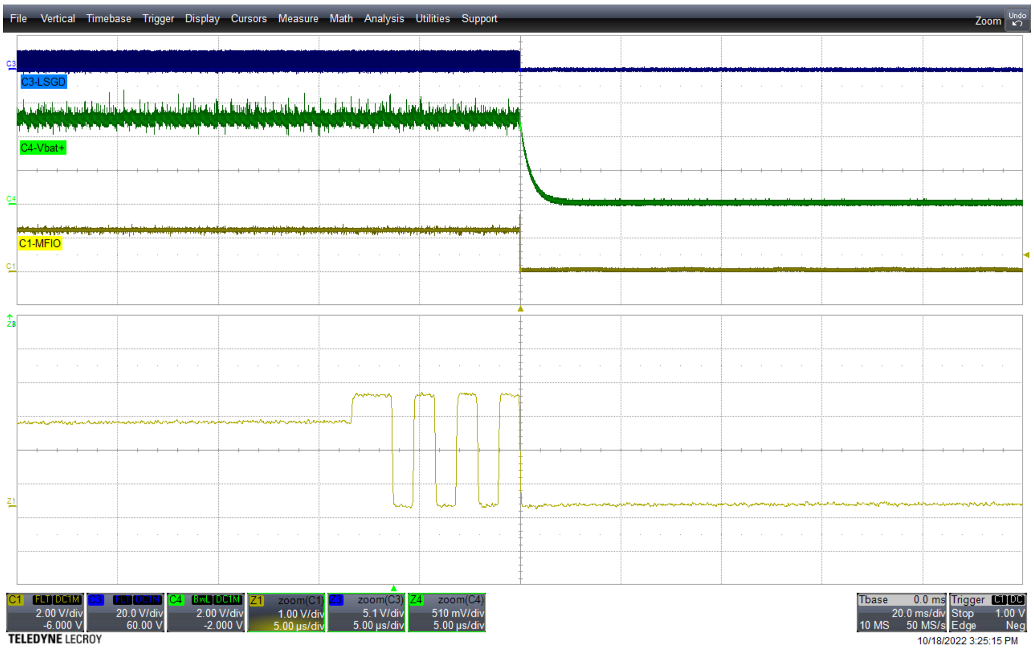


Figure 25 Vout_UVP triggering at overload of 3.3 Ω resistor at the output

6 Bill of materials and specifications

6.1 BOM of XDP™ digital power XDPS2201 170W AC-DC

Table 7 BOM of main board

Designator	Description	Manufacturer	Part number
C0	Capacitor 100 pF/50 V/0603/C0G/5%		
C1	Capacitor 1 µF/630 V/THT 22.5//10%	TDK Corporation	B32923C3105K189
C2, Cbuf	Capacitor 1 µF/50 V/1206/X7R/10%		
C3	Capacitor 100 nF/500 V/1210/X7R/10%		
C4	Capacitor 680 nF/630 V/THT 22.5 mm//10%	Epcos	B32923C3684K189
C5, C6, C7	Capacitor 56 µF/400 V/D14.5 mm x L25 mm//20%	Rubycon	400BXW56MEFR14.5X25
C8	Capacitor 330 pF/50 V/0603/X7R/10%		
C10, C15, C16, C18, C19, C25	Capacitor 1 nF/50 V/0603/C0G/1%		
C11	Capacitor 47 µF/16 V/1206/X5R/20%		
C12, C23	Capacitor 100 nF/50 V/0805/X7R/5%		
C13	Capacitor 220 µF/25 V/THT/Radial//20%	Würth Elektronik	860010473011
C17	Capacitor 10 nF/50 V/0805/X7R/10%		
C21, C22	Capacitor 2.2 µF/50 V/0805/X5R/10%		
C24	Capacitor 15nF/ 50V/ 0805/ X7R/5%		
C26	Capacitor 6.8nF/ 50V/ 0603/ X7R/5%		
C29	Capacitor 1 nF/630 V/1206/X7R/10%	Murata	GRM31AR72J102KW01
C40	Capacitor 3.2 nF/760 V/THT/Radial//20%	Vishay	440LD32-R
Cbs	Capacitor 100 nF/50 V/0805/X7R/10%		
Ccs	Capacitor 22 pF/50 V/0805//5%		
Cfb	Capacitor 150 pF/50 V/0805/C0G/5%		
Cout	Capacitor 100 µF/50 V/D10 x L17 L/A = 5 mm//20%	Kemet	ESX107M050AH2AA
Cout1	Capacitor 680 µF/50 V/THT//20%	Rubycon	50PX680MEFC12.5X20
Cr	Capacitor 220 nF/400 V/THT 15 mm//5%	Epcos	B32652A4224J000
CVcc	Capacitor 47 µF/35 V/THT/Radial//20%	Würth Elektronik	860020572006
CVcc1	Capacitor 1uF/ 50V/ 0805/ X7R/10%		
D0	Diode GBU8K	ON Semiconductor	GBU8K
D1	Diode 12 V//SOD-80//	Vishay	TZMB12-GS08
D2	Diode PMEG6020AELRX//SOD-123//	Nexperia	PMEG6020AELRX
D3	Diode BAW156//SOT-23//	Infineon Technologies	BAW156

DauxDB, DauxH, DauxL, DgH, DgL	Diode RF05VAM2STR//TUMD2M//	ROHM Semiconductors	RF05VAM2STR
Dbs	Diode US1M//DO-214AC (SMA)//	Vishay	US1M-E3/61T
Ddb	Diode 1N4148WX-TP//SOD-323//	Micro Commercial Components	1N4148WX-TP
DVcc	Diode 24 V//SOD-80C//	Nexperia	BZV55C24
F1	0215002.MXEP/250 V/Cylindrical leaded//	Littelfuse	0215002.MXEP
JP.debug	Connector HTSW-103-07-G-S//CON-THT-2.54-3-1-8.38//	Samtec	HTSW-103-07-G-S
L1	15 mH//THT size L//30%	Würth Elektronik	7448040515
MOV	560 V/460 V/THT//	Bourns	MOV-10D561K
Q1	BSC160N15NS5//PG-TDSON-8-46, PG-TDSON-8-7//	Infineon Technologies	BSC160N15NS5
QH, QL	IPA60R280P7S//PG-TO220-3-312//	Infineon Technologies	IPA60R280P7S
QVcc	BSS169//PG-SOT-23//	Infineon Technologies	BSS169
R3, R4, R5	Resistor 330 k/200 V/1206//1%		
R6, R7, R8	Resistor 2.2 MEG/200 V/1206//1%		
R9	Resistor 82 k/150 V/0805//1%		
R10	Resistor 75 k/150 V/0805//1%		
R11, R12	Resistor 56 k/200 V/1206//1%		
R13, R22	Resistor 100 k/150 V/0805//1%		
R14	Resistor 20 k/150 V/0805//1%		
R15	Resistor 300 R/150 V/0805//1%		
R16	Resistor 150 k/75 V/0603//1%		
R18, R33	Resistor 2.2k/ 75V/ 0603/ /1%		
R21	Resistor 3.9 k/150 V/0805//1%		
R26, R29, R36	Resistor 24k/ 75V/ 0603/ /1%		
R27	Resistor 0 R/50 V/0603//0 R		
R28	Resistor 2k/ 75V/ 0603/ /1%		
R30	Resistor 47 k/150 V/0805//1%		
R31	Resistor 130 k/75 V/0603//1%		
R32	Resistor 3 k/75 V/0603//1%		
R37	Resistor 5.1 k/75 V/0603//1%		
R38	Resistor 36k/ 75V/ 0603/ /1%		
R40	Resistor 33k/ 150V/ 0805/ /1%		
R41	Resistor 120k/ 150V/ 0805/ /1%		

R42, R43, RH, RL	Resistor 0 R/150 V/0805//		
Rbs	Resistor 1.5R/ 200V/ 1206/ /1%		
Rcr	Resistor 1 MEG/200 V/1206//1%		
Rcs	Resistor 1 k/150 V/0805//1%		
Rg1, Rg2, Rg4, Rg5, RgL	Resistor 22 R/150 V/0805//1%		
Rg3	Resistor 22 k/150 V/0805//1%		
Rg6	Resistor 22 k/150 V/0805//1%		
Rs0	Resistor 220 mR/675 mV/1206//1%	Bourns	CRM1206-FX-R220 E LF
Rs1, Rs2	Resistor 330 mR/675 V/1206//1%	Bourns	CRM1206-FX-R330 E LF
Rs3, Rs4, Rs5	Resistor 50 mR//1206//1%	Vishay	WFC1206R0500FE66
S1	EVQ9P701K//SMD four pads//	Panasonic	EVQ9P701K
TR0	NP2022-15647-B/	ICT	NP2022-15647-B
U0	XDPS2201//PG-DSO-14//	Infineon Technologies	XDPS2201
U1	MP6908AGJ-P//TSOT23-6//	Monolithic Power Systems	MP6908AGJ-P
U2	TLV9102IDR//SOIC-8//	Texas Instruments	TLV9102IDR
U3, U4	Optocoupler VOL618A-3X001T//LSOP-4//	Vishay	VOL618A-3X001T
Xin	Connector 691412120003B//WR-TBL//	Würth Elektronik	691412120003B
Xout1	Connector 691322310004//WR-TBL//	Würth Elektronik	691322310004
Xout2	Connector 613007143121/ / THT 7 PIN 2.54mm pitch/ /	Würth Elektronik	613007143121

6.2 BOM of 170 W AC-DC CoolSET™-DB

Table 8 BOM of CoolSET™ daughterboard

Designator	Description	Manufacturer	Part number
C12	Capacitor 1nF/500 V/THT/Radial//20%	Murata	DE1E3RA102MA4BQ01F
C13, C13A	Capacitor 4.7 µF/400 V/THT/Radial//20%	Würth Elektronik	860021374008
C16	Capacitor 10 µF/50 V/1206/X7R//10%		
C17	Capacitor 100 nF/50 V/0603/X7R//10%		
C18	Capacitor 1 nF/50 V/0603/X7R//10%		
C22	Capacitor 820 µF/6.3 V/SMD//20%	Würth Elektronik	875075155009
C24	Capacitor 10 µF/25 V/1206/C0G//10%		
C25	Capacitor 220 nF/10 V/0603/X7R//5%		

C26	Capacitor 1 nF/25 V/0402/C0G//2%		
C111	Capacitor 22 nF/50 V/0603//10%		
D12	RS1DL	Taiwan Semiconductor	RS1DL
D21	Diode PMEG6030EP//SOD-128//	Nexperia	PMEG6030EP
IC11	ICE5AR4770AG//PG-DSO-12//	Infineon Technologies	ICE5AR4770AG
IC21	TL431BMFDT, 215	Nexperia	TL431BMFDT,215
L11	Inductor 100 µH//WE_7447462//10%	Würth Elektronik	7447462101
L21	Inductor 2.2 µH//SMD//20%	Würth Elektronik	74438343022
R12	Resistor 27 R/75 V/0603//1%		
R14	Resistor 3.90 R/200 V/1206//1%		
R16, R16A, R16B, R16C	Resistor 15 MEGR/150 V/0805//0R		
R16D	Resistor 15 MEGR/75 V/0603//1%		
R17	Resistor 750 kR/75 V/0603//1%		
R18, R18A	Resistor 8.2 MEGR/150 V/0805//0R		
R19	Resistor 121 kR/75 V/0603//1%		
R22	Resistor 120 R/75 V/0603//1%		
R23	Resistor 1.2 kR/75 V/0603//1%		
R24, R25, R26	Resistor 10 k/75 V/0603//1%		
R25A	Resistor 0 R/75 V/0603//1%		
TR1	750344058 (Rev. 02)/1.96 mH	Würth Elektronik	750344058
U1	Optocoupler VOL618A-3X001T//LSOP-4//	Vishay	VOL618A-3X001T

6.3 Transformer specifications

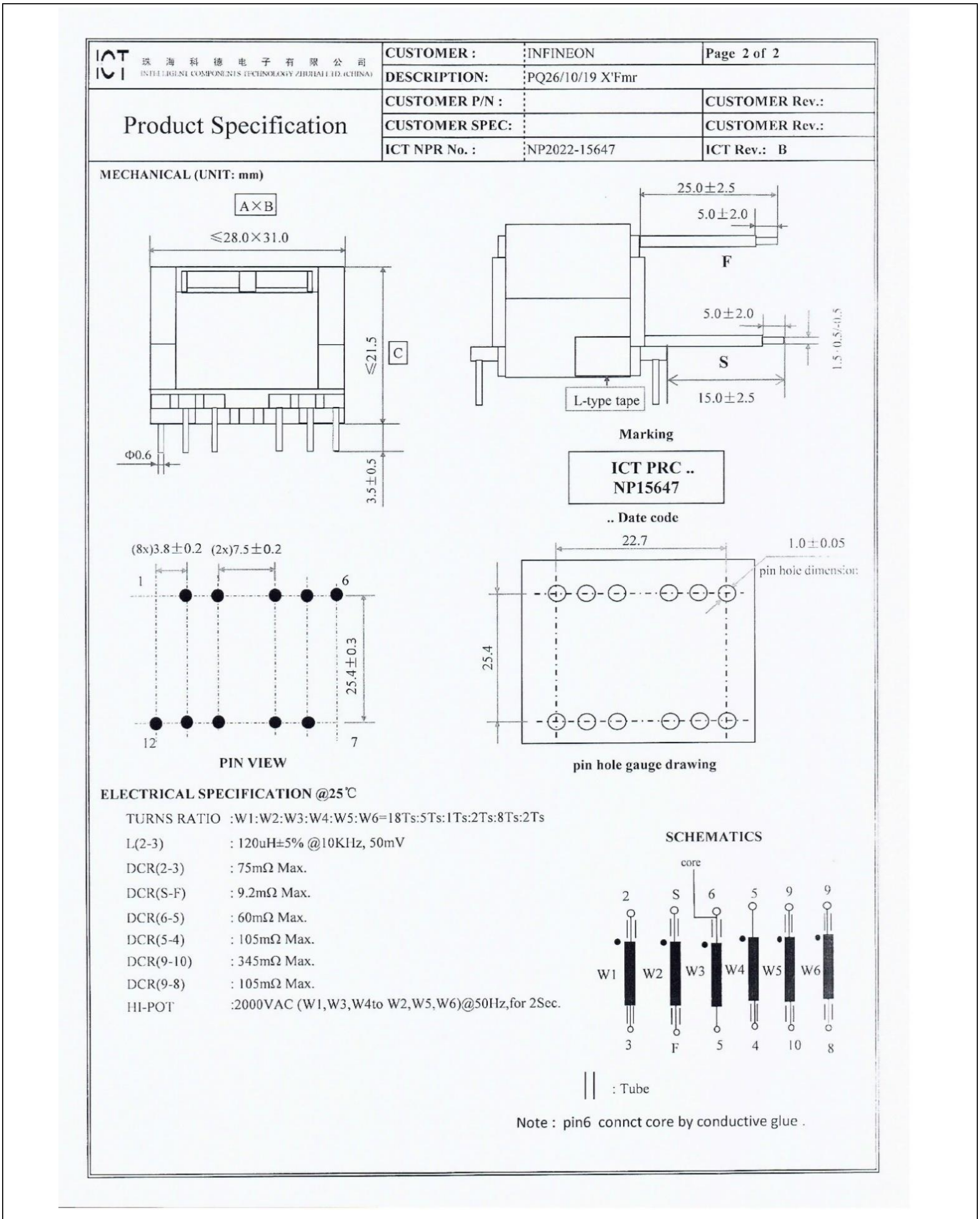


Figure 26 Transformer specifications of NP2022-15647-B

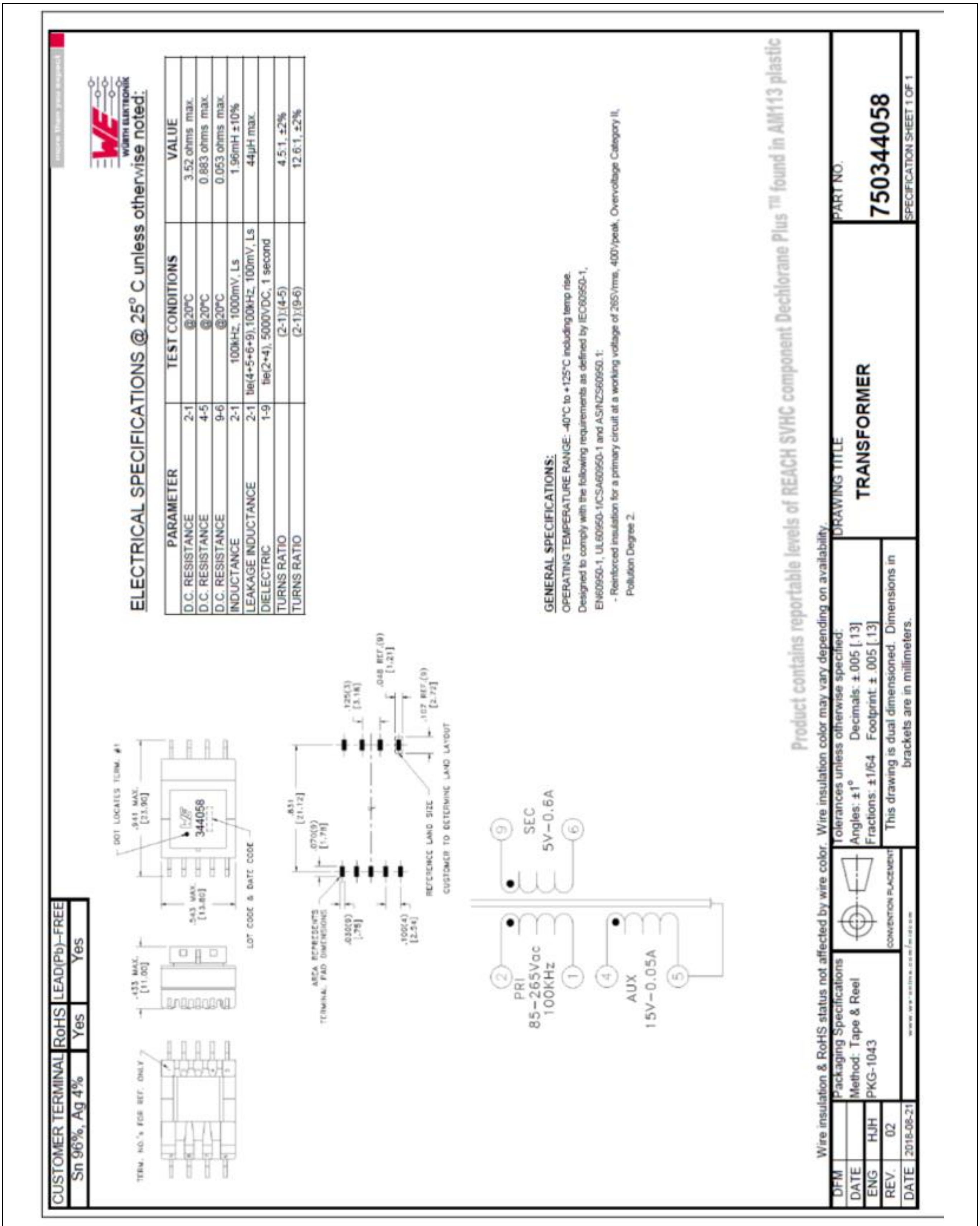


Figure 27 Transformer specifications of 75034405

References

[1] Infineon Technologies AG: *Hybrid-flyback converter design with XDP™ digital power XDPS2201*; **Available online**

[2] Infineon Technologies AG: *XDPS2201 Datasheet*; **Available online**

Revision history

Document revision	Date	Description of changes
V 1.0	2023-01-24	Initial release

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Edition 2023-01-24

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference

ER_2210_PL21_2211_140530