RD-24 45W USB PD REPORT

RD-24 Description

This reference design describes a 45 W universal input offline power supply with programmable output voltage (5 V/3 A, 9 V/3 A, 15V/3A, 20 V/2.25A). The power supply uses SZ1131 (Flyback PWM controller with integrated active clamp circuit) IC, and Weltrend WT6633P USB PD controller. This design shows the high-power density and efficiency that can be achieved due to the high level of integration of the SZ1131 controller.

This document contains the power supply specification, schematic, bill-of-materials, transformer documentation, printed circuit layout and performance data.

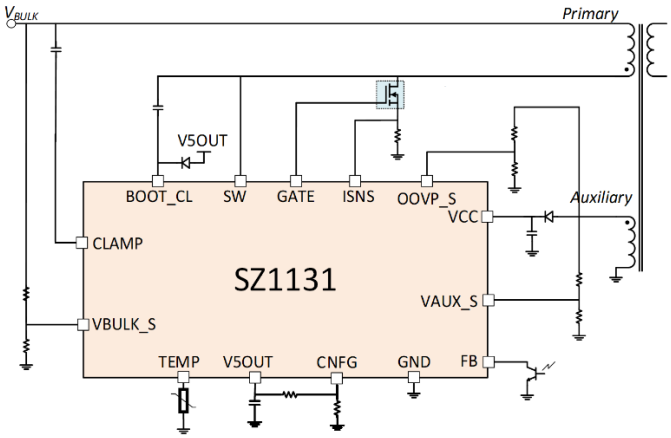
Key Specs	
Input	90 Vac - 265 Vac
Output Voltages	5 V, 9 V, 15 V, 20 V
Max Output Current	3 A @ 5 V, 9 V, 15V, 2.25 A @ 20V
Max Output Power	45 W
Output Port	USB-PD Type C Connector
Standby power (no-load)	< 20 mW
Form factor (volume)	35mm x 50mm x 18mm or 31.5 cm^3 (1.92 in^3)
Power Density (uncased)	> 23.4 W/in^3
Efficiency	> 90% 45W Efficiency @ 90 Vac > 91% 45W Efficiency @ 115 Vac > 92% 45W Efficiency @ 230 Vac

SZ1131 Features

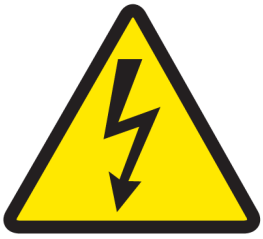
- Integrated High Voltage Active Clamp FET, Active Clamp Driver, and Start-up Regulator
- Capable of Over 95% Efficiency
- Flat Efficiency Across Universal (90-265 VAC) Input Voltage and Load
- < 20mW No Load Power Consumption
- Tight Switching Frequency Regulation for Improved Input EMI Filter Utilization
- Up to 140 kHz Switching Frequency Operation
- OptiMode™ Cycle-by-Cycle Adaptive Digital Control
- Multi-Mode Operation (Burst Mode, Quasi-Resonant, Valley Mode Switching)
- Advanced Valley Mode Switching for low EMI
- Self-Tuning Valley Detection
- OTP, UVLO, OVLO, PCL, OPP and OSCP Protections
- Up to 65 W Output Power for Universal AC Input
- 100W+ Output Power with Front-End PFC

Applications

- High-Power-Density USB-PD AC/DC Power Supplies



Warning



Disclaimers:

1. **Caution – High Voltage Operation:** Lethal high voltages are present when this evaluation board is powered from AC mains. Improper contact with high voltages could lead to electrical shock, burn and/or fire hazards, risking property damage, personal injury, and death.
2. **Evaluation Purpose Only:** This evaluation board is intended for evaluation purpose only and not for commercial use. Care must be taken when testing the board, and an isolation transformer should be utilized.
3. **Patents:** The evaluation board design, along with circuits shown in this test report, may be covered by one or more U.S. and foreign existing/pending patents.

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Power Supply Specifications

The reference design performance data presented in this report meets the power supply specifications listed in the following table.

Table 1: Key Specifications

Description		Symbol	Min.	Typ.	Max.	Units	Comments
Input							
Voltage		V_{in}	90	115/230	265	VAC	2 Wire Input
Frequency		f_{line}	47	60/50	63	Hz	
Output							
Current		I_{out}			3	A	5V, 9V, 15V Output
					2.25	A	20V Output
Output Power Continuous		P_{out}			45	W	
Efficiency							
DoE Level VI 4-Point Average Efficiency							
5 V		η_{ave_5V}		81.39%		%	DoE Level VI 4-point (25%, 50%, 75%, 100%) average efficiency
9 V		η_{ave_9V}		86.62%		%	
15 V		η_{ave_15V}		87.73%		%	
20 V		η_{ave_20V}		87.73%		%	
CoC V5 Tier-2 4-Point Average Efficiency							
5 V		η_{ave_5V}		81.84%		%	CoC version 5 tier 2 4-point (25%, 50%, 75%, 100%) average efficiency
9 V		η_{ave_9V}		87.30%		%	
15 V		η_{ave_15V}		88.85%		%	
20 V		η_{ave_20V}		88.85%		%	
CoC V5 Tier-2 10% Efficiency							
5 V		$\eta_{10\%\_5V}$		72.48%			CoC Version 5 Tier-2 10% load efficiency requirements.
9 V		$\eta_{10\%\_9V}$		77.30%			
15 V		$\eta_{10\%\_15V}$		78.85%			
20 V		$\eta_{10\%\_20V}$		78.85%			
No-Load Input Power		P_{in}			20	mW	@ 230 Vac, 25 °C ambient
Programmable Output Voltage		V_{OUT}	5		20	V	
Environmental Conducted & Radiated EMI		Meets CISPR22B/EN55022 (>3dB margin)					
Ambient Temperature		T_{AMB}	0		40	˚C	No airflow, sea level.

Note: The circuit board needs to be evaluated for additional tests, such as ESD and Line Surge to use the evaluation board design presented in this test report as a charger/adapter. Furthermore, the layout of the board needs to be adjusted according to the target shape and form factor of the end application.

Board Pictures

Figure 1: Top Side

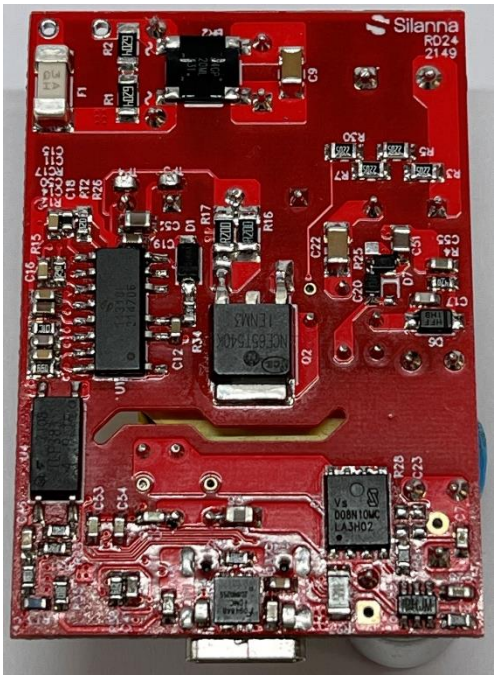


Figure 2: Bottom Side

Schematics

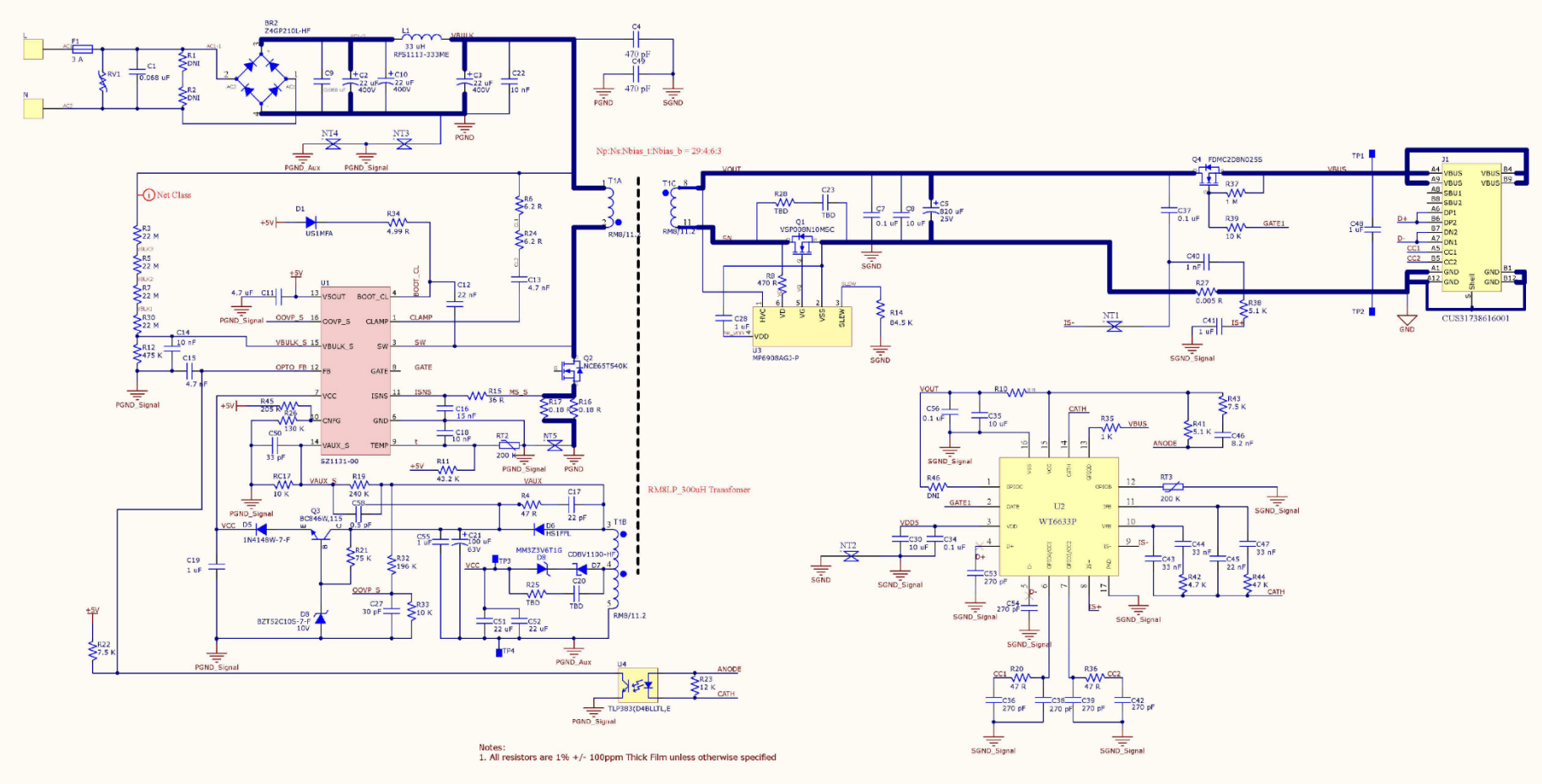


Figure 3: 45W Schematic

PCB Layout

Top View

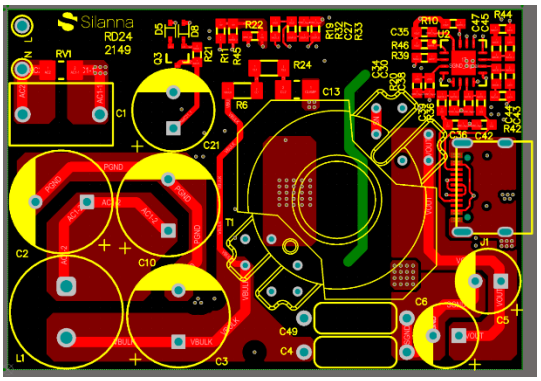


Figure 4: Top layer, component side

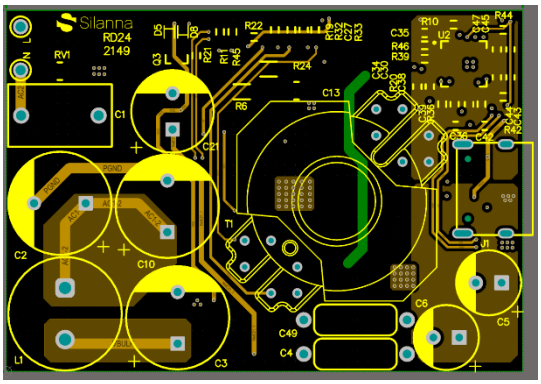


Figure 5: Middle 1 Layer

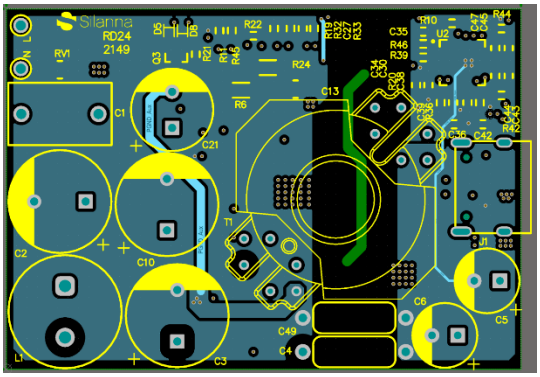


Figure 6: Middle 2 Layer

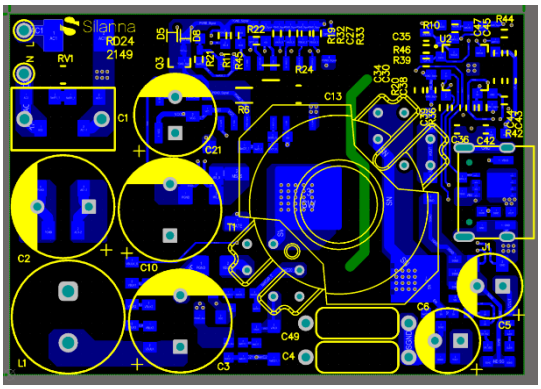


Figure 7: Bottom layer

Bottom View

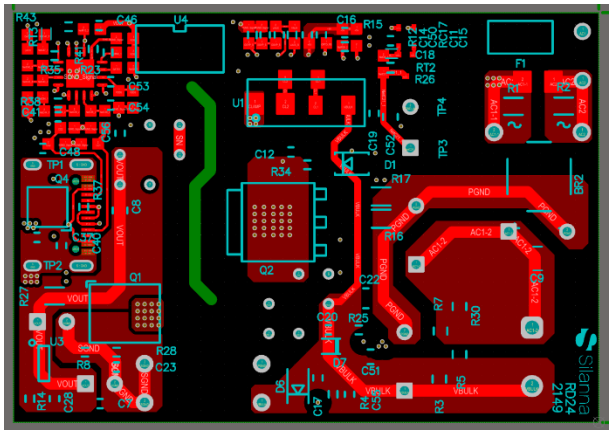


Figure 8: Top layer

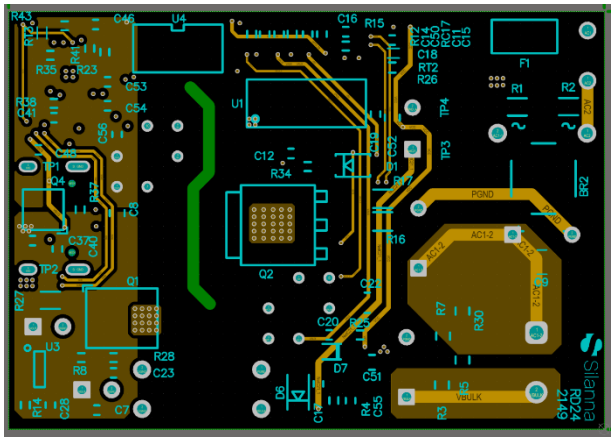


Figure 9: Middle 1 Layer

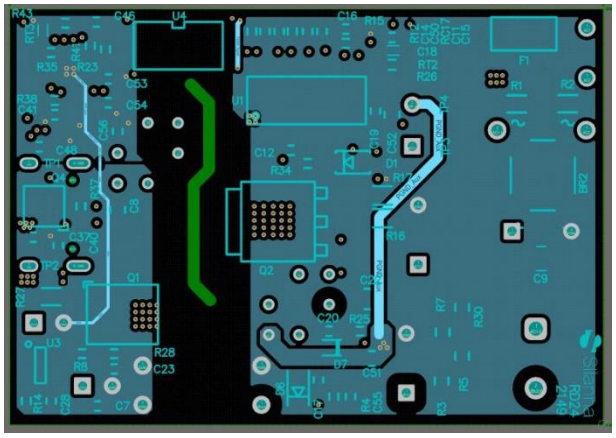


Figure 10: Middle 2 Layer

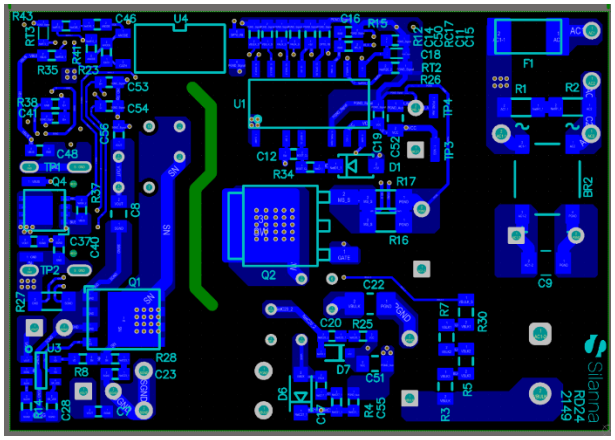


Figure 11: Bottom layer, solder side

Bill of Materials (BOM)

Table 2: Reference Design BOM

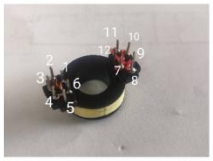
Note: “DNI” means Do Not Include

Designator	Value	Manufacturer Part Number	Description
U1	SZ1131-00	SZ1131-00	Flyback PWM Controller with Integrated Active Clamp Circuit
R33, R39, RC17	10 K	RMCF0603FT10K0	RES 10K OHM 1% 1/10W 0603
R25, R28	TBD		
R38, R41	5.1 K	RC0603FR-075K1L	RES SMD 5.1K OHM 1% 1/10W 0603
R44	47 K	AC0603FR-0747KL	RES SMD 47K OHM 1% 1/10W 0603
R42	4.7 K	RC0603FR-074K7L	RES SMD 4.7K OHM 1% 1/10W 0603
R37	1 M	RC0603FR-071ML	RES SMD 1M OHM 1% 1/10W 0603
R35	1 K	RC0603FR-071KL	RES SMD 1K OHM 1% 1/10W 0603
R14	84.5 K	RC0603FR-0784K5L	RES SMD 84.5K OHM 1% 1/10W 0603
R8	470 R	RC0603FR-07470RL	RES SMD 470 OHM 1% 1/10W 0603
R46	DNI		DNI RES 0603
R1, R2	DNI		DNI RES 1206
R10	0 R	RC0603JR-070RL	RES SMD 0 OHM 1/10W 0603
R21	75 K	RC0603FR-0775KL	RES SMD 75K OHM 1% 1/10W 0603
R11	43.2 K	RC0603FR-0743K2L	RES SMD 43.2K OHM 1% 1/10W 0603
R16, R17	0.18 R	RL1206FR-070R18L	RES 0.18 OHM 1% 1/4W 1206
R27	0.005 R	CFN1206-FX-R005ELF	RES 0.005 OHM 1% 1W 1206
R4, R10, R36	47 R	RC0603FR-0747RL	RES SMD 47 OHM 1% 1/10W 0603
R3, R5, R7, R30	22 M	RMCF0805FT22M0	RES 22M OHM 1% 1/8W 0805
R22, R43	7.5 K	AC0603FR-077K5L	RES SMD 7.5K OHM 1% 1/10W 0603
R12	475 K	RC0603FR-07475KL	RES SMD 475K OHM 1% 1/10W 0603
R34	4.99 R	RMCF0603FT4R99	RES 4.99 OHM 1% 1/10W 0603
R6, R24	6.2 R	CRCW12066R20FKEAHP	6.2 Ohms ±1% 0.75W, 3/4W Chip Resistor 1206 (3216 Metric)
R15	36 R	RC0603FR-0736RL	RES SMD 36 OHM 1% 1/10W 0603
R45	205 K	RT0603FRE07205KL	RES SMD 205K OHM 1% 1/10W 0603
R32	196 K	RC0603FR-07196KL	196 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric)
R26	130 K	RC0603FR-07130KL	130 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric)
R19	240 K	RC0603FR-07240KL	RES 240K OHM 1% 1/10W 0603
R23	12 K	RMCF0603FG12K0	RES 12K OHM 1% 1/10W 0603
C7, C34, C37, C56	0.1 uF	CL10B104KB8NNNC	CAP CER 0.1UF 50V X7R 0603
C40	1 nF	C0603C102K3RACTU	CAP CER 1000PF 25V X7R 0603
C50	33 pF	885012006020	CAP CER 33PF 16V C0G/NP0 0603
C14, C16, C18	10 nF	CL10B103KA8NNNC	CAP CER 10000PF 25V X7R 0603
C13	4.7 nF	C3216X7R2J472K115AA	CAP CER 4700PF 630V X7R 1206
C12, C45	22 nF	CC0603KRX7R9BB223	CAP CER 0.022UF 50V X7R 0603
C43, C44, C47	33 nF	CC0603KRX7R9BB333	CAP CER 0.033UF 50V X7R 0603
C19, C28, C41, C48	1 uF	CGA3E1X7R1V105K080AC	CAP CER 1UF 35V X7R 0603
C11	4.7 uF	GRM188C81E475KE11D	CAP CER 4.7UF 25V X6S 0603

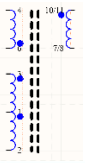
Designator	Value	Manufacturer Part Number	Description
C51, C52	22 uF	GRM21BC81C226ME44L	CAP CER 22UF 16V X6S 0805
C4, C49	470 pF	DE1B3KX471KB4BP01F	CAP CER 470PF 300VAC RADIAL
C8	10 uF	CL21X106KAYNNNE	CAP CER 10UF 25V X6S 0805
C55	1 uF	UMK107AB7105KA-T	CAP CER 1UF 50V X7R 0603
C22	10 nF	C1206C103KBRACTU	CAP CER 10000PF 630V X7R 1206
C46	8.2 nF	C0603C822K5RACTU	CAP CER 8200PF 50V X7R 0603
C30, C35	10 uF	GRM188R61E106MA73D	CAP CER 10UF 25V X5R 0603
C36, C38, C39, C42, C53, C54	270 pF	CC0603KRX7R9BB271	CAP CER 270PF 50V X7R 0603
C17	22 pF	885012006034	CAP CER 22PF 25V C0G/NP0 0603
C15	4.7 nF	06033C472KAT2A	CAP CER 4700PF 25V X7R 0603
C27	30 pF	06031A300J4T2A	CAP CER 30PF 100V C0G/NP0 0603
C9	0.068 uF	C1206C683KCRACTU	CAP CER 0.068UF 500V X7R 1206
C5	820 uF	UPD1E821MP51012ERU	Conductive Polymer Aluminum Solid Capacitors, 820uF, 25V
C1	0.068 uF	890334022017	0.068 µF Film Capacitor 310V - Polypropylene (PP), Metallized
C2, C3, C10	22 uF	KCXE1352G220MF	22uF 400V ±20% Radial Leaded,10x13.5mm Aluminum Electrolytic
C21	100 uF	LKMD0901J101MF	CAP ALUM 100UF ±20% 63V T/H
C58	0.5 pF	C0603C508B1GAC7867	CAP CER 0.5PF 100V C0G/NP0 0603
C20, C23	TBD		TBD CAP 0603
L1	33 uH	RFS1113-333ME	Fixed Inductors 33uH Shld 20% 3.2A 52mOhm
D1	US1MFA	US1MFA	DIODE GEN PURP 1KV 1A SOD123FA
D8	BZT52C10S-7-F	BZT52C10S-7-F	DIODE ZENER 10V 200MW SOD323
D5	1N4148W-7-F	1N4148W-7-F	DIODE GEN PURP 100V 300MA SOD123
D6	HS1FFL	HS1FFL	50NS 1A 300V HIGH EFFICIENT RECO
D7	CDBV1100-HF	CDBV1100-HF	DIODE SCHOTTKY 100V 1A SOD323
BR2	Z4GP210L-HF	Z4GP210L-HF	Bridge Rectifier Single Phase Standard 1 kV Surface Mount
D8	MM3Z6V2B	MM3Z6V2B	DIODE ZENER 6.2V 200MW SOD323F
Q4	FDMC2D8N025S	FDMC2D8N025S	MOSFET N-CH 25V 124A 8PQFN
Q1	VSP008N10MSC	VSP008N10MSC	N-Channel 100V 85A 7.7mO @ 15A PDFN5x6 MOSFET
Q3	BC846W,115	BC846W,115	TRANS NPN 65V 100MA SOT323
Q2	NCE65T540K	NCE65T540K	650V 8A 540mO TO-252 MOSFET
U2	WT6633P		WT6633P USB PD Controller
U3	MP6908AGJ-P	MP6908AGJ-P	FAST TURN-OFF INTELLIGENT RECTIF
T1	RM8/11.2	RM8LP-12P-TH-D5-11	RM8LP-12P-TH-D5-11, CORE RM8/11.2
J1	CUS31738616001	CUS31738616001	CONN USB-C FEMALE 16P SMT
U4	TLP383(D4BLLTL,E	TLP383(D4BLLTL,E	OPTOISO 5KV TRANSISTOR SO6L
F1	3 A	0679H3000-05	FUSE BOARD MNT 3A 350VAC 60VDC
RV1	QV1206P431KT201	QV1206P431KT201	430V 200A SMD 1206 Varistor
RT2, RT3	200 K	NTHS0603N17N2003JE	THERMISTOR NTC 200K OHM 5% 0603

Transformer Specification

Transformer Specification



Pinout



Electrical

Actual Picture

Winding Specification

Winding	1	2-a	2-b	3	4	5	6	7
Material	AWG31	AWG34	AWG34	AWG36	LITZ 7x34	LITZ 7x34	AWG36	AWG31
Turns	15	3	6	4.5	4	4	4.5	14
Parallel wires	1	2	2	5	1	1	5	2
Layers	1	1	1	1	1	1	1	1
Start Pin	6	1	3	2	11	10	2	-
End Pin	-	2	1	NC	7 / 8	7 / 8	NC	4
Comment	PRI1 - First half of primary winding	AUX - auxiliary windings top and bottom wound simultaneously		SHIELD1 - inner shield winding	SEC1 - first secondary winding layer. Terminate after PRI2 winding.	SEC2 - second secondary winding layer. Terminate after PRI2 winding.	SHIELD2 - outer shield winding	PRI2 - Second half of primary winding. Fold SEC windings after 1 tape layer.
Insulation		TAPE A (1 Layer)	TAPE A (1 Layer)	TAPE A (1 Layer)		TAPE A (1 Layer)	TAPE A (1 Layer)	TAPE A (3 Layer)

Copper Shield: Wrap one complete loop of copper tape (3mm wide) around the core, without insulation in-between (e.g. kapton tape). Terminate the copper tape to PIN 2 (PGND pin) with a wire.

Note: Unused pins can be cut or removed

Electrical Test Parameters:

INDUCTANCE @ 100kHz/0.1VAC
L (6-4) = 300uH ± 5%

INDUCTANCE @ 100kHz/0.1VAC
SHORT PINS: FL1, FL2
LL (6-4) =< 4.6uH MAX
LL (6-4) >= 3.6uH MIN

TURNS RATIO/POLARITY
APPLY: 1.00V @ 10kHz TO PINS (6-4)

DC RESISTANCE OHMS (Ω) @ 25ºC
DCR (2-3) = 0.5Ω MAX
DCR (11-8) = 0.015Ω MAX

Table 3: Transformer Materials List

Material	***Specification***	***Manufacturer***	***Mfr. Part Number***
Bobbin	RM8 Low Profile	Pin Shine Industrial	T-H BOBBIN RM-8
Core	ML29D	Hitachi Metals	ML29D RM-8S-11.6
AWG31	Magnet wire, dual insulation layer	Various	
AWG34	Magnet wire, dual insulation layer	Various	
AWG36	Magnet wire, dual insulation layer	Various	
LITZ 7x34	7 strand AWG34 LITZ wire	Rubadue or equivalent	TXXL07/34T2XX-1.5(MW80)
TAPE A	5kV Insulation Tape	3M or equivalent	

Performance Data

This test report represents the typical performance of the RD-24 45W boards. Some board-to-board variations are expected due to component tolerances, test measurement setup, etc.

Efficiency

The following efficiency data are typical values of the RD-24 45W board. The board is soaked for 10 minutes at low line, full power, before measuring the efficiency with output measured at the end of board (after the USB-PD disconnect FET).

Table 4: Load Efficiency Summary

115Vac

Vout/Iout	4 - Point Average Efficiency Measurements	DOE level VI 4 - Point Average Efficiency Requirements	CoC version 5 tier 2 4 - Point Average Efficiency Requirements	Margin (Worst Case)
5 V/3 A	89.89 %	81.39%	81.84%	8.05%
9 V/3 A	90.83 %	86.62%	87.30%	3.53%
15 V/3 A	90.91 %	87.73%	88.85%	2.06%
20 V/2.25 A	91.30 %	88.00%	89.00%	2.30%

230Vac

Vout/Iout	4 - Point Average Efficiency Measurements	DOE level VI 4 - Point Average Efficiency Requirements	CoC version 5 tier 2 4 - Point Average Efficiency Requirements	Margin (Worst Case)
5 V/3 A	87.76 %	81.39%	81.84%	5.92%
9 V/3 A	89.43 %	86.62%	87.30%	2.13%
15 V/3 A	90.47 %	87.73%	88.85%	1.62%
20 V/2.25 A	90.72 %	88.00%	89.00%	1.72%

115 Vac 4-point average efficiency

V_{OUT} / I_{LOAD_MAX} = 5 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	90.38 %	89.89 %
75	90.62 %	
50	89.88 %	
25	88.67 %	
10	86.61 %	

V_{OUT} / I_{LOAD_MAX} = 9 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	91.45 %	90.83 %
75	91.59 %	
50	91.07 %	
25	89.21 %	
10	87.21 %	

V_{OUT} / I_{LOAD_MAX} = 15 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	91.44 %	90.91 %
75	91.49 %	
50	91.25 %	
25	89.45 %	
10	85.56 %	

V_{OUT} / I_{LOAD_MAX} = 20 V / 2.25 A

%LOAD	Efficiency	Average Efficiency
100	91.74 %	91.30 %
75	91.94 %	
50	91.59 %	
25	89.92 %	
10	85.62 %	

The listed efficiency values are the average of the data collected from RD24 EVB's. The boards are soaked for 10 minutes before measuring the efficiency with output measured at end of board (TP1 to TP2).

The boards pass the DOE Level VI, CoC V5 Tier-2 Average Efficiency and CoC V5 Tier-2 10% efficiency targets with more than 2% margin at all the operating conditions.

230 Vac 4-point average efficiency

V_{OUT} / I_{LOAD_MAX} = 5 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	89.53 %	87.76 %
75	88.52 %	
50	87.34 %	
25	85.63 %	
10	82.92 %	

V_{OUT} / I_{LOAD_MAX} = 9 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	91.29 %	89.43 %
75	90.71 %	
50	89.16 %	
25	86.55 %	
10	84.17 %	

V_{OUT} / I_{LOAD_MAX} = 15 V / 3 A

%LOAD	Efficiency	Average Efficiency
100	92.06 %	90.47 %
75	91.67 %	
50	90.66 %	
25	87.48 %	
10	83.81 %	

V_{OUT} / I_{LOAD_MAX} = 20 V / 2.25 A

%LOAD	Efficiency	Average Efficiency
100	92.33 %	90.72 %
75	91.85 %	
50	90.98 %	
25	87.72 %	
10	84.41 %	

The listed efficiency values are the average of the data collected from RD24 EVB's. The boards are soaked for 10 minutes before measuring the efficiency with output measured at end of board (TP1 to TP2).

The boards pass the DOE Level VI, CoC V5 Tier-2 Average Efficiency and COC V5 Tier-2 10% efficiency targets with more than 2% margin at all the operating conditions.

Full Load Efficiencies at 90 Vac/115 Vac/230 Vac/265 Vac; 5 V/9 V/15 V/20 V

Vout = 5 V

Vin	Iout	Efficiency
90 Vac @ 60 Hz	3 A	89.57 %
115 Vac @ 60 Hz	3 A	90.38 %
230 Vac @ 50 Hz	3 A	89.53 %
265 Vac @ 50 Hz	3 A	88.82 %

Vout = 9 V

Vin	Iout	Efficiency
90 Vac @ 60 Hz	3 A	90.45 %
115 Vac @ 60 Hz	3 A	91.45 %
230 Vac @ 50 Hz	3 A	91.29 %
265 Vac @ 50 Hz	3 A	90.9 %

Vout = 15 V

Vin	Iout	Efficiency
90 Vac @ 60 Hz	3 A	90.11 %
115 Vac @ 60 Hz	3 A	91.44 %
230 Vac @ 50 Hz	3 A	92.06 %
265 Vac @ 50 Hz	3 A	91.9 %

Vout = 20 V

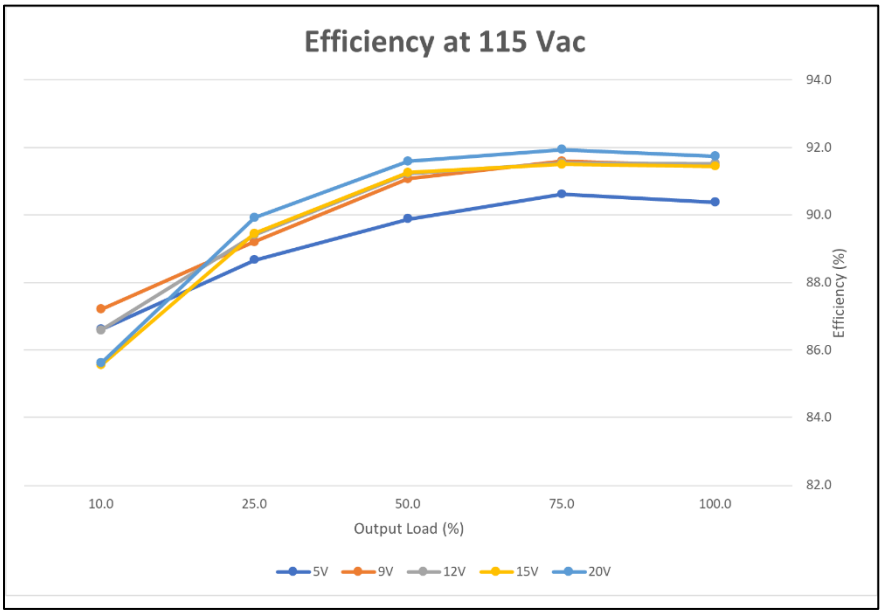
Vin	Iout	Efficiency
90 Vac @ 60 Hz	2.25 A	90.81 %
115 Vac @ 60 Hz	2.25 A	91.74 %
230 Vac @ 50 Hz	2.25 A	92.33 %
265 Vac @ 50 Hz	2.25 A	92.1 %

The listed efficiency values are the average of the data collected from RD29 EVB's. The boards are soaked for 10 minutes before measuring the efficiency with output measured at end of board (TP1 to TP2).

The boards pass the DOE Level VI, CoC V5 Tier-2 Average Efficiency and COC V5 Tier-2 10% efficiency targets with more than 2% margin at all the operating conditions.

Efficiency Graphs

The following graphs demonstrate 5 V, 9 V, 15 V and 20 V efficiency results with output measured at end of board (TP1 to TP2).



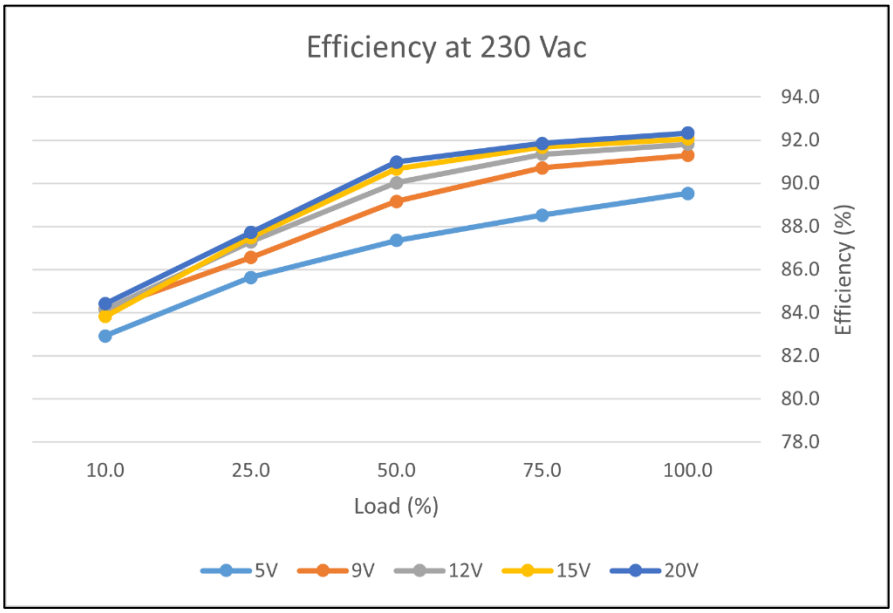


Figure 12: Efficiency graphs for various output voltages and load conditions

No Load / Light Load Input Power

Error! Reference source not found. lists the average no-load input power consumption measured at nominal line voltages 115 Vac and 230 Vac. The measurement of the input power has an integration time of 5 minutes.

Table 5: No-load Power Consumption

115Vac

Output Power	No-Load Input Power Measurements
0 W	14 mW

230Vac

Output Power	No-Load Input Power Measurements
0 W	18 mW

Table 6 lists the average light load input power consumption measured at nominal line voltages 115 Vac and 230 Vac. The measurement of the input power has an integration time of 5 minutes.

Table 6: Light Load Power Consumption

115Vac

Output Voltage	Load Current	Light Load Input Power Measurements
15 V	15 mA	602 mW
20 V	10 mA	533 mW

230Vac

Output Voltage	Load Current	Light Load Input Power Measurements
15 V	15 mA	625 mW
20 V	10 mA	530 mW

Load/Line Regulation

The following table shows voltage regulation for 5 V-20 V output voltages for variation of the line input voltage (115 Vac – 230 Vac) measured at the end of the board.

Table 7: Line/Load Regulation Summary (End of Board)

Output Voltage	Line / Load Range		Measured Regulation	
	Min	Max	Min	Max
5 V	0 A	3 A	5.01 V	5.18 V
9 V	0 A	3 A	9.07 V	9.26 V
15 V	0 A	3 A	15.09 V	15.28 V
20 V	0 A	2.25 A	20.05 V	20.19 V

The following table shows typical voltage regulation for 5 V-20 V output voltages for variation of line input voltage (115 Vac – 230 Vac) measured at the end of a 1 meter output cable connector (E-mark cable).

Output voltage regulation at the end of the cable can be improved by adding cable drop compensation.

Table 8: Line/Load Regulation Summary (End of 1.0m Meter E-mark Cable)

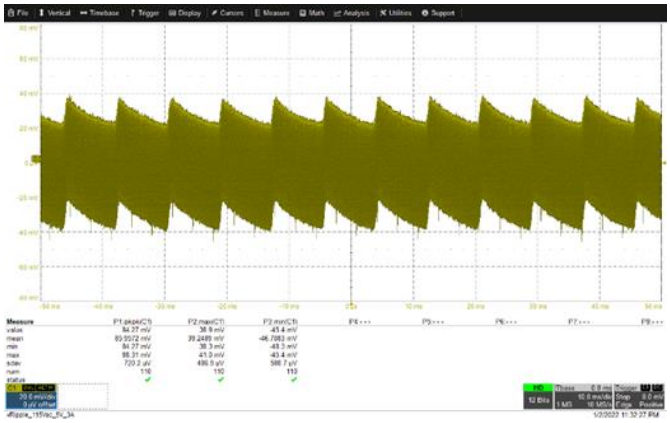
Output Voltage	Line / Load Range		Measured Regulation	
	Min	Max	Min	Max
5 V	0 A	3 A	4.81 V	4.99 V
9 V	0 A	3 A	8.88 V	9.06 V
15 V	0 A	3 A	14.90 V	15.09 V
20 V	0 A	2.25 A	19.91 V	20.05 V

Output Voltage Ripple Noise

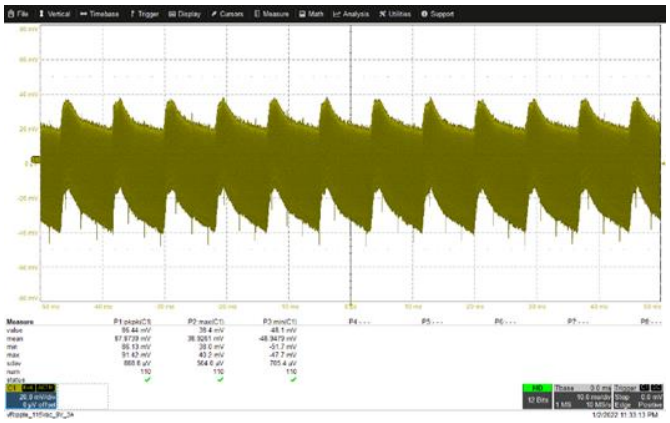
The output voltage ripple was measured using a voltage probe with two capacitors (1 µF/50 V ceramic and 33 µF/50 V low ESR electrolytic) tied in parallel across it. Measurements are done at the end of 1 meter output cable connector (E-mark cable).

Table 9: 115Vac Output Ripple Noise Summary

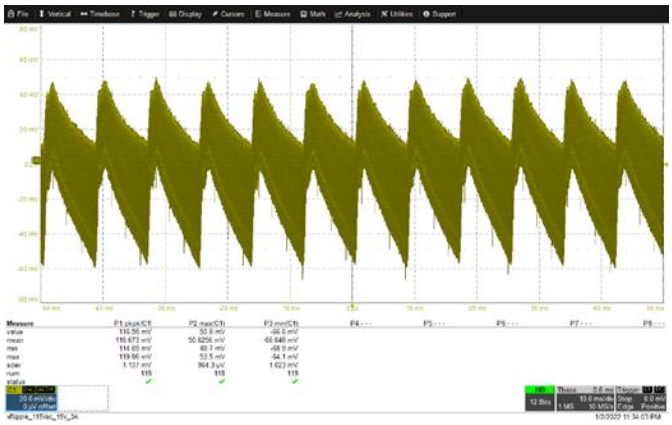
Vout/Iout	Measured Output Ripple at 3A load	Measured Output Ripple at 0A load
5 V/3 A	88 mV	28 mV
9 V/3 A	91 mV	25 mV
15 V/3 A	120 mV	21 mV
20 V/3.25 A	113 mV	26 mV



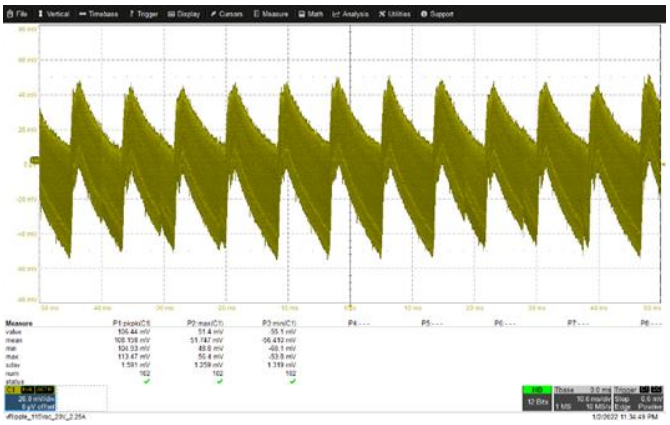
Vin=115 Vac, Vout=5 V @ 3A



Vin=115 Vac, Vout=9 V @ 3A



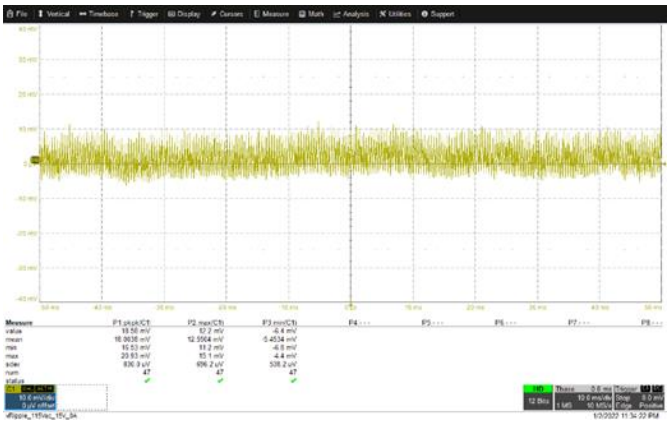
Vin=115 Vac, Vout=15 V @ 3A



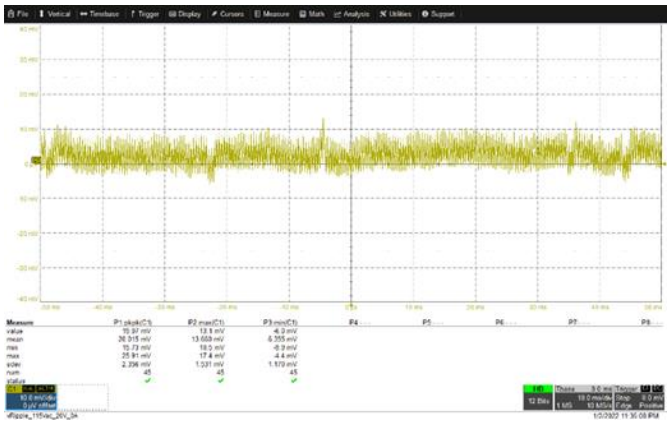
Vin= 115 Vac, Vout=20 V 3.25A

Vin=115 Vac, Vout=5 V @ 0A

Vin=115 Vac, Vout=9 V @ 0A



Vin=115 Vac, Vout=15 V @ 0A



Vin=115 Vac, Vout=20V @ 0A

Figure 13: Output voltage ripple measurements at 115Vac input voltage and 5 V/9 V/15 V/20 V full-power and No-load (end of 1.0m cable)

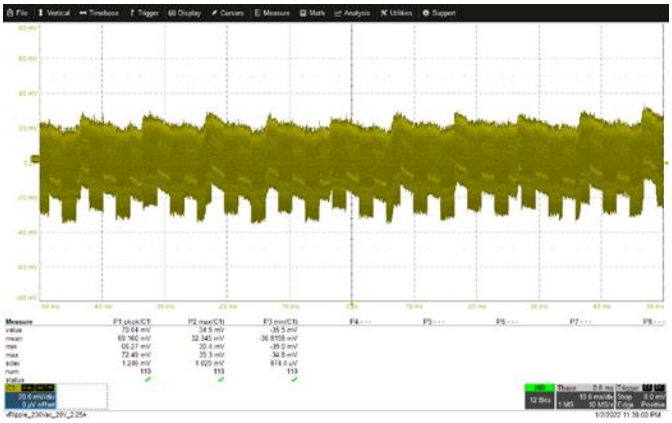
Table 10: 230Vac Output Ripple Noise Summary

Vout/Iout	Measured Output Ripple at 3A load	Measured Output Ripple at 0A load
5 V/3 A	77 mV	34 mV
9 V/3 A	84 mV	31 mV
15 V/3 A	87 mV	27 mV
20 V/3.25 A	72 mV	24 mV

Vin=230 Vac, Vout=5 V @ 3A

Vin=230 Vac, Vout=9 V @ 3A

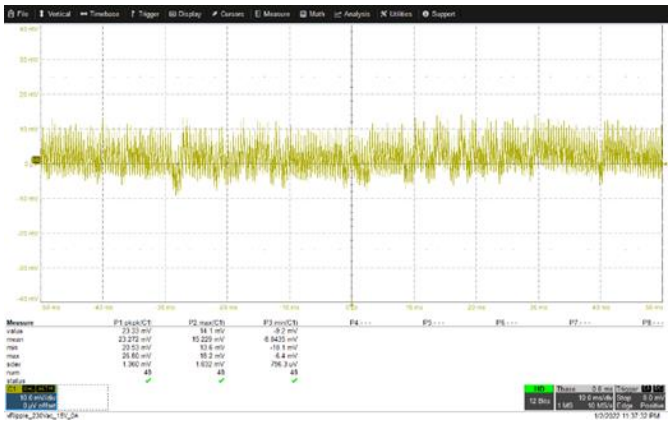
Vin=230 Vac, Vout=15 V @ 3A



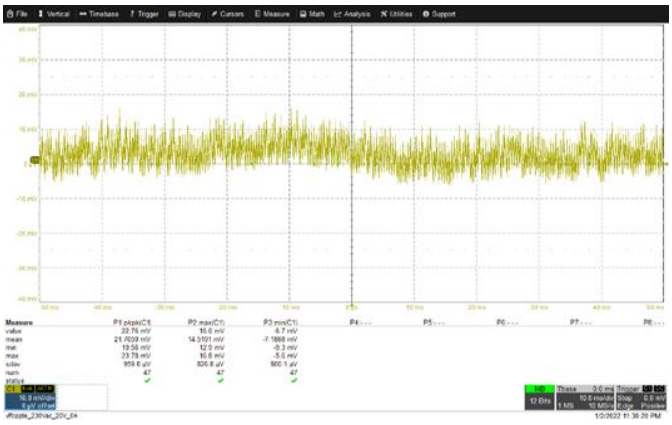
Vin= 230 Vac, Vout=20 V 3.25A

Vin=230 Vac, Vout=5 V @ 0A

Vin=230 Vac, Vout=9 V @ 0A



Vin=230 Vac, Vout=15 V @ 0A

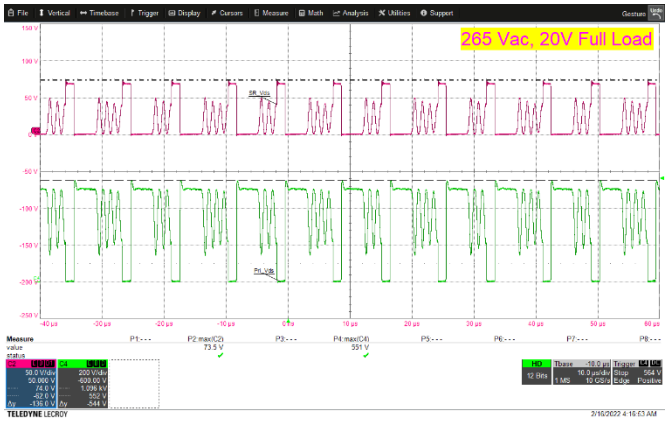


Vin=230 Vac, Vout=20V @ 0A

Figure 14: Output voltage ripple measurements at 230Vac input voltage and 5 V/9 V/15 V/20 V full-power and no-load (end of 1.0m cable)

Drain Voltage Waveforms at Steady State

The waveforms presented in this section show no components are over stressed under normal operating conditions. Measurement done at 265 Vac 20V output voltage, full load condition as well as no-load condition.



Vin=265 Vac, Vout=20 V, Iout=2.25 A, V_{ds_MAIN}=551 V

Vin=265 Vac, Vout=20 V, Iout=0 A, V_{ds_SRFET}=74.2 V

Figure 15: Main Primary and SR FET drain voltage waveforms under various operating conditions at 265 Vac input

Conducted EMI Measurements

This section presents the conducted EMI measurements taken on the reference design. Tests were performed at the maximum load currents for various output voltages. The quasi-peak and average measurements for 115 V_{AC} and 230 V_{AC} input voltages are shown for floating output.

Under all operating conditions, the results show the evaluation board passes EN55022 standard for conducted EMI measurement with >6dB margin.

Conducted EMI Test Setup

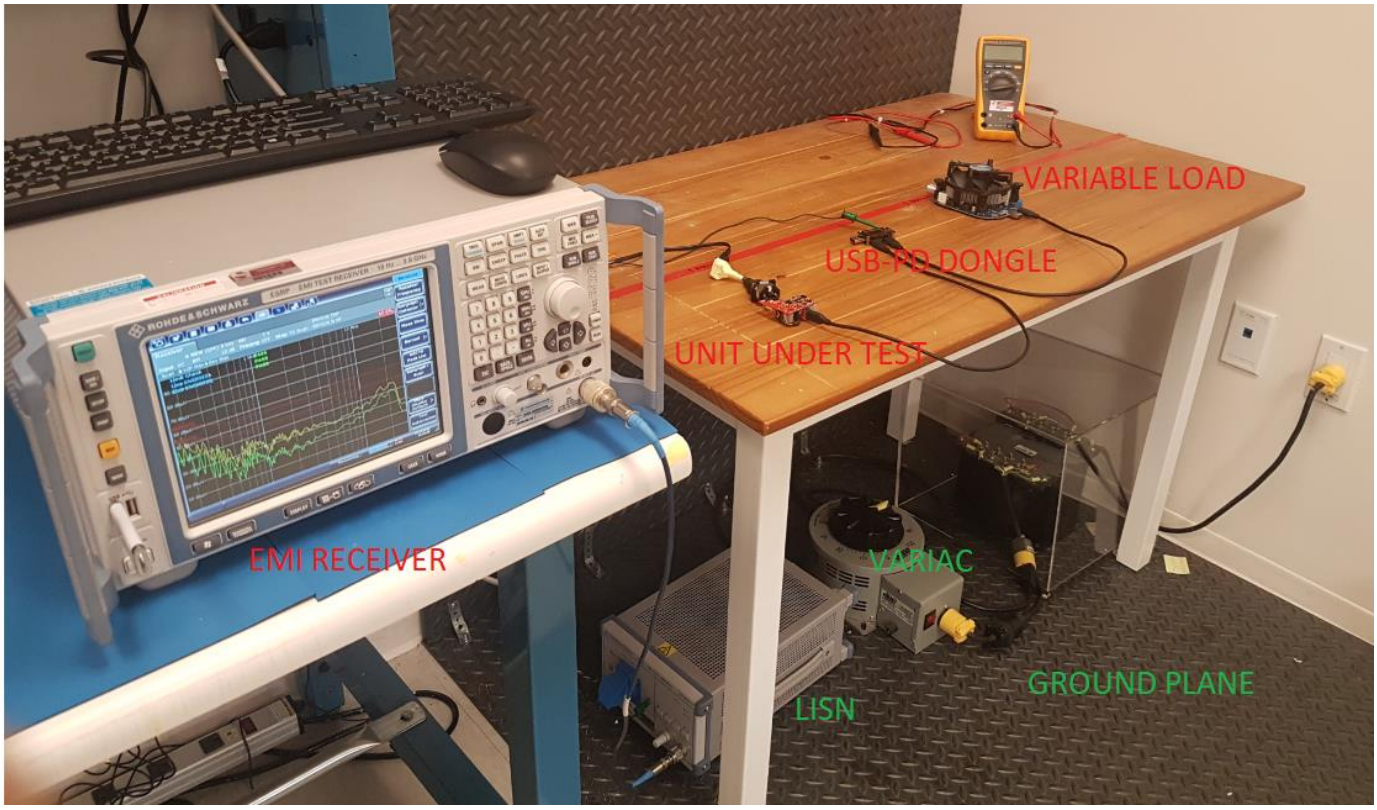
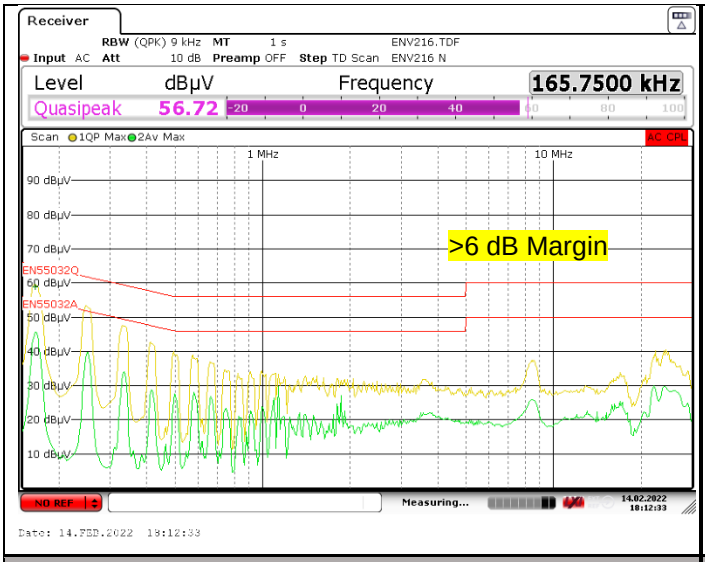


Figure 34: Generic Conducted EMI Test Setup

Output Floating

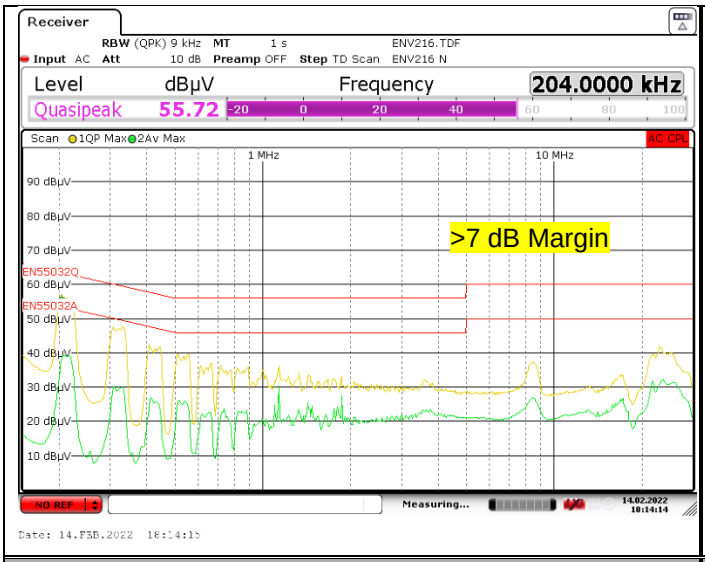
V_{out}/ I_{out}: 5 V/ 3 A



V_{input}=115 V_{ac}; V_{out}=5 V, I_{out}=3 A → Line/Neutral	V_{input}= 230 V_{ac}; V_{out}=5 V, I_{out}=3 A → Line/Neutral

Figure 35: 5 V/ 3 A conducted EMI measurement results (Line and Neutral) with output floating for 115 Vac and 230 Vac input

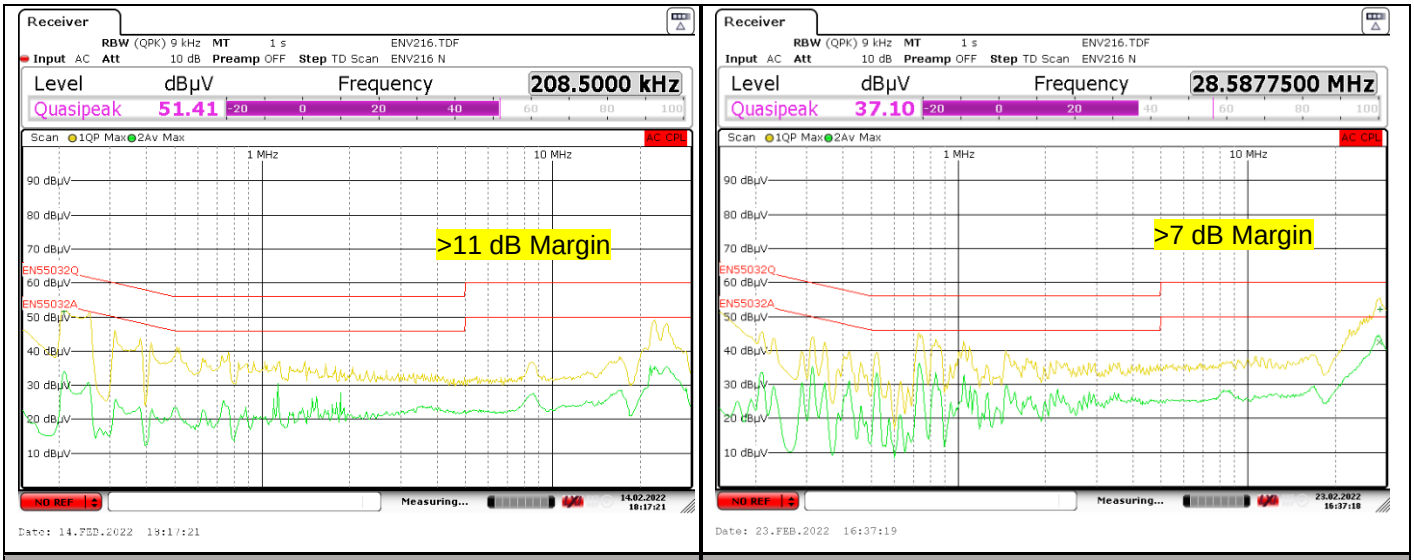
V_{out}/ I_{out}: 9 V/ 3 A



V_{input}=115 V_{ac}; V_{out}=9 V, I_{out}=3 A → Line/Neutral	V_{input}= 230 V_{ac}; V_{out}=9 V, I_{out}=3 A → Line/Neutral

Figure 36: 9 V/ 3 A conducted EMI measurement results (Line and Neutral) with output floating for 115 Vac and 230 Vac inputs

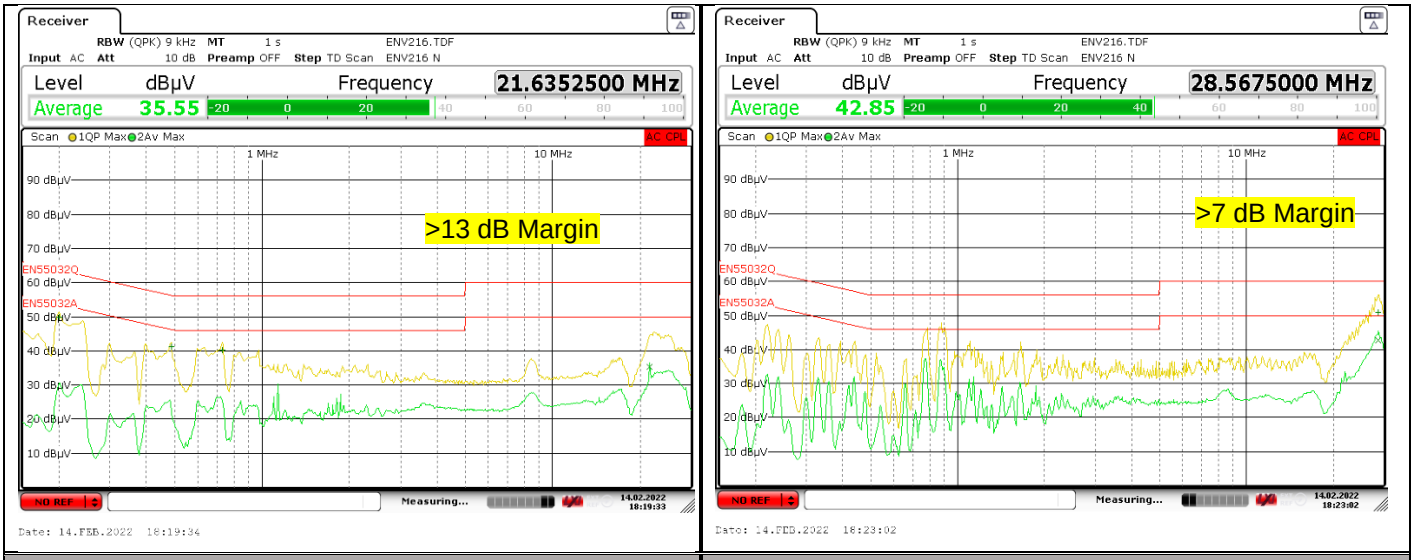
V_{out}/ I_{out}: 15 V/ 3.0 A



V_{input}=115 Vac; V_{out}=15 V, I_{out}=3 A → Line/Neutral	V_{input}= 230 Vac; V_{out}=15 V, I_{out}=3 A → Line/Neutral

Figure 37: 15 V/ 3.0 A conducted EMI measurement results (Line and Neutral) with output floating for 115 Vac and 230 Vac inputs

V_{out}/ I_{out}: 20 V/ 2.25 A



V_{input}=115 Vac; V_{out}=20V, I_{out}=2.25 A → Line/Neutral	V_{input}= 230 Vac; V_{out}=20 V, I_{out}= 2.25A → Line/Neutral

Figure 38: 20 V/ 2.25 A conducted EMI measurement results (Line and Neutral) with output floating for 115 Vac and 230 Vac inputs

Radiated EMI Measurements

This section presents the radiated EMI measurement taken on the reference design. Test was performed at full power operation in a 10-meter semi-anechoic chamber, following the methodology defined in IEC 61000-4-3, CISPR 32 Class B, over the frequency range of 30MHz to 1.0GHz. The peak measurements for 115Vac and 230Vac input voltages are shown below for floating output load.

Radiated EMI Test Set-up

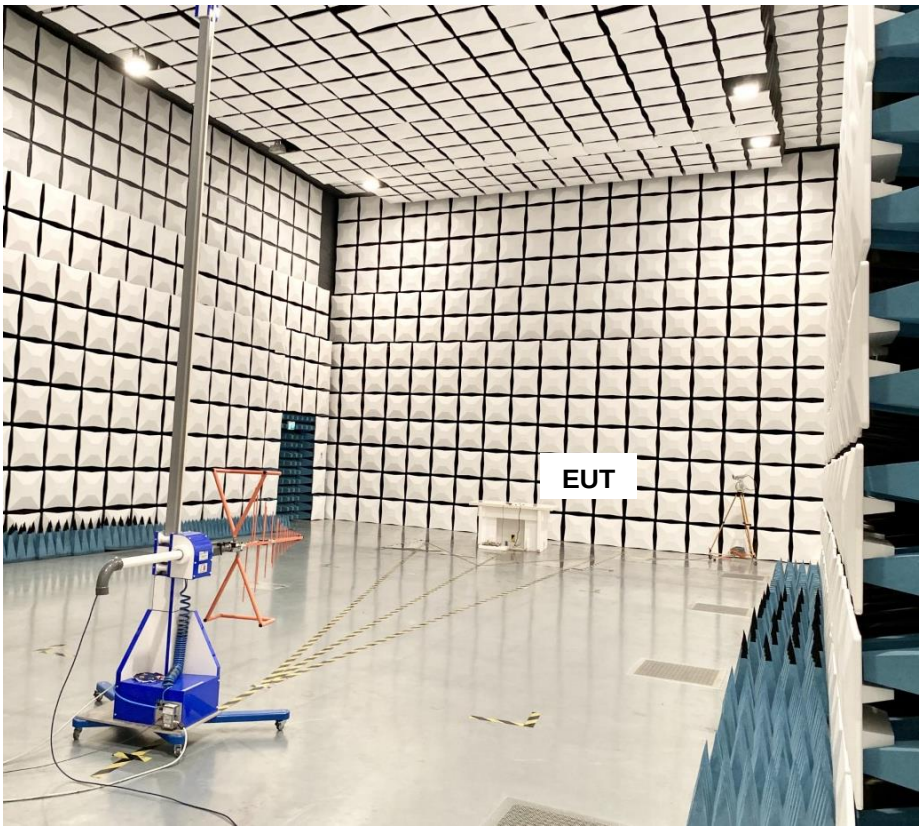
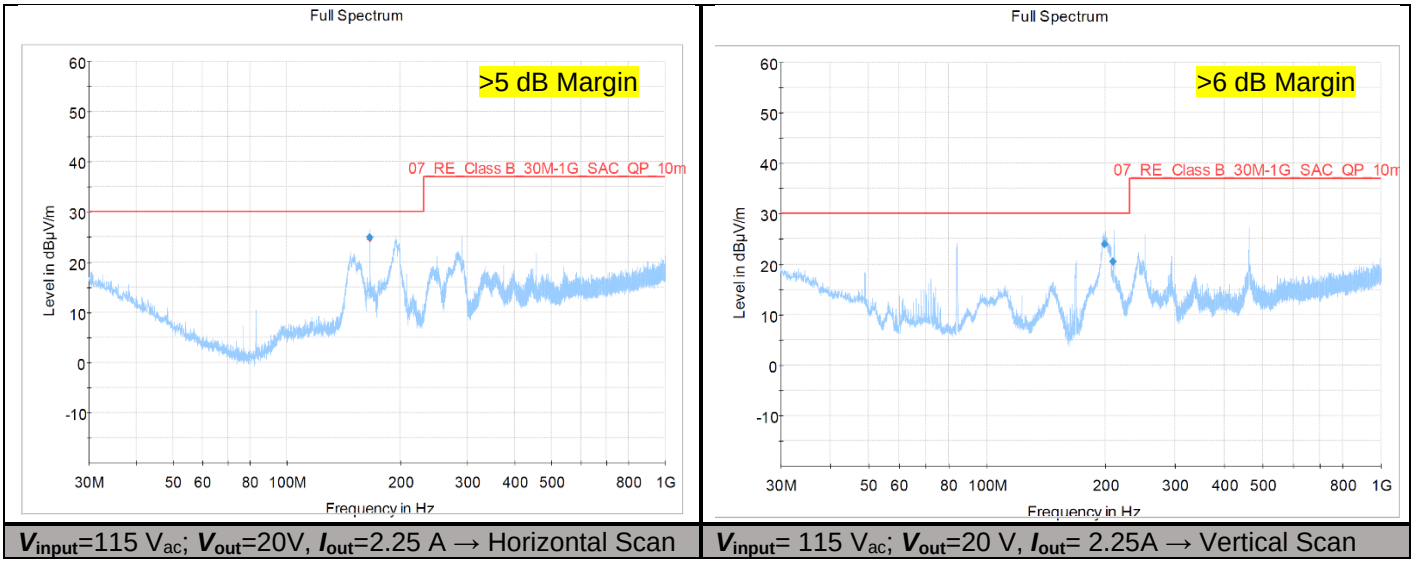


Figure 39: Radiated EMI Test Set-up at DOST-ASTI EPDC 10-meter Semi-Anechoic Chamber

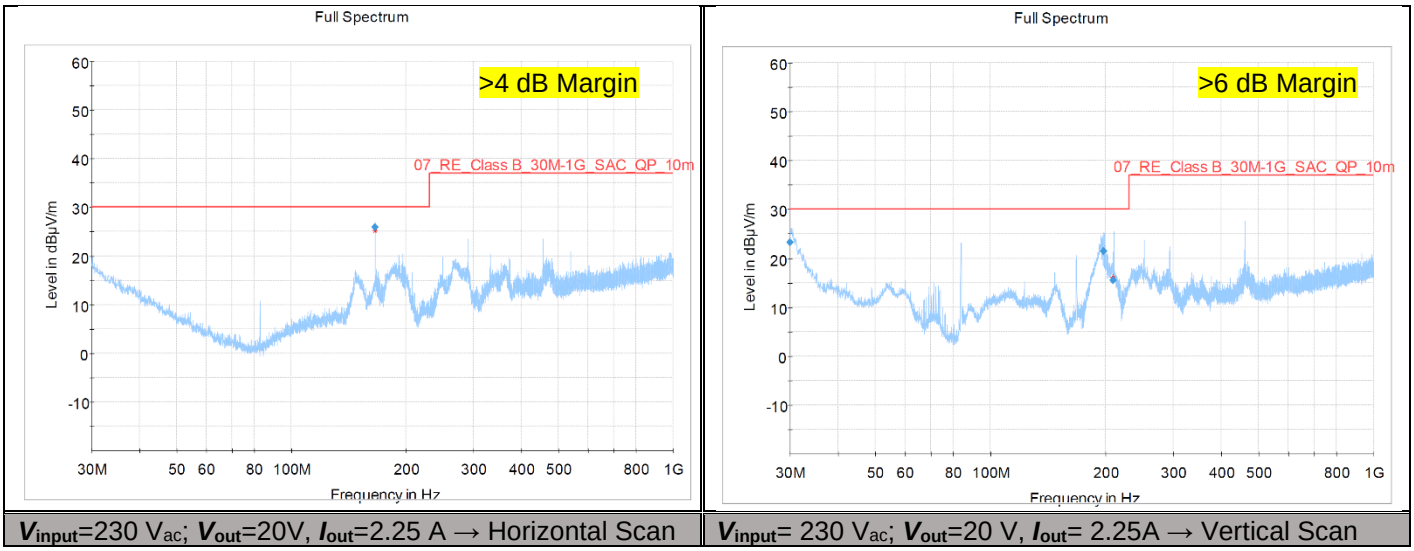
115Vac



V_{input}=115 V_{ac}; V_{out}=20V, I_{out}=2.25 A → Horizontal Scan	V_{input}= 115 V_{ac}; V_{out}=20 V, I_{out}= 2.25A → Vertical Scan

Figure 40: Radiated EMI Measurement (Horizontal and Vertical Orientations) at 115Vac, 20V/2.25A

230Vac



V_{input}=230 V_{ac}; V_{out}=20V, I_{out}=2.25 A → Horizontal Scan	V_{input}= 230 V_{ac}; V_{out}=20 V, I_{out}= 2.25A → Vertical Scan

Figure 41: Radiated EMI Measurement (Horizontal and Vertical Orientations) at 230Vac, 20V/2.25A

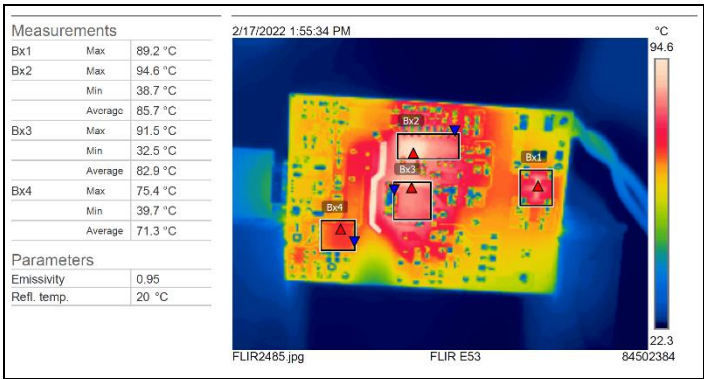
Thermal Measurements

The following thermal images show the temperatures of key components after one hour if continuous operation at low line (90 V_{ac}) input and high line (265 V_{ac}) with output conditions V_{out} = 20 V and I_{out} = 2.25 A. The measurement was done with the board uncased and with ambient temperature of ~25°C.

Table 11: Thermal Measurements of Key Components

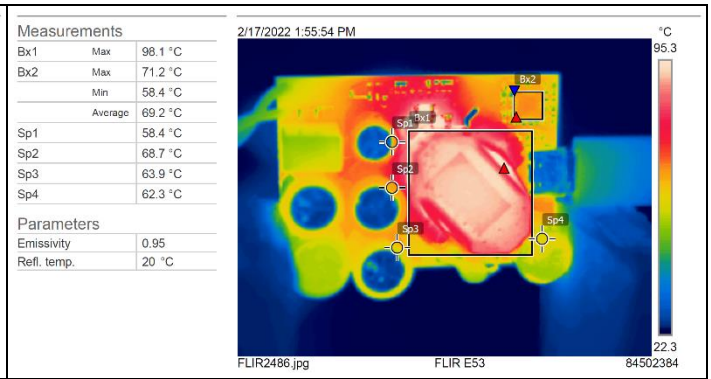
Reference Designator	Description	Temp. at 90 Vac	Temp. at 265 Vac
BR2	Bridge Rectifier	89.2°C	60.1°C
Q2	Primary MOSFET	91.5°C	89.7°C
U1	SZ1131	94.6°C	92.3°C
Q1	Secondary Rectifier MOSFET	75.4°C	75.1°C
T1	Flyback Transformer	98.1°C	97.0°C

90 Vac



BOTTOM SIDE

V_{input}=90 V_{ac}; V_{out}=20V, I_{out}=2.25 A



TOP SIDE

V_{input}=90 V_{ac}; V_{out}=20V, I_{out}=2.25 A

Legend:

Bx1 = Bridge Rectifier
Bx2 = SZ1131
Bx3 = Primary MOSFET
Bx4 = SR MOSFET

Bx1 = Flyback Transformer
Sp1 = Auxiliary Electrolytic Capacitor
Sp2 = Bulk Capacitor
Sp3 = Bulk Capacitor
Sp4 = Output Capacitor

265 Vac

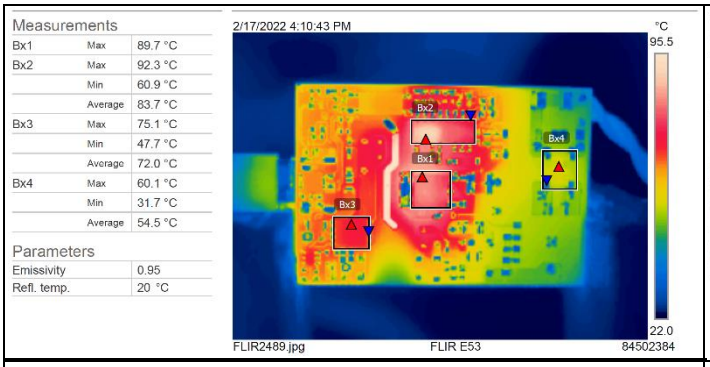
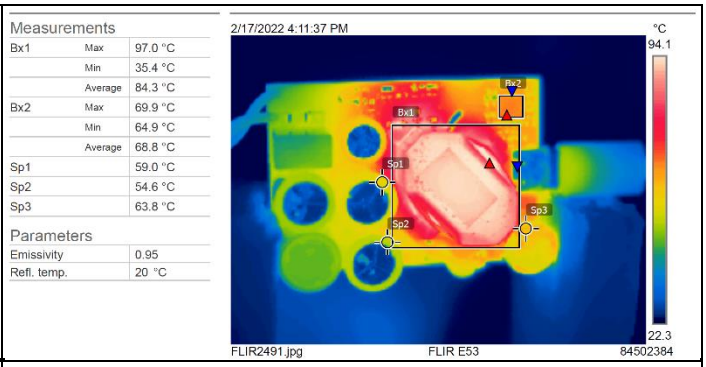
	
BOTTOM SIDE V_{input}=265 V_{ac}; V_{out}=20V, I_{out}=2.25 A	TOP SIDE V_{input}=265 V_{ac}; V_{out}=20V, I_{out}=2.25 A
Legend: Bx1 = Primary MOSFET Bx2 = SZ1131 Bx3 = SR MOSFET Bx4 = Bridge Rectifier	Bx1 = Flyback Transformer Sp1 = Bulk Capacitor Sp2 = Bulk Capacitor Sp3 = Output Capacitor

Figure 16: Thermal image at each side of the PCB during 65W load at 90 Vac and 265 Vac

Revision History

Revision	Date	Author	Note
1.0	03/09/2022	ACE Team	Initial Release

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