RD23 33W USB PD REPORT

RD-23 Description

This reference design describes a 33 W universal input offline power supply with programmable output voltage (5 V/3 A, 9 V/3 A, 15 V/2.2 A, 20 V/1.65 A). The power supply uses SZ1131 (Flyback PWM controller with integrated active clamp circuit) IC and Cypress CYPD3174 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.

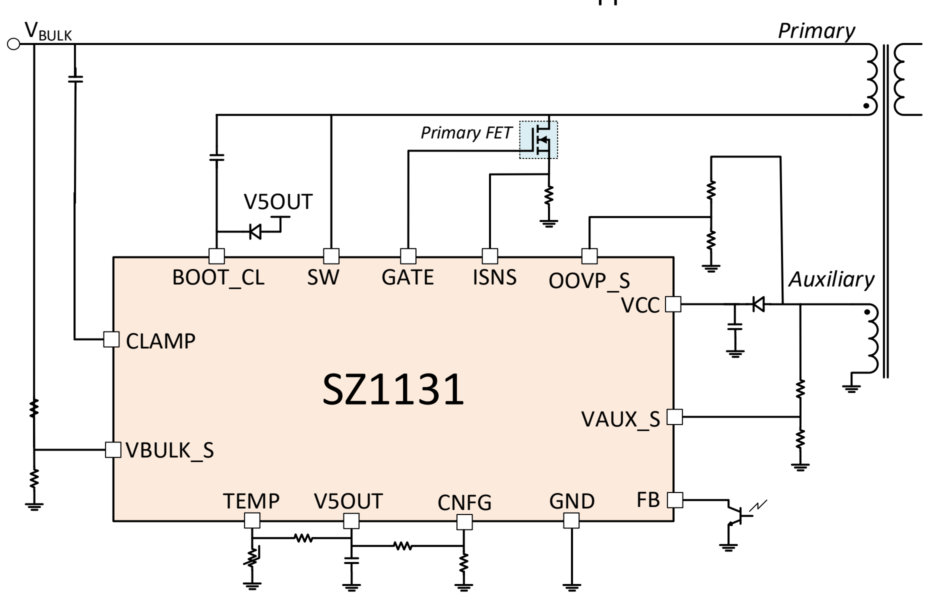
Key Specs	
Input	90-265 Vac
Output Voltages	5 V, 9 V, 15 V, 20 V
Max Output Current	3 A @ 5 V, 9 V, 2.2 A @15V,1.65 A @ 20V
Max Output Power	33 W
Output Port	USB-PD
Efficiency	>92% Full Power Efficiency

SZ1131 Features

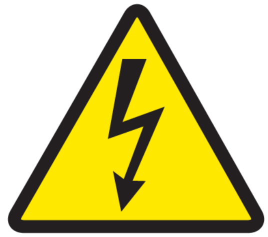
- Integrated High Voltage Active Clamp FET, Active Clamp Driver, and Start-up Regulator
- Capable of Over 95% Efficiency
- Flat Efficiency Across Universal (90-265 VAC) Input Voltage and Load
- < 20 mW System No Load Power Consumption
- Up to 146 kHz Switching Frequency Operation
- OptiMode™ Cycle-by-Cycle Adaptive Digital Control
- Self-tuning Valley Mode Switching (VMS)
- Advanced QR VMS for > 6 dB EMI Margin
- Tight Switching Frequency Regulation for Improved Input EMI Filter Utilization
- Multi-Mode Operation (Burst Mode, QR, VMS)
- OTP, OVP, OCP, OPP, OSCP, TSP Protections
- Up to 65 W Output Power for Universal AC Input
- 100W+ Output Power with Front-End PFC
- 16-pin SOIC Package

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.

Contents

Tables

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	
NOTE: Output (measured at the end of a 1m 3A USB-C cable)						
Current	I_{out}			3.0	A	
Output Power Continuous	P_{out}			33	W	
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}		84.61%		%	
15 V	η_{ave_15V}		85.44%		%	
20 V	η_{ave_20V}		85.44%		%	
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}		85.42%		%	
15 V	η_{ave_15V}		86.43%		%	
20 V	η_{ave_20V}		86.43%		%	
CoC V5 Tier-2 10% Efficiency						
5 V	$\eta_{10\%\_5V}$		72.48%			CoC Version 5 Tier-2 10% load efficiency requirements.
9 V	$\eta_{10\%\_9V}$		75.86%			
15 V	$\eta_{10\%\_15V}$		76.77%			
20 V	$\eta_{10\%\_20V}$		76.77%			
No-Load Input Power	P_{in}			20	mW	@ 230 Vac, 25 °C ambient
Programmable Output Voltage	V_{OUT}	5		20	V	
Environmental Conducted EMI	Meets CISPR32B/EN55032					
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

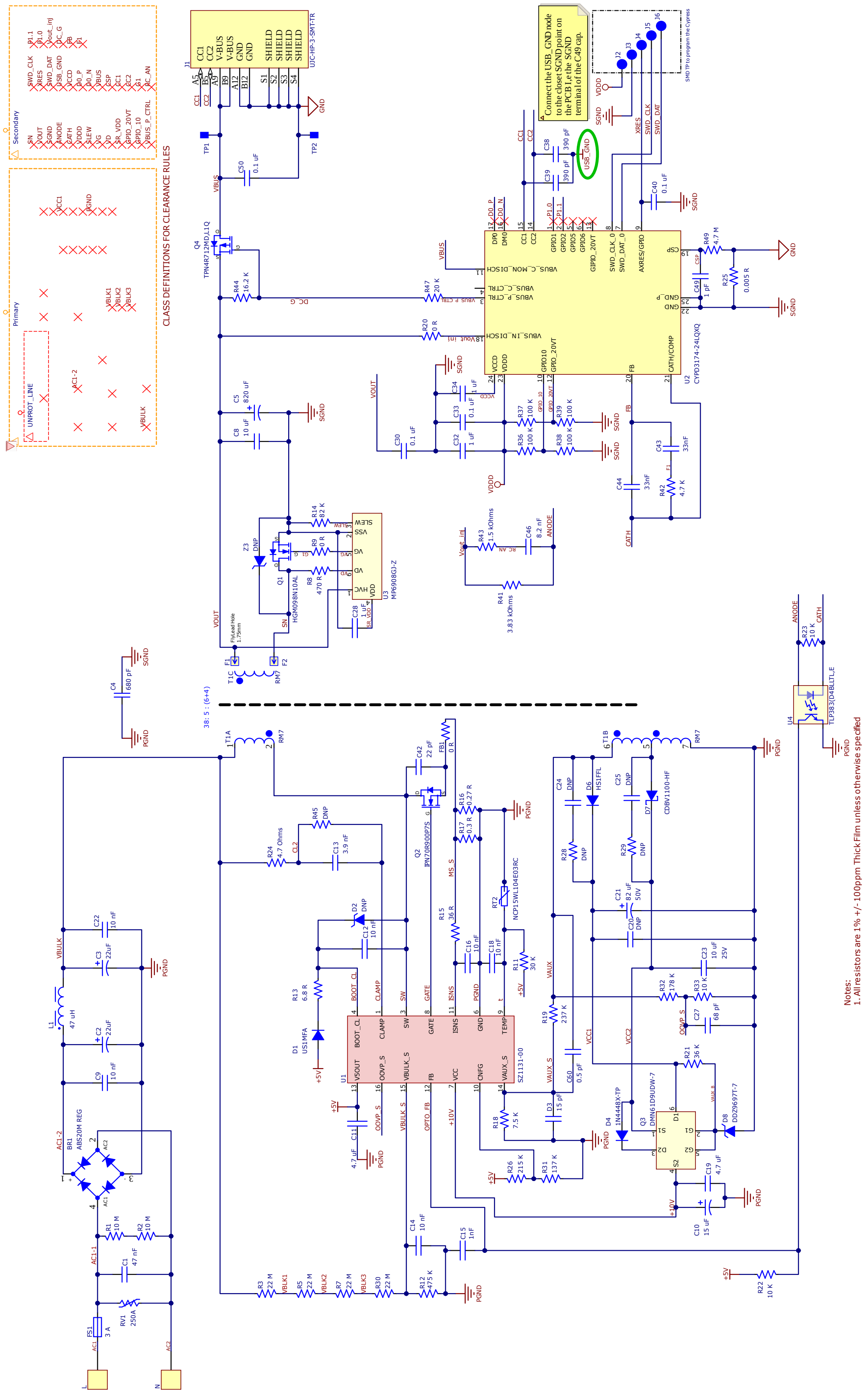


Figure 3: 33W Schematic

PCB Layout

PCB Prints

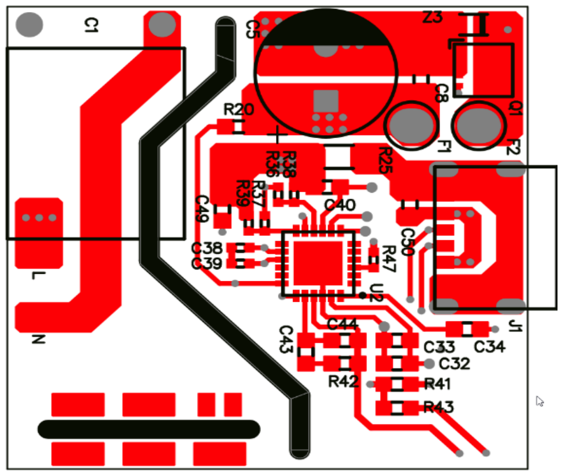


Figure 4: Component side horizontal board, top

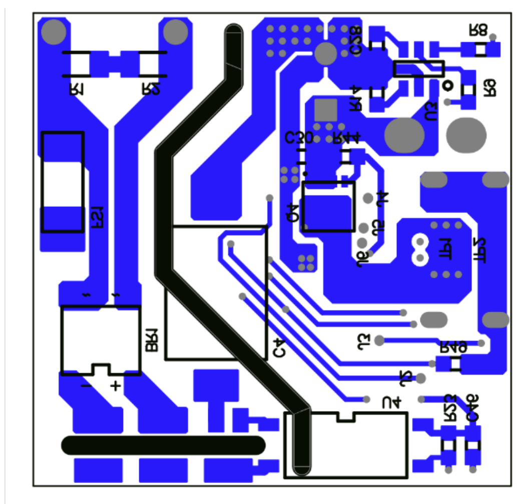


Figure 5: Solder side horizontal, bottom

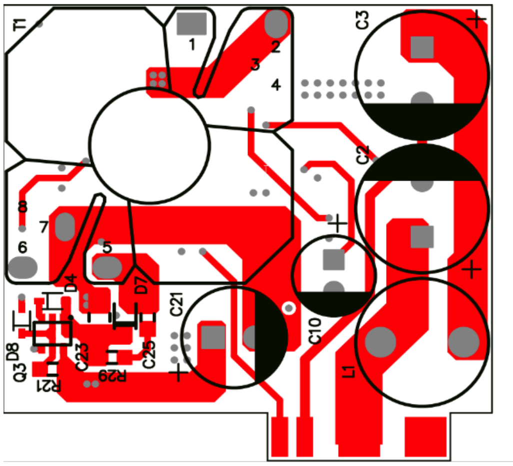


Figure 6: Component side vertical board, top

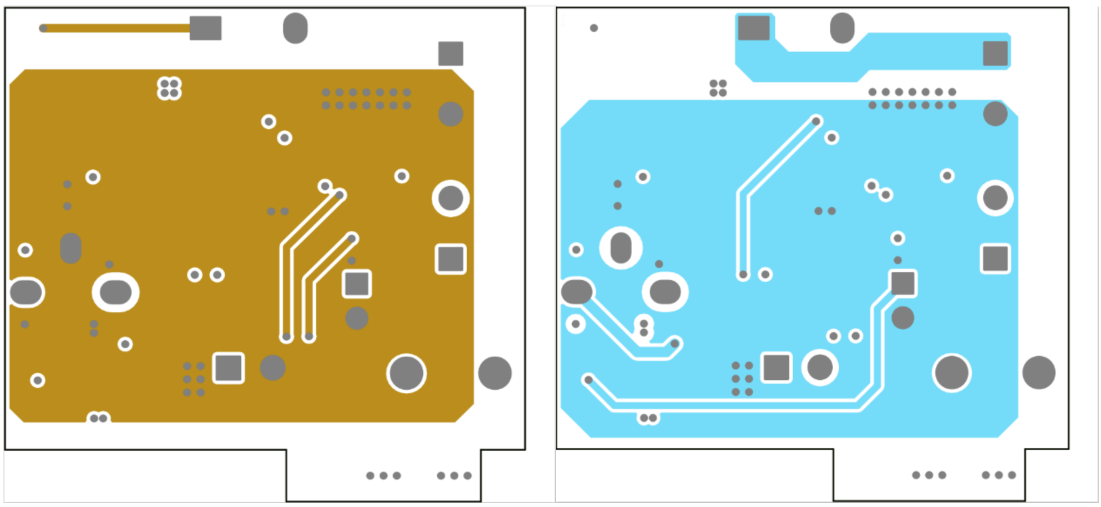


Figure 7: Solder side vertical board, middle 1 (left) and 2 (right)

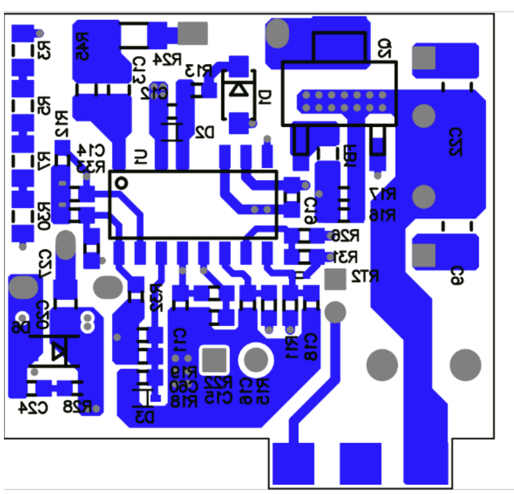


Figure 8: Solder side vertical board, bottom

Bill of Materials (BOM)

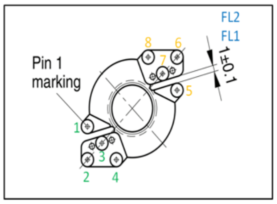
Table 2: Reference Design BOM

Designator Description	Manufacturer	Manufacturer Part Number	Designator
Horizontal Board (USB Type-C Connector)			
DNP	Rohm Semiconductor	UDZLVFHTE-1791	Z3
OPTOISO 5KV TRANSISTOR SO6L	Toshiba Semiconductor and Storage	TLP383(D4BLLTL,E	U4
FAST TURN-OFF INTELLIGENT RECTIF	Monolithic Power Systems Inc.	MP6908GJ-Z	U3
IC USB TYPE-C CONTROLLER 24QFN	Cypress Semiconductor Corp	CYPD3174-24LQXQ	U2
PC TEST POINT NATURAL	TE Connectivity AMP Connectors	RCU-0C	TP1, TP2
RES 4.7 M OHM 5% 1/10W 0603 SMD	Panasonic	ERJ-U03J475V	R49
RES SMD 20K OHM 1% 1/16W 0402	Yageo	RC0402FR-0720KL	R47
RES SMD 16.2K OHM 1% 1/10W 0603	Yageo	RC0603FR-0716K2L	R44
1.5 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603	Yageo	RC0603FR-071K5L	R43
RES SMD 4.7K OHM 1% 1/10W 0603	Yageo	RC0603FR-074K7L	R42
3.83 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603	Yageo	RC0603FR-073K83L	R41
RES SMD 100K OHM 1% 1/16W 0402	Yageo	RC0402FR-07100KL	R36, R37, R38, R39
RES 0.005 OHM 1% 1W 1206	Bourns Inc.	CFN1206-FX-R005ELF	R25
RES SMD 10K OHM 1% 1/10W 0603	Yageo	RC0603FR-0710KL	R23
RES SMD 0 OHM JUMPER 1/10W 0603	Yageo	RC0603JR-070RL	R20
RES SMD 82K OHM 1% 1/10W 0603	Yageo	RC0603FR-0782KL	R14
RES 0 OHM JUMPER 1/10W 0603	Stackpole Electronics Inc	RMCF0603ZT0R00	R9
RES SMD 470 OHM 1% 1/10W 0603	Yageo	RC0603FR-07470RL	R8
RES SMD 10M OHM 0.5% 1/4W 1206	Vishay Dale	CRCW120610M0DHEAP	R1, R2
P-Channel 20 V 36A (Tc) 42W (Tc) Surface Mount 8-TSON	Toshiba Semiconductor and Storage	TPN4R712MD,L1Q	Q4
100V N-Ch Power MOSFET	HUNTECK	HGM098N10AL	Q1
USB JACK, C TYPE, POWER ONLY, 6	CUI Devices	UJC-HP-3-SMT-TR	J1
FUSE BOARD MOUNT 3A 280VAC	Littlefuse Inc.	0443003.DRLC	FS1
CAP CER 1PF 25V NP0 0603	KEMET	C0603C109D3GACTU	C49
8200 pF ±5% 50V Ceramic Capacitor X7R 0603	Samsung Electro-Mechanics	CL10B822KB8NNNC	C46
25V 0.033uF X7R 0603 10%	KEMET	C0603C333K3RACTU	C43, C44
CAP CER 390PF 50V C0G/NPO 0402	Yageo	CC0402JRNPO9BN391	C38, C39
CAP CER 0.1UF 50V X7R 0603	Samsung Electro-Mechanics	CL10B104KB8NNNC	C30, C33, C40, C50
CAP CER 1UF 25V X7R 0603	Samsung Electro-Mechanics	CL10B105KA8NNNC	C28
CAP CER 1UF 25V X7R 0603	TDK Corporation	CGA3E1X7R1E105M080AC	C32, C34
CAP CER 10UF 16V X6S 0603	Murata Electronics	GRM188C81C106MA73D	C8
820uF ±20% 25V 16 mO @ 100kHz 5.05A @ 100kHz	Ymin	NPXD21E821MF	C5
CAP Y1 680pF	Thomas & Betts	CT7-400VAC-Y1-B-681K	C4
CAP FILM 0.047UF 20% 760VDC RAD	KEMET	PHE840MK5470MK04R17	C1
BRIDGE RECT 1PHASE 1KV 2A ABS	Taiwan Semiconductor Corporation	ABS210-13	BR1
Vertical Board			
Silanna Flyback controller	Silanna Semiconductor	SZ1131	U1
BOBBIN COIL TRANSFORMER RM 7	TDK Electronics Inc.	B65820W1008D001	T1
THERM NTC 100KOHM 4485K 0402	Murata Electronics	NCP15WL104E03RC	RT2
DNP	Yageo	RC0805JR-071ML	R45

Designator Description	Manufacturer	Manufacturer Part Number	Designator
RES SMD 178K OHM 0.5% 1/10W 0603	Yageo	RT0603DRD07178KL	R32
RES SMD 137K OHM 1% 1/10W 0603	Yageo	RMCF0603FT137K	R31
DNP	Yageo	RC0603FR-07100RL	R28, R29
RES SMD 215K OHM 0.1% 1/10W 0603	Yageo	ERJ-3EKF2153V	R26
RES SMD 4.7 OHM 1% 1/4W 1206	Yageo	RC1206FR-074R7L	R24
RES SMD 10K OHM 1% 1/10W 0603	Yageo	RC0603FR-0710KL	R22, R33
RES 36K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT36K0	R21
RES SMD 237K OHM 1% 1/10W 0603	Yageo	RC0603FR-07237KL	R19
RES SMD 7.5K OHM 1% 1/10W 0603	Yageo	AC0603FR-077K5L	R18
RES 0.3 OHM 1% 1/4W 0603	Panasonic Electronic Components	ERJ-3BQFR30V	R17
RES 0.27 OHM 1% 1/4W 0603	Panasonic Electronic Components	ERJ-3BQFR27V	R16
RES SMD 36 OHM 1% 1/10W 0603	Yageo	RC0603FR-0736RL	R15
RES SMD 6.8 OHM 1% 1/10W 0603	Yageo	CRCW06036R80FKEBC	R13
RES SMD 475K OHM 1% 1/10W 0603	Yageo	RC0603FR-07475KL	R12
RES SMD 30K OHM 1% 1/10W 0603	Yageo	RC0603FR-0730KL	R11
RES 22M OHM 1% 1/8W 0805	Stackpole Electronics Inc	RMCF0805FT22M0	R3, R5, R7, R30
MOSFET 2N-CH 60V 0.35A	Diodes Incorporated	DMN61D9UDW-7	Q3
N-Channel 700 V 6A (Tc) 6.5W (Tc) Surface Mount PG-SOT223	Infineon Technologies	IPN70R900P7SATMA1	Q2
Fixed Inductors WE-TI RadXtnd Ld8095 WW47uH 2.3A .12Ohm	Wurth Elektronik	744772470	L1
SMD 0805 0ohm Jumper 5% CS Mtl Strp AEC-Q200	ROHM Semiconductor	PMR10EZPJ000	FB1
Zener Diode 10 V 150 mW ±5% Surface Mount SOD-523	Diodes Incorporated	DDZ9697T-7	D8
DIODE SCHOTTKY 100V 1A SOD323	Comchip Technology	CDBV1100-HF	D7
50NS 1A 300V HIGH EFFICIENT RECO	Taiwan Semiconductor Corporation	HS1FFL	D6
DIODE GEN PURP 75V 250MA SOD523	Micro Commercial Co	1N4448X-TP	D4
DNP	Diodes Incorporated	DDZ9689T-7	D2
DIODE GEN PURP 1KV 1A SOD123FA	ON Semiconductor	US1MFA	D1
CAP CER 0.5PF 100V NP0 0603	KEMET	C0603C508B1GAC7867	C60
CAP CER 68PF 50V C0G/NP0 0603	Yageo	C0603C680J5GACTU	C27
DNP	Yageo	CC0603JRNPOABN101	C24, C25
CAP CER 10UF 25V X6S 0805	Samsung Electro-Mechanics	CL21X106KAYNNNE	C23
CAP ALUM 82UF 63V 20% T/H	YMIN	LKMC1201J820MF	C21
DNP	CAP DNP	CAP DNP	C20
CAP CER 1000PF 16V X7R 0603	Yageo	CC0603KRX7R7BB102	C15
CAP CER 10000PF 25V X7R 0603	Samsung Electro-Mechanics	CL10B103KA8NNNC	C14, C16, C18
CAP CER 4.7UF 25V X6S 0603	Murata Electronics	GRM188C81E475KE11D	C19
Multilayer Ceramic Capacitors MLCC - SMD/SMT 250V 3.9nF C0G 0805 5% AECQ200	KEMET	C0805C392JAGAC7800	C13

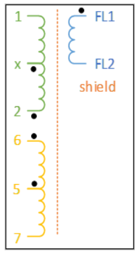
Designator Description	Manufacturer	Manufacturer Part Number	Designator
CAP CER 10000PF 25V X7R 0603	Samsung Electro-Mechanics	CL10B103KA8NNNC	C12
CAP CER 4.7UF 25V X6S 0603	Murata Electronics	GRM188C81E475KE11D	C11
15 µF 25 V Aluminum Electrolytic Capacitors Radial, Can - 2000 Hrs @ 105°C	YMIN	LKM	C10
CAP CER 10000PF 630V X7R 1206	KEMET	C1206C103KBRACTU	C9, C22
22uF ±20% 400V 8x20 2000Hrs @ 105C ,8x20mm Aluminum Electrolytic Capacitors	Man Yue Tech	EKM226M2GF20RR	C2, C3
CAP CER 15PF 50V C0G 0402	KEMET	CGA2B2C0G1H150J050BA	D3
CAP CER 1206 22PF 630V C0G 5%	KEMET	C1206C220JBGACAUTO	C42

Transformer Specification



*remove pins 3,4, and 8.

Pinout



Electrical

Winding Specification

Winding	1	2	3	4	5	6	7
Material*	AWG29	AWG34	AWG34	AWG36	210/44 Litz	AWG36	AWG29
Turns	19	6	4	6	5	6	19
Parallel wires	1	1	1	7	1	7	1
Layers	1	1	1	1	1	1	1
Start Pin	2	6	5	7	FL1	7	(from the end of winding 1)
End Pin	(none, to connect to sec half pri, winding 7)	5	7	nc (notch of FL2)	FL2	nc (notch of FL2)	1
Comment	PRI1 - First half of primary. High voltage winding. Needs slivers on terminal	Aux windings. 1. Winding 2 & 3 should be on the same layer. Centered. 2. Low votlage winding. No sliver needed.		1. Shield 1 - CM shield (low voltage winding, no slivers needed.)	SEC - Secondary winding	1. Shield 2 - CM shield (low voltage winding, no slivers needed.)	PRI2 - Second half of primary. High voltage winding. Needs
Insulation Tape	Tape A (1 Layer)		Tape A (1 Layer)	Tape A (1 Layer)	Tape A (1 Layer)	Tape A (1 layer)	

Copper shield — Wrap one complete loop of copper coil (9.5 mm wide) around the core. Connect the copper coil to Pin 7.

ELECTRICAL TEST PARAMETERS:

INDUCTANCE @ 100kHz/0.1VAC
L(1-2) = 360µH ±5%

INDUCTANCE @ 100kHz/0.1VAC
SHORT PINTS: FL1, FL2
LL(1-2) =< 4.8µH MAX

TURNS RATIO/POLARITY
APPLY: 1.00V @ 10kHz TO PINS (4-5)

DC RESISTANCE OHMS (Ω) @ 25°C

DCR: (1-2) = 0.5Ω MAX
DCR: (FL1-FL2) = 0.015Ω MAX

Table 3: Transformer Material Lists

Material	*Specification*	*Manufacturer*	*Mfr. Part Number*
Bobbin	RM7 8pin	EPCOS - TDK Electronics	B65820W1008D001
Core	ML29D RM-7S	Hitachi Metals	
AWG28	Magnet wire, dual insulation layer	Various	
AWG34	Magnet wire, dual insulation layer	Various	
TIW	Litz AWG44 x 220 strands	Rubadue or equivalent	TXXL220/44F3XX-2 (MW80)
TAPE A	Insulating Tape 5kV	3M or equivalent	

Performance Data

Electrical Data

Efficiency

Table 4: Load Efficiency Summary

115Vac

Vout/Iout	4 - Point Average Efficiency Measurements	DOE level VI 4 - Point Average Efficiency Requirements	Efficiency Margin	CoC version 5 tier 2 4 - Point Average Efficiency Requirements	Efficiency Margin
5 V/3 A	89.58%	81.39%	8.19%	81.84%	7.74%
9 V/3 A	90.63%	84.61%	6.02%	85.42%	5.21%
15 V/2.2 A	91.12%	85.44%	5.68%	86.43%	4.69%
20 V/1.65 A	90.36%	85.44%	4.92%	86.43%	3.93%

230Vac

Vout/Iout	4 - Point Average Efficiency Measurements	DOE level VI 4 - Point Average Efficiency Requirements	Efficiency Margin	CoC version 5 tier 2 4 - Point Average Efficiency Requirements	Efficiency Margin
5 V/3 A	87.25%	81.39%	5.86%	81.84%	5.41%
9 V/3 A	89.42%	84.61%	4.81%	85.42%	4.00%
15 V/2.2 A	90.39%	85.44%	4.95%	86.43%	3.96%
20 V/1.65 A	89.78%	85.44%	4.34%	86.43%	3.35%

The listed efficiency values are the average of the data collected from 3 R23 EVK's.

115 Vac 4-point average efficiency

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

%LOAD	Efficiency	Average Efficiency
100	89.90%	89.58%
75	90.16%	
50	89.87%	
25	88.38%	
10	86.49%	

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

%LOAD	Efficiency	Average Efficiency
100	91.07%	90.63%
75	91.39%	
50	91.05%	
25	89.02%	
10	86.58%	

V_{OUT} / I_{LOAD_MAX} = 15 V / 2.2 A

%LOAD	Efficiency	Average Efficiency
100	91.68%	91.12%
75	91.87%	
50	91.41%	
25	89.52%	
10	85.94%	

V_{OUT} / I_{LOAD_MAX} = 20 V / 1.65 A

%LOAD	Efficiency	Average Efficiency
100	91.53%	90.36%
75	91.41%	
50	90.59%	
25	87.91%	
10	83.17%	

The listed efficiency values are the average of the data collected from 3 RD23 EVK's. The boards pass the DOE Level VI, CoC V5 Tier-2 Average Efficiency and COC V5 Tier-2 10% efficiency targets with more than 3% 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	88.64%	87.25%
75	87.78%	
50	87.27%	
25	85.30%	
10	82.66%	

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

%LOAD	Efficiency	Average Efficiency
100	91.02%	89.42%
75	90.59%	
50	89.30%	
25	86.76%	
10	83.59%	

V_{OUT} / I_{LOAD_MAX} = 15 V / 2.2 A

%LOAD	Efficiency	Average Efficiency
100	91.97%	90.39%
75	91.53%	
50	90.41%	
25	87.63%	
10	84.10%	

V_{OUT} / I_{LOAD_MAX} = 20 V / 1.65 A

%LOAD	Efficiency	Average Efficiency
100	91.80%	89.78%
75	91.21%	
50	89.76%	
25	86.35%	
10	81.76%	

The listed efficiency values are the average of the data collected from 3 RD23 EVK's. The boards pass the DOE Level VI, CoC V5 Tier-2 Average Efficiency and COC V5 Tier-2 10% efficiency targets with more than 3% 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 @ 50 Hz	3.0 A	89.29%
115 Vac @ 60 Hz	3.0 A	89.90%
230 Vac @ 50 Hz	3.0 A	88.64%
265 Vac @ 50 Hz	3.0 A	87.84%

Vout = 9 V

Vin	Iout	Efficiency
90 Vac @ 50 Hz	3.0 A	90.01%
115 Vac @ 60 Hz	3.0 A	91.07%
230 Vac @ 50 Hz	3.0 A	91.02%
265 Vac @ 50 Hz	3.0 A	90.55%

Vout = 15 V

Vin	Iout	Efficiency
90 Vac @ 50 Hz	2.2 A	90.83%
115 Vac @ 60 Hz	2.2 A	91.68%
230 Vac @ 50 Hz	2.2 A	91.97%
265 Vac @ 50 Hz	2.2 A	91.62%

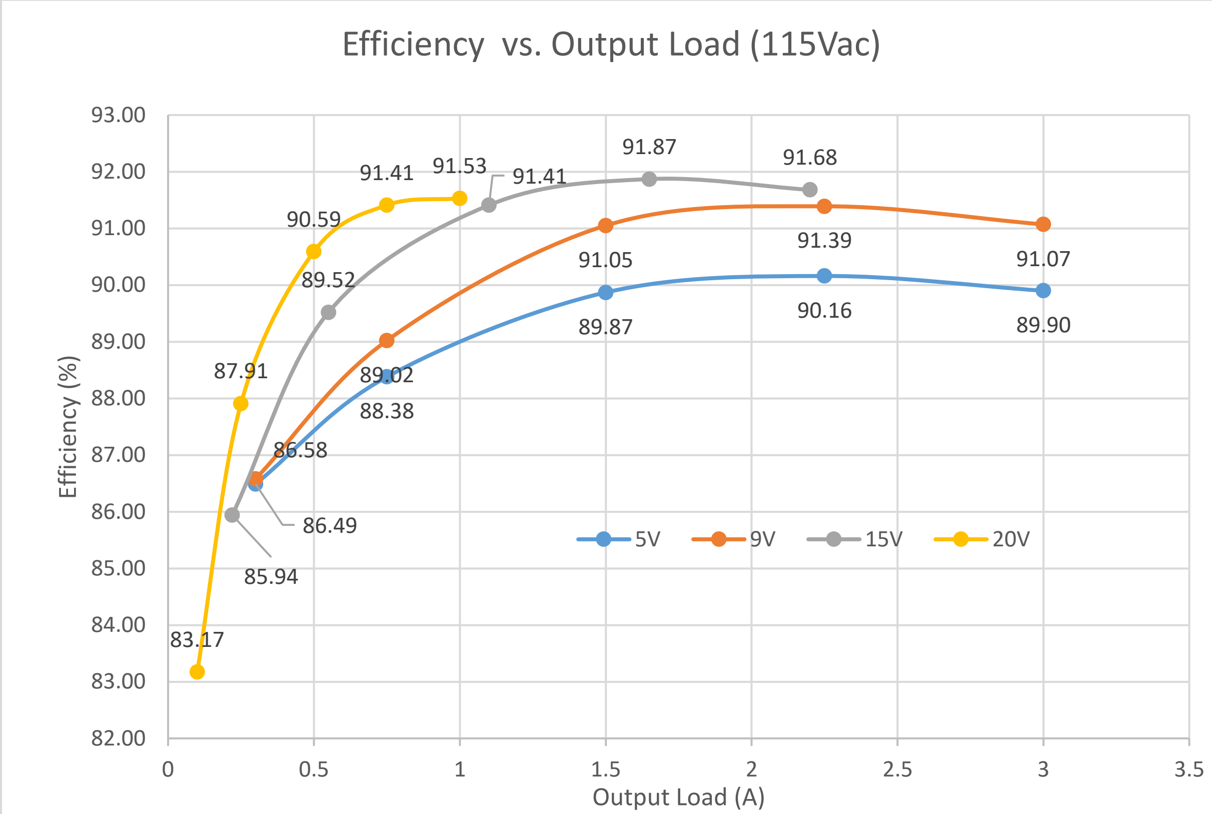
Vout = 20 V

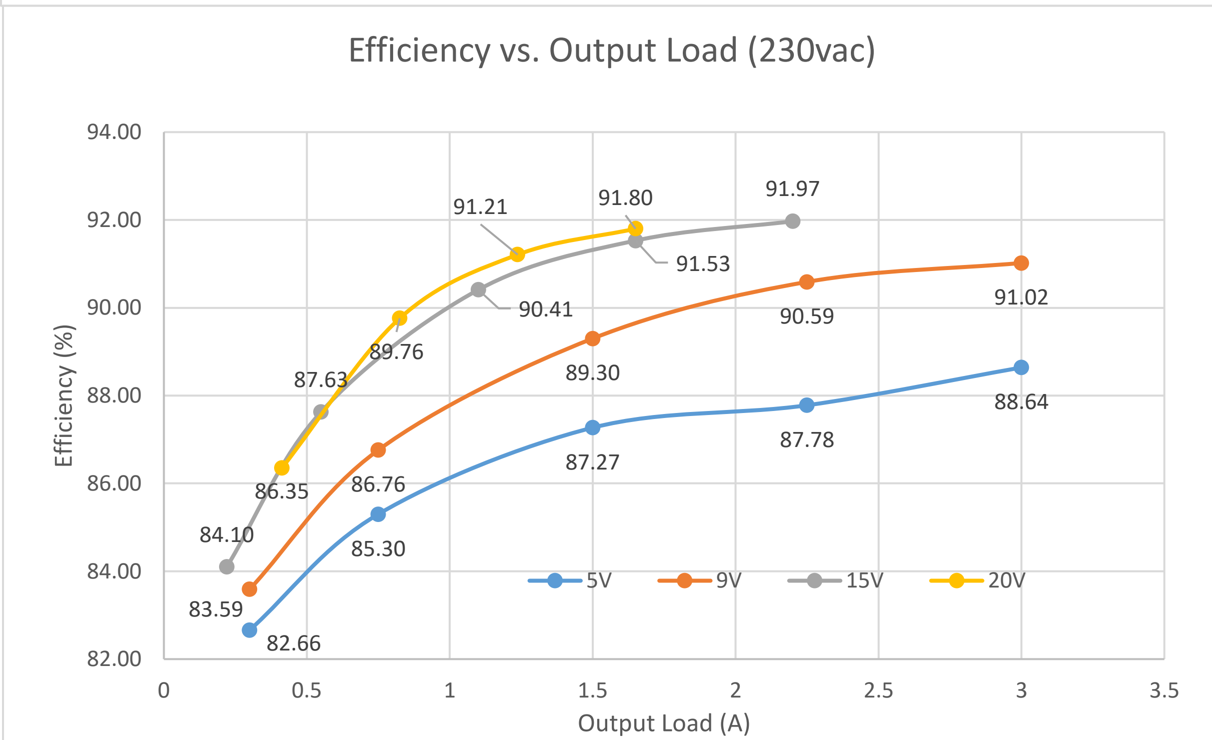
Vin	Iout	Efficiency
90 Vac @ 50 Hz	1.65 A	90.55%
115 Vac @ 60 Hz	1.65 A	91.53%
230 Vac @ 50 Hz	1.65 A	91.80%
265 Vac @ 50 Hz	1.65 A	91.50%

The listed efficiency values are the average of the data collected from 3 RD23 EVK’s.

Efficiency Graphs

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





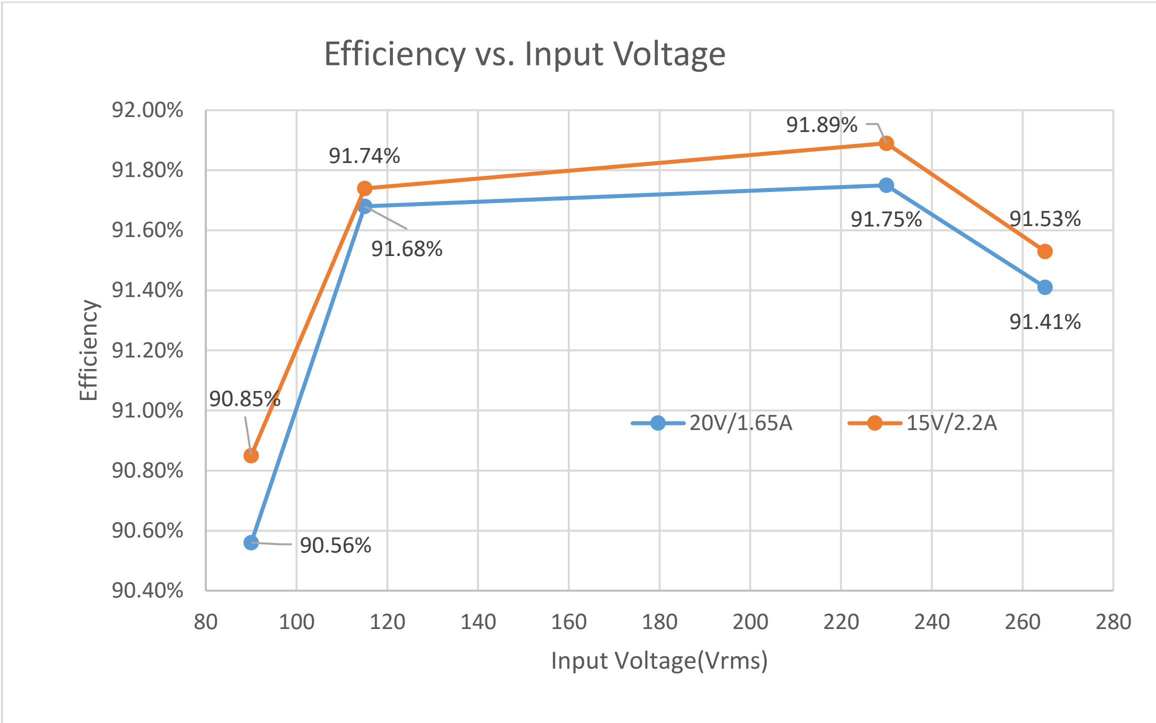


Figure 9: Efficiency graphs for various output voltages and load currents

No Load / Light Load Input Power

Table 5 list no-load input power consumption of the reference design measured across line voltages.

Table 5: No-load/Light-load Input Power Consumption

Input Voltage	No-Load Power Measurements	15V/15mA (225mW)	20V/10mA (200mW)
90Vac	13.41 mW	399.8 mW	448.5 mW
115Vac	13.79 mW	402.9 mW	439.3 mW
230Vac	14.59 mW	408.4 mW	450.5 mW
265Vac	17.08 mW	423.0 mW	457.0 mW

The listed no-load values are the average of the data collected from 3 RD23 EVK's.

Static Output Characteristics

The following table shows load/line regulation (at the output cable connector) for 5 V-20 V output voltages for variation of the line input voltage. That data below is without the Cable drop compensation.

Table 6: Line/Load Regulation Summary (End of Board)

Output Voltage	Line / Load Range		Measured Regulation	
	Min	Max	Min	Max
5 V	0 A	3 A	5.00 V	5.05 V
9 V	0 A	3 A	8.94 V	9.01 V
15 V	0 A	2 .2A	14.97 V	15.21V
20 V	0 A	1.65 A	19.98 V	20.01 V

The following table shows load/line regulation (at the end of 1 meter 3A USB-C Cable) for 5 V-20 V output voltages for variation of the line input voltage. That data below is without the Cable drop compensation.

Table 7: Line/Load Regulation Summary (End of 1 Meter 3A Cable)

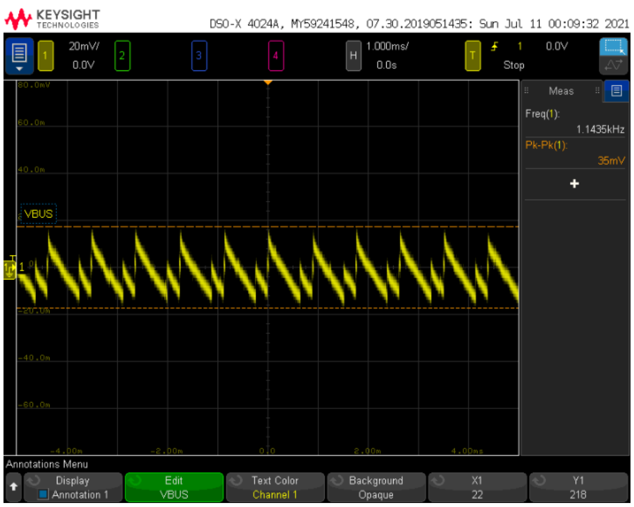
Output Voltage	Line / Load Range		Measured Regulation	
	Min	Max	Min	Max
5 V	0 A	3 A	4.45 V	5.04 V
9 V	0 A	3 A	8.37 V	8.97 V
15 V	0 A	2.2 A	14.56 V	14.98 V
20 V	0 A	1.65 A	19.67 V	19.97 V

Output Voltage Ripple Noise

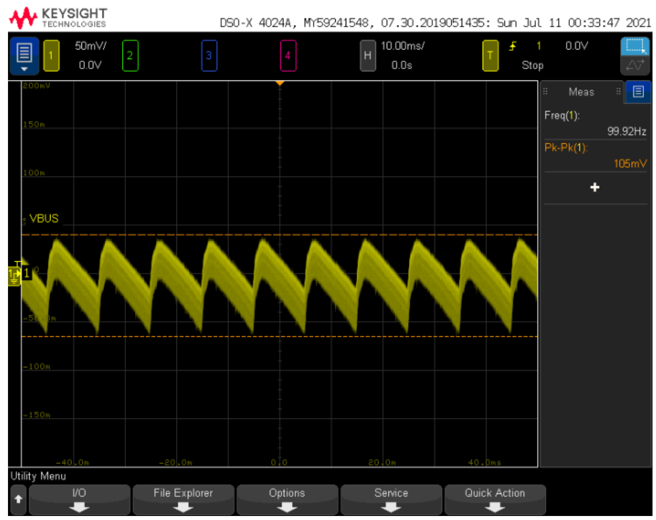
The output voltage ripple was measured using a voltage probe with two capacitors (1 µF/50 V ceramic and 10 µF/50 V low ESR electrolytic) tied in parallel across it. Measurment done at the end of 1 cable.

Table 8: 90Vac Output Ripple Noise Summary

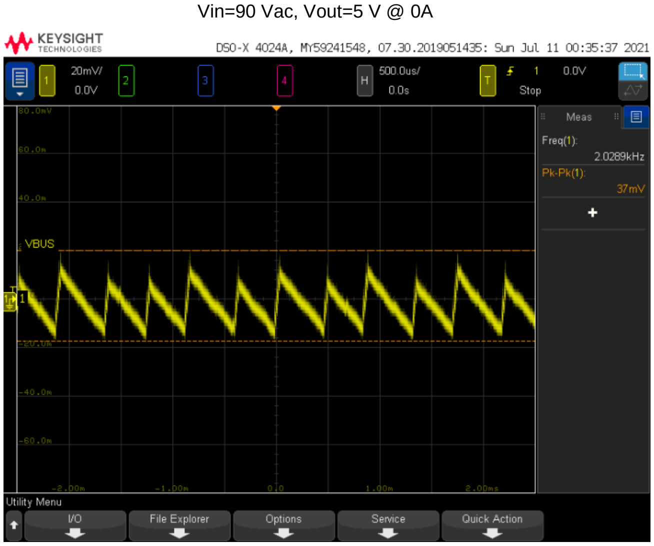
Vout/Iout	Measured Output Ripple at No Load	Measured Output Ripple at Full Load
5 V/3 A	35 mV	105 mV
9 V/3 A	37 mV	201 mV
15 V/2.2 A	39 mV	261 mV
20 V/1.65 A	37 mV	258 mV



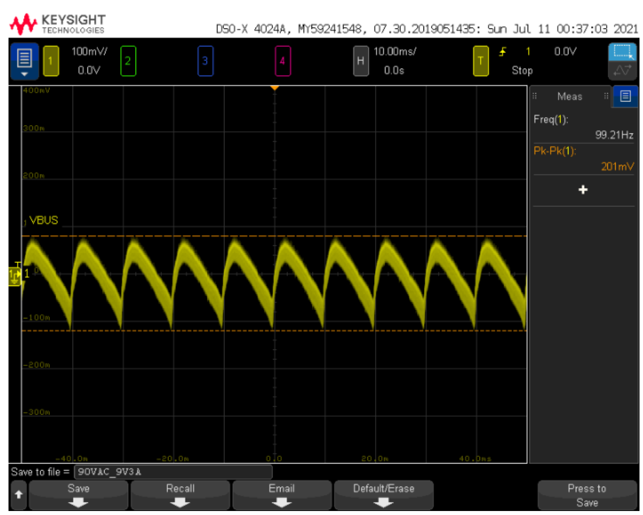
Vin=90 Vac, Vout=5 V @ 0A



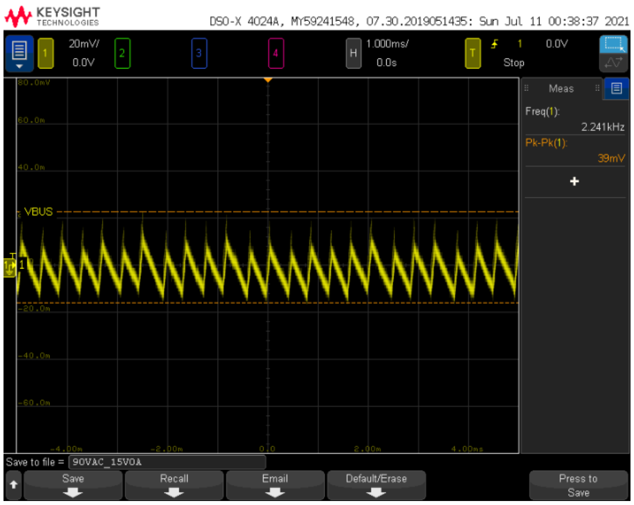
Vin=90 Vac, Vout=5 V @ 3A



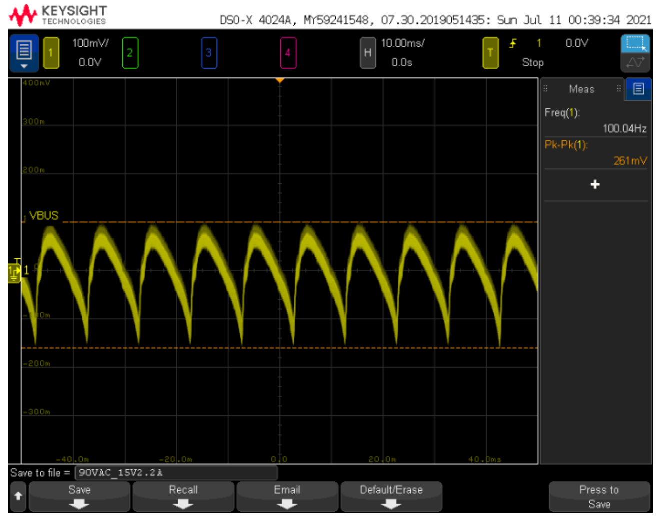
Vin=90 Vac, Vout=9 V @ 0A



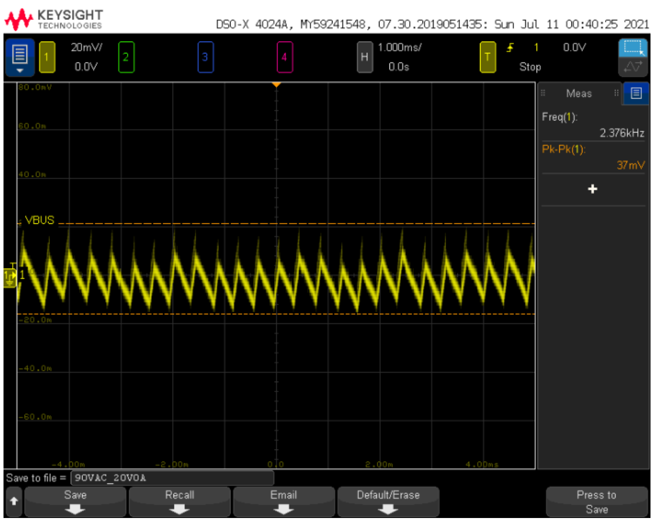
Vin= 90 Vac, Vout=9 V 2.2A



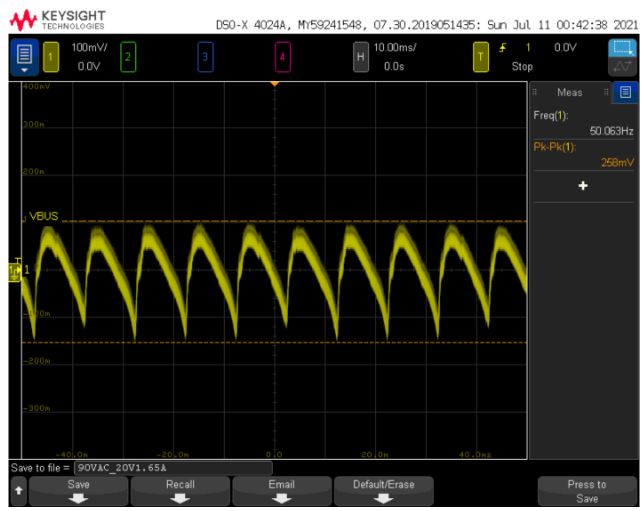
Vin=90 Vac, Vout=15 V @ 0A



Vin=90 Vac, Vout=15 V @ 2.2A



Vin=90 Vac, Vout=20 V @ 0A

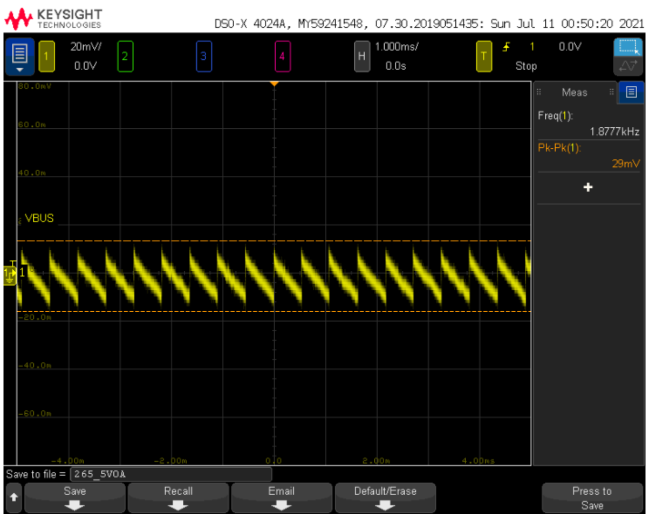


Vin= 90 Vac, Vout=20 V 1.65A

Figure 10: Output voltage ripple measurements at 90Vac input voltage and 5 V/9 V/15 V/20 V full-power & No-load (end of cable)

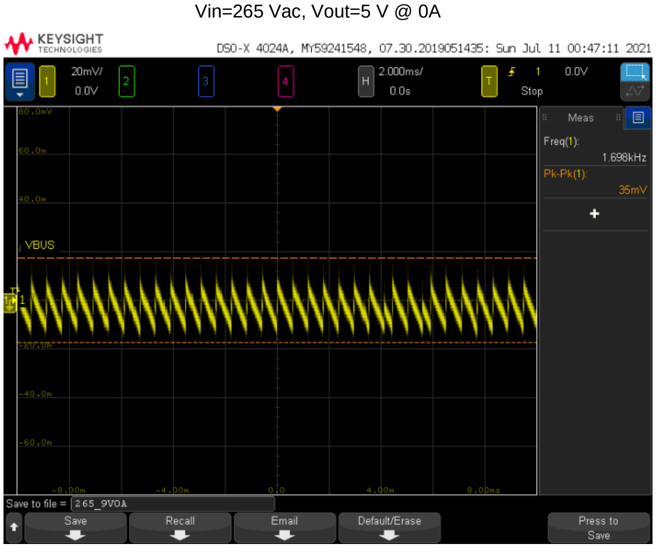
Table 9: 265Vac Output Ripple Noise Summary

Vout/Iout	Measured Output Ripple No Load	Measured Output Ripple Full Load
5 V/3 A	52 mV	56 mV
9 V/3 A	62 mV	80 mV
15 V/2.2 A	60 mV	69 mV
20 V/1.65 A	47 mV	64 mV

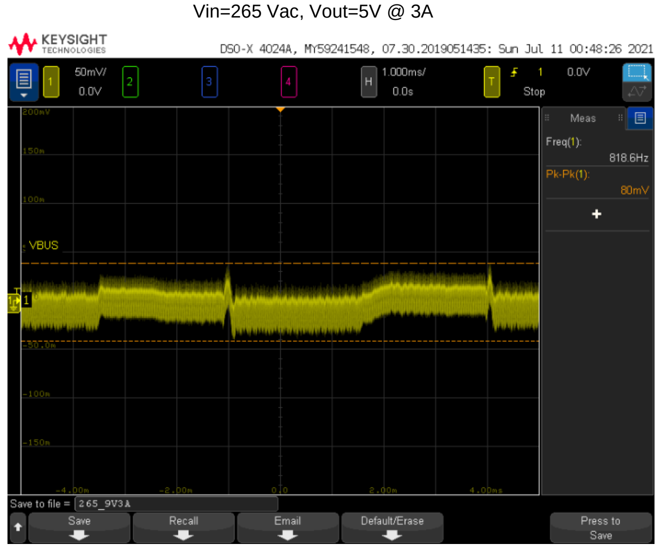


Vin=265 Vac, Vout=5 V @ 0A

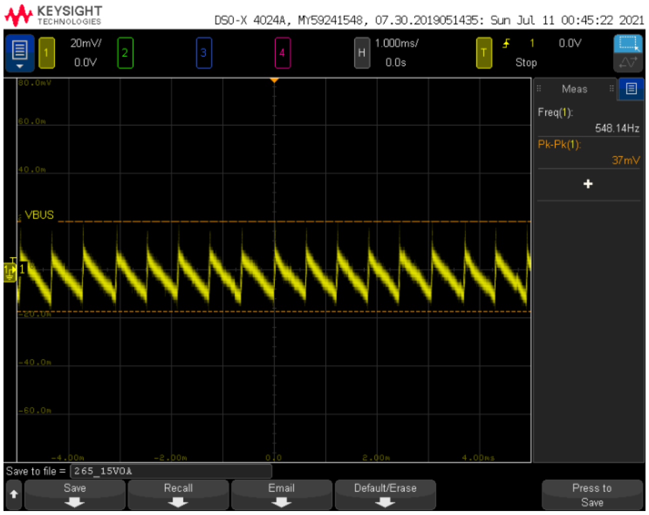
Vin=265 Vac, Vout=5V @ 3A



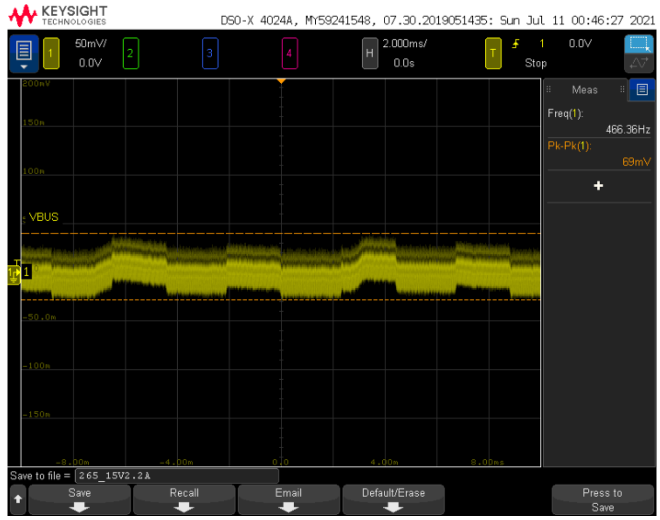
Vin=265 Vac, Vout=9 V @ 0A



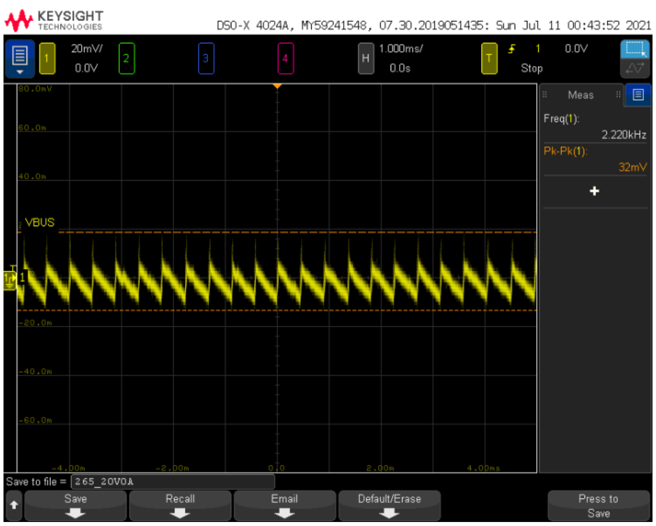
Vin= 265 Vac, Vout=9 V 3A



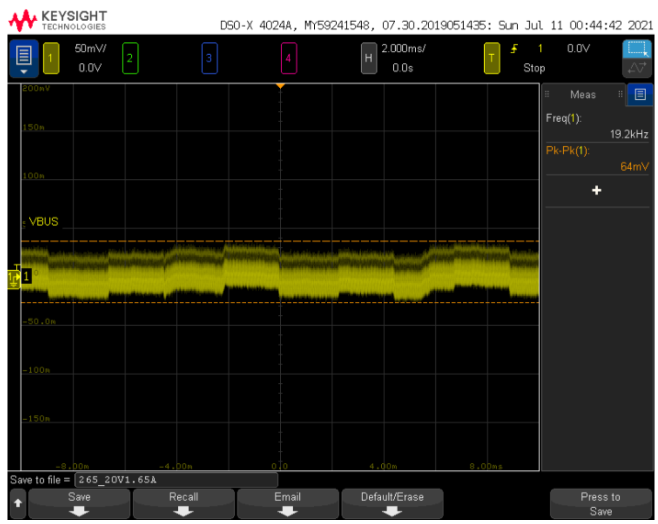
Vin=265 Vac, Vout=15 V @ 0A



Vin=265 Vac, Vout=15 V @ 2.2A



Vin=265 Vac, Vout=20 V @ 0A



Vin= 265 Vac, Vout=20 V 1.65A

Figure 11: Output voltage ripple measurements at 265Vac input voltage and 5 V/9 V/15 V/20 V full-power (end of cable)

Dynamic Output Characteristics

The following tables show dynamic responses (1 Hz & 1000 Hz) for different output voltages under 115 Vac and 230 Vac input voltages. Load variations from 0% to 50% and 0% to 100% at 50% duty cycle. Measured at output cable connector and e-load slew rate set to 1A/us.

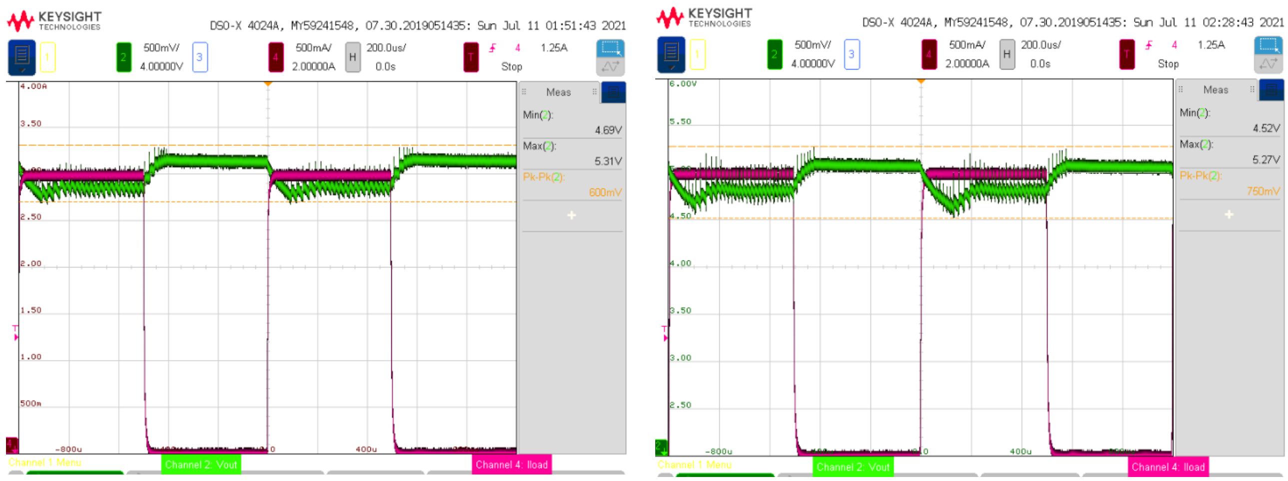
Table 10: Dynamic Output Characteristics Summary (End of Board)

90Vac

Output Voltage	Load Range		Measured Regulation (1 Hz)		Measured Regulation (1 kHz)	
	Min	Max	Min	Max	Min	Max
5 V	0.0 A	1.5 A	4.77 V	5.27 V	4.8 V	5.29 V
	0.0 A	3.0 A	4.62 V	5.41 V	4.69 V	5.31 V
9 V	0.0 A	1.5 A	8.64 V	9.17 V	8.65 V	9.17 V
	0.0 A	3.0 A	8.49 V	9.32 V	8.52 V	9.26 V
15 V	0.0 A	1.1 A	14.57 V	15.12 V	14.6 V	15.12 V
	0.0 A	2.2 A	14.4 V	15.22 V	14.5 V	15.21 V
20 V	0.0 A	0.825 A	19.5 V	20.12 V	19.52 V	20.1 V
	0.0 A	1.65 A	19.45 V	20.24 V	19.49 V	20.17 V

265Vac

Output Voltage	Load Range		Measured Regulation (1 Hz)		Measured Regulation (1 kHz)	
	Min	Max	Min	Max	Min	Max
5 V	0.0 A	1.5 A	4.65 V	5.26 V	4.64 V	5.26 V
	0.0 A	3.0 A	4.52 V	5.32 V	4.52 V	5.27 V
9 V	0.0 A	1.5 A	8.64 V	9.21 V	8.6 V	9.26 V
	0.0 A	3.0 A	8.49 V	9.29 V	8.49 V	9.32 V
15 V	0.0 A	1 A	14.59 V	15.12 V	14.59 V	15.12 V
	0.0 A	2.2 A	14.44 V	15.22 V	14.5 V	15.29 V
20 V	0.0 A	0.75 A	19.5 V	20.15 V	19.52 V	20.19 V
	0.0 A	1.65 A	19.47 V	20.17 V	19.44 V	20.32 V



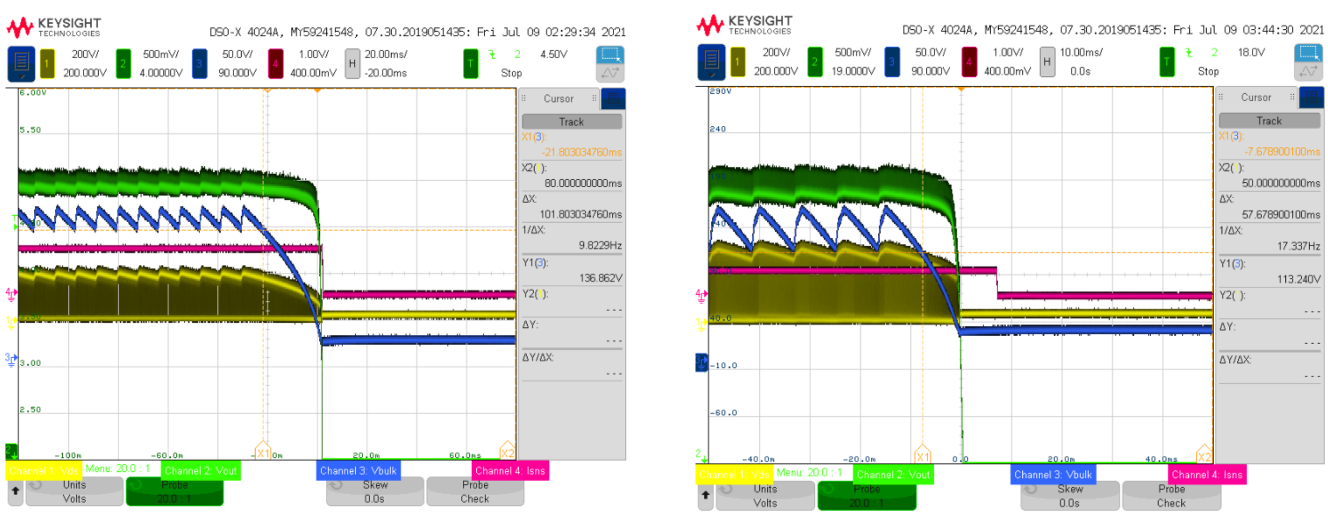
Vin=90 Vac, Vout=5 V, 0 to 3A, 1kHz transient

Vin=265 Vac, Vout=5 V,0 to 3A,1kHz transient

Figure 12: 0A to 3A Load Transient waveforms for 5V.

Table 11: 115Vac Hold Up Time

Output Load	Hold Up Measurement
5 V / 3 A	21.80 ms
9 V / 3 A	9.73 ms
15 V / 2.2 A	7.52 ms
20 V / 1.65 A	7.68 ms



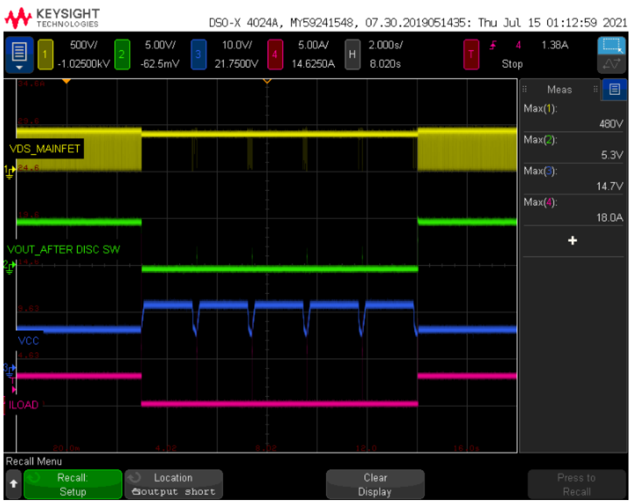
Vin=115 Vac, Vout=5 V @ 3A

Vin=115 Vac, Vout=20 V @ 1.65A

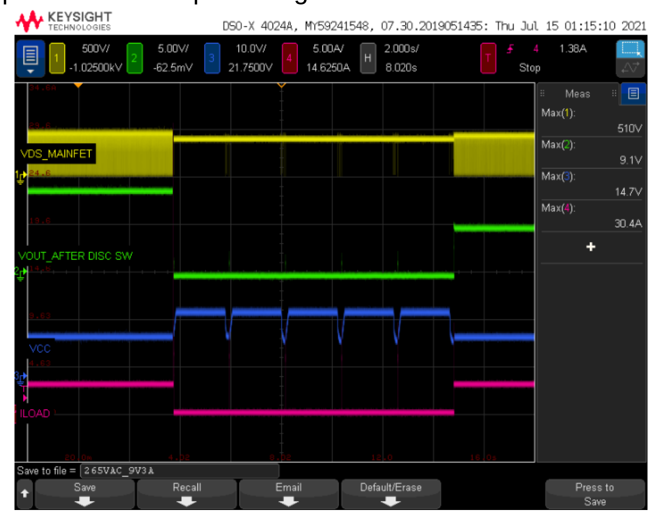
Figure 13: Hold-up time key voltage waveforms for 5 V/3A and 20 V/1.65A.

Output Short and Auto-recovery

The reference design features Hiccup Mode Fault Protections using SZ1131-01. Under applicable fault conditions (all except over-temperature protections), the device attempts to auto-restart. Figure 14 shows hiccup mode fault recovery behaviour when a short is applied at the VBUS output (after the USB-PD disconnect FET). The OCP fault protection in the Cypress PD controller is disabled.Once the short is detected, the device triggers output short circuit protection (OSCP) fault, the device attempts to auto-restart and will continue to do so until the fault is cleared. During output short at higher voltage, the device will auto-restart to 5V output once the output voltage short fault is removed.

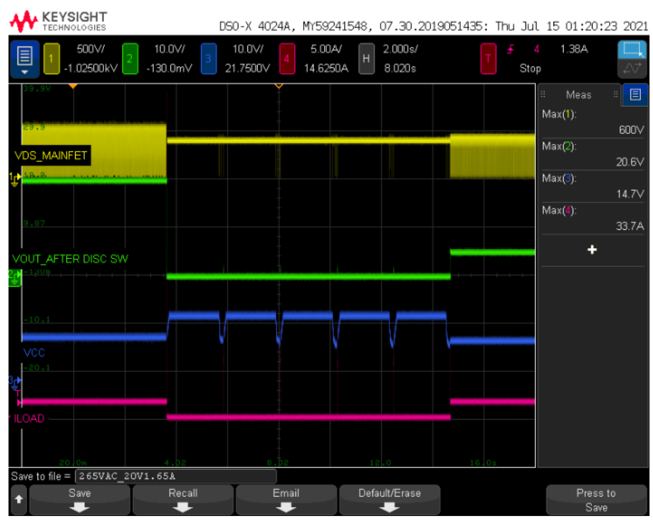


Vin=265 Vac, Vout=5 V, normal running then short, Recovery=5 V



Vin=265 Vac, Vout=9 V, normal running then short, Recovery=5V

Vin=265 Vac, Vout=15 V, normal running then short, Recovery=5 V



Vin=265 Vac, Vout=20 V, normal running then short, Recovery=5 V

Figure 14: Hiccup mode fault recovery behavior under output short circuit protection (OSCP)

Table 12 list input power a short circuit fault as the device continuously attempts to auto-restart. The short was applied by physically shorting the output terminals of the reference design (metal insert between V_{BUS} and USB ground).

Table 12: Short Circuit Input Power

Input Voltage (Vin)	Input Power (Short Circuit)	Maximum Primary FET Drain Voltage
90 Vac (50 Hz)	63.96 mW	210 V
265 Vac (60 Hz)	236.71 mW	460 V

Output Over-Current Protection (OCP)

The reference design features Hiccup Mode Fault Protections using SZ1131-01. Under applicable fault conditions, the device attempts to auto-restart. Figure 14 shows hiccup mode fault recovery behaviour when an output over current occur. Once the over current is detected, the device triggers output over current protection (OOCP) fault, the device attempts to auto-restart and will continue to do so until the fault is cleared. During over current at higher voltage, the device will auto-restart to 5V output once the output voltage over current fault is removed. The OCP fault protection in the Cypress controller is disabed.

Table 13: Over-Current Level Summary

Output Voltage	Measured OCP/SW Voltage	
	90 Vac	265 Vac
5 V	4.7 A/ 227 V	5.8 A/ 468 V
9 V	3.7 A/ 223 V	5.3 A/ 481 V
15 V	2.7 A/ 247 V	4.1 A/ 548 V
20 V	2.1 A/ 300 V	3.3 A/ 608 V

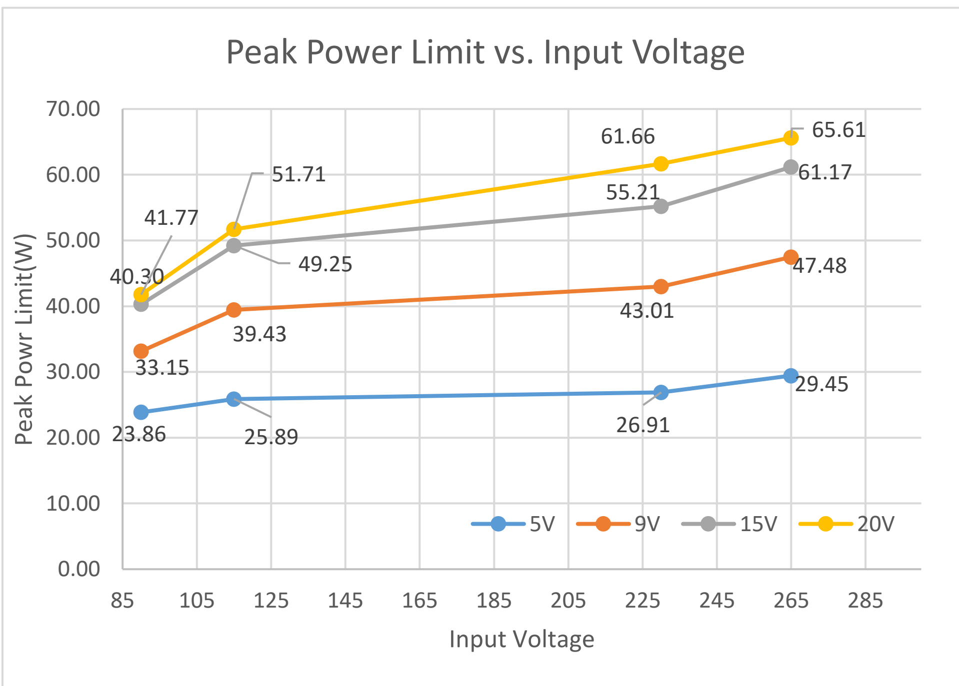


Figure 15: Peak power limit versus input voltage for different output voltages.

Output Over-Voltage Protection / Feedback Loop Open Protection

The reference design features Hiccup Mode Fault Protections using SZ1131-01. Under applicable fault conditions, the device attempts to auto-restart.

Figure 16 shows hiccup mode fault recovery behaviour when output over-voltage protection occur via loss of feedback. Tests were done via shorting the diode side (secondary) of the optocoupler. Whenever the optocoupler diode is shorted, no current will flow on the optocoupler transistor side, hence pulling the FB pin to 5V. Once the FB pin is pulled to high, the PWM switching stops after several cycles and will enter auto-restart mode. This prevents the output voltage and drain to source voltage to get high that may damage critical components such as the main FET, SZ1131, Cypress IC and output capacitors.

Table 14: Over-Voltage Level Summary

90Vac

Output Voltage	Voltage before the Disconnect FET		Voltage after the Disconnect FET	
	No Load OVP	Full Load OVP	No Load OVP	Full Load OVP
5 V	21.9 V	22.2 V	6.1 V	6.1 V
9 V	21.9 V	21.9 V	11.5 V	9.75 V
15 V	21.9 V	21.9 V	17.2 V	15.8 V
20 V	21.9 V	21.9 V	21.5 V	20.8V

265Vac

Output Voltage	Voltage before the Disconnect FET		Voltage after the Disconnect FET	
	No Load OVP	Full Load OVP	No Load OVP	Full Load OVP
5 V	22.2 V	21.9 V	6.1 V	6.4 V
9 V	22.2 V	21.9 V	11.8 V	10.5 V
15 V	21.9 V	21.9 V	17.8 V	16.5 V
20 V	22.2 V	21.9 V	21.5 V	21.2 V

Vin=90 Vac, Vout=5 V, 0 A, Opto Shorted, VDS_max=321 V

Vin=90 Vac, Vout=5 V, 3 A, Opto Shorted, VDS_max=310 V

Vin=265 Vac, Vout=5 V, 0 A, Opto Shorted, VDS_max=580 V

Vin=265 Vac, Vout=5 V, 3 A, Opto Shorted, VDS_max=570 V

Vin=90 Vac, Vout=20 V, 0 A, Opto Shorted, VDS_max=310 V

Vin=90 Vac, Vout=20 V, 1.65A, Opto Shorted, VDS_max=317 V

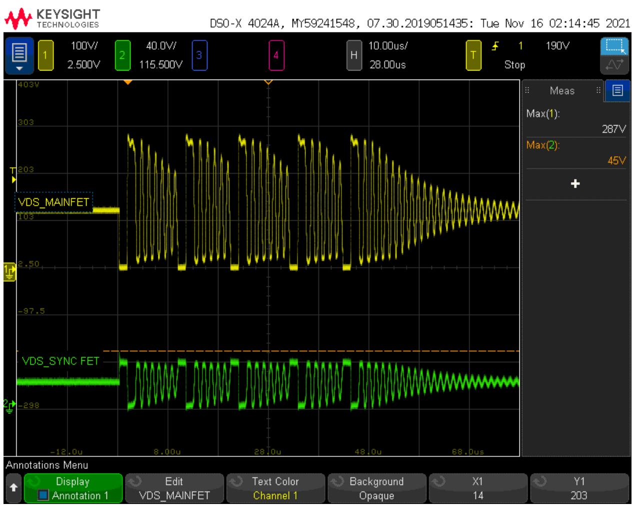
Vin=265 Vac, Vout=20 V, 0 A, Opto Shorted, VDS_max=580 V

Vin=265 Vac, Vout=20 V, 1.65 A, Opto Shorted, VDS_max=590 V

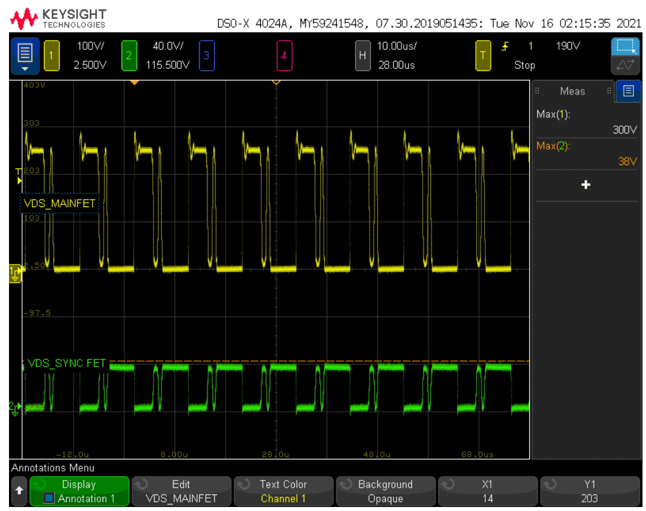
Figure 16: Fault recovery behavior under Over-Voltage Protection via optocoupler diode short

Drain Voltage and Current Waveforms at Steady State

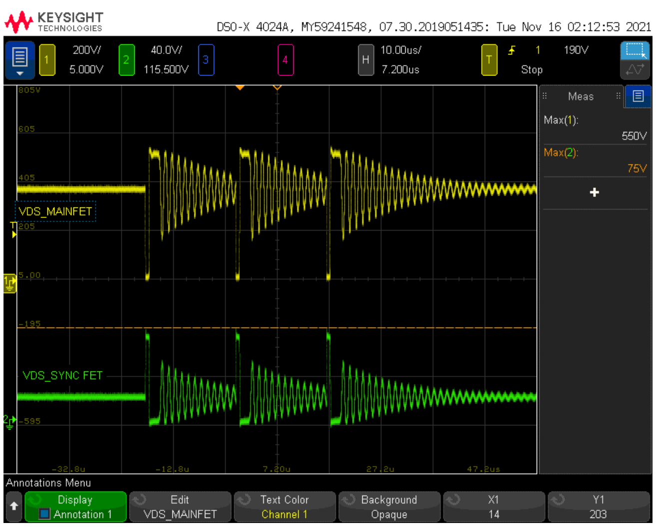
The waveforms presented in this section show no components are over stressed under normal operating conditions. Measurement done at 265 Vac at full and no-load condition and 20V output voltage.



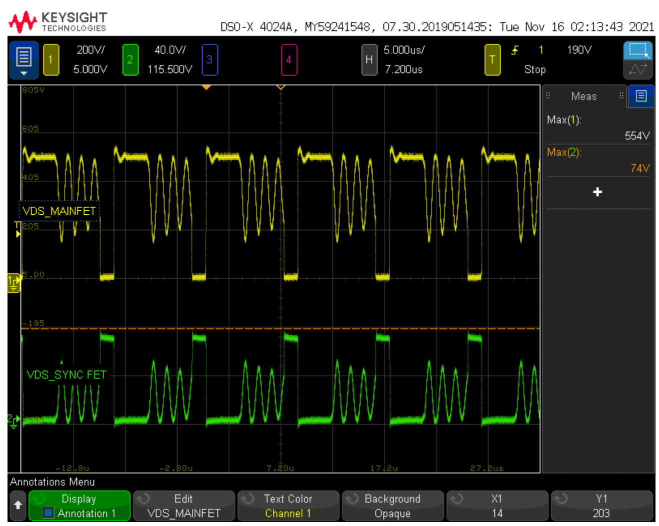
Vin=90 Vac, Vout=20 V, Iout=0 A, V_{ds_MAIN}=287 V



Vin=90 Vac, Vout=20 V, Iout=1.65 A, V_{ds_MAIN}=300 V



Vin=265 Vac, Vout=20 V,Iout=0A, V_{ds_MAIN}=550.0 V, V_{ds_SRFET}=75 V



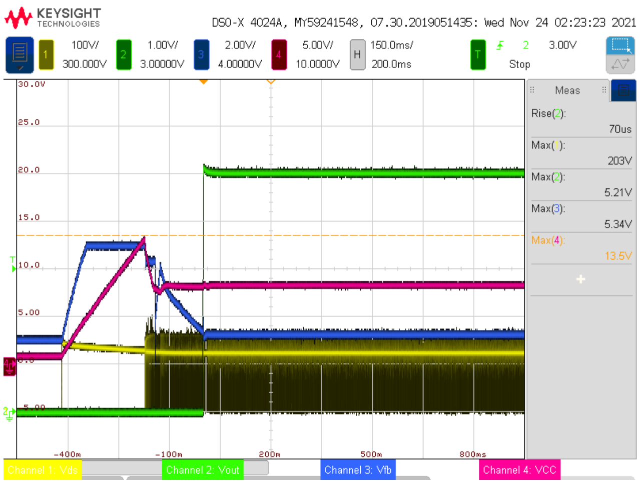
Vin=265 Vac, Vout=20 V, Iout=1.65 A, , V_{ds_MAIN}=554.0 V, V_{ds_SRFET}=74 V

Figure 17: Main Primary and SR FET drain voltage waveforms under various operating conditions at 265 Vac input

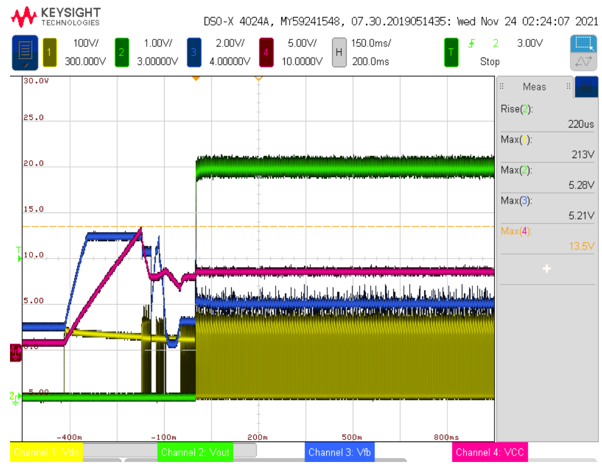
Start-up Captured Across Temp

85°C Ambient

The waveforms presented in this section show no components are over stressed under start-up operating conditions. Measurement done at 90 Vac and 265 Vac at full and no-load conditions.

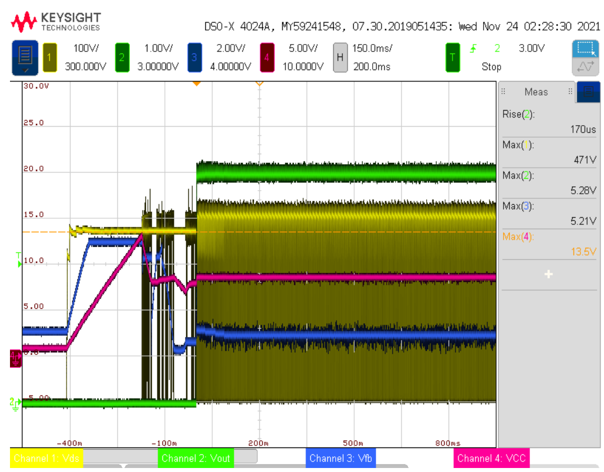


Vin=90 Vac, Vout=5 V, Iout=0 A, V_{ds_MAIN}=203.0 V



Vin=90 Vac, Vout=5 V, Iout=3 A, V_{ds_MAIN}=213.0 V

Vin=265 Vac, Vout=5 V, Iout=0 A, V_{ds_MAIN}=504.0 V

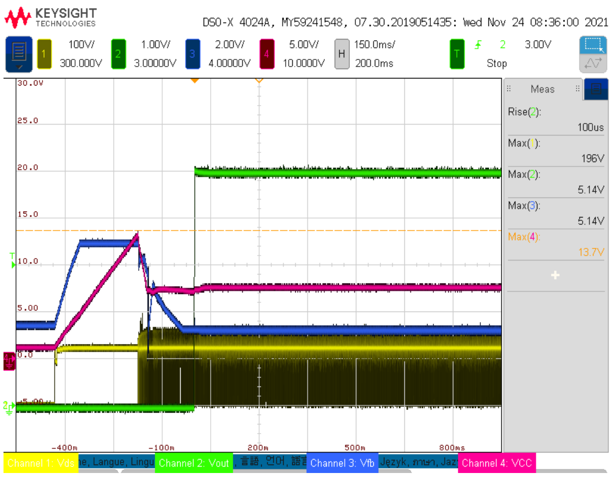


Vin=265 Vac, Vout=5 V, Iout=3 A, V_{ds_MAIN}=471.0 V

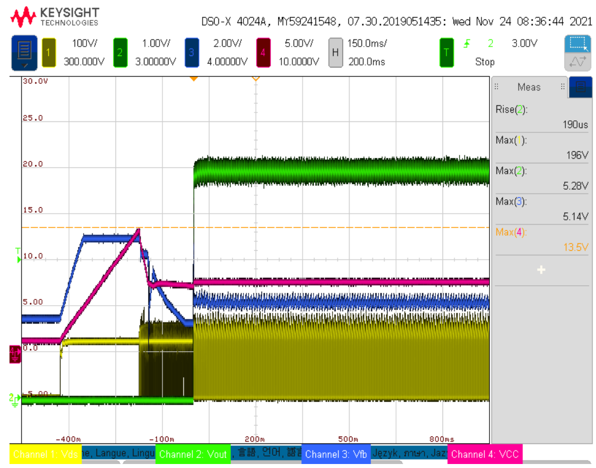
Figure 18: Primary FET drain voltage waveforms during start-up at 90 Vac and 265 Vac input at 80°C .

-30°C Ambient

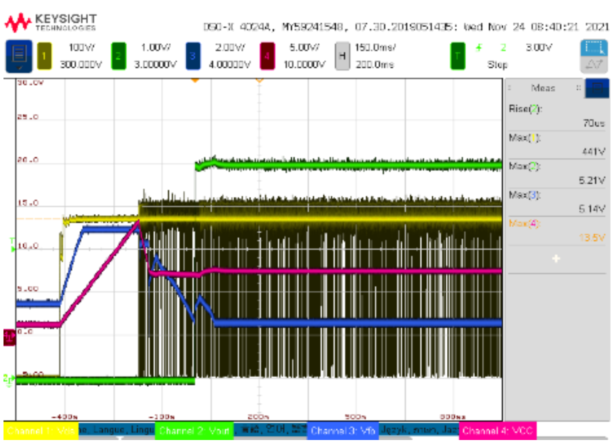
The waveforms presented in this section show no components are over stressed under start-up operating conditions. Measurement done at 90 Vac and 265 Vac at full and no-load conditions.



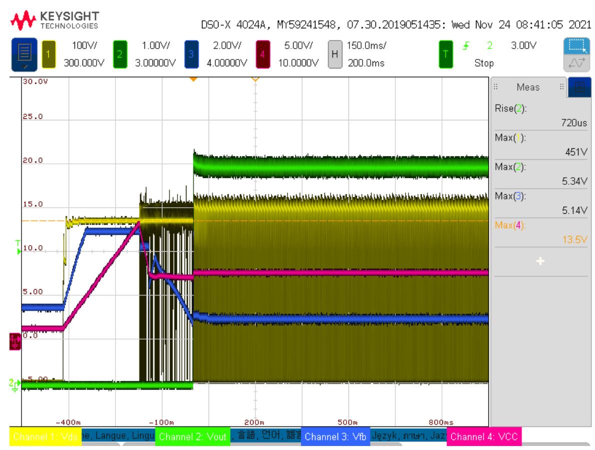
Vin=90 Vac, Vout=5 V, Iout=0 A, V_{ds_MAIN}=196.0 V



Vin=90 Vac, Vout=5 V, Iout=3 A, V_{ds_MAIN}=196.0 V



Vin=265 Vac, Vout=5 V, Iout=0 A, V_{ds_MAIN}=441.0 V



Vin=265 Vac, Vout=5 V, Iout=3 A, V_{ds_MAIN}=451 V

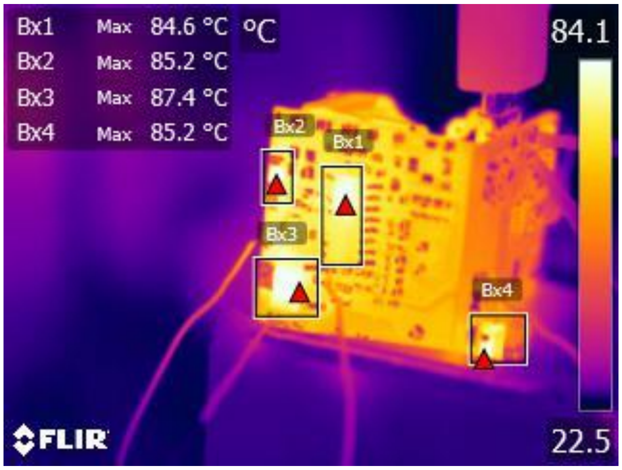
Figure 19: Primary FET drain voltage waveforms during start-up at 90 Vac and 265 Vac input at 0°C .

Thermal Measurements

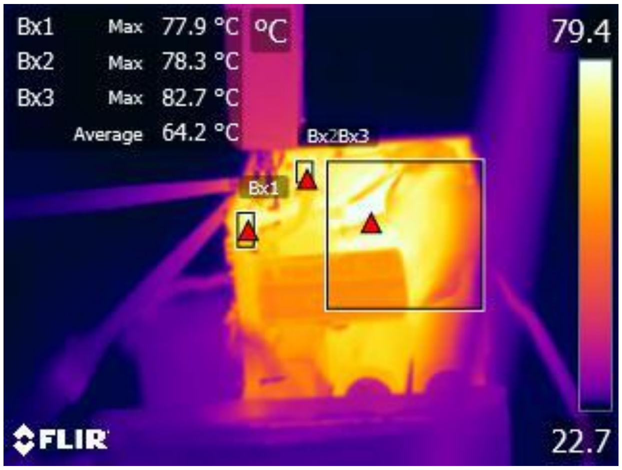
The following thermal data show the temperatures of key semiconductor components after 1hr operation at 90Vac/20V/33W. No thermal management was utilized, and the unit was outside of the case with ambient temperature ~25 degrees Celsius.

Table 15: Measured Components Temperature with 20V, 1.65A

RefDes	Description	90VAC
U1	SZ1131-02	84.6°C
BR1	Bridge Rectifier	85.2°C
T1	Transformer	82.7°C
Q2	Primary MOSFET	87.4°C
Q1	Secondary SR MOSFET	73.9°C
U3	SR FET Controller	68°C
R24	Clamp Resistors	85.2°C
Q3	External LDO MOSFETs	85.2°C

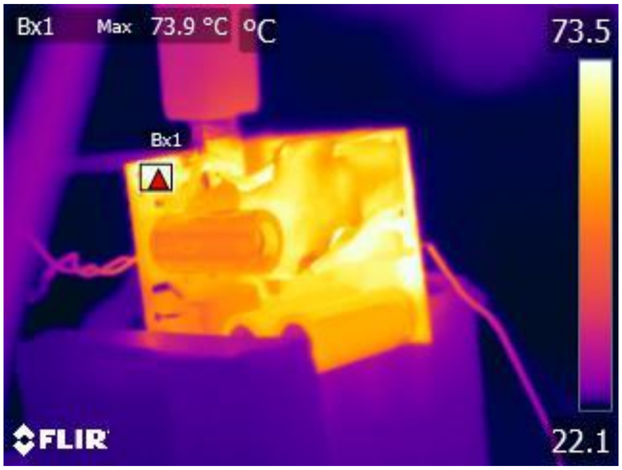


Vin=90 Vac, Vout=20 V, Iout=1.65 A (top)



Vin=90 Vac, Vout=20 V, Iout=1.65 A (bottom)

Vin=90 Vac, Vout=20 V, Iout=1.65 A (side left)



Vin=90 Vac, Vout=20 V, Iout=1.65 A (side right)

Figure 20: Thermal images captured at 90 Vac/20V/1.65A condition.

Gain-Phase Measurement

To check the loop stability, a gain-phase measurement was performed for all the outputs at 90 Vac and 265Vac. The system gain margin, phase margin and bandwidth are shown below.

Table 16: Measured gain-phase and bandwidth of the compensator loop

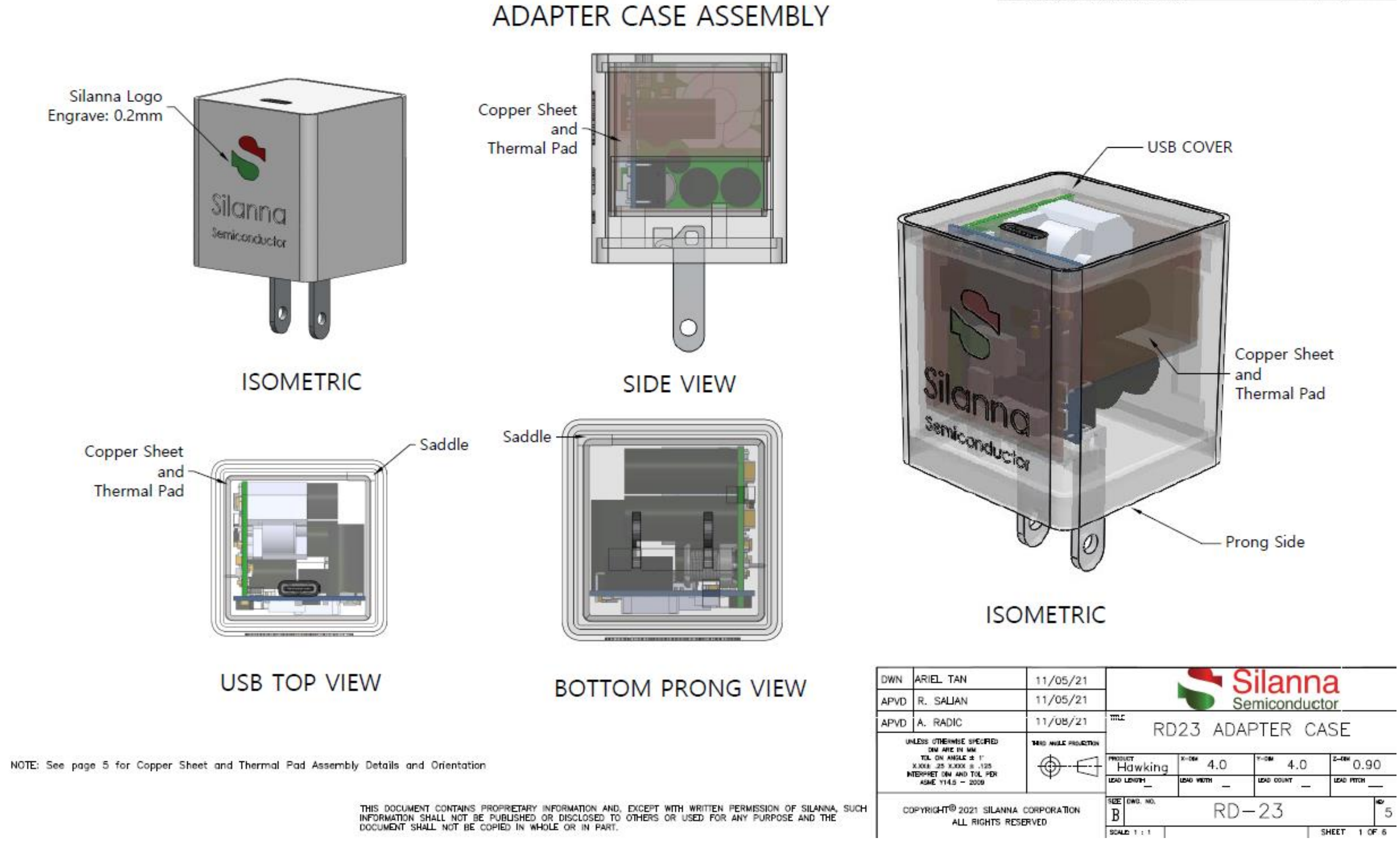
100% Load	Bandwidth (KHz)			
	5 V	9 V	15 V	20 V
90 Vac	3.63	3.07	2.17	2.17
115 Vac	2.7	3.92	2.78	2.7
230 Vac	2.84	3.38	2.81	2.79
265 Vac	3.12	3	2.17	2.1

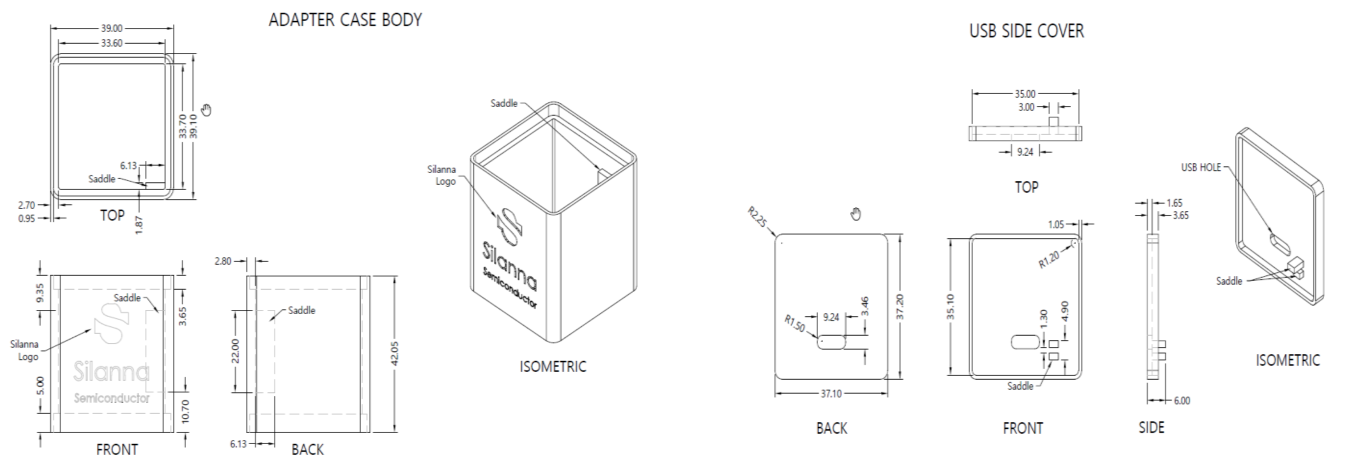
100% Load	Phase Margin (°)			
	5 V	9 V	15 V	20 V
90 Vac	44.44	53.64	59.94	63.18
115 Vac	57.74	45.35	58.33	56.66
230 Vac	54.41	49.84	56.54	56.47
265 Vac	51.84	51.08	58.8	61.59

100% Load	Gain Margin (dB)			
	5 V	9 V	15 V	20 V
90 Vac	-7.6	-9.17	-12.2	-12.86
115 Vac	-12.04	-8.36	-11.86	-11.18
230 Vac	-12.54	-9.17	-13.41	-12.64
265 Vac	-11.7	-11.62	-15.12	-15.26

Case & Heatsink details

REVISION HISTORY			
REV	DESCRIPTION	DATE	APPROVED
1	INITIAL RELEASE	09/30/21	R. SALIAN
2	Remove case body saddle holder, Update both end cover designs	11/05/21	R. SALIAN
3	Add Copper Sheet and Thermal pad details in page 5, update saddle in P1	11/08/21	R. SALIAN
4	Remove USB cover side saddle, update 3D view in page 1 and 5	11/09/21	R. SALIAN
5	Added page 5, Actual System Unit Assembly	11/10/21	R. SALIAN





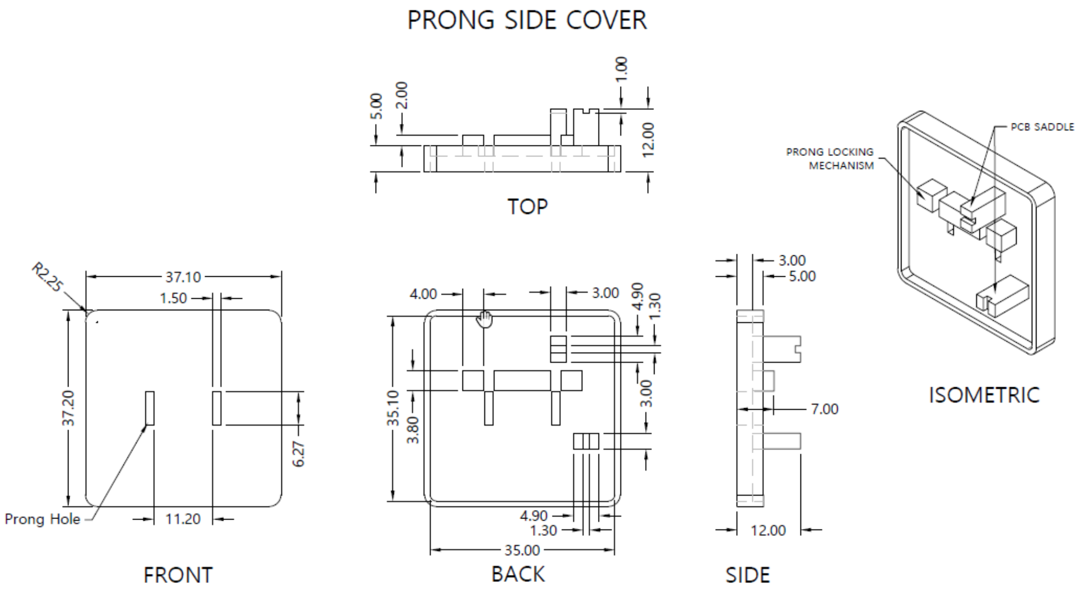


Figure 21: RD23 Adapter case assembly, Adapter case body , USB side cover & Prong side cover dimensions .

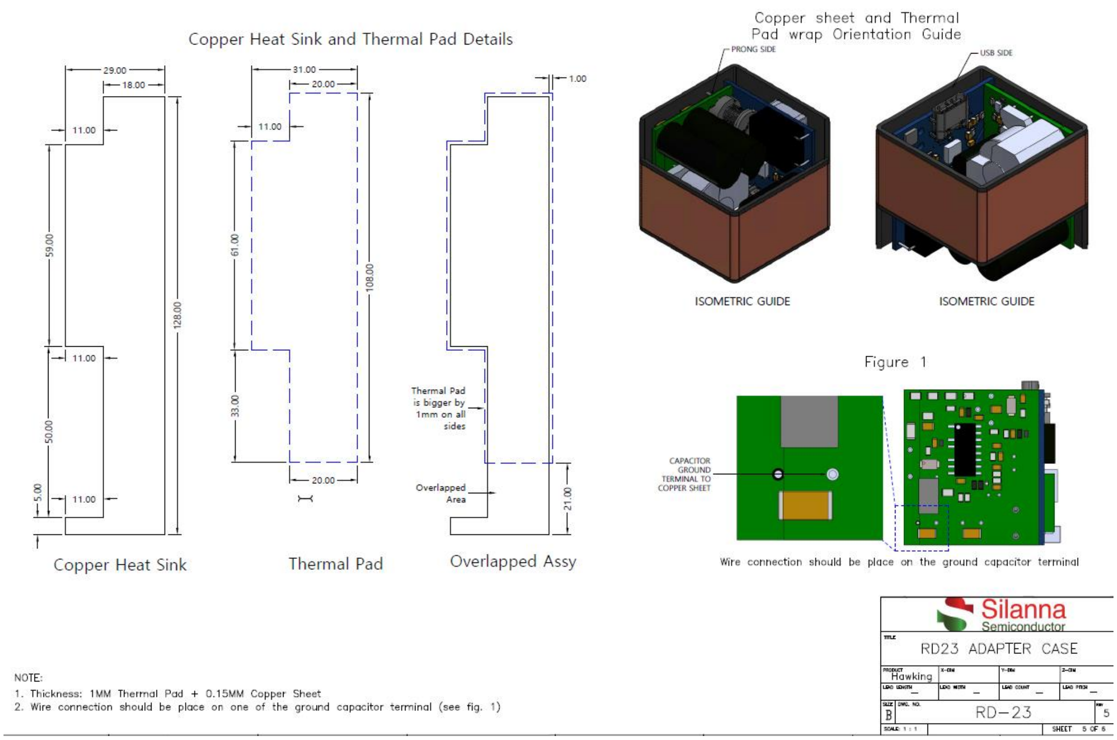


Figure 22: Copper Heatsink & Thermal Pad details .

Efficiency Summary Across Temp (Inside case with heatsink)

90 Vac

Output	25°C	0°C	40°C	Delta (40°C V/s 25°C)
5V/3A	87.75%	87.45%	87.71%	0.17%
9V/3A	89.86%	89.72%	89.79%	0.12%
15V/2.2A	90.91%	90.73%	90.87%	0.16%
20V/1.65A	90.71%	90.33%	90.78%	0.07%

115 Vac

Output	25°C	0°C	40°C	Delta (40°C V/s 25°C)
5V/3A	88.16%	88.39%	88.44%	-0.05%
9V/3A	91.10%	90.85%	91.01%	0.02%
15V/2.2A	91.68%	91.66%	91.80%	-0.08%
20V/1.65A	91.50%	91.38%	91.75%	-0.17%

230 Vac

Output	25°C	0°C	40°C	Delta (40°C V/s 25°C)
5V/3A	87.48%	87.45%	87.36%	-0.03%
9V/3A	91.06%	90.96%	90.95%	-0.17%
15V/2.2A	92.18%	92.03%	92.12%	0.02%
20V/1.65A	92.04%	91.79%	92.06%	0.02%

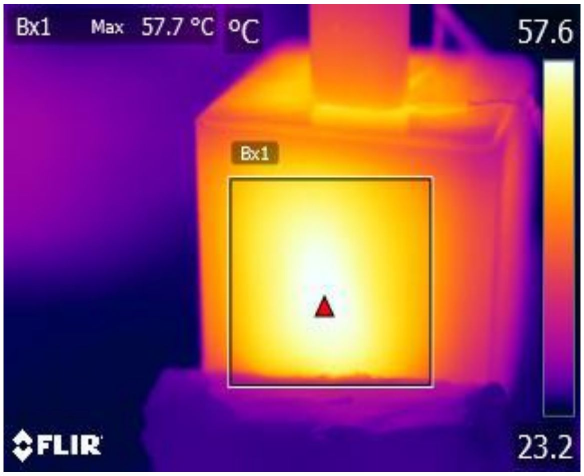
265 Vac

Output	25°C	0°C	40°C	Delta (40°C V/s 25°C)
5V/3A	86.58%	86.63%	86.57%	-0.03%
9V/3A	90.61%	90.49%	90.54%	0.12%
15V/2.2A	91.77%	91.67%	91.79%	-0.03%
20V/1.65A	91.63%	91.46%	91.67%	0.03%

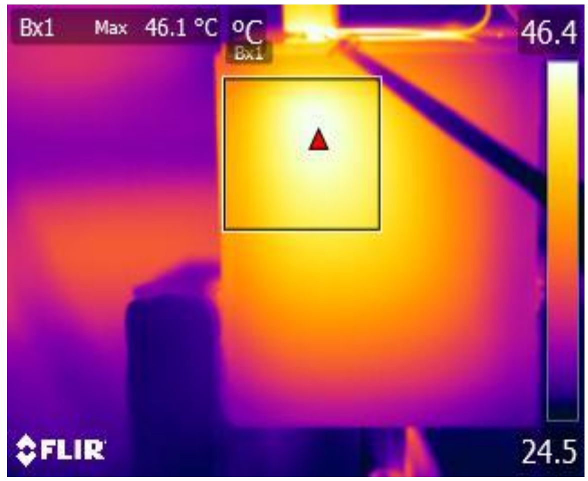
Thermal Measurements (Inside case with heatsink)

The following thermal data show the temperatures of key semiconductor components after 1hr operation at 90Vac/20V/33W. The RD23 unit was placed inside the case and thermal management was utilized. The outside ambient temperature was ~25 degrees Celsius.

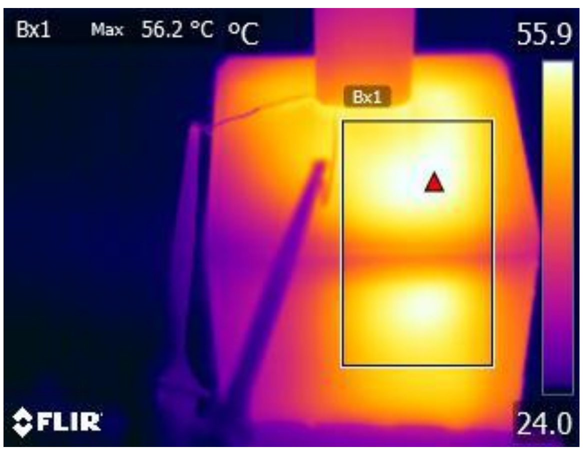
Measured Ambient Temperature inside the case	67°C
Max Temperature on the case	58°C



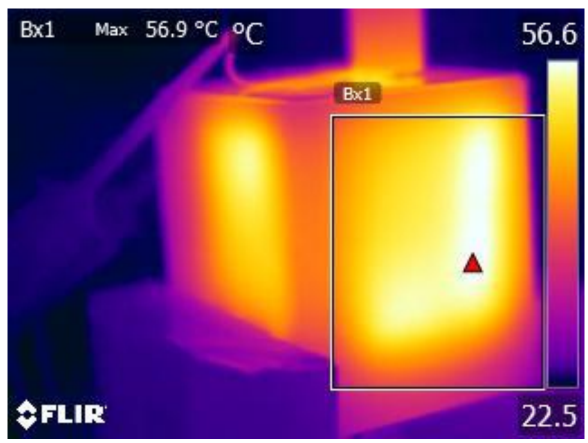
Hot Spot: Diode Bridge



Hot spot : Sync FET+ Output Cap



Hot Spot: Transformer



Hot Spot : SZ1131 + Main FET

Figure 23: Thermal images captured at 90 Vac/20V/1.65A condition.

Conducted EMI Measurements (with heatsink and w/o case)

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.

Conducted EMI Test Setup

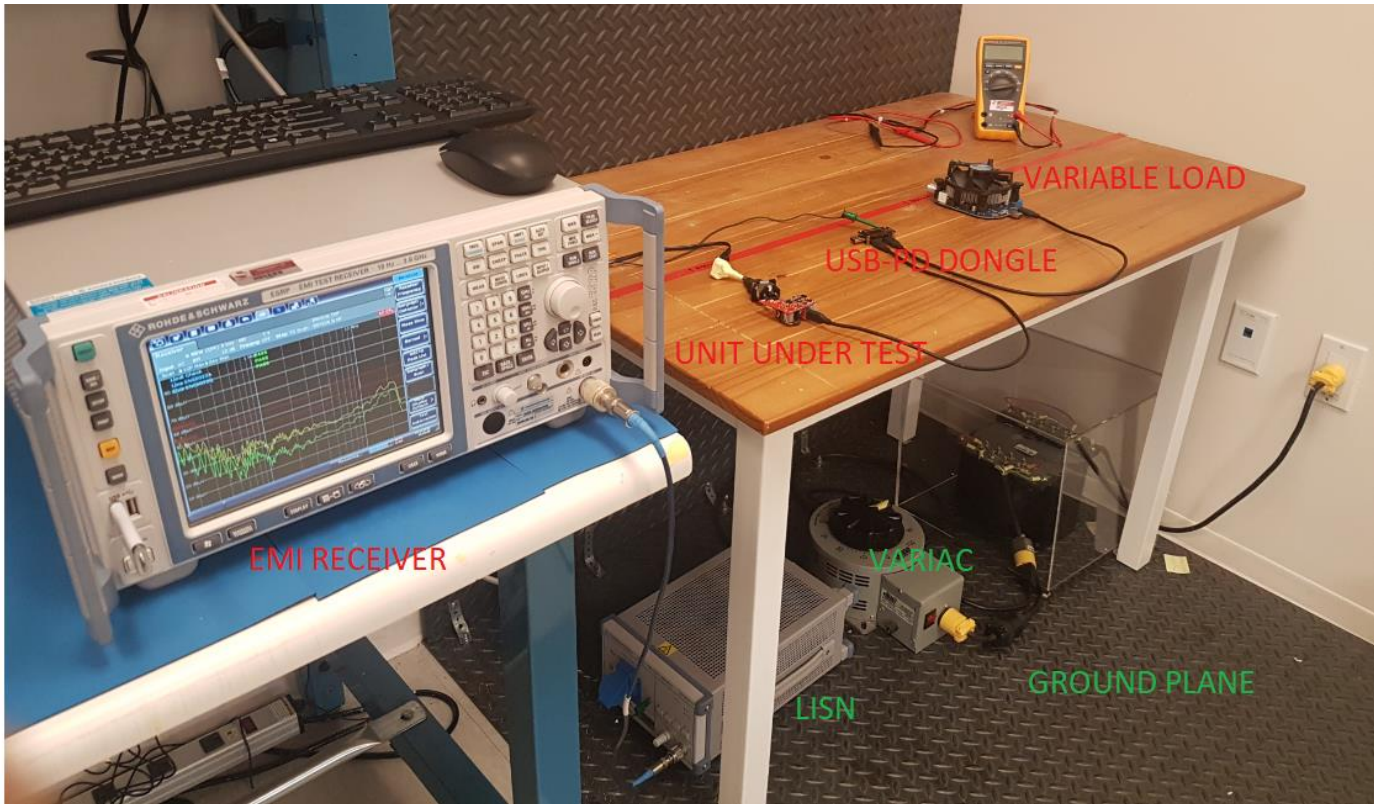
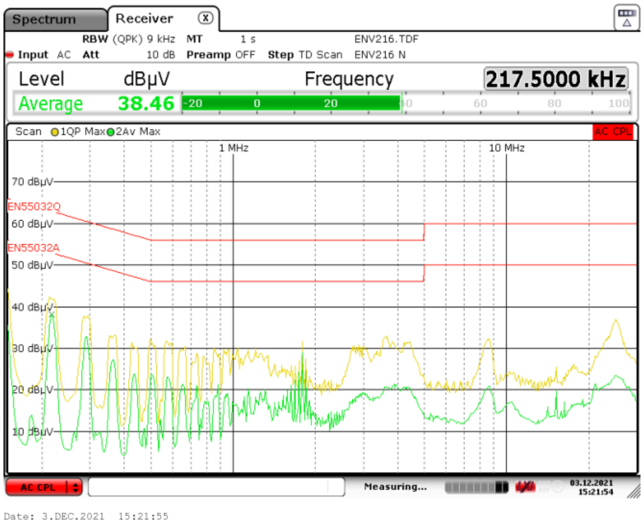
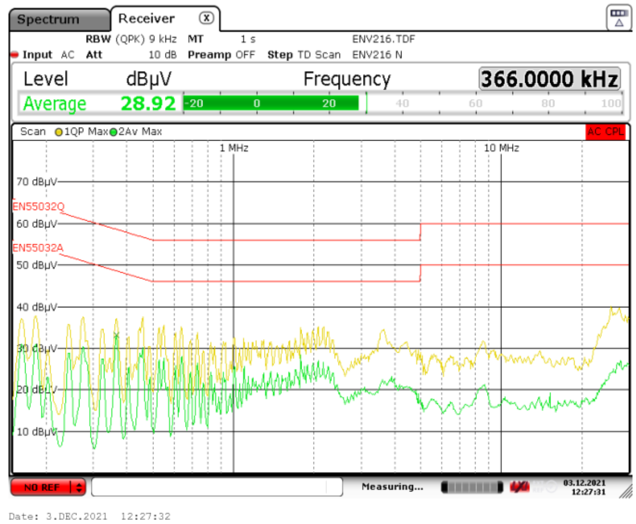


Figure 24: Conducted EMI Test Setup

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



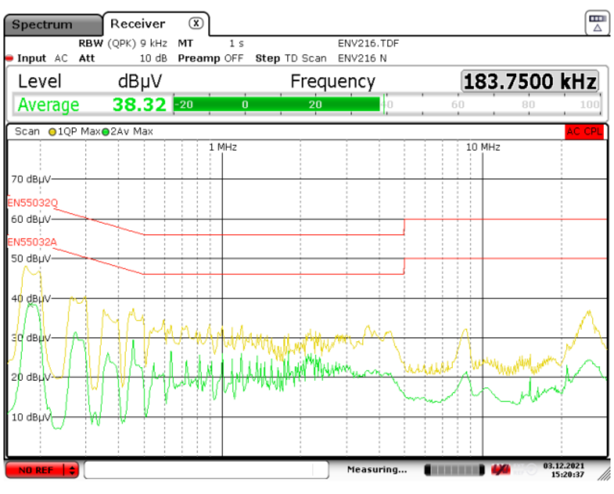
115 Vac (Line/ Neutral),>10 dB margin



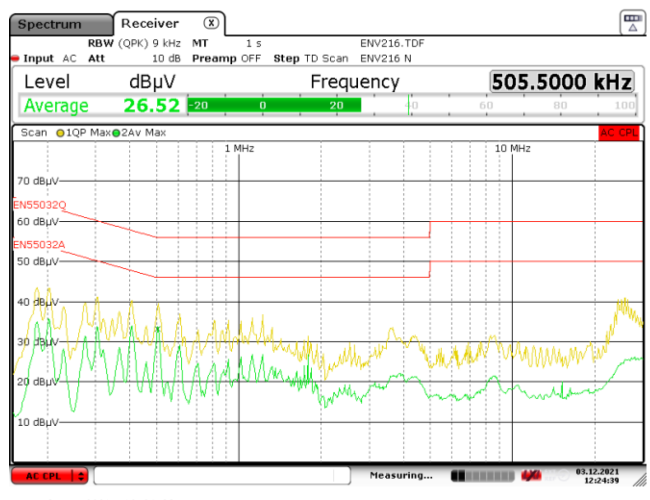
230 Vac (Line/ Neutral),>10 dB margin.

Figure 25: 5 V/ 3 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac input

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



115 Vac (Line/ Neutral), >10 dB margin

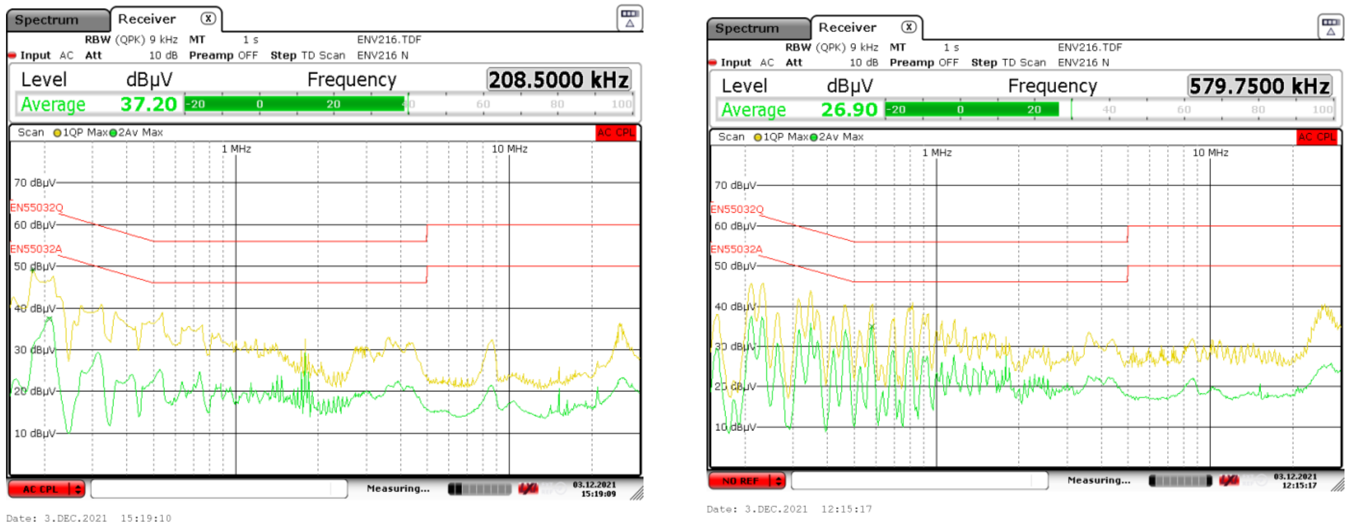


230 Vac (Line/ Neutral), 8.9 dB margin

Figure 26: 9 V/ 3 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

The RD23 EVKs pass the Conducted EMI at 5V,9V output with >10dB margin at 115Vac and 230Vac.

V_{out}/ I_{out}: 15 V/ 2.2 A

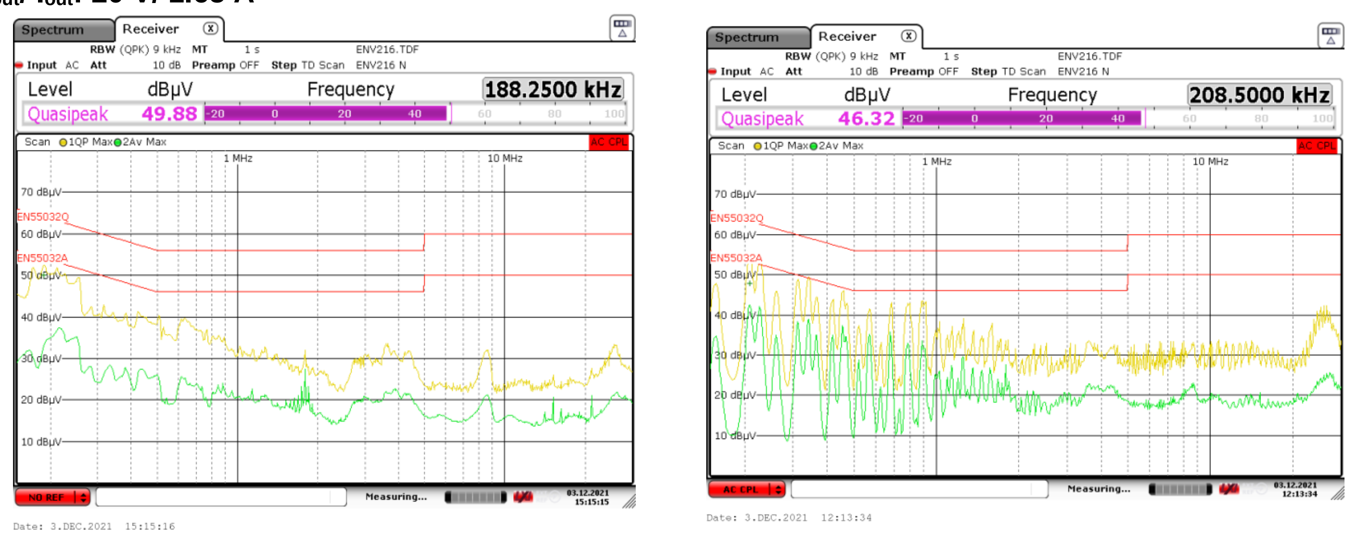


115 Vac (Line/ Neutral),>10 dB Margin

230 Vac (Line/ Neutral),8.55 dB Margin

Figure 27: 15 V/ 2.2 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

V_{out}/ I_{out}: 20 V/ 1.65 A



115 Vac (Line/ Neutral), 8 dB Margin

230 Vac (Line/ Neutral), 7.91 dB Margin

Figure 28: 20 V/ 1.65 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

The RD23 EVKs pass the Conducted EMI at 15V,20V output with > 10dB margin at 115Vac and 230Vac.

Radiated EMI Test Result (Inside case with heatsink)

	Input Voltage	
Orientation	**120Vac**	**230Vac**
Horizontal	12.5 dBuV (Peak)	9.0dBuV (QP)
Vertical	8.8dBuV (Peak)	7.9dBuV (QP)

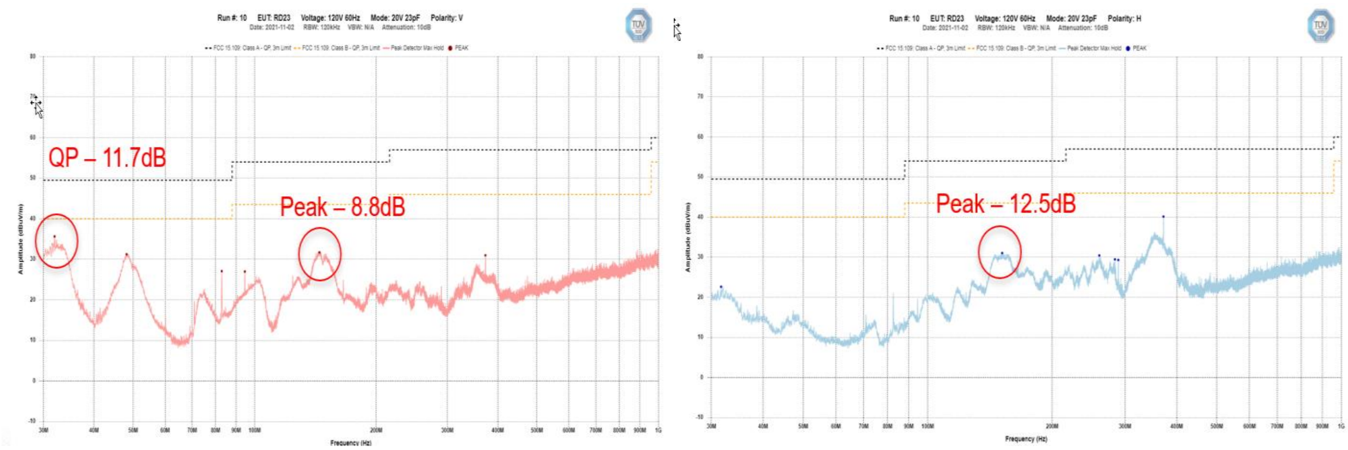


Figure 29: 20 V/ 1.65 A Radiated EMI measurement results for 120 Vac in Horizontal and Vertical orientation .

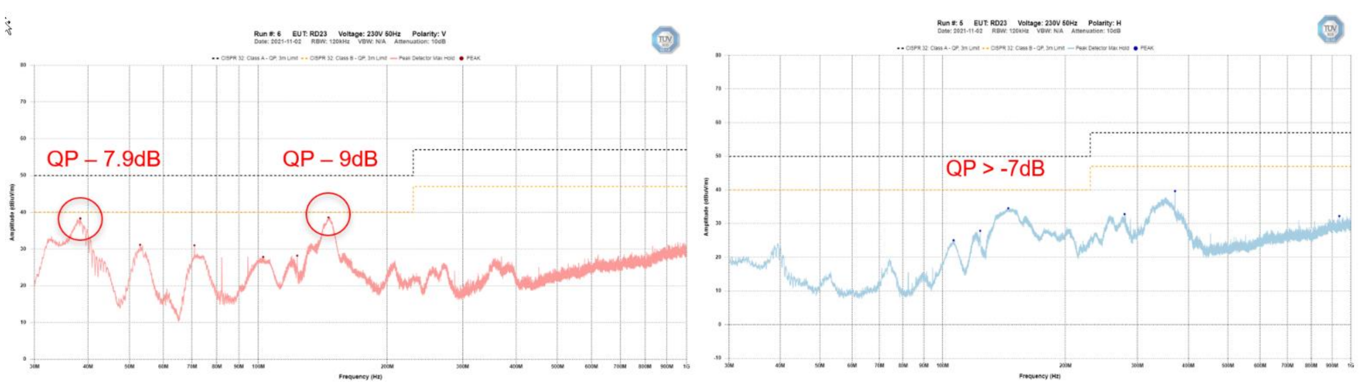


Figure 30:20 V/ 1.65 A Radiated EMI measurement results for 230 Vac in Horizontal and Vertical orientation.

Revision History

Revision	Date	Author	Note
1.0	7/19/2021	RS	Initial Release
2.0	12/1/2021	RS	Updated