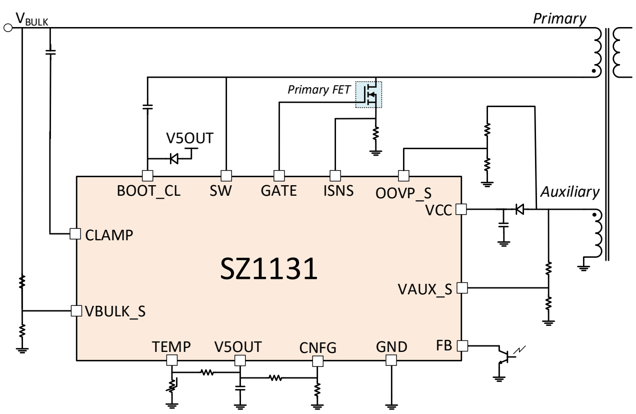
RD31 65W USB PD REPORT

RD-31 Description

This reference design describes an all-silicon 65 W universal input offline power supply with programmable output voltage (5 V/3 A, 9 V/3 A, 15 V/3 A, 20 V/3.25 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	3A @ 5V/9V/15V, 3.25A @ 20V
Max Output Power	65 W
Output Port	USB-PD
Efficiency	> 93.7% 65W Efficiency
CE and RE Margins	> 6 dB



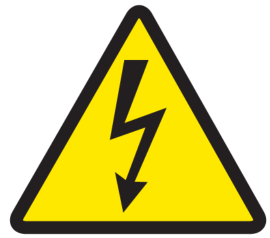
SZ1131 Features

- Integrated High Voltage Active Clamp FET, Active Clamp Driver, and Start-up Regulator
- Capable of Over 94.5% Efficiency
- Flat Efficiency Across Universal (90-265 VAC) Input Voltage and Load
- 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
- < 20mW No Load Power Consumption
- Up to 65 W Output Power for Universal 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.

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	
Output (measured at the end of a 1.6m 3A USB-C cable)						
Current	I_{out}			3.25	A	
Output Power Continuous	P_{out}			65	W	
DoE Level VI 4-Point Average Efficiency						
5 V	η_{ave_5V}		81.9%		%	DoE Level VI 4-point (25%, 50%, 75%, 100%) average efficiency
9 V	η_{ave_9V}		86.9%		%	
15 V	η_{ave_15V}		87.8%		%	
20 V	η_{ave_20V}		88.0%		%	
CoC V5 Tier-2 4-Point Average Efficiency						
5 V	η_{ave_5V}		82.4%		%	CoC version 5 tier 2 4-point (25%, 50%, 75%, 100%) average efficiency
9 V	η_{ave_9V}		87.6%		%	
15 V	η_{ave_15V}		89.0%		%	
20 V	η_{ave_20V}		89.2%		%	
CoC V5 Tier-2 10% Efficiency						
5 V	$\eta_{10\%\_5V}$		73.0%			CoC Version 5 Tier-2 10% load efficiency requirements.
9 V	$\eta_{10\%\_9V}$		77.6%			
15 V	$\eta_{10\%\_15V}$		79.0%			
20 V	$\eta_{10\%\_20V}$		79.2%			
No-Load Input Power	P_{in}			25	mW	@ 230 Vac, 25 °C ambient
Programmable Output Voltage	V_{OUT}	5		20	V	
Environmental Conducted EMI	Meets CISPR22B/EN55022 (>6dB 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

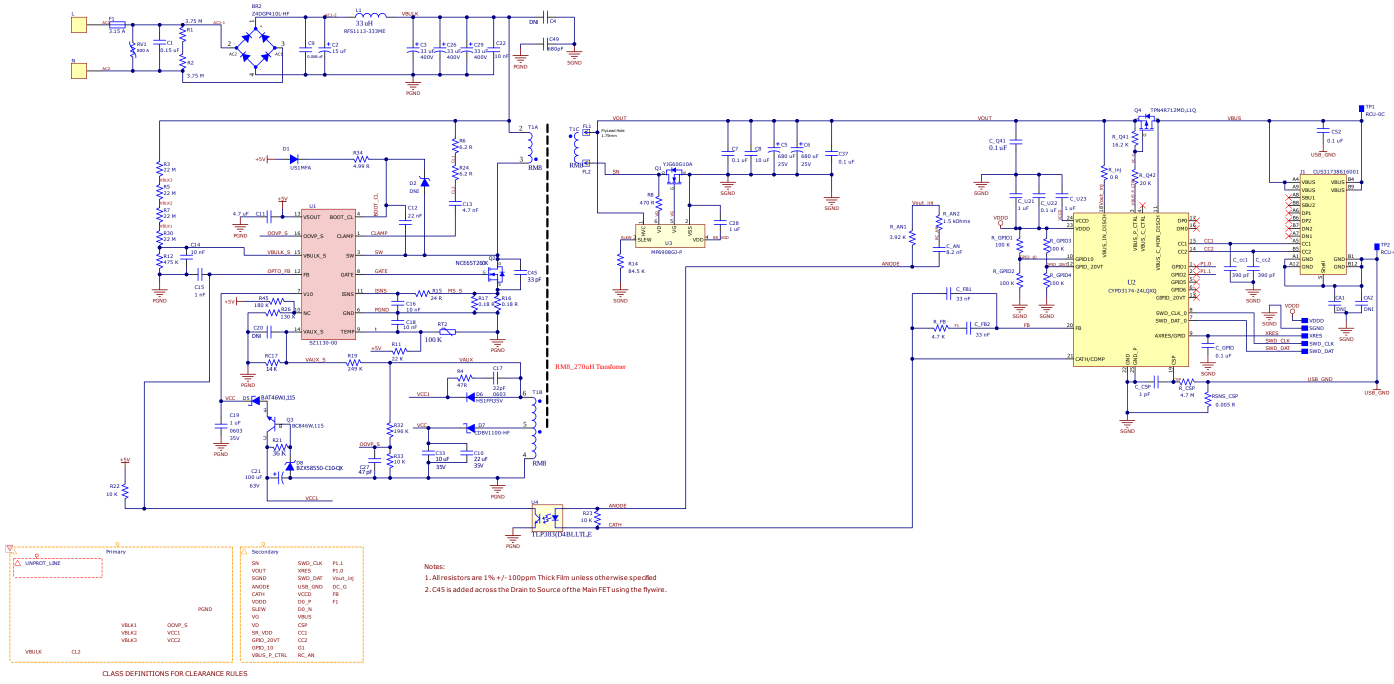


Figure 3: 65W Schematic

PCB Layout

PCB Prints

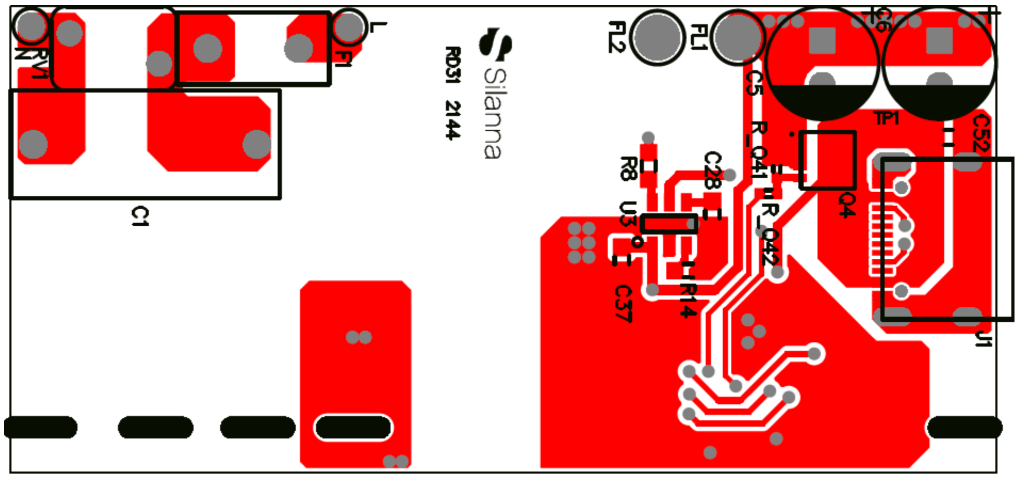


Figure 4: Component side horizontal board, top

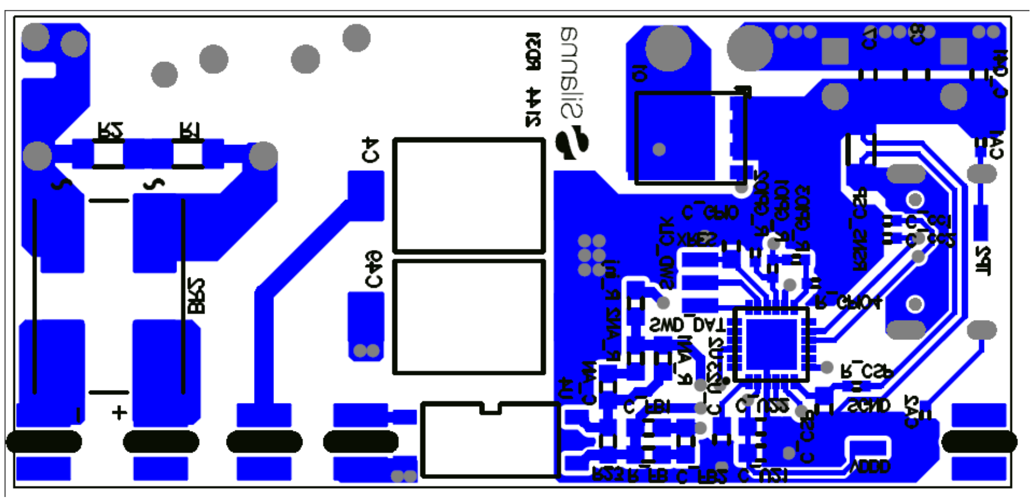


Figure 5: Solder side horizontal, bottom

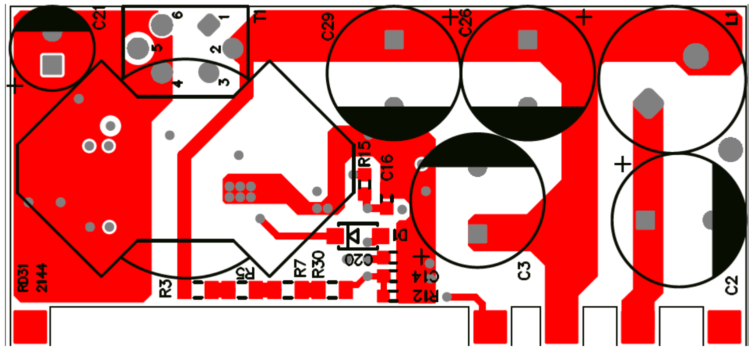


Figure 6: Component side vertical board, top

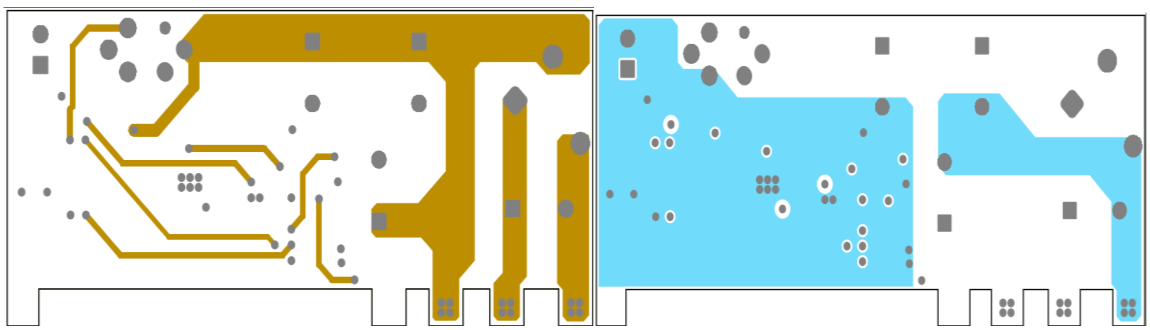


Figure 7: Solder side vertical board, middle 1 (left) and 2 (right)

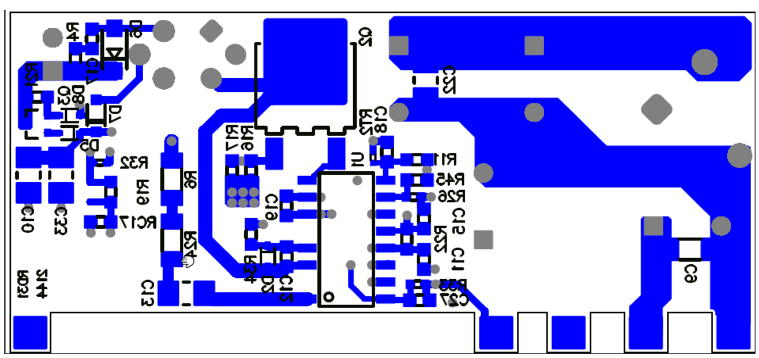


Figure 8: Solder side vertical board, bottom

Bill of Materials (BOM)

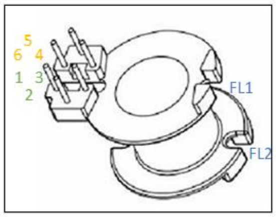
Table 2: Reference Design BOM

Description	Manufacturer	Manufacturer Part Number	Designator
Horizontal Board (USB Type-C Connector)			
BRIDGE RECT 1PHASE 1KV 4A Z4-D	Comchip Technology	Z4DGP410L-HF	BR2
CAP FILM 0.15UF 10% 310VAC RAD	Würth Elektronik	890334024001	C1
CAP CER DNI CT7-400VAC-Y1-B-681K			C4
CAP ALUM 680uF ±20% 25V Radial	Yunxing	SPT1EM681E16OR	C5, C6
CAP CER 0.1UF 50V X7R 0603	Samsung Electro-Mechanics	CL10B104KB8NNNC	C7, C37, C52, C_GPIO, C_Q41, C_U22
CAP CER 10UF 25V X6S 0805	Samsung Electro-Mechanics	CL21X106KAYNNNE	C8
CAP CER 1UF 25V X7R 0603	Samsung Electro-Mechanics	CL10B105KA8NNNC	C28
Plastic package type chip 400VAC-Y1 safety capacitor	Anshan Qifa Electronic Ceramic Technology Co., Ltd.	CT7-400VAC-Y1-B-681K	C49
CAP CER 8200PF 50V X7R 0603	KEMET	C0603C822K5RACTU	C_AN
CAP CER 390PF 50V C0G/NPO 0402	Yageo	CC0402JRNPO9BN391	C_cc1, C_cc2
CAP CER 0603 1PF 16V ULTRA STABL	KEMET	C0603C109D4HAC7867	C_CSP
Multilayer Ceramic Capacitors MLCC - SMD/SMT 25V 0.033uF X7R 0603 10%	KEMET	C0603C333K3RACTU	C_FB1, C_FB2
CAP CER 1UF 25V X7R 0603	TDK Corporation	CGA3E1X7R1E105M080AC	C_U21, C_U23
CAP CER DNI 0402			CA1, CA2
FUSE BRD MNT 3.15A 300VAC RADIAL	Littelfuse Inc.	36913150000	F1
FLYLEAD 1.75MM			FL1, FL2
CONN USB-C FEMALE 16P SMT	CSCONN	CUS31738616001	J1
N-CH MOSFET 100V 60A PDFN5060-8L	Yangzhou Yangjie Electronic Technology Co.,Ltd	YJG60G10A	Q1
P-Channel 20 V 36A (Tc) 42W (Tc) Surface Mount 8-TSON Advance (3.3x3.3)	Toshiba Semiconductor and Storage	TPN4R712MD,L1Q	Q4
RES SMD 3.75M OHM 1% 1/4W 1206	Meritek	CR083754F	R1, R2
RES SMD 470 OHM 1% 1/10W 0603	Yageo	RC0603FR-07470RL	R8
RES SMD 84.5K OHM 1% 1/10W 0603	Yageo	RC0603FR-0784K5L	R14
RES SMD 10K OHM 1% 1/10W 0603	Yageo	RC0603FR-0710KL	R23
RES SMD 3.92K OHM 1% 1/10W 0603	Yageo	RC0603FR-073K92L	R_AN1
1.5 kOhms ±1% 0.1W, 1/10W Chip Resistor 0603 (1608 Metric) Moisture Resistant Thick Film	Yageo	RC0603FR-071K5L	R_AN2
RES SMD 4.7M OHM 1% 1/16W 0402	YAGEO	RC0402FR-074M7L	R_CSP
RES SMD 4.7K OHM 1% 1/10W 0603	Yageo	RC0603FR-074K7L	R_FB
RES SMD 100K OHM 1% 1/16W 0402	Yageo	RC0402FR-07100KL	R_GPIO1, R_GPIO2, R_GPIO3, R_GPIO4
RES SMD 0 OHM JUMPER 1/10W 0603	Yageo	RC0603JR-070RL	R_inj
RES SMD 16.2K OHM 1% 1/16W 0402	Yageo	RC0402FR-0716K2L	R_Q41
RES SMD 20K OHM 1% 1/16W 0402	Yageo	RC0402FR-0720KL	R_Q42
RES 0.005 OHM 1% 1W 1206	Bourns Inc.	CFN1206-FX-R005ELF	RSNS_CSP
VARISTOR 470V 800A DISC 5MM	EPCOS - TDK Electronics	B72205S2301K101	RV1
PC TEST POINT NATURAL	TE Connectivity AMP Connectors	RCU-0C	SGND, SWD_CLK, SWD_DAT, TP1,

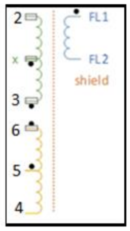
Description	Manufacturer	Manufacturer Part Number	Designator
			TP2, VDDD, XRES
IC USB TYPE-C CONTROLLER 24QFN	Cypress Semiconductor Corp	CYPD3174-24LQXQ	U2
FAST TURN-OFF INTELLIGENT RECTIF	Monolithic Power Systems Inc.	MP6908GJ-P	U3
OPTOISO 5KV TRANSISTOR SO6L	Toshiba Semiconductor and Storage	TLP383(D4BLLTL,E	U4
Horizontal Board			
5mm 12mm 400V ±20% 2000hrs 105degC 10mm 15uF Radial Leaded,10x12mm Aluminum Electrolytic Capacitors - Leaded ROHS	AISHI(Aihua Group)	EWH2GM150G12OT	C2
CAP ALUM 33UF 20% 400V T/H	YMIN	KCX(33UF-10X18P5)	C3, C26, C29
CAP CER 0.068UF 500V X7R 1206	KEMET	C1206C683KCRACTU	C9
CAP CER 22UF 35V X5R 1206	TDK Corporation	C3216X5R1V226M160AC	C10
CAP CER 4.7UF 25V X6S 0603	Murata Electronics	GRM188C81E475KE11D	C11
CAP CER 0.022UF 50V X7R 0603	Yageo	CC0603KRX7R9BB223	C12
CAP CER 4700PF 630V X7R 1206	TDK Corporation	C3216X7R2J472K115AA	C13
CAP CER 10000PF 25V X7R 0603	Samsung Electro-Mechanics	CL10B103KA8NNNC	C14, C16, C18
CAP CER 1000PF 16V X7R 0603	Yageo	CC0603KRX7R7BB102	C15
CAP CER 1UF 35V X7R 0603	Taiyo Yuden	GMK107AB7105KAHT	C17, C19
CAP CER DNI 0603			C20
CAP ALUM 100uF ±20% 63V Radial	Ymin	LKMC2001J101MF	C21
CAP CER 10000PF 630V X7R 1206	KEMET	C1206C103KBRACTU	C22
CAP CER 47PF 50V C0G/NP0 0603	Murata Electronics Murata Electronics	GRM1885C1H470JA01D	C27
CAP CER 10UF 35V X7R 1206	Taiyo Yuden	GMJ316BB7106MLHT	C33
CAP CER 33PF 630V C0G/NP0 1206	Murata Electronics	GRM31A5C2J330JW01D	C45
DIODE GEN PURP 1KV 1A SOD123FA	ON Semiconductor	US1MFA	D1
DNI DIODE SOD523			D2
DIODE SCHOTTKY 100V 250MA SOD323	Nexperia USA Inc.	BAT46WJ,115	D5
50NS 1A 300V HIGH EFFICIENT RECO	Taiwan Semiconductor Corporation	HS1FFL	D6
DIODE SCHOTTKY 100V 1A SOD323	Comchip Technology	CDBV1100-HF	D7
Zener Diode 10 V 300 mW ±5% Surface Mount SOD-523	Nexperia USA Inc.	BZX58550-C10-QX	D8
Fixed Inductors 33uH Shld 20% 3.2A 52mOhm	Coilcraft	RFS1113-333ME	L1
MOSFET N-CH 650V 0.22OHM 15A TO-252	NCE Power	NCE65T260K	Q2
TRANS NPN 65V 100MA SOT323	Nexperia USA Inc.	BC846W,115	Q3
RES 22M OHM 1% 1/8W 0805	Stackpole Electronics Inc	RMCF0805FT22M0	R3, R5, R7, R30
RES SMD 200K OHM 1% 1/10W 0603	Yageo	RC0603FR-07200KL	R4
6.2 Ohms ±1% 0.75W, 3/4W Chip Resistor 1206 (3216 Metric) Automotive AEC-Q200, Pulse Withstanding Thick Film	Vishay Dale	CRCW12066R20FKEAHP	R6, R24
RES SMD 22K OHM 1% 1/10W 0603	Yageo	RC0603FR-0722KL	R11
RES SMD 475K OHM 1% 1/10W 0603	Yageo	RC0603FR-07475KL	R12
RES SMD 24 OHM 1% 1/4W 0603	Vishay Dale	RCS060324R0FKEA	R15
RES 0.18 OHM 1% 1/4W 0603	Panasonic Electronic Components	ERJ-3BSFR18V	R16, R17
RES SMD 249K OHM 1% 1/10W 0603	Panasonic Electronic Components	ERJ-3EKF2493V	R19
RES 36K OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT36K0	R21
RES SMD 10K OHM 1% 1/10W 0603	Yageo	RC0603FR-0710KL	R22
RES SMD 130K OHM 1% 1/16W 0402	Yageo	RC0402FR-07130KL	R26
RES SMD 196K OHM 1% 1/16W 0402	YAGEO	RC0402FR-07196KL	R32
RES 10K OHM 0.5% 1/16W 0402	Stackpole Electronics Inc	RNCF0402DTE10K0	R33
RES 4.99 OHM 1% 1/10W 0603	Stackpole Electronics Inc	RMCF0603FT4R99	R34

Description	Manufacturer	Manufacturer Part Number	Designator
RES SMD 180K OHM 1% 1/10W 0603	Yageo	RC0603FR-07180KL	R45
RES SMD 14K OHM 0.1% 1/10W 0603	Yageo	RT0603BRD0714KL	RC17
THERM NTC 100KOHM 4485K 0402	Murata Electronics	NCP15WL104E03RC	RT2
TRANSFORMER RM 8	TBD	YT-0803	T1
Flyback PWM Controller with Integrated Active Clamp Circuit (Hiccup Mode Fault Protection)	Silanna Semiconductor	SZ1131-00	U1

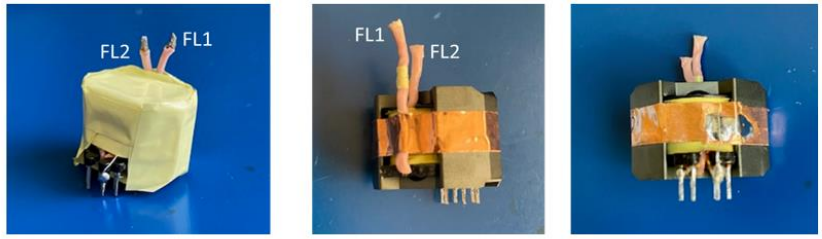
Transformer Specification



Pinout



Electrical



Actual Picture

Winding Specification

Winding	1	2	3	4	5	6	7	8
Material*	AWG31	AWG34	AWG34	AWG34	400/44 Litz	AWG34	AWG31	
Turns	18	8	3	5.5	5	5.5	18	
Parallel wires	2	1	1	8	1	8	2	
Layers	1	1	1	1	1	1	1	
Start Pin	3	6	5	4	FL1	4	x	
End Pin	x	5	4	nc (notch of FL2)	FL2	nc (notch of FL2)	2	
Comment	PRI1 - First half of primary. High Vol winding. Needs slivers on terminal	Aux windings. 1> Winding 2 & 3 should be on the same layer. 2> sliver on starting terminal.		1. Shield 1 - CM shield (low voltage winding, no slivers needed.) 2. Wires end at the notch where FL2 exits. 3. The winding should be flat and evenly aross the bobbin	SEC - Secondary winding	1. Shield 2 - CM shield (low voltage winding, no slivers needed.) 2. Wires end at the notch where FL2 exits. 3. The winding should be flat and evenly aross the bobbin	PRI2 - Second half of primary. High Vol winding. Needs slivers on terminal.	
Insulation Tap	Tape A (1 Layer)		Tape A (1 Layer)	**Tape A (2 Layers)**	Tape A (2 Layer)	Tape A (1 layer)		

ELECTRICAL TEST PARAMETERS:

INDUCTANCE @ 100kHz/0.1VAC
L(2-3) = 270uH ±5%

INDUCTANCE @ 100kHz/0.1VAC
SHORT PINTS: FL1, FL2
LL(2-3) =< 4.6uH MAX
LL(2-3) >= 3.6uH Min

TURNS RATIO/POLARITY
APPLY: 1.00V @ 10kHz TO PINS (5-6)

DC RESISTANCE OHMS (Ω) @ 25°C

Table 3: Transformer Material Lists

Material	*Specification*	*Manufacturer*	*Mfr. Part Number*
Bobbin	RM8 6pin	DONGUAN YANGTONG ELECTRONICS Co.	
Core	Air gap for 270uH	Hitachi ML29D	RM8 /I-ML29D
AWG31	Magnet wire, dual insulation layer	Various	
AWG34	Magnet wire, dual insulation layer	Various	
TIW	400 strand AWG44 Litz wire	Rubadue or equivalent	TXXL400/44T9XX-1.5(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	CoC version 5 tier 2 4 - Point Average Efficiency Requirements	Margin (Worst Case)
5 V/3 A	90.23%	81.9%	82.4%	7.8%
9 V/3 A	91.7%	86.9%	87.6%	4.1%
15 V/3 A	92.31%	87.8%	89.0%	3.3%
20 V/3.25 A	92.92%	88.0%	89.2%	3.7%

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	86.97%	81.9%	82.4%	4.6%
9 V/3 A	89.58%	86.9%	87.6%	2.0%
15 V/3 A	91.12%	87.8%	89.0%	2.1%
20 V/3.25 A	92.45%	88.0%	89.2%	3.2%

The listed efficiency values are the average of the data collected from three RD31 boards.

115 Vac 4-point average efficiency

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

%LOAD	Efficiency(%)	Average Efficiency
100	90.97	90.23%
75	90.66	
50	90.22	
25	89.05	
10	87.09	

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

%LOAD	Efficiency(%)	Average Efficiency
100	92.72	91.70%
75	92.52	
50	91.79	
25	89.78	
10	87.60	

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

%LOAD	Efficiency(%)	Average Efficiency
100	93.35	92.31%
75	93.29	
50	92.54	
25	90.07	
10	86.49	

V_{OUT} / I_{LOAD_MAX} = 20 V / 3.25 A

%LOAD	Efficiency(%)	Average Efficiency
100	93.37	92.92%
75	93.39	
50	93.22	
25	91.71	
10	88.32	

The listed efficiency values are the average of the data collected from three RD31 boards. 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	88.06	86.97%
75	87.91	
50	86.54	
25	85.37	
10	82.48	

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

%LOAD	Efficiency(%)	Average Efficiency
100	91.54	89.58%
75	90.42	
50	89.21	
25	87.13	
10	84.48	

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

%LOAD	Efficiency(%)	Average Efficiency
100	93.17	91.12%
75	92.62	
50	90.81	
25	87.86	
10	84.62	

V_{OUT} / I_{LOAD_MAX} = 20 V / 3.25 A

%LOAD	Efficiency	Average Efficiency
100	93.79	92.45%
75	93.47	
50	92.67	
25	89.89	
10	86.49	

The listed efficiency values are the average of the data collected from three RD31 boards. 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
90Vac @ 60Hz	3 A	90.77%
115 Vac @ 60 Hz	3 A	90.97%
230 Vac @ 50 Hz	3 A	88.06%
265 Vac @ 50Hz	3 A	87.53%

Vout = 9 V

Vin	Iout	Efficiency
90Vac @ 60Hz	3 A	92.33%
115 Vac @ 60 Hz	3 A	92.72%
230 Vac @ 50 Hz	3.A	91.54%
265 Vac @ 50Hz	3 A	90.84%

Vout = 15 V

Vin	Iout	Efficiency
90Vac @ 60Hz	3 A	92.81%
115 Vac @ 60 Hz	3 A	93.10%
230 Vac @ 50 Hz	3.A	93.17%
265 Vac @ 50Hz	3 A	92.78%

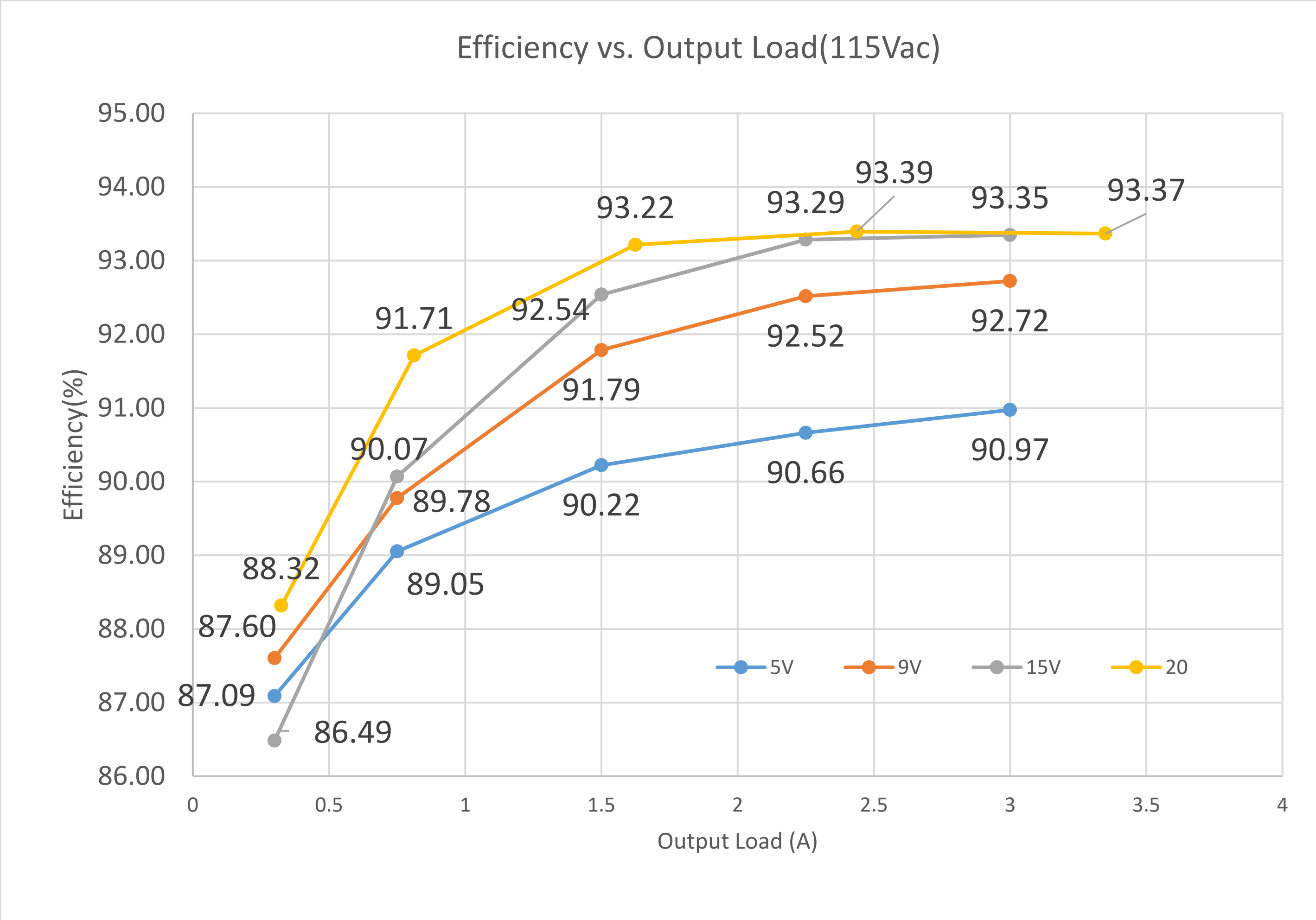
Vout = 20 V

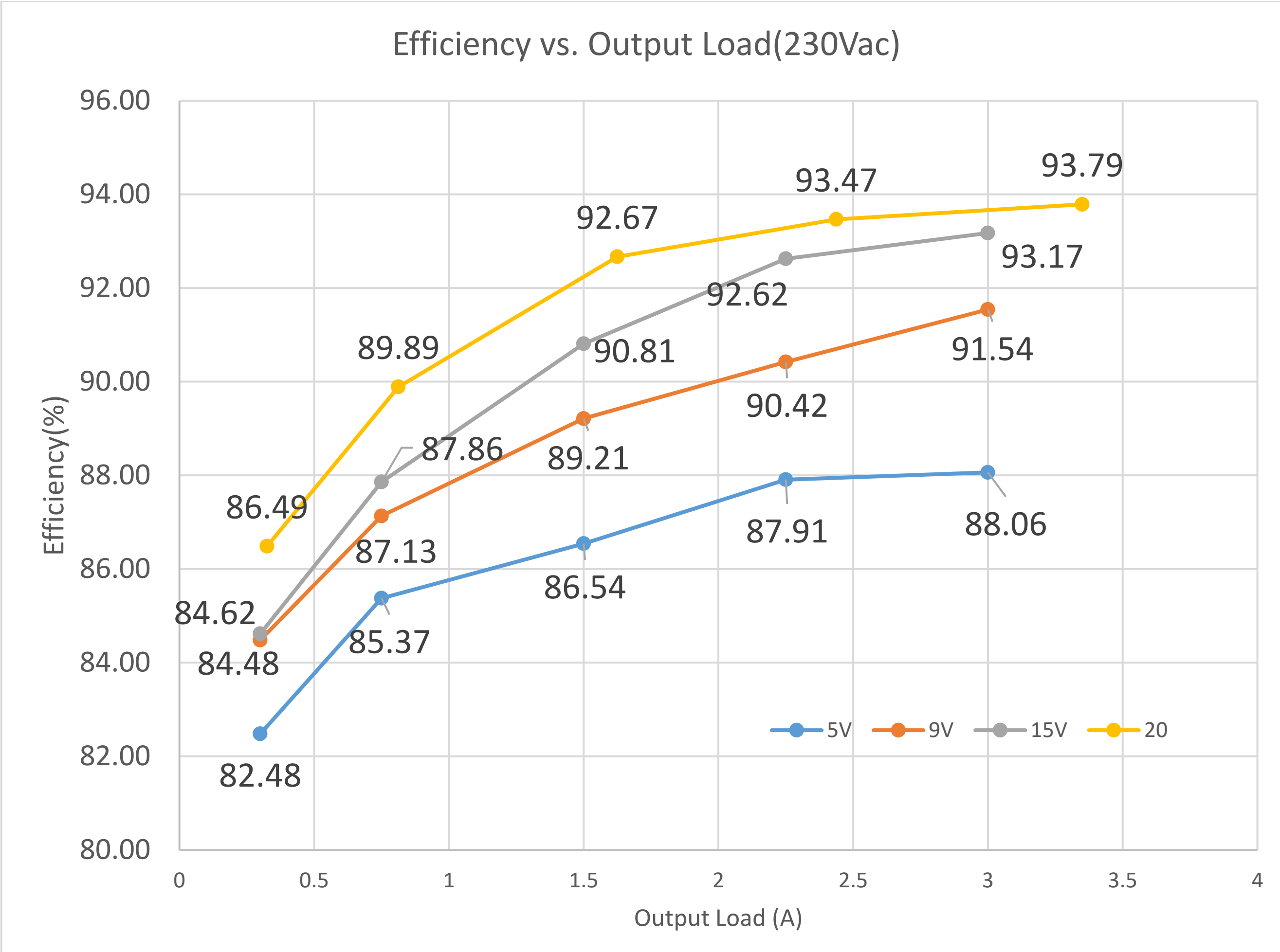
Vin	Iout	Efficiency
90Vac @ 60Hz	3.25 A	92.35%
115 Vac @ 60 Hz	3.25 A	93.37%
230 Vac @ 50 Hz	3.25 A	93.79%
265 Vac @ 50Hz	3.25 A	93.44%

The listed efficiency value is the average of the data collected from three RD31 boards. 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).




Efficiency vs. Output Load(230Vac)
Efficiency(%)
Output Load (A)
96.00
94.00
92.00
90.00
88.00
86.00
84.00
82.00
80.00
0
0.5
1
1.5
2
2.5
3
3.5
4
93.79
93.47
92.67
93.17
92.62
89.89
90.81
91.54
90.42
87.86
89.21
86.49
87.13
87.91
88.06
86.54
84.62
84.48
85.37
82.48
5V
9V
15V
20

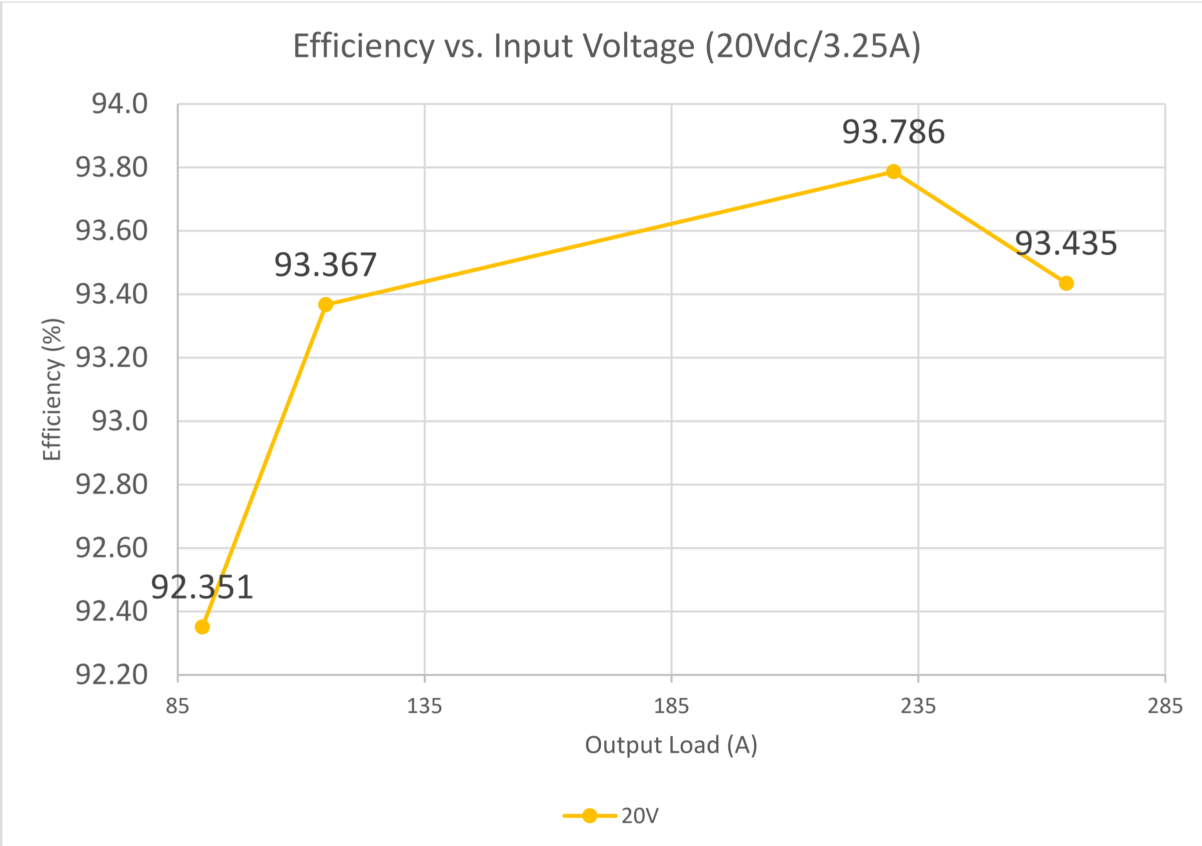


Figure 9: Efficiency graphs for various input voltages and 65W

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 Power Consumption

Input Voltage	No-Load Power Measurements
90Vac	10.57mW
115Vac	11.36mW
230Vac	20.26mW
265Vac	27.48mW

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. The data listed 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	4.98 V	5.1 V
9 V	0 A	3 A	8.93 V	8.99 V
15 V	0 A	3 A	14.94 V	15.01 V
20 V	0 A	3.25 A	19.89 V	20.05 V

The following table shows load/line regulation (at the end of 1.6 meter 3A USB-C Cable) for 5 V-20 V output voltages for variation of the line input voltage. No cable compensation is set for USB Type-C Cable.

Table 7: Line/Load Regulation Summary (End of 1.6m Meter 3A Cable)

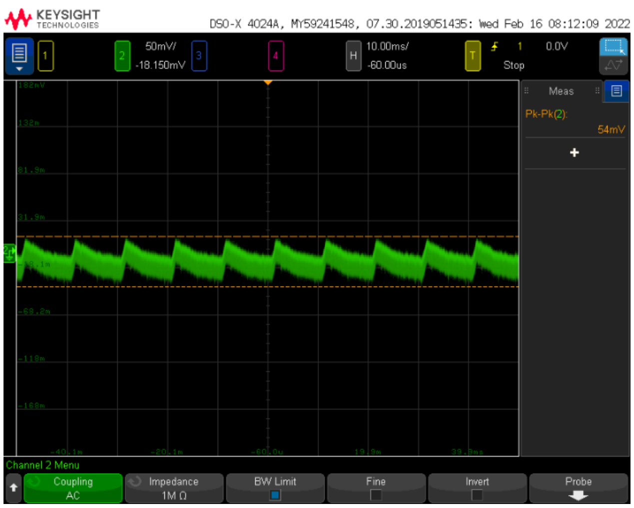
Output Voltage	Line / Load Range		Measured Regulation	
	Min	Max	Min	Max
5 V	0 A	3 A	4.48 V	4.99 V
9 V	0 A	3 A	8.49 V	8.97 V
15 V	0 A	3 A	14.31 V	14.85 V
20 V	0 A	3.25 A	19.33 V	19.87 V

Output Voltage Ripple Noise

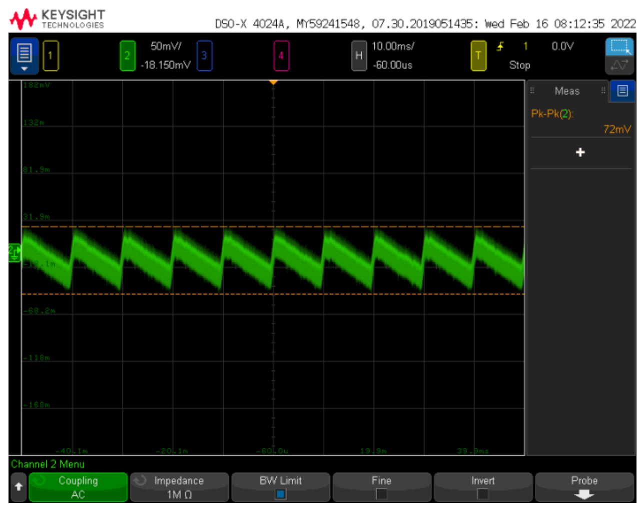
The output voltage ripple was measured using a voltage probe with two capacitors (1 µF/50 V ceramic and 10 µF/50 V low ESR electrolytic) tied in parallel across it. Measurment done at the end of 1.6m cable.

Table 8: 90Vac Output Ripple Noise Summary

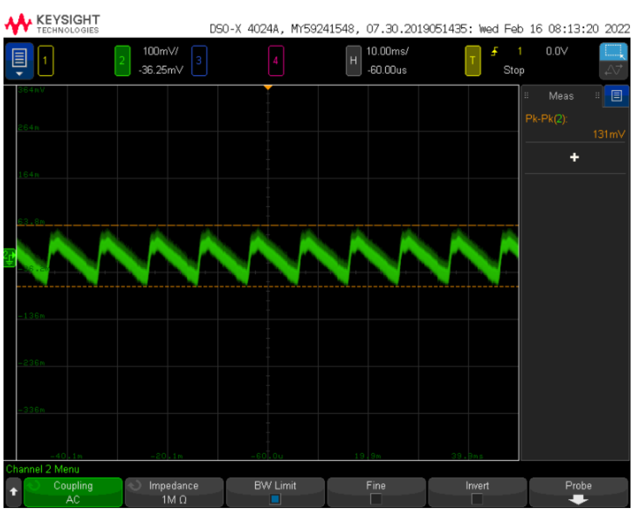
Vout/Iout	Measured Output Ripple at 3A load	Measured Output Ripple at 0A load
5 V/3 A	54 mV	24 mV
9 V/3 A	72 mV	27 mV
15 V/3 A	131 mV	31 mV
20 V/3.25 A	241 mV	28 mV



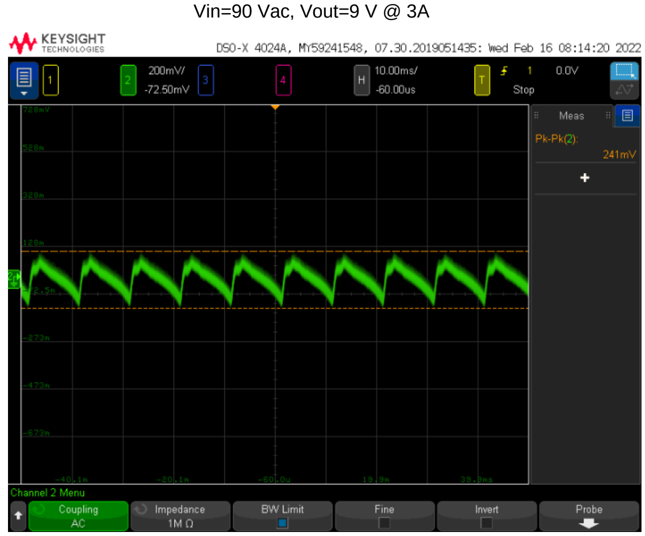
Vin=90 Vac, Vout=5 V @ 3A



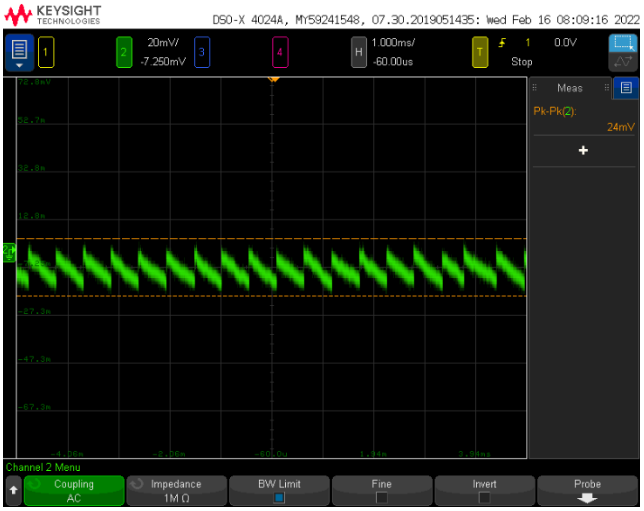
Vin=90 Vac, Vout=9 V @ 3A



Vin=90 Vac, Vout=15 V @ 3A

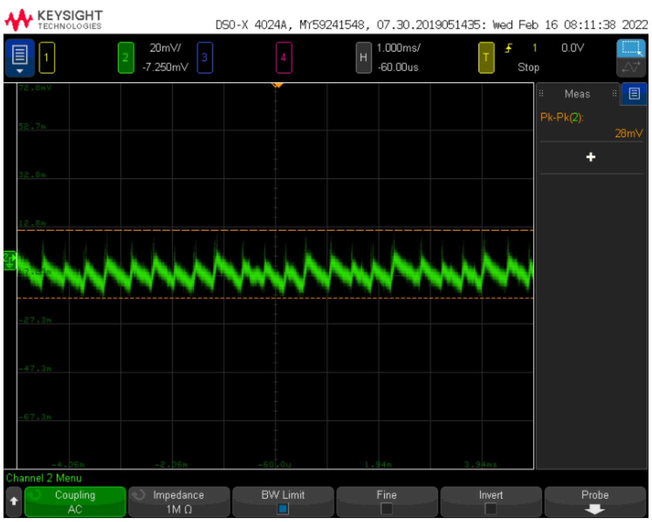


Vin= 90 Vac, Vout=20 V 3.25A

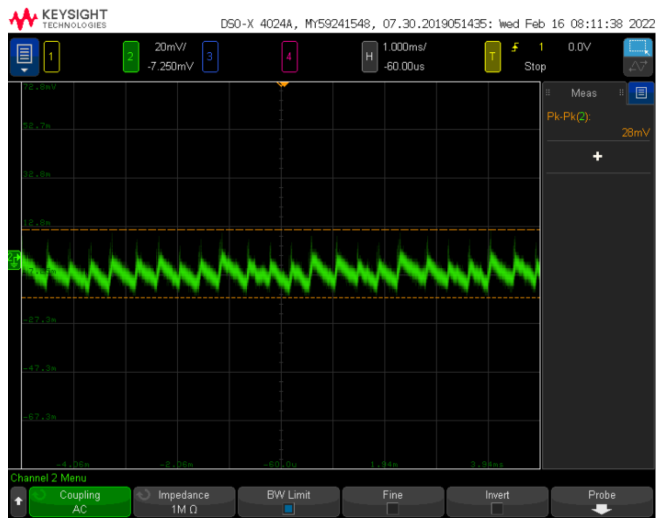


Vin=90 Vac, Vout=5 V @ 0A

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



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

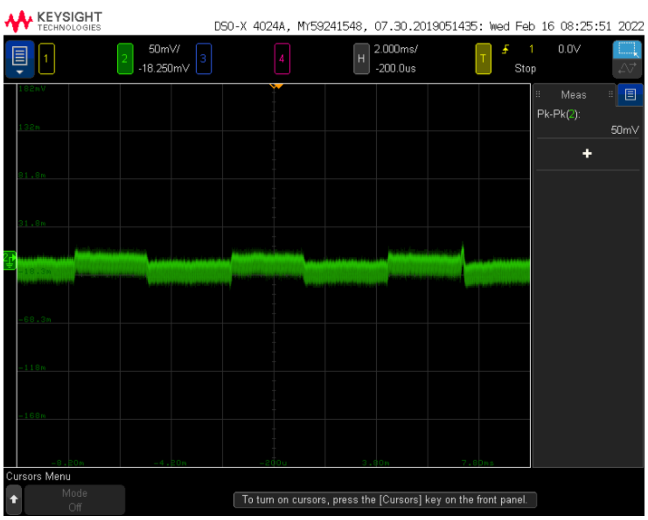


Vin=90 Vac, Vout=20V @ 0A

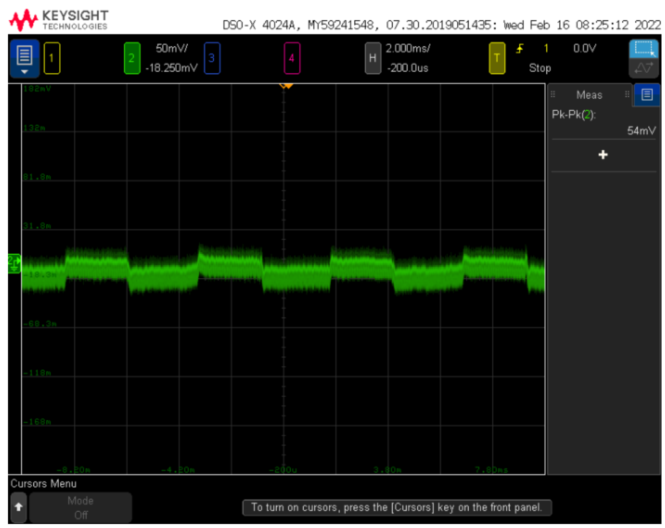
Figure 10: Output voltage ripple measurements at 90Vac input voltage and 5 V/9 V/15 V/20 V full-power and No-load (end of 1.6m cable)

Table 9: 265Vac Output Ripple Noise Summary

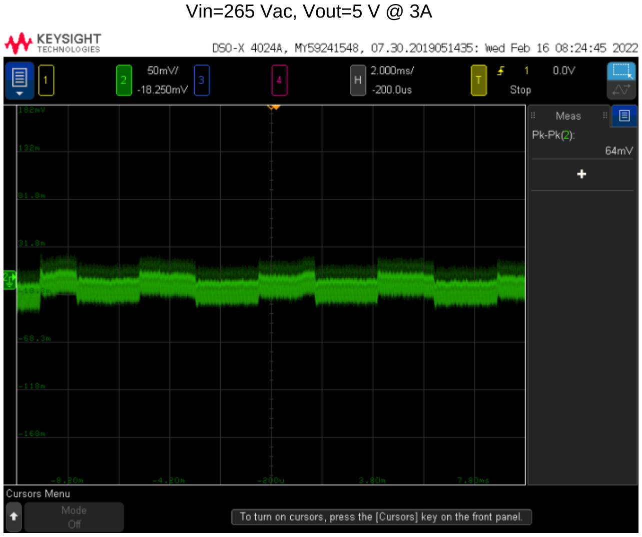
Vout/Iout	Measured Output Ripple at 3A load	Measured Output Ripple at 0A load
5 V/3 A	50 mV	31 mV
9 V/3 A	54 mV	27 mV
15 V/3 A	64 mV	32 mV
20 V/3.25 A	82 mV	36 mV



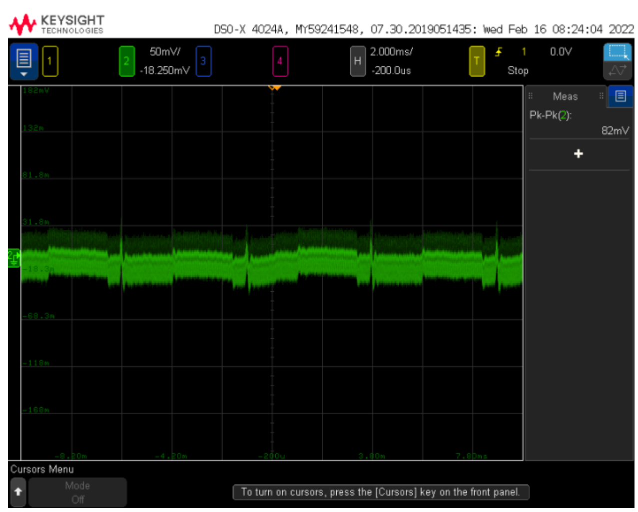
Vin=265 Vac, Vout=5 V @ 3A



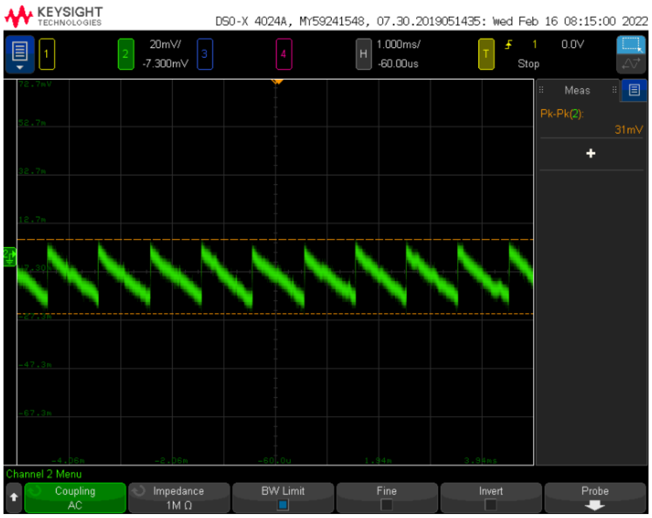
Vin=265 Vac, Vout=9 V @ 3A



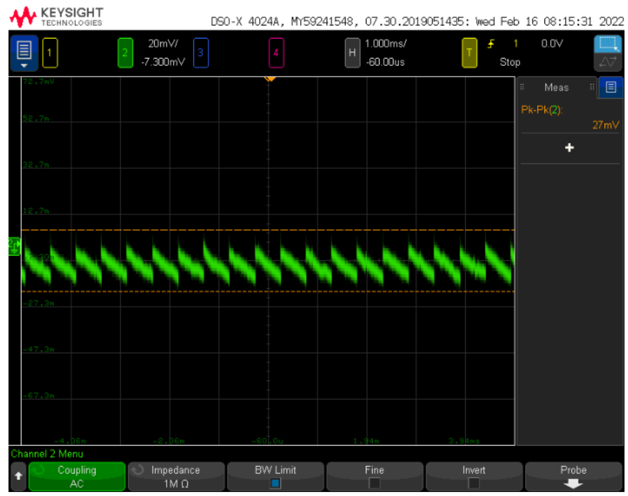
Vin=265 Vac, Vout=15 V @ 3A



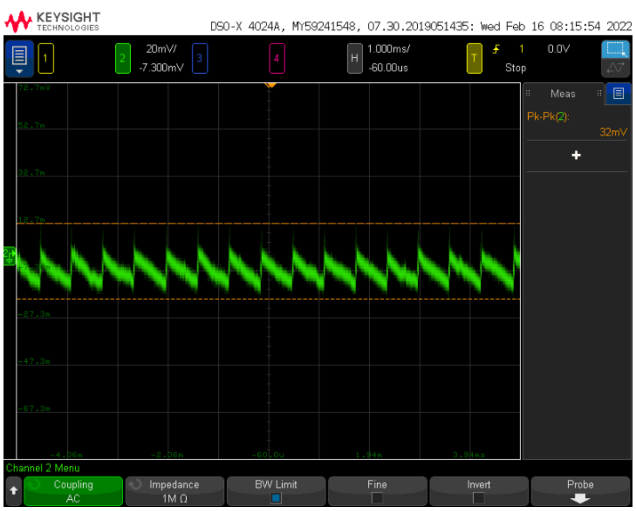
Vin= 265 Vac, Vout=20 V 3.25A



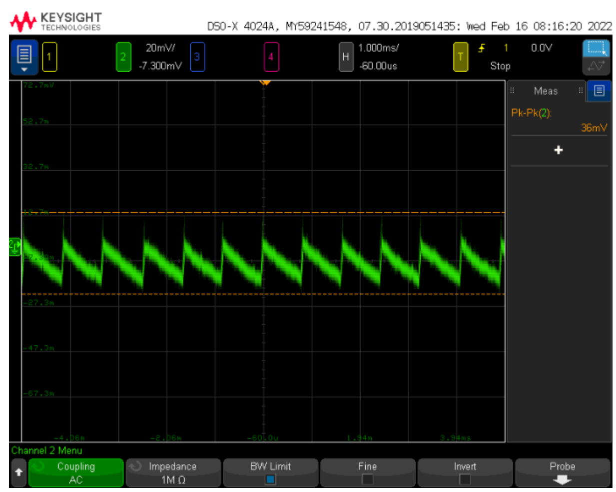
Vin=265 Vac, Vout=5 V @ 0A



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



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



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

Figure 11: Output voltage ripple measurements at 265Vac input voltage and 5 V/9 V/15 V/20 V full-power and no-load (end of 1.6m 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 TP1 to TP2)

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	4.84 V	5.19 V	4.79 V	5.21 V
	0.0 A	3.0 A	4.7 V	5.29 V	4.65 V	5.26 V
9 V	0.0 A	1.5 A	8.8 V	9.17 V	8.77 V	9.21 V
	0.0 A	3.0 A	8.69 V	9.27 V	8.72 V	9.24 V
15 V	0.0 A	1.5 A	14.8 V	15.31 V	14.85 V	15.29 V
	0.0 A	3 A	14.74 V	15.42 V	14.79 V	15.36 V
20 V	0.0 A	1.625 A	19.87 V	20.32 V	19.87 V	20.31 V
	0.0 A	3.25 A	19.7 V	20.51 V	19.77 V	20.44 V

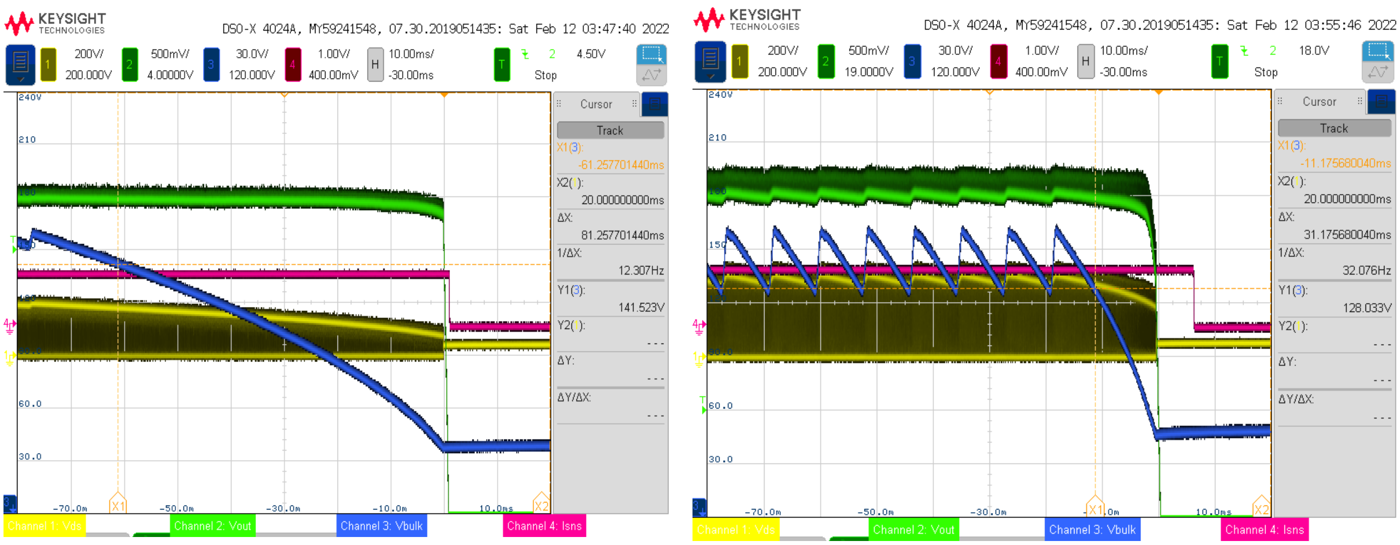
265Vac

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	4.8 V	5.22 V	4.79 V	5.19 V
	0.0 A	3.0 A	4.67 V	5.31 V	4.59 V	5.27 V
9 V	0.0 A	1.5 A	8.79 V	9.21 V	8.75 V	9.21 V
	0.0 A	3.0 A	8.7 V	9.27 V	8.64 V	9.26 V
15 V	0.0 A	1.5 A	14.85 V	15.32 V	14.8 V	15.31 V
	0.0 A	3 A	14.77 V	15.36 V	14.74 V	15.34 V
20 V	0.0 A	1.625 A	19.8 V	20.32 V	19.84 V	20.32 V
	0.0 A	3.25 A	19.7 V	20.42 V	19.77 V	20.39 V

Hold Up Time

Table 11: 115Vac Hold Up Time

Output Load	Hold Up Measurement
5 V / 3 A	61 ms
9 V / 3 A	39 ms
15 V / 3 A	21 ms
20 V / 3.25 A	11 ms



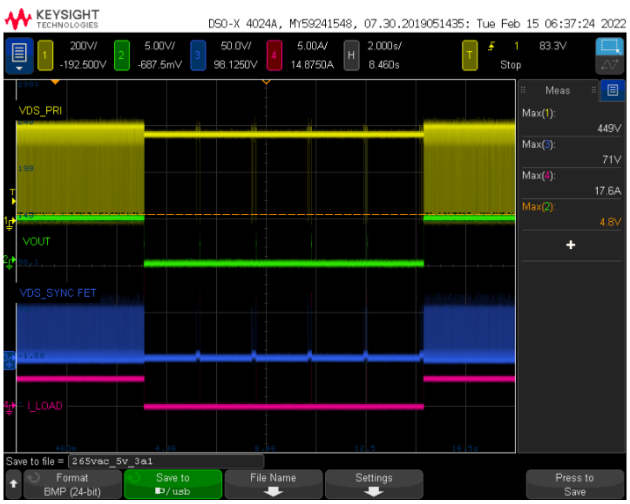
Vin=115 Vac, Vout=5 V @ 3A

Vin=115 Vac, Vout=20 V @ 3.25A

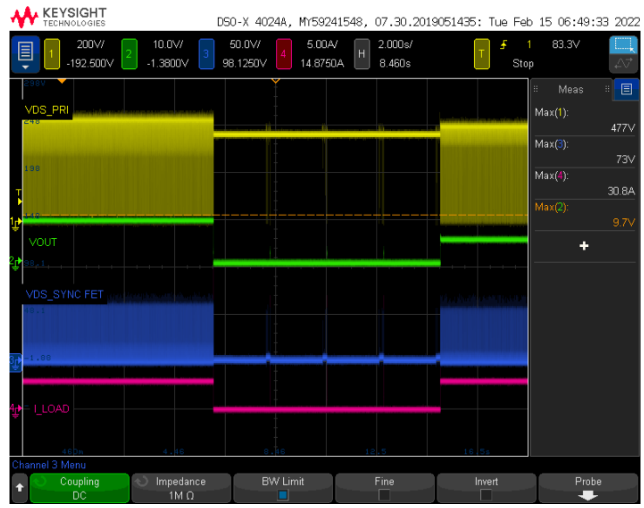
Figure 12: Hold-up time key voltage waveforms for 5 V/3A and 20 V/3.25A.

Output Voltage Short and Auto-recovery

The reference design features Hiccup Mode Fault Protections using SZ1131. Under applicable fault conditions (all except over-temperature protections), the device attempts to auto-restart. Figure 13 shows hiccup mode fault recovery behaviour when a short is applied at the VBUS output (after the USB-PD disconnect FET). 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.

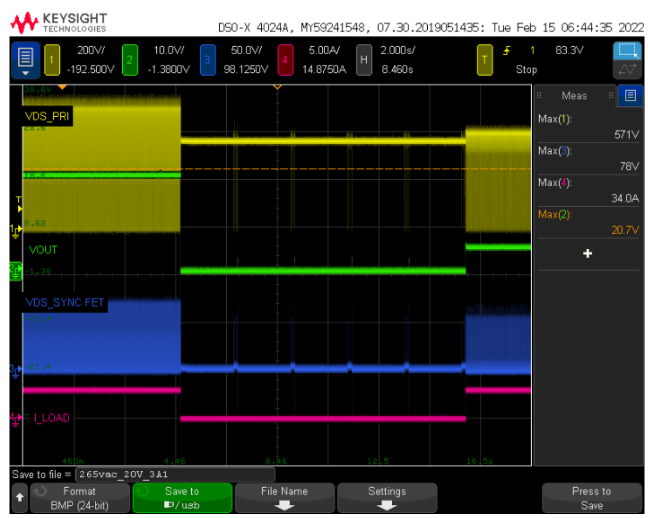


Vin=265 Vac, Vout=5 V, normal running then short, Recovery=5 V



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 13: 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)	68 mW	190 V
265 Vac (60 Hz)	267 mW	417 V

Output Voltage Over-Current Protection (OCP)

The reference design features Hiccup Mode Fault Protections using SZ1130-02. Under applicable fault conditions (all except over-temperature protections), the device attempts to auto-restart. Figure 13 shows peak power when load is applied before disconnect switch, which indicates the peak power SZ1130 could provide. Figure 14 shows peak output power when load is applied after disconnect switch. 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 trigger level and Peak power limit is captured at the end of the board.

Table 13: Over-Current Level Summary when load is applied after disconnect switch

Output Voltage	Measured OCP/SW Voltage	
	90 Vac	265 Vac
5 V	3.9A/ 203 V	3.9A/ 448 V
9 V	3.9A/ 233 V	3.9A/ 488 V
15 V	3.9A/ 287 V	3.9A/ 528 V
20 V	3.9A/ 354 V	3.9A/ 575 V

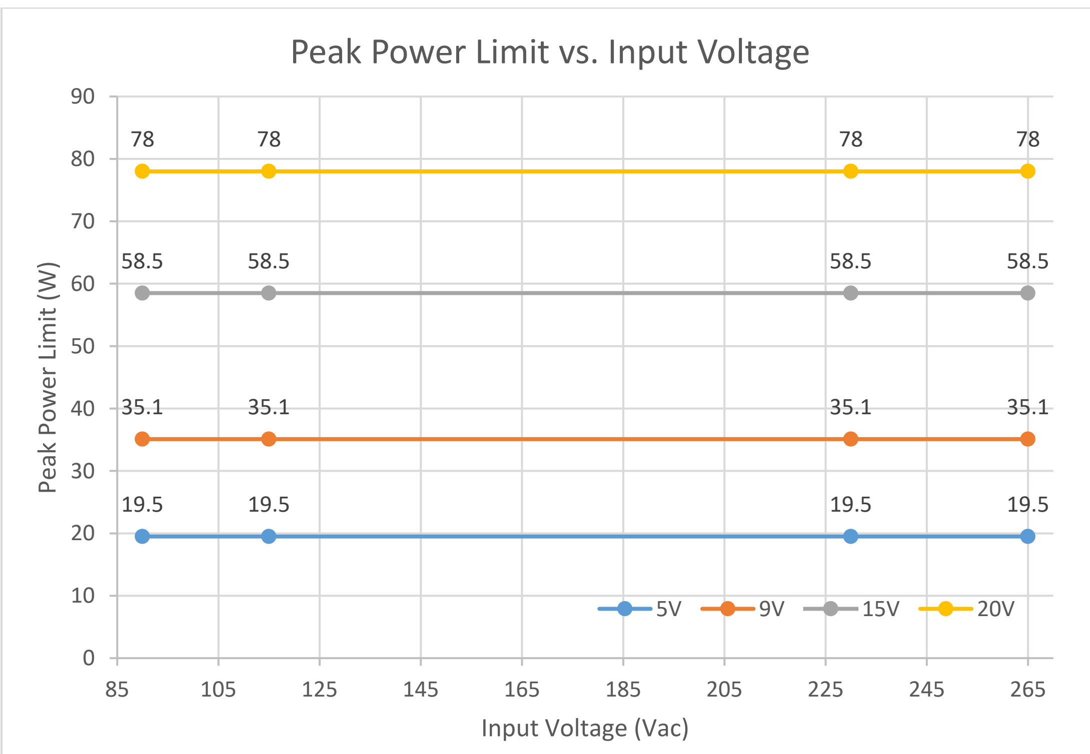


Figure 14: Peak power limit versus input voltage for different output voltages.

Output Over-Voltage Protection / Feedback Loop Open Protection

The reference design features Hiccup Mode Fault Protections using SZ1131. Under applicable fault conditions (all except over-temperature protections), the device attempts to auto-restart.

Figure 15 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.

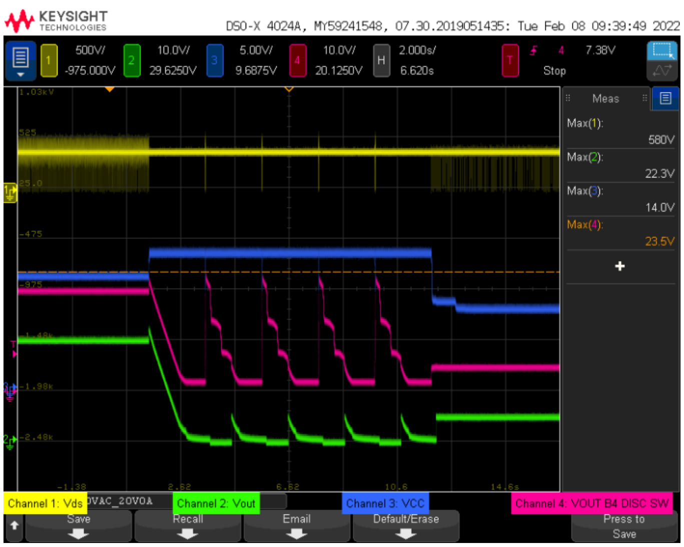
Table 14: Over-Voltage Level Summary

20V output

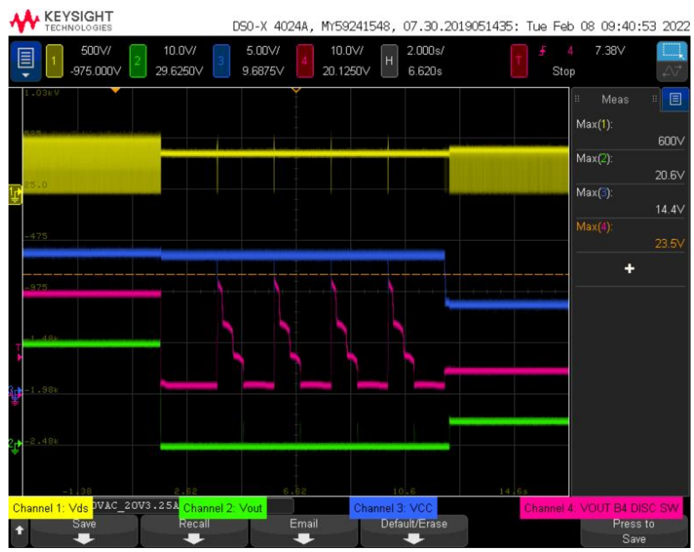
	Max output Voltage before the disconnect FET		Max output Voltage after the disconnect FET	
Input Voltage	**No Load OVP**	**Full Load OVP**	**No Load OVP**	**Full Load OVP**
90 Vac	23.8 V	22.3 V	23.5 V	20.6 V
265 Vac	23.5 V	22.3 V	23.5 V	20.6 V

Vin=90 Vac, Vout=20 V, 0 A, Opto Shorted, VDS_max=339 V

Vin=90 Vac, Vout=20 V, 3.25 A, Opto Shorted, VDS_max=326 V



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

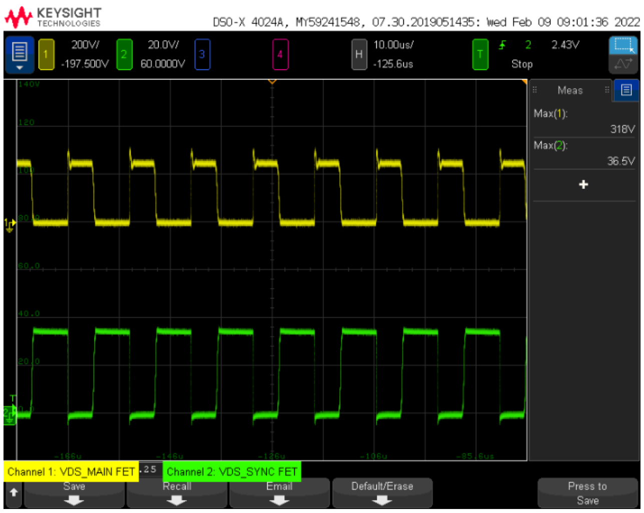


Vin=265 Vac, Vout=20 V, 3.25 A, Opto Shorted, VDS_max=600 V

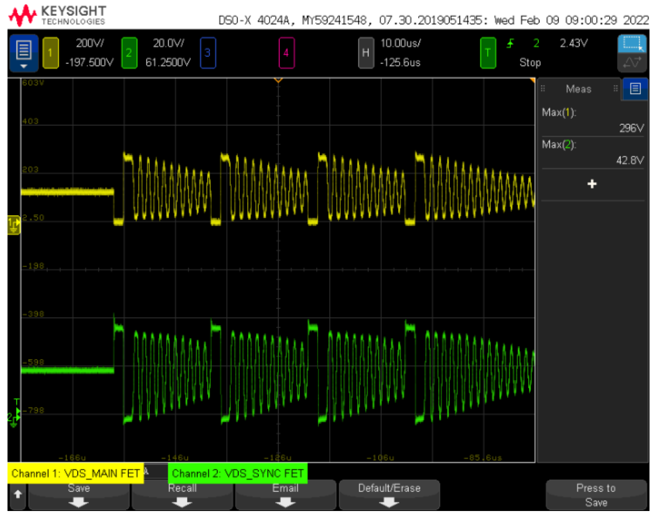
Figure 15: Fault recovery behavior under Over-Voltage Protection via optocoupler diode short

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 90 Vac and 265 Vac at full and no-load condition and 20V output voltage.

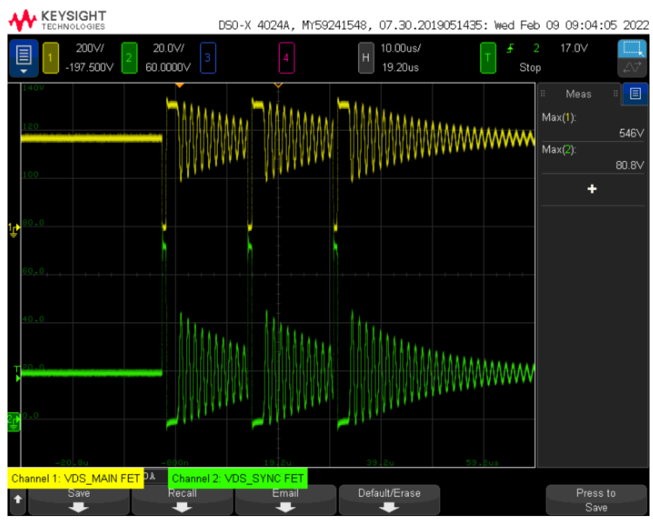


Vin=90 Vac, Vout=20 V, Iout=3.25 A, V_{ds_MAIN}=318 V



Vin=90 Vac, Vout=20 V, Iout=0 A, V_{ds_SRFET}=42.8 V

Vin=265 Vac, Vout=20 V, Iout=3.25 A, V_{ds_MAIN}=559.0 V

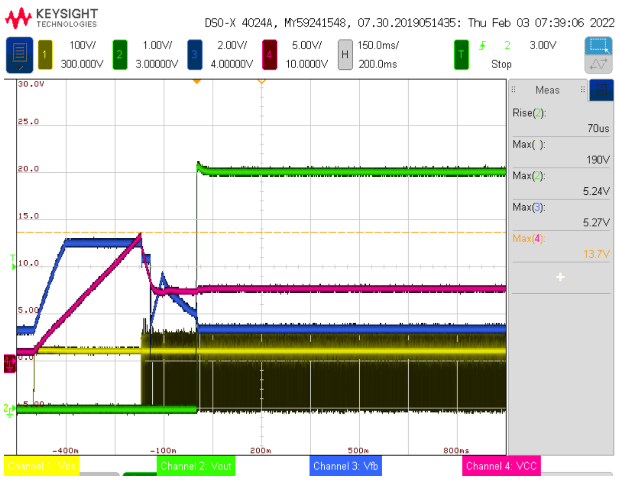


Vin=265 Vac, Vout=20 V, Iout=0 A, V_{ds_SRFET}=80.8 V

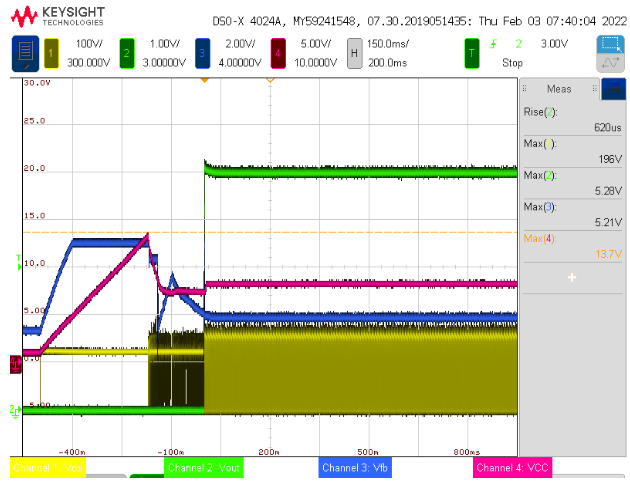
Figure 16: Main Primary and SR FET drain voltage waveforms under various operating conditions at 265 Vac input

Drain Voltage Waveforms at Start-up

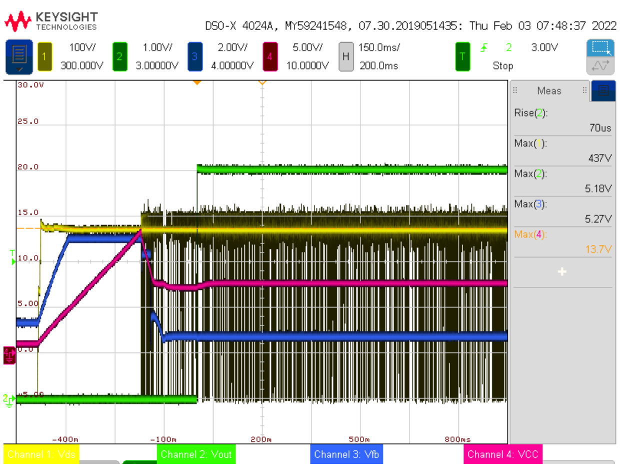
The waveforms presented in this section show no components are over stressed under start-up operating conditions. Measurement done at 90 Vac and 265 Vac at full and no-load conditions.



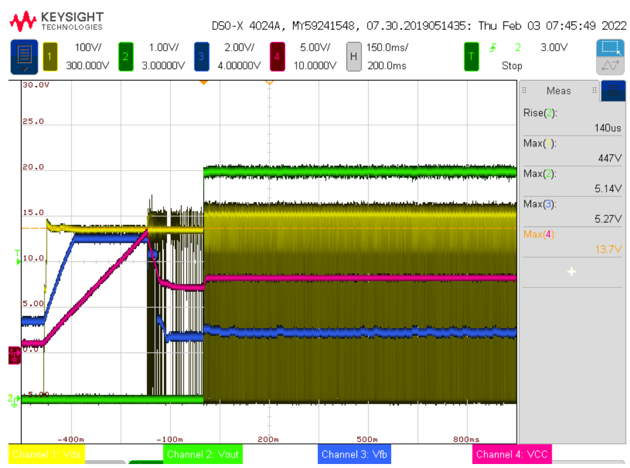
Vin=90 Vac, Vout=5 V, Iout=0 A, V_{ds_MAIN}=190.0 V



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}=437.0 V



Vin=265 Vac, Vout=5 V, Iout=3 A, V_{ds_MAIN}=447.0 V

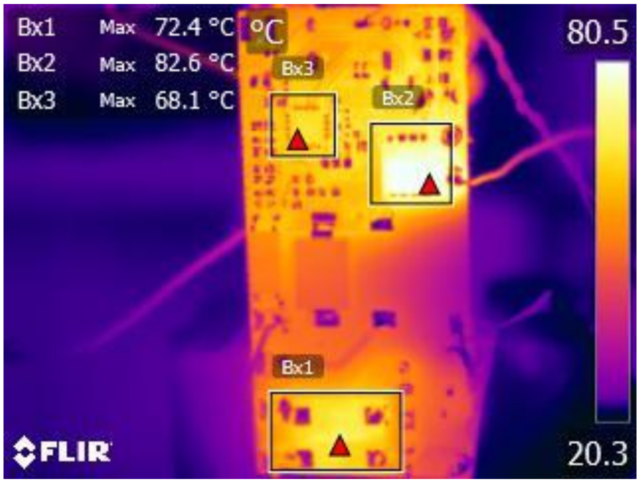
Figure 17: Primary FET drain voltage waveforms during start-up at 90 Vac and 265 Vac input

Thermal Measurements

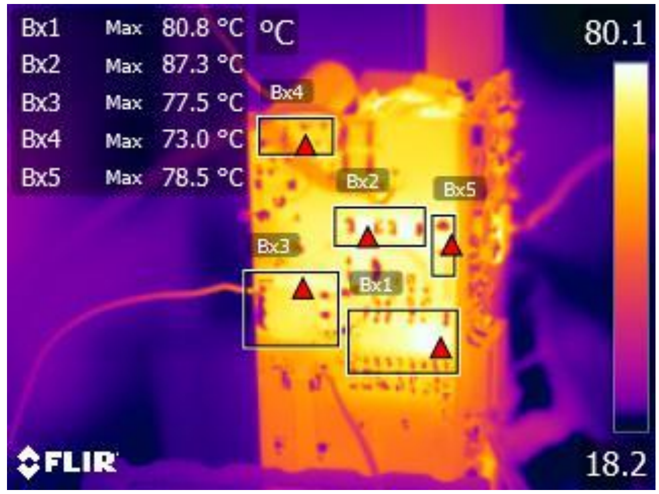
The following thermal data show the temperatures of key semiconductor components after 1hr operation at 20V/3.25A and 100Vac and 265Vac input voltages. No thermal management was utilized, and the unit was outside of the case with ambient temperature ~25 degrees Celsius.

Table 15: Measured Components Temperature with 20V, 3.25A

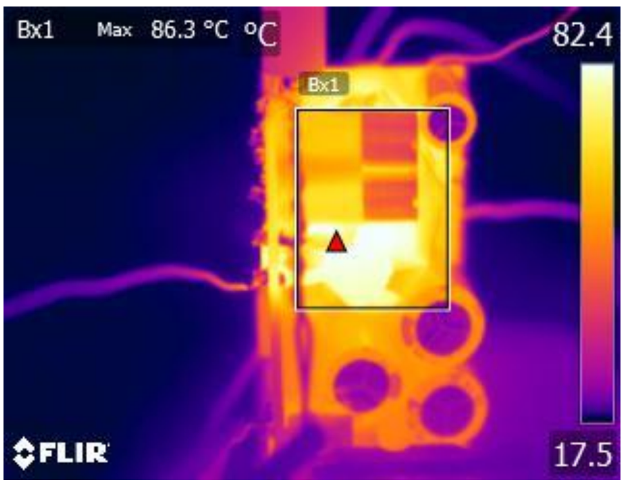
Designator	Components	100Vac	265Vac
U2	SZ1131	80.8°C	74.5°C
Q1	Secondary SR MOSFET	82.6°C	84.6°C
Q2	Primary MOSFET	77.5°C	78.7°C
BR1	Bridge Rectifier	72.4°C	47.4°C
T1	Flyback Transformer	86.3°C	79°C



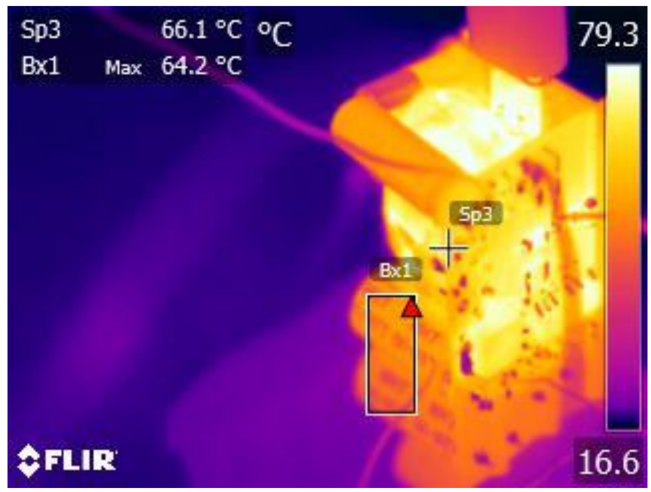
Vin=100 Vac, Vout=20 V, Iout=3.25 A (Side A)



Vin=100 Vac, Vout=20 V, Iout=3.25 A (Side B)



Vin=100 Vac, Vout=20 V, Iout=3.25 A (Side D)



Vin=100 Vac, Vout=20 V, Iout=3.25 A (Side C)

Figure 18: Thermal images captured at 100 Vac/20V/3.25A condition.

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.

Conducted EMI Test Setup

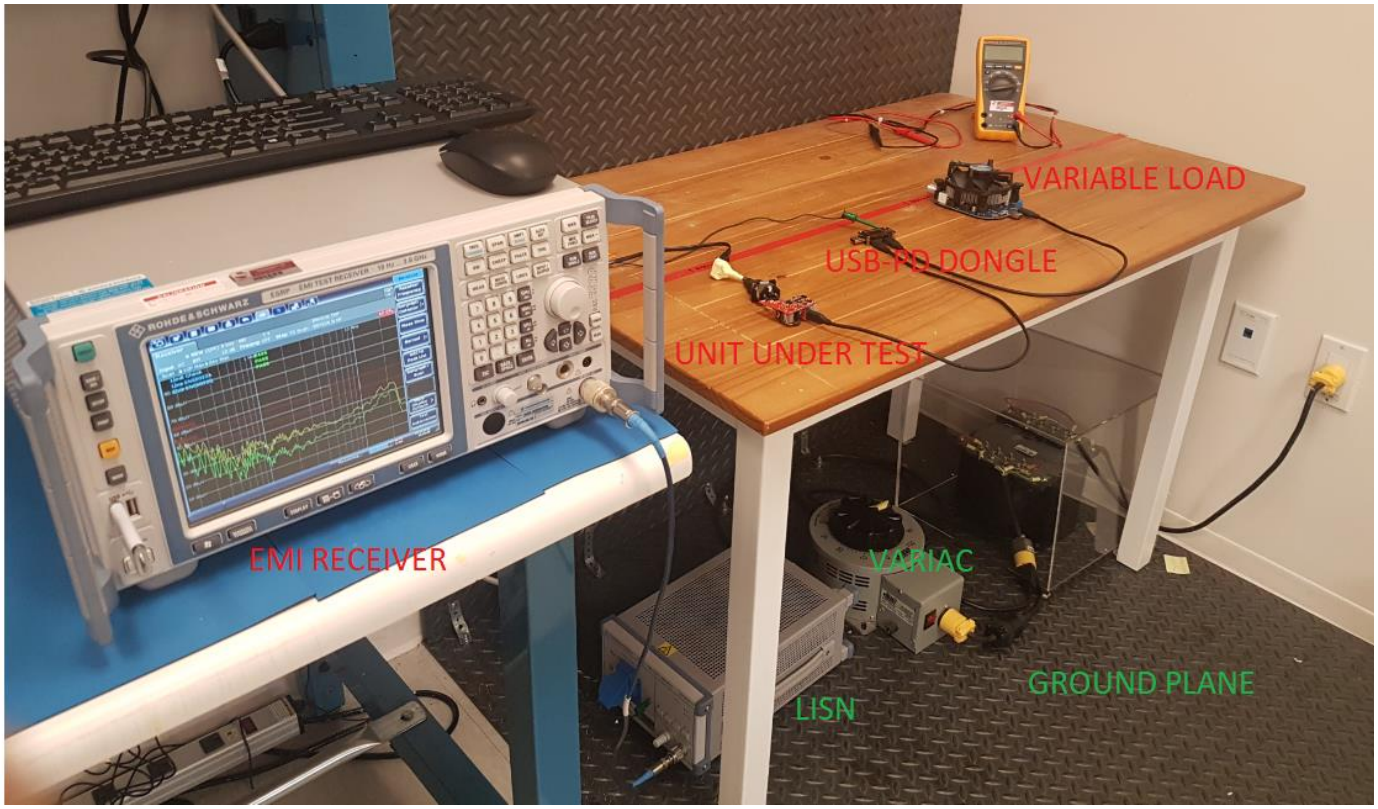
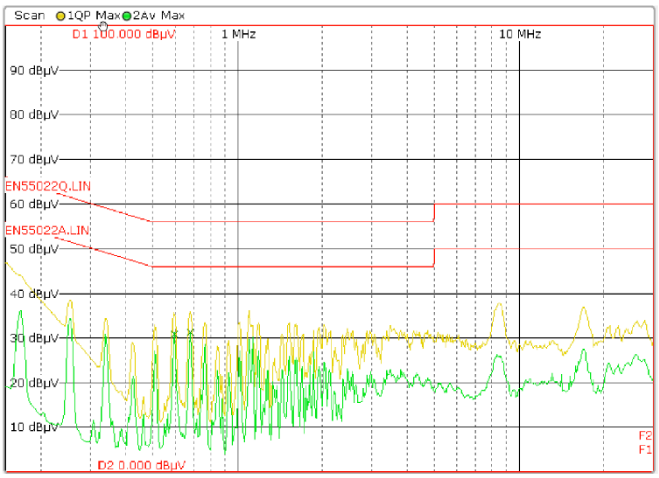
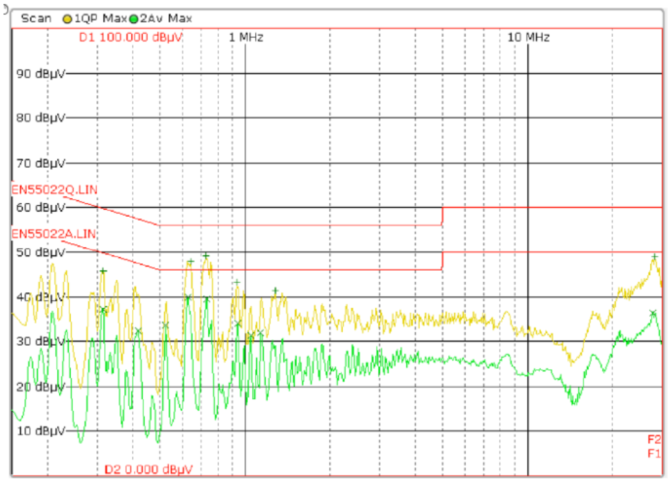


Figure 19: Conducted EMI Test Setup

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



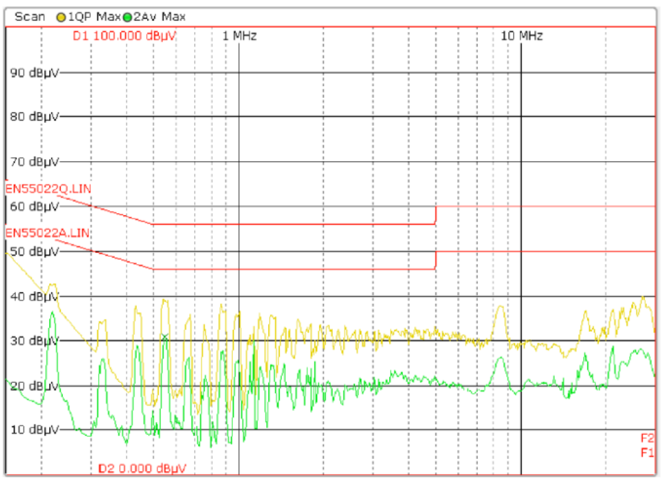
115 Vac (Line/ Neutral)



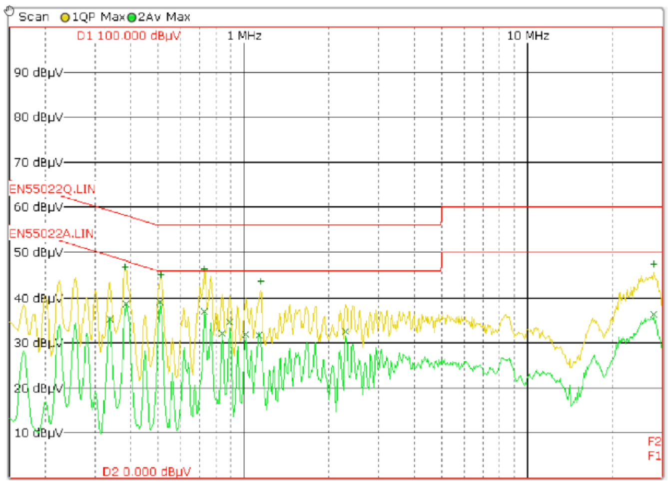
230 Vac (Line/ Neutral)

Figure 20: 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



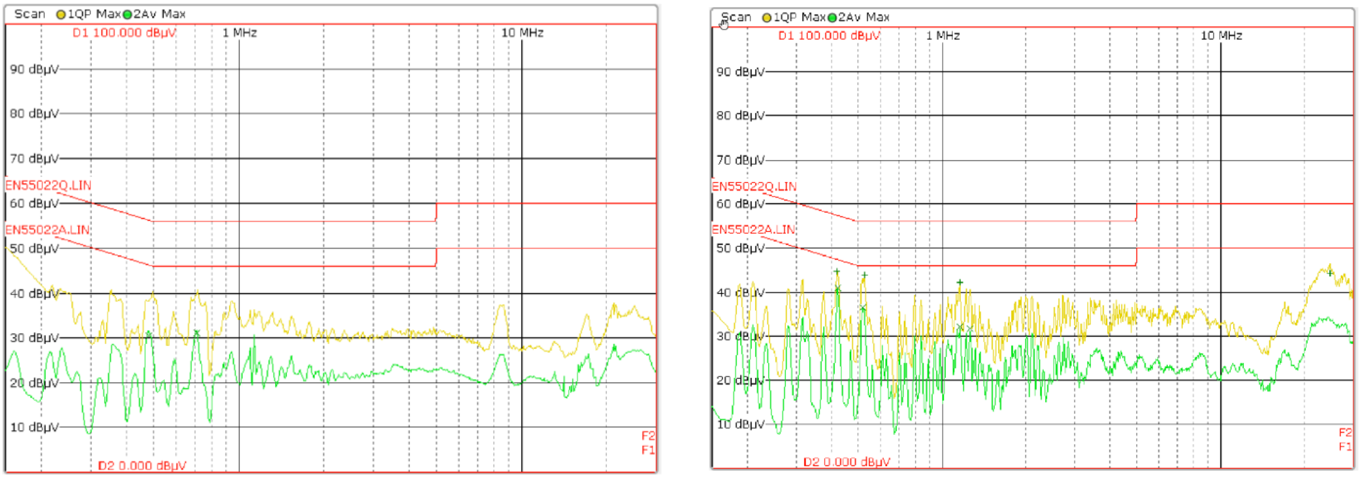
115 Vac (Line/ Neutral)



230 Vac (Line/ Neutral)

Figure 21: 9 V/ 3 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

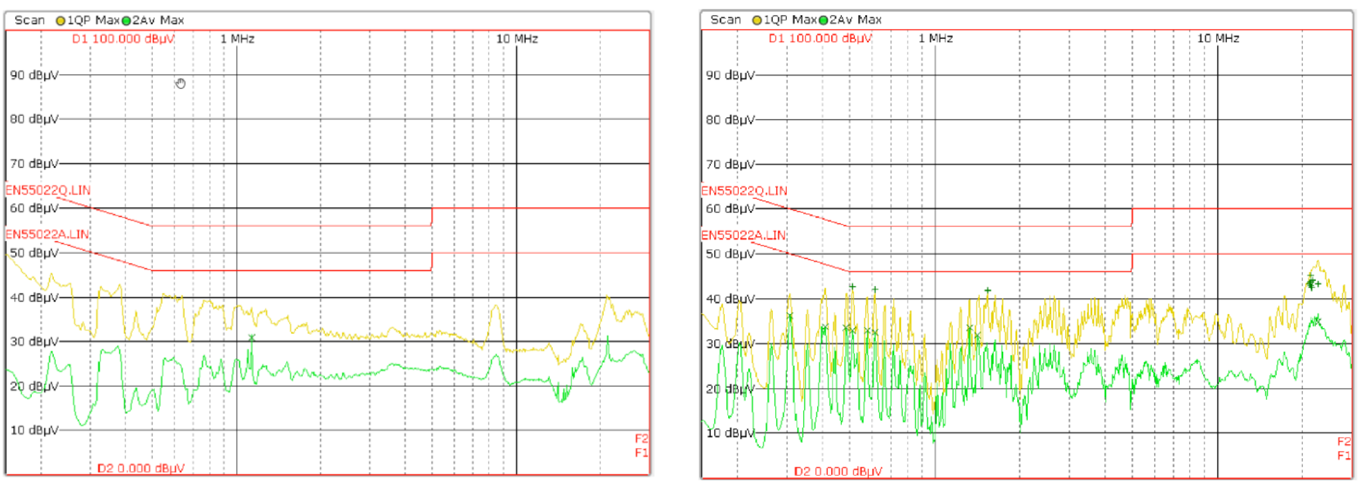
V_{out}/ I_{out}: 15 V/ 3 A



115 Vac (Line/ Neutral) 230 Vac (Line/ Neutral)

Figure 22: 15 V/ 3 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

V_{out}/ I_{out}: 20 V/ 3.25 A



115 Vac (Line/ Neutral) 230 Vac (Line/ Neutral)

Figure 23: 20 V/ 3.25 A conducted EMI measurement results (Line and Neutral) for 115 Vac and 230 Vac inputs

RD31 passes the Conducted EMI with >6dB margin at 115Vac and 230Vac.

Radiated EMI Measurements

This section presents the radiated EMI measurements taken on the reference design. Tests were performed at the worst condition with maximum load current (3.25A) for maximum output voltage (20V).

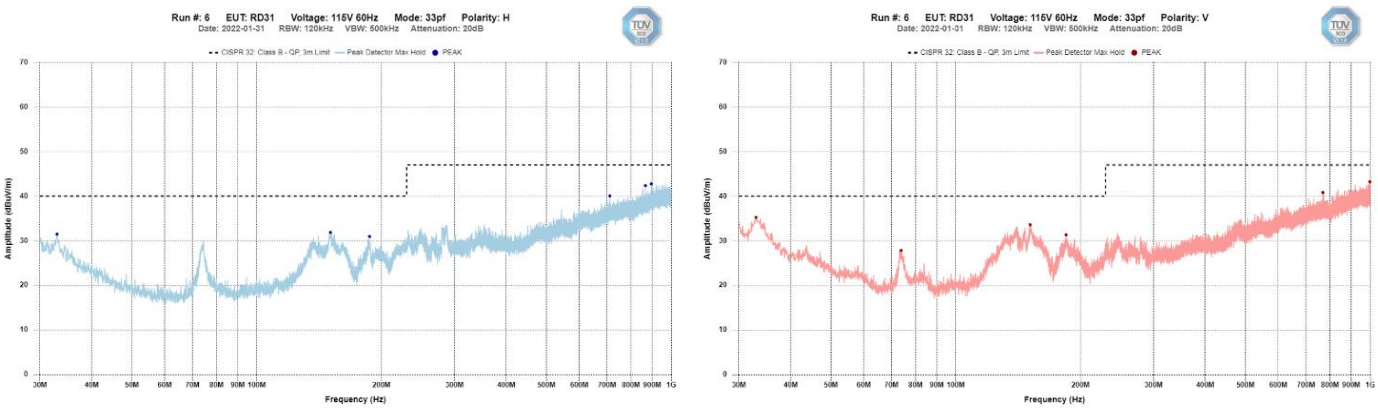


Figure 24: 20 V/ 3.25 A radiated EMI measurement results (Horizontal and Vertical) for 115 Vac (>7dB QP margin)

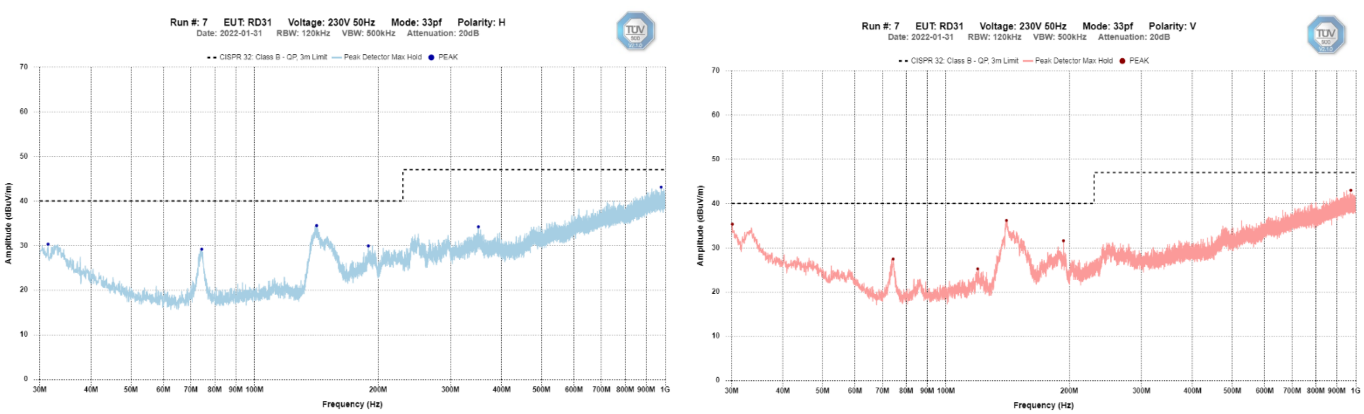


Figure 25: 20 V/ 3.25 A radiated EMI measurement results (Horizontal and Vertical) for 230 Vac (>6dB QP margin)

Revision History

Revision	Date	Author	Note
1.0	02/17/2022	Internal Application Team	Initial Release