Design Example Report

Title	***60 W Power Supply Using InnoSwitch™3-EP PowiGaN™ INN3679C-H606***
Specification	90 VAC – 265 VAC Input; 12 V / 5.0 A Output
Application	Industrial Power Supply
Author	Applications Engineering Department
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Date	February 4, 2022
Revision	1.3

Summary and Features

- InnoSwitch3-EP is industry first AC/DC IC with isolated, safety rated integrated feedback
- All the benefits of secondary-side control with the simplicity of primary-side regulation
  - Insensitive to transformer variation
  - Built-in synchronous rectification for high efficiency
- Meets DOE6 and CoC Tier 2 V5 2016
- <30 mW no-load input power
- Primary sensed overvoltage protection
- Very low component count: 45 components
- >6db margin on conducted EMI
- Very high average efficiency
  - 92.5% at 115 VAC and 230 VAC
- Very high full-load efficiency
  - 92.0% at 115 VAC and 93.5% at 230 VAC

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This document is an engineering report describing a 12 V / 5 A output power supply using the InnoSwitch3-EP. This design shows the high power density and efficiency that is possible due to the high level of integration of the InnoSwitch3-EP controller providing exceptional performance.

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

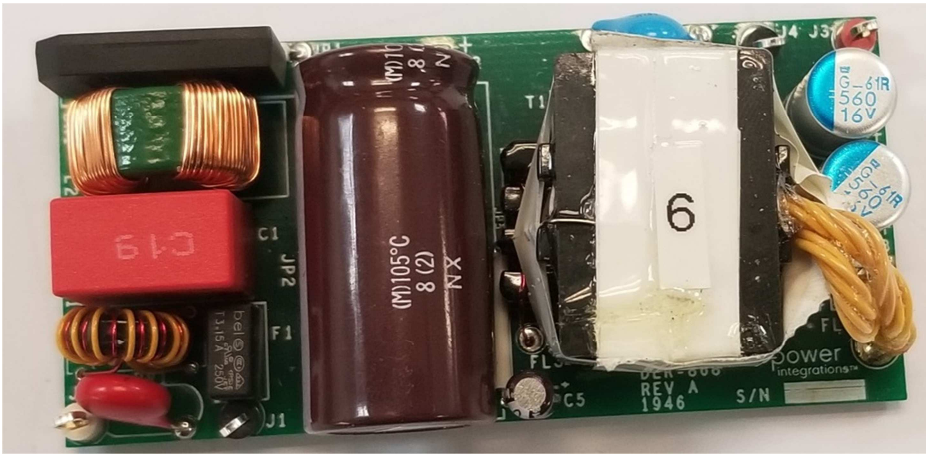


Figure 1 – Populated Circuit Board Photograph, Top.

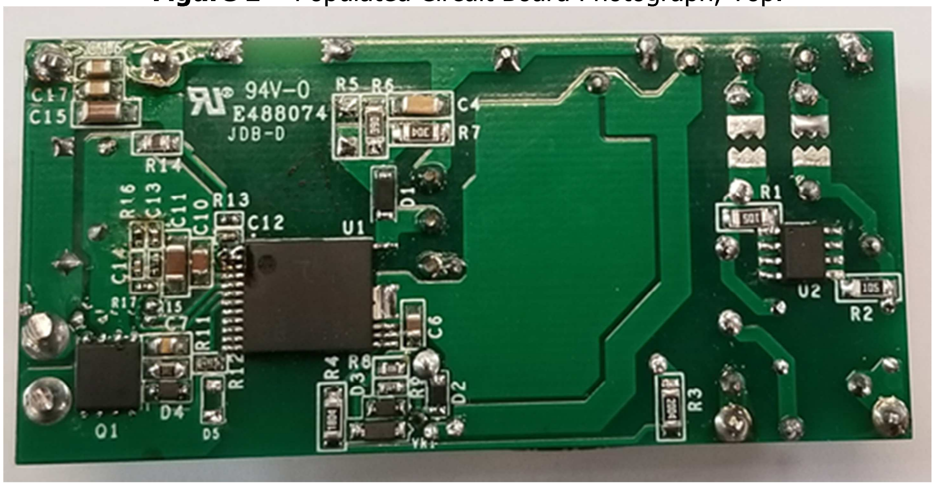


Figure 2 – Populated Circuit Board Photograph, Bottom.

2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the result section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				30	mW	Measured at 230 VAC.
20 V Output						
Output Voltage	V_{OUT1}		12		V	±5%
Output Ripple Voltage	V_{RIPPLE}			250	mV	On Board.
Output Current	I_{OUT}	5			A	On Board.
Continuous Output Power	P_{OUT}			60	W	
Conducted EMI						Meets CISPR22B / EN55022B
Safety						Designed to meet IEC60950 / UL1950 Class II.
Ambient Temperature	T_{AMB}	0		40	^{o}C	Enclosed in Adapter, Sea Level.

3 Schematic

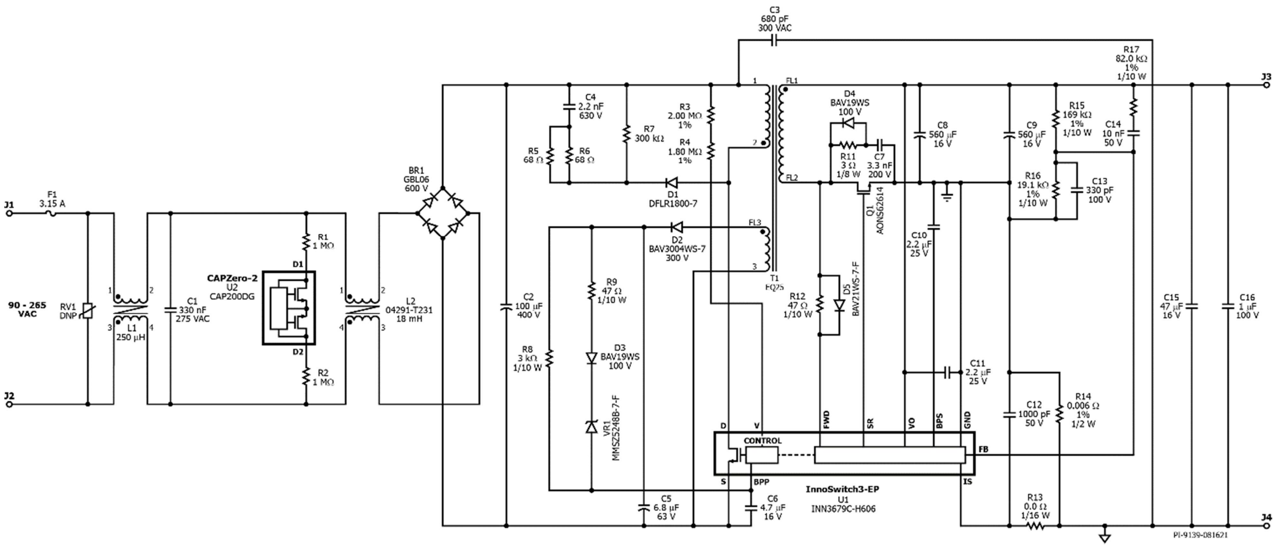


Figure 3 – Power Stage Schematic.

4 Circuit Description

4.1 *Input EMI Filtering*

Fuse F1 isolates the circuit and provides protection from component failure, and the common mode choke L1 and L2 with capacitor C1 attenuation for EMI. Bridge rectifier BR1 rectifies the AC line voltage and provides a full wave rectified DC across the filter capacitor C2. Capacitor C3 is used to mitigate the common mode EMI.

Resistors R1 and R2 along with U2 discharges capacitor C1 when the power supply is disconnected from AC mains.

4.2 *InnoSwitch3-EP IC Primary*

One end of the transformer (T1) primary is connected to the rectified DC bus; the other is connected to the drain terminal of the switch inside the InnoSwitch3-EP IC (U1). Resistors R3 and R4 provide Input voltage sense protection for under voltage and over voltage conditions.

A low cost RCD clamp formed by diode D1, resistors R5, R6, and R7, and capacitor C4 limits the peak drain voltage of U1 at the instant of turn off of the switch inside U1. The clamp helps to dissipate the energy stored in the leakage reactance of transformer T1.

The IC is self-starting, using an internal high-voltage current source to charge the BPP pin capacitor (C6) when AC is first applied. During normal operation the primary-side block is powered from an auxiliary winding on the transformer T1. Output of the auxiliary (or bias) winding is rectified using diode D2 and filtered using capacitor C5. Resistor R8 limits the current being supplied to the BPP pin of the InnoSwitch3-EP IC (U1).

Zener diode VR1 along with R9 and D3 offers primary sensed output over voltage protection. In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In case of over voltage at output of the converter, the auxiliary winding voltage increases and causes breakdown of VR1 which then causes a current to flow into the BPP pin of InnoSwitch3-EP IC U1. If the current flowing into the BPP pin increases above the I_{SD} threshold, the InnoSwitch3-EP controller will latch off and prevent any further increase in output voltage.

4.3 *InnoSwitch3-EP IC Secondary*

The secondary-side of the InnoSwitch3-EP IC provides output voltage, output current sensing and drive to a MOSFET providing synchronous rectification. The secondary of the transformer is rectified by MOSFET Q1 and filtered by capacitors C8 and C9. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via a RCD snubber R11, C7 and D4. Diode D4 was used to minimize the dissipation in resistor R11.

The gate of Q1 is turned on by secondary-side controller inside IC U1, based on the winding voltage sensed via resistor R12 and fed into the FWD pin of the IC.

In continuous conduction mode of operation, the MOSFET is turned off just prior to the secondary-side commanding a new switching cycle from the primary. In discontinuous mode of operation, the power MOSFET is turned off when the voltage drop across the MOSFET falls below a threshold of approximately 3 mV. Secondary side control of the primary-side power switch avoids any possibility of cross conduction of the two switches and provides extremely reliable synchronous rectification.

The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. Capacitor C10 connected to the BPS pin of InnoSwitch3-EP IC U1 provides decoupling for the internal circuitry. Capacitor C11 provides decoupling for the VO pin.

Output Current is sensed by monitoring the voltage drop across resistor R14 between the IS and GND pins with a threshold of approximately 35 mV to reduce losses. C12 provides filtering on the IS pin from external noise.

Below the CC threshold, the device operates in constant voltage mode. During constant voltage mode operation, output voltage regulation is achieved through sensing the output voltage via divider resistors R15 and R16. The voltage across R16 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. Output Voltage is regulated so as to achieve a voltage of 1.265 V on the FB pin. Capacitor C13 provides noise filtering of the signal at the FB pin.

The capacitors C15 and C16 are used to reduce the high frequency output voltage ripple.

5 PCB Layout

PCB copper thickness is 2.0 oz.

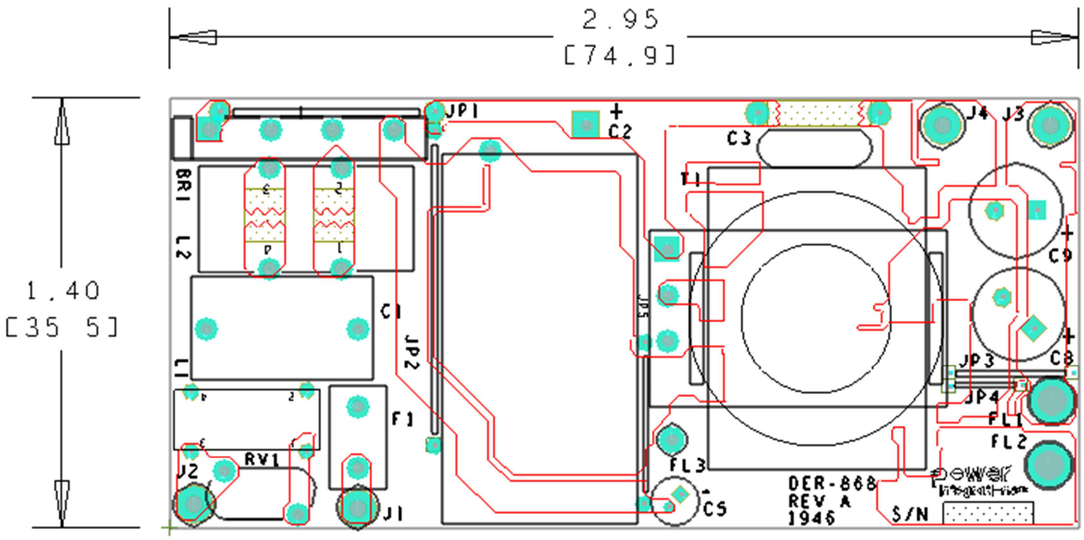


Figure 4 – Printed Circuit Layout, Top.

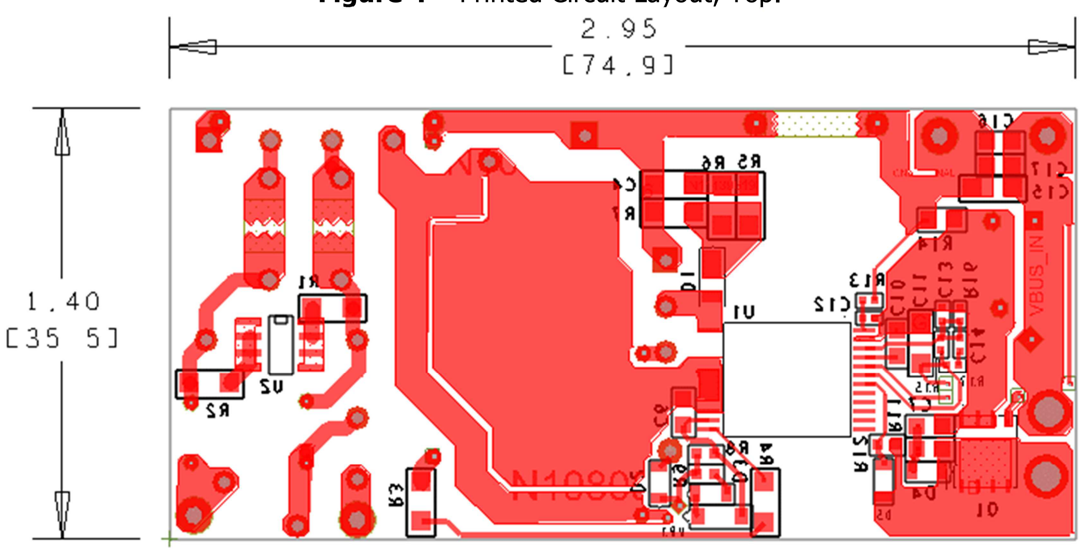


Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

28	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	DIODE BRIDGE 600V 4A GB	GBL06	Genesic Semi
2	1	C1	330 nF, ±10%, 275 VAC, Polypropylene Film, X2, 15.00 mm x 8.50 mm	890324024003CS	Wurth
3	1	C2	100 μF, 400 V, Electrolytic, Low ESR, (16 x 30)	EPAG401ELL101ML30S	Nippon Chemi-Con
4	1	C3	680 pF, ±10%, 300 VAC, Radial, Disc	DE1B3RA681KA4BP01F	Murata
5	1	C4	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K	TDK
6	1	C5	6.8 μF, ±20%, 63 V, Electrolytic, Gen Purpose, (4 mm x 11 mm)	UPW1J6R8MDD6	Nichicon
7	1	C6	4.7 μF, ±10%, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KE51L	Murata
8	1	C7	3.3 nF, 200 V, Ceramic, X7R, 0805	08052C332KAT2A	AVX
9	2	C8 C9	560 μF, 16 V, Al Organic Polymer, Gen. Purpose, 20%	APSG160ELL561MHB5J	United Chemi-con
10	1	C10	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
11	1	C11	2.2 μF, 25 V, Ceramic, X7R, 1206	TMK316B7225KL-T	Taiyo Yuden
12	1	C12	1000 pF, ±10%, 50V, X7R, -55°C ~ 125°C, Low ESL, 0402	C0402C102K5RACTU	Kemet
13	1	C13	330 pF, +/-10%, 100 V, Ceramic, X7R, 0402	HMK105B7331KV-F	Taiyo Yuden
14	1	C14	10 nF 50 V, Ceramic, X7R, 0402	CL05B103KB5NNNC	Samsung
15	1	C15	47 μF, 16 V, X5R, 1206	3216X5R1C476M	TDK
16	2	C16	1 μF, 100 V, Ceramic, X7S, 0805	C2012X7S2A105K125AB	TDK
17	1	D1	800 V, 1 A, Rectifier, POWERDI123	DFLR1800-7	Diodes, Inc.
18	1	D2	DIODE, GEN PURP, FAST RECOVERY, 300 V, 225 mA, SOD323	BAV3004WS-7	Diodes, Inc.
19	2	D3 D4	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
20	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
21	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
22	2	FL1 FL2	Flying Lead, Hole size 100 mils	N/A	N/A
23	1	FL3	Flying Lead, Hole size 50 mils	N/A	N/A
24	1	J1	Test Point, WHT,THRU-HOLE MOUNT	5012	Keystone
25	2	J2 J4	Test Point, BLK,THRU-HOLE MOUNT	5011	Keystone
26	1	J3	Test Point, RED,THRU-HOLE MOUNT	5010	Keystone
27	1	JP1	Wire Jumper, Insulated, #24 AWG, 0.7 in	C2003A-12-02	Gen Cable
28	1	JP2	Wire Jumper, Insulated, #24 AWG, 1.0 in	C2003A-12-02	Gen Cable
29	1	JP3	Wire Jumper, Insulated, #28 AWG, 0.5 in	2842/1 WH005	Alpha Wire
30	1	JP4	Wire Jumper, Insulated, #28 AWG, 0.3 in	2842/1 WH005	Alpha Wire
31	1	L1	250 μH, Toroidal CMC, custom, wound on 32-00275-00 core CMC Assembly	32-00397-00 TSD-4500	Power Integrations Premier Magnetics
32	1	L2	Custom, CMC, 18 mH @ 10 kHz, Toroidal, 17.5 mm OD x 11.0 mm thick. 40 turns x 2, 0.40 mm wire 190 mΩ max CMC Assembly	04291-T231 TSD-4501	Sumida Premier Magnetics
33	1	Q1	MOSFET, N-Channel, 60 V, 142 W (Ta), 70W (Tc), Surface Mount, 8-DFN-EP (5x6)	AONS62614	Alpha & Omega Semi
34	2	R1 R2	RES, 1.0 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
35	1	R3	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
36	1	R4	RES, 1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
37	2	R5 R6	RES, 68 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ680V	Panasonic
38	1	R7	RES, 300 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ304V	Panasonic
39	1	R8	RES, 3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ302V	Panasonic
40	2	R9 R12	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
41	1	R11	RES, 3 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ3R0V	Panasonic

42	1	R13	RES, 0 Ω, 1/16 W, Thick Film, 0402	CRCW04020000Z0ED	Panasonic
443	1	R14	RES, 0.006 Ω, ±1%, 1/2W, 0805, Current Sense, Thick Film, ±300ppm/°C, -55°C ~ 155°C	ERJ-6LWFR006V	Panasonic
44	1	R15	RES, 169.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1693X	Panasonic
45	1	R16	RES, 19.1 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1912X	Panasonic
46	1	R17	RES, 82.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF8202X	Panasonic
47	1	RV1	275 VAC, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
48	1	T1	Bobbin, EQ25, 4 pins, 4pri, 0sec Transformer	TBI-235-01091.1206 POL-INN049	TBI Transformer Bobbin Industrial Co tbi-tw.com Premier Magnetics
49	1	U1	InnoSwitch3-EP Switch Integrated Circuit, InSOP24D	INN3679C-H606	Power Integrations
50	1	U2	CAPZero-2, SO-8C	CAP200DG	Power Integrations
51	1	VR1	DIODE ZENER 12 V 500 mW SOD123	MMSZ5242B-7-F	Diodes, Inc.

7 Transformer Specification

7.1 *Electrical Diagram*

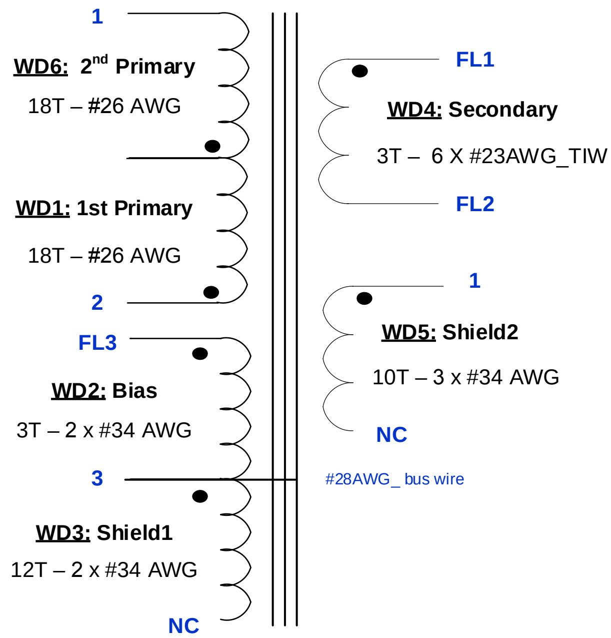


Figure 6 – Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V pk-pk, 100 kHz switching frequency, between pin 2 and 1, with all other windings open.	550 µH± 4%
Resonant Frequency	Between pin 2 and 1, other windings open.	1,000 kHz (Min.)
Primary Leakage Inductance	Between pin 2 and 1, with pins: FL1-FL2 shorted.	7 µH (Max.)

7.3 *Material List*

Item	Description
[1]	Core: EQ25, Ferroxcube: 3C95.
[2]	Bobbin: EQ25-Vert-4pins (4/0); PI#: 25-01141-00.
[3]	Magnet Wire: #26 AWG, Double Coated.
[4]	Magnet Wire: #34 AWG, Double Coated.
[5]	Magnet Wire: #35 AWG, Double Coated.
[6]	Magnet Wire: #24 AWG, Triple Insulated Wire.
[7]	Bus Wire: #26AWG, Alpha Wire, Tinned Copper.
[8]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 8.2 mm Width.
[9]	Tape: 3M 13450-F, Polyester Film, 1 mil Thickness, 33 mm x 58 mm.
[10]	Varnish: Dolph BC-359.

7.4 *Transformer Build Diagram*

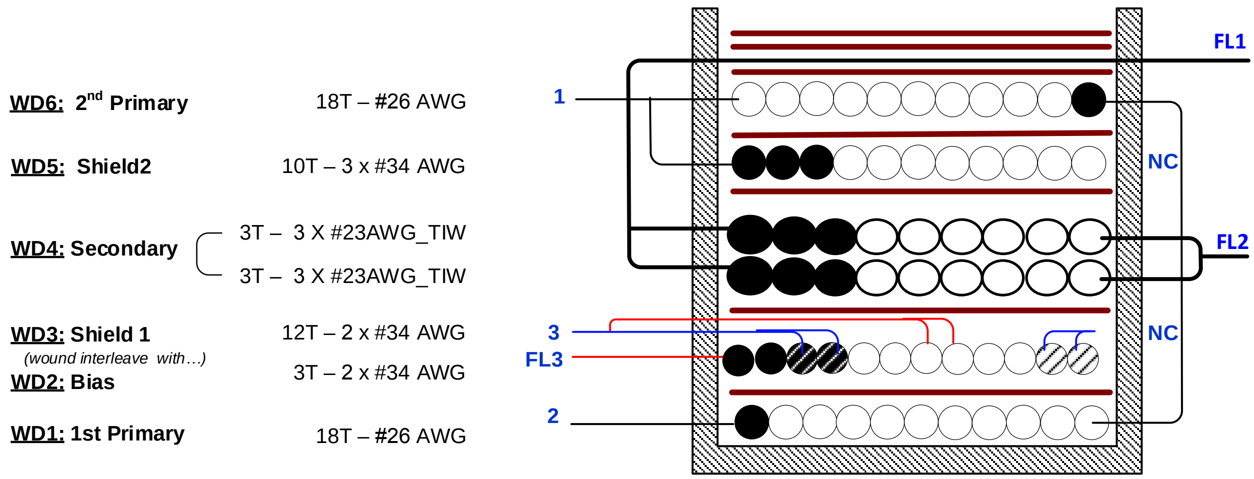


Figure 7 – Transformer Build Diagram.

8 Common Mode Choke Specifications

8.1 *250 µH Common Mode Choke (L1)*

8.1.1 Electrical Diagram

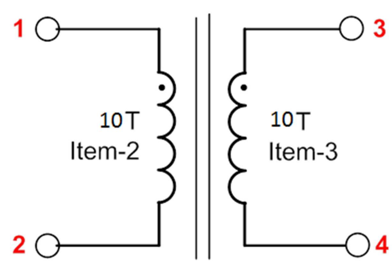


Figure 8 – Inductor Electrical Diagram.

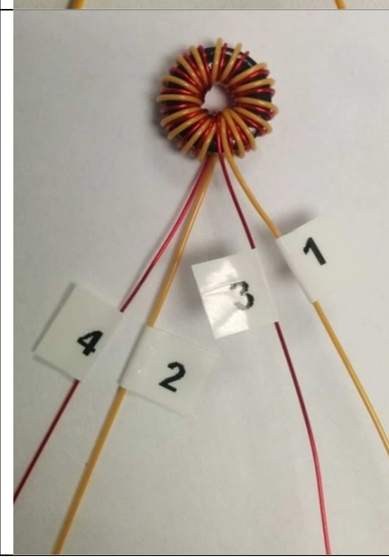
8.1.2 Electrical Specifications

Inductance	Pins 1 - 2 measured at 100 kHz, 0.4 RMS.	250 µH ±20%
Primary Leakage Inductance	Pins 1 - 2, with 3 - 4 shorted.	1 µH

8.1.3 Material List

Item	Description
[1]	Toroid: FERRITE INDUCTR TOROID .415" O.D.;Mfg Part number: 35T0375-10H. Dim: 9.53 mm O.D. x 4.75 mm I.D. x 3.18 mm L.
[2]	Magnet Wire: #27 AWG.
[3]	Triple Insulated Wire #27 AWG.

8.1.4 Common Mode Choke Construction

Mark the start end of the winding as 1 and wind 10 turns of Item [2] on Item [1]. Mark the end of this winding as 2	
Repeat the same procedure as above for the other winding using Item [3], making sure that the start/end and the direction of winding is the same as the first winding. Varnish using Item [4]. Mark the start of this winding as 3 and the end as 4.	

9 Transformer Design Spreadsheet

1	ACDC_InnoSwitch3-EP_Flyback_031620; Rev.1.5; Copyright Power Integrations 2020	INPUT	INFO	OUTPUT	UNITS	InnoSwitch3 EP Flyback Design Spreadsheet
2	**APPLICATION VARIABLES**					
3	VIN_MIN	90		90	V	Minimum AC input voltage
4	VIN_MAX			265	V	Maximum AC input voltage
5	VIN_RANGE			UNIVERSAL		Range of AC input voltage
6	LINEFREQ			60	Hz	AC Input voltage frequency
7	CAP_INPUT	100.0		100.0	uF	Input capacitor
8	VOUT			12.00	V	Output Voltage at the board
9	CDC			0.00	mV	Cable drop compensation desired at full load
10	IOUT	5.000		5.000	A	Output Current
11	POUT			60.00	W	Output power
12	EFFICIENCY	0.91		0.91		AC-DC efficiency estimate at full load given that the converter is switching at the valley of the rectified minimum input AC voltage
13	FACTOR_Z	0.50		0.50		Z-factor estimate
14	ENCLOSURE	ADAPTER		ADAPTER		Power supply enclosure
18	**PRIMARY CONTROLLER SELECTION**					
19	ILIMIT_MODE	INCREASED		INCREASED		Device current limit mode
20	DEVICE_GENERIC	INN36X9		INN36X9		Generic device code
21	DEVICE_CODE			INN3679C		Actual device code
22	POUT_MAX			75	W	Power capability of the device based on thermal performance
23	RDSON_100DEG			0.62	Ω	Primary switch on time drain resistance at 100 degC
24	ILIMIT_MIN			1.980	A	Minimum current limit of the primary switch
25	ILIMIT_TYP			2.130	A	Typical current limit of the primary switch
26	ILIMIT_MAX			2.279	A	Maximum current limit of the primary switch
27	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
28	VDRAIN_ON_PRSW			0.44	V	Primary switch on time drain voltage
29	VDRAIN_OFF_PRSW			585.4	V	Peak drain voltage on the primary switch during turn-off
33	**WORST CASE ELECTRICAL PARAMETERS**					
34	FSWITCHING_MAX	70000		70000	Hz	Maximum switching frequency at full load and valley of the rectified minimum AC input voltage
35	VOR	142.0		142.0	V	Secondary voltage reflected to the primary when the primary switch turns off
36	VMIN			89.57	V	Valley of the minimum input AC voltage at full load
37	KP			0.78		Measure of continuous/discontinuous mode of operation
38	MODE_OPERATION			CCM		Mode of operation
39	DUTYCYCLE			0.614		Primary switch duty cycle
40	TIME_ON		Info	12.70	us	Primary switch on-time is greater than 12.4us: Increase the controller switching frequency or increase the VOR
41	TIME_OFF			5.51	us	Primary switch off-time
42	LPRIMARY_MIN			521.8	uH	Minimum primary inductance
43	LPRIMARY_TYP			549.3	uH	Typical primary inductance

44	LPRIMARY_TOL	5.0		5.0	%	Primary inductance tolerance
45	LPRIMARY_MAX			576.7	uH	Maximum primary inductance
47	**PRIMARY CURRENT**					
48	IPEAK_PRIMARY			2.102	A	Primary switch peak current
49	IPEDESTAL_PRIMARY			0.421	A	Primary switch current pedestal
50	IAVG_PRIMARY			0.706	A	Primary switch average current
51	IRIPPLE_PRIMARY			1.904	A	Primary switch ripple current
52	IRMS_PRIMARY			0.999	A	Primary switch RMS current
54	**SECONDARY CURRENT**					
55	IPEAK_SECONDARY			25.225	A	Secondary winding peak current
56	IPEDESTAL_SECONDARY			5.049	A	Secondary winding current pedestal
57	IRMS_SECONDARY			9.498	A	Secondary winding RMS current
61	**TRANSFORMER CONSTRUCTION PARAMETERS**					
62	**CORE SELECTION**					
63	CORE	EQ25		EQ25		Core selection
64	CORE CODE			EQ25-3C95		Core code
65	AE			100.00	mm^2	Core cross sectional area
66	LE			41.40	mm	Core magnetic path length
67	AL			5710	nH/turns^2	Ungapped core effective inductance
68	VE			4145.0	mm^3	Core volume
69	BOBBIN			TBI-235-01091.1206		Bobbin
70	AW	52.00		52.00	mm^2	Window area of the bobbin
71	BW	7.60		7.60	mm	Bobbin width
72	MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
74	**PRIMARY WINDING**					
75	NPRIMARY			36		Primary turns
76	BPEAK			3737	Gauss	Peak flux density
77	BMAX			3322	Gauss	Maximum flux density
78	BAC			1480	Gauss	AC flux density (0.5 x Peak to Peak)
79	ALG			424	nH/turns^2	Typical gapped core effective inductance
80	LG			0.274	mm	Core gap length
81	LAYERS_PRIMARY	2		2		Number of primary layers
82	AWG_PRIMARY	26	Info	26	AWG	Overwriting the primary AWG may not guarantee the required number of layers as calculated by the spreadsheet
83	OD_PRIMARY_INSULATED			0.465	mm	Primary winding wire outer diameter with insulation
84	OD_PRIMARY_BARE			0.405	mm	Primary winding wire outer diameter without insulation
85	CMA_PRIMARY			254	Cmil/A	Primary winding wire CMA
87	**SECONDARY WINDING**					
88	NSECONDARY	3		3		Secondary turns
89	AWG_SECONDARY			17	AWG	Secondary winding wire AWG
90	OD_SECONDARY_INSULATED			1.454	mm	Secondary winding wire outer diameter with insulation
91	OD_SECONDARY_BARE			1.150	mm	Secondary winding wire outer diameter without insulation
92	CMA_SECONDARY			216	Cmil/A	Secondary winding wire CMA
94	**BIAS WINDING**					
95	NBIAS			4		Bias turns
99	**PRIMARY COMPONENTS SELECTION**					
100	**LINE UNDERVOLTAGE**					
101	BROWN-IN REQURED			72.0	V	Required AC RMS line voltage brown-in threshold

102	RLS			3.64	MΩ	Connect two 1.82 MOhm resistors to the V-pin for the required UV/OV threshold
103	BROWN-IN ACTUAL			73.0	V	Actual AC RMS brown-in threshold
104	BROWN-OUT ACTUAL			66.0	V	Actual AC RMS brown-out threshold
106	**LINE OVERVOLTAGE**					
107	OVERVOLTAGE_LINE			304.2	V	Actual AC RMS line over-voltage threshold
109	**BIAS DIODE**					
110	VBIAS			12.0	V	Rectified bias voltage
111	VF_BIAS			0.70	V	Bias winding diode forward drop
112	VREVERSE_BIASDIODE			53.49	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
113	CBIAS			22	uF	Bias winding rectification capacitor
114	CBPP			4.70	uF	BPP pin capacitor
118	**SECONDARY COMPONENTS**					
119	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
120	RFB_LOWER			11.80	kΩ	Lower feedback resistor
121	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
125	**MULTIPLE OUTPUT PARAMETERS**					
126	**OUTPUT 1**					
127	VOUT1			12.00	V	Output 1 voltage
128	IOUT1			5.00	A	Output 1 current
129	POUT1			60.00	W	Output 1 power
130	IRMS_SECONDARY1			9.498	A	Root mean squared value of the secondary current for output 1
131	IRIPPLE_CAP_OUTPUT1			8.075	A	Current ripple on the secondary waveform for output 1
132	AWG_SECONDARY1			17	AWG	Wire size for output 1
133	OD_SECONDARY1_INSULATED			1.454	mm	Secondary winding wire outer diameter with insulation for output 1
134	OD_SECONDARY1_BARE			1.150	mm	Secondary winding wire outer diameter without insulation for output 1
135	CM_SECONDARY1			1900	Cmils	Bare conductor effective area in circular mils for output 1
136	NSECONDARY1			3		Number of turns for output 1
137	VREVERSE_RECTIFIER1			43.11	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
138	SRFET1	AUTO		AON6244		Secondary rectifier (Logic MOSFET) for output 1
139	VF_SRFET1			0.031	V	SRFET on-time drain voltage for output 1
140	VBREAKDOWN_SRFET1			60	V	SRFET breakdown voltage for output 1
141	RDSON_SRFET1			6.2	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 1
143	**OUTPUT 2**					
144	VOUT2			0.00	V	Output 2 voltage
145	IOUT2			0.000	A	Output 2 current
146	POUT2			0.00	W	Output 2 power
147	IRMS_SECONDARY2			0.000	A	Root mean squared value of the secondary current for output 2
148	IRIPPLE_CAP_OUTPUT2			0.000	A	Current ripple on the secondary waveform for output 2
149	AWG_SECONDARY2			0	AWG	Wire size for output 2

150	OD_SECONDARY2_INSULATED			0.000	mm	Secondary winding wire outer diameter with insulation for output 2
151	OD_SECONDARY2_BARE			0.000	mm	Secondary winding wire outer diameter without insulation for output 2
152	CM_SECONDARY2			0	Cmils	Bare conductor effective area in circular mils for output 2
153	NSECONDARY2			0		Number of turns for output 2
154	VREVERSE_RECTIFIER2			0.00	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 2
155	SRFET2	AUTO		NA		Secondary rectifier (Logic MOSFET) for output 2
156	VF_SRFET2			NA	V	SRFET on-time drain voltage for output 2
157	VBREAKDOWN_SRFET2			NA	V	SRFET breakdown voltage for output 2
158	RDSON_SRFET2			NA	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 2
160	**OUTPUT 3**					
161	VOUT3			0.00	V	Output 3 voltage
162	IOUT3			0.000	A	Output 3 current
163	POUT3			0.00	W	Output 3 power
164	IRMS_SECONDARY3			0.000	A	Root mean squared value of the secondary current for output 3
165	IRIPPLE_CAP_OUTPUT3			0.000	A	Current ripple on the secondary waveform for output 3
166	AWG_SECONDARY3			0	AWG	Wire size for output 3
167	OD_SECONDARY3_INSULATED			0.000	mm	Secondary winding wire outer diameter with insulation for output 3
168	OD_SECONDARY3_BARE			0.000	mm	Secondary winding wire outer diameter without insulation for output 3
169	CM_SECONDARY3			0	Cmils	Bare conductor effective area in circular mils for output 3
170	NSECONDARY3			0		Number of turns for output 3
171	VREVERSE_RECTIFIER3			0.00	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 3
172	SRFET3	AUTO		NA		Secondary rectifier (Logic MOSFET) for output 3
173	VF_SRFET3			NA	V	SRFET on-time drain voltage for output 3
174	VBREAKDOWN_SRFET3			NA	V	SRFET breakdown voltage for output 3
175	RDSON_SRFET3			NA	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 3
177	PO_TOTAL			60.00	W	Total power of all outputs
178	NEGATIVE OUTPUT	N/A		N/A		If negative output exists, enter the output number; e.g. If VO2 is negative output, select 2
182	**TOLERANCE ANALYSIS**					
183	USER_VAC	115		115	V	Input AC RMS voltage corner to be evaluated
184	USER_ILIMIT	TYP		2.130	A	Current limit corner to be evaluated
185	USER_LPRIMARY	TYP		549.3	uH	Primary inductance corner to be evaluated
186	MODE_OPERATION			DCM		Mode of operation

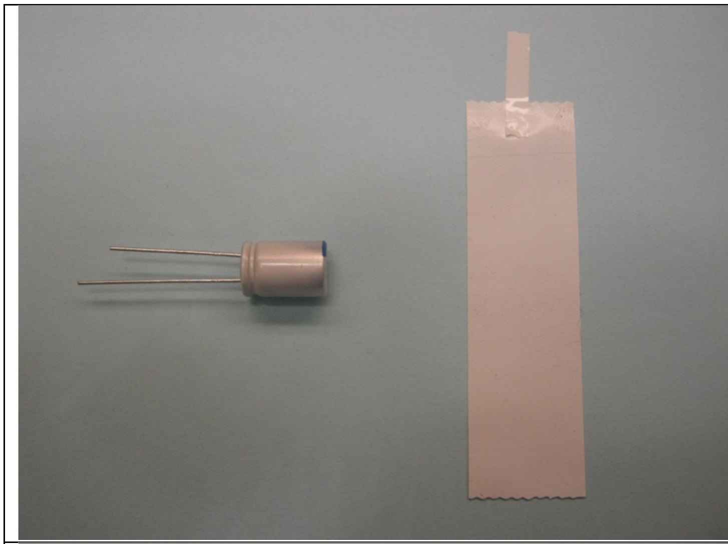
187	KP			1.170		Measure of continuous/discontinuous mode of operation
188	FSWITCHING			58219	Hz	Switching frequency at full load and valley of the rectified minimum AC input voltage
189	VMIN			133.33	V	Valley of the minimum input AC voltage at full load
190	DUTYCYCLE			0.477		Steady state duty cycle
191	TIME_ON			8.19	us	Primary switch on-time
192	TIME_OFF			8.98	us	Primary switch off-time
193	IPEAK_PRIMARY			1.984	A	Primary switch peak current
194	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
195	IAVERAGE_PRIMARY			0.473	A	Primary switch average current
196	IRIPPLE_PRIMARY			1.984	A	Primary switch ripple current
197	IRMS_PRIMARY			0.791	A	Primary switch RMS current
198	BPEAK			3326	Gauss	Peak flux density
199	BMAX			3028	Gauss	Maximum flux density
200	BAC			1514	Gauss	AC flux density (0.5 x Peak to Peak)

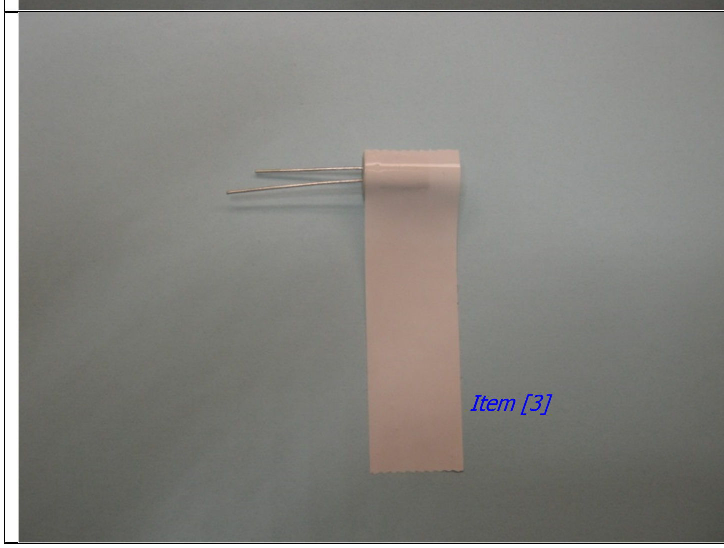
10 PCB Assembly Instructions

10.1 *Materials*

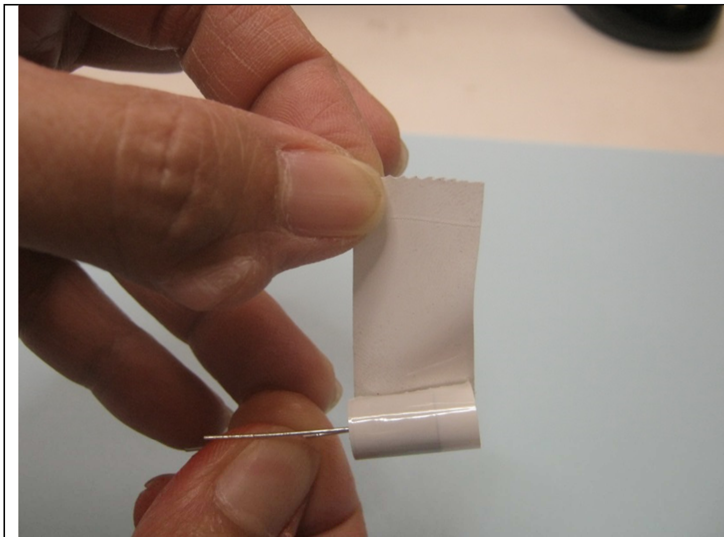
Item	Description
[1]	Capacitor C8 on DER-868 Schematic.
[2]	Capacitor C9 on DER-868 Schematic.
[3]	Tape: 3M 1298 Polyester Film, 1 mil Thick, 16.4 mm Wide, 25 mm Long.
[4]	Tape: 3M 1298 Polyester Film, 1 mil Thick, 5.0 mm Wide, 15 mm Long.
[5]	Tape: 3M 4026W Double Coated Urethane Foam Tape 1.6 mm Thick, 12.7 mm Wide, 22 mm Long.

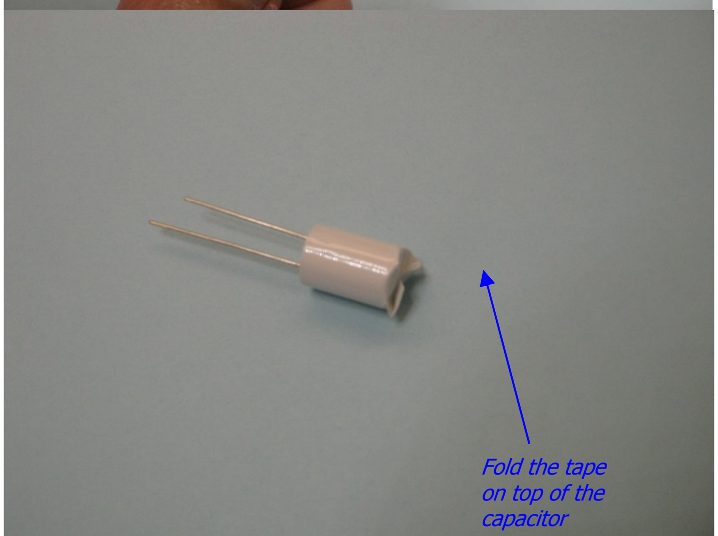
10.2 *Output Capacitor Assembly Instructions*

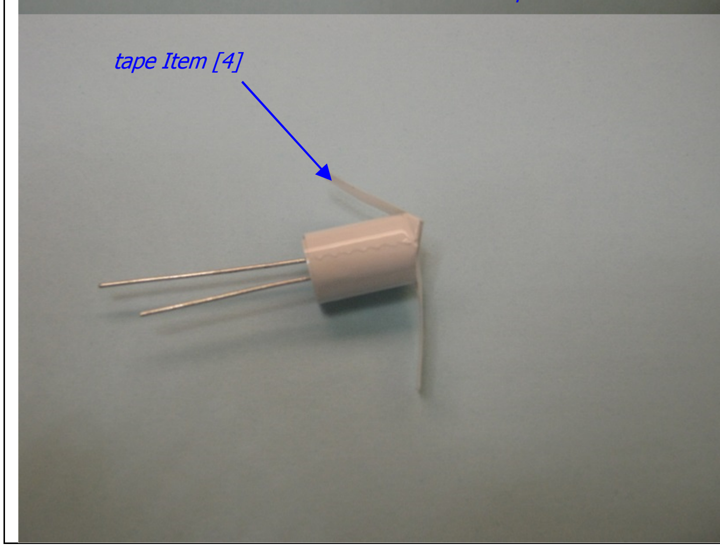


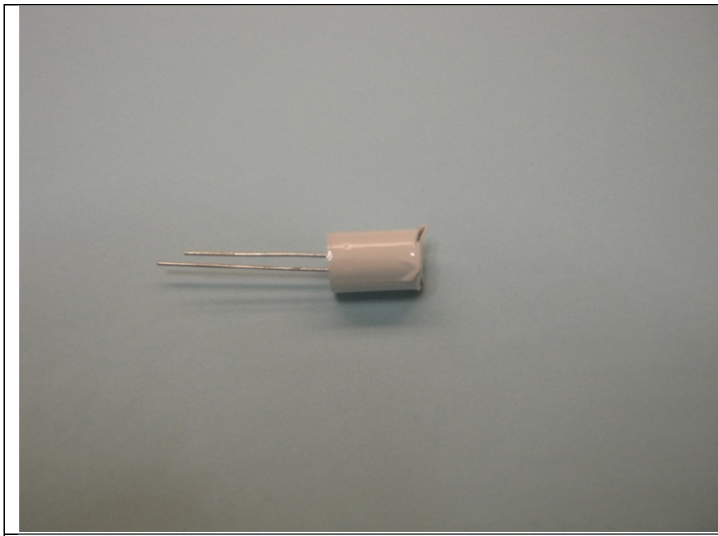
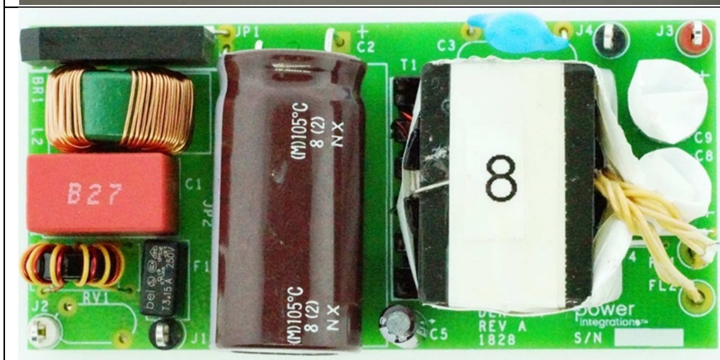


Wrap C8 and C9 with tape Item [3] to insulate the capacitor form transformer core.




Fold the tape
on top of the
capacitor


tape Item [4]

	
	Finish assembly.

Note: Cut all the TH (PTH and NPTH) pins to <0.5 mm on the bottom side of the board after completing the assembly.

11 Performance Data

All the performance data have been taken on the board unless otherwise specifically mentioned.

11.1 *Full-load Efficiency vs. Line*

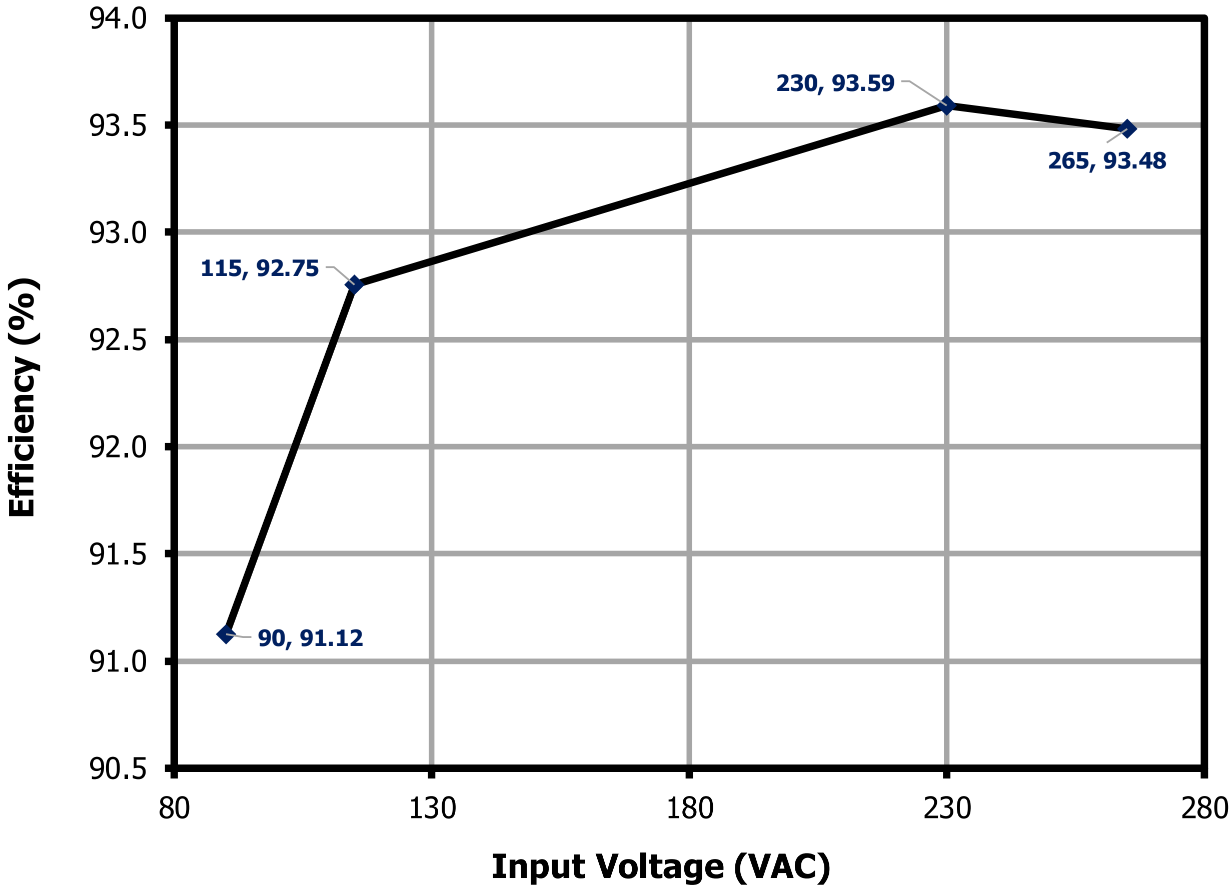


Figure 9 – Full-load Efficiency vs. Line, Room Ambient.

11.2 ***No-Load Input Power***

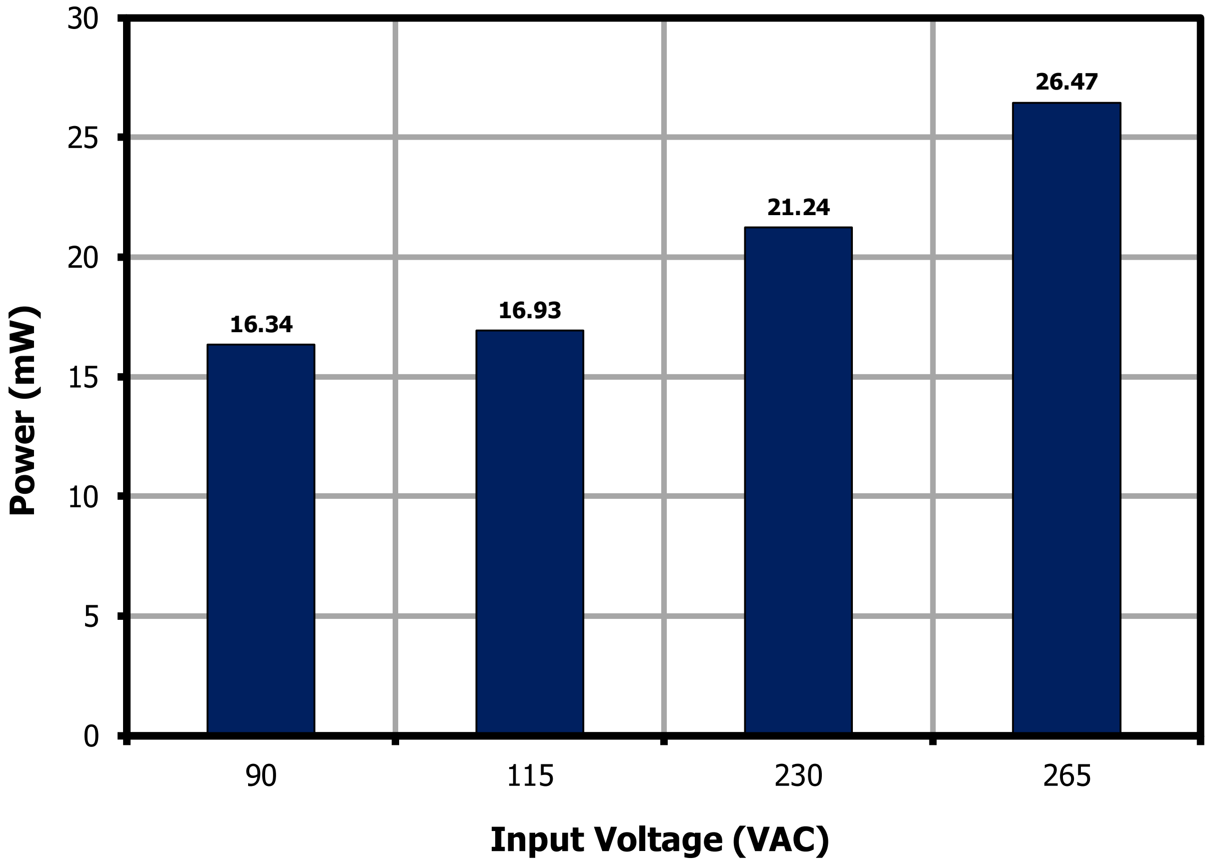


Figure 10 – No-Load Input Power vs. Input Line Voltage, Room Temperature.

11.3 *Average Efficiency*

		Test	Average	Average	10% Load
Output Voltage	**Model**	**Power [W]**	**DOE6 Limit**	**CoC v5 Tier 2**	**CoC v5 Tier 2**
12	>6 V	60	88.00%	89.00%	79.00%

11.4 *Average and 10% Efficiency at 90 VAC Input*

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	60.36	91.12	92.02
75	45.65	92.12	
50	30.71	92.42	
25	15.51	92.40	
10	6.18	90.44	

11.5 *Average and 10% Efficiency at 115 VAC Input*

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	60.67	92.75	92.83
75	45.89	92.88	
50	30.78	93.03	
25	15.53	92.66	
10	6.18	90.41	

11.6 *Average and 10% Efficiency at 230 VAC Input*

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	61.05	93.59	93.18
75	46.07	93.48	
50	30.84	93.29	
25	15.54	92.38	
10	6.18	88.82	

11.7 *Average and 10% Efficiency at 265 VAC Input*

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	61.16	93.48	92.97
75	46.04	93.32	
50	30.85	93.10	
25	15.53	91.97	
10	6.18	88.03	

12 Thermal Performance

12.1 *90 VAC, 60 W at 25.9 ºC Ambient*

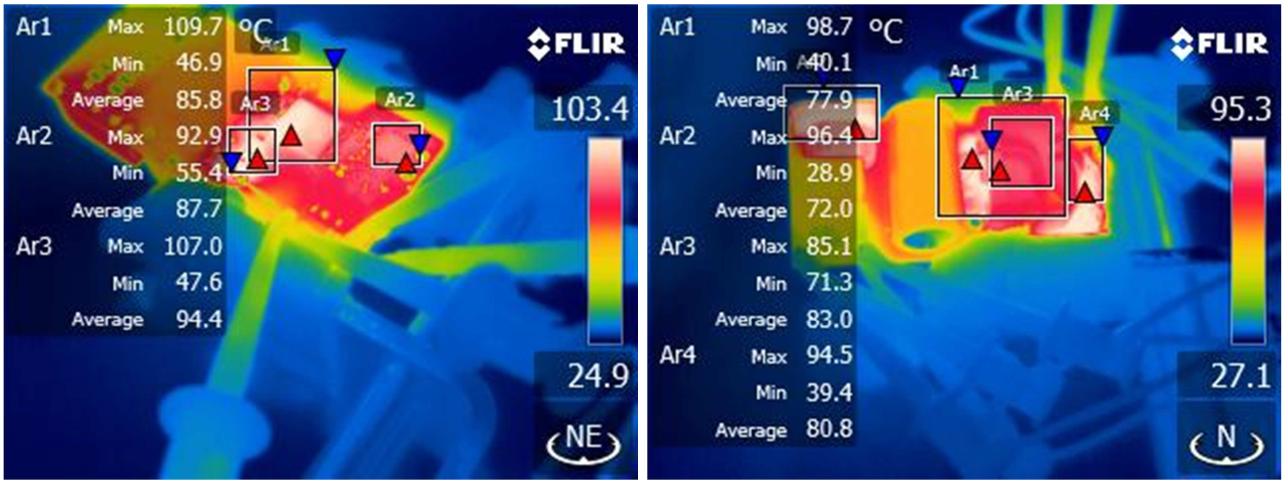


Figure 11 – Thermal Performance.

Test condition setting: full load soaking up for 120 mins

Component	**Transformer Core (EQ25)**	**Transformer Winding (T1)**	**Bridge Rectifier (BR1)**	**InnoSwitch3-EP (U1)**	**Primary-side RCD Snubber**	**SR FET (Q1)**
Max Temperature (ºC)	85.1	98.7	96.4	109.7	107	92.9

12.2 *265 VAC Input, 60 W at 25.2 ºC Ambient*

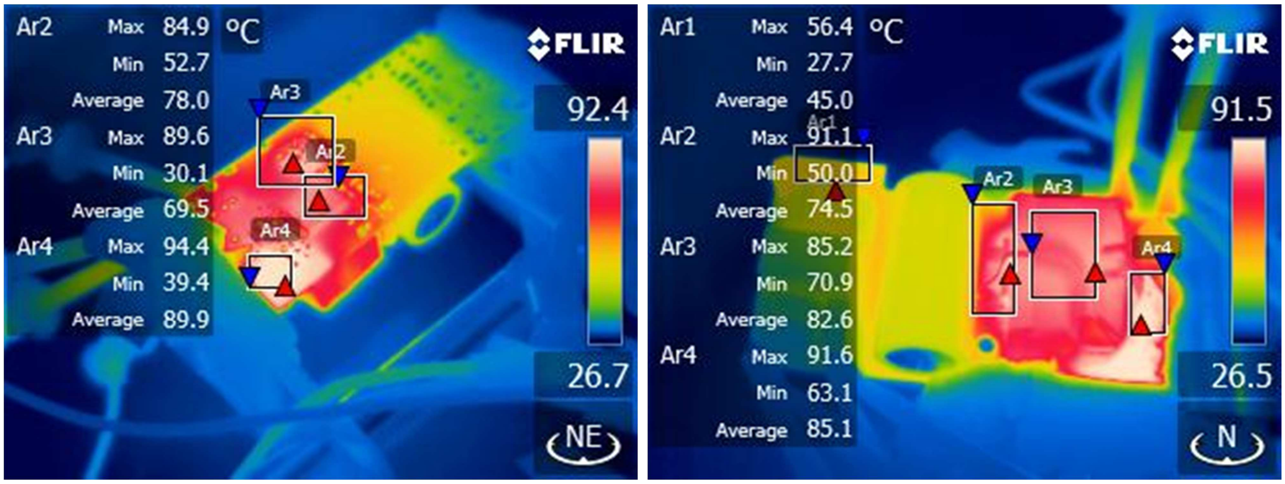


Figure 12 – Thermal Performance Over Time.

Test condition setting: full load soaking up for 120 mins.

Component	Transformer Core (EQ25)	Transformer Winding (T1)	Bridge Rectifier (BR1)	InnoSwitch3-EP (U1)	Primary-side RCD Snubber	SR FET (Q1)
Max Temperature (ºC)	85.2	91.1	56.4	84.9	89.6	94.4

13 Waveforms

13.1 *Output Voltage Start-up waveforms:*

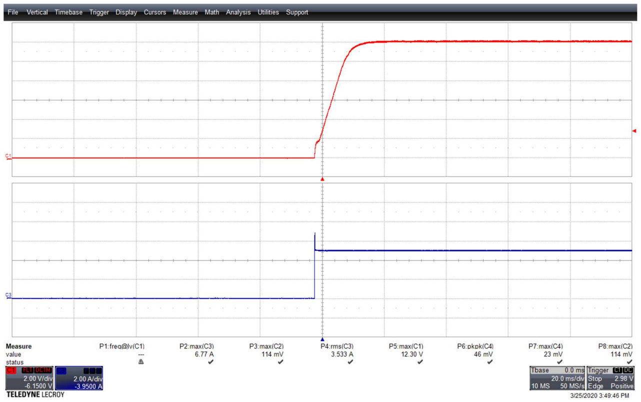


Figure 13 – Output Voltage Start-up – 100% Load
90 VAC.
C1/Upper – Output Voltage – 2 V / div.
C3/Lower – Output Current – 2 A / div.
10 ms / div.

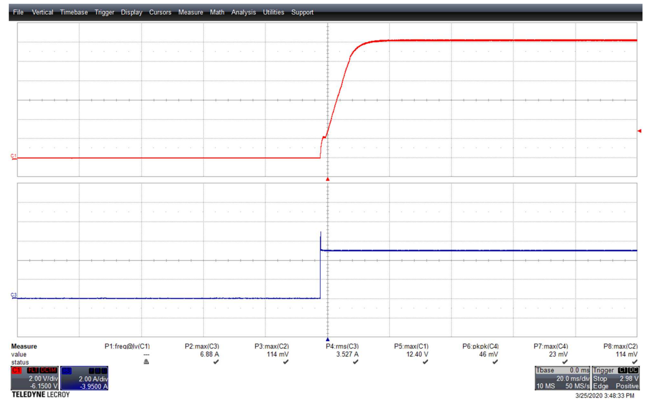


Figure 14 – Output Voltage Start-up – 100% Load
265 VAC.
C1/Upper – Output Voltage – 2 V / div.
C3/Lower – Output Current – 2 A / div.
20 ms / div.

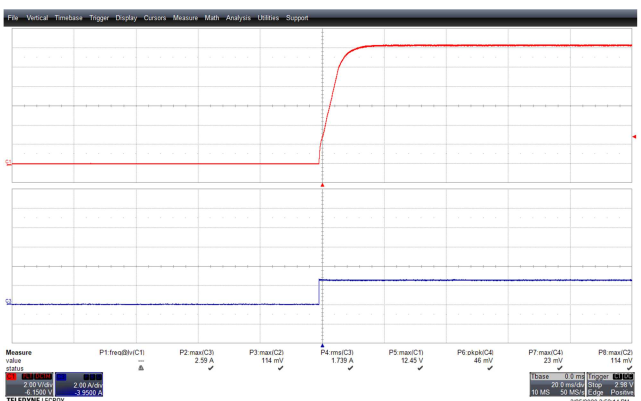


Figure 15 – Output Voltage Start-up – 50%Load 90 VAC.
C1/Upper – Output Voltage – 2 V / div.
C2/Lower – Output Current – 2 A / div.
10 ms / div.

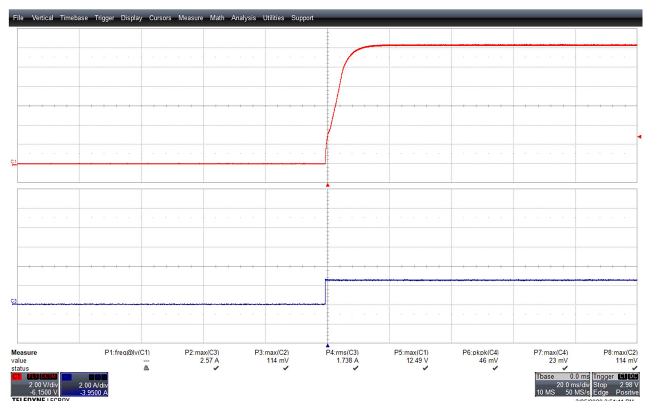


Figure 16 – Output Voltage Start-up – 50% Load
265 VAZ.
C1/Upper – Output Voltage – 2 V / div.
C3/Lower – Output Current – 2 A / div.
20 m s/ div.

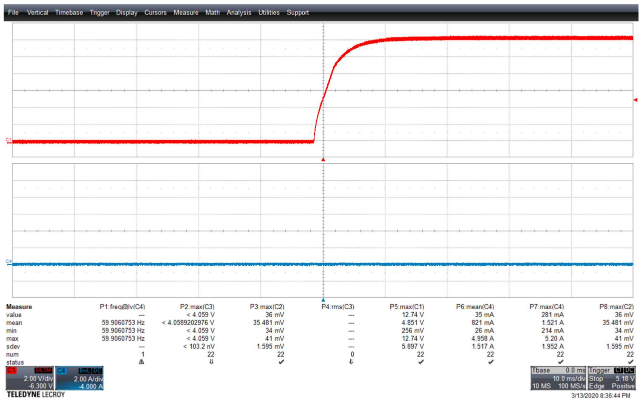


Figure 17 – Output Voltage Start-up – No-Load 90 VAC.
C1/Upper – Output Voltage – 2 V / div.
C2/Lower – Output Current – 2 A / div.
10 ms / div.

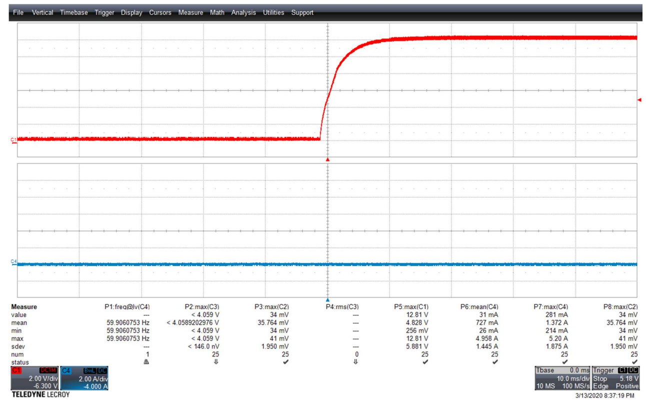


Figure 18 – Output Voltage Start-up – No-Load 265 VAC.
C1/Upper – Output Voltage – 2 V / div.
C2/Lower – Output Current – 2 A / div.
10 ms / div.

13.2 *Load Transient Response (On Board)*

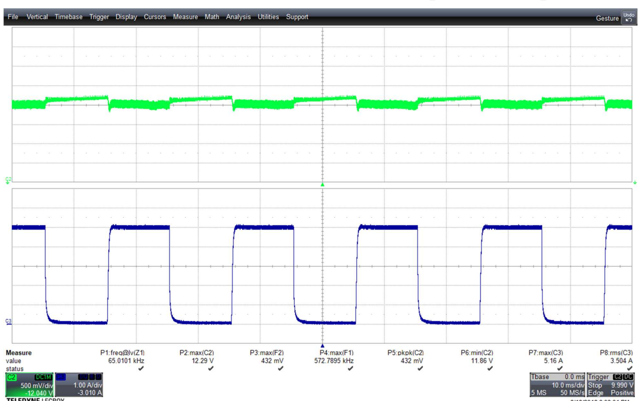


Figure 19 – Transient Response.
90 VAC, 0% – 100% Load Step.
V_{MIN}: 11.86 V, V_{MAX}: 12.29 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

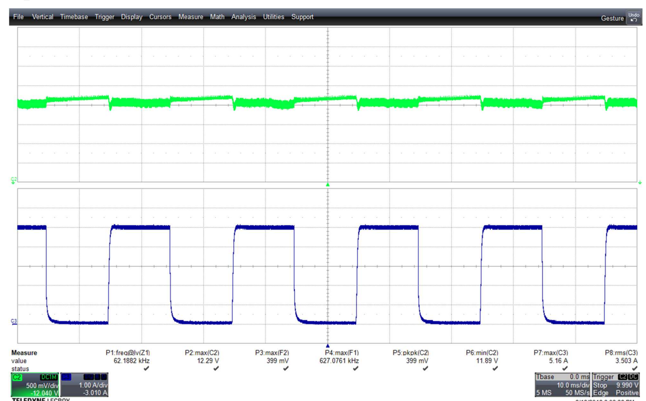


Figure 20 – Transient Response.
115 VAC, 0% – 100% Load Step.
V_{MIN}: 11.89 V, V_{MAX}: 12.29 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

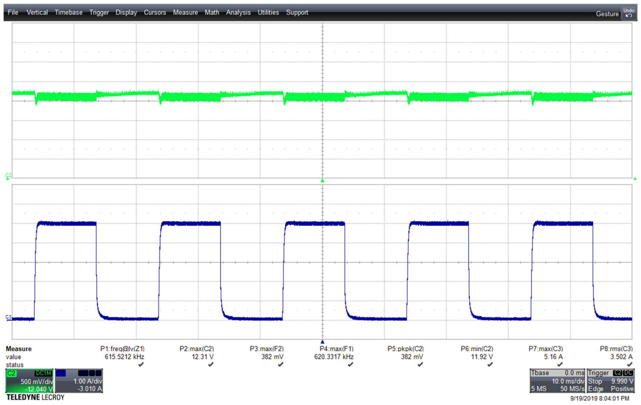


Figure 21– Transient Response.
230 VAC, 0% – 100% Load Step.
V_{MIN}: 11.92 V, V_{MAX}: 12.31 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

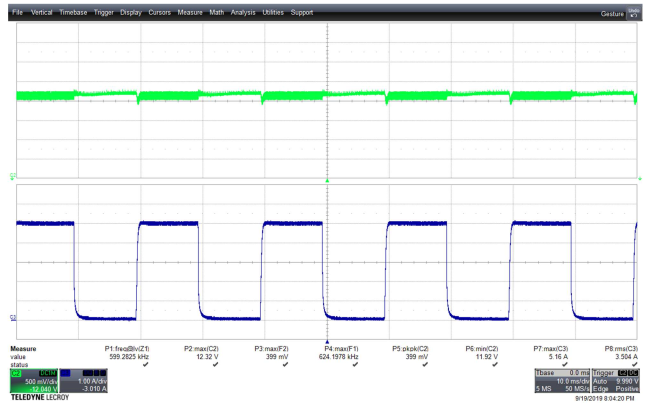


Figure 22 – Transient Response.
265 VAC, 0% – 100% Load Step.
V_{MIN}: 11.92 V, V_{MAX}: 12.32 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

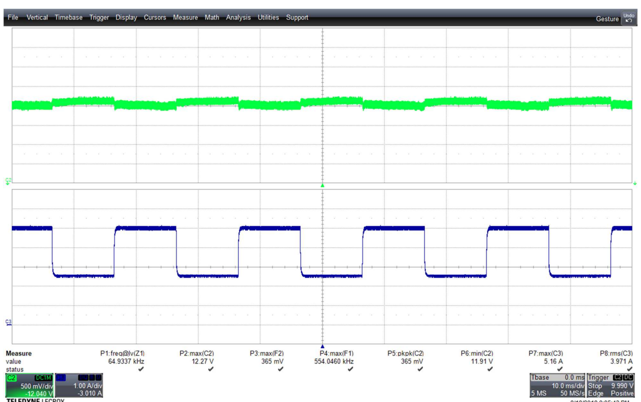


Figure 23– Transient Response.
90 VAC, 50% – 100% Load Step.
V_{MIN}: 11.86 V, V_{MAX}: 12.29 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

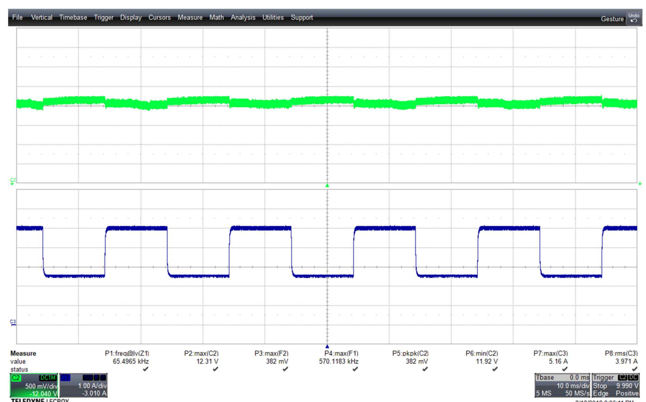


Figure 24 – Transient Response.
115 VAC, 50% – 100% Load Step.
V_{MIN}: 11.89 V, V_{MAX}: 12.29 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

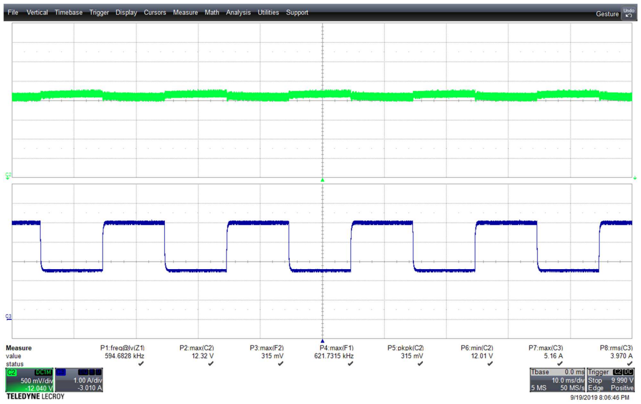


Figure 25– Transient Response.
230 VAC, 50% – 100% Load Step.
V_{MIN}: 11.92 V, V_{MAX}: 12.31 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

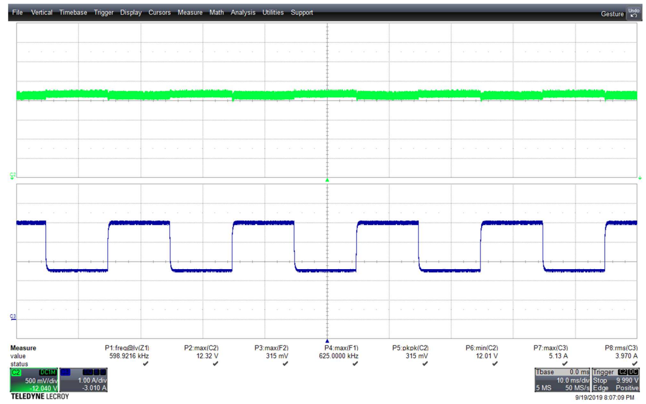


Figure 26 – Transient Response.
265 VAC, 50% – 100% Load Step.
V_{MIN}: 11.92 V, V_{MAX}: 12.32 V.
Upper: V_{OUT}, 0.5 V / div., 10 ms / div.
Lower: I_{LOAD}, 1 A / div.

13.3 ***Switching Waveforms***

13.3.1 Drain Voltage and Current

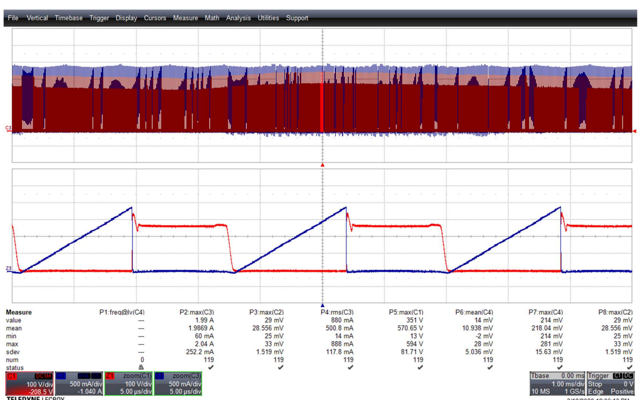


Figure 27 – Drain Voltage and Current Waveforms.
90 VAC, 100% Load.
C1/Z1: V_{DRAIN}, 100 V / div.
C3/Z3: I_{DRAIN}, 0.5 A / div., 5 μs / div.

Figure 28 – Drain Voltage and Current Waveforms.
265 VAC, 100% Load.
C1/Z1: V_{DRAIN}, 100 V / div.
C3/Z3: I_{DRAIN}, 0.5 A / div., 5 μs / div.

13.3.2 SR FET Voltage

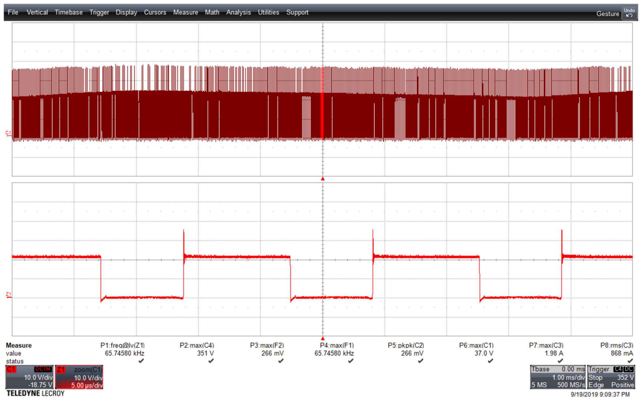


Figure 29 – SR FET Voltage Waveforms.
90 VAC, 100% Load, (37.0 V_{MAX}).
C1: SR_V_{DRAIN}, 10 V / div., 5 µs / div.

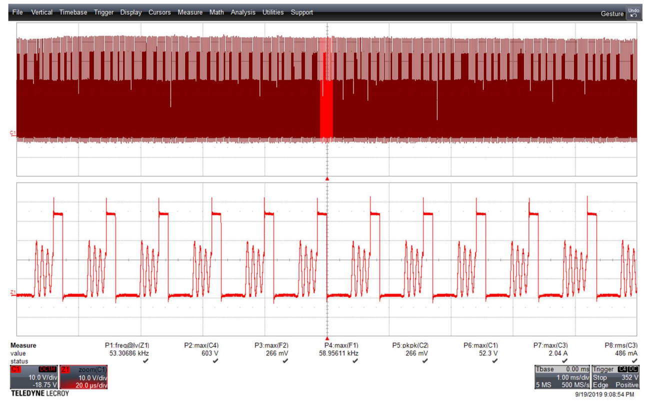


Figure 30 – SR FET Voltage Waveforms.
265 VAC, 100% Load, (52.3 V_{MAX}).
C1: SR_V_{DRAIN}, 10 V / div., 5 µs / div.

13.4 ***Output Ripple Measurements***

13.4.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick-up. Details of the probe modification are provided in the Figures below.

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 47 μF/50 V aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

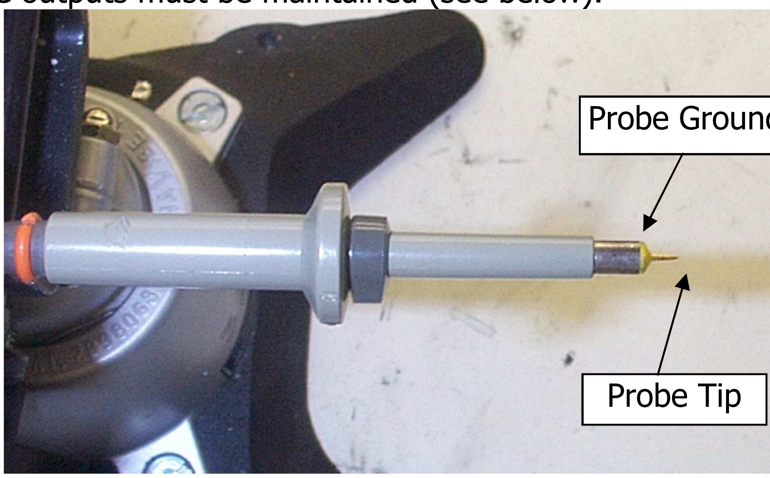


Figure 31 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

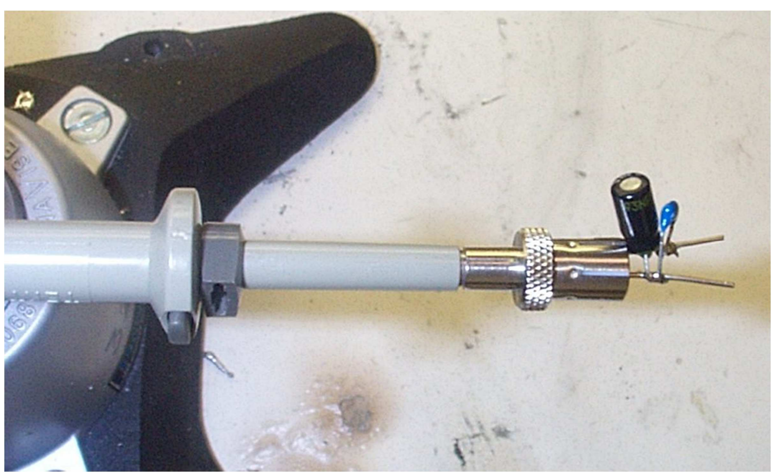


Figure 32 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

13.5 ***Ripple waveforms***

13.5.1.1 100% Load

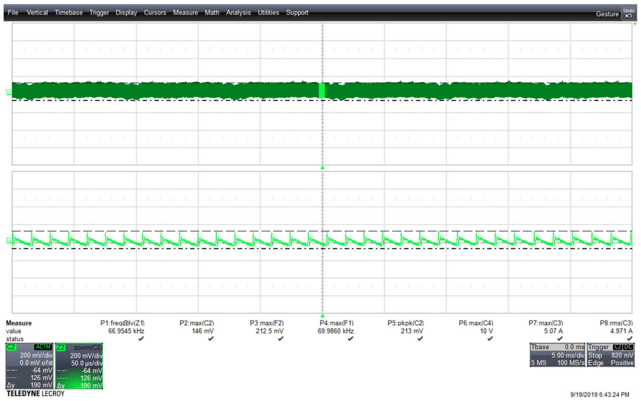


Figure 33 – Output Ripple.(PK-PK – 213 mV).
90 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

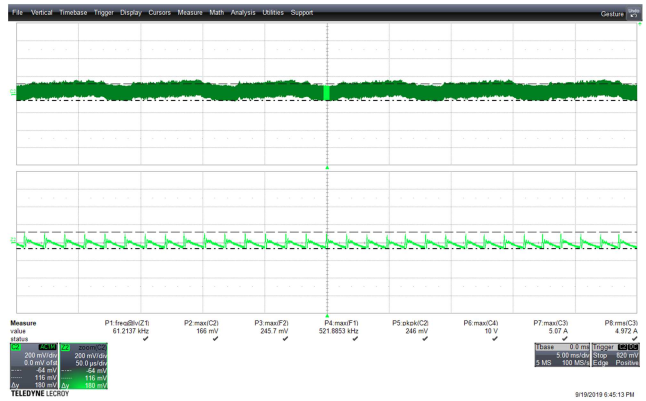


Figure 34 – Output Ripple.(PK-PK – 246 mV).
115 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

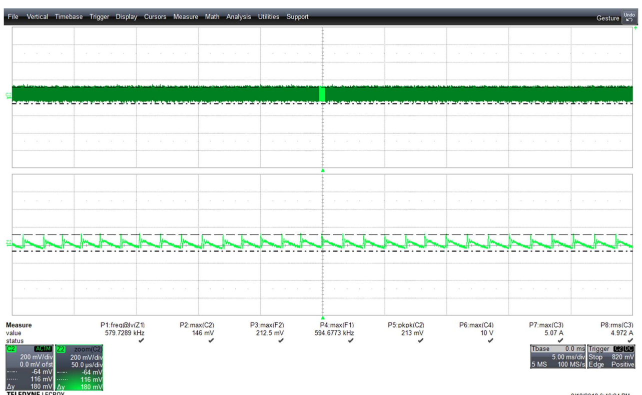


Figure 35 – Output Ripple.(PK-PK – 213 mV).
230 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

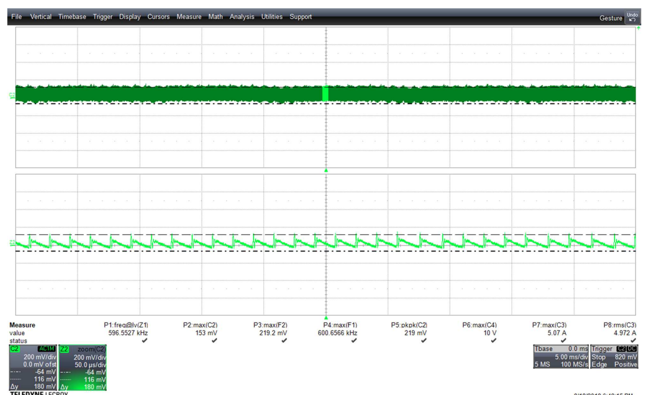


Figure 36 – Output Ripple.(PK-PK – 219 mV).
265 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

13.5.1.2 75% Load

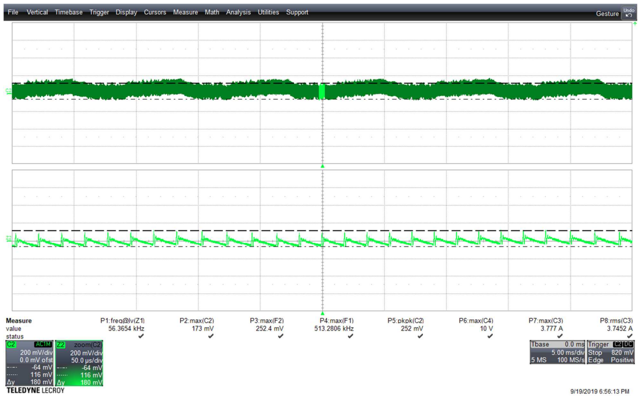


Figure 37 – Output Ripple.(PK-PK – 252 mV).
90 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

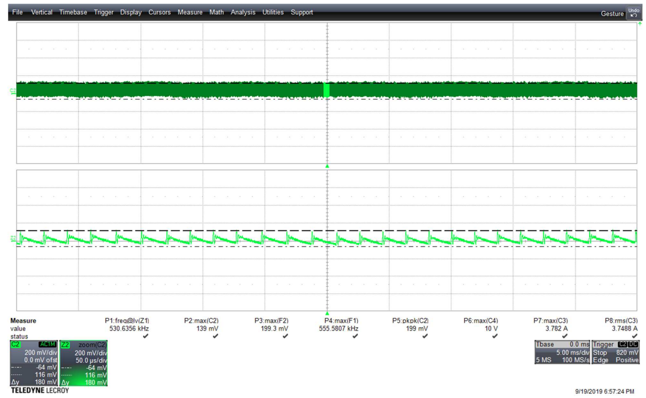


Figure 38 – Output Ripple.(PK-PK – 199 mV).
115 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

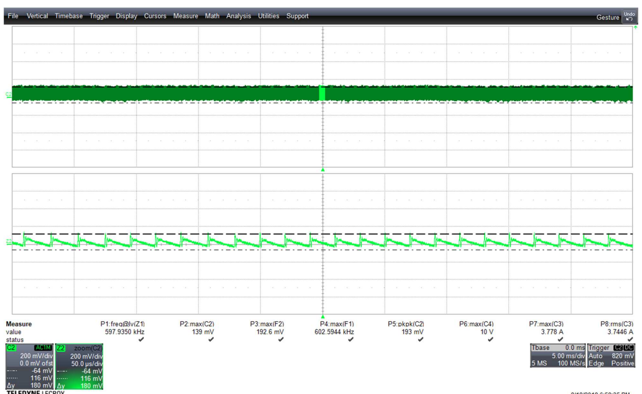


Figure 39 – Output Ripple.(PK-PK – 193 mV).
230 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

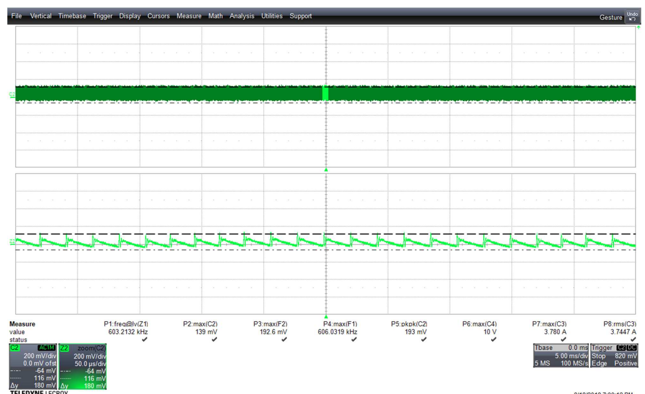


Figure 40 – Output Ripple.(PK-PK – 219 mV).
265 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

13.5.1.3 50% Load

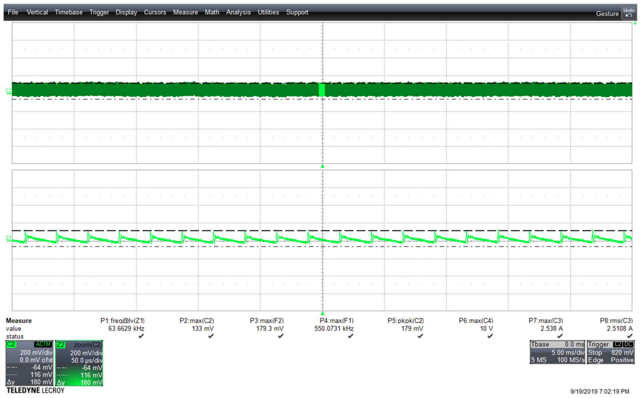


Figure 41 – Output Ripple.(PK-PK – 179 mV).
90 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

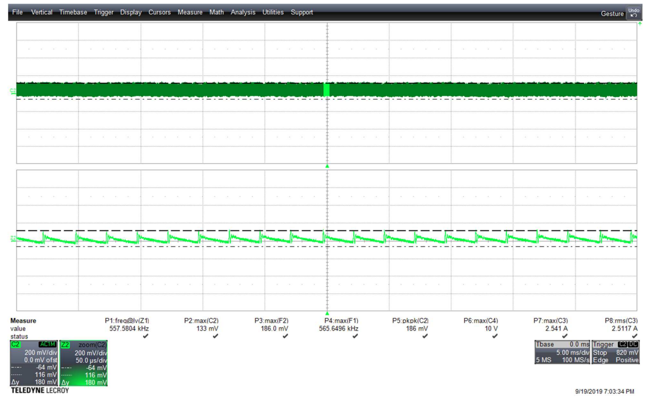


Figure 42 – Output Ripple.(PK-PK – 186 mV).
115 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

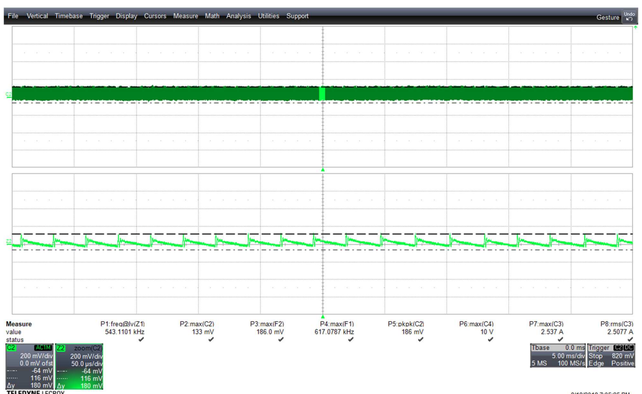


Figure 43 – Output Ripple.(PK-PK – 186 mV).
230 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

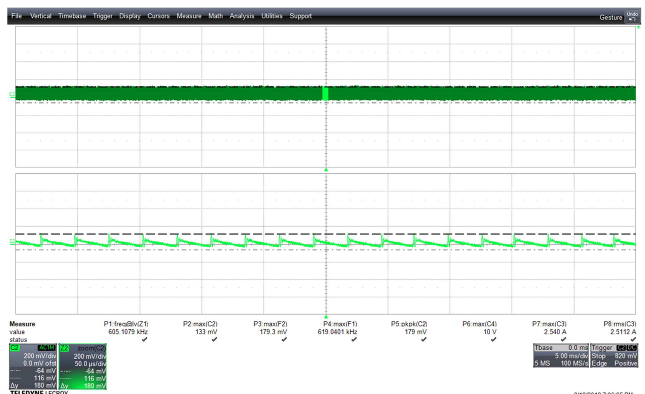


Figure 44 – Output Ripple.(PK-PK – 179 mV).
265 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

13.5.1.4 25% Load

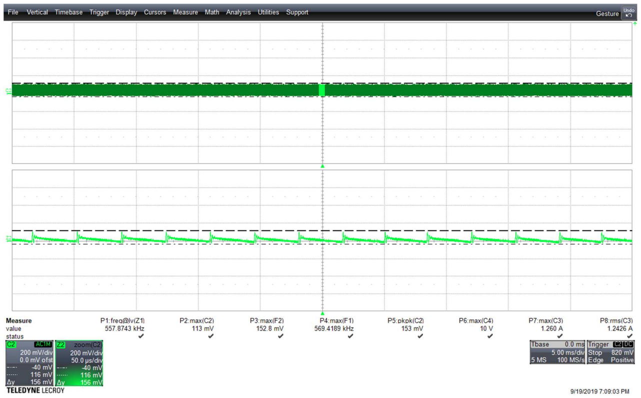


Figure 45 – Output Ripple.(PK-PK – 153 mV).
90 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

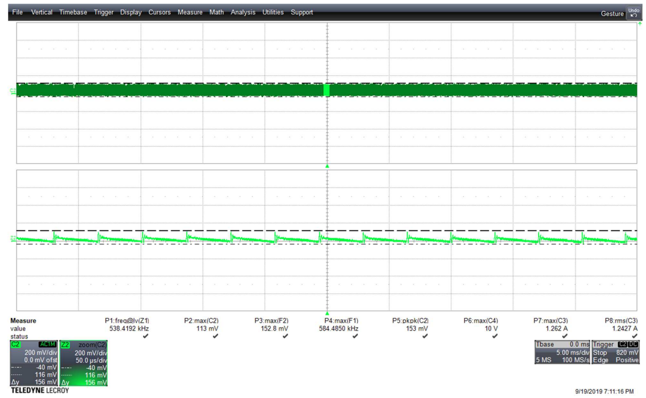


Figure 46 – Output Ripple.(PK-PK – 153 mV).
115 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

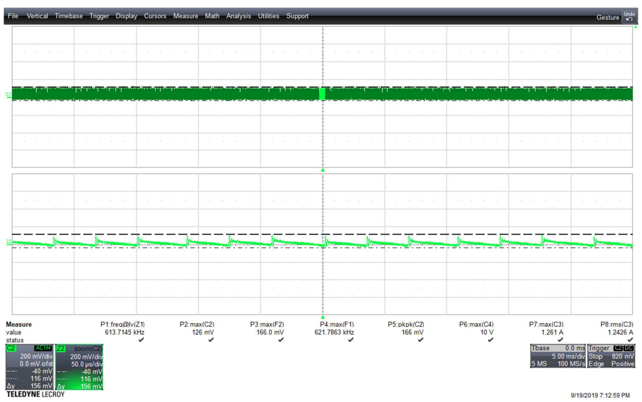


Figure 47 – Output Ripple.(PK-PK – 166 mV).
230 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

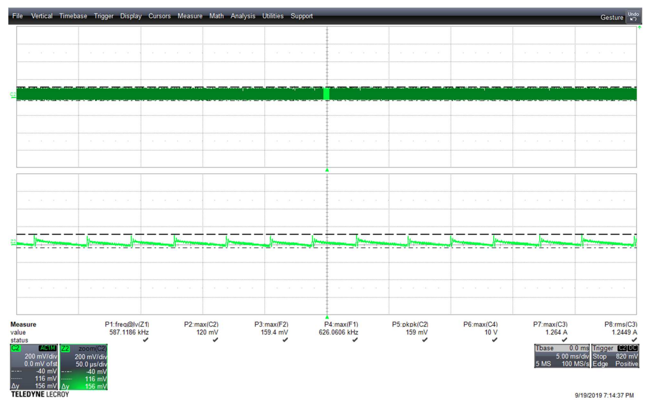


Figure 48 – Output Ripple.(PK-PK – 159 mV).
265 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

13.5.1.5 10% Load

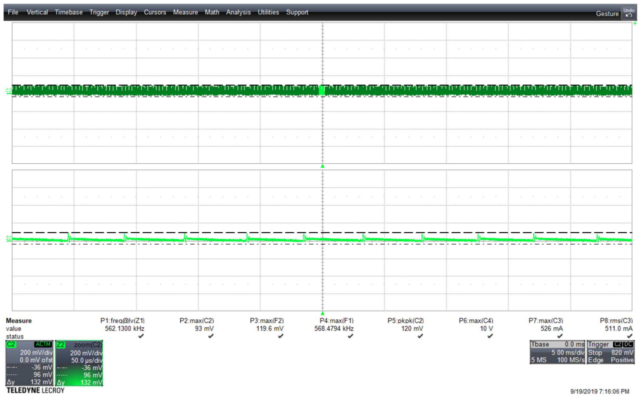


Figure 49 – Output Ripple.(PK-PK – 120 mV).
90 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

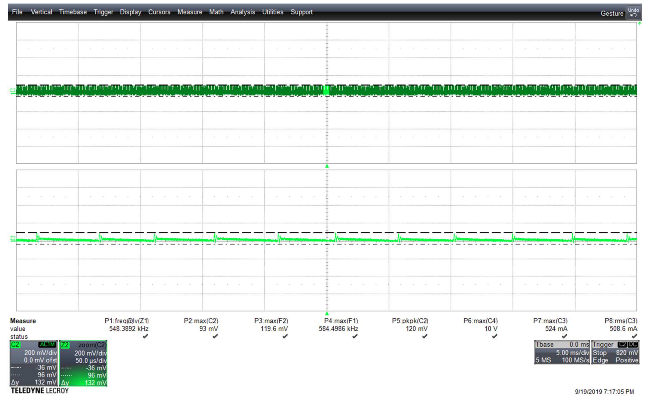


Figure 50 – Output Ripple.(PK-PK – 120 mV).
115 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

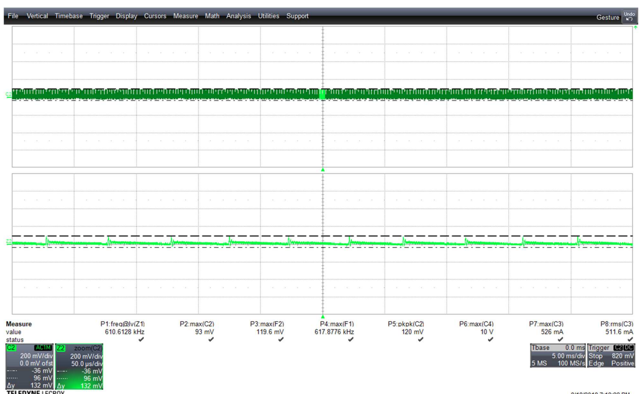


Figure 51 – Output Ripple.(PK-PK – 120 mV).
230 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

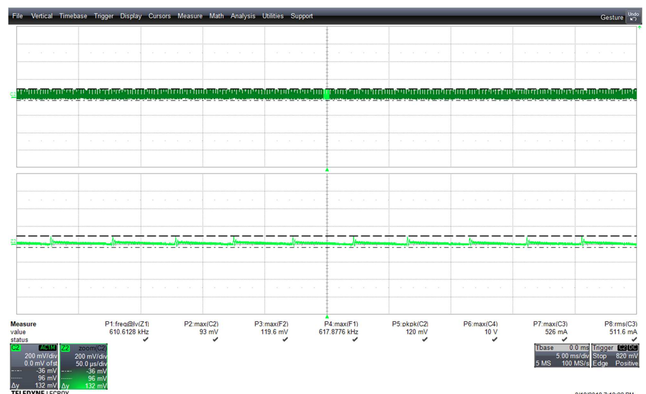


Figure 52 – Output Ripple.(PK-PK – 120 mV).
265 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

14 Conducted EMI

14.1 *Earth Ground(QP / AV)*

14.1.1 12 V, 100% Load

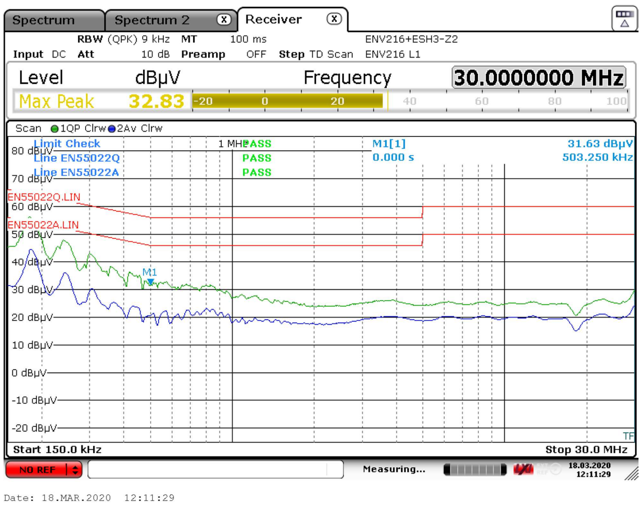


Figure 53 – Earth Ground EMI 12 V / 100% Load for 115 VAC – Line L1.

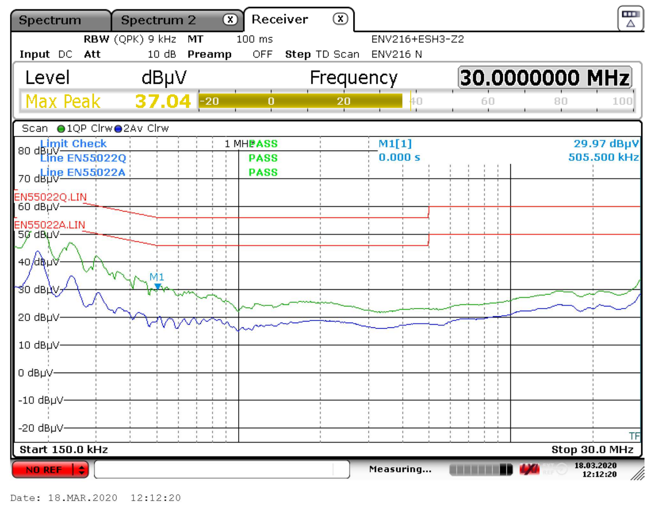


Figure 54 – Earth Ground EMI , 12 V / 100% Load for 115 VAC - Neutral.

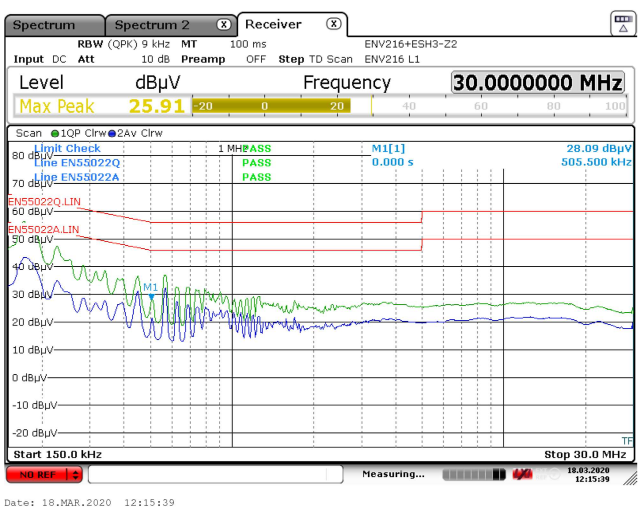


Figure 55 – Earth Ground EMI , 12 V / 100% Load for 230 VAC – L1.

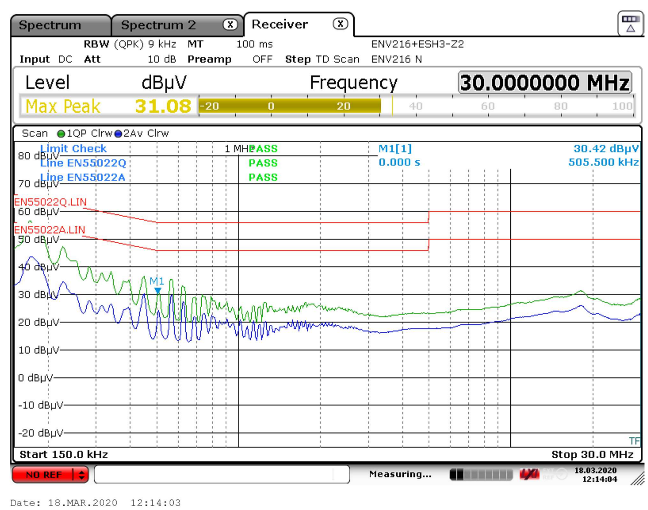


Figure 56 – Earth Ground EMI , 12 V / 100% Load for 230 VAC - Neutral.

15 Line Surge

15.1 *Combination Wave Differential Mode Test*

Passed ±1 kV.

Surge Voltage (kV)	Phase Angle (°)	Generator Impedance (W)	Number of Strikes	Test Result
±1	0	2	10	PASS
±1	90	2	10	PASS
±1	180	2	10	PASS
±1	270	2	10	PASS

Note: Input line OVP gets triggered when the test is done at no-load.

16 ESD

Passed ±15 kV air discharge and ±8.8 kV contact discharge at both output positive and negative terminals, under both full-load and no-load conditions.

Air Discharge (kV)	Number of Strikes	Test Result
+15.0	10	PASS
-15.0	10	PASS

Contact Discharge (kV)	Number of Strikes	Test Result
+8.8	10	PASS
-8.8	10	PASS

17 Revision History

Date	Author	Revision	Description & Changes	Reviewed
23-Apr-20	SK	1.0	First draft	SS
09-Aug-21	KM	1.1	Updated Transformer Details.	Apps & Mktg
18-Aug-21	SS	1.2	Added J1-J2-J3-J4 to the BOM	Apps & Mktg
04-Feb-22	KM	1.3	Added Supplier Information for T1 L1 L2	Apps & Mktg

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