Design Example Report

Title	***45 W Isolated Flyback Power Supply Using InnoSwitch™3-EP PowiGaN™ INN3678C-H606***
Specification	90 VAC – 265 VAC Input; 20 V / 2.25 A Output
Application	Adapter
Author	Applications Engineering Department
Document Number	DER-909
Date	September 22, 2022
Revision	1.0

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 at 230 VAC input
- Primary sensed overvoltage protection
- Very low component count: 39 components
- >6db margin on conducted EMI
- Very high average efficiency
  - >93% at 115 VAC and 230 VAC
- Very high full-load efficiency
  - 93.57% at 115 VAC and 93.92% at 230 VAC

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
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www.power.com

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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 engineering report describes a 20 V / 2.25 A output charger using the InnoSwitch3-EP INN3678C-H606 IC. 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.

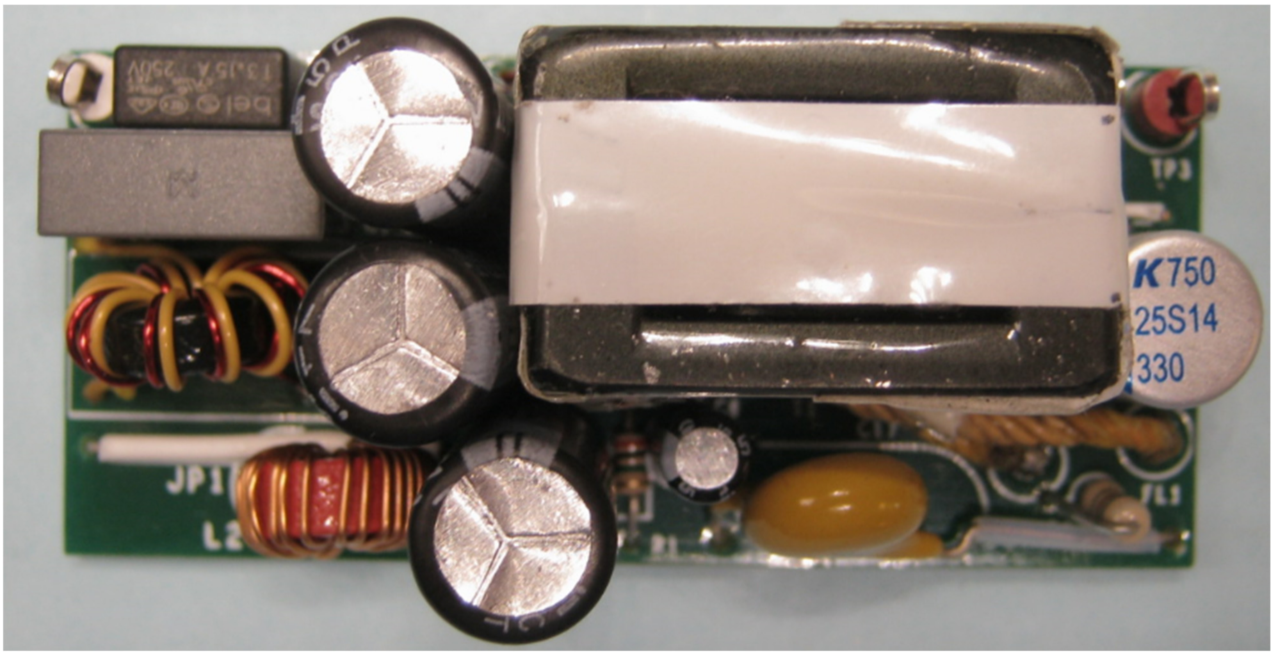


Figure 1 – Populated Circuit Board Photograph, Top.

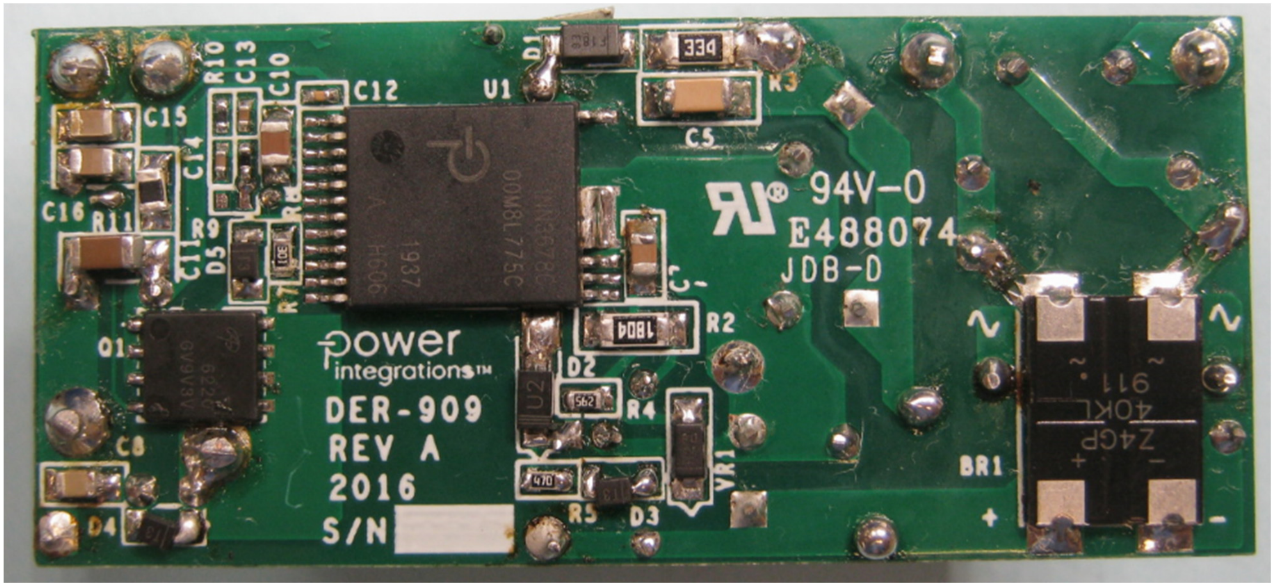


Figure 2 – Populated Circuit Board Photograph, Bottom.

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_{OUT}		20		V	±5%
Output Ripple Voltage	V_{RIPPLE}			600	mV	On Board.
Output Current	I_{OUT}	2.25			A	On Board.
Continuous Output Power	P_{OUT}			45	W	
Conducted EMI						Meets CISPR22B / EN55022B.
Safety						Designed to meet IEC60950 / UL1950 Class II.
Ambient Temperature	T_{AMB}	0		40	ºC	Enclosed in Adapter, Sea Level.

3 Schematic

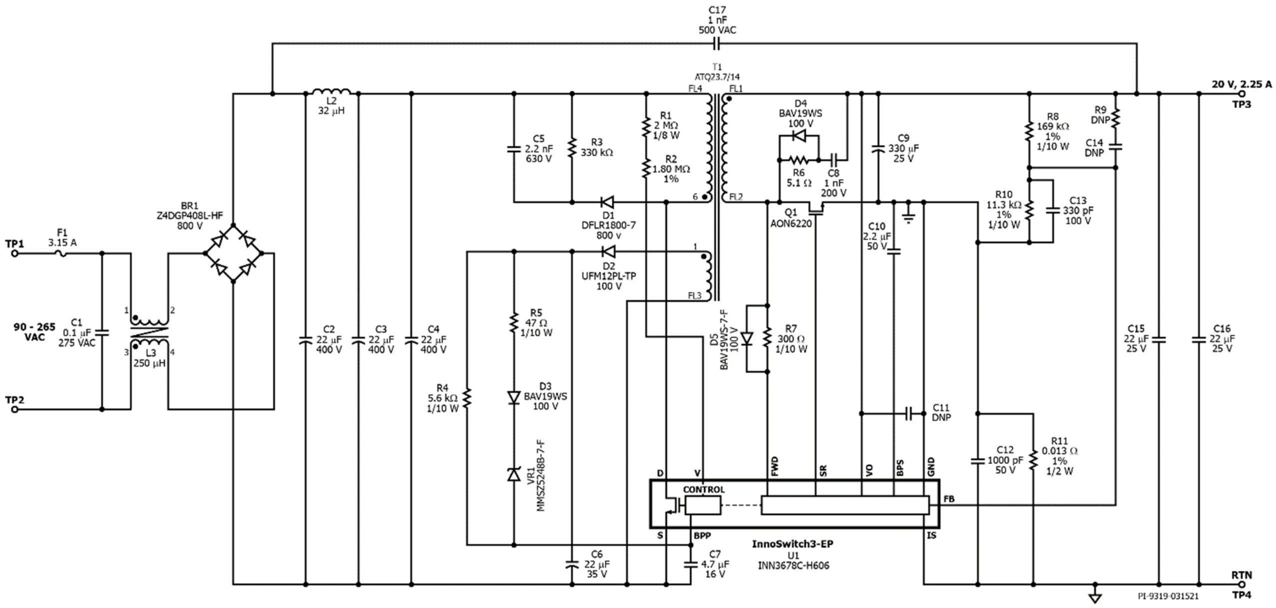


Figure 3 – Power Stage Schematic.

4 Circuit Description

4.1 *Input EMI Filtering*

Fuse F1 isolates the circuit and provides protection from component failure, and the common mode choke L3 and 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. Capacitors C2, C3, C4 along with L2 forms pi filtering and attenuates differential mode noise. Capacitor C17 is used to mitigate the common mode EMI.

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 R1 and R2 provide Input voltage sense protection for under voltage and over voltage conditions.

A low cost RCD clamp formed by diode D1, resistors R3 and capacitor C5 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 C6. Resistor R4 limits the current being supplied to the BPP pin of the InnoSwitch3-EP IC (U1).

Zener diode VR1 along with R5 and D3 offers primary sensed output overvoltage protection. In a flyback converter, output of the auxiliary winding tracks the output voltage of the converter. In case of overvoltage 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 capacitor C9. High frequency ringing during switching transients that would otherwise create radiated EMI is reduced via an RCD snubber R6, C8 and D4. Diode D4 was used to minimize the dissipation in resistor R6.

The gate of Q1 is turned on by secondary-side controller inside IC U1, based on the winding voltage sensed via resistor R7 and fed into the FWD pin of the IC. Diode D5 is used to supply the secondary-side of the IC U1 during power supply start-up.

In continuous conduction mode of operation, the power 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 power 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.

Output current is sensed by monitoring the voltage drop across resistor R11 between the IS and GND pins with a threshold of approximately 35 mV to reduce losses. Capacitor C12 provides filtering on the IS pin from external noise.

The device operates in constant voltage mode before reaching the current limit set by resistor R11. During constant voltage mode operation, output voltage regulation is achieved through sensing the output voltage via divider resistors R8 and R10. The voltage across R10 is fed into the FB pin with an internal reference voltage threshold of 1.265 V. Output voltage is regulated to achieve a voltage of 1.265 V on the FB pin. Capacitor C12 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.

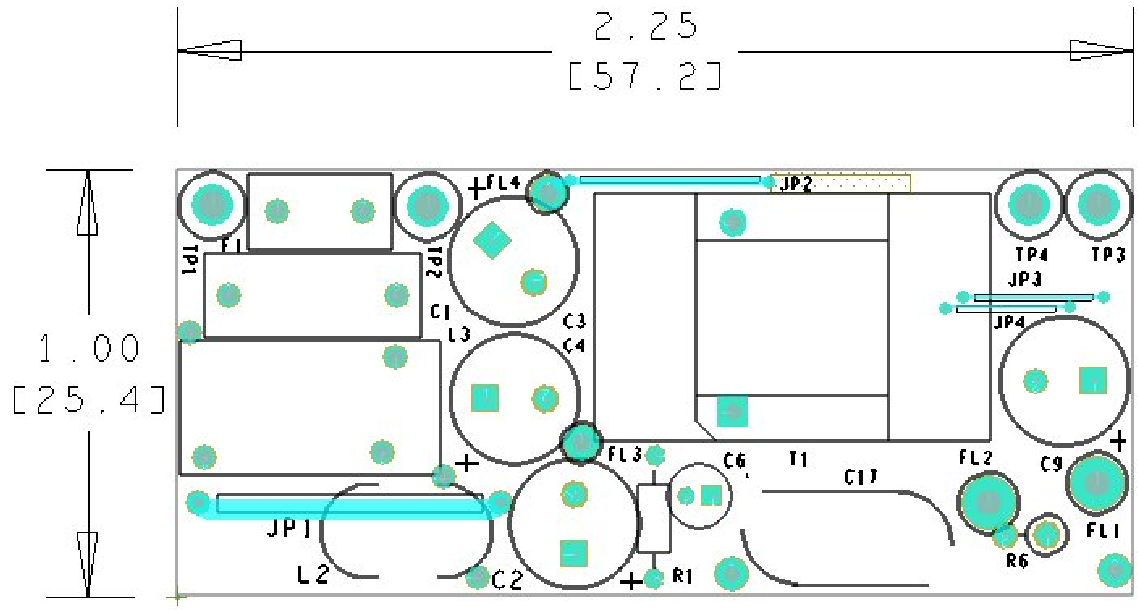


Figure 4 – Printed Circuit Layout, Top.

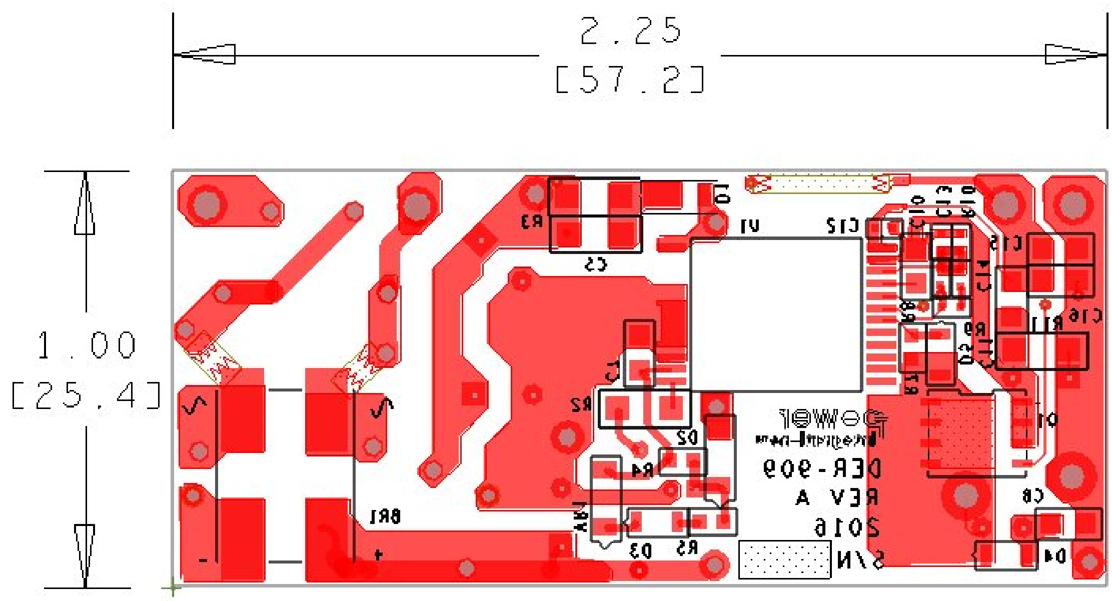


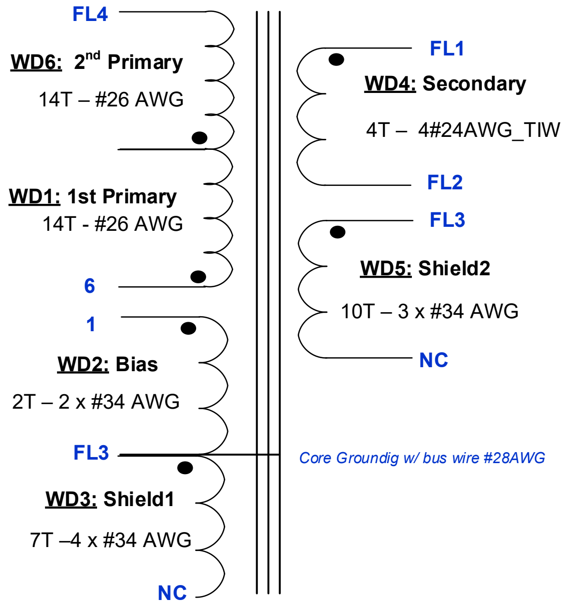
Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Ref Des	Qty	Description	Mfg	Mfg Part Number
1	BR1	1	RECT BRIDGE, GP, 800 V, 4 A, Z4-D	Z4DGP408L-HF	Comchip
2	C1	1	0.1 µF, 20%, 275 VAC, 560 VDC, X2, -40°C ~ 110°C, 5 mm W x 13 mm L x 11.1 mm H	R46KF310000P1M	KEMET
3	C2 C3 C4	3	22 µF, 400 V, Electrolytic, (8 x 20)	ERK2GM220F20OT	AISHI
4	C5	1	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K	TDK
5	C6	1	22 µF, 35 V, Electrolytic, Gen. Purpose, (4 x 12.5)	UVR1V220MDD6TP	Nichicon
6	C7	1	4.7 µF, 16 V, Ceramic, X7R, 0805	CL21B475KOFNNNE	Samsung
7	C8	1	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
8	C9	1	330 µF, ±20%, 25 V, Al Organic Polymer, Gen. Purpose, Can, 18 mΩ, 2000 Hrs @ 105 °C, (8 mm x 13 mm)	A750KS337M1EAAE018	KEMET
9	C10	1	2.2 µF, ±10%, 50 V, Ceramic, X7R, 0805	UMK212BB7225KG-T	Taiyo Yuden
10	C12	1	1000 pF, ±10%, 50 V, X7R, -55°C ~ 125°C, Low ESL, 0402	C0402C102K5RACTU	Kemet
11	C13	2	330 pF, ±10%, 100 V, Ceramic, X7R, 0402	HMK105B7331KV-F	Taiyo Yuden
12	C15 C16	2	22 µF, ±20%, 25 V, Ceramic, X5R, 0805 (2012 Metric)	GRM21BR61E226ME44L	Murata
13	C17	1	1 nF, 500 VAC, Ceramic, Y1	VY1102M35Y5UG63V0	Visha
14	D1	1	800 V, 1 A, Rectifier, POWERDI123	DFLR1800-7	Diodes, Inc.
15	D2	1	100 V, 1 A, Fast Recovery, SOD-123FL	UFM12PL-TP	Micro Commercia
16	D3 D4 D5	3	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
17	F1	1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
18	FL1 FL2	2	Flying Lead, Hole size 70mils	N/A	N/A
19	FL3 FL4	2	Flying Lead, Hole size 50mils	N/A	N/A
20	JP1	1	Wire Jumper, Insulated, #24 AWG, 0.7 in	C2003A-12-02	Gen Cable
21	JP2	1	Wire Jumper, Insulated, #28 AWG, 0.5 in	2842/1 WH005	Alpha Wire
22	JP3 JP4	2	Wire Jumper, Insulated, #28 AWG, 0.3 in	2842/1 WH005	Alpha Wire
23	L2	1	Inductor, 32 µH @ 10 kHz, 2.6A, 0.045ohm, Toroidal,	7447052	Wurth
24	L3	1	250 µH, Toroidal CMC, custom, wound on 32-00275-00 core.	32-00367-00	Power Integrations
25	Q1	1	MOSFET, N-CH, 100V, 48A (Tc), 113.5W (Tc), DFN5X6, 8-DFN (5x6)	AON6220	Alpha & Omega Semi
26	R1	1	RES, 2 MΩ, 5%, 1/8 W, Carbon Film	CF18JT2M00	Stackpole
27	R2	1	RES, 1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
28	R3	1	RES, 330 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ334V	Panasonic
29	R4	1	RES, 5.6 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ562V	Panasonic
30	R5	1	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
31	R6	1	RES, 5.1 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-5R1	Yageo
32	R7	1	RES, 300 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ301V	Panasonic
33	R8	1	RES, 169.0 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1693X	Panasonic
34	R10	1	RES, 11.3 kΩ, 1%, 1/10 W, Thick Film, 0402	ERJ-2RKF1132X	Panasonic
35	R11	1	RES, 0.013 Ω, 0.5 W, 1%, 0805	ERJ-6BWFR013V	Panasonic
36	T1	1	Bobbin, ATQ23.7/14, Horizontal, 4 pins. Mates with core 99-00072-00.		
37	TP1	1	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
38	TP2 TP4	2	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
39	TP3	1	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
40	U1	1	InnoSwitch3-EP InSOP24D	INN3678C-H606	Power Integrations
41	VR1	1	DIODE ZENER 12 V 500 mW SOD123	MMSZ5242B-7-F	Diodes, Inc.

7 Transformer Specification

7.1 *Electrical Diagram:*



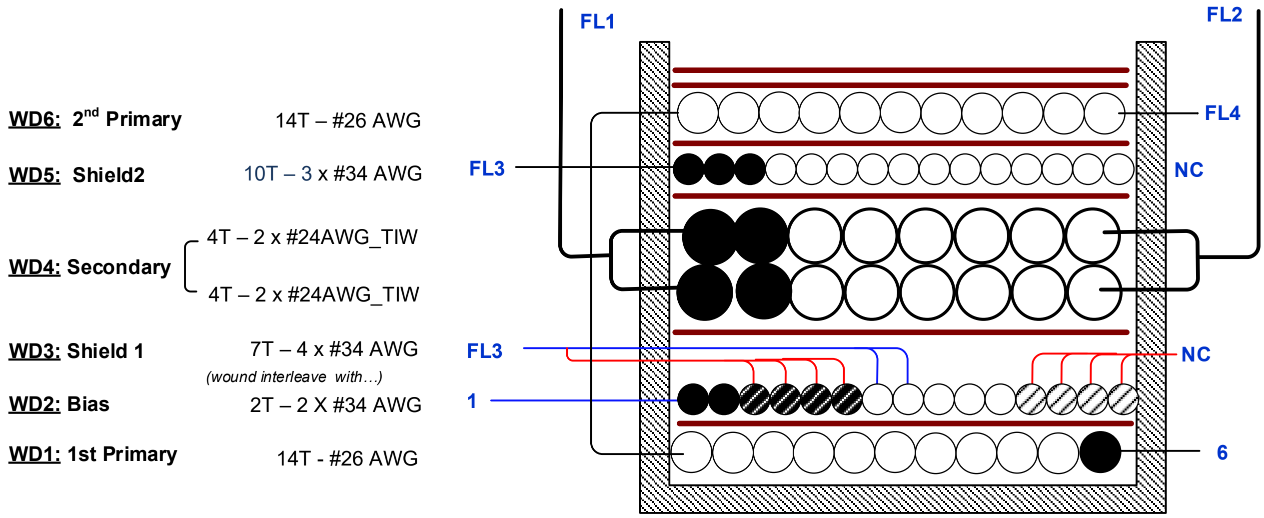
7.2 *Electrical Specifications*

Electrical Strength	1 second, 60 Hz, from pins 6-FL4 to FL1-FL2.	3000 VAC
Primary Inductance	Pins 6-FL4, all other open, measured at 100 kHz, 0.4 V_{RMS}.	493 µH ±5%
Resonant Frequency	Pins 6-FL4, all other open.	2,000 kHz (Min.)
Primary Leakage	Pins 6-FL4, with FL1-FL2 shorted, measured at 100 kHz.	5.0 µH (Max.)

7.3 *Materials List*

Item	Description
[1]	Core: ATQ23.7-14, PI# 99-00072-00: or equivalent. Gapped ALG: 540nH/T².
[2]	Bobbin: ATQ23.7-14, Horizontal, 3pins (3/0), PI#: 25-01171-00.
[3]	Magnet Wire: #26 AWG, Double Coated.
[4]	Magnet Wire: #34 AWG, Double Coated.
[5]	Magnet Wire: #24 AWG, Triple Insulated Wire.
[6]	Tape: 3M 1298 Polyester Film, 1 mil thick, 6.8 mm Wide.
[7]	Tape: 3M 1298 Polyester Film, 1 mil thick, 20.0 mm Wide.
[8]	Bus wire: #28 AWG, Alfa Wire, Tinned Copper; or Equivalent.
[9]	Varnish: Dolph BC-359; or Equivalent.

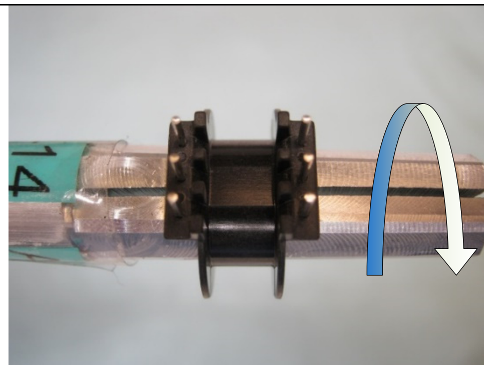
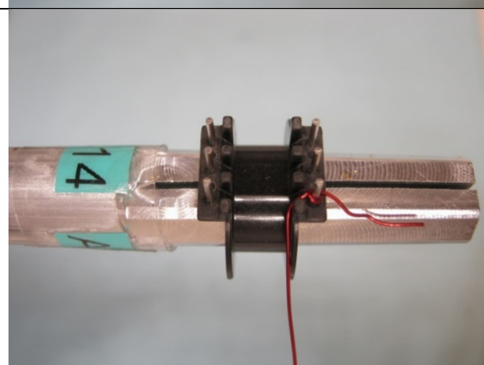
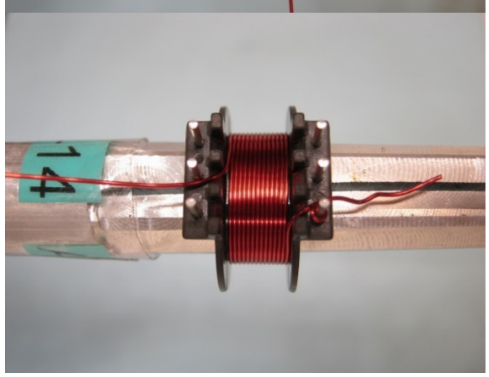
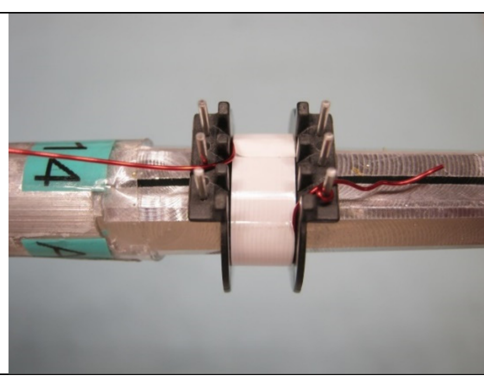
7.4 *Transformer Build Diagram:*

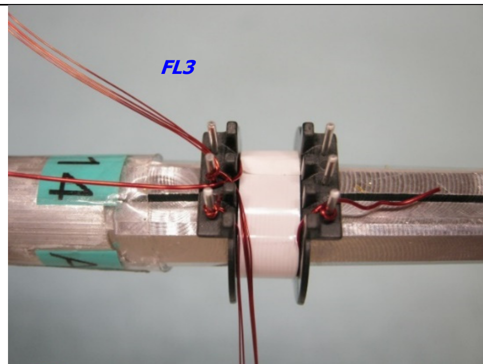


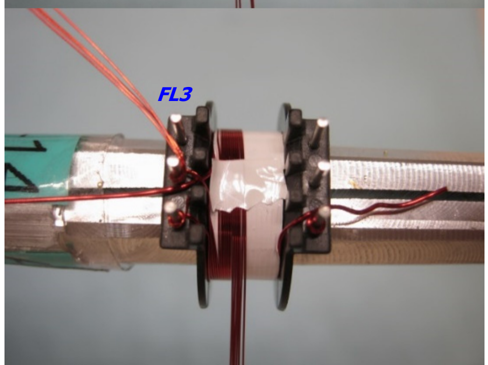
7.5 *Transformer Instruction:*

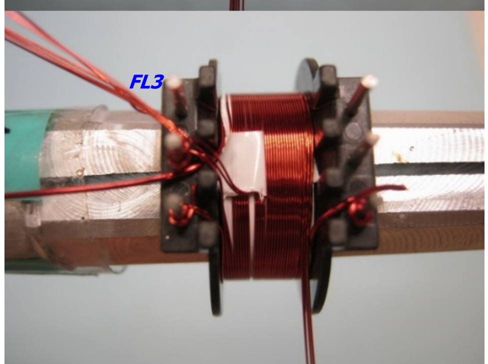
Winding preparation	Position the bobbin Item [2] on the mandrel, pin 1-3 on the left and pin 4-6 on the right. Winding direction is clock-wise direction for forward direction.
WD1 1st Primary	Start at pin 6, wind 14 turns of wire Item [3], from right to left in 1 layer. At the last turn, exit the wire, and leave enough length of wire-floating for WD6-2nd Primary.
Insulation	1 layer of tape Item [6].
WD2: Bias & WD3: Shield1	Use 2 wires Item [4] start at pin 1 for Bias winding, also use 4 wires same Item [4] floating with 30 mm long, start as FL3 for Shield1 winding. Wind all 6 wires in parallel, at the 2nd turn: - place 1 small piece of tape Item [6] to hold all wires, then bring 2 wires for Bias winding to the left, and floating 30mm long to end this winding as FL3. - continue winding 5 more turns for Shield 1and cut short these 4 wires as No-Connect.
Insulation	1 layer of tape Item [6].
WD4 Secondary	Start from left side of bobbin, close to pin2, use 2 wires Item [5], leaving ~30 mm floating, and mark as FL1. Wind 4 turns in 1 layer, from left to right, at the last turn exit the wires to the right of bobbin close to pin 5, also leaving ~ 30.0mm floating, and mark FL2. Repeat the same winding above on top previous winding, also mark start and finish ends as FL1 and FL2.
Insulation	1 layer of tape Item [6].
WD5 Shield2	Use 3 wires Item [4]; floating with 30 mm long, start as FL3, wind 10 turns from left to right. At the last turn, cut short to leave as No-Connect.
Insulation	1 layer of tape Item [6].
WD6 2nd Primary	Use floating wire from WD1-1st Primary, wind 14 turns from left to right. At the last turn, exit the wire, leave 30 mm floating and terminate as FL4.
Insulation	2 layers of tape Item [6] to secure all windings.
Finish	Gap core halves to get 493 μH. Remove pins: 2, 3, 4, and 5. Use bus wire Item [8] lean along core halves and secure it with tape. Varnish with Item [9]. Place 2 layers of tape Item [7] to wrap the right side of transformer. Pull wires FL2 to the left, the wrap 1 turn of tape Item [6] in the center of transformer (see pictures beside).

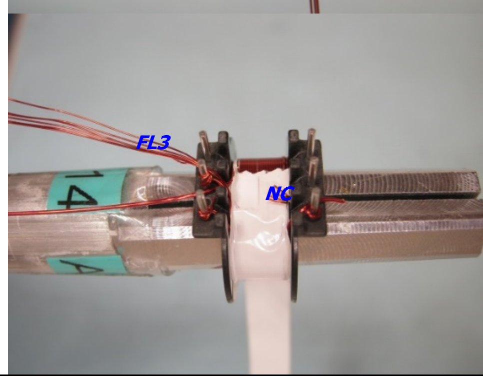
7.6 *Winding Illustrations*

Winding Preparation		Position the bobbin Item [2] on the mandrel, pin 1-3 on the left and pin 4-6 on the right. Winding direction is clock-wise direction for forward direction.
WD1 **1st Primary**	 	Start at pin 6, wind 14 turns of wire Item [3], from right to left in 1 layer. At the last turn, exit the wire, and leave enough length of wire-floating for WD6-2nd Primary.
Insulation		1 layer of tape Item [6].

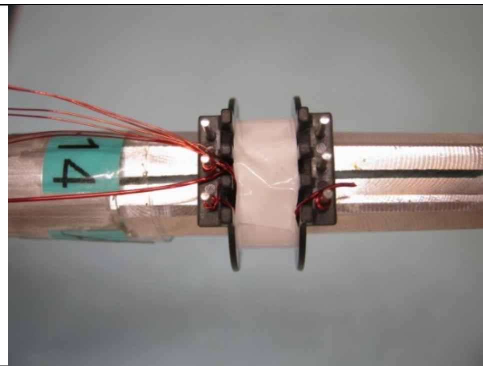
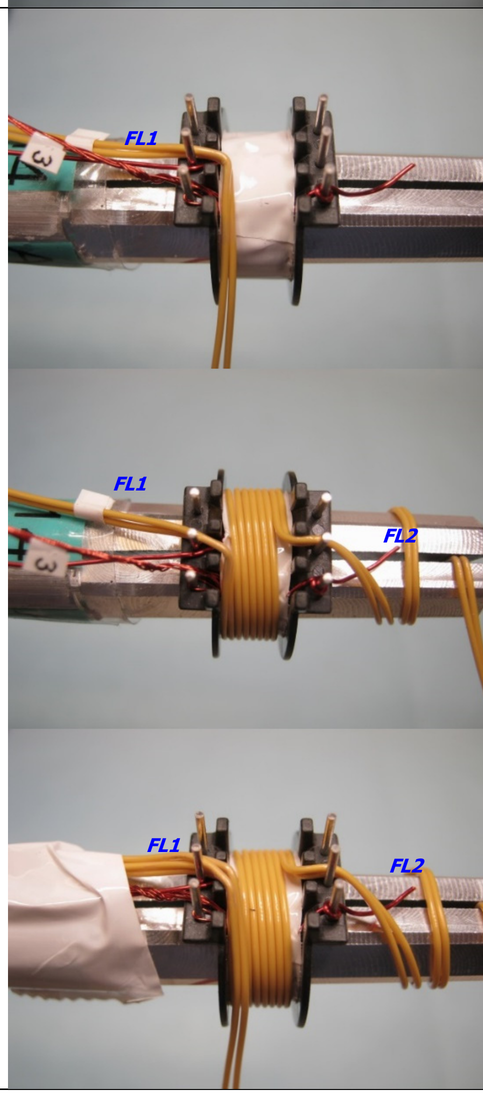
<table>
<tr>
<td>WD2: Bias
&
WD3: Shield1</td>
<td>


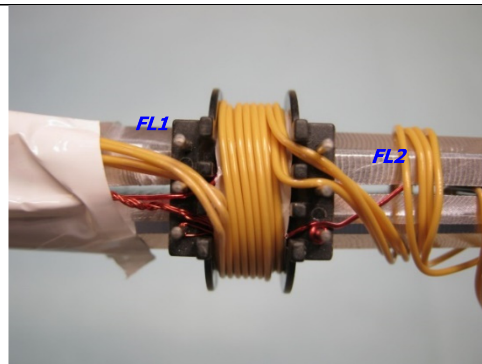
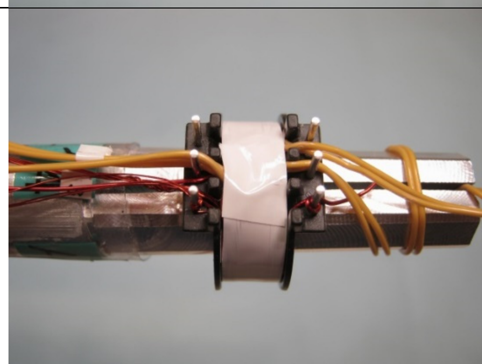
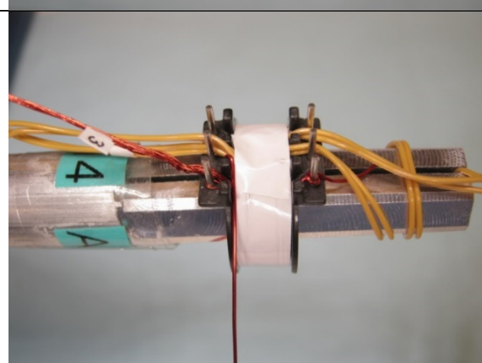
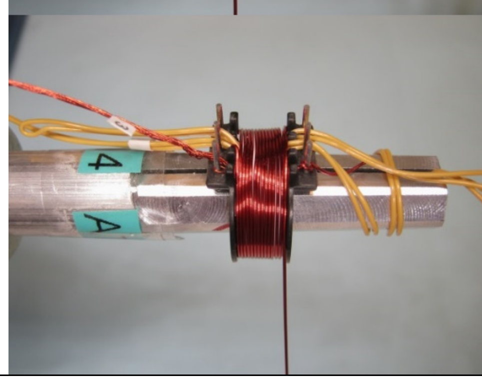


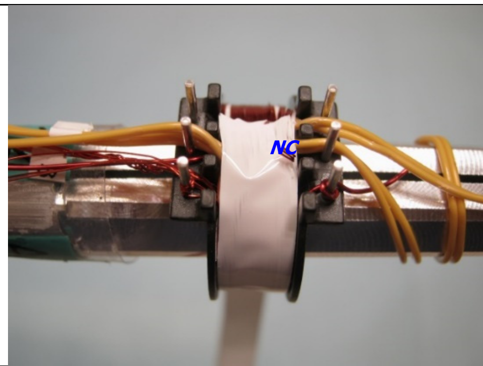
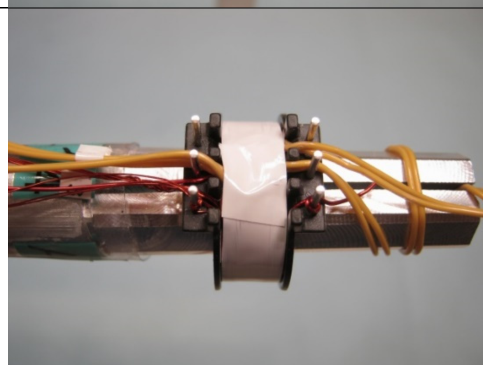
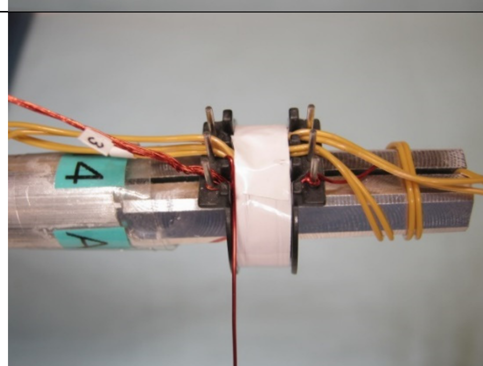
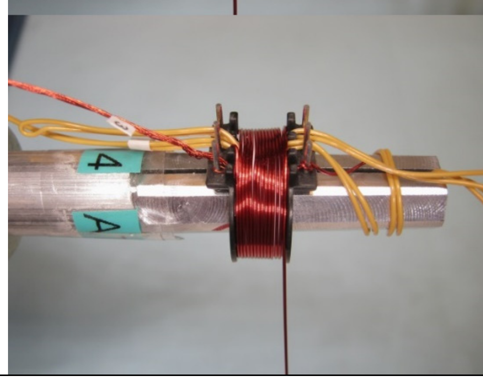


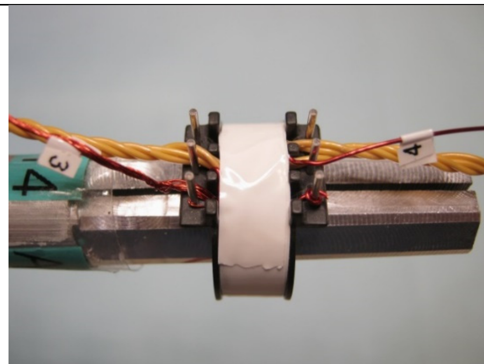
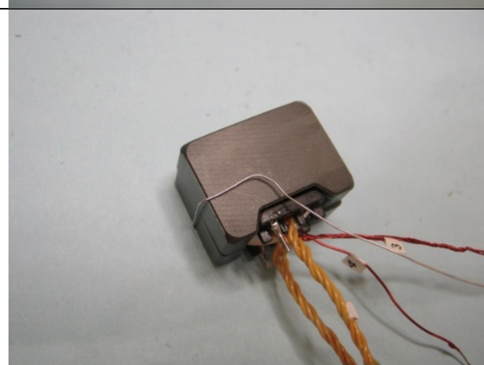
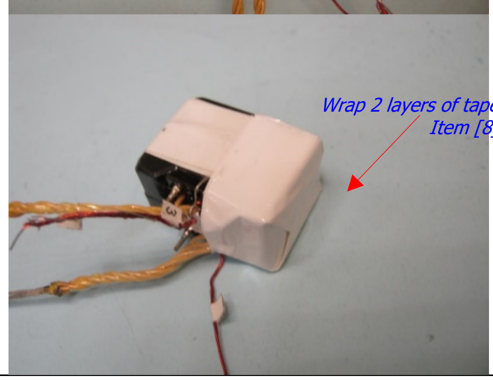


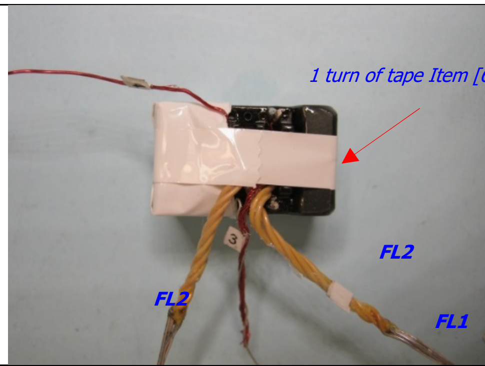
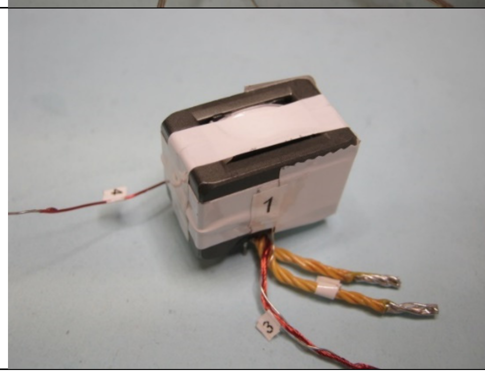
</td>
<td>Use 2 wires Item [4] start at pin 1 for Bias winding, also use 4 wires same Item [4] floating with 30 mm long, start as FL3 for Shield1 winding. Wind all 6 wires in parallel, at the 2nd turn:
- place 1 small piece of tape Item [6] to hold all wires, then bring 2 wires for Bias winding to the left, and floating 30 mm long to end this winding as FL3.
- continue winding 5 more turns for Shield 1and cut short these 4 wires as No-Connect.</td>
</tr>
</table>

Insulation		1 layer of tape Item [6].
WD4 Secondary		Start from left side of bobbin, close to pin 2, use 2 wires Item [5], leaving ~30 mm floating, and mark as FL1.Wind 4 turns in 1 layer, from left to right, at the last turn exit the wires to the right of bobbin close to pin 5, also leaving ~30.0 mm floating, and mark FL2. Repeat the same winding above on top previous winding, also mark start and finish ends as FL1 and FL2.

		
Insulation		1 layer of tape Item [6].
WD5 Shield2	 	Use 3 wires Item [4]; floating with 30 mm long, start as FL3, wind 10 turns from left to right. At the last turn, cut short to leave as No-Connect.

		
Insulation		1 layer of tape Item [6].
WD6 **2nd Primary**	 	Use floating wire from WD1-1st Primary, wind 14 turns from left to right. At the last turn, exit the wire, leave 30 mm floating and terminate as FL4.

Insulation		2 layers of tape Item [6] to secure all windings.
Finish	  	Gap core halves to get 493 μH. Remove pins: 2, 3, 4, and 5. Use bus wire Item [8] lean along core halves and secure it with tape. Varnish with Item [9]. Place 2 layers of tape Item [7] to wrap the right side of transformer. Pull wires FL2 to the left, the wrap 1 turn of tape Item [6] in the center of transformer (see pictures beside).

		
Finished Transformer		

8 Common Mode Choke Specifications

8.1 *250 µH Common Mode Choke*

8.2 *Electrical Diagram*

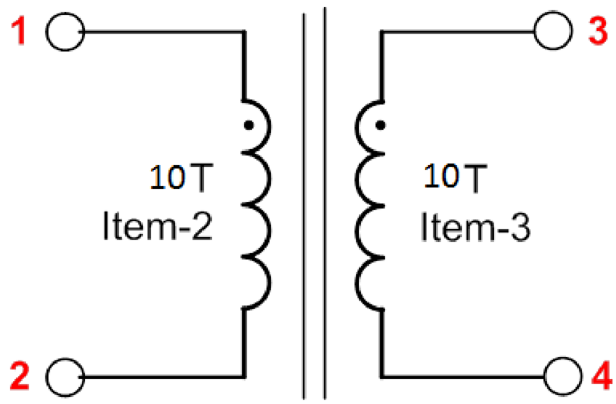


Figure 6 – Choke Electrical Diagram.

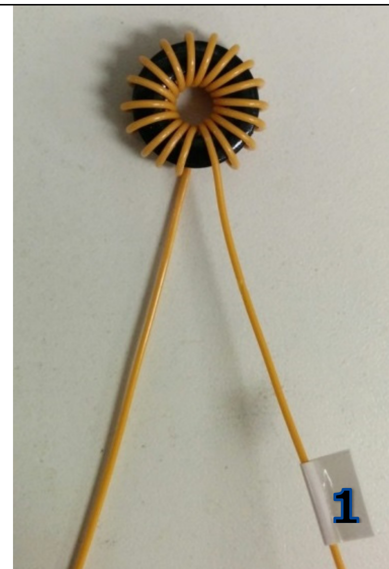
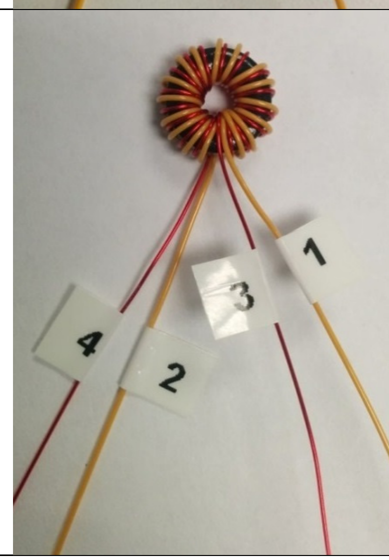
8.3 *Electrical Specifications*

Winding Inductance	Pin 1 - pin 2 (pin 3 - pin 4), all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	250 µH ±20%

8.4 *Material List*

Item	Description
[1]	Toroidal Core: 35T0375-10H, PI#: 32-00275-00.
[2]	Triple Insulated Wire: #27 AWG, Triple Coated.
[3]	Magnet Wire: #27 AWG, Double Coated.

8.5 *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_050420; 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	66.0		66.0	uF	Input capacitor
8	VOUT	20.00		20.00	V	Output voltage at the board
9	CDC			0.00	mV	Cable drop compensation desired at full load
10	IOUT	2.250		2.250	A	Output current
11	POUT			45.00	W	Output power
12	EFFICIENCY	0.92		0.92		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		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	INN36X8		INN36X8		Generic device code
21	DEVICE_CODE			INN3678C		Actual device code
22	POUT_MAX			65	W	Power capability of the device based on thermal performance
23	RDSON_100DEG			1.02	Ω	Primary switch on time drain resistance at 100 degC
24	ILIMIT_MIN			1.767	A	Minimum current limit of the primary switch
25	ILIMIT_TYP			1.900	A	Typical current limit of the primary switch
26	ILIMIT_MAX			2.033	A	Maximum current limit of the primary switch
27	VDRAIN_BREAKDOWN			750	V	Device breakdown voltage
28	VDRAIN_ON_PRSW			0.57	V	Primary switch on time drain voltage
29	VDRAIN_OFF_PRSW			583.4	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	140.0		140.0	V	Secondary voltage reflected to the primary when the primary switch turns off
36	VMIN			84.83	V	Valley of the minimum input AC voltage at full load
37	KP			0.93		Measure of continuous/discontinuous mode of operation
38	MODE_OPERATION			CCM		Mode of operation
39	DUTYCYCLE			0.624		Primary switch duty cycle
40	TIME_ON			11.41	us	Primary switch on-time
41	TIME_OFF			5.37	us	Primary switch off-time
42	LPRIMARY_MIN			468.2	uH	Minimum primary inductance
43	LPRIMARY_TYP			492.9	uH	Typical primary inductance
44	LPRIMARY_TOL			5.0	%	Primary inductance tolerance
45	LPRIMARY_MAX			517.5	uH	Maximum primary inductance
47	**PRIMARY CURRENT**					
48	IPEAK_PRIMARY			1.884	A	Primary switch peak current
49	IPEDESTAL_PRIMARY			0.109	A	Primary switch current pedestal
50	IAVG_PRIMARY			0.557	A	Primary switch average current
51	IRIPPLE_PRIMARY			1.884	A	Primary switch ripple current
52	IRMS_PRIMARY			0.837	A	Primary switch RMS current
54	**SECONDARY CURRENT**					

55	IPEAK_SECONDARY			13.188	A	Secondary winding peak current
56	IPEDESTAL_SECONDARY			0.765	A	Secondary winding current pedestal
57	IRMS_SECONDARY			4.543	A	Secondary winding RMS current
61	**TRANSFORMER CONSTRUCTION PARAMETERS**					
62	**CORE SELECTION**					
63	CORE	CUSTOM	Info	CUSTOM		The transformer windings may not fit: pick a bigger core or bobbin and refer to the Transformer Parameters tab for fit calculations
64	CORE CODE	ATQ23.7/14		ATQ23.7/14		Core code
65	AE	103.00		103.00	mm^2	Core cross sectional area
66	LE	36.00		36.00	mm	Core magnetic path length
67	AL	5100		5100	nH/turns^2	Ungapped core effective inductance
68	VE	3300.0		3300.0	mm^3	Core volume
69	BOBBIN	AT23.7/14		AT23.7/14		Bobbin
70	AW	25.00		25.00	mm^2	Window area of the bobbin
71	BW	6.60		6.60	mm	Bobbin width
72	MARGIN			0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
74	**PRIMARY WINDING**					
75	NPRIMARY			28		Primary turns
76	BPEAK			3734	Gauss	Peak flux density
77	BMAX			3334	Gauss	Maximum flux density
78	BAC			1667	Gauss	AC flux density (0.5 x Peak to Peak)
79	ALG			629	nH/turns^2	Typical gapped core effective inductance
80	LG			0.181	mm	Core gap length
81	LAYERS_PRIMARY			2		Number of primary layers
82	AWG_PRIMARY			26	AWG	Primary winding wire AWG
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			304	Cmil/A	Primary winding wire CMA
87	**SECONDARY WINDING**					
88	NSECONDARY	4		4		Secondary turns
89	AWG_SECONDARY			20	AWG	Secondary winding wire AWG
90	OD_SECONDARY_INSULATED			1.118	mm	Secondary winding wire outer diameter with insulation
91	OD_SECONDARY_BARE			0.812	mm	Secondary winding wire outer diameter without insulation
92	CMA_SECONDARY			225	Cmil/A	Secondary winding wire CMA
94	**BIAS WINDING**					
95	NBIAS			2		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	9.0	Info	9.0	V	The rectified bias voltage maybe too low to supply the BP pin: Increase the rectified bias voltage to a value higher than 10V
111	VF_BIAS			0.70	V	Bias winding diode forward drop

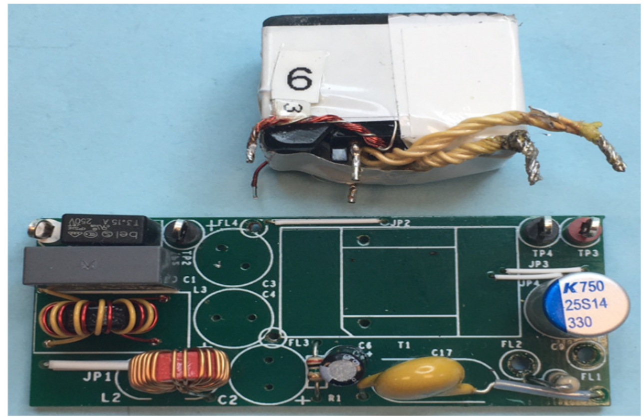
112	VREVERSE_BIASDIODE			35.67	V	Bias diode reverse voltage (not accounting parasitic voltage ring)
113	CBIAS			22	uF	Bias winding rectification capacitor
114	CBPP			4.70	uF	BPP pin capacitor
118	**SECONDARY COMPONENTS**					
119	RFB_UPPER			100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
120	RFB_LOWER			6.81	kΩ	Lower feedback resistor
121	CFB_LOWER			330	pF	Lower feedback resistor decoupling capacitor
125	**MULTIPLE OUTPUT PARAMETERS**					
126	**OUTPUT 1**					
127	VOUT1			20.00	V	Output 1 voltage
128	IOUT1			2.25	A	Output 1 current
129	POUT1			45.00	W	Output 1 power
130	IRMS_SECONDARY1			4.543	A	Root mean squared value of the secondary current for output 1
131	IRIPPLE_CAP_OUTPUT1			3.947	A	Current ripple on the secondary waveform for output 1
132	AWG_SECONDARY1			20	AWG	Wire size for output 1
133	OD_SECONDARY1_INSULATED			1.118	mm	Secondary winding wire outer diameter with insulation for output 1
134	OD_SECONDARY1_BARE			0.812	mm	Secondary winding wire outer diameter without insulation for output 1
135	CM_SECONDARY1			909	Cmils	Bare conductor effective area in circular mils for output 1
136	NSECONDARY1			4		Number of turns for output 1
137	VREVERSE_RECTIFIER1			73.34	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
138	SRFET1	AONS62922		AONS62922		Secondary rectifier (Logic MOSFET) for output 1
139	VF_SRFET1			0.016	V	SRFET on-time drain voltage for output 1
140	VBREAKDOWN_SRFET1			120	V	SRFET breakdown voltage for output 1
141	RDSON_SRFET1			7.0	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			45.00	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		1.900	A	Current limit corner to be evaluated
185	USER_LPRIMARY	TYP		492.9	uH	Primary inductance corner to be evaluated
186	MODE_OPERATION			DCM		Mode of operation
187	KP			1.572		Measure of continuous/discontinuous mode of operation
188	FSWITCHING			60132	Hz	Switching frequency at full load and valley of the rectified minimum AC input voltage
189	VMIN			129.78	V	Valley of the minimum input AC voltage at full load
190	DUTYCYCLE			0.408		Steady state duty cycle
191	TIME_ON			6.78	us	Primary switch on-time
192	TIME_OFF			9.85	us	Primary switch off-time
193	IPEAK_PRIMARY			1.780	A	Primary switch peak current
194	IPEDESTAL_PRIMARY			0.000	A	Primary switch current pedestal
195	IAVERAGE_PRIMARY			0.363	A	Primary switch average current
196	IRIPPLE_PRIMARY			1.780	A	Primary switch ripple current
197	IRMS_PRIMARY			0.656	A	Primary switch RMS current
198	BPEAK			3323	Gauss	Peak flux density
199	BMAX			3042	Gauss	Maximum flux density
200	BAC			1521	Gauss	AC flux density (0.5 x Peak to Peak)

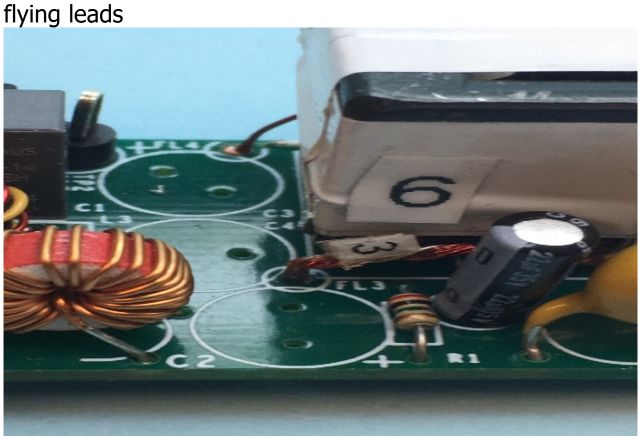
10 PCB Assembly Instructions

10.1 *Transformer and Y Capacitor Assembly*

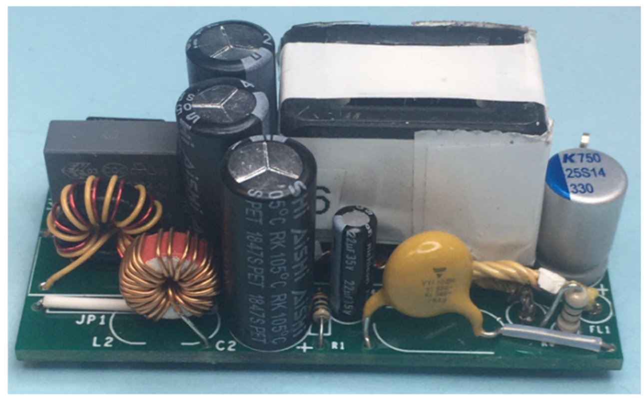
Cut transformer flying leads to required length and tin the flying leads



Assemble the Y-cap on the board as shown in picture



Insert the transformer flying leads on to the board



Assemble C2, C3 and C4 after assembling the transformer

11 Performance Data

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

11.1 *Full-load Efficiency vs. Line*

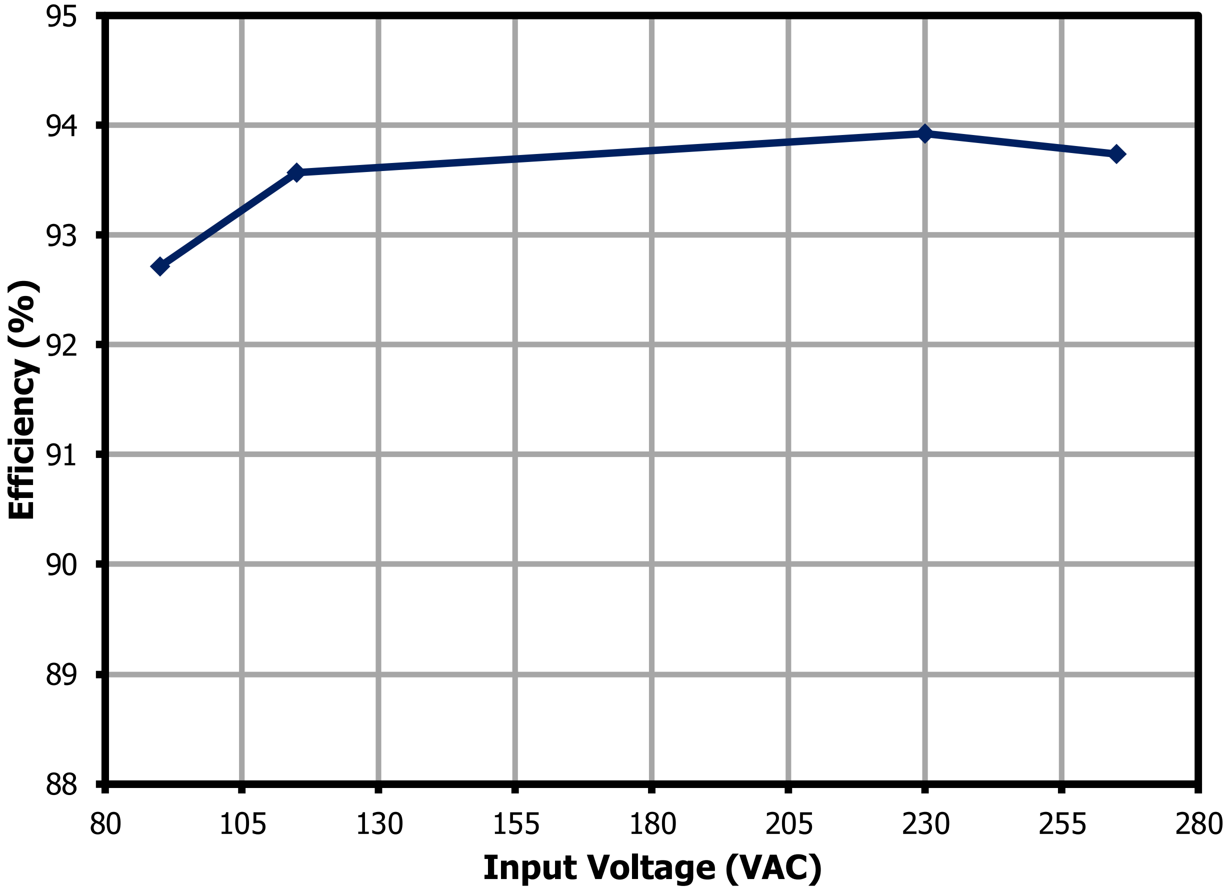


Figure 7 – Full-load Efficiency vs. Line, Room Ambient.

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

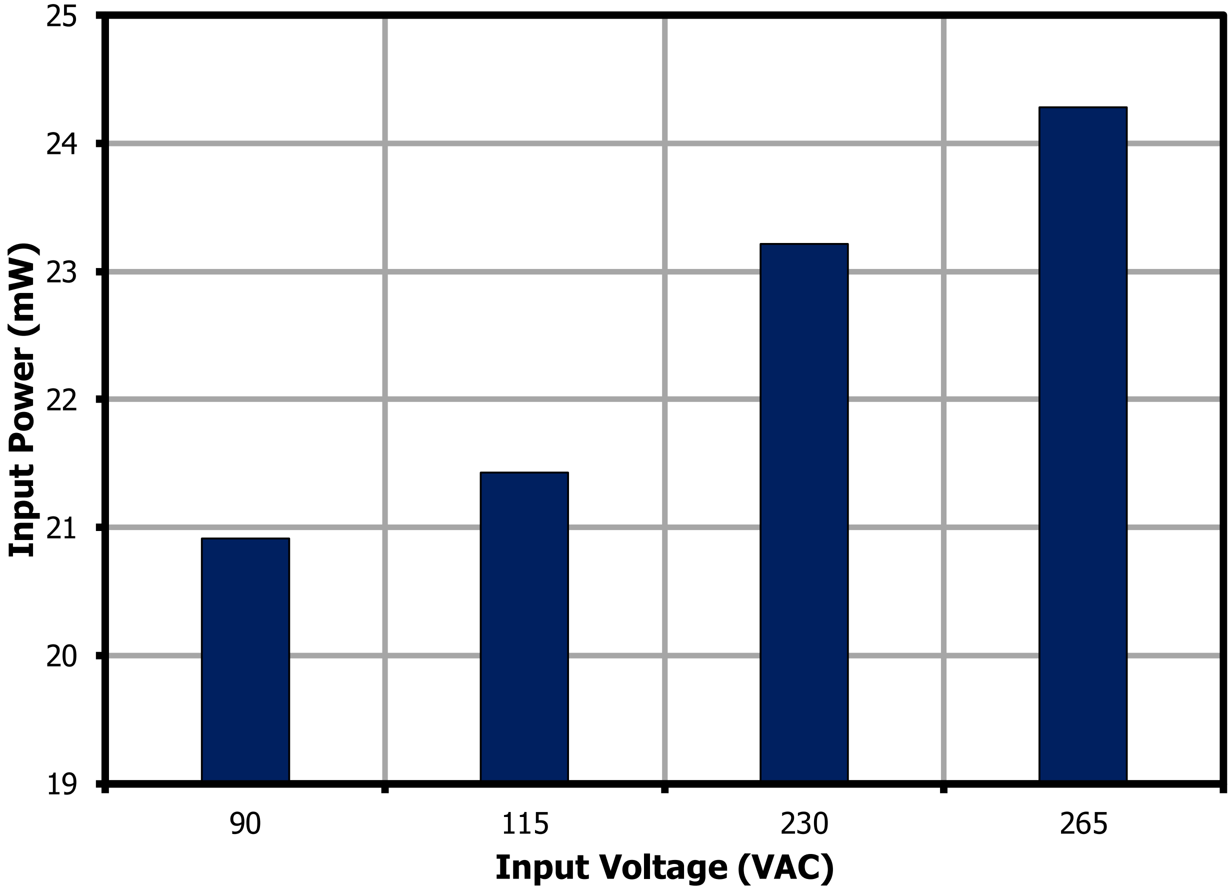


Figure 8 – No-Load Input Power vs. Input Line Voltage, Room Temperature.

11.3 *Average Efficiency*

		Test	Average	Average	10% Load
Output Voltage (V)	Model (V)	Power [W]	DOE6 Limit (%)	CoC v5 Tier 2 (%)	CoC v5 Tier 2 (%)
20	>6	45	87.73	88.85	78.85%

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

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	44.57	92.72	92.64
75	33.67	93.04	
50	22.55	93.01	
25	11.29	91.78	
10	4.53	90.12	

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

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	44.84	93.57	93.1
75	33.75	93.19	
50	22.56	93.36	
25	11.30	92.29	
10	4.53	89.06	

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

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	44.98	93.92	93.15
75	33.80	93.69	
50	22.58	93.25	
25	11.30	91.74	
10	4.54	87.55	

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

% Load	P_{OUT} (W)	Efficiency (%)	Average Efficiency (%)
100	44.98	93.74	92.88
75	33.80	93.49	
50	22.59	93.00	
25	11.30	91.31	
10	4.54	85.52	

12 Regulation (On Board)

12.1 *Line Regulation*

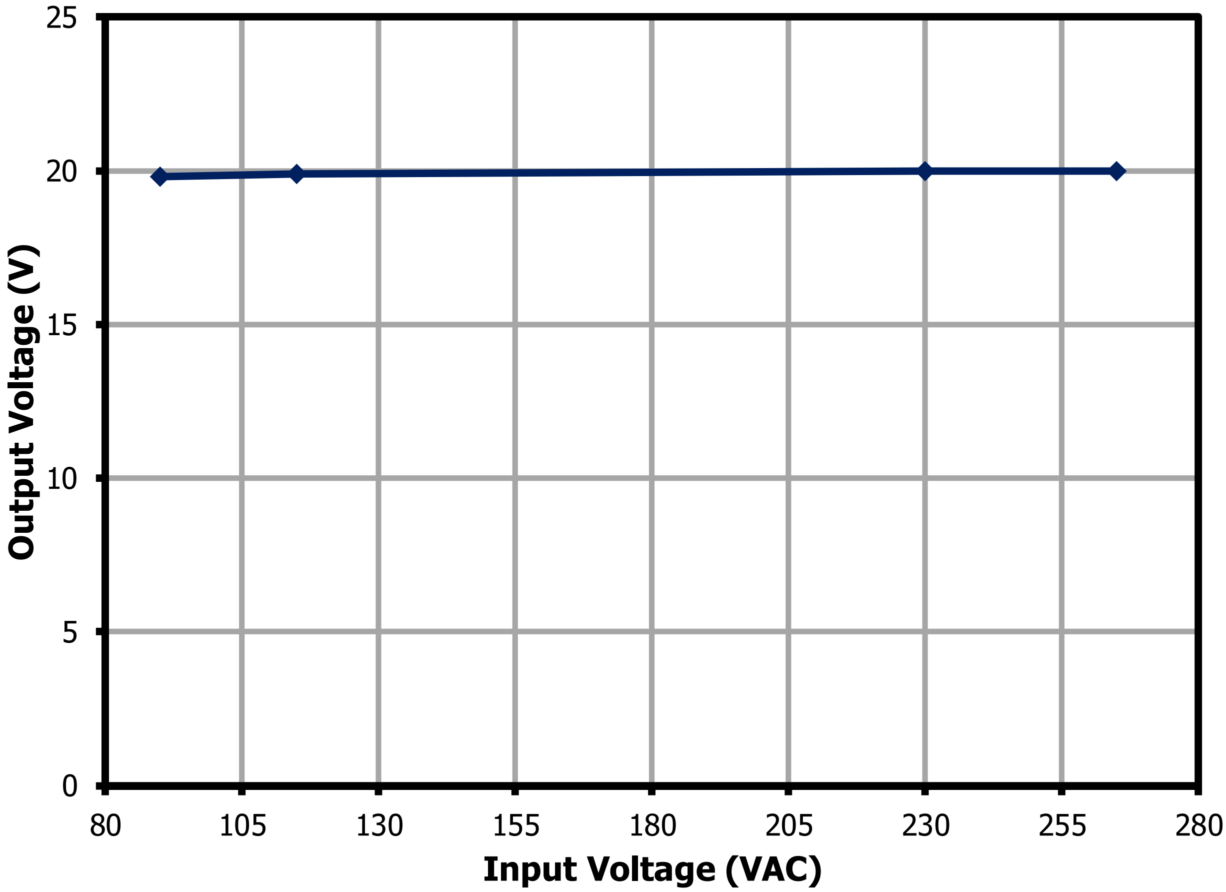


Figure 9 – Line Regulation.

12.2 *Load Regulation*

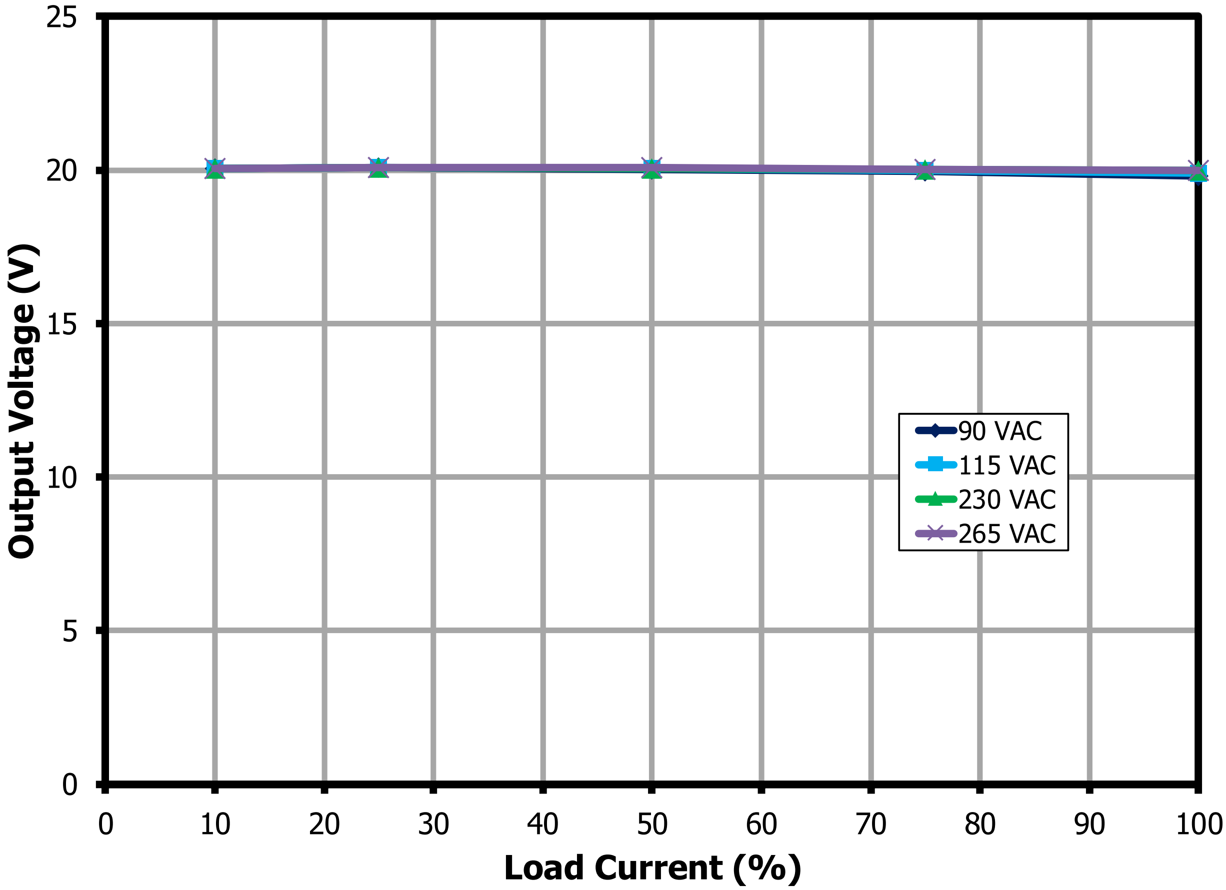


Figure 10 – Load Regulation.

13 Thermal Performance

Thermal performance is measured inside an enclosed acrylic box at room temperature. Thermal data was captured after soaking for 2 hours.

13.1 *90 VAC, 45 W at 25.3 ºC Ambient*

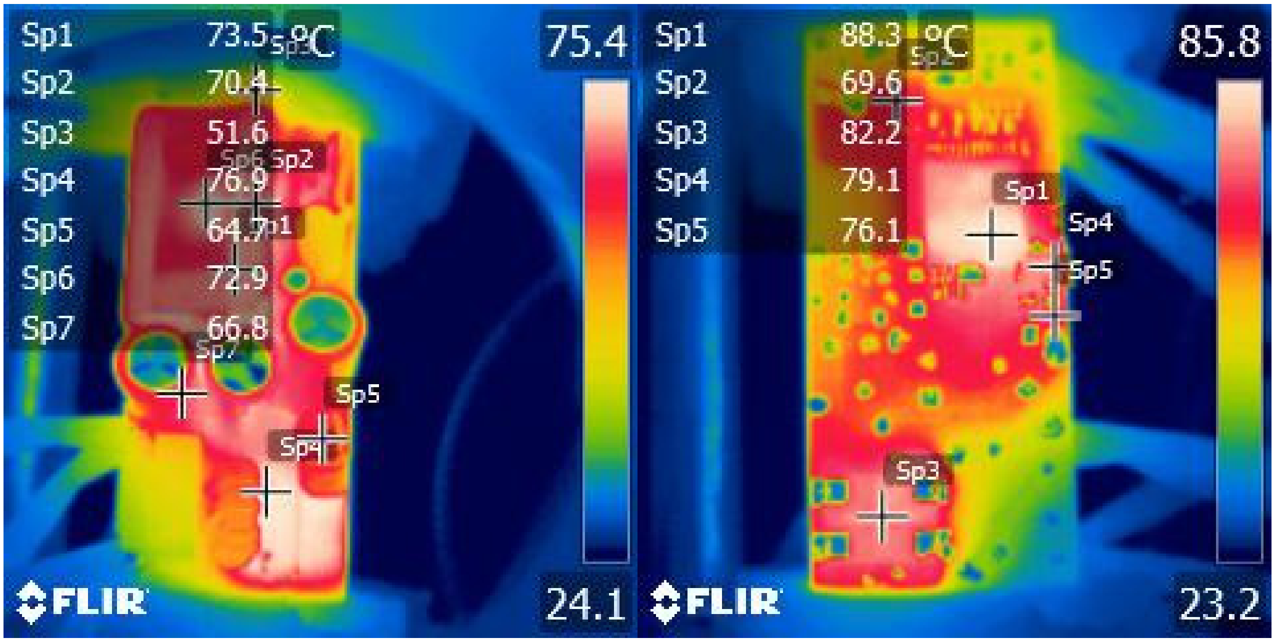


Figure 11 – Thermal Performance at 90 VAC Input.

Component	Max Temperature (ºC)
Primary Snubber Diode (D1)	79.1
Primary Snubber Resistor (R3)	76.1
Transformer Core (T1)	70.4
Transformer Winding (T1)	73.5
Bridge Rectifier (BR1)	82.2
InnoSwitch3-EP (U1)	88.3
Inductor (L2)	64.7
Bulk Capacitor (C3)	66.8
SR FET (Q1)	69.6
Output Capacitor (C9)	51.6

13.2 *265 VAC Input, 45 W at 24.8 ºC Ambient*

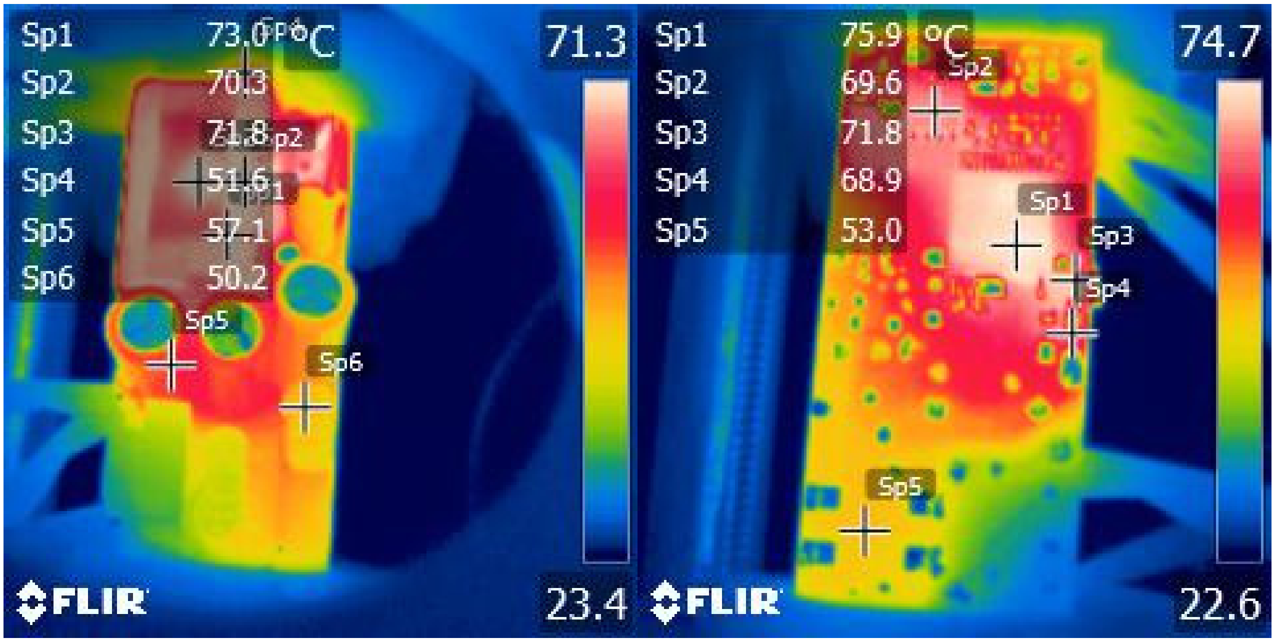


Figure 12 – Thermal Performance at 265 VAC Input.

Component	Max Temperature (ºC)
Primary Snubber Diode (D1)	71.8
Primary Snubber Resistor (R3)	68.9
Transformer Core (T1)	70.3
Transformer Winding (T1)	73
Bridge Rectifier (BR1)	53
InnoSwitch3-EP (U1)	75.9
Inductor (L2)	50.2
Bulk Capacitor (C3)	57.1
SR FET (Q1)	69.6
Output Capacitor (C9)	51.6

14 Waveforms

14.1 *Output Voltage Start-up waveforms:*

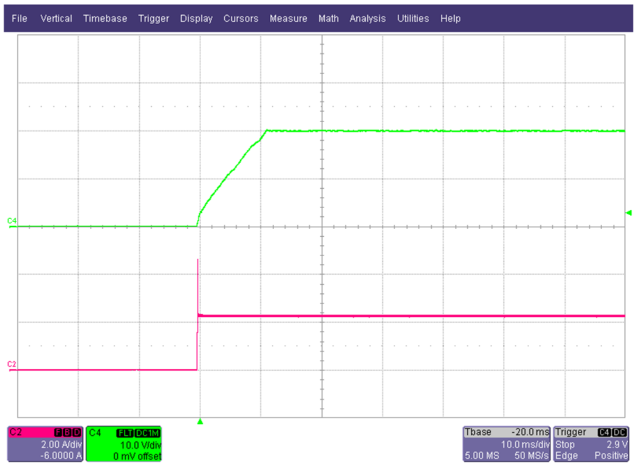


Figure 13 – Output Voltage Start-up – 100% Load 90 VAC.
C4 – Output Voltage – 10 V / div.
C2 – Output Current – 2 A / div. 10 ms / div.

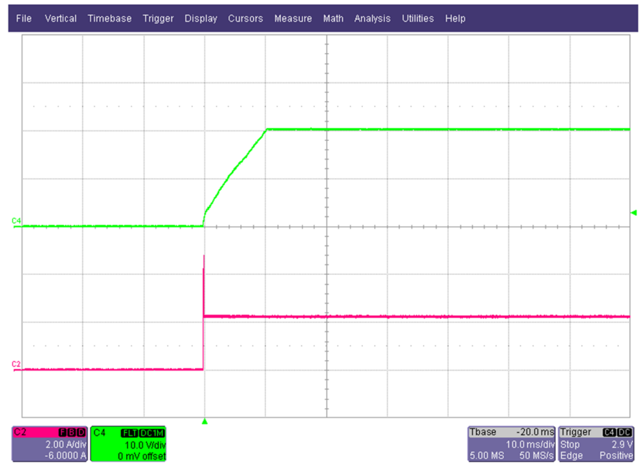


Figure 14 – Output Voltage Start-up – 100% Load 265 VAC.
C4 – Output Voltage – 5 V / div.
C2 – Output Current – 1 A / div. 10 ms / div.

Figure 15 – Output Voltage Start-up – No-Load 90 VAC.
C4 – Output Voltage – 5 V / div.
C2 – Output Current – 1 A / div. 10 ms / div.

Figure 16 – Output Voltage Start-up – No-Load 265 VAC.
C4 – Output Voltage – 5 V / div.
C2 – Output Current – 1 A / div. 10 ms / div.

14.2 *Load Transient Response (On Board)*

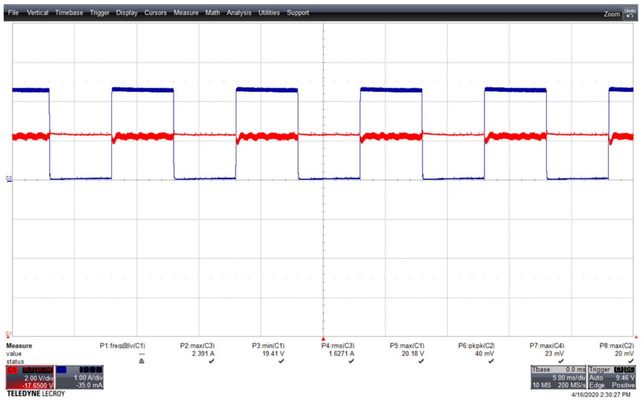


Figure 17 – Transient Response.
90 VAC, 0% – 100% Load Step.
V_{MIN}: 19.41 V, V_{MAX}: 20.18 V.
C1: V_{OUT}, 2 V / div., 5 ms / div.
C2: I_{LOAD}, 1 A / div.

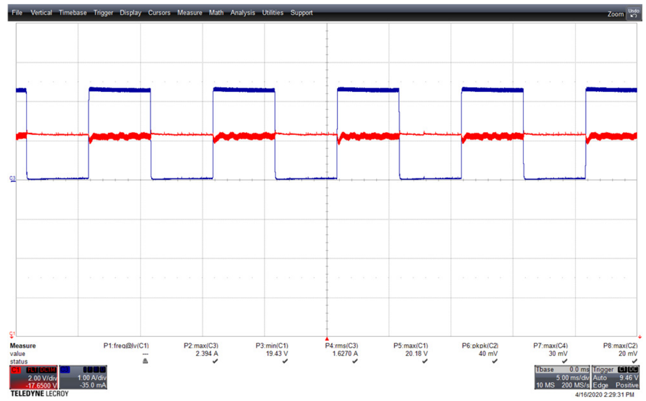


Figure 18 – Transient Response.
265 VAC, 0% – 100% Load Step.
V_{MIN}: 19.43 V, V_{MAX}: 20.18 V.
C1: V_{OUT}, 2 V / div., 5 ms / div.
C2: I_{LOAD}, 1 A / div.

14.3 *Switching Waveforms*

14.3.1 Drain Voltage and Current

Figure 19 – Drain Voltage and Current Waveforms.
90 VAC, 100% Load, (310 V_{MAX}).
C4/Z4: V_{DRAIN}, 100 V / div., 2 ms / div.
C2/Z2: I_{DRAIN}, 1 A / div.

Figure 20 – Drain Voltage and Current Waveforms.
265 VAC, 100% Load, (563 V_{MAX}).
C4/Z4: V_{DRAIN}, 200 V / div., 2 ms / div.
C2/Z2: I_{DRAIN}, 1 A / div.

14.3.2 SR FET Voltage

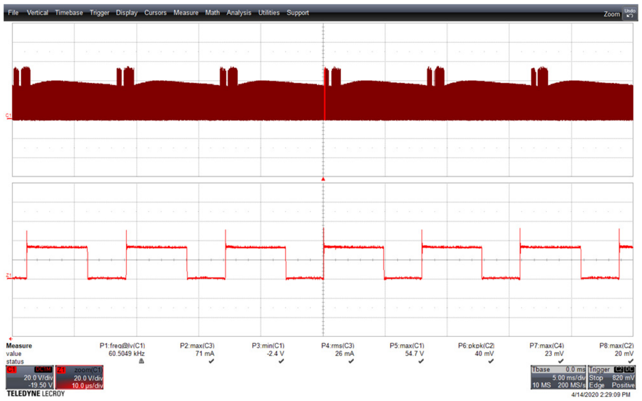


Figure 21 – SR FET Voltage Waveforms.
90 VAC, 100% Load, (54.7 V_{MAX}).
C1: SR_V_{DRAIN}, 20 V / div., 5 ms / div.

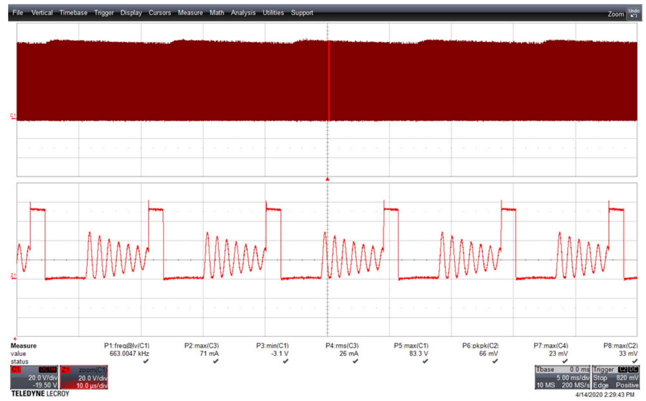


Figure 22 – SR FET Voltage Waveforms.
265 VAC, 100% Load, (83.3 V_{MAX}).
C1: SR_V_{DRAIN}, 20 V / div., 5 ms / div.

14.4 *Output Ripple Measurements*

14.4.1 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).

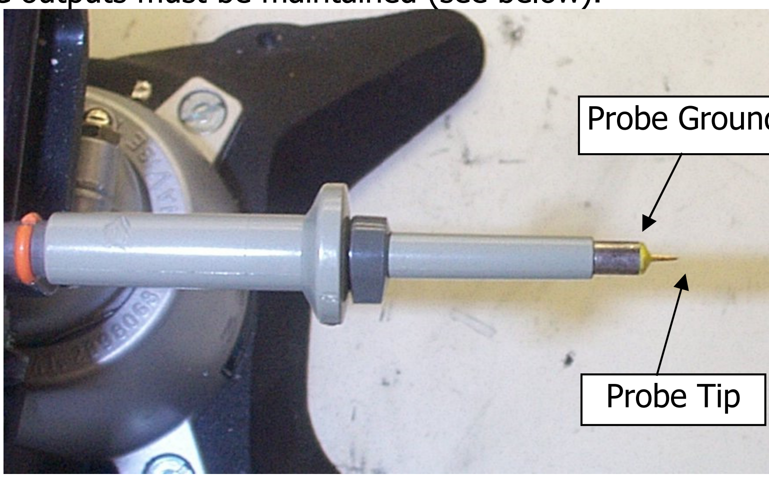


Figure 23 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

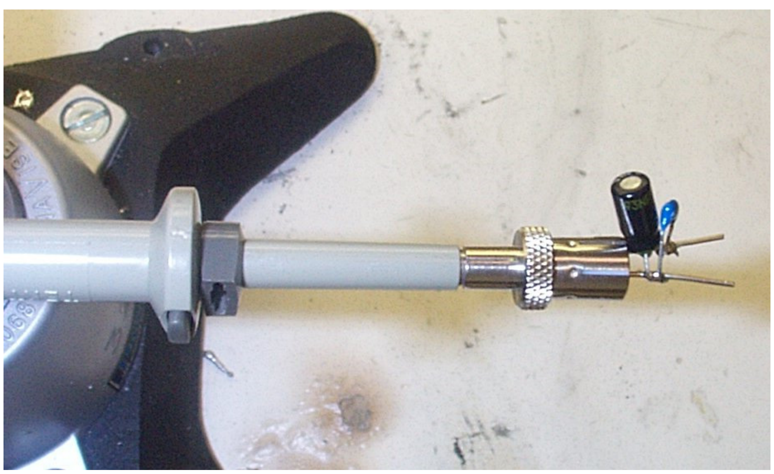


Figure 24 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

14.4.1.1 Ripple waveforms (Measured on board)

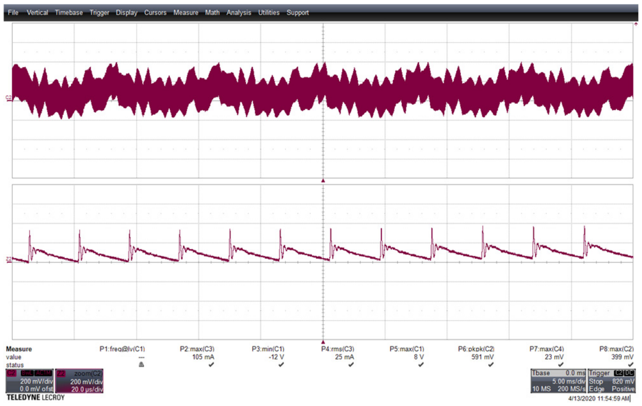


Figure 25 – Output Ripple.(PK-PK – 591 mV).
90 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

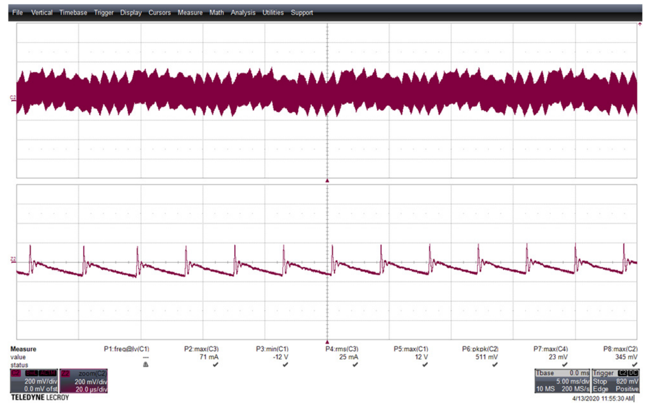


Figure 26 – Output Ripple.(PK-PK – 511 mV).
115 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

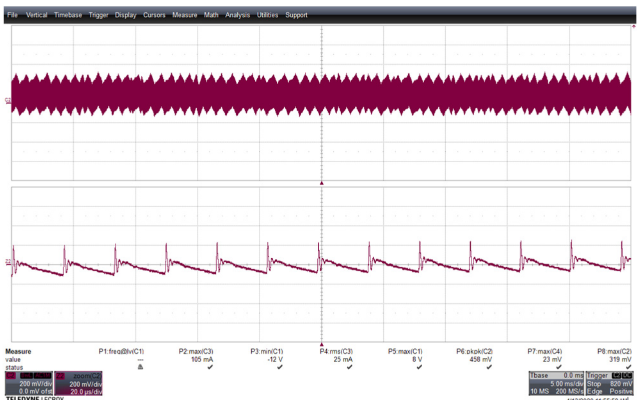


Figure 27 – Output Ripple.(PK-PK – 458 mV).
230 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

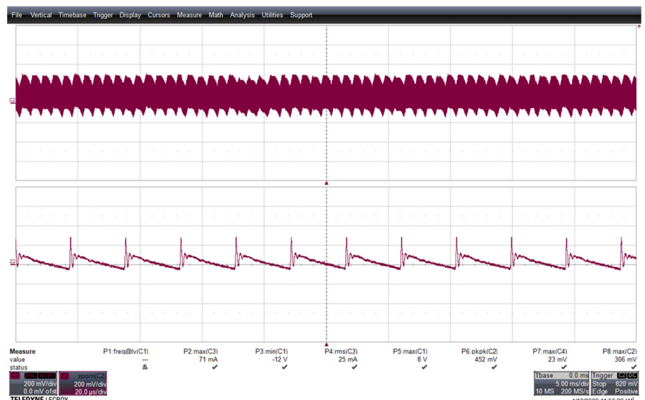


Figure 28 – Output Ripple.(PK-PK – 452 mV).
265 VAC Input, 100% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

14.4.1.2 75% Load

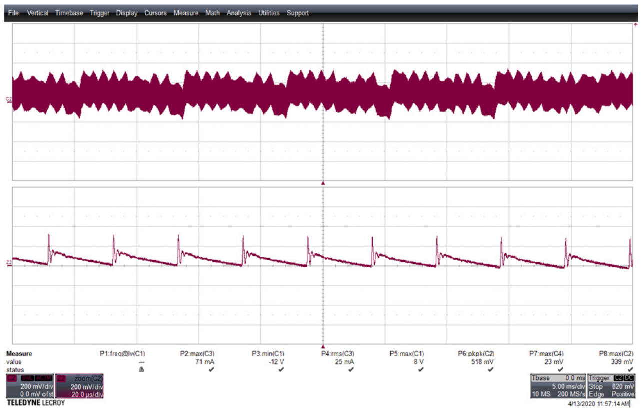


Figure 29 – Output Ripple.(PK-PK – 518 mV).
90 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

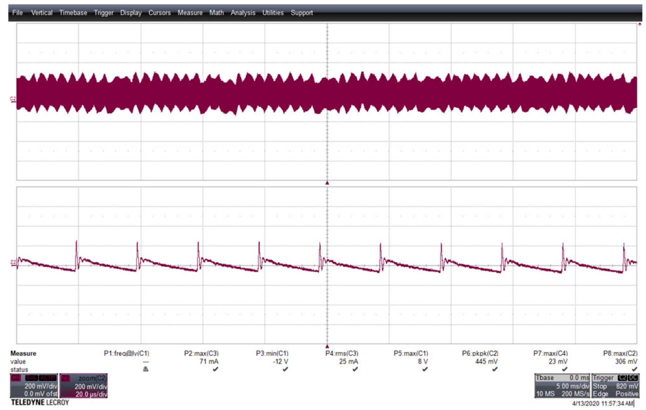


Figure 30 – Output Ripple.(PK-PK – 445 mV).
115 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

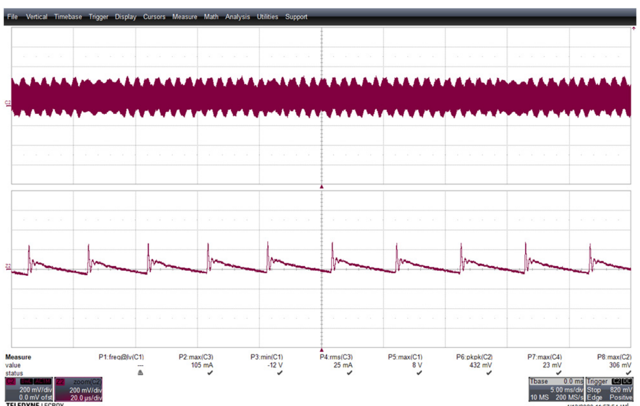


Figure 31 – Output Ripple.(PK-PK – 432 mV).
230 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

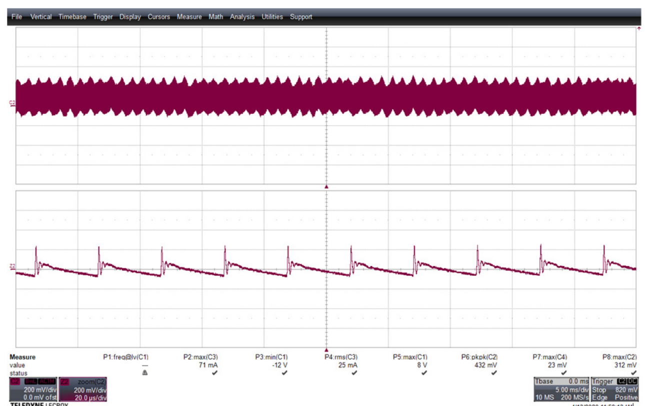


Figure 32 – Output Ripple.(PK-PK – 432 mV).
265 VAC Input, 75% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

14.4.1.3 50% Load

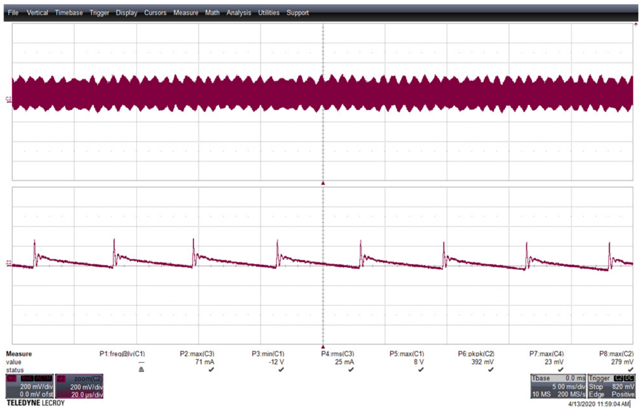


Figure 33 – Output Ripple.(PK-PK – 392 mV).
90 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

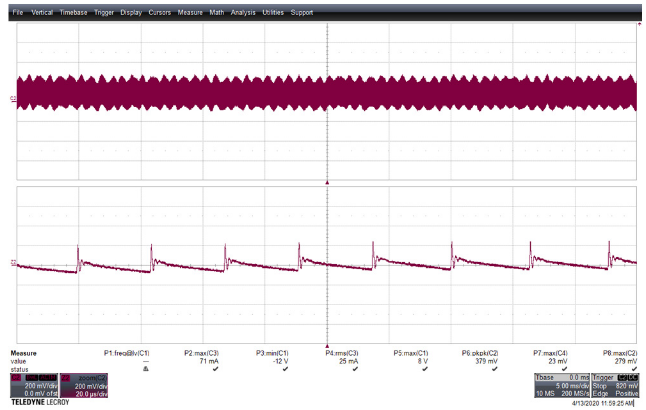


Figure 34 – Output Ripple.(PK-PK – 372 mV).
115 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

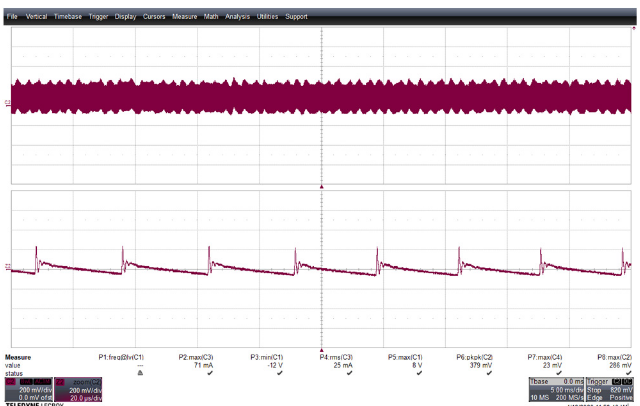


Figure 35 – Output Ripple.(PK-PK – 379 mV).
230 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

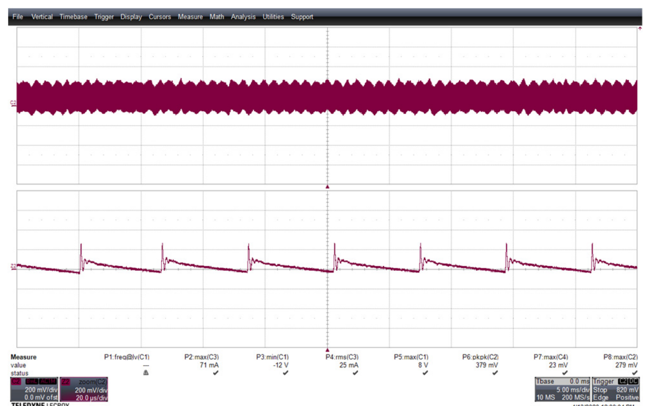


Figure 36 – Output Ripple.(PK-PK – 379 mV).
265 VAC Input, 50% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

14.4.1.4 25% Load

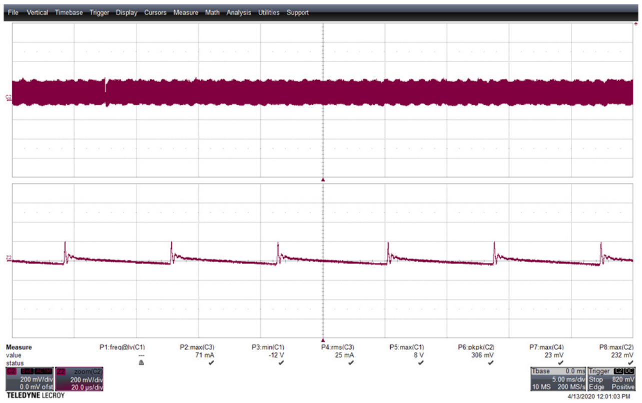


Figure 37 – Output Ripple.(PK-PK – 306 mV).
90 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

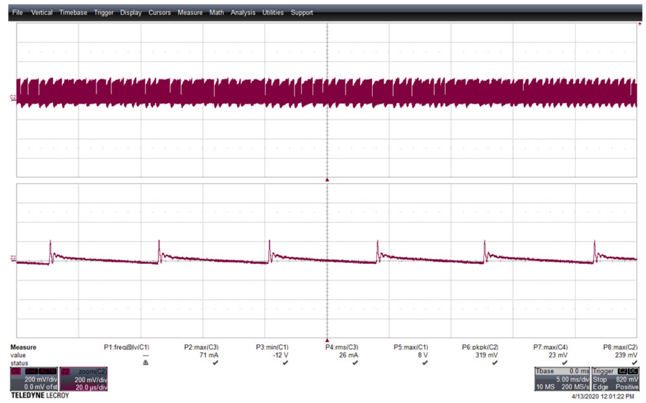


Figure 38 – Output Ripple.(PK-PK – 319 mV).
115 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

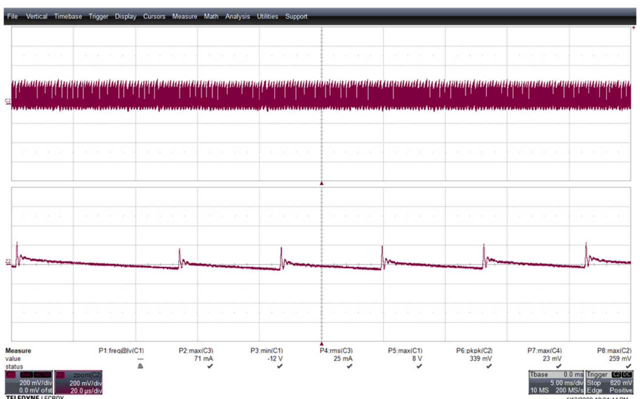


Figure 39 – Output Ripple.(PK-PK – 339 mV).
230 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

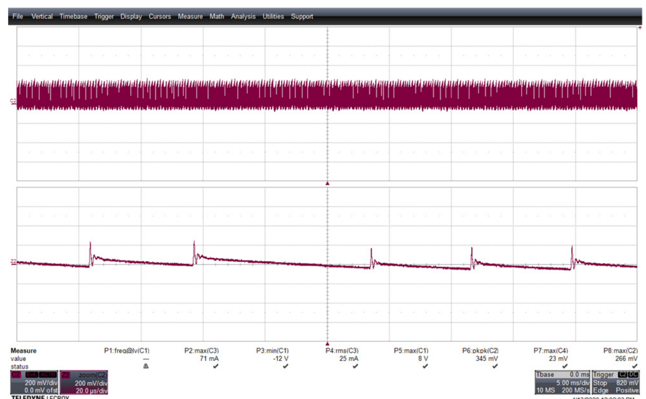


Figure 40 – Output Ripple.(PK-PK – 345 mV).
265 VAC Input, 25% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

14.4.1.5 10% Load

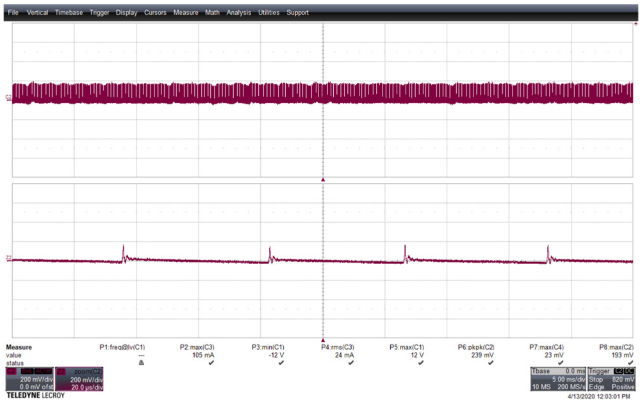


Figure 41 – Output Ripple.(PK-PK – 239 mV).
90 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

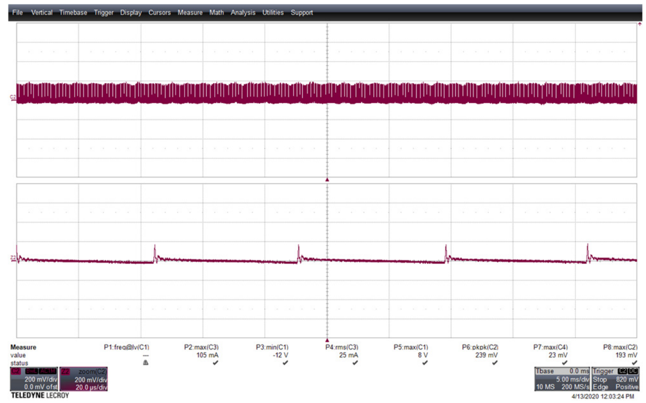


Figure 42 – Output Ripple.(PK-PK – 239 mV).
115 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

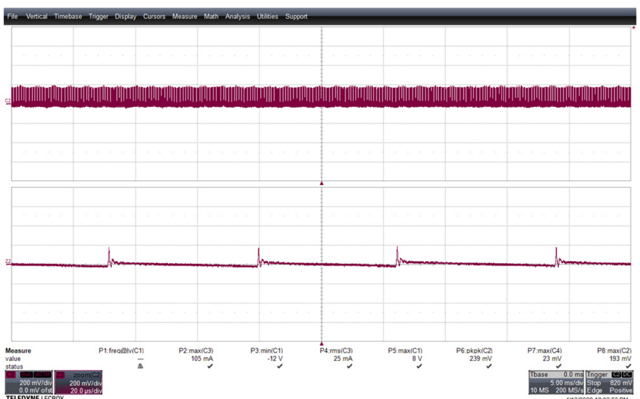


Figure 43 – Output Ripple.(PK-PK – 239 mV).
230 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

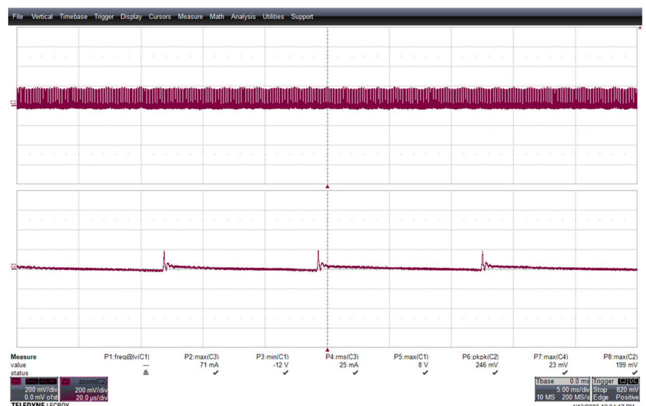


Figure 44 – Output Ripple.(PK-PK – 246 mV).
265 VAC Input, 10% Load.
V_{OUT}, 200 mV / div., 5 ms / div.

15 Conducted EMI

15.1 *Floating Output (QP / AV)*

15.1.1 20 V, 100% Load

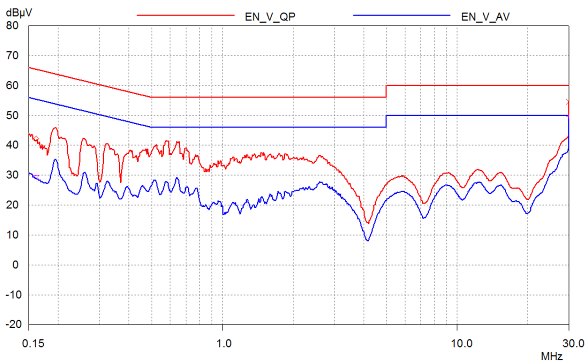


Figure 45 – Floating Ground EMI, 20 V / 100% Load for 115 VAC.

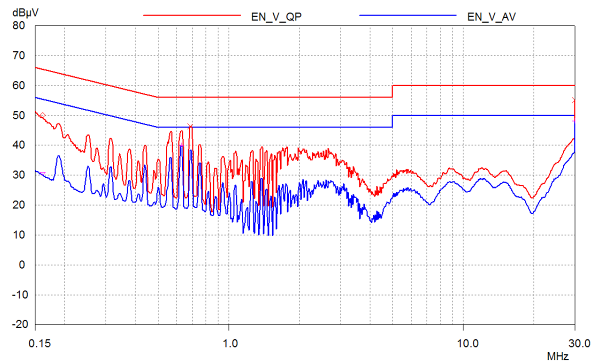


Figure 46 – Floating Ground EMI, 20 V / 100% Load for 230 VAC.

16 Line Surge

16.1 *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.

17 ESD

Passed ±15 kV air discharge and ±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	10	PASS
-15	10	PASS

Contact Discharge (kV)	Number of Strikes	Test Result
+8	10	PASS
-8	10	PASS

18 Revision History

Date	Author	Revision	Description & Changes	Reviewed
22-Sep-22	SS	1.0	First draft	Apps & Mktg

For the latest updates, visit our website: www.power.com

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