Design Example Report

Title	***25 W High Power Charger Using InnoSwitch^{TM}3-CE INN3165C-H101***
Specification	85 VAC – 265 VAC Input; 5 V, 5.0 A Output
Application	Charger
Author	Applications Engineering Department
Document Number	DER-538
Date	July 2, 2020
Revision	1.1

Summary and Features

- InnoSwitch3-CE industry first AC/DC IC with isolated, safety rated integrated feedback
- Built-in synchronous rectification for high efficiency
- All the benefits of secondary-side control with the simplicity of primary-side regulation
  - Insensitive to transformer variation
  - Extremely fast transient response independent of load timing
- Meets DOE6 and CoC V5 tier 2
- <30 mW no-load input power
- <15 mW across line input
- Efficiency >90% at 230 VAC
- Efficiency >85% at 10% load across line input
- Low conducted EMI earthed, >10% db margin at 115 VAC and 230VAC

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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.

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1 Introduction

This document is an engineering report describing a 5 A, 5.0 V charger utilizing a device from the InnoSwitch3-CE family of ICs. This design is intended to show the high power density and efficiency that is possible due to the high level of integration while still providing exceptional performance.

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

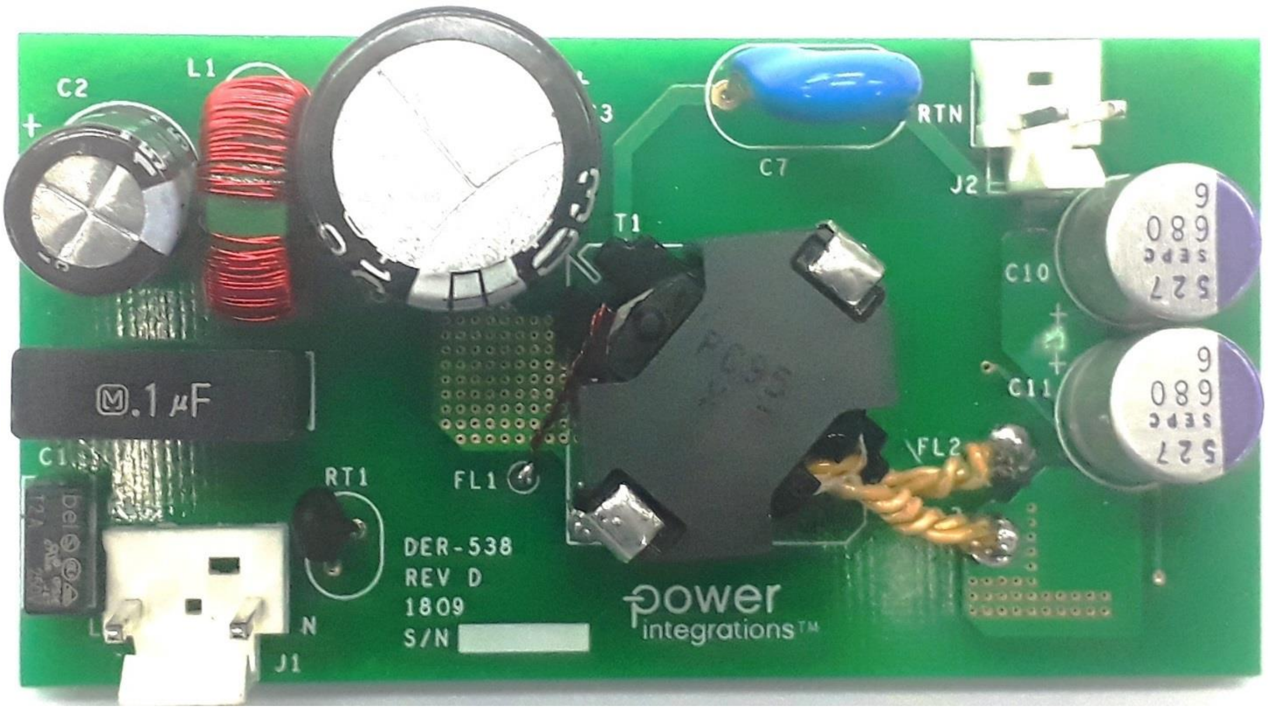

Figure 1 – Populated Circuit Board Photograph, Top.

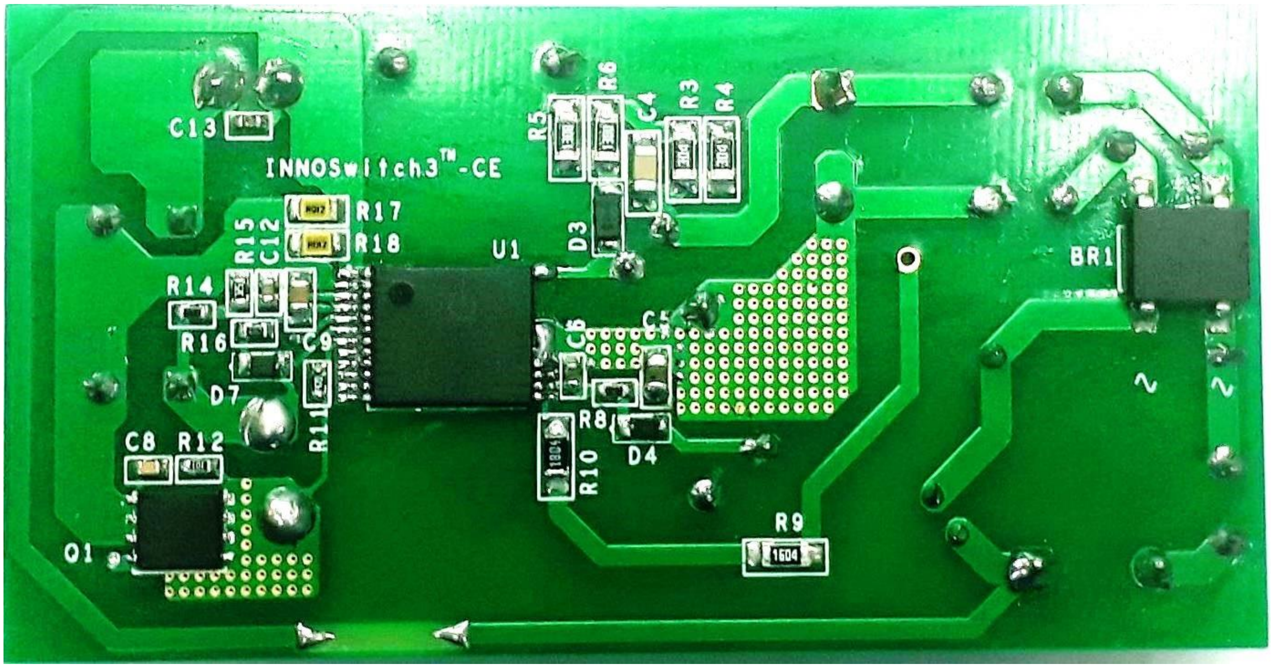

Figure 2 – Populated Circuit Board Photograph, Bottom.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	
Frequency	f_{LINE}	47	50/60	63	Hz	
No-load Input Power				30	mW	230 VAC
Output						
Output Voltage	V_{OUT}	4.75	5	5.25	V	Measured on the Board Terminal.
Output Current	I_{OUT}		5		A	
Output Ripple Voltage	V_{RIPPLE}			150	mV	Measured at the End of Cable with a 47 μF Capacitor Connected at the End of 60 mΩ Cable.
Continuous Output Power	P_{OUT}	25			W	
Efficiency						
Full Load	$\eta_{100\%}$	88			%	115 VAC, 230 VAC.
Average 25%, 50%, 75%, and 100%	η_{AVE}	88			%	Meets DOE VI and COC V5 Tier2. Measured at Output Terminal.
10% Load	$\eta_{100\%}$	85			%	
Environmental						
Line Surge Common Mode (L1/L2-PE)				6	kV	100 kHz Ring Wave, 12 Ω Common Mode.
Line Surge Differential Mode				1	kV	1.2 / 50 μs surge, IEC 1000-4-5, Series Impedance Differential Mode: 2 Ω.
Conducted EMI						Meets CISPR22B / EN55022B
Safety						Designed to Meet IEC60950 / UL1950 Class II.
ESD						
Contact Discharge				±8	kV	
Air Discharge				±16	kV	
Ambient Temperature	T_{AMB}	0		50	ºC	Free Convection, Sea level in Sealed Enclosure.

3 Schematic

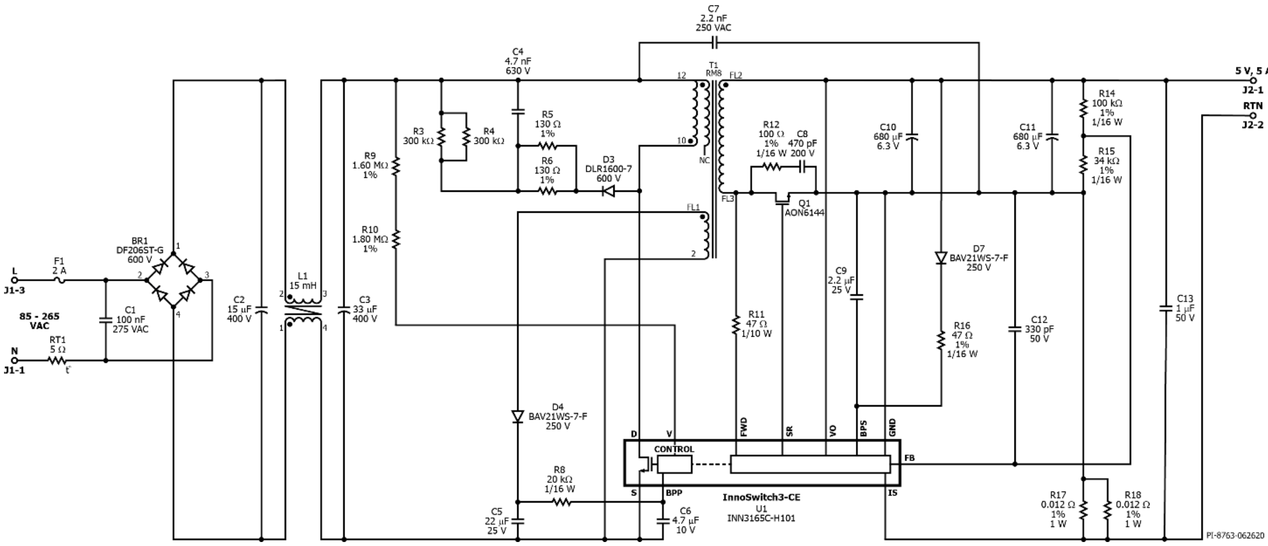

Figure 3 – Schematic.

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4 Circuit Description

The InnoSwitch3-CE IC combines primary, secondary and feedback circuits in a single surface mounted off-line flyback switcher IC. The IC incorporates the primary MOSFET, the primary-side controller, the secondary-side controller for synchronous rectification and the Fluxlink™ technology that eliminates the need for an optocoupler needed on a secondary sensed feedback system.

4.1 *Input Circuit Description*

Fuse F1 isolates the circuit and provides protection from component failure and thermistor RT1 suppresses inrush current. Bridge rectifier BR1 rectifies the AC line voltage and provides a full wave rectified DC across the input capacitor, C2 and C3. X capacitor C1, together with the common mode inductor L1 and capacitors C2 and C3 form a π–filter that provides filtering for both common mode and differential mode noise.

4.2 *Primary Circuit*

One end of the transformer primary winding is connected to the rectified DC bus, the other end is connected to the integrated power MOSFET inside the InnoSwitch-CE IC (U1).

A low cost RCD clamp formed by D3, R3, R4, R5, R6 and C4 limits the peak Drain voltage during turn-off. The clamp helps 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. The output of this is configured as a flyback winding which is rectified and filtered using diode D4 and capacitor C5, and fed in the BPP pin via current limiting resistors R8.

4.3 *Secondary Circuit*

The secondary-side of the InnoSwitch3-CE provides output voltage, output current sensing and drive to a MOSFET providing synchronous rectification.

Output rectification is provided by SR FET Q1. Very low ESR capacitor C10 and C11 provide filtering and the SMD capacitor C13 added for output connector filtering. RC snubber network comprising R12 and C8 for Q1 damps high frequency ringing across SR FETs, which results from leakage inductance of the transformer windings and the secondary trace inductances. The gate of Q1 is turned on based on the winding voltage sensed via R11 and the FWD pin of the IC. In continuous conduction mode operation, the power MOSFET is turned off just prior to the secondary side controller commanding a new switching cycle from the primary. In discontinuous mode the MOSFET is turned off when the voltage drop across the MOSFET falls below ground. Secondary-side control of the primary side MOSFET ensure that it is never on simultaneously with the synchronous rectification MOSFET. The MOSFET drive signal is output on the SR pin. The secondary-side of the IC is self-powered from either the secondary winding forward voltage or the output voltage. The output voltage powers the device which is fed into the VO pin. It will charge the decoupling capacitor C9 via an internal regulator.

Resistors R14 and R15 form a voltage divider network that senses the output voltage. InnoSwitch-CE IC has an FB internal reference of 1.265 V. Capacitor C12 provides decoupling from high frequency noise affecting power supply operation. Secondary-side output overvoltage protection is through D7 and R16. The output current is sensed by the parallel combination of R17 and R18 with a threshold of approximately 35 mV to reduce losses. Once the current sense threshold across these resistors is exceeded, the device adjusts the number of switch pulses to maintain a fixed output current. If no fixed current requirement, the IS and GND pins can be shorted.

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5 PCB Layout

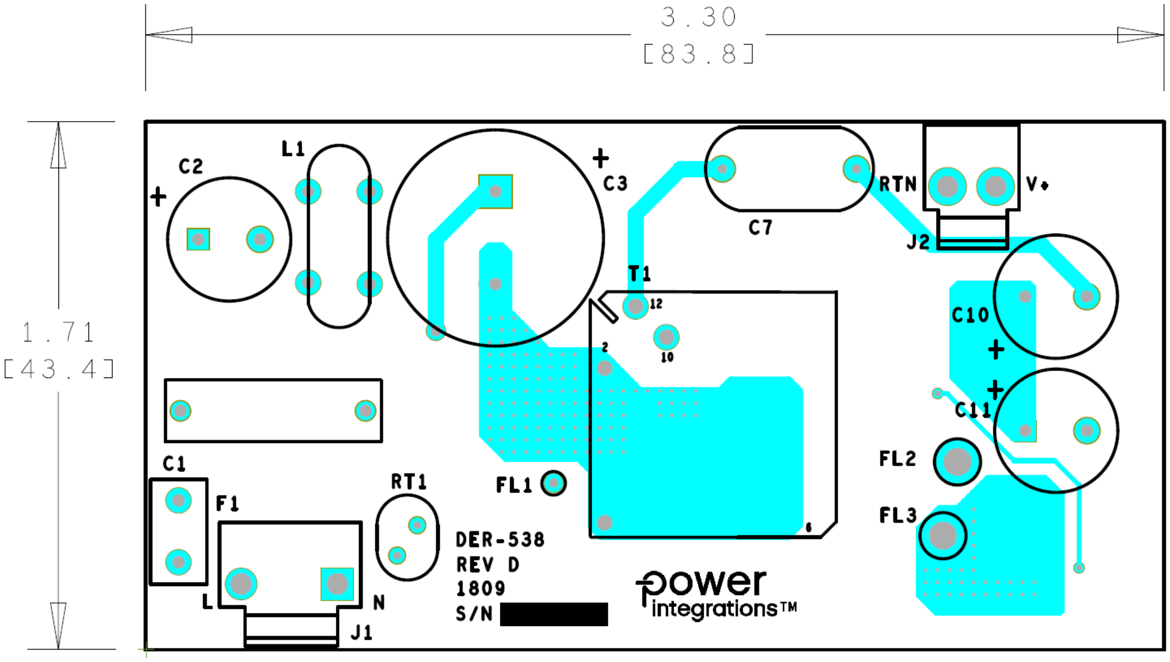

Figure 4 – Printed Circuit Layout, Top.

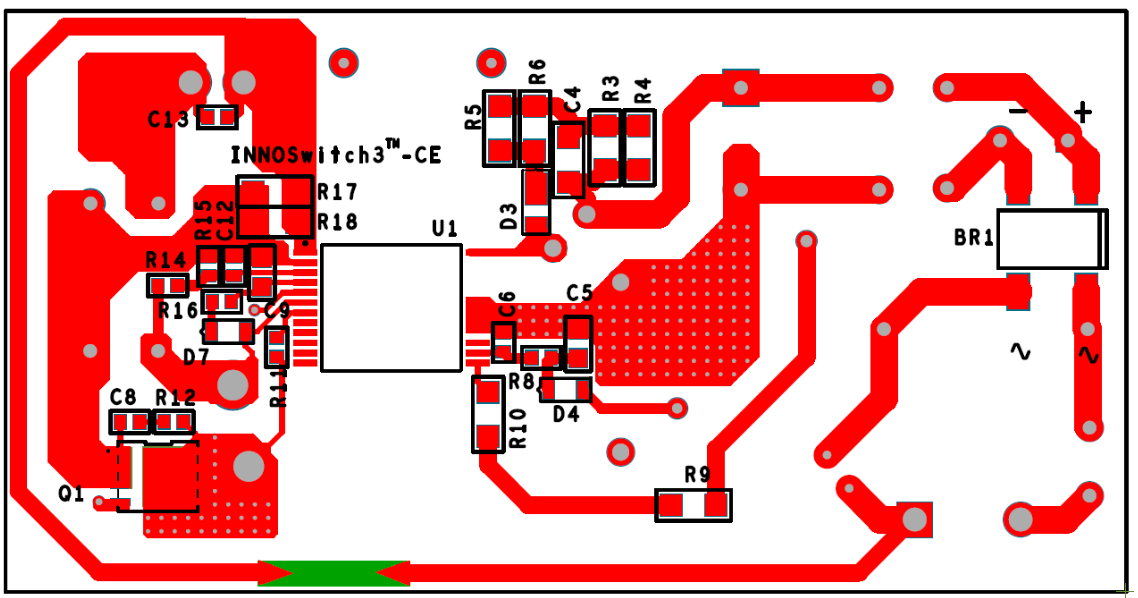

Figure 5 – Printed Circuit Layout, Bottom.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 2 A, Bridge Rectifier, SMD, DFS	DF206ST-G	Comchip
2	1	C1	100 nF, 275 VAC, Film, X2	PHE840MB6100KB05R17	Kemet
3	1	C2	15 μF, 400 V, Electrolytic, (10 x 16)	UVC2G150MPD	Nichicon
4	1	C3	33 μF, 400 V, Electrolytic Low ESR, 240 mΩ, (18 x 20)	EEU-EB2G330S	Panasonic
5	1	C4	4.7 nF, 630 V, Ceramic, X7R, 1206	RM31BR72J472KW01L	Murata
6	1	C5	22 μF, 25 V, Ceramic, X5R, 0805	GRM21BR61E226ME44L	Murata
7	1	C6	4.7 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A475M/0.50	TDK
8	1	C7	2.2 nF, 250 VAC, Film, X1Y1	DE1E3KX222MN4AN01F	Murata
9	1	C8	470 pF, 200 V, Ceramic, X7R, 0603	06032C471KAT2A	AVX
10	1	C9	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
11	1	C10	680 μF, 6.3 V, Al Organic Polymer, Gen. Purpose, 20%	6SEPC680M	Panasonic
12	1	C11	680 μF, 6.3 V, Al Organic Polymer, Gen. Purpose, 20%	6SEPC680M	Panasonic
13	1	C12	330 pF 50 V, Ceramic, X7R, 0603	CC0603KRX7R9BB331	Yageo
14	1	C13	1 μF, 50 V, Ceramic, X5R, 0603	CL10A105KB8NNNC	Samsung
15	1	D3	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
16	1	D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
17	1	D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
18	1	F1	2 A, 250 V, Slow, Long Time Lag, RST	RST 2	Belfuse
19	1	L1	15 mH, Common Mode Choke		
20	1	Q1	40 V, 100A N-Channel, 8DFN	AON6144	Alpha & Omega Semi
21	1	R3	RES, 300 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ304V	Panasonic
22	1	R4	RES, 300 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ304V	Panasonic
23	1	R5	RES, 130 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1300V	Panasonic
24	1	R6	RES, 130 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1300V	Panasonic
25	1	R8	RES, 20 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2002V	Panasonic
26	1	R9	RES, 1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1604V	Panasonic
27	1	R10	RES, 1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
28	1	R11	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
29	1	R12	RES, 100 Ω, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1000V	Panasonic
30	1	R14	RES, 100 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1003V	Panasonic
31	1	R15	RES, 34 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3402V	Panasonic
32	1	R16	RES, 47 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ470V	Panasonic
33	1	R17	0.012 Ω, ±1%, ±100ppm/°C, 1 W, 1206, Current Sense, Moisture Resistant, Thick Film, -55°C ~ 155°C	RUK3216FR012CS	Samsung
34	1	R18	0.012 Ω, ±1%, ±100ppm/°C, 1 W, 1206, Current Sense, Moisture Resistant, Thick Film, -55°C ~ 155°C	RUK3216FR012CS	Samsung
35	1	RT1	NTC Thermistor, 5 Ω, 1 A	MF72-005D5	Cantherm
36	1	T1	Bobbin, RM8, Vertical, 12 pins	BRM08-1112CP-W-P5.0	MH&W
37	1	U1	InnoSwitch3-CE Integrated Circuit, InSOP24D	INN3165C-H101	Power Integrations

Miscellaneous Parts

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	J1	CONN HEADER 3POS (1x3).156 VERT TIN	0026604030	Molex
2	1	J2	2 Position (1 x 2) header, 0.156 pitch, Vertical	26-60-4020	Molex

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7 Magnetics

7.1 *Transformer Specification*

7.1.1 Electrical Diagram

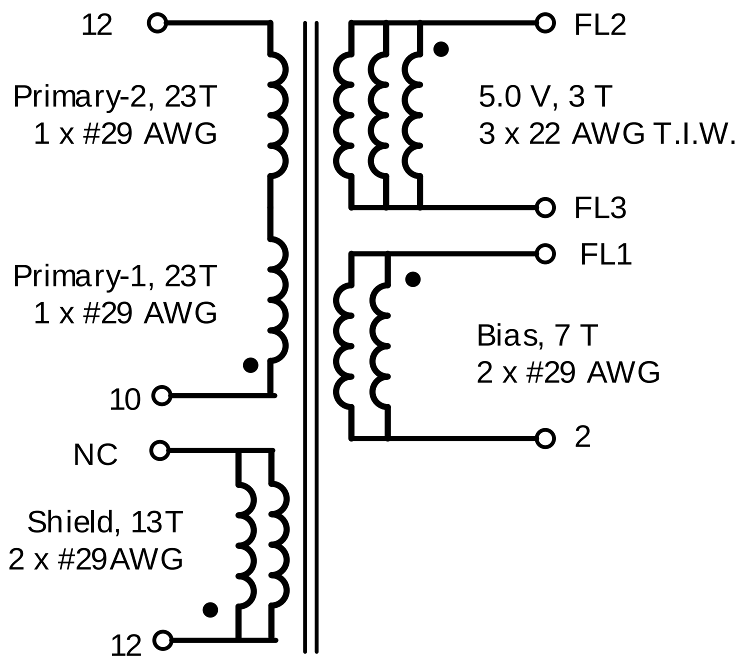

Figure 6 – Transformer Electrical Diagram.

7.1.2 Electrical Specifications

Primary Inductance	Measured between pin 12 and pin 10, at 1 V_{PK-PK}, 100 kHz switching frequency, with all other windings open.	830 μH ±6%
Primary Leakage Inductance	Measured between pin 12 and pin 10, with pins FL2/FL3 shorted and FL1/2 shorted.	10 μH (Max).

7.1.3 Material List

Item	Description
[1]	Core: RM8, PC95RM08Z-12 with Clip Attachment.
[2]	Bobbin: BRM08-1112CP-W-P5.0.
[4]	Magnet Wire: #29 AWG, Solderable Double Coated.
[5]	Magnet Wire: #22 AWG, Triple Insulated Wire.
[6]	Tape: Polyester Film, 3M 1350-1, 9 mm Wide.
[7]	Varnish.

7.1.4 Transformer Build Diagram

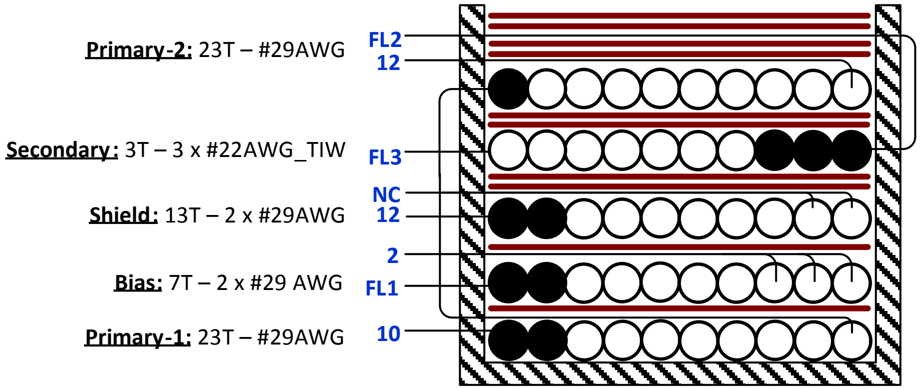

Figure 7 – Transformer Build Diagram.

7.1.5 Transformer Construction

Bobbin Preparation	Prepare the RM8 core, bobbin and the clips. For the purpose of these instructions, bobbin is oriented on winder such that pin side is on the left side. Winding direction is clockwise looking from the side of the pins.
WD1 Primary-1 Winding	Start at pin 10. Wind 23 turns of Item [4] in 1 layer. Return wire to the left and temporarily float the wire.
Insulation	Use 1.25 layer of Item [6] for insulation.
WD2 BIAS Winding	Starting at FL1 (fly lead), wind and spread evenly the 7 turns bifilar of Item [4] in 1 layer. Return wire to the left and terminate at pin 2.
Insulation	Use 1.25 layer of Item [6] for insulation.
WD3 Shield	Starting at pin12, wind 13 turns bifilar of Item [4] in 1 layer. Cut the end for no connection (NC).
Insulation	Use 2.25 layers of Item [6] for insulation.
WD4 Secondary Winding	Starting on the right, at the no-pins side, marked as FL2 (fly lead), wind and spread evenly 3 turns trifilar of Item [5] and end it at FL3 (fly lead, pins side).
Insulation	Use 2.25 layers of Item [6] for insulation.
WD1 Primary-2 Winding	Continue winding the primary from the floating wire of Item [4], another 23 turns in 1 layer. Start from the left pins-side going to the right.
Insulation	Use 1 layers of Item [6] for insulation. Return the wire of the primary winding to the left and terminate at pin 12. Use 1.25 layers of Item [6] for insulation.
Trifilar FL2	Return the fly lead wire FL2 to the left (pins-side).
Final Assembly	Use 3 layers of Item [6] for insulation. Cut the pins 1, 3, 4, 5, 6, 7, 8, 9 and 11. Insert cores, gapped for the inductance specified. Secure core halves using clips. Twist the trifilar wires as shown. Cut length of FL2 to 22 mm from the body. Do the same for FL3 and cut to 20 mm. Dip varnish Item [7].

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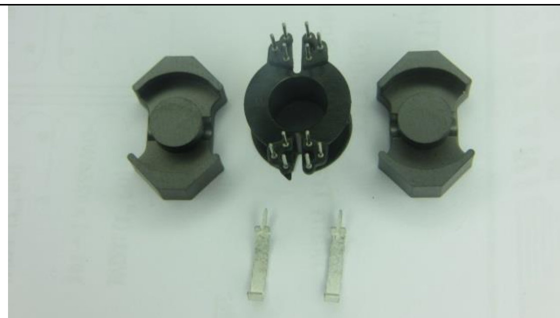
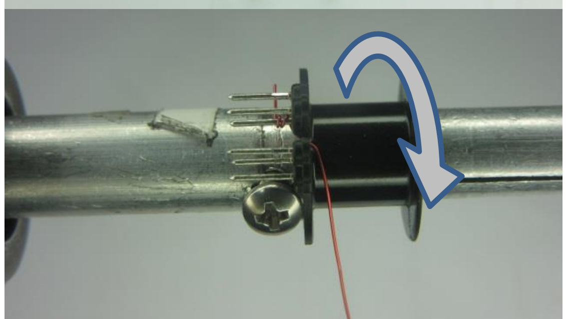
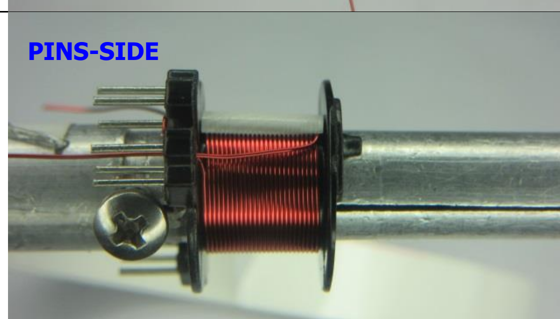
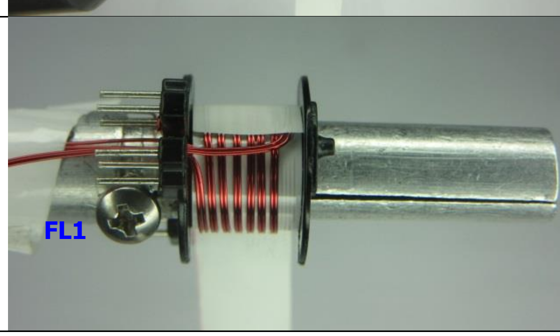
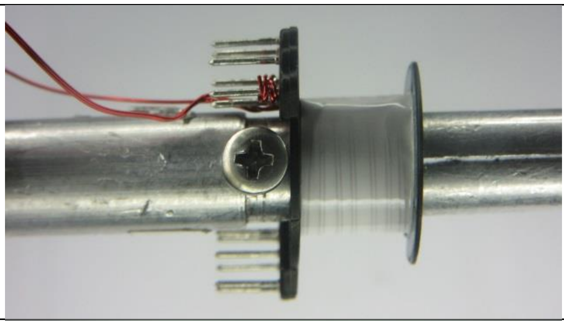
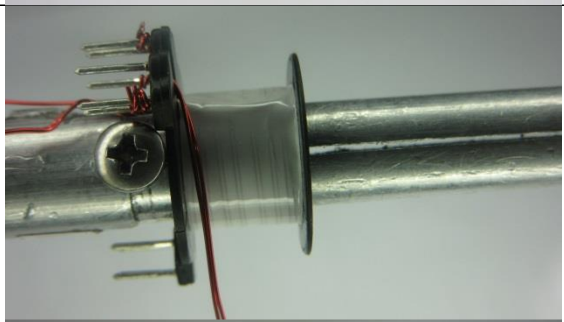
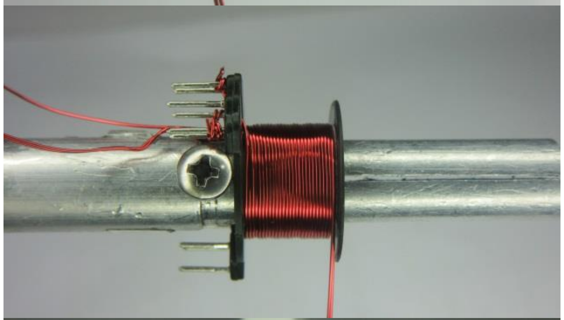
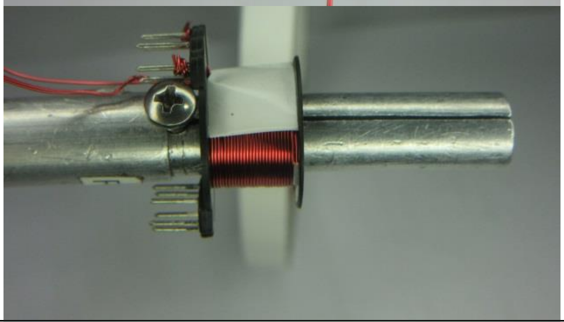
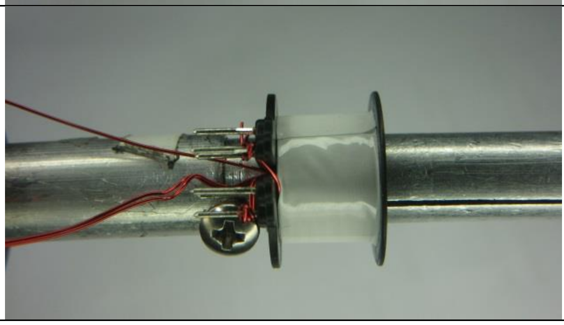
7.1.6 Transformer Winding Illustrations

Bobbin Preparation	 	Prepare the RM8 core, bobbin and the clips. For the purpose of these instructions, bobbin is oriented on winder such that pin side is on the left side. Winding direction is clockwise looking from the side of the pins.
WD1 Primary-1 Winding		Start at pin 10. Wind 23 turns of Item [4] in 1 layer. Return wire to the left and temporarily float the wire.
Insulation		Use 1.25 layer of Item [6] for insulation.
WD2 BIAS Winding		Starting at FL1 (fly lead), wind and spread evenly the 7 turns bifilar of Item [4] in 1 layer. Return wire to the left and terminate at pin 2.

Insulation		Use 1.25 layer of Item [6] for insulation.
WD3 Shield	  	Starting at pin 12, wind 13 turns bifilar of Item [4] in 1 layer. Cut the end for no connection (NC).
Insulation		Use 2.25 layers of Item [6] for insulation.

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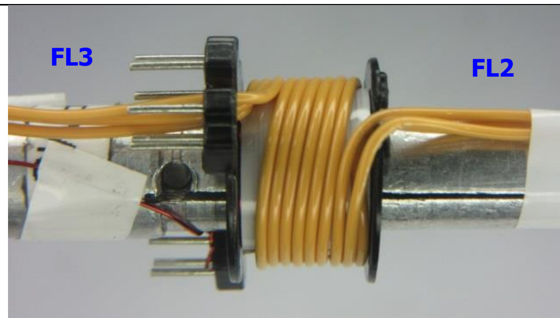
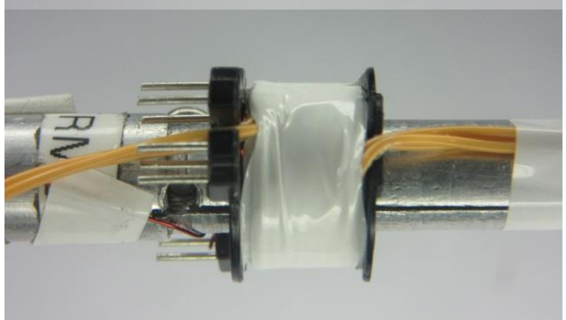
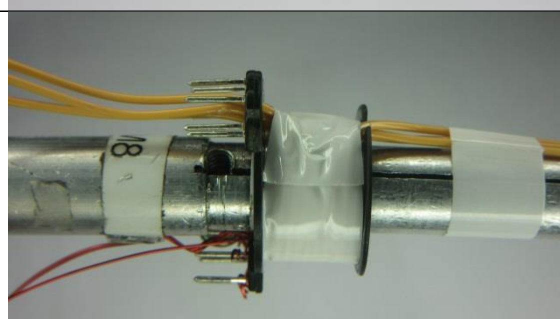
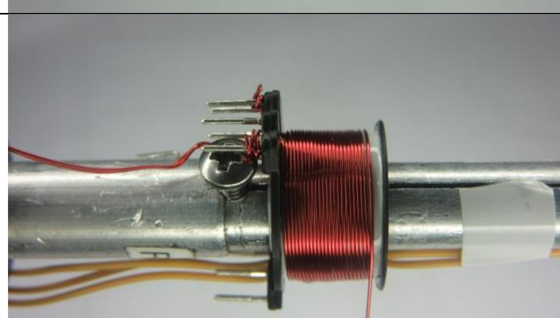
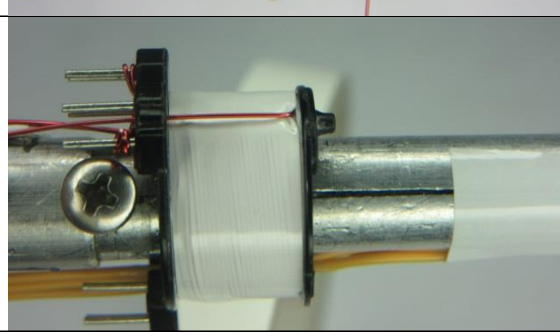
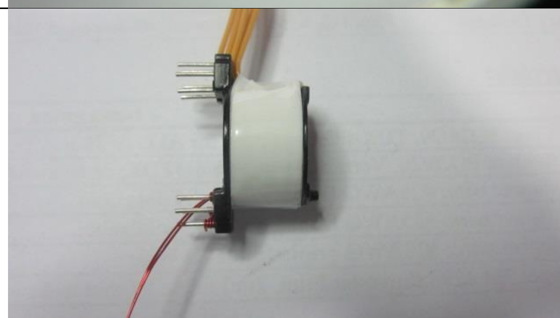
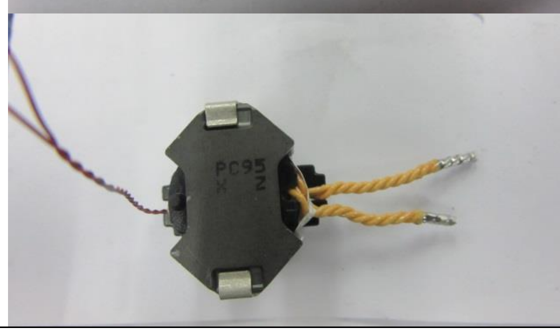
WD4 **Secondary Winding**	 	Starting on the right, at the no-pins side, marked as FL2 (fly lead), wind and spread evenly 3 turns trifilar of Item [5] and end it at FL3 (fly lead, pins side).
Insulation		Use 2.25 layers of Item [6] for insulation.
WD1 **Primary-2 Winding**		Continue winding the primary from the floating wire of Item [4], another 23 turns in 1 layer. Start from the left pins-side going to the right.
Insulation		Use 1 layers of Item [6] for insulation. Return the wire of the primary winding to the left and terminate at pin 12. Use 1.25 layers of Item [6] for insulation.

Trifilar FL2		Return the fly lead wire FL2 to the left (pins-side).
Final Assembly	  	Use 3 layers of Item [6] for insulation. Cut the pins 1, 3, 4, 5, 6, 7, 8, 9 and 11. Insert cores, gapped for the inductance specified. Secure core halves using clips. Twist the trifilar wires as shown. Cut length of FL2 to 22 mm from the body. Do the same for FL3 and cut to 20 mm. Dip varnish Item [7].

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7.2 *Transformer Design Spreadsheet*

1	**ACDC_InnoSwitch3-CE_Flyback_112817; Rev.1.1; Copyright Power Integrations 2017**	**INPUT**	**OUTPUT**	**UNITS**	**InnoSwitch3-CE Flyback Design Spreadsheet**
2	**APPLICATION VARIABLES**				
3	VIN_MIN		85	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	48.0	48.0	uF	Input capacitor
8	VOUT		5.00	V	Output voltage at the board
9	PERCENT_CDC	0%	0%		Percentage (of output voltage) cable drop compensation desired at full load
10	IOUT	5.000	5.000	A	Output current
11	POUT		25.00	W	The specified output power exceeds the device power capability: Verify thermal performance if no other warnings
12	EFFICIENCY	0.85	0.85		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
16	**PRIMARY CONTROLLER SELECTION**				
17	ILIMIT_MODE	INCREASED	INCREASED		Device current limit mode
18	DEVICE_GENERIC	INN31X5	INN31X5		Generic device code
19	DEVICE_CODE		INN3165C		Actual device code
20	POUT_MAX		22	W	Power capability of the device based on thermal performance
21	RDSON_100DEG		3.47	Ω	Primary MOSFET on time drain resistance at 100 degC
22	ILIMIT_MIN		1.046	A	Minimum current limit of the primary MOSFET
23	ILIMIT_TYP		1.150	A	Typical current limit of the primary MOSFET
24	ILIMIT_MAX		1.254	A	Maximum current limit of the primary MOSFET
25	VDRAIN_BREAKDOWN		650	V	Device breakdown voltage
26	VDRAIN_ON_MOSFET		1.16	V	Primary MOSFET on time drain voltage
27	VDRAIN_OFF_MOSFET		521.4	V	Peak drain voltage on the primary MOSFET during turn-off
29	**WORST CASE ELECTRICAL PARAMETERS**				
30	FSWITCHING_MAX	76000	76000	Hz	Maximum switching frequency at full load and valley of the rectified minimum AC input voltage
31	VOR	78.0	78.0	V	Secondary voltage reflected to the primary when the primary MOSFET turns off
32	VMIN		82.75	V	Valley of the minimum input AC voltage at full load
33	KP		0.64		Measure of continuous/discontinuous mode of operation
34	MODE_OPERATION		CCM		Mode of operation
35	DUTYCYCLE		0.489		Primary MOSFET duty cycle
36	TIME_ON		9.70	us	Primary MOSFET on-time
37	TIME_OFF		6.73	us	Primary MOSFET off-time
38	LPRIMARY_MIN		789.0	uH	Minimum primary inductance
39	LPRIMARY_TYP		830.5	uH	Typical primary inductance
40	LPRIMARY_TOL	5.0	5.0	%	Primary inductance tolerance
41	LPRIMARY_MAX		872.0	uH	Maximum primary inductance
43	**PRIMARY CURRENT**				
44	IPEAK_PRIMARY		1.152	A	Primary MOSFET peak current
45	IPEDESTAL_PRIMARY		0.359	A	Primary MOSFET current pedestal
46	IAVG_PRIMARY		0.333	A	Primary MOSFET average current

47	IRIPPLE_PRIMARY		0.939	A	Primary MOSFET ripple current
48	IRMS_PRIMARY		0.513	A	Primary MOSFET RMS current
50	**SECONDARY CURRENT**				
51	IPEAK_SECONDARY		17.657	A	Secondary winding peak current
52	IPEDESTAL_SECONDARY		5.510	A	Secondary winding current pedestal
53	IRMS_SECONDARY		8.884	A	Secondary winding RMS current
55	**TRANSFORMER CONSTRUCTION PARAMETERS**				
56	**CORE SELECTION**				
57	CORE	RM8	RM8		The transformer windings may not fit: pick a bigger core or bobbin and refer to the Transformer Parameters tab for fit calculations
58	CORE CODE		PC95RM08Z		Core code
59	AE		64.00	mm^2	Core cross sectional area
60	LE		38.00	mm	Core magnetic path length
61	AL		5290	nH/turns^2	Ungapped core effective inductance
62	VE		2430.0	mm^3	Core volume
63	BOBBIN		B-RM08-V		Bobbin
64	AW		30.00	mm^2	Window area of the bobbin
65	BW		8.80	mm	Bobbin width
66	MARGIN		0.0	mm	Safety margin width (Half the primary to secondary creepage distance)
68	**PRIMARY WINDING**				
69	NPRIMARY		46		Primary turns
70	BPEAK		3802	Gauss	The peak flux density of the core has exceeded the saturation flux density: Increase the number of secondary turns
71	BMAX		3366	Gauss	Maximum flux density
72	BAC		1345	Gauss	AC flux density (0.5 x Peak to Peak)
73	ALG		392	nH/turns^2	Typical gapped core effective inductance
74	LG		0.190	mm	Core gap length
75	LAYERS_PRIMARY	2	2		Number of primary layers
76	AWG_PRIMARY		28	AWG	Primary winding wire AWG
77	OD_PRIMARY_INSULATED		0.375	mm	Primary winding wire outer diameter with insulation
78	OD_PRIMARY_BARE		0.321	mm	Primary winding wire outer diameter without insulation
79	CMA_PRIMARY		311	Cmil/A	Primary winding wire CMA
81	**SECONDARY WINDING**				
82	NSECONDARY	3	3		Secondary turns
83	AWG_SECONDARY		18	AWG	Secondary winding wire AWG
84	OD_SECONDARY_INSULATED		1.328	mm	Secondary winding wire outer diameter with insulation
85	OD_SECONDARY_BARE		1.024	mm	Secondary winding wire outer diameter without insulation
86	CMA_SECONDARY		202	Cmil/A	Secondary winding wire CMA
88	**BIAS WINDING**				
89	NBIAS		7		Bias turns
91	**PRIMARY COMPONENTS SELECTION**				
92	**Line undervoltage**				
93	BROWN-IN REQURED		68.0	V	Required AC RMS line voltage brown-in threshold
94	RLS		3.38	MΩ	Connect two 1.69 MOhm resistors to the V-pin for the required UV/OV threshold
95	BROWN-IN ACTUAL		67.8	V	Actual AC RMS brown-in threshold
96	BROWN-OUT ACTUAL		61.3	V	Actual AC RMS brown-out threshold
98	**Line overvoltage**				
99	OVERVOLTAGE_LINE		282.5	V	Actual AC RMS line over-voltage threshold
101	**Bias diode**				
102	VBIAS	10.0	10.0	V	Rectified bias voltage
103	VF_BIAS		0.70	V	Bias winding diode forward drop
104	VREVERSE_BIASDIODE		66.82	V	Bias diode reverse voltage (not accounting

					parasitic voltage ring)
105	CBIAS		22	uF	Bias winding rectification capacitor
106	CBPP		4.70	uF	BPP pin capacitor
108	**SECONDARY COMPONENTS**				
109	RFB_UPPER		100.00	kΩ	Upper feedback resistor (connected to the first output voltage)
110	RFB_LOWER		34.00	kΩ	Lower feedback resistor
111	CFB_LOWER		330	pF	Lower feedback resistor decoupling capacitor
113	**MULTIPLE OUTPUT PARAMETERS**				
114	**OUTPUT 1**				
115	VOUT1		5.00	V	Output 1 voltage
116	IOUT1		5.00	A	Output 1 current
117	POUT1		25.00	W	Output 1 power
118	IRMS_SECONDARY1		8.048	A	Root mean squared value of the secondary current for output 1
119	IRIPPLE_CAP_OUTPUT1		6.307	A	Current ripple on the secondary waveform for output 1
120	AWG_SECONDARY1		18	AWG	Wire size for output 1
121	OD_SECONDARY1_INSULATED		1.328	mm	Secondary winding wire outer diameter with insulation for output 1
122	OD_SECONDARY1_BARE		1.024	mm	Secondary winding wire outer diameter without insulation for output 1
123	CM_SECONDARY1		1610	Cmils	Bare conductor effective area in circular mils for output 1
124	NSECONDARY1		3		Number of turns for output 1
125	VREVERSE_RECTIFIER1		29.35	V	SRFET reverse voltage (not accounting parasitic voltage ring) for output 1
126	SRFET1	AON6232	AON6232		SRFET selection for output 1
127	VF_SRFET1		0.018	V	SRFET on-time drain voltage for output 1
128	VBREAKDOWN_SRFET1		40	V	SRFET breakdown voltage for output 1
129	RDSON_SRFET1		3.6	mΩ	SRFET on-time drain resistance at 25degC and VGS=4.4V for output 1
131	PO_TOTAL		25.00	W	Total power of all outputs
134	**TOLERANCE ANALYSIS**				
135	CORNER_VAC		85	V	Input AC RMS voltage corner to be evaluated
136	CORNER_ILIMIT	TYP	1.150	A	Current limit corner to be evaluated
137	CORNER_LPRIMARY	TYP	830.5	uH	Primary inductance corner to be evaluated
138	MODE_OPERATION		CCM		Mode of operation
139	KP		0.735		Measure of continuous/discontinuous mode of operation
140	FSWITCHING		60553	Hz	Switching frequency at full load and valley of the rectified minimum AC input voltage
141	DUTYCYCLE		0.489		Steady state duty cycle
142	TIME_ON		8.07	us	Primary MOSFET on-time
143	TIME_OFF		8.44	us	Primary MOSFET off-time
144	IPEAK_PRIMARY		1.079	A	Primary MOSFET peak current
145	IPEDESTAL_PRIMARY		0.286	A	Primary MOSFET current pedestal
146	IAVERAGE_PRIMARY		0.333	A	Primary MOSFET average current
147	IRIPPLE_PRIMARY		0.793	A	Primary MOSFET ripple current
148	IRMS_PRIMARY		0.503	A	Primary MOSFET RMS current
149	CMA_PRIMARY		318	Cmil/A	Primary winding wire CMA
150	BPEAK		3321	Gauss	Peak flux density
151	BMAX		3043	Gauss	Maximum flux density
152	BAC		1119	Gauss	AC flux density (0.5 x Peak to Peak)

7.3 ***15 mH (L1) Common Mode Choke Specification***

7.3.1 Electrical Diagram

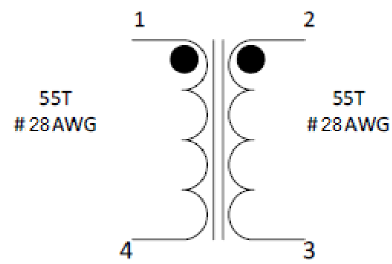

Figure 8 – Inductor Electrical Diagram.

7.3.2 Electrical Specifications

Inductance	Pins 1-4 and pins 2-3 measured at 100 kHz, 0.4 RMS.	15 mH ±10%
Core effective Inductance		4400 nH/N^2
Primary Leakage Inductance	Pins 1-4, with 2-3 shorted.	80 μH

7.3.3 Material List

Item	Description
[1]	Toroid: FERRITE INDUCTOR TOROID T14 x 8 x 5.5.
[2]	Divider: Fish Paper, Insulating Cotton Rag, 0.010" Thick.
[3]	Magnet Wire: #28 AWG Heavy Nyleze
[4]	Epoxy: Devcon, 14270, 5 min Epoxy; or Equivalent.

7.3.4 Winding Instructions

- Place fish paper Item [2] onto toroid Item [1] to divide 2 equal sections.
- Use 4 ft of wire Item [3], start as pin 1, wind 55 turns and end at pin 4.
- Do the same for the other half section of the toroid, start at pin 2, then end at pin 3 symmetrically with last winding.

7.3.5 Illustrations

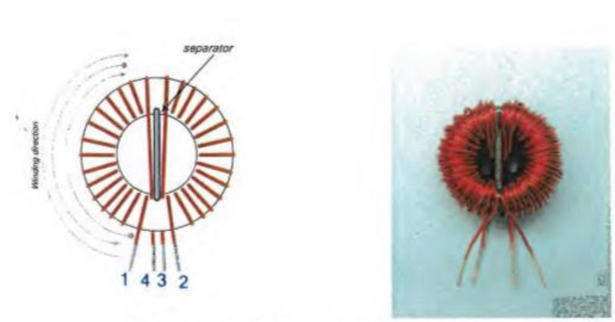

Figure 9 – Side View.

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8 Performance Data

8.1 *Efficiency*

8.1.1 Average & 10% Load Efficiency

Specification

Test	Average	Average	10% Load
Model	Low Voltage	Low Voltage	Low Voltage
Power [W]	**DOE VI**	**CoC v5 Tier 2**	**CoC v5 Tier 2**
25 (5 V / 5 A)	84.25%	85%	75.47%

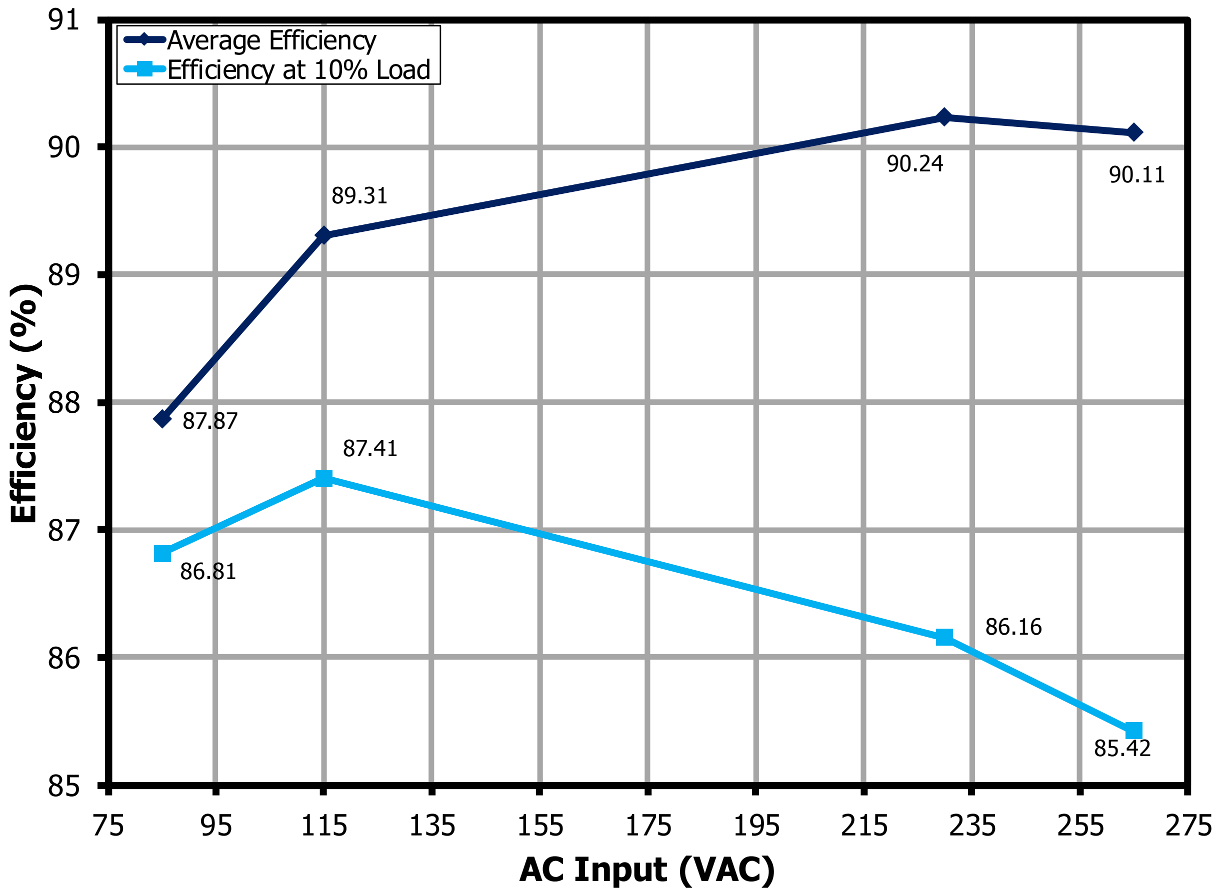

Figure 10 – Efficiency Measured at the Board Output Terminal.

8.1.2 Efficiency vs. Line

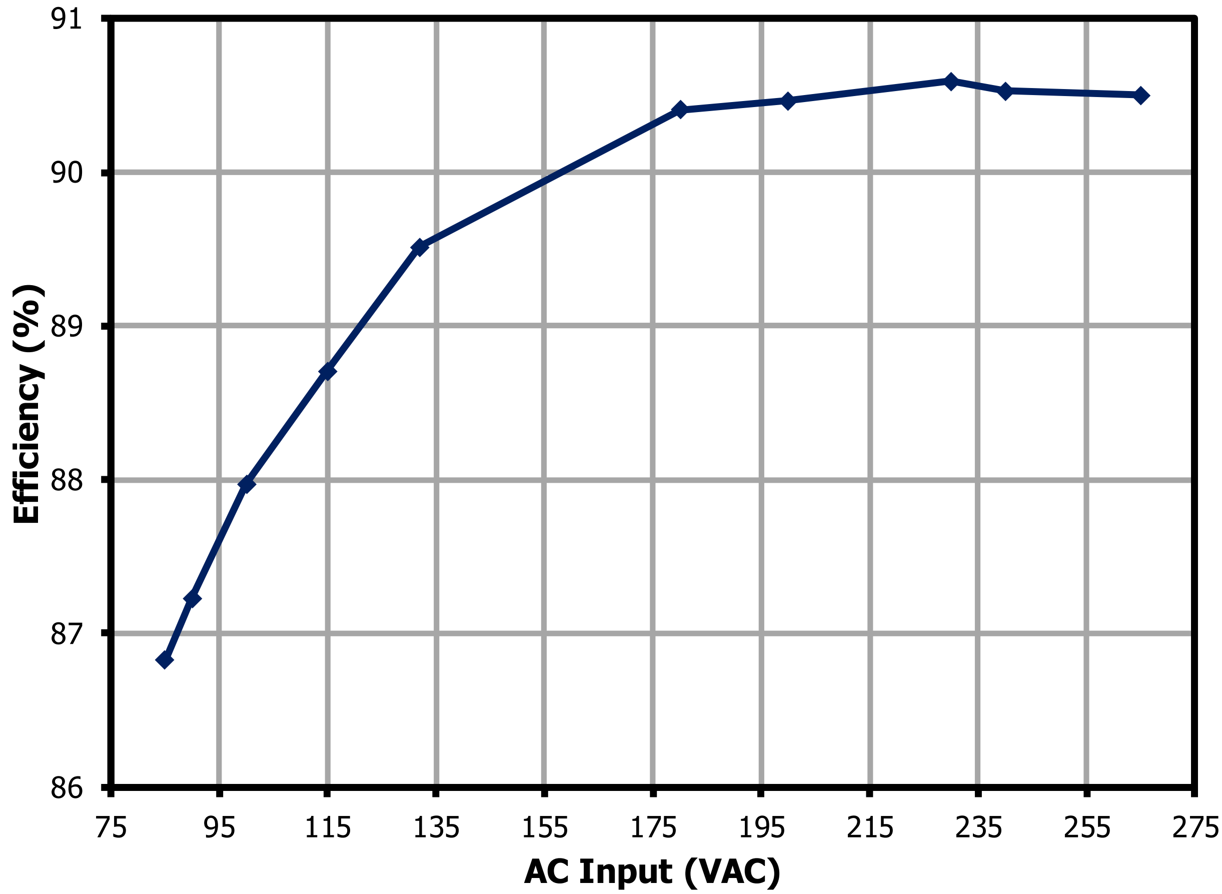

Figure 11 – Efficiency Measured at the Board Output Terminal.

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8.1.3 Efficiency vs. Load

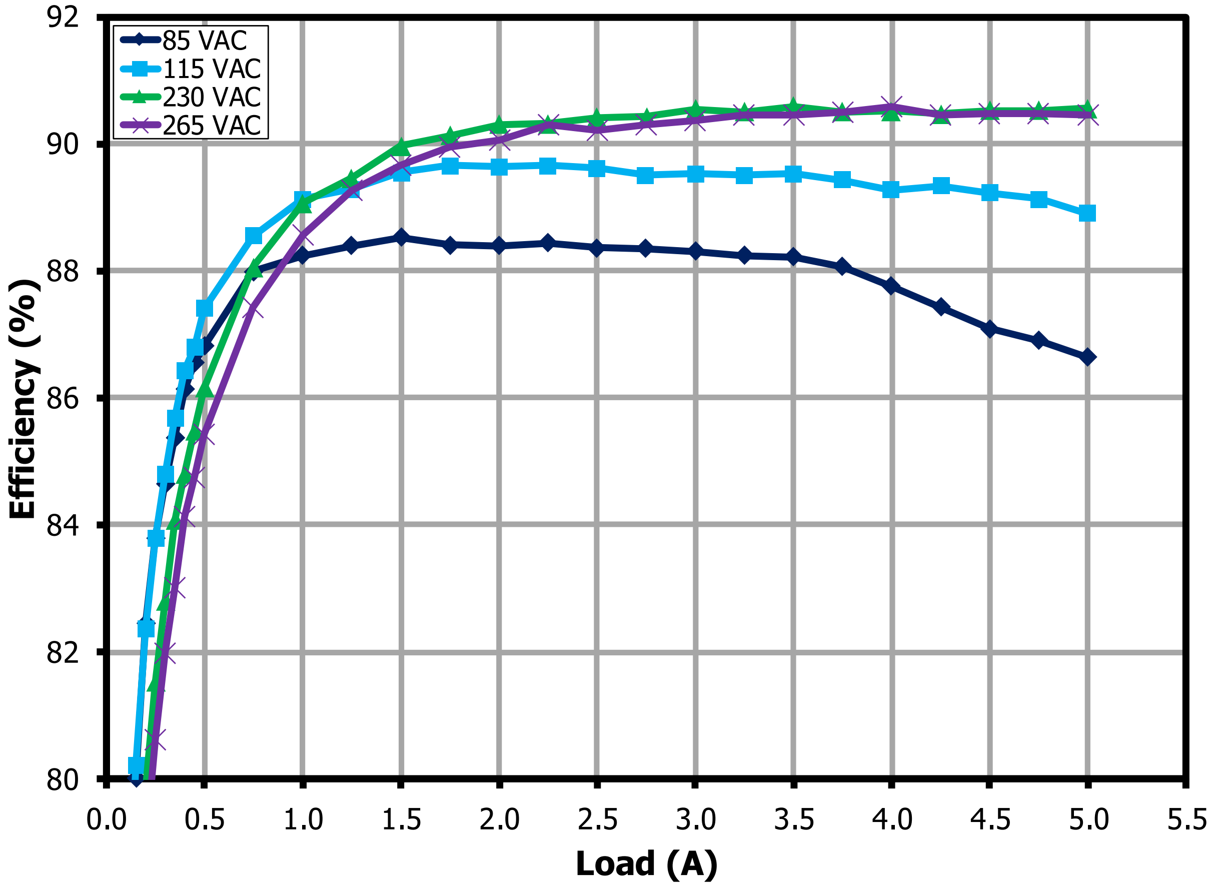

Figure 12 – Efficiency Measured at the Board Output Terminal.

8.2 ***No-Load Input Power***

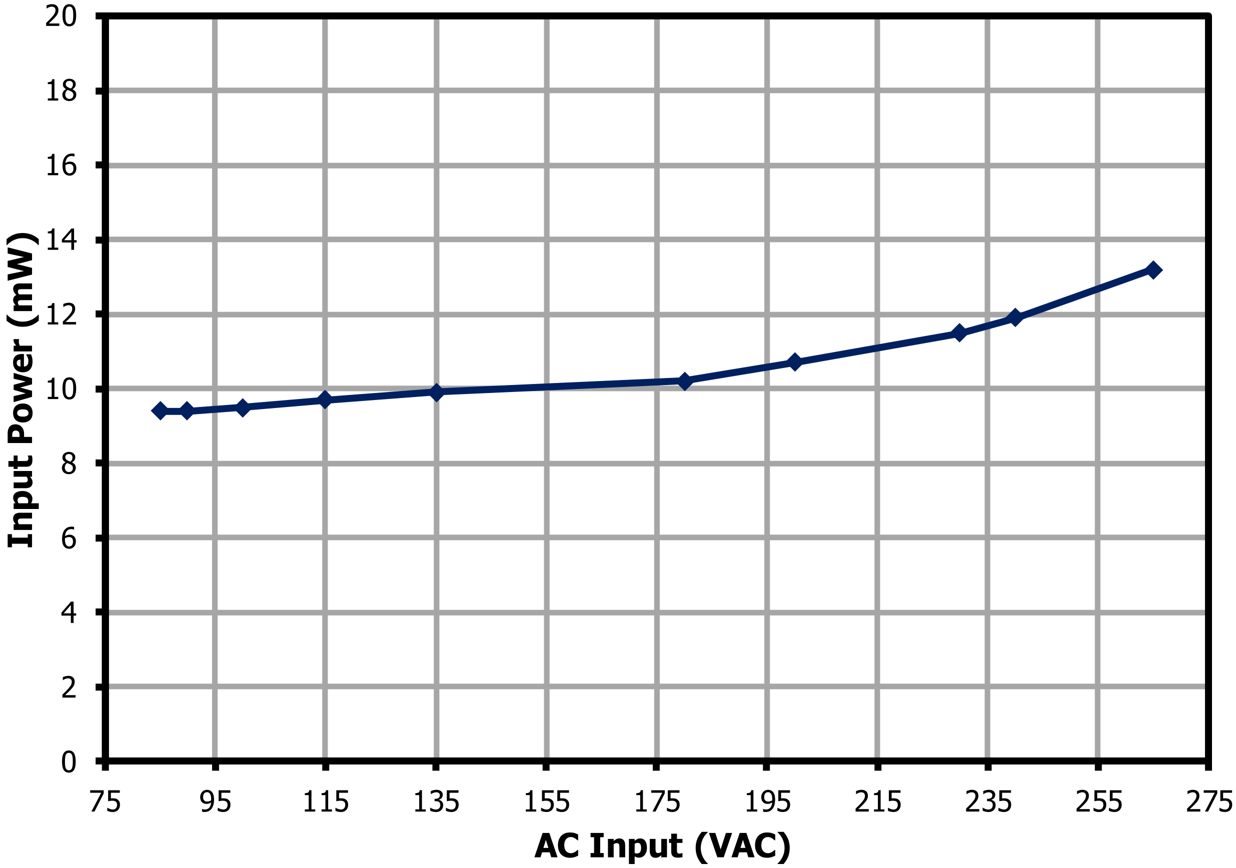

Figure 13 – No-Load Input Power.

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8.3 *Output Voltage Regulation*

8.3.1 Line Regulation

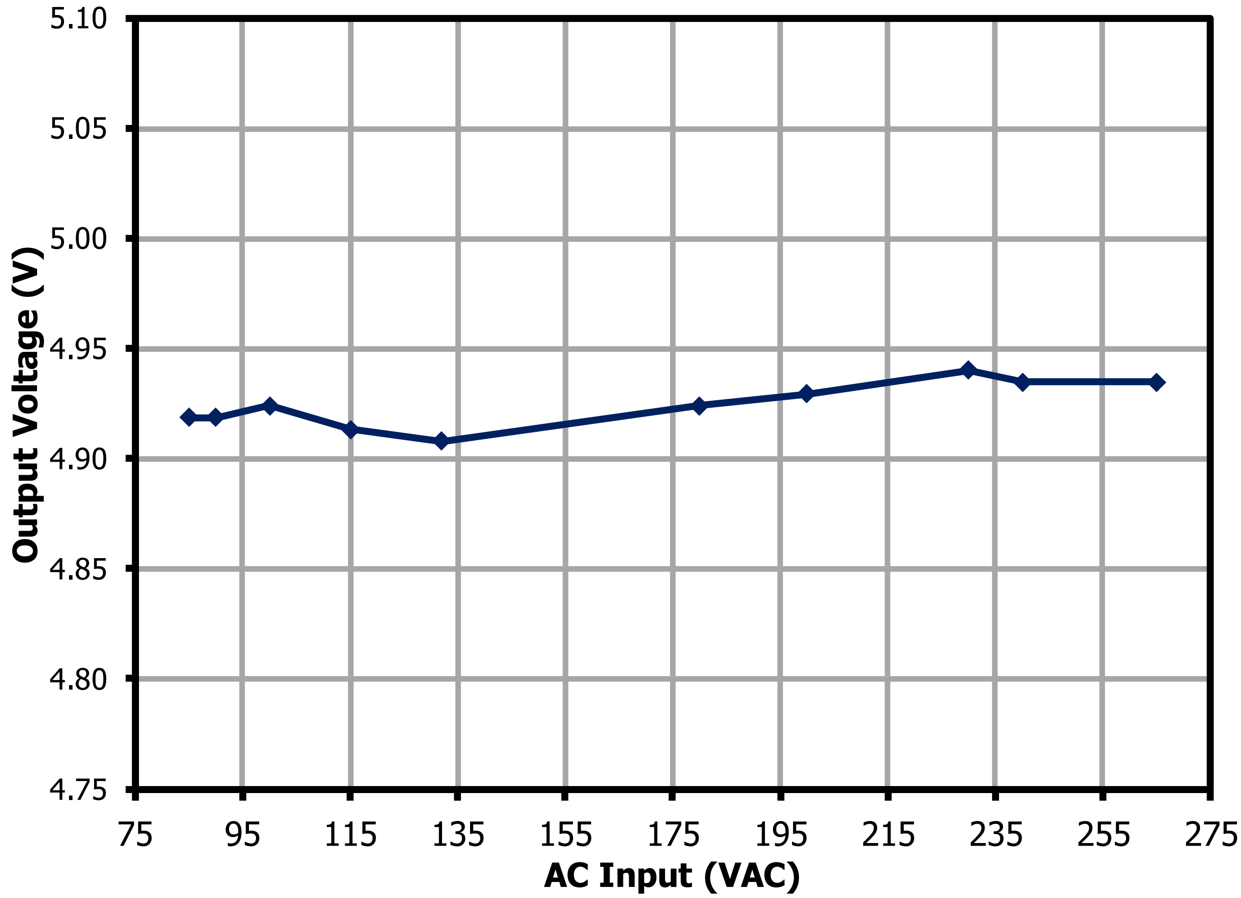

Figure 14 – Line Regulation Measured at the Board Output Terminal.

8.3.2 Load Regulation

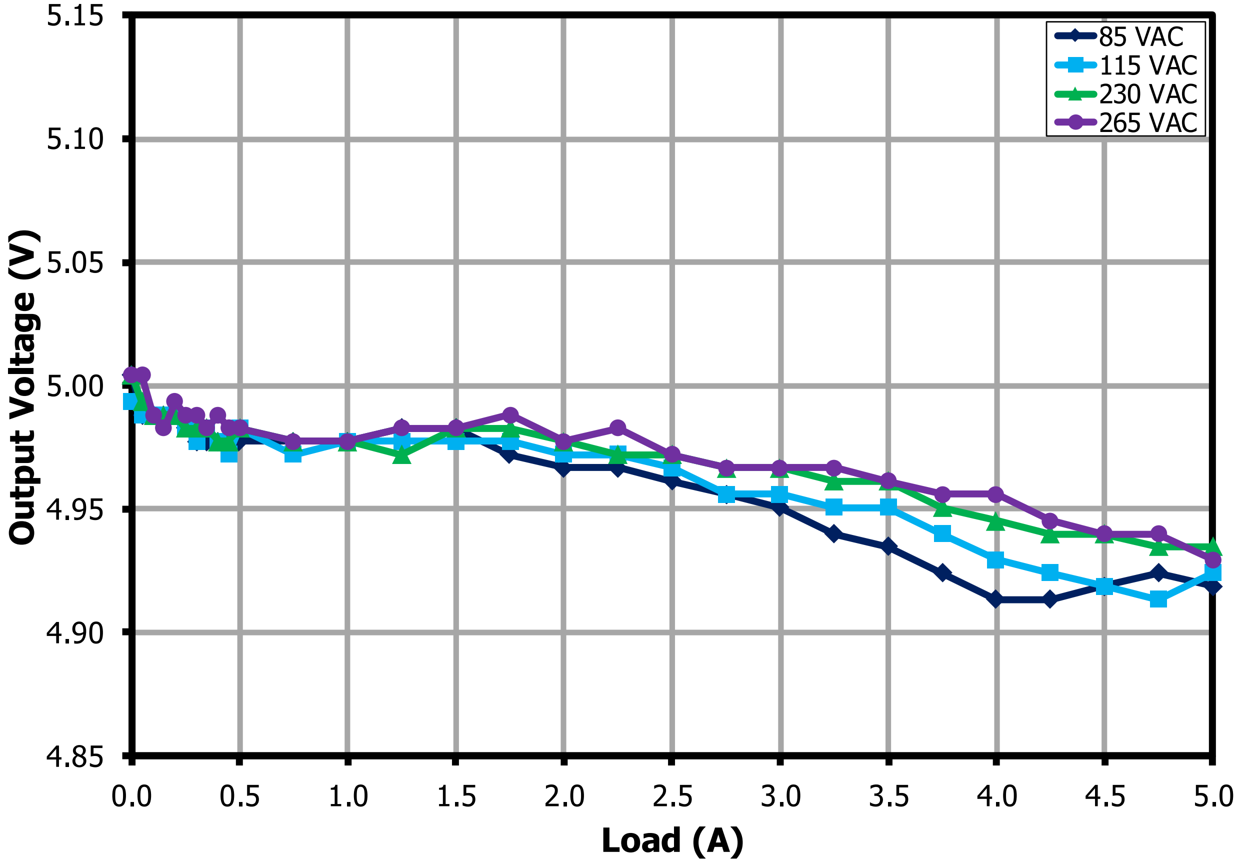

Figure 15 – Load Regulation Measured at the Board Output Terminal.

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8.4 ***Output Ripple Measurements***

8.4.1 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).

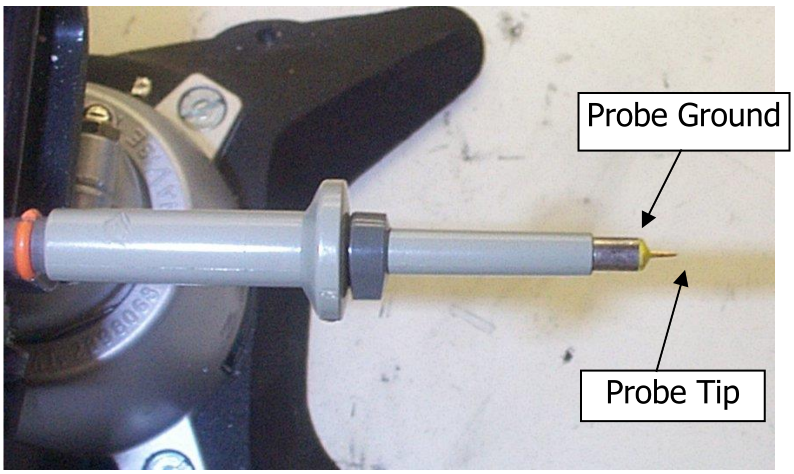

Figure 16 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

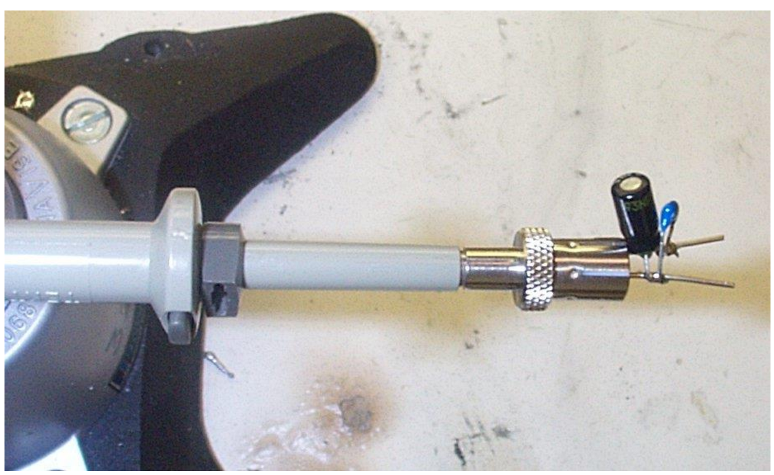

Figure 17 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

8.4.2 Output Ripple

Measured at the end of a 60 mΩ cable.

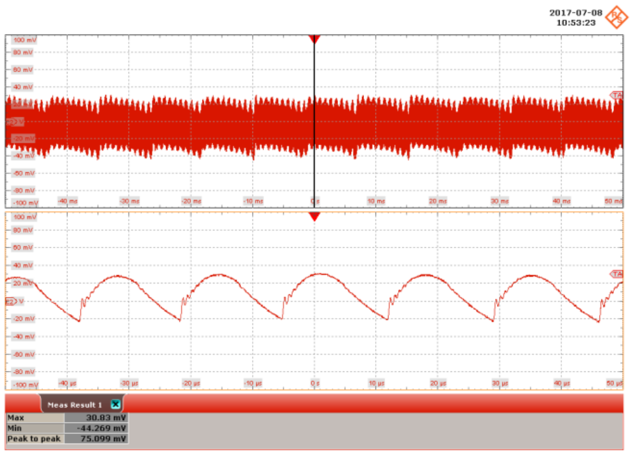

Figure 18 – 85 VAC, 60 Hz; 100% load.
$V_{OUTRIPPLE}$, 20 mV / div., 10 ms / div.
Measured $V_{OUTRIPPLE}$ = 75.1 mV_{PK-PK}.

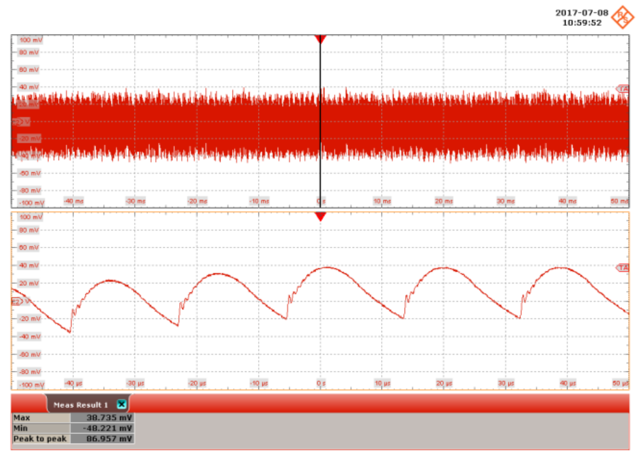

Figure 19 – 265 VAC, 50 Hz; 100% load.
$V_{OUTRIPPLE}$, 20 mV / div., 10 ms / div.
Measured $V_{OUTRIPPLE}$ = 86.96 mV_{PK-PK}.

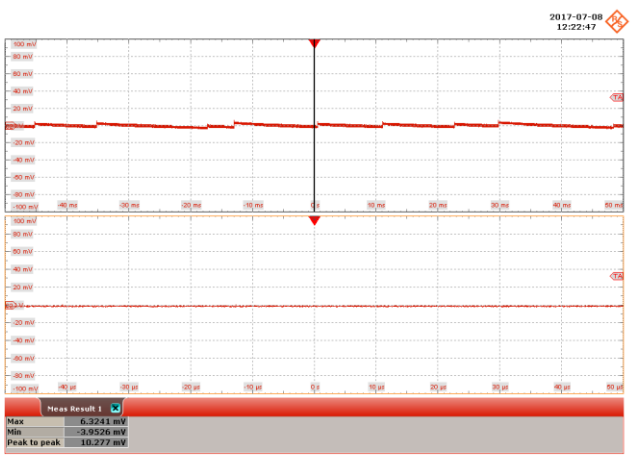

Figure 20 – 85 VAC, 60 Hz; 0% load.
$V_{OUTRIPPLE}$, 20 mV / div., 10 ms / div.
Measured $V_{OUTRIPPLE}$ = 10.28 mV_{PK-PK}.

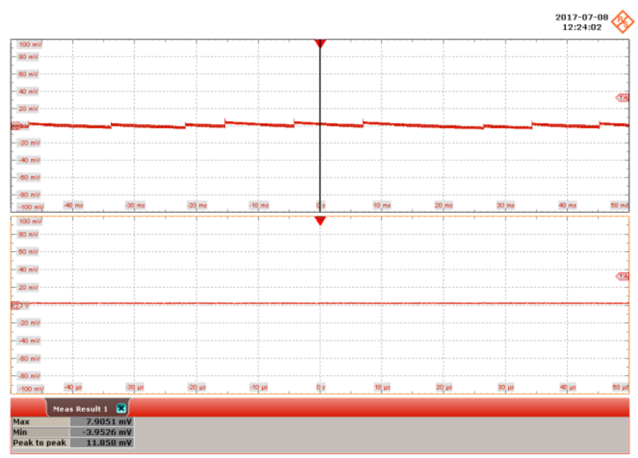

Figure 21 – 265 VAC, 50 Hz; 0% load.
$V_{OUTRIPPLE}$, 20 mV / div., 10 ms / div.
Measured $V_{OUTRIPPLE}$ = 11.86 mV_{PK-PK}.

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8.4.3 Output Ripple Graph

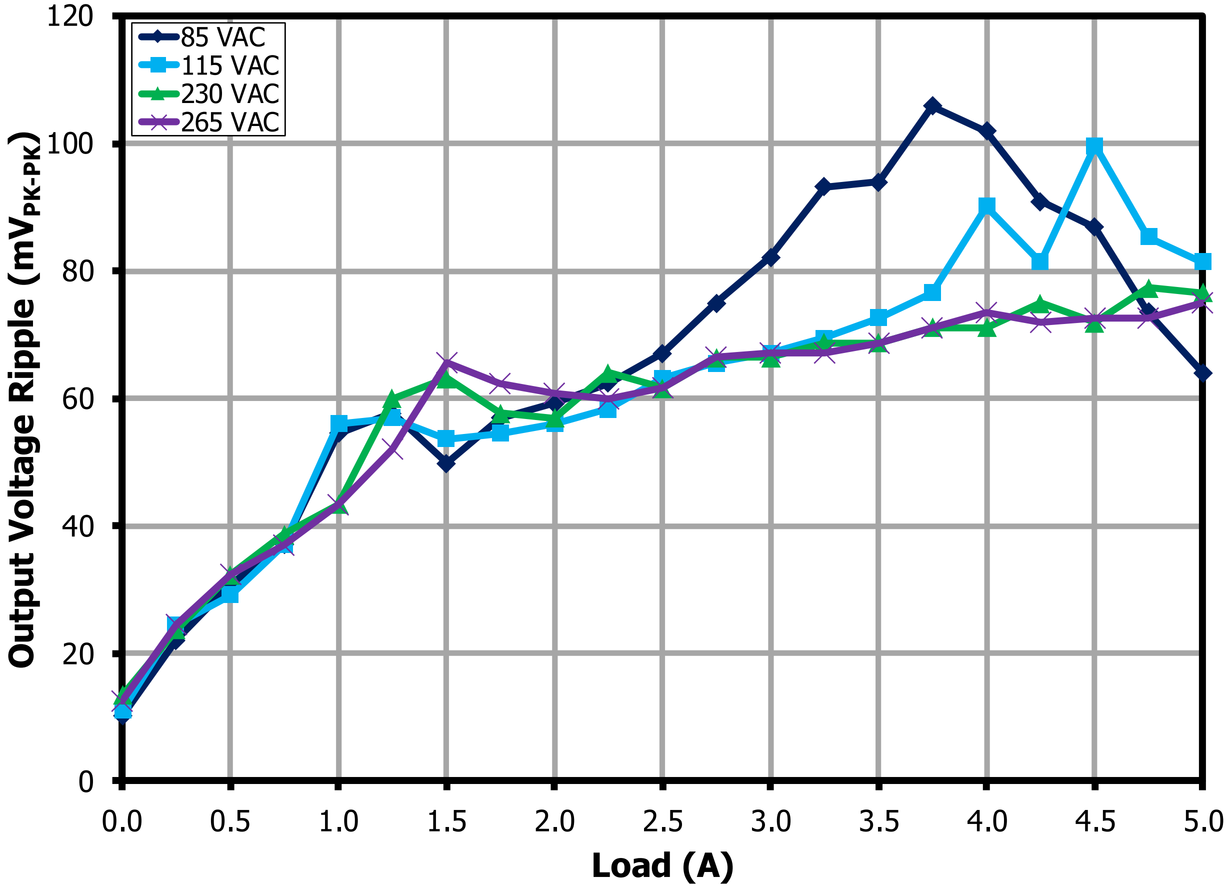

Figure 22 – Output Ripple Measured at the End of a 60 mΩ Cable.

8.5 *CV/CC Graph*

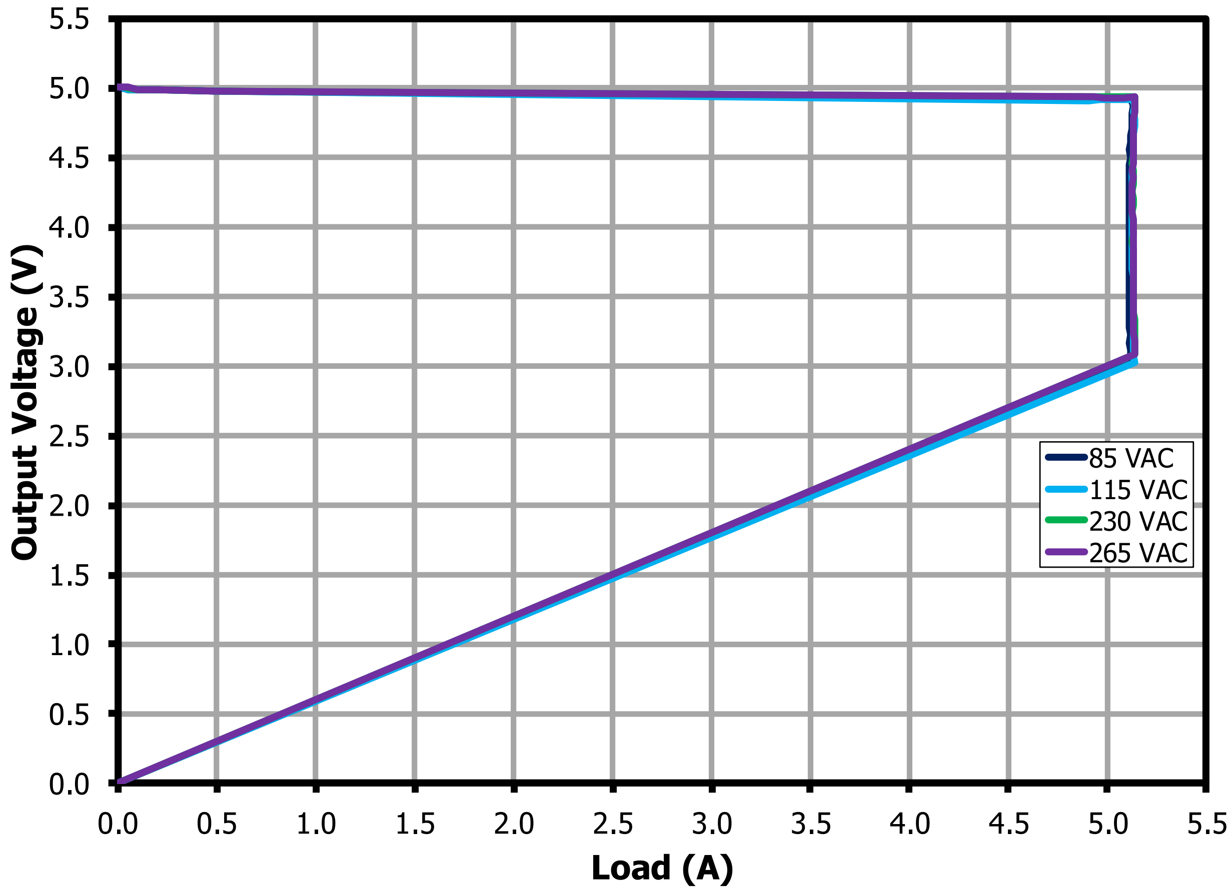

Figure 23 – CV/CC at 25 ºC, Measured at the Board Terminal.

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9 Thermal Performance

9.1 *Thermal Performance at 100% Load, Room Temperature*

Component	Temperature (°C) 85 VAC	Temperature (°C) 265 VAC
Ambient	28.9	27.9
InnoSwitch3	91.1	74.2
Primary Snubber (R5 & R6)	93.9	78.8
Current Sense (R17 & R18)	91.2	85.3
SR FET	77.4	74.5
Bridge	68.6	44.6
Transformer	76	68
Thermistor (RT1)	84.1	56.5
Output Terminal	90.7	87.7

9.1.1 85 VAC

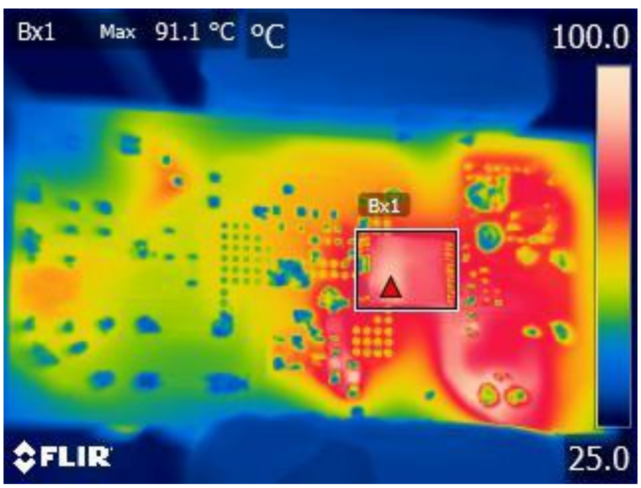

Figure 24 – Bottom Solder Side.

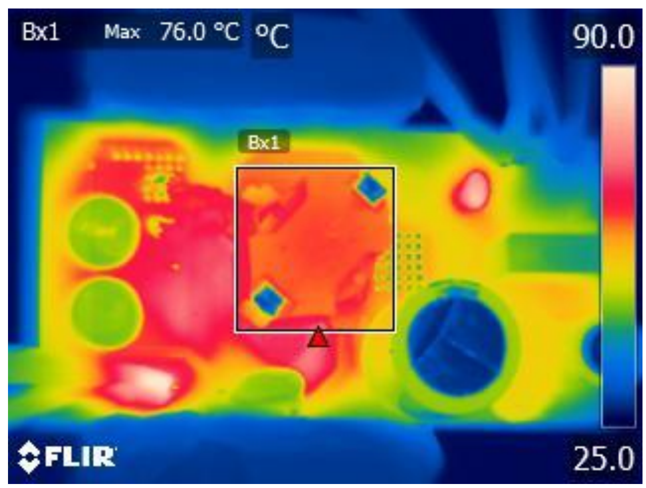

Figure 25 – Top Component Side.

9.1.2 265 VAC

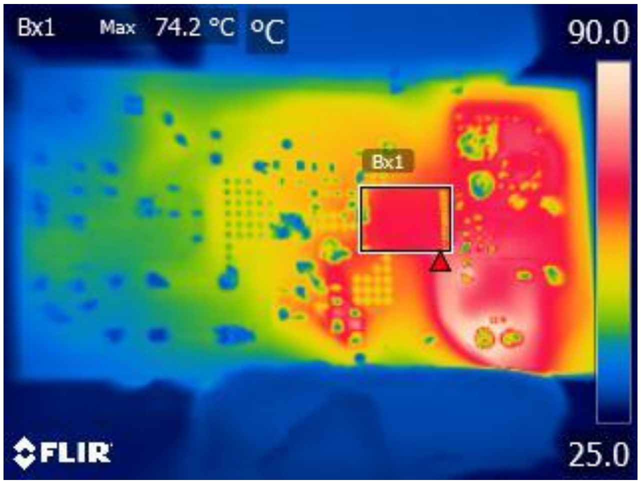

Figure 26 – Bottom Solder Side.

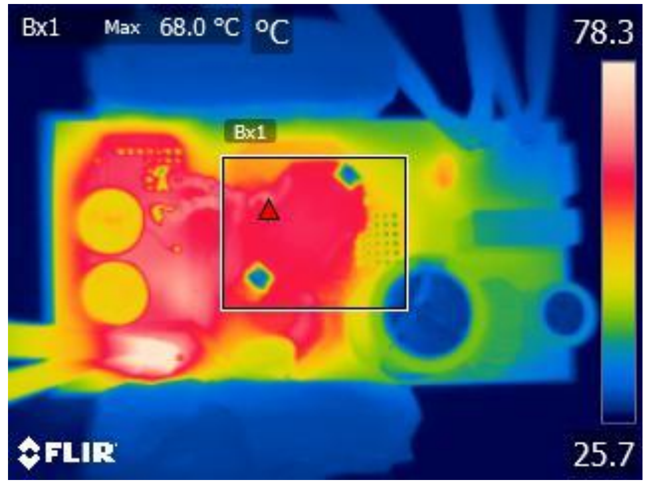

Figure 27 – Top Component Side.

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10 Waveforms

10.1 *Drain Voltage and Current*

10.1.1 Normal Operation, Full Load

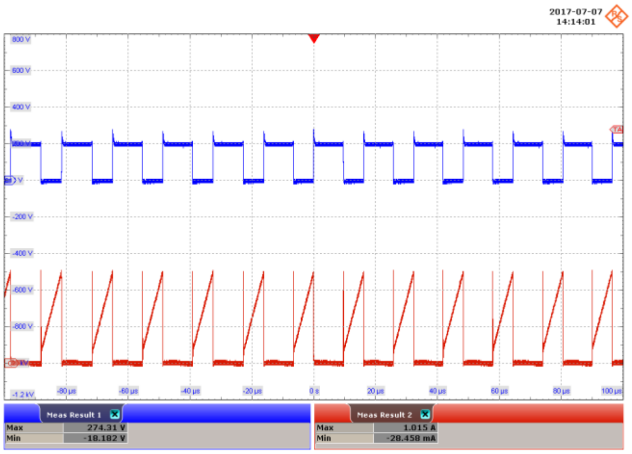

Figure 28 – 85 VAC, 60 Hz.
Upper: V_{DRAIN}, 200 V / div., 20 µs / div.
Lower: I_{DRAIN}, 400 mA / div., 20 µs / div.
Measured V_{PK} = 274.31 V_{PK}.
Measured I_{PK} = 1.02 A_{PK}.

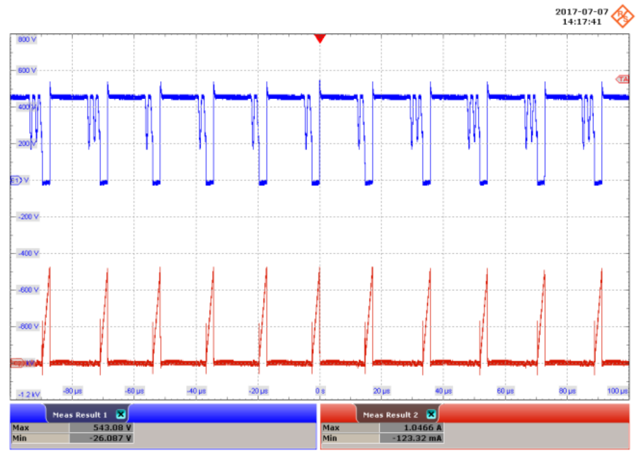

Figure 29 – 265 VAC, 50 Hz.
Upper: V_{DRAIN}, 200 V / div., 20 µs / div.
Lower: I_{DRAIN}, 400 mA / div., 20 µs / div.
Measured V_{PK} = 543.08 V_{PK}.
Measured I_{PK} = 1.05 A_{PK}.

10.1.2 Start-up Operation, Full Load

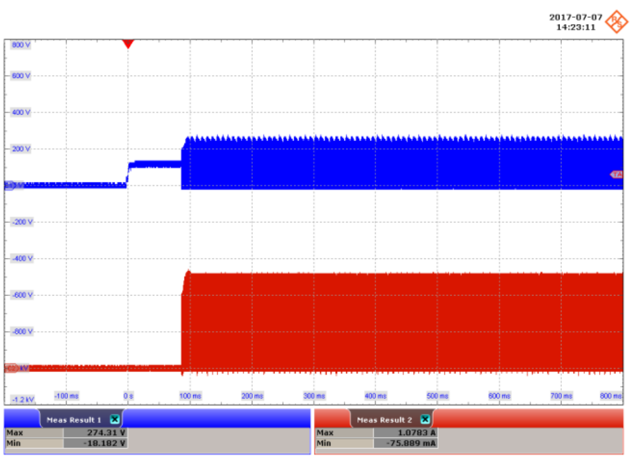

Figure 30 – 85 VAC, 60 Hz.
Upper: V_{DRAIN}, 200 V / div., 100 ms / div.
Lower: I_{DRAIN}, 400 mA / div., 100 ms / div.
Measured V_{PK} = 274.31 V_{PK}.
Measured I_{PK} = 1.08 A_{PK}.

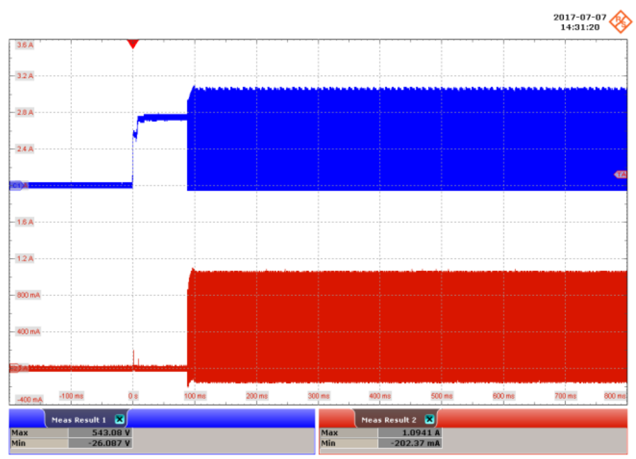

Figure 31 – 265 VAC, 50 Hz.
Upper: V_{DRAIN}, 200 V / div., 100 ms / div.
Lower: I_{DRAIN}, 400 mA / div., 100 ms /div.
Measured V_{PK} = 543.08 V_{PK}.
Measured I_{PK} = 1.09 A_{PK}.

10.2 ***Synchronous Rectifier Voltage***

10.2.1 Normal Operation, Full Load

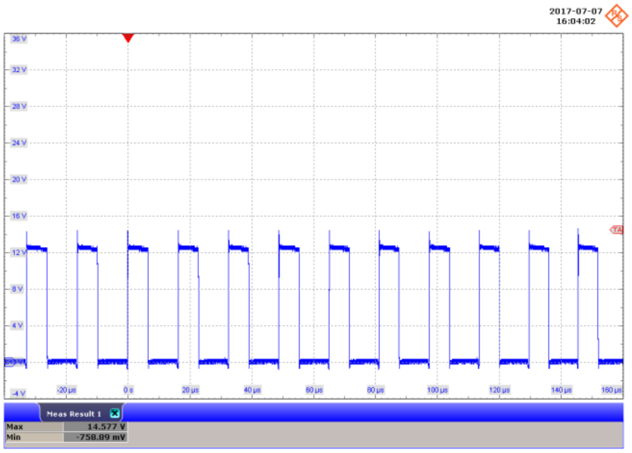

Figure 32 – 85 VAC, 60 Hz.
$V_{SYNCRECT}$, 4 V / div., 20 µs / div.
Measured V_{PK} = 14.58 V_{PK}.

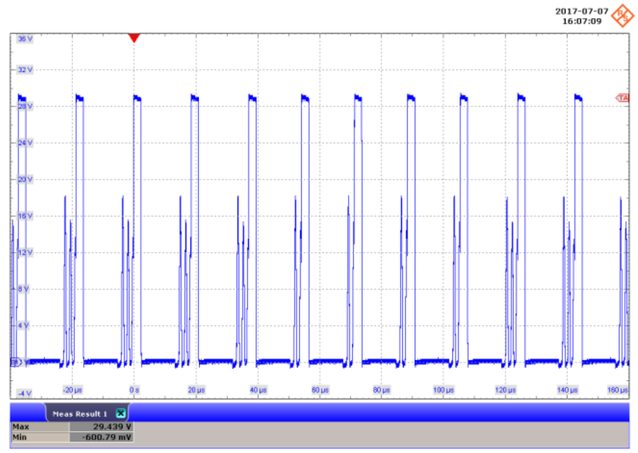

Figure 33 – 265 VAC, 50 Hz.
$V_{SYNCRECT}$, 4 V / div., 20 µs / div.
Measured V_{PK} = 29.44 V_{PK}.

10.2.2 Start-up Operation, Full Load

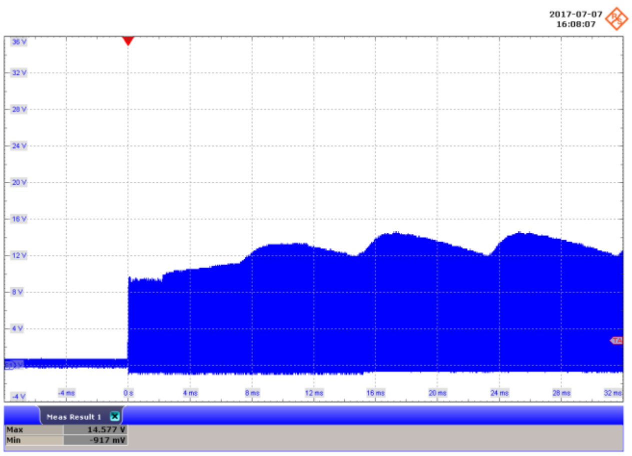

Figure 34 – 85 VAC, 60 Hz.
$V_{SYNCRECT}$, 4 V / div., 4 ms / div.
Measured V_{PK} = 14.58 V_{PK}.

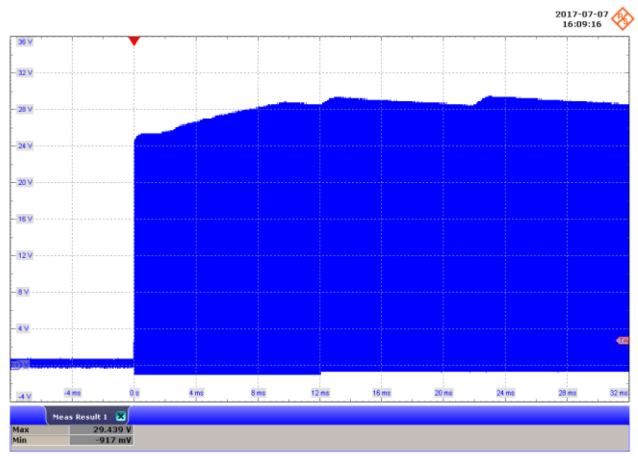

Figure 35 – 265 VAC, 50 Hz.
$V_{SYNCRECT}$, 4 V / div., 4 ms / div.
Measured V_{PK} = 29.44 V_{PK}.

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10.3 ***Output Start-up***

Measured at the end of the 60 mΩ cable.

10.3.1 Full Load (5 A), CC Mode

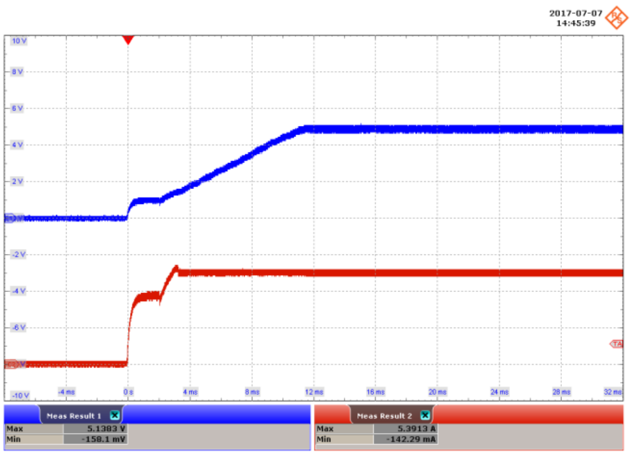

Figure 36 – 85 VAC, 60 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.14 $V_{PK.}$
Measured I_{PK} = 5.39 $A_{PK.}$

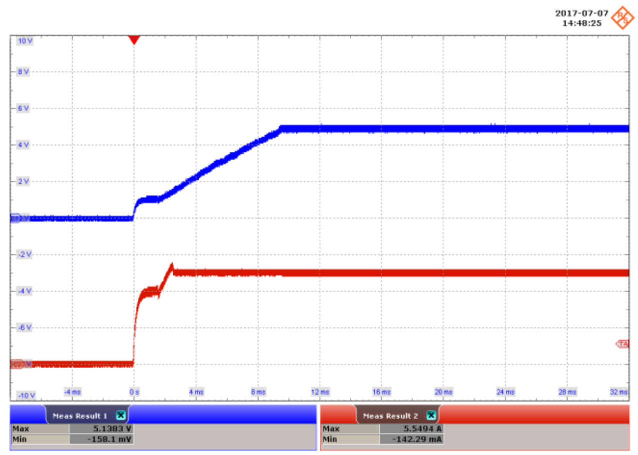

Figure 37 – 265 VAC, 50 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.14 $V_{PK.}$
Measured I_{PK} = 5.55 A_{PK}.

10.3.2 No-Load

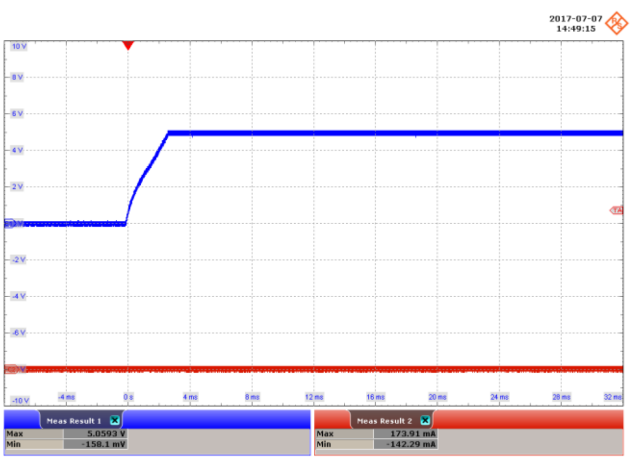

Figure 38 – 85 VAC, 60 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.06 $V_{PK.}$

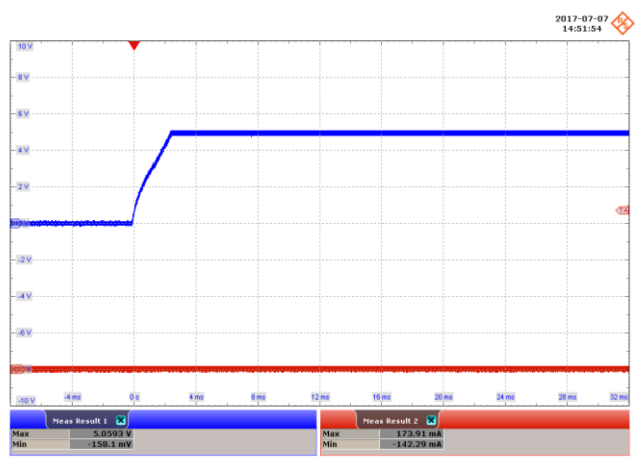

Figure 39 – 265 VAC, 50 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.06$V_{PK.}$

10.3.3 Full Load (0.85 Ω), CR Mode

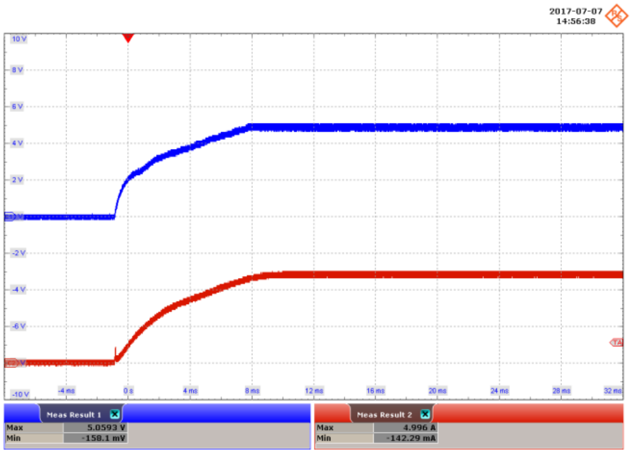

Figure 40 – 85 VAC, 60 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.06 $V_{PK.}$
Measured I_{PK} = 5 $A_{PK.}$

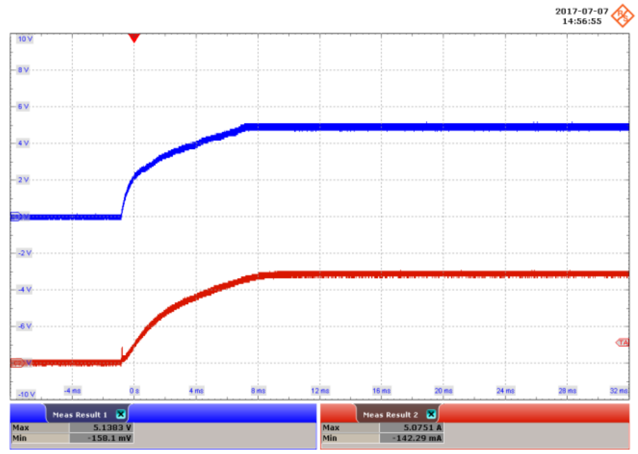

Figure 41 – 265 VAC, 50 Hz.
Upper: V_{OUT}, 2 V / div., 4 ms / div.
Lower: I_{OUT}, 2 A / div., 4 ms / div.
Measured V_{PK} = 5.14 $V_{PK.}$
Measured I_{PK} = 5.08 $A_{PK.}$

10.4 *Output Load Transient*

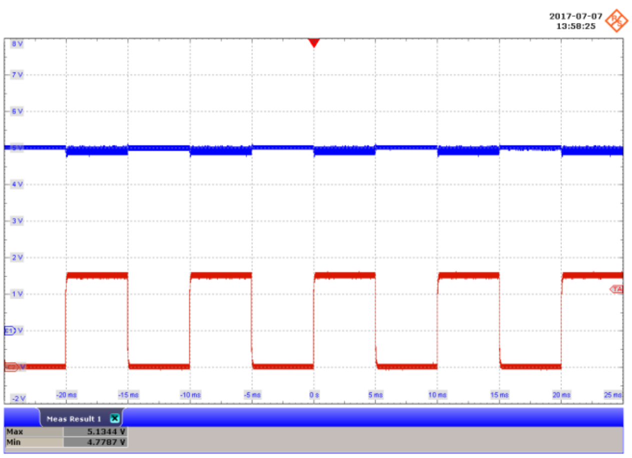

Figure 42 – 85 VAC, 60 Hz; 0 – 5 A Load Step.
Upper: V_{OUT}, 1 V / div., 5 ms / div.
Lower: I_{OUT}, 2 A / div., 5 ms / div.
Measured Max Peak Voltage = 5.13 $V_{PK.}$
Measured Min Undershoot = 4.78 $V_{PK.}$

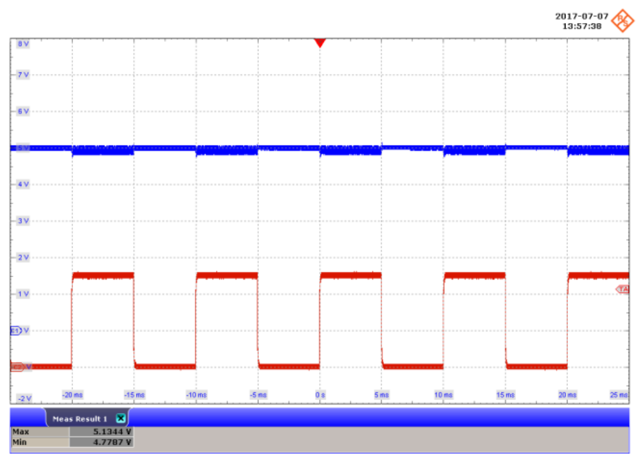

Figure 43 – 265 VAC, 50 Hz; 0 – 5 A Load Step
Upper: V_{OUT}, 1 V / div., 5 ms / div.
Lower: I_{OUT}, 2 A / div., 5 ms / div.
Measured Max Peak Voltage = 5.13 $V_{PK.}$
Measured Min Undershoot = 4.78 $V_{PK.}$

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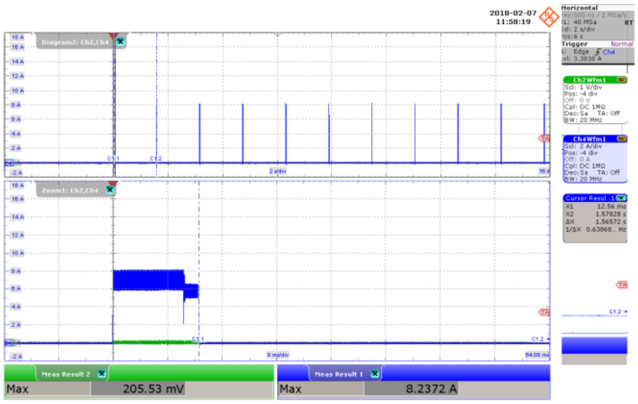
10.5 *Output Waveforms with Shorted Output*



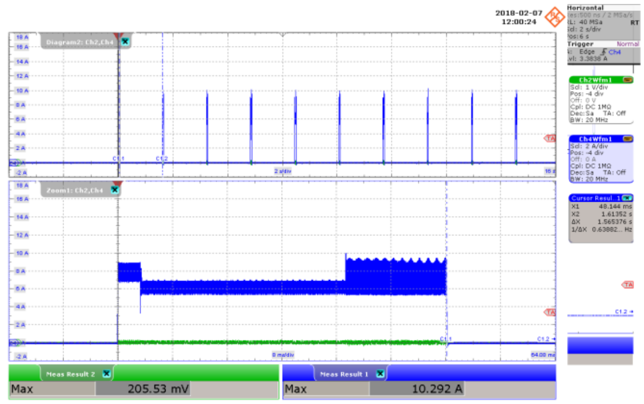


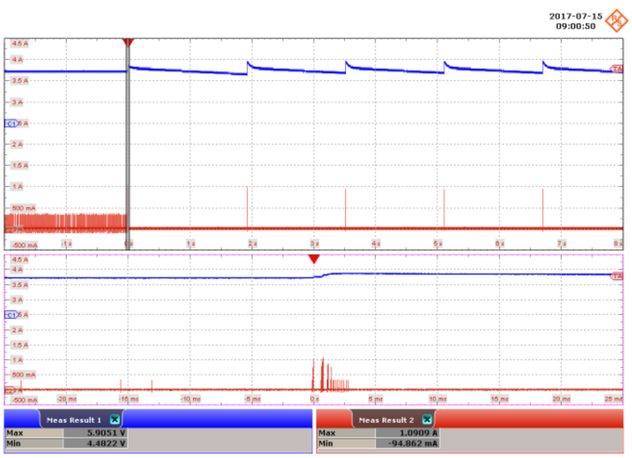
Figure 44 – 85 VAC, 60 Hz.
V_{OUT}, 1 V / div., 2 s / div.
I_{OUT}, 2 A / div., 2 s / div.
Max Peak Voltage = 205 $mV_{PK.}$
Max Peak Current = 8.24 $A_{PK.}$

Figure 45 – 265 VAC, 50 Hz.
V_{OUT}, 1 V / div., 2 s / div.
I_{OUT}, 2 A / div., 2 s / div.
Max Peak Voltage = 205 $mV_{PK.}$
Max Peak Current = 10.3 $A_{PK.}$

10.6 *Overvoltage Protection*

Output waveforms with the lower feedback resistor shorted.

10.6.1 No-Load



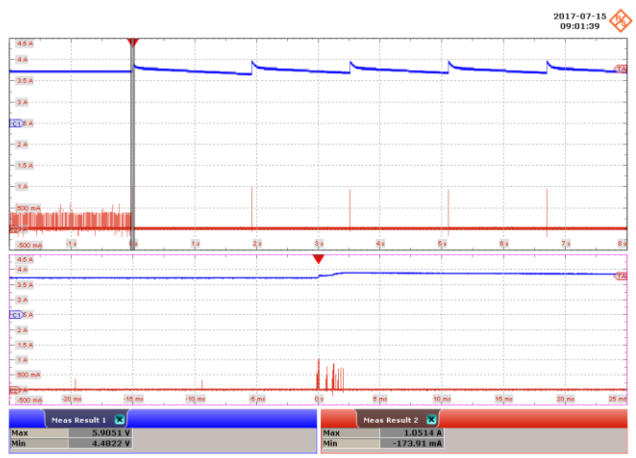


Figure 46 – 85 VAC, 60 Hz.
Upper: V_{OUT}, 2 V / div., 1 s / div.
Lower: I_{OUT}, 500 mA / div., 1 s / div.
Max Peak Voltage = 5.91 $V_{PK.}$

Figure 47 – 265 VAC, 50 Hz.
Upper: V_{OUT}, 2 V / div., 1 s / div.
Lower: I_{OUT}, 500 mA / div., 1 s / div.
Max Peak Voltage = 5.91 $V_{PK.}$

10.6.2 Full Load

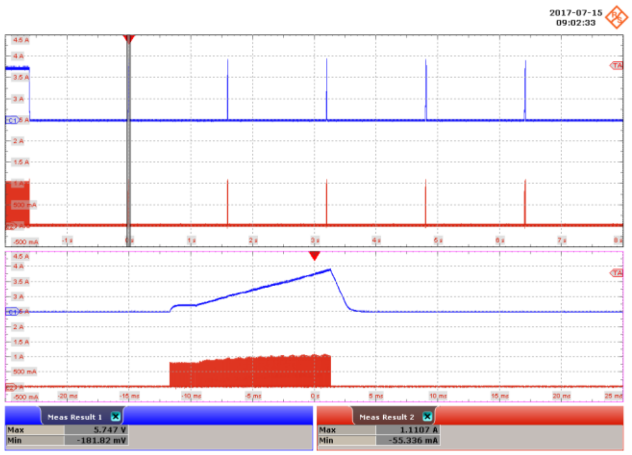


Figure 48 – 85 VAC, 60 Hz.
Upper: V_{OUT}, 2 V / div., 1 s / div.
Lower: I_{OUT}, 500 mA / div., 1 s / div.
Max Peak Voltage = 5.75 V_{PK}.

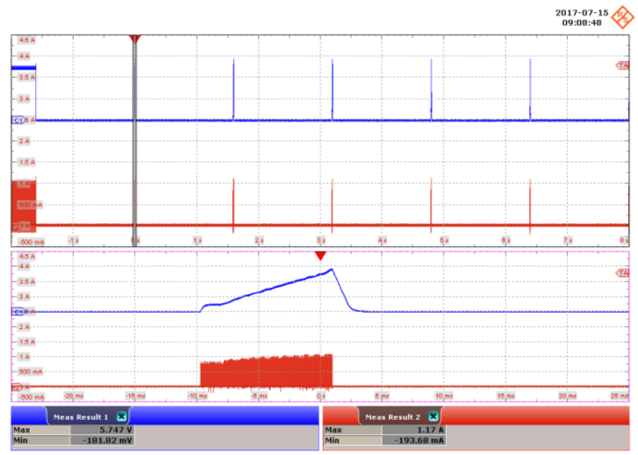


Figure 49 – 265 VAC, 50 Hz.
Upper: V_{OUT}, 2 V / div., 1 s / div.
Lower: I_{OUT}, 500 mA / div., 1 s / div.
Max Peak Voltage = 5.75 V_{PK}.

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10.7 *Line Undervoltage and Overvoltage*

The DC input voltage was used.

Figure 50 – Line Undervoltage; DC Input.
V_{UV-}: 75.6 V.
Upper: V_{OUT}, 4 V /div, 1 s / div.
Middle: Bulk Voltage, 100 V /div.
Lower: V_{DS}, 200 V / div.

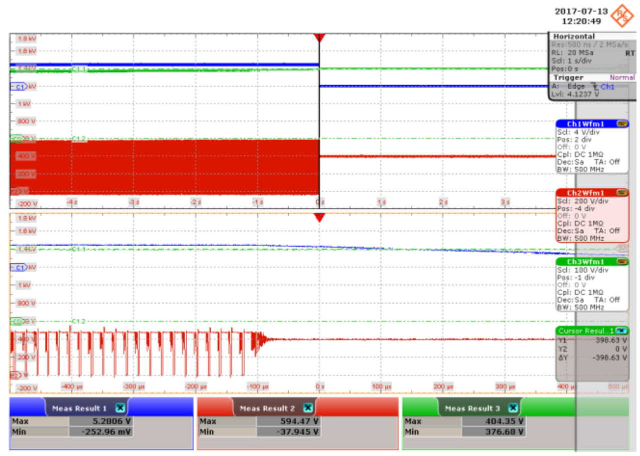

Figure 51 – Line Overvoltage; DC Input.
V_{OV+}: 399 V.
Upper: V_{OUT}, 4 V /div, 1 s / div.
Middle: Bulk Voltage, 100 V /div.
Lower: V_{DS}, 200 V / div.

10.8 *Brown-in and Brown-out*

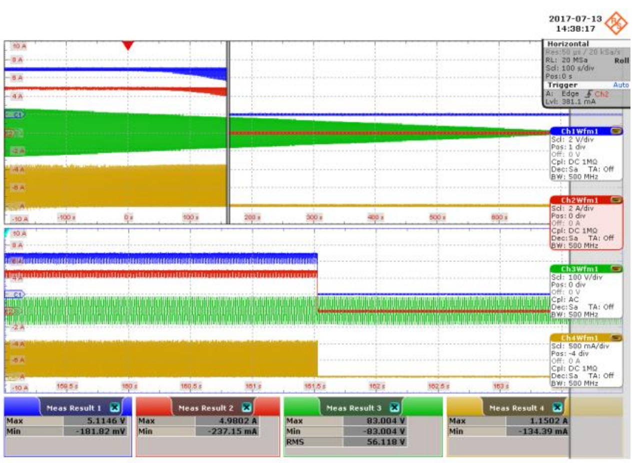

Figure 52 –Brown-out at No-Load; 90 V to 0 V Input.
90 VAC input, 6 V / min.
CH1: V_{OUT}, 2 V / div., 100 s / div.
CH2: I_{OUT}, 2 A / div.
CH3: AC Input, 100 V / div.
CH4: I_{DS}, 500 mA / div.
AC Input Threshold: 56.12 V_{RMS}.

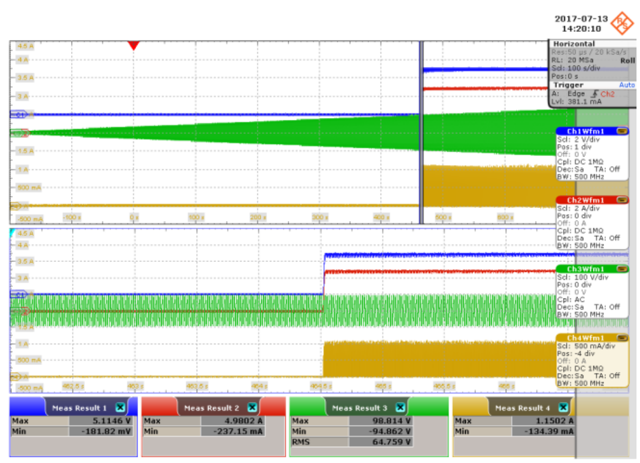

Figure 53 – Brown-in at No-Load; 0 V to 90 V Input.
90 VAC input, 6 V / min.
CH1: V_{OUT}, 2 V / div., 100 s / div.
CH2: I_{OUT}, 2 A / div.
CH3: AC Input, 100 V / div.
CH4: I_{DS}, 500 mA / div.
AC Input Threshold: 64.76 V_{RMS}.

11 EMI Results

11.1 *Test Set-up*

Equipment:

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. Full Load with input voltage set at 230 VAC and 115 VAC, 60Hz.

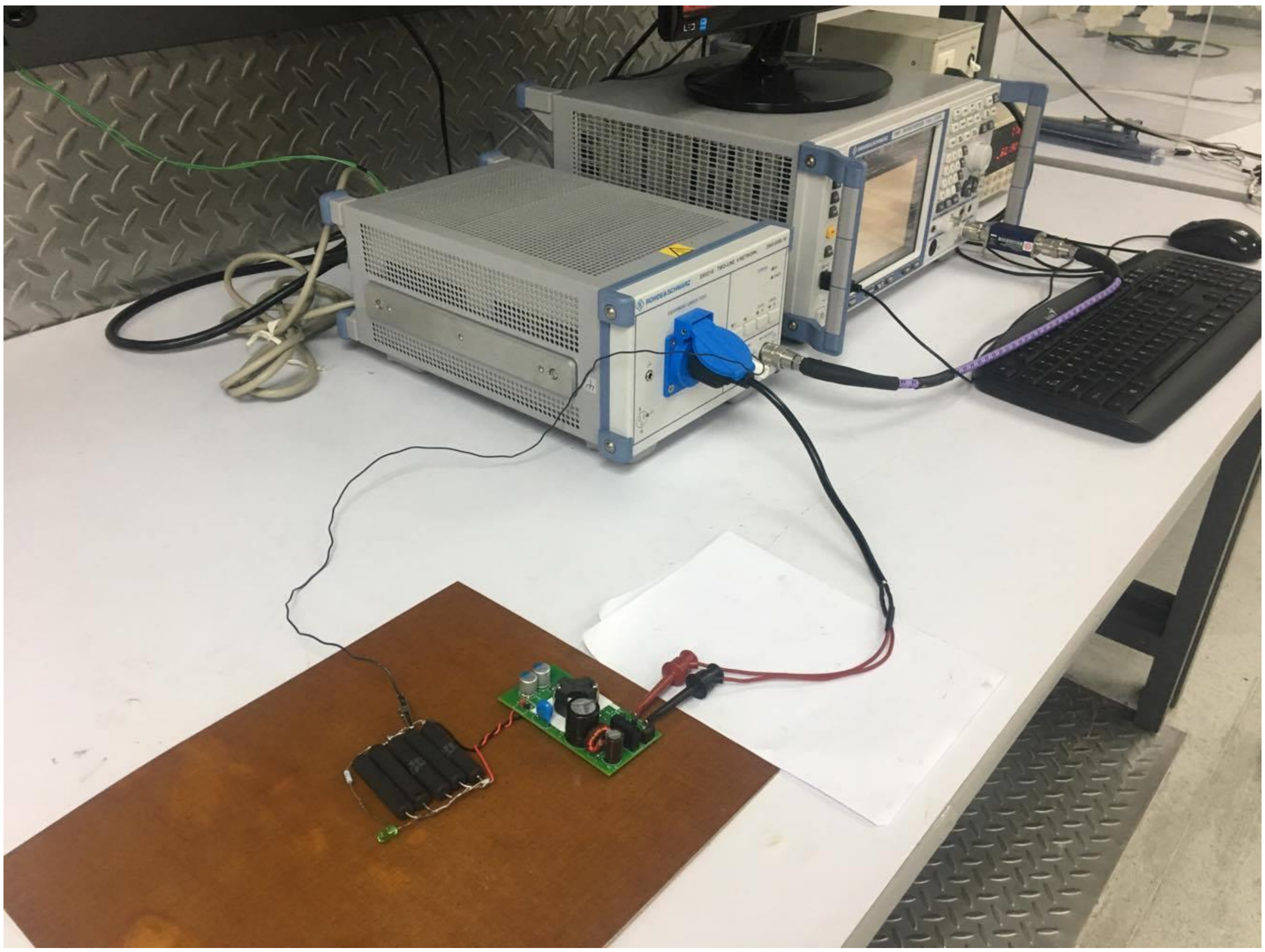

Figure 54 – Conducted EMI Test Set-up.

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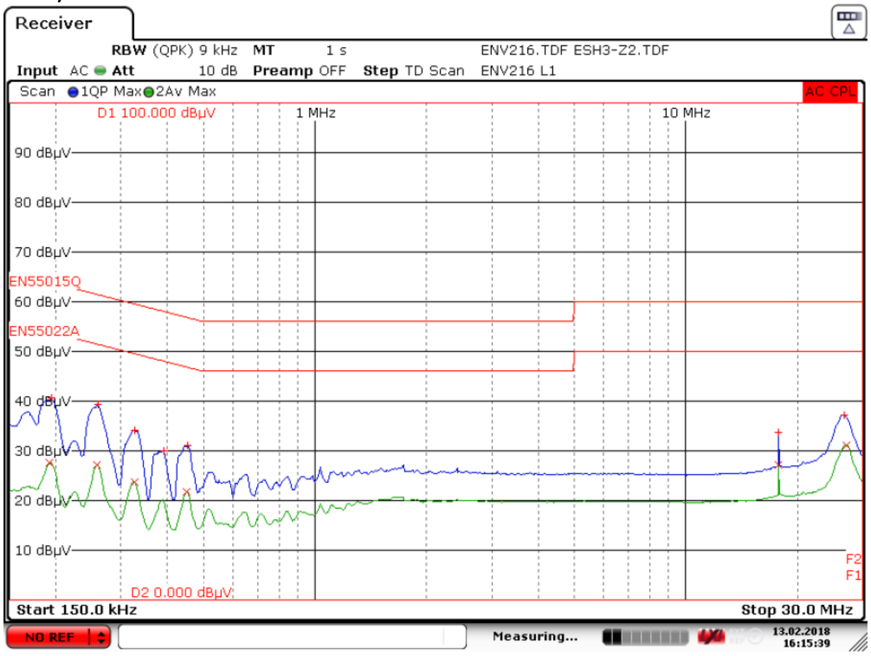
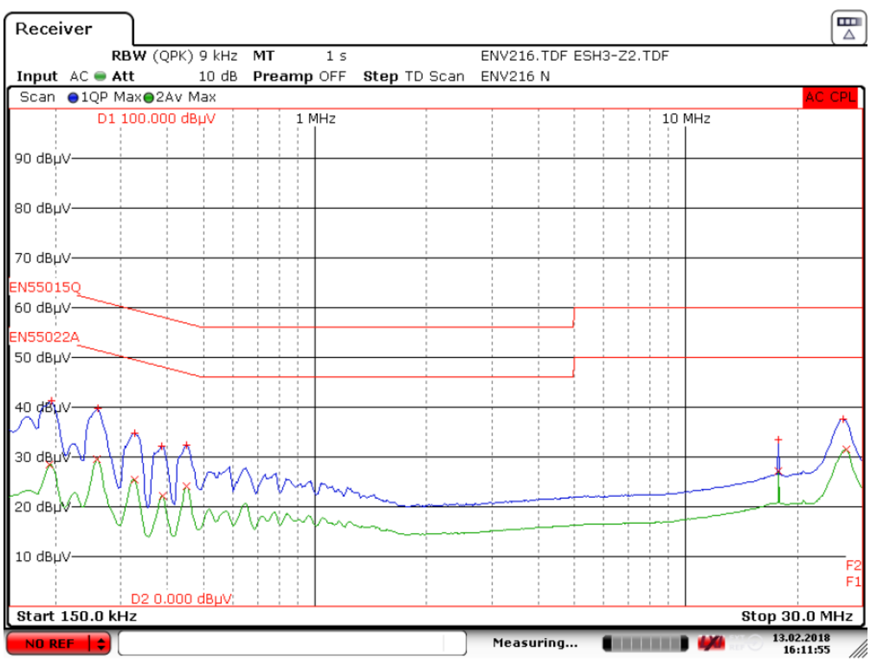
11.2 *Floating Output*

11.2.1 115 VAC, Line



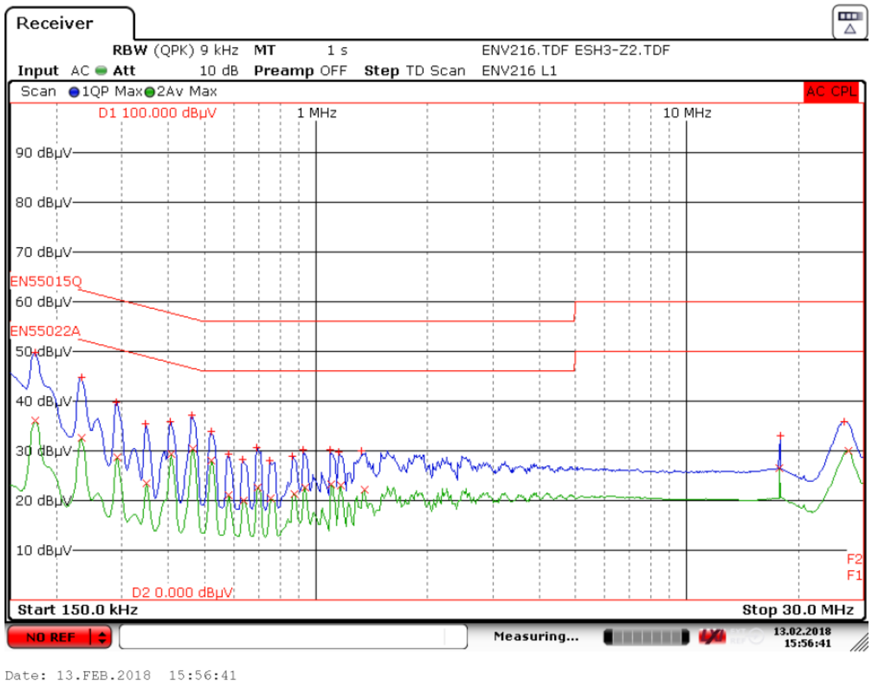
Date: 13.FEB.2018 16:15:39

11.2.2 115 VAC, Neutral

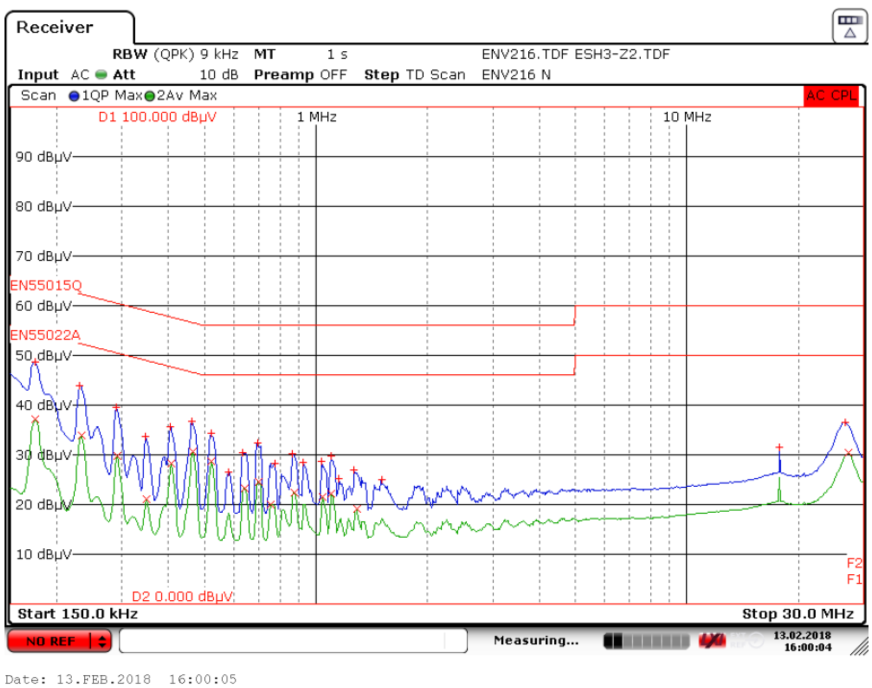


Date: 13.FEB.2018 16:11:56

11.2.3 230 VAC, Line



11.2.4 230 VAC, Neutral



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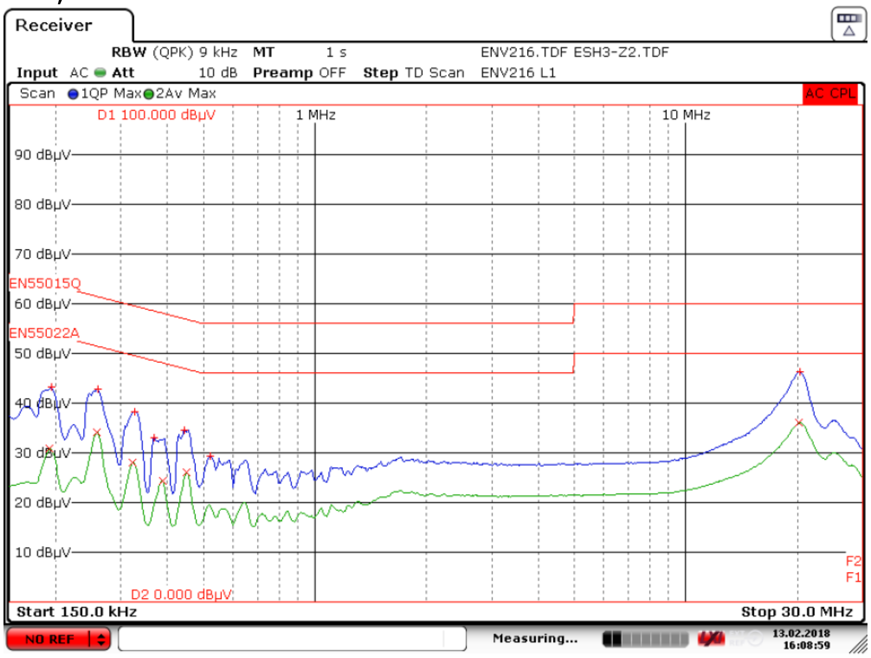
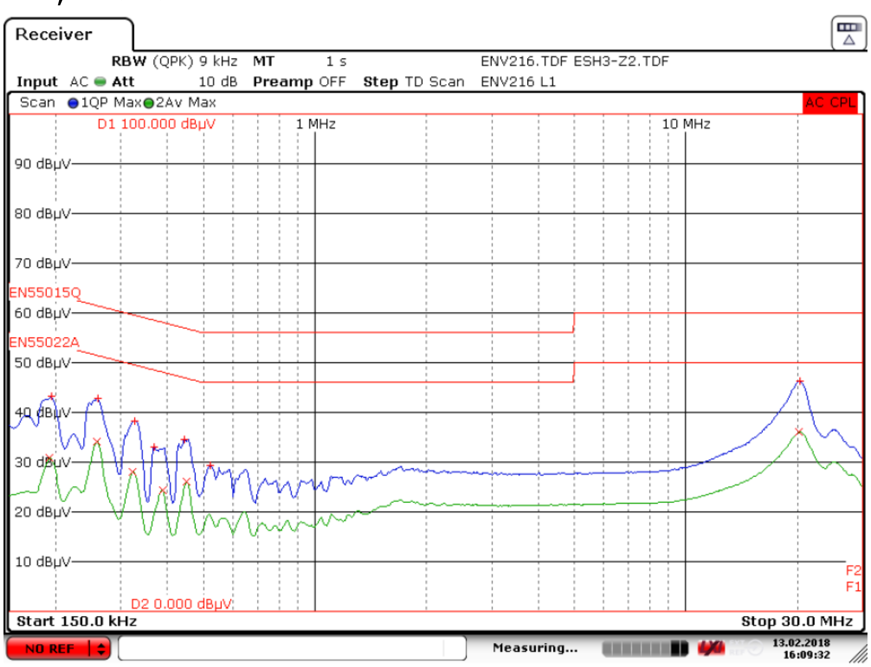
11.3 ***Negative Output Connected to Earth***

11.3.1 115 VAC, Line



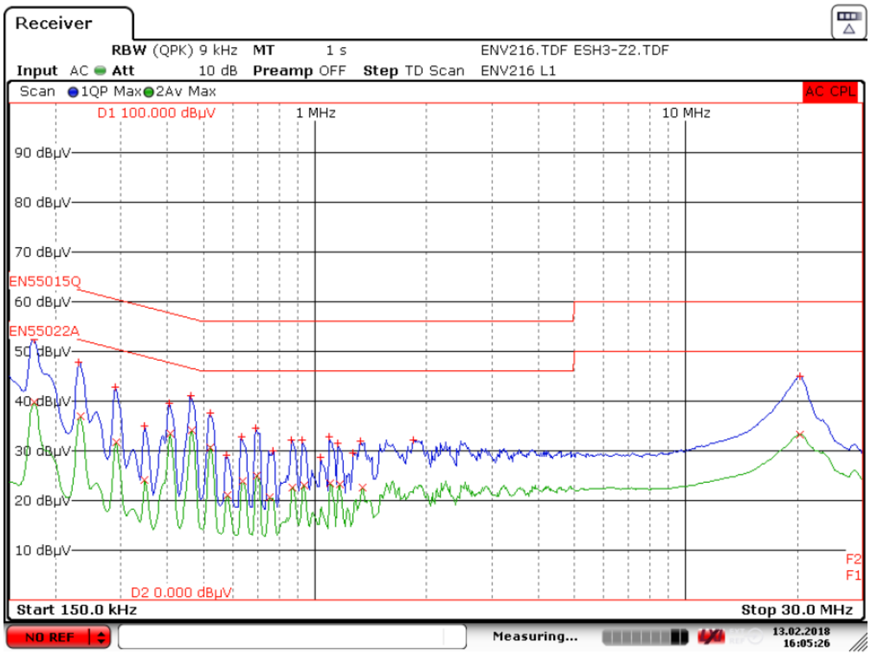
Date: 13.FEB.2018 16:08:59

11.3.2 115 VAC, Neutral



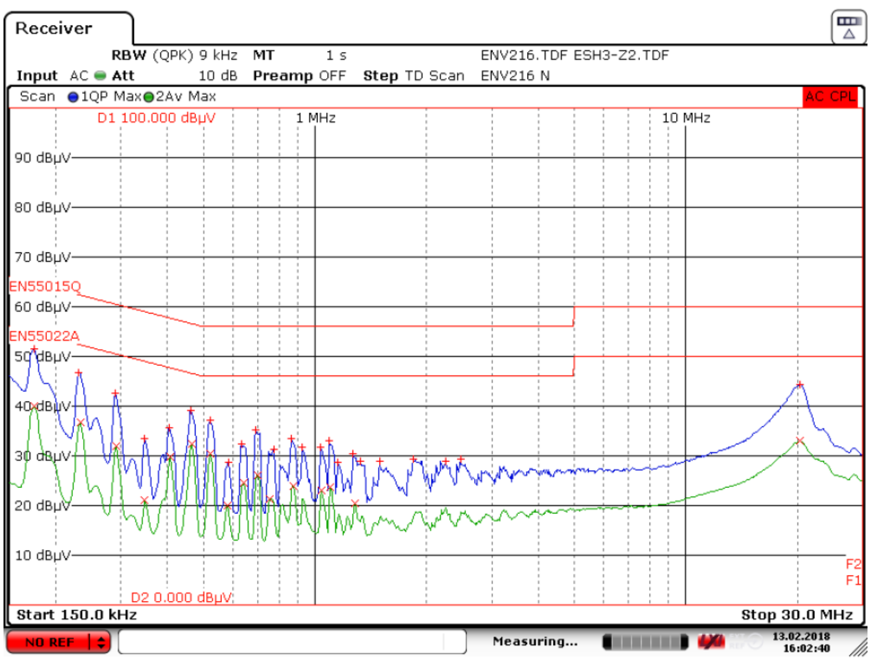
Date: 13.FEB.2018 16:09:32

11.3.3 230 VAC, Line



Date: 13.FEB.2018 16:05:26

11.3.4 230 VAC, Neutral



Date: 13.FEB.2018 16:02:40

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12 Line Surge

The unit was subjected to ±6000 V, common mode surge and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

12.1 *Differential Mode Surge Test*

Differential Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass
+1000	230	L to N	180	Pass
-1000	230	L to N	180	Pass
+1000	230	L to N	270	Pass
-1000	230	L to N	270	Pass

12.2 *Common Mode Ring Wave Surge Test*

Ring Wave Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+6000	230	L, N to PE	0	Pass
-6000	230	L, N to PE	0	Pass
+6000	230	L, N to PE	90	Pass
-6000	230	L, N to PE	90	Pass
+6000	230	L, N to PE	180	Pass
-6000	230	L, N to PE	180	Pass
+6000	230	L, N to PE	270	Pass
-6000	230	L, N to PE	270	Pass

13 ESD Test

Passed ±8 kV contact discharge.

Contact Voltage (kV)	Applied to	Number of Strikes	Test Result
8	Positive	10	PASS
-8	Negative	10	PASS

Passed ±16 kV air discharge.

Differential Voltage (kV)	Applied to	Number of Strikes	Test Result
16	Positive	10	PASS
-16	Negative	10	PASS

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14 Revision History

Date	Author	Revision	Description and Changes	Reviewed
28-Sep-18	MA/AO	1.0	Initial Release	Apps & Mktg
02-Jul-20	MA	1.1	Updated R16 in Schematic and BOM.	Apps & Mktg

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

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