POWER INTEGRATIONS

Title	***Reference Design Report for a High Performance 347 W PFC Stage Using HiperPFS™ PFS714EG***
Specification	90 VAC – 264 VAC Input; 380 VDC Output
Application	PFC Front End Stage
Author	Applications Engineering Department
Document Number	RDR-236
Date	November 18, 2010
Revision	1.1

Summary and Features

- Low component count, high performance PFC
- EN61000–3–2 Class–D compliance
- High PFC efficiency enables 80+ PC Main design
- Frequency sliding maintains high efficiency across load range
- Feed forward line sense gain - maintains relatively constant loop gain over entire operating voltage range
- Excellent transient load response
- Power Integration eSIP low-profile, thermal resistance package

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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 PFC power supply utilizing a HiperPFS PFS714EG integrated PFC controller. This power supply is intended as a general purpose evaluation platform that operates from universal input and provides a regulated 380 V DC output voltage and a continuous output power of 347 W.

This power supply can deliver the rated power at 110 VAC or higher at a room temperature of 25 ºC. For operation at higher temperatures or lower input voltages, use of forced air cooling is recommended.

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

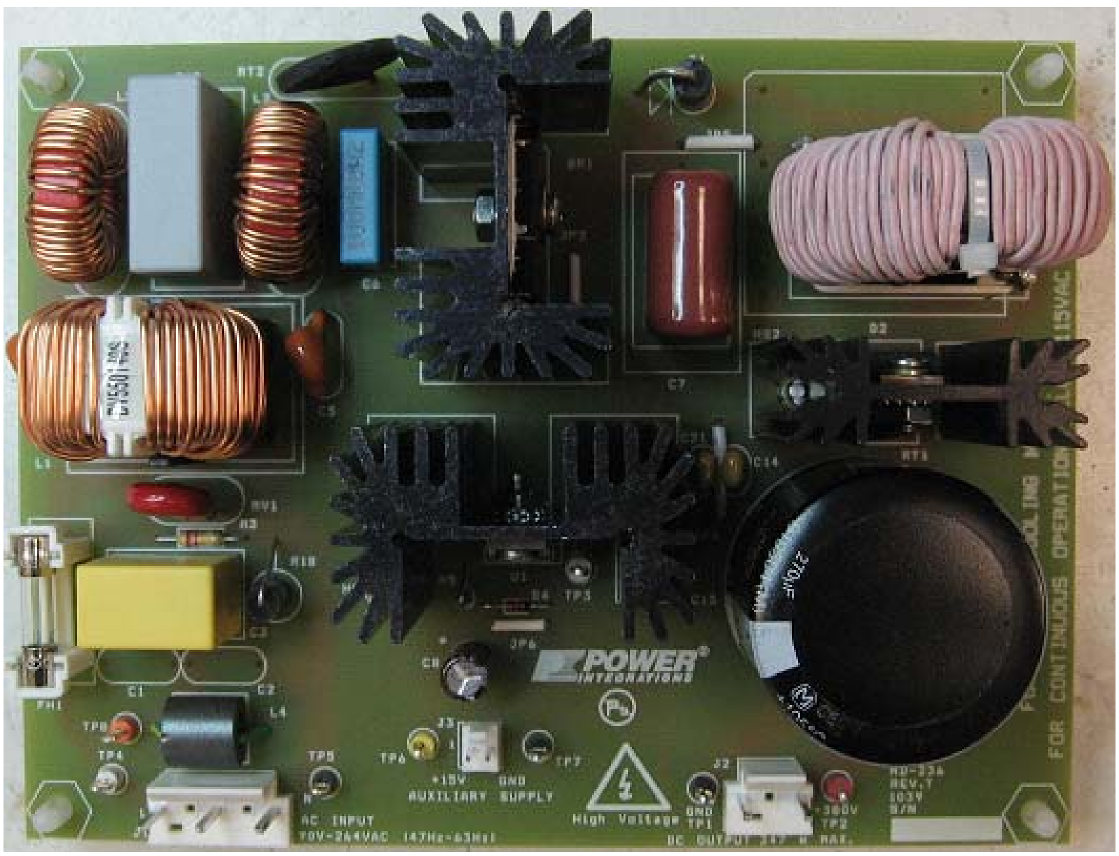

Figure 1 – Populated Circuit Board Photograph.

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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}	90		264	VAC	3 Wire
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage	V_{OUT}	370	380	390	V	
Output Ripple Voltage p-p	V_{RIPPLE}			30	V	20 MHz bandwidth
Output Current	I_{OUT}		0.913		A	
Total Output Power						
Continuous Output Power	P_{OUT}		347		W	
Efficiency						
Full Load	η	94			%	Measured at P_{OUT} 25 °C
Minimum efficiency at 20, 50 and 100 % of P_{OUT}	η_{80+}	94			%	Measured at 115 VAC Input
Environmental						
Line Surge						1.2/50 µs surge, IEC 1000-4-5, Series Impedance:
Differential Mode (L1-L2)			1		kV	Differential Mode: 2 Ω
Common mode (L1/L2-PE)			2		kV	Common Mode: 12 Ω
Ambient Temperature	T_{AMB}	0		50	°C	Forced convection required at T_{AMB} >25 °C and/or V_{IN} <115 V, sea level
Auxiliary Supply Input						
Auxiliary Supply	V_{AUX}	15		24	V	DC Supply

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3 Schematic

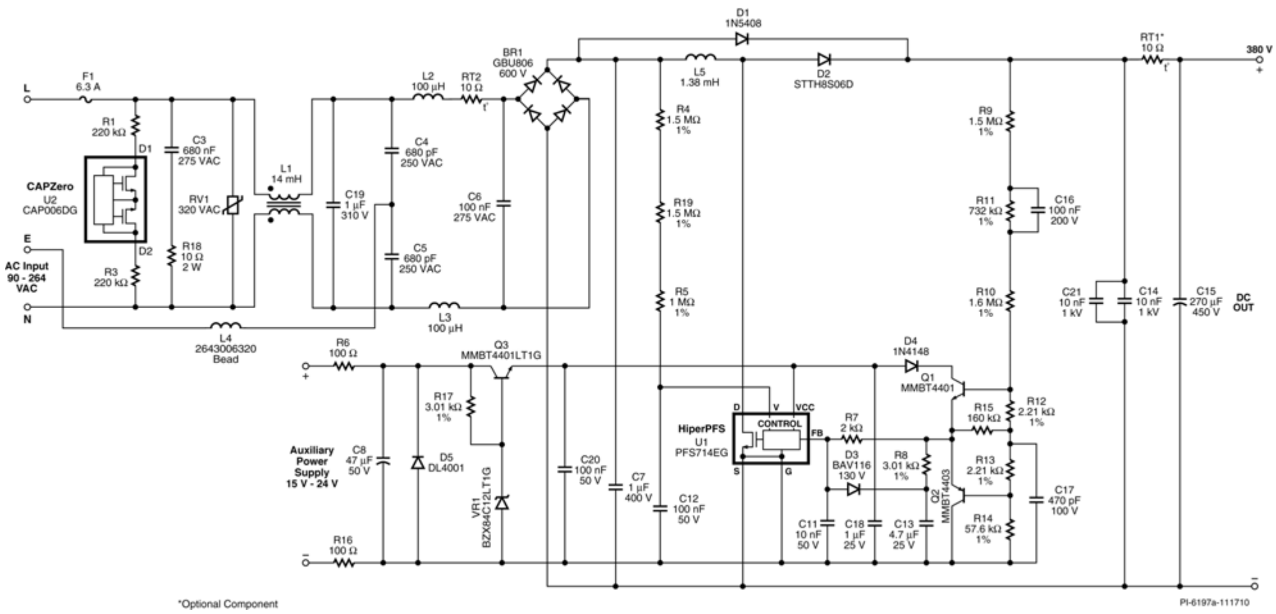

Figure 2 – Schematic.

4 Circuit Description

This PFC is designed using PFS714EG Power Integrations Integrated PFC controller. This design is rated for a continuous output power of 347 W and provides a regulated output voltage of 380 VDC nominal maintaining a high input power factor and overall efficiency from light load to full load.

4.1 Input EMI Filter and Rectifier

Fuse F1 provides protection to the circuit and isolates it from the AC supply in case of a fault. Diode Bridge BR1 rectifies the AC input. Capacitors C3, C4, C5, C6 and C19 together with inductors L1, L2 and L3 form the EMI filter reducing the common mode and differential mode noise. Resistors R1, R3 and CAPZero, IC U2 are required to discharge the EMI filter capacitors once the AC is disconnected. The use of CAPZero eliminates the static loss of R1 and R3, reducing standby and no-load input.

4.2 PFS714EG Boost Converter

The boost converter stage consists of inductor L5, diode rectifier D2, C15 and the PFS714EG IC U1. This converter stage controls the input current of the power supply while simultaneously regulating the output DC voltage. Diode D1 prevents a resonant build up of output voltage at start–up by bypassing inductor L5 while simultaneously charging output capacitor C15. Thermistors RT1 and RT2 limit the inrush current of the circuit at start–up, but they are not required simultaneously. In most high–performance designs, thermistor RT2 will often be used, in which case typically a relay will be used to bypass the thermistor after start–up to improve power supply efficiency. When thermistor RT2 is used, thermistor RT1 is replaced with a short. When thermistor RT1 is used, thermistor RT2 will be replaced with a short. When used, RT1 is in circuit at all times and results in slightly lower efficiency however saves the cost of the relay. Both locations of the thermistors are provided in the design to enable circuit configuration to suit the application. For efficiency measurement that represents the high performance configuration, both thermistors should be shorted. Capacitors C14 and C21 are used for reducing the loop length and area of the output circuit to reduce EMI and overshoot of voltage across the drain and source of the MOSFET inside U1 at each switching instant.

4.3 Bias Supply Regulator

The PFS714EG IC requires a regulated supply of 12 V for operation and must remain <13.4 V to avoid IC damage. Resistors R6, R16, R17, Zener diode VR1, and transistor Q3 form a shunt regulator that prevents the supply voltage to IC U1 from exceeding 12 V. Capacitors C8, C18 and C20 filter the supply voltage to ensure reliable operation of IC U1.

4.4 Input Feed Forward Sense Circuit

The input voltage of the power supply is sensed by the IC U1 using resistors R4, R5 and R19. The capacitor C12 filters any noise on this signal.

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4.5 Output Feedback

Divider network comprising of resistors R9, R10, R11, R12, R13 and R14 are used to scale the output voltage and provide feedback to the IC U1. The circuit comprising of diode D4, transistor Q1, Q2 and the resistors R12 and R13 form a non–linear feedback circuit which help in improving the transient response by increasing the response time of the PFC circuit to large output voltage changes..

Resistors R7, R8, R15 and capacitors C13 and C17 are required for shaping the loop response of the feedback circuit. The combination of resistor R8 and capacitor C13 provide a low frequency zero.

5 PCB Layout

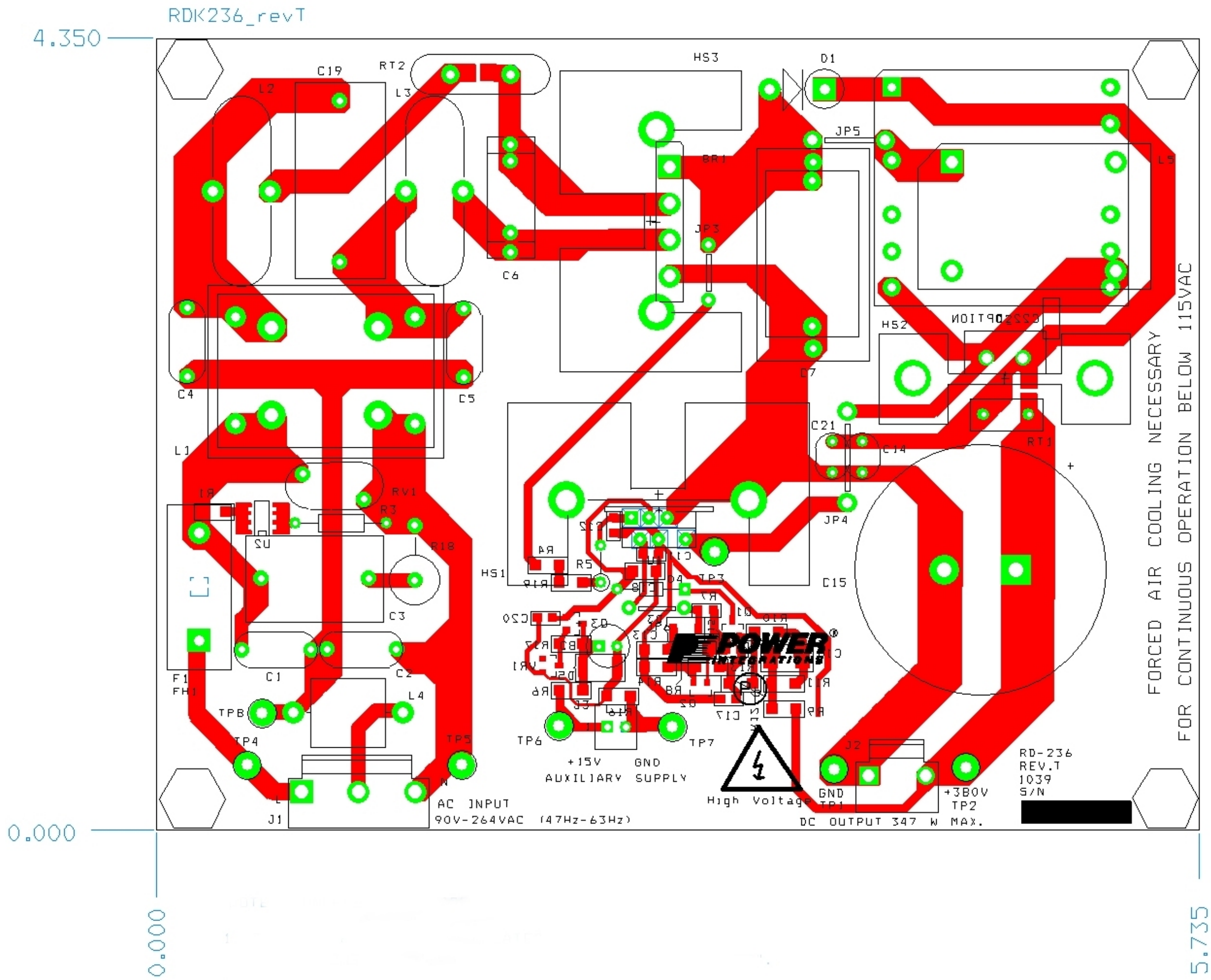

Figure 3 – Printed Circuit Layout.

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6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 8 A, Bridge Rectifier	GBU806	Vishay
2	1	C3	680 nF, 275 VAC, Film,MPX Series, X2	PX684K3ID6	Carli
3	2	C4 C5	680 pF, Ceramic, Y1	440LT68–R	Vishay
4	1	C6	100 nF, 275 VAC, Film, X2	PHE840MB6100KB05R17	Kemet
5	1	C7	1 μF, 400 V, Polypropylene Film	ECW–F4105JL	Panasonic–ECG
6	1	C8	47 μF, 50 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG500ELL470MF11D	Nippon Chemi–Con
7	1	C11	10 nF, 50 V, Ceramic, X7R, 0805	ECJ–2VB1H103K	Panasonic
8	2	C12 C20	100 nF, 50 V, Ceramic, X7R, 0805	C2012X7R1H104K	TDK
9	1	C13	4.7 μF, 25 V, Ceramic, X7R, 1206	ECJ–3YB1E475M	Panasonic
10	2	C14 C21	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
11	1	C15	270 μF, 450 V, Electrolytic (35 x 35)	EET–ED2W271EA	Panasonic
12	1	C16	100 nF, 200 V, Ceramic, X7R, 1812	18122C104KAT2A	AVX
13	1	C17	470 pF, 100 V, Ceramic, X7R, 0805	ECJ–2VB2A471K	Panasonic
14	1	C18	1 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK
15	1	C19	1 μF, 310 VAC, Polyester Film, X2	BFC233820105	BC components
16	1	D1	1000 V, 3 A, Rectifier, DO–201AD	1N5408–T	Diodes Inc.
17	1	D2	600 V, 8 A, Ultrafast Recovery, 12 ns, TO-220AC	STTH8S06D	ST Semiconductor
18	1	D3	130 V, 5%, 250 mW, SOD–123	BAV116W–7–F	Diodes Inc
19	1	D4	75 V, 300 mA, Fast Switching, DO–35	1N4148TR	Vishay
20	1	D5	50 V, 1 A, Rectifier, Glass Passivated, DO–213AA (MELF)	DL4001–13–F	Diodes Inc
21	1	ESIPCLIP M4 METAL1	Heatsink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk	NP975864	Aavid Thermalloy
22	1	F1	6.3 A, 250 V, Fast, 5 mm x 20 mm, Cartridge	021706.3HXP	Littelfuse
23	1	FH1	FUSEHOLDER OPEN 5 MM X 20 MM PC MNT	64900001039	Wickmann USA
24	2	HS1 HS3	HEATSINK, Alum, TO–220, TO218, 4.4 Deg C per Watt, Screw Type mounting with pins, L 1.00" (25.4mm), W 1.65" (41.91 mm) H 1.500" (38.1 mm)	6398BG	Aavid Thermaloy
25	1	HS2	HEATSINK, Alum, TO–220, 11 Deg C per Watt, Screw Type mounting with pins, L 1.375" (34.92 mm), W 0.5" (12.7 mm) H 1.5" (38.1 mm)	513102B02500G	Aavid Thermaloy
26	1	HSPREADER_ESIPPFISW1	HEATSPREADER, Custom, Al, 3003, 0.030" Thk	61–00040–00	Custom
27	1	J1	5 Position (1 x 5) header, 0.156 pitch, Vertical	26–64–4050	Molex
28	1	J2	CONN HEADER 3POS (1x3).156 VERT TIN	26–64–4030	Molex
29	1	J3	2 Position (1 x 2) header, 0.1 pitch, Vertical	22–23–2021	Molex
30	2	JP3 JP6	Wire Jumper, Insulated, 22 AWG, 0.3 in	C2004–12–02	Gen Cable
31	2	JP4 JP5	Wire Jumper, Insulated, 18 AWG, 0.4 in	C2052A–12–02	Gen Cable
32	1	L1	14 mH, 5 A, Common Mode Choke	DV550140S	TNC
33	2	L2 L3	100 μH, 5A, INDUCTOR TORD HI AMP 100UH VERT	7447070	Wurth Elect
34	1	L4	43 Shield Bead, 0.375 (9.5 mm) Dia x 0.410 (10.40 mm) L x 0.193 (4.75 mm) I.D. with PCBFP 22 AWG	2643006302	Fair–Rite Products

35	1	L5	Custom, 350 W PFC Inductor, 1.38 mH, constructed on Lodestone Pacific base PN VTM160–4	SNX–R1540	Santronics
36	1	LABEL1	High Voltage (small)		
37	1	LABEL2	High Voltage (large)		
38	1	NUT1	Nut, Hex 4–40, SS		
39	2	NUT2 NUT3	Nut, Hex, Kep 4–40, S ZN Cr3 plating RoHS	4CKNTZR	Any RoHS Compliant Mfg.
40	4	POST PCB 6–32 HEX1-4	Post, Circuit Board, Female, Hex, 6–32, snap, 0.375L, Nylon	561–0375A	Eagle Hardware
41	2	Q1 Q3	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT–23	MMBT4401LT1G	OnSemi
42	1	Q2	PNP, Small Signal BJT, 40 V, 0.6 A, SOT–23	MMBT4403–7–F	Diodes, Inc.
43	1	R1	220 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ–8GEYJ224V	Panasonic
44	1	R3	220 kΩ, 5%, 1/4 W, Carbon Film	CFR–25JB–220K	Yageo
45	3	R4 R9 R19	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF1504V	Panasonic
46	1	R5	1 MΩ, 1%, 1/4 W, Metal Film	MFR–25FBF–1M00	Yageo
47	2	R6 R16	100 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF1000V	Panasonic
48	1	R7	2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ–6GEYJ202V	Panasonic
49	2	R8 R17	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF3011V	Panasonic
50	1	R10	1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF1604V	Panasonic
51	1	R11	732 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF7323V	Panasonic
52	2	R12 R13	2.21 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF2211V	Panasonic
53	1	R14	57.6 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ–8ENF5762V	Panasonic
54	1	R15	160 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ–6GEYJ164V	Panasonic
55	1	R18	10 Ω, 1%, 2 W, Wire Wound	WHC10RFET	Ohmite
56	1	RT1	NTC Thermistor, 10 Ω, 3.2 A	CL–110	GE Sensing
57	1	RT2	NTC Thermistor, 10 Ω, 5 A	CL–60	GE Sensing
58	1	RTV1	Thermally conductive Silicone Grease	120–SA	Wakefield
59	1	RV1	320 V, 23 J, 10 mm, RADIAL	V320LA10P	Littlefuse
60	3	SCREW1 SCREW2 SCREW3	SCREW MACHINE PHIL 4–40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners
61	1	TO-220 PAD1	HEATPAD TO–247 .006" K10	K10–104	Bergquist
62	3	TP1 TP5 TP7	Test Point, BLK,THRU–HOLE MOUNT	5011	Keystone
63	1	TP2	Test Point, RED,THRU–HOLE MOUNT	5010	Keystone
64	2	TP3 TP4	Test Point, WHT,THRU–HOLE MOUNT	5012	Keystone
65	1	TP6	Test Point, YEL,THRU–HOLE MOUNT	5014	Keystone
66	1	TP8	Test Point, ORG,THRU–HOLE MOUNT	5013	Keystone
67	1	U1	HiperPFS, PFS714EG, eSIP7/6–TH	PFS714EG	Power Integrations
68	1	U2	CAPZero, CAP006DG,SO–8C	CAP006DG	Power Integrations
69	1	VR1	12 V, 5%, 225 mW, SOT23	BZX84C12LT1G	OnSemi
70	4	WASHER1 WASHER2 WASHER3 WASHER4	WASHER FLAT #4 SS	FWSS 004	Building Fasteners
71	1	WASHER5	Washer, Lk, #4 SS	4NSLWS	Olander
72	1	WASHER6	Washer,Shoulder, #4, 0.095 Shoulder x 0.117 Dia , Polyphenylene Sulfide PPS	7721–10PPSG	Aavid Thermalloy
73	1	WASHER7	Washer Teflon #6, ID 0.156, OD 0.312, Thk 0.031	FWF–6	

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7 Inductor Specification

7.1 Electrical Diagram

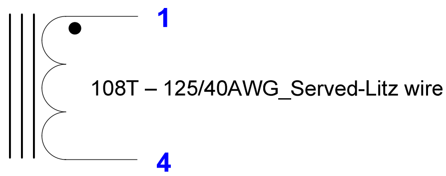


Figure 4 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 1–4 measured at kHz, 0.4 V RMS	1.38 mH, ±8%

7.3 Materials

Item	Description
[1]	Core: Magnetics Inc, Mfg: 77324A7.
[2]	Magnet wire: 125/40 Served – Litz wire.
[3]	Base: Toroid mounting base, Lodestone Pacific, P/N VTM160–4, or similar. See below. PI P/N: 76–00004–00.
[4]	High Temperature Epoxy, Mfg: MG Chemicals, P/N: 832HT–375ML, Digikey: 473–1085–ND, or similar, PI P/N: 66–00087–00.
[5]	Divider: Tie–wrap, Panduit, P/N: PLT.7M–M or similar.

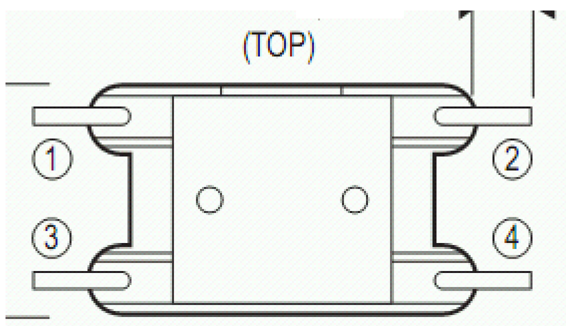
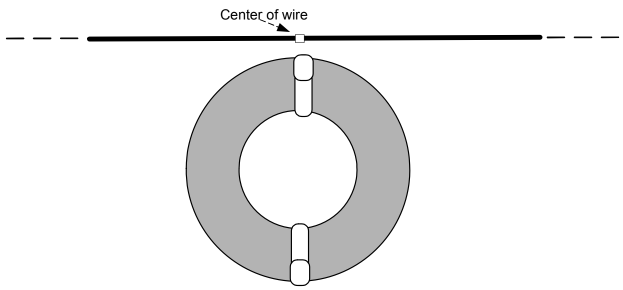


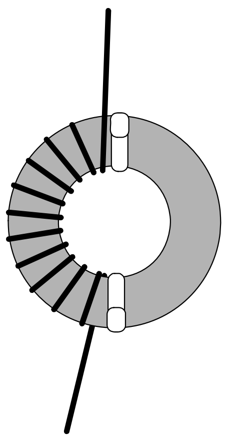
Figure 5 – Top View of Toroid Mounting Base Item [3]

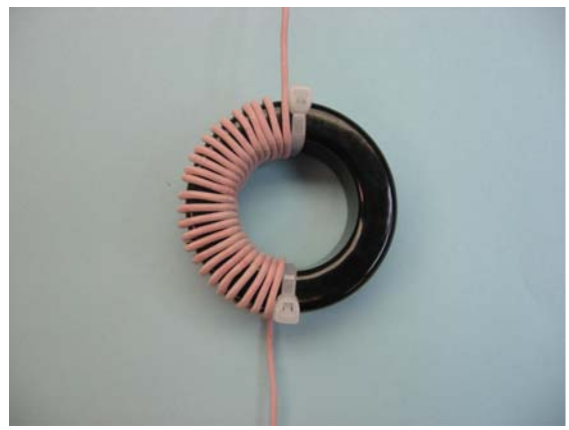
7.4 Inductor Winding Instruction

- Insert 2 dividers item [5] in the core item [1] to divide into 2 sections equally. See picture beside. Take about 15ft of wire item [2],]. Align center of wire with 1 divider.

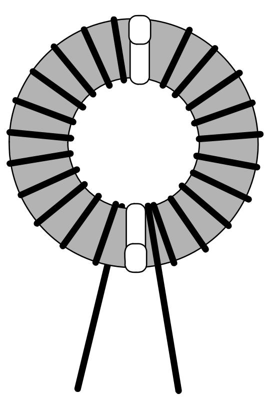


- Start winding on the left section with 23 turns of wire item [2], for the 1st layer, spread wire evenly and ensure that turns do not overlap.





- Also wind another 23 turns on the right section.



- Continue winding on the right section for the 2nd layer 18 turns, spread wire evenly and ensure that turns do not overlap.

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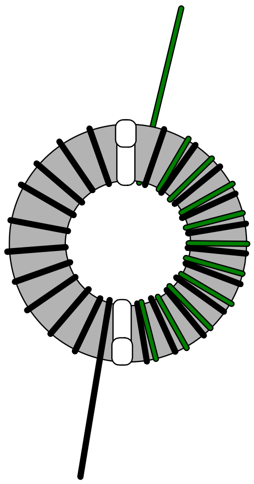
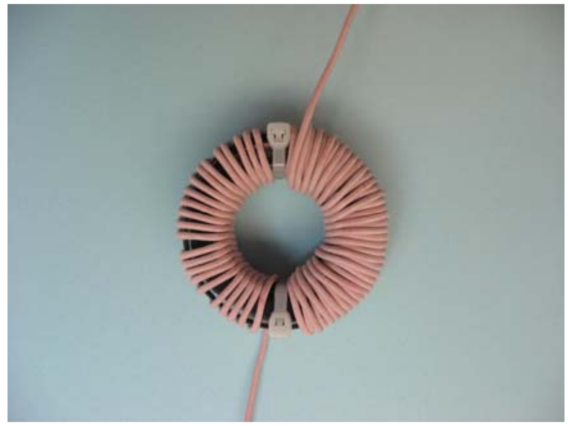
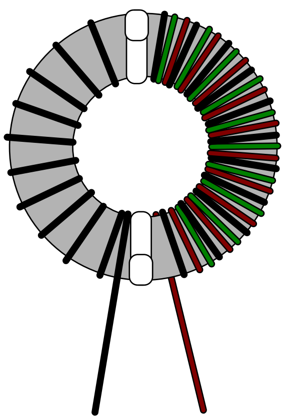
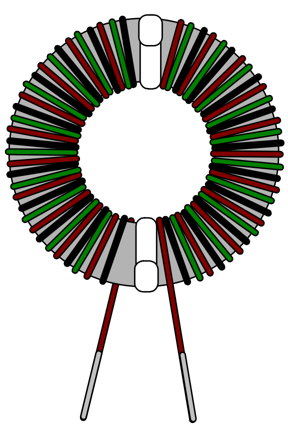




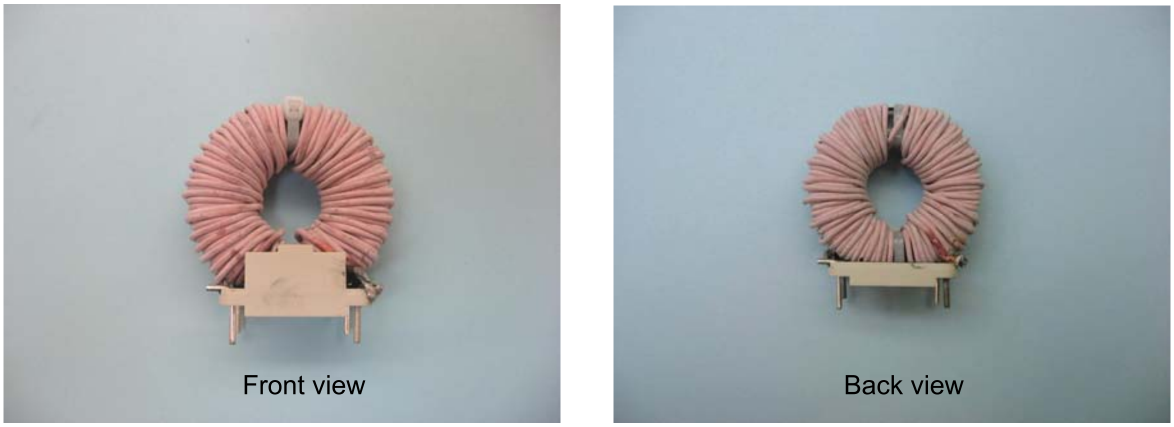
- Continue winding on the right section on the 3rd layer 13turns, scatter wire evenly and ensure that turns do not overlap.



- Wind the same as above for the 2nd and 3rd layer on the left section.



- Secure the inductor with the base by using High Temperature Epoxy item [4].



- Solder the leads to the pin 1 and 4 of mounting base item [3].

Figure 6 – Finished Inductor

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8 Performance Data

All measurements performed at room temperature, 60 Hz input frequency for voltages below 150 VAC and input frequency of 50 Hz for 150 VAC and higher.

All performance data except for data presented in the appendix is with Thermistors RT1 and RT2 shorted to represent the high performance configuration which uses RT2 to limit inrush current and shorts thermistor RT2 using a relay after start-up to improve operating efficiency.

8.1 Efficiency (RT1 and RT2 Shorted)

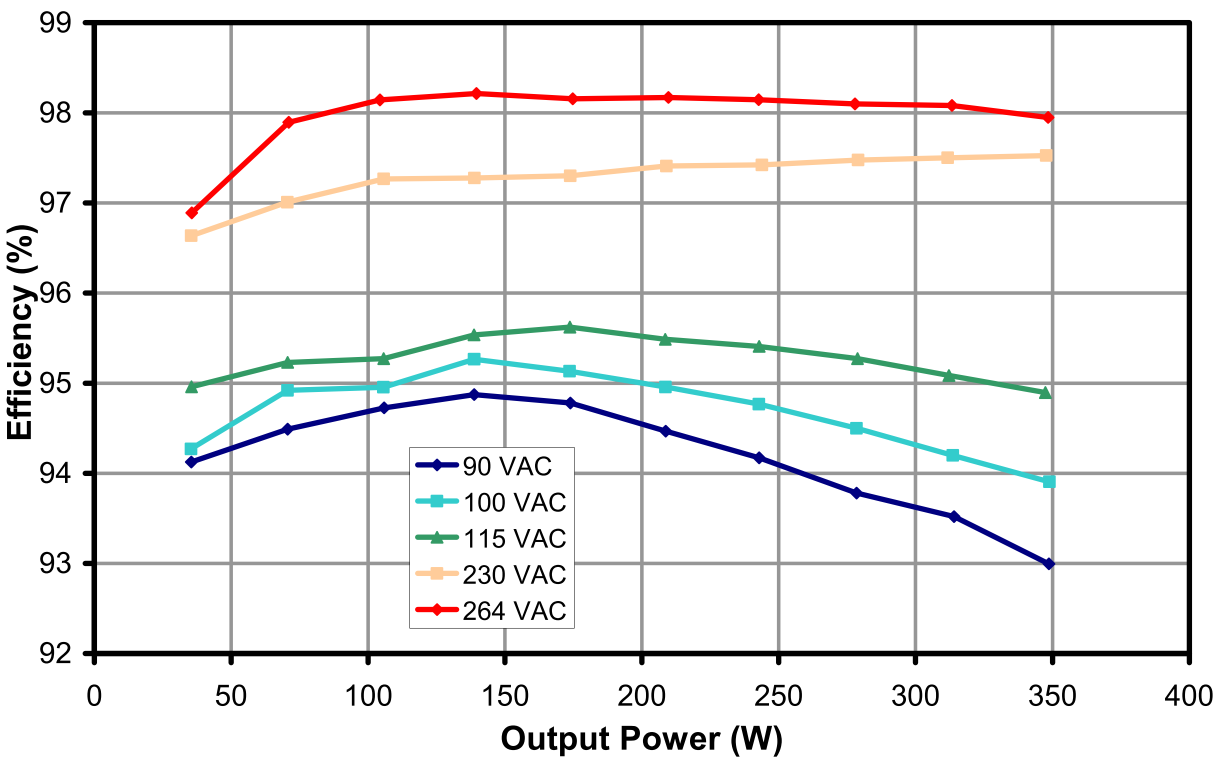

Figure 7 – Efficiency vs. Output Power.

8.2 Input Power Factor

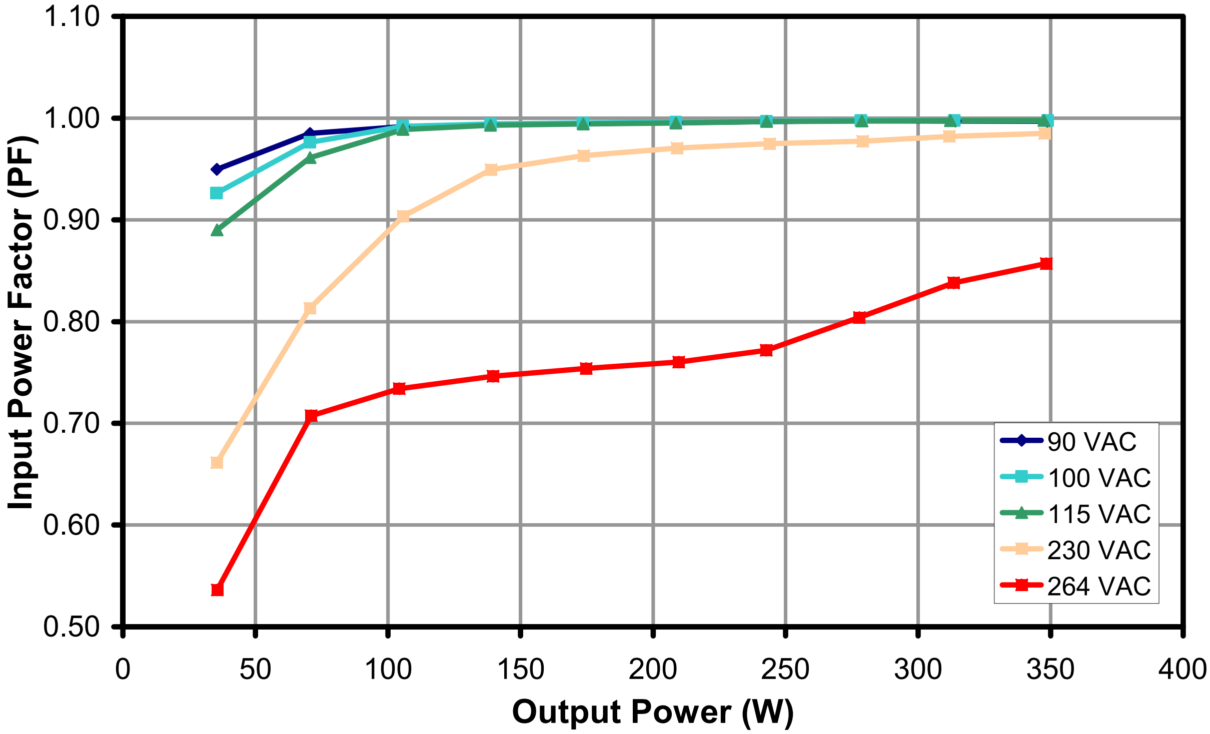

Figure 8 – Input Power Factor vs. Output Power.

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8.3 Regulation

8.3.1 Load

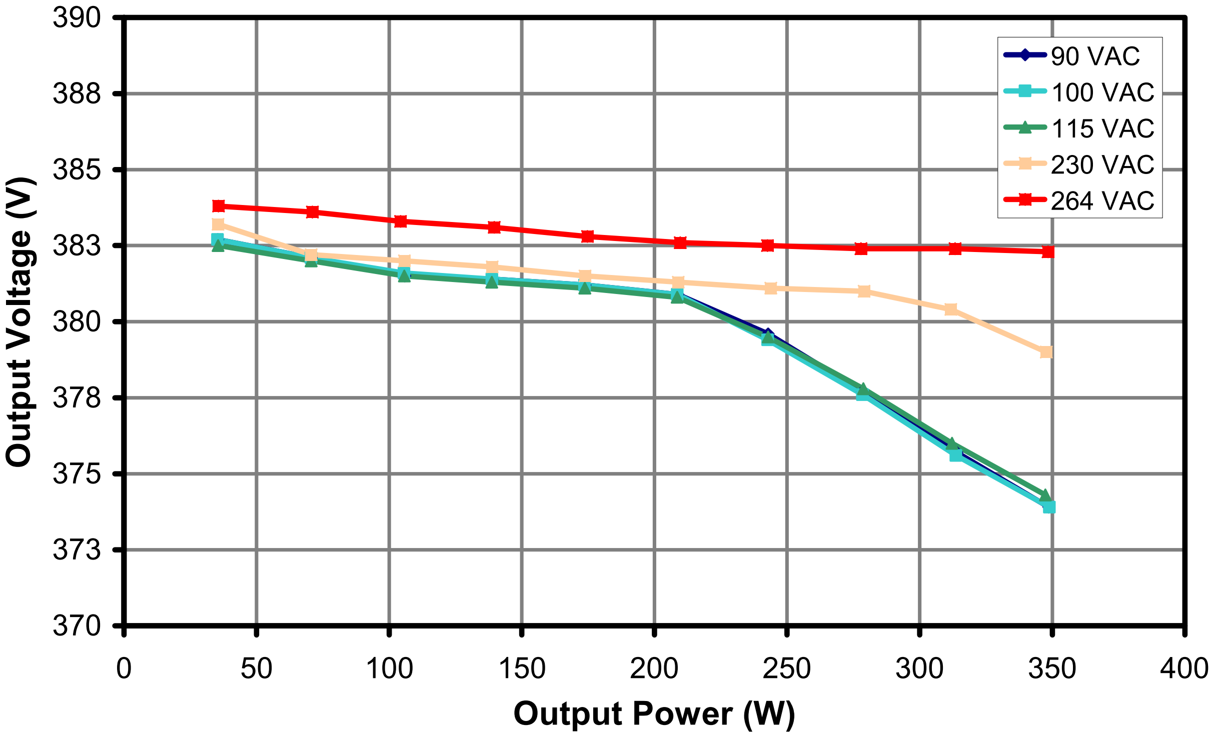

Figure 9 – Load Regulation.

8.3.2 Line

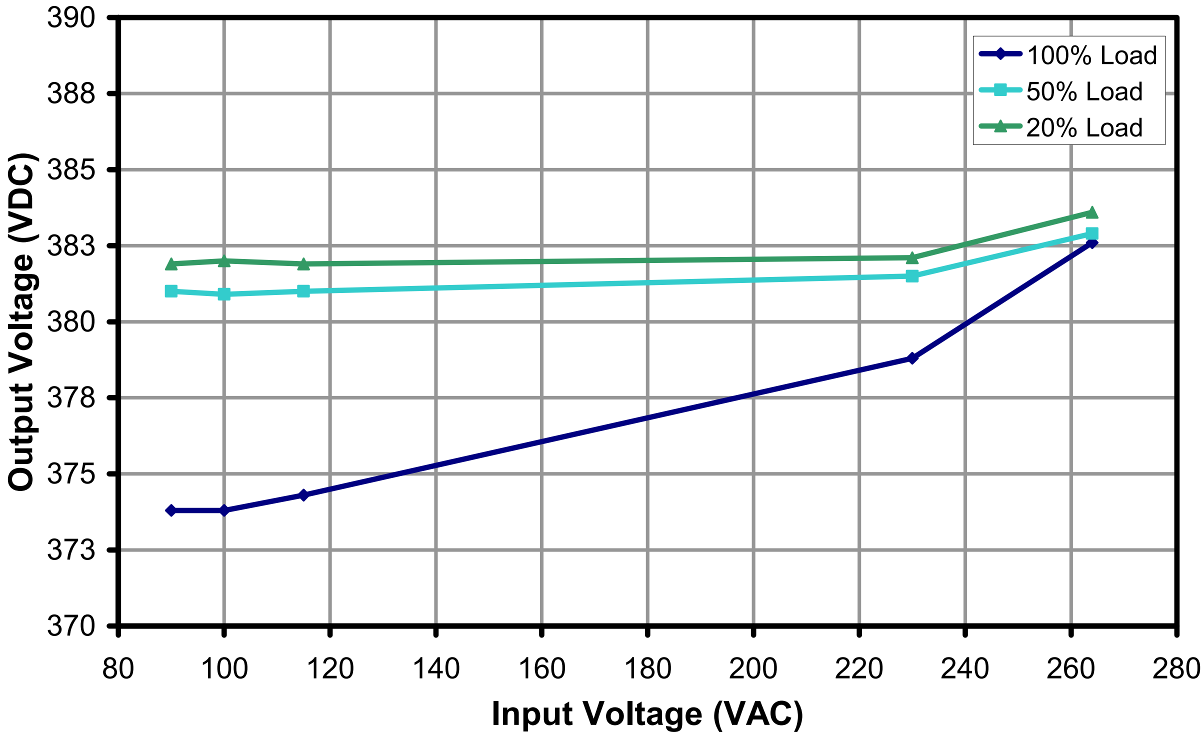

Figure 10 – Line Regulation.

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8.4 Input Current Harmonic Distortion (IEC 61000–3–2 Class–D)

Measured at 230 VAC Input 50Hz

8.4.1 50% Load at Output

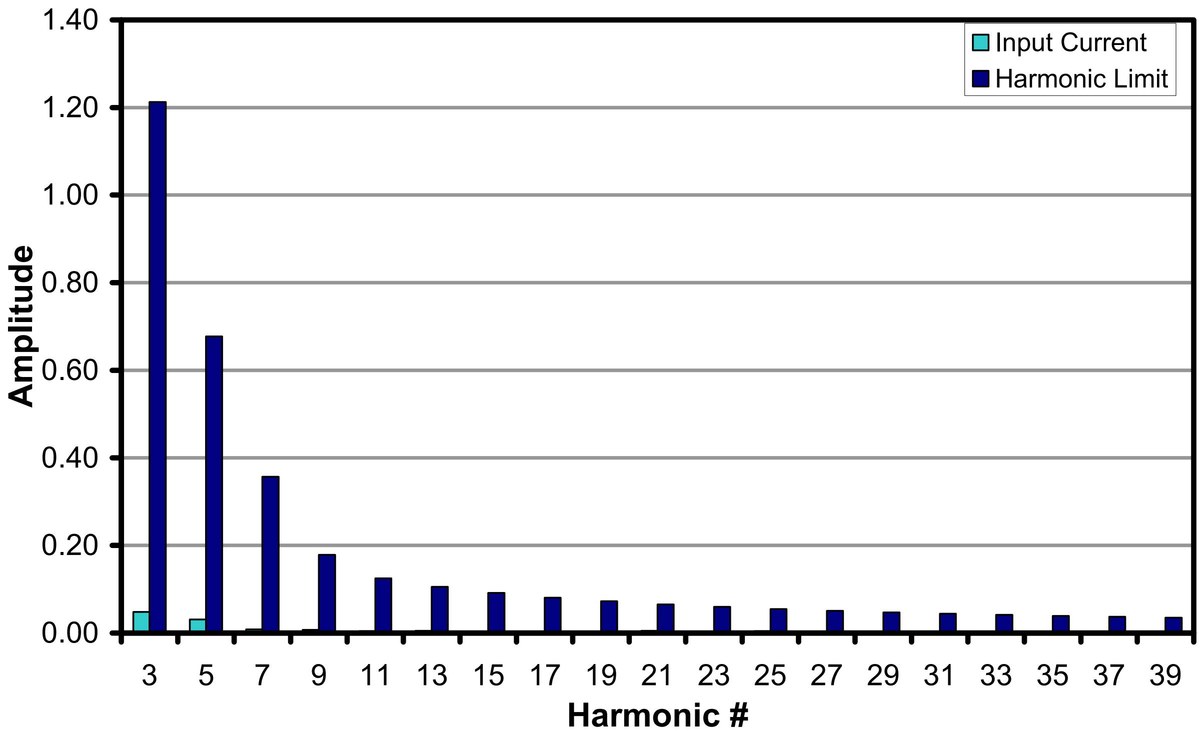

Figure 11 – Amplitude of Input Current Harmonics for 50% Load at 230 VAC Input.

8.4.2 100% Load at Output

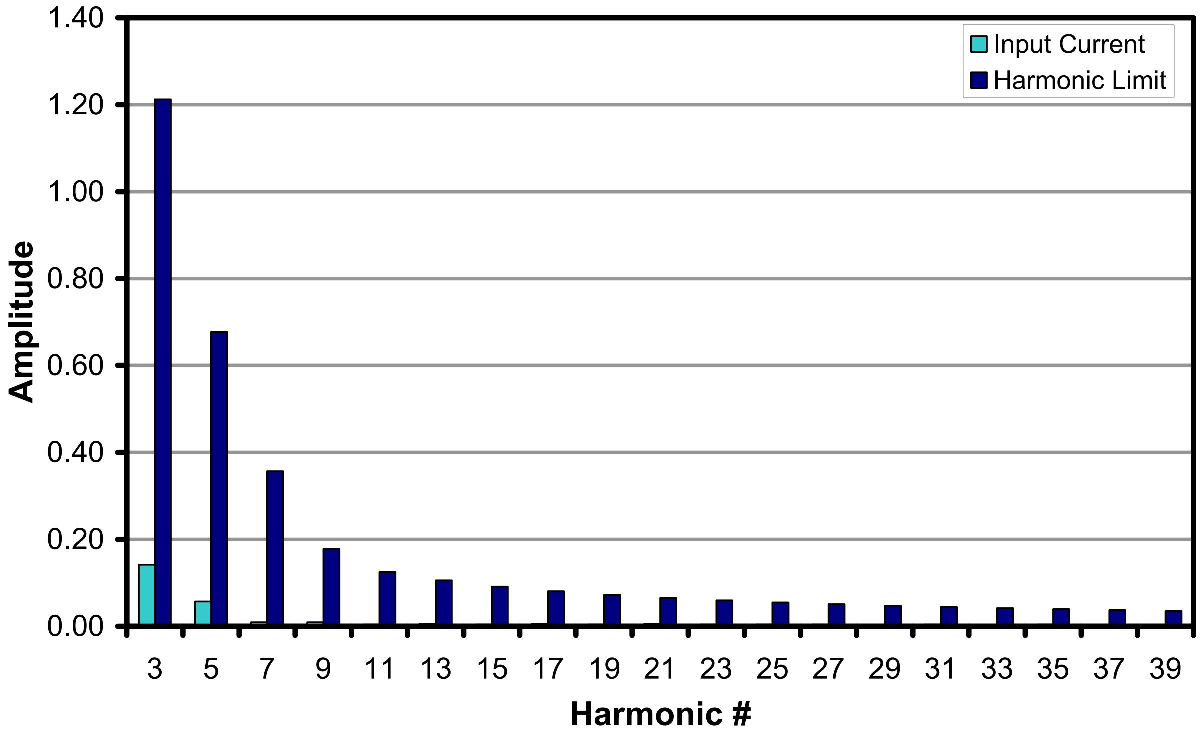

Figure 12 – Amplitude of Input Current Harmonics for 100% Load at 230 VAC Input.

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9 Thermal Performance

The unit was allowed to reach thermal equilibrium prior to the measurement. Table 1 shows full load temperature of key components at equilibrium, room temperature and without any forced air cooling.

Component	Temperature (º C)	
	240 VAC	115 VAC
C3	28.1	29.9
C6	36.0	47.2
C7	41.1	53.2
C15	35.6	42.8
C19	36.2	40.3
D2	53.4	68.4
L1	33.0	47.5
L2	31.8	41.9
L3	36.8	54.9
L5	57.6	78.9
BR1	59.5	95.0
Heatsink – BR1	51.8	76.3
Heatsink – D2	51.6	62.8
Heatsink – U1	50.8	78.1
U1	59.5	98.2
Ambient Temperature:	25.0	25.0

Table 1 – Thermal Performance of Key Components at Full Load.

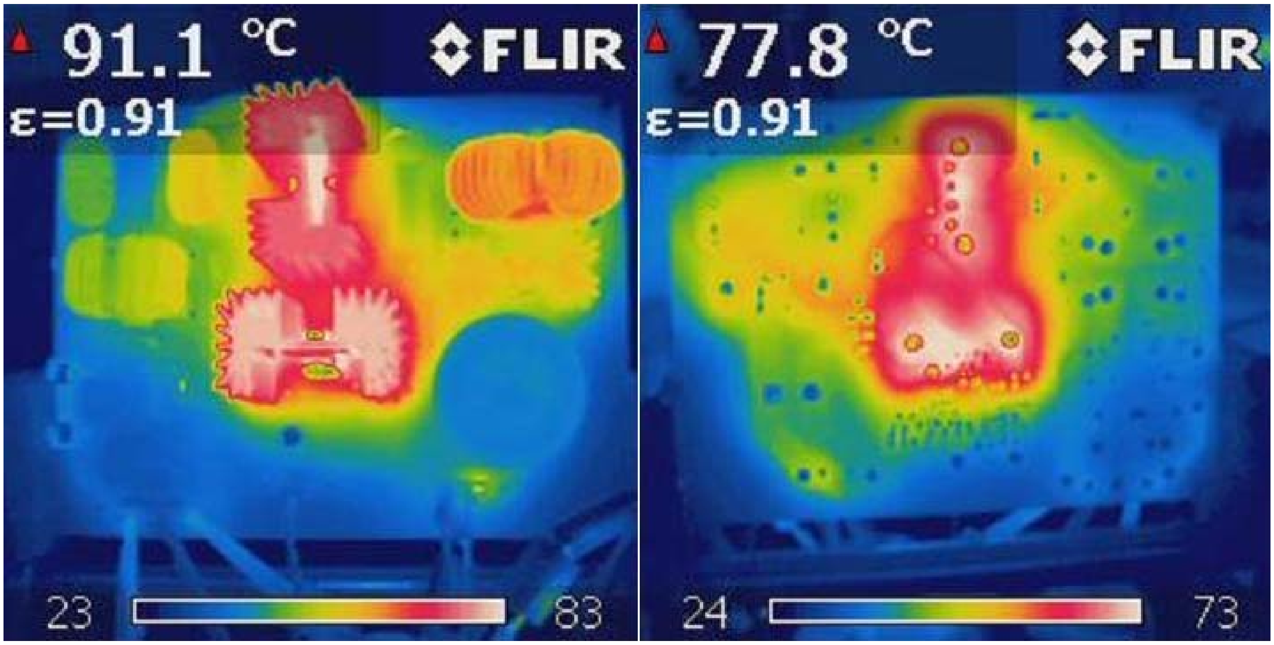

Figure 13 – Infrared Image of the Top and Bottom Side of the Board at Thermal Equilibrium. 115 VAC, Full Load, No Forced–Air Flow, 25ºC Ambient.

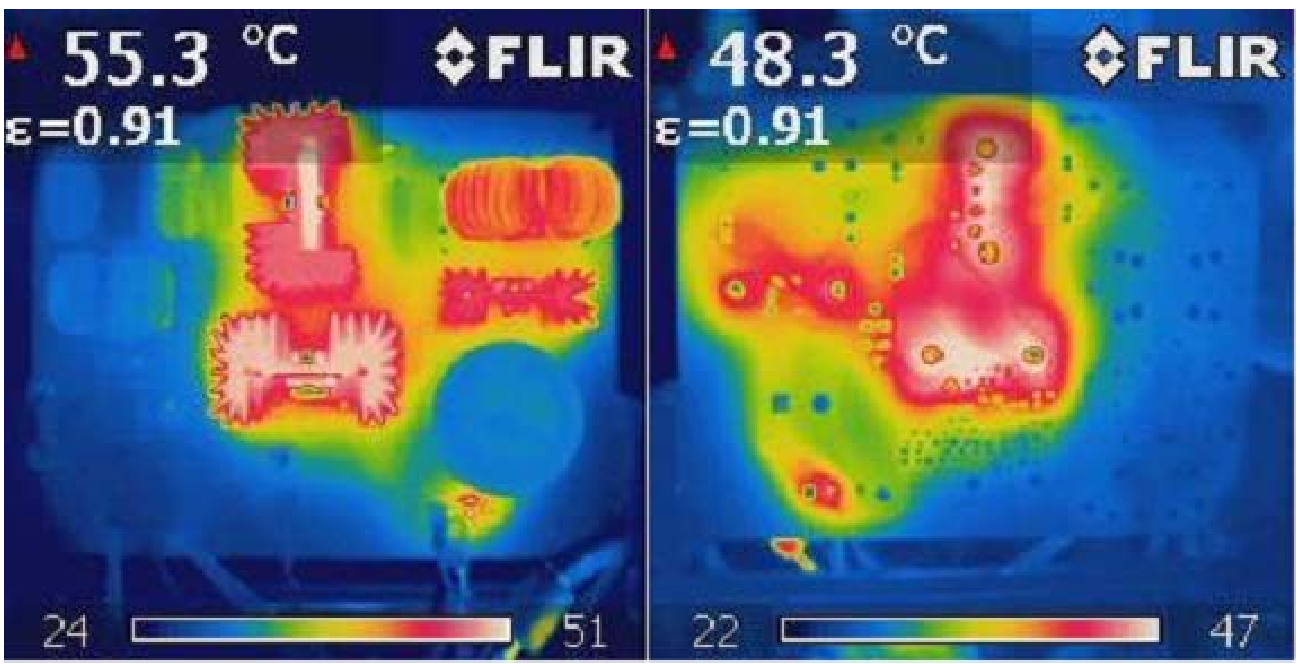

Figure 14 – Infrared Image of the Top and Bottom Sides of the Board at Thermal Equilibrium. 230 VAC, Full Load, No Forced–Air Flow, 25ºC Ambient.

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10 Waveforms

10.1 Input Current at 115 VAC and 60 Hz

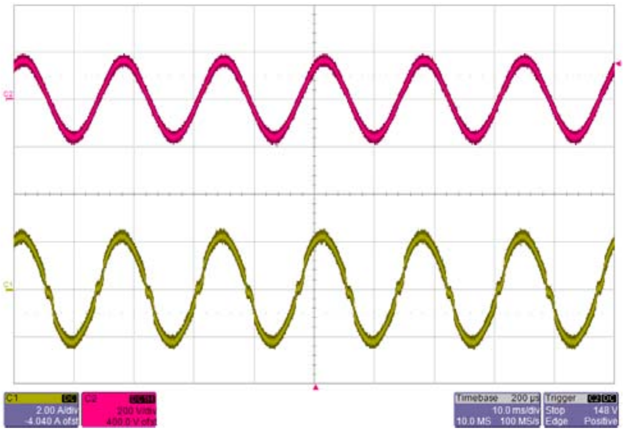

Figure 15– 115 VAC, 50% Load.
Top: V_{IN}, 200 V / div.
Bottom: I_{IN}, 2 A, 10 ms / div.

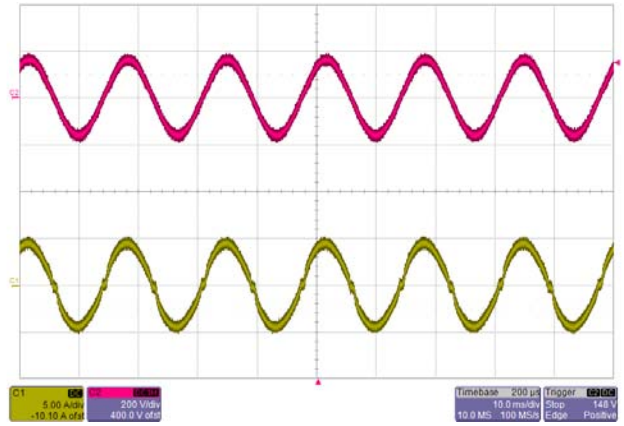

Figure 16 – 115 VAC, 100% Load.
Top: V_{IN}, 200 V / div.
Bottom: I_{IN}, 5 A, 10 ms / div.

10.2 Input Current at 230 VAC and 50 Hz

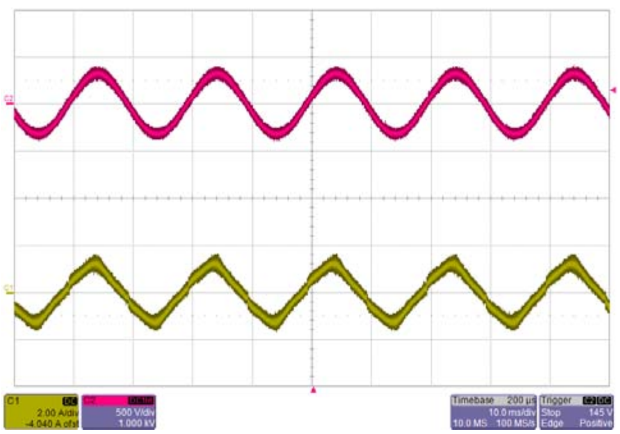

Figure 17 – 230 VAC, 50% Load.
Top: V_{IN}, 500 V / div.
Bottom: I_{IN}, 2 A, 10 ms / div.

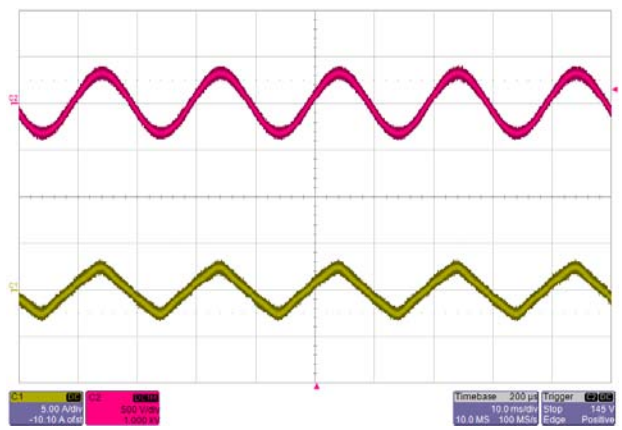

Figure 18 – 230 VAC, 100% Load.
Top: V_{IN}, 500 V / div.
Bottom: I_{IN}, 5 A, 10 ms / div.

10.3 Start-up at 90 VAC and 60 Hz

Load in CC mode during turn–on of PFC

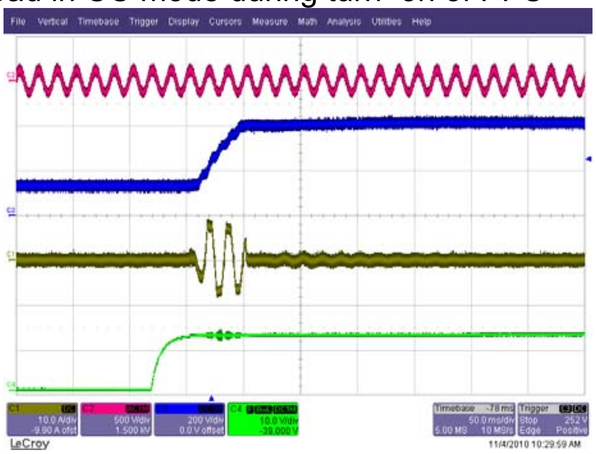

Figure 19 – 90 VAC, No Load.
Top: V_{IN}, 500 V / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V / div., 50 ms / div.

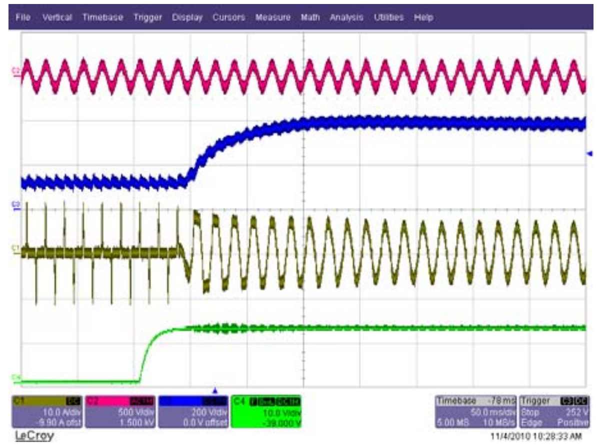

Figure 20 – 90 VAC, Full Load.
Top: V_{IN}, 500 V / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V / div., 50 ms / div.

10.4 Start-up at 115 VAC and 60 Hz

Load in CC mode during turn–on of PFC

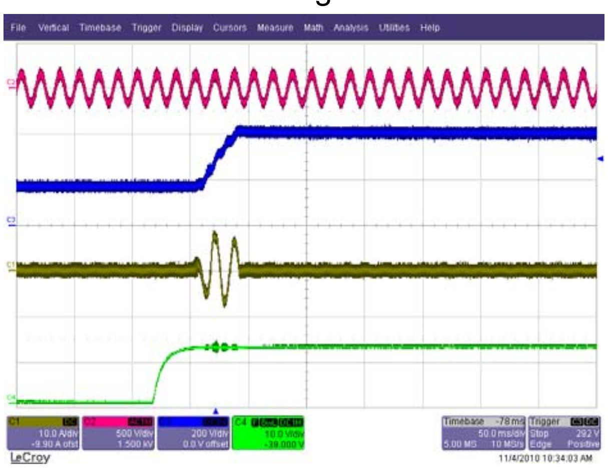

Figure 21 – 115 VAC, No Load.
Top: V_{IN}, 500 V / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V / div., 50 ms / div.

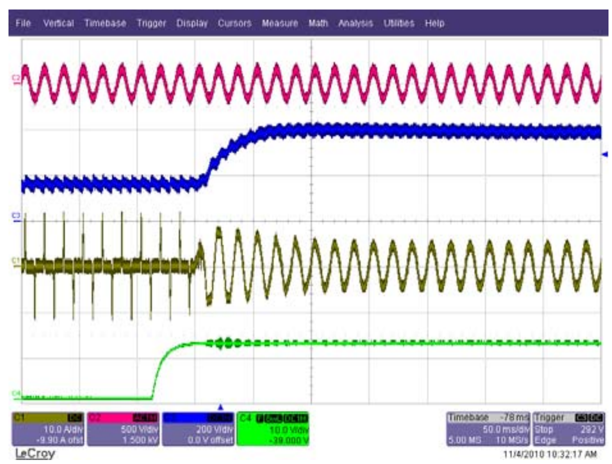

Figure 22 – 115 VAC, Full Load.
Top: V_{IN}, 500 V / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V / div., 50 ms / div.

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10.5 Start-up at 230 VAC and 50 Hz

Load in CC mode during turn–on of PFC

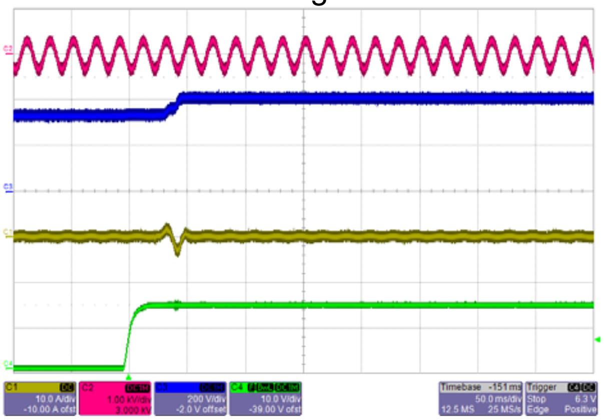

Figure 23 – 230 VAC, No-load.
Top: V_{IN}, 1 kV / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V, 50 ms / div.

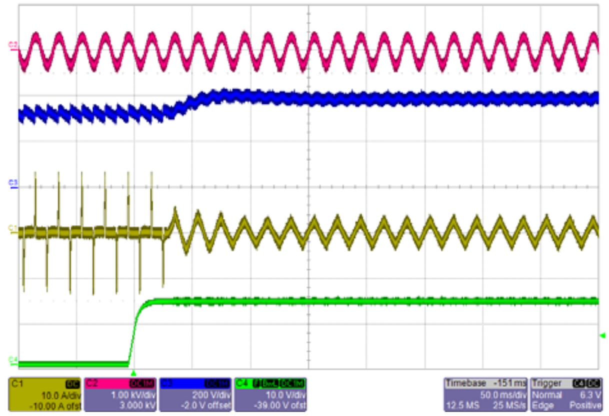

Figure 24 – 230 VAC, Full Load.
Top: V_{IN}, 1 kV / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V, 50 ms / div.

10.6 Start-up at 264 VAC and 50 Hz

Load in CC mode during turn–on of PFC

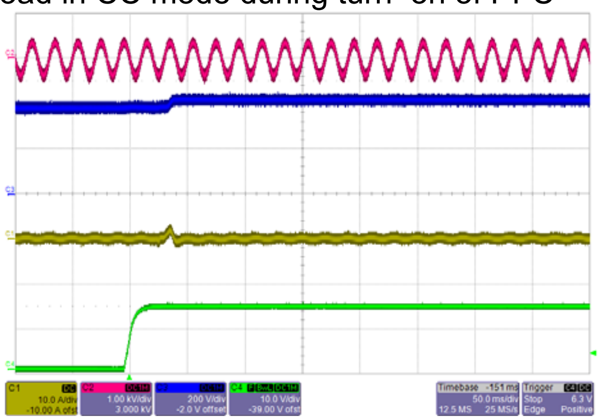

Figure 25 – 264 VAC, No-load.
Top: V_{IN}, 1 kV / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div.
Bottom: V_{CC}, 10 V, 50 ms / div.

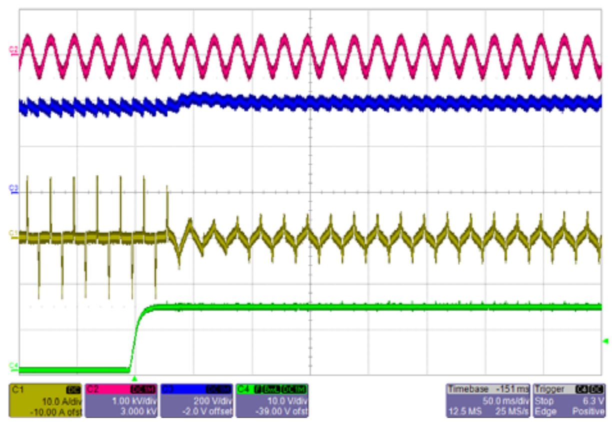

Figure 26 – 264 VAC, Full Load.
Top: V_{IN}, 1 kV / div.
Second: Output Voltage, 200 V / div.
Third: I_{IN}, 10 A / div
Bottom: V_{CC}, 10 V, 50 ms / div.

10.7 *Load Transient Response (90 VAC, 60 Hz)*

In the figures shown below, signal averaging was used to better enable viewing the load transient response. The oscilloscope was triggered using the load current step as a trigger source. Since the output switching and line frequency occur essentially at random with respect to the load transient, contributions to the output ripple from these sources will average out, leaving the contribution only from the load step response.

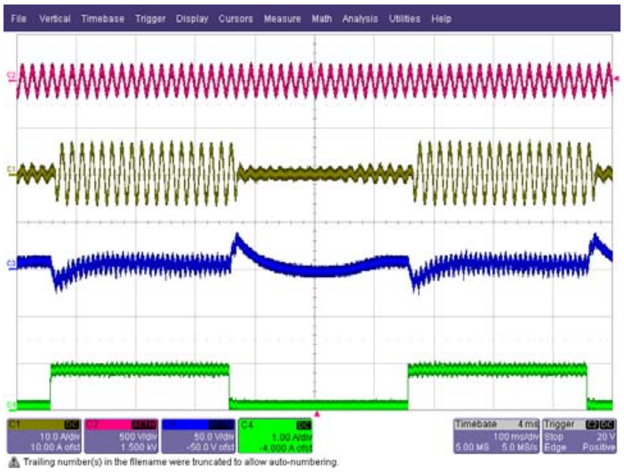

Figure 27 – Transient Response, 90 VAC, 10–100–10% Load Step.
Top: Input Voltage, 500 V / div.
Second: Input Current, 10 A /div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

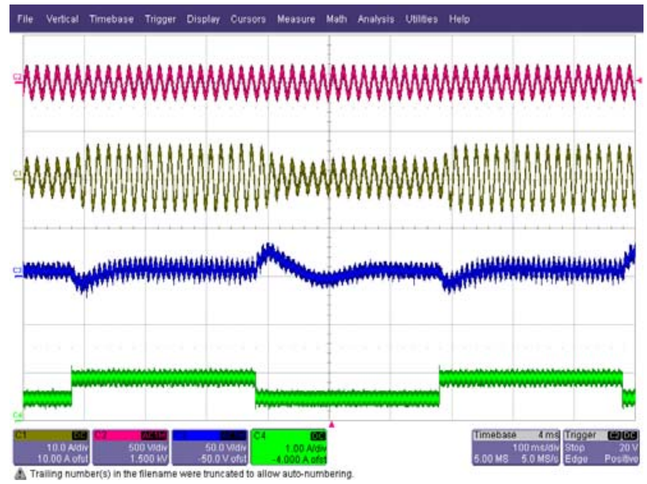

Figure 28 – Transient Response, 90 VAC, 50–100–50% Load Step
Top: Input Voltage, 500 V / div.
Second: Input Current, 10 A / div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

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10.8 Load Transient Response (115 VAC, 60 Hz)

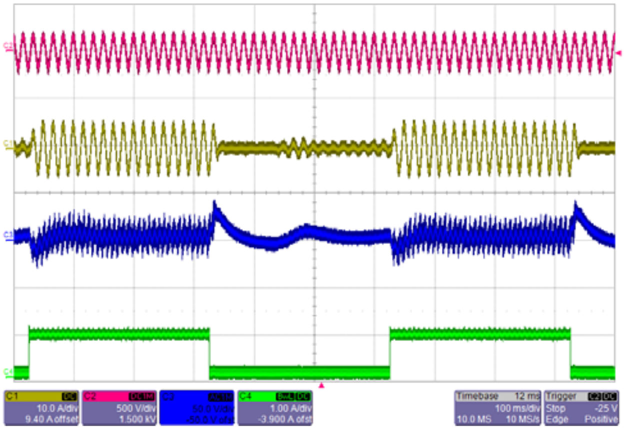

Figure 29 – Transient Response, 115 VAC, 10–100–10% Load Step.
Top: Input Voltage, 500 V / div.
Second: Input Current, 10 A /div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

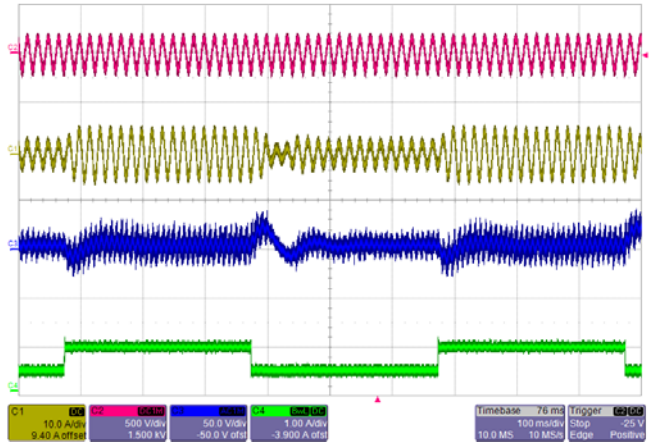

Figure 30 – Transient Response, 115 VAC, 50–100–50% Load Step
Top: Input Voltage, 500 V / div.
Second: Input Current, 10 A /div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

10.9 Load Transient Response (230 VAC, 50 Hz)

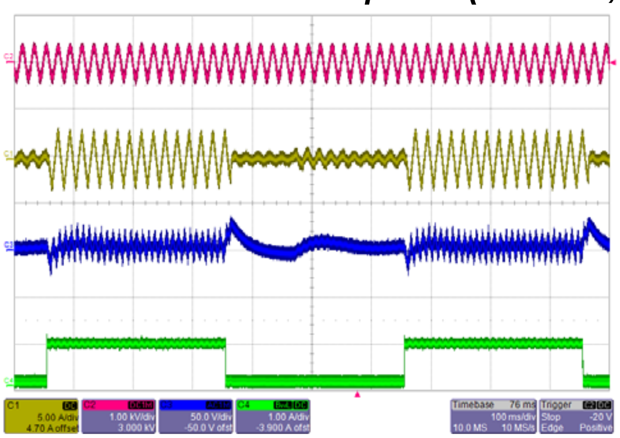

Figure 31 – Transient Response, 230 VAC, 10–100–10% Load Step.
Top: Input Voltage, 1 KV / div.
Second: Input Current, 5 A / div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

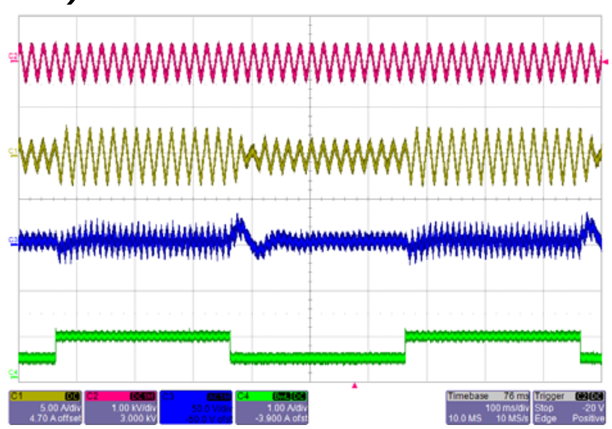

Figure 32 – Transient Response, 230 VAC, 50–100–50% Load Step
Top: Input Voltage, 1 KV / div.
Second: Input Current, 5 A / div.
Third: Output Voltage (AC Coupled), 50 V / div.
Bottom: Load Current 1 A, 100 ms / div

10.10 Load Transient Response (264 VAC, 50 Hz)

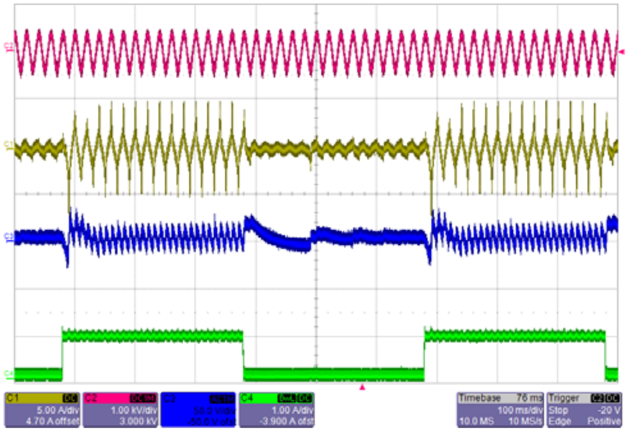

Figure 33 – Transient Response, 264 VAC,
10–100–10% Load Step.
Top: Input Voltage, 1 KV / div.
Second: Input Current, 5 A / div.
Third: Output Voltage (AC Coupled),
50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

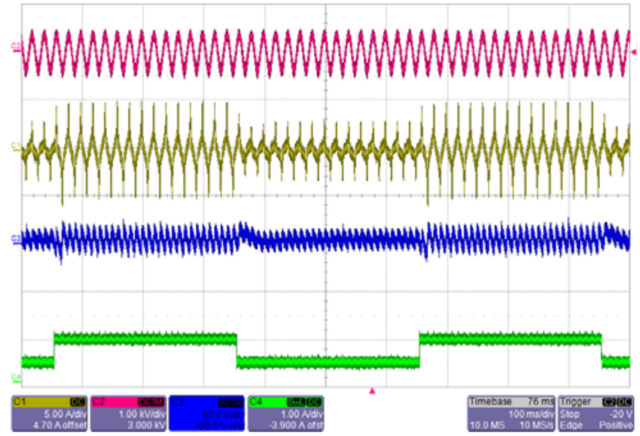

Figure 34 – Transient Response, 264 VAC,
50–100–50% Load Step.
Top: Input Voltage, 1 KV / div.
Second: Input Current, 5 A / div.
Third: Output Voltage (AC Coupled),
50 V / div.
Bottom: Load Current 1 A, 100 ms / div.

10.11 1000 ms Line Dropout (115 VAC / 60 Hz and 230 VAC / 50 Hz)

10.11.1 50% Load at Output

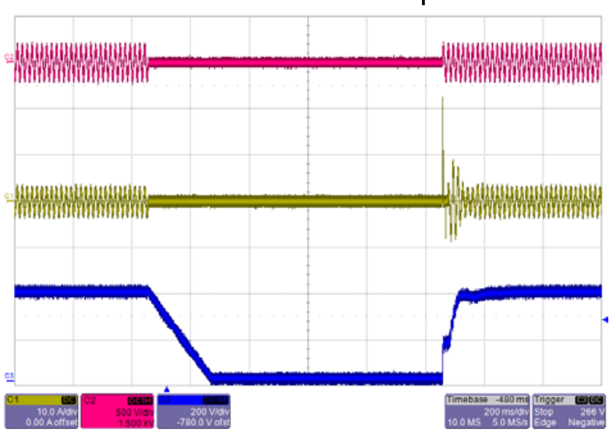

Figure 35 – Line Dropout 115 VAC, 1000 ms.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A / div.
Bottom: Output Voltage, 200 V,
200 ms / div.

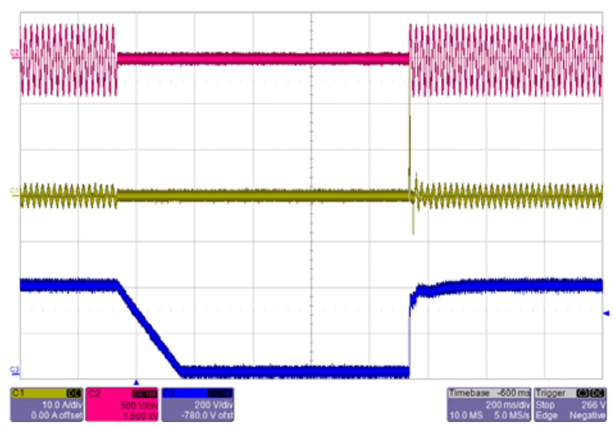

Figure 36 – Line Dropout 230 VAC, 1000 ms.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A / div.
Bottom: Output Voltage, 200 V,
200 ms / div.

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10.11.2 Full Load at Output

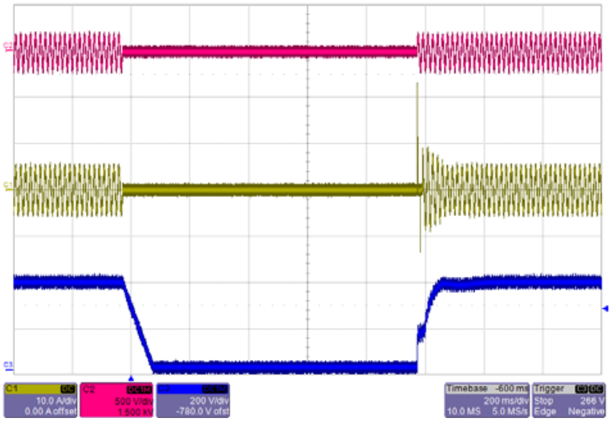

Figure 37 – Line Dropout 115 VAC, 1000 ms.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A / div.
Bottom: Output Voltage, 200 V, 200 ms / div.

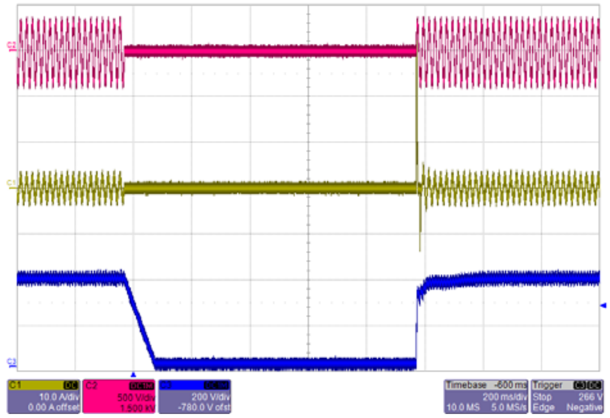

Figure 38 – Line Dropout 230 VAC, 1000 ms.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A / div.
Bottom: Output Voltage, 200 V, 200 ms / div.

10.12 One Cycle Line Dropout (115 VAC / 60 Hz and 230 VAC / 50 Hz)

10.12.1 Full Load at Output

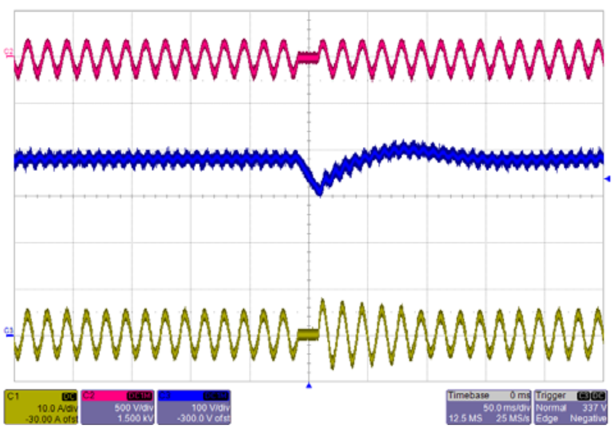

Figure 39 – Line Dropout 115 VAC, 60 Hz
Top: Input Voltage, 500 V / div.
Middle: Output Voltage, 100 V /div.
Bottom: Input Current, 10 A, 50 ms / div.

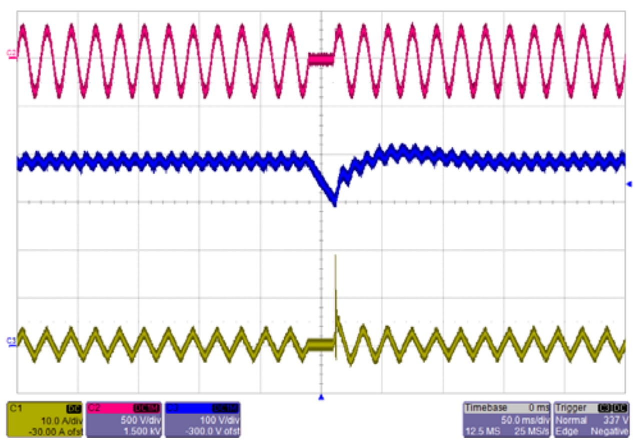

Figure 40 – Line Dropout 230 VAC, 50 Hz
Top: Input Voltage, 500 V / div.
Middle: Output Voltage, 100 V / div.
Bottom: Input Current, 10 A, 50 ms /div.

10.13 Line Sag (115 VAC – 85 VAC – 115 VAC, 60 Hz)

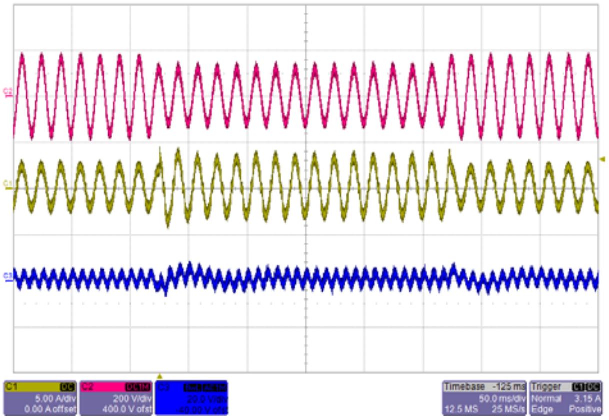

Figure 41 – Line Sag 115 VAC, 50% Load.
Top: Input Voltage, 200 V / div.
Middle: Input Current, 5 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div.

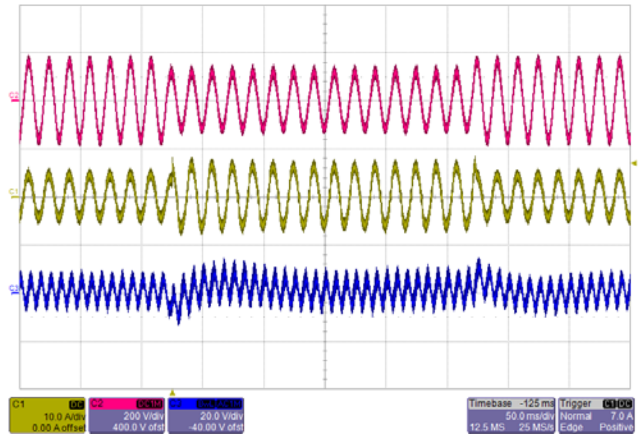

Figure 42 – Line Sag 115 VAC, 100% Load.
Top: Input Voltage, 200 V / div.
Middle: Input Current, 10 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div.

10.14 Line Surge (132 VAC – 147 VAC – 132 VAC, 60 Hz)

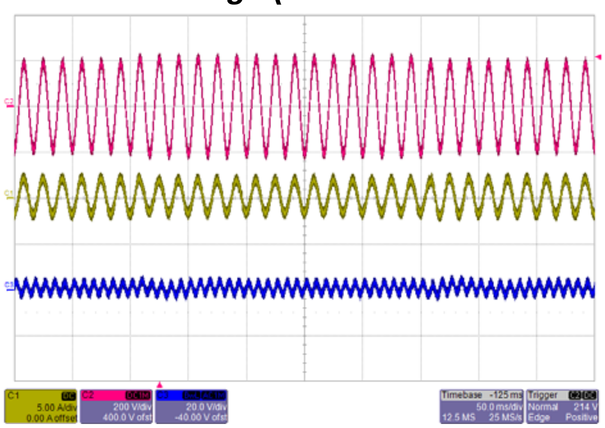

Figure 43 – Line Surge 132 VAC, 50% Load.
Top: Input Voltage, 200 V / div.
Middle: Input Current, 5 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div.

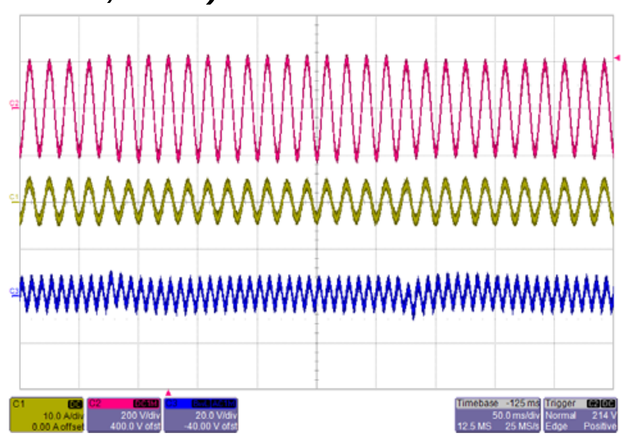

Figure 44 – Line Surge 132 VAC, 100% Load.
Top: Input Voltage, 200 V / div.
Middle: Input Current, 10 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div.

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10.15 Line Sag (230 VAC – 170 VAC – 230 VAC, 50 Hz)

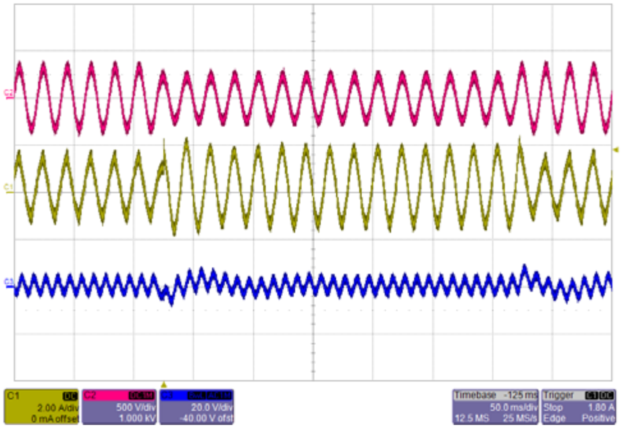

Figure 45 – Line Sag 230 VAC, 50% Load.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 2 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div.

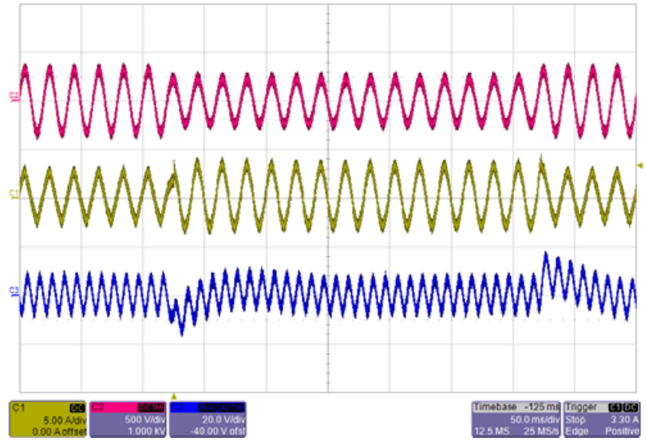

Figure 46 – Line Sag 230 VAC, 100% Load.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 5 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 20 V / div

10.16 Line Surge (264 VAC – 293 VAC – 264 VAC, 50 Hz)

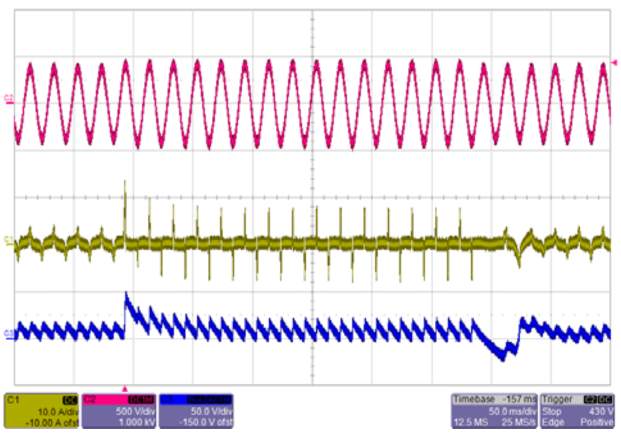

Figure 47 – Line Surge 264 VAC, 50% Load.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A, 50 ms / div.
Bottom: Output Voltage (AC Coupled), 50 V / div.

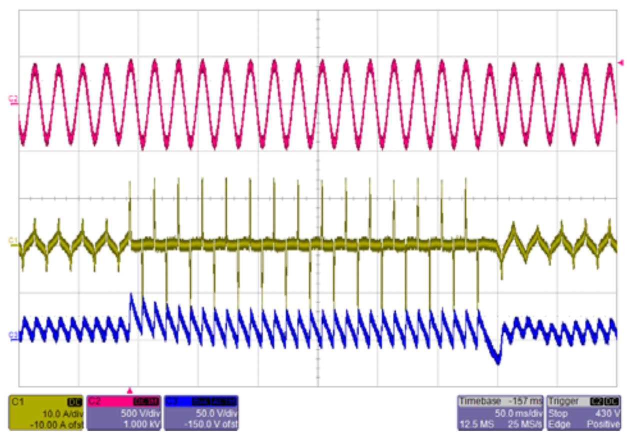

Figure 48 – Line Surge 264 VAC, 100% Load.
Top: Input Voltage, 500 V / div.
Middle: Input Current, 10 A, 50 ms / div
Bottom: Output Voltage (AC Coupled), 50 V / div.

10.17 Brown–In and Brown–Out at 6 V / Minute Rate

Test conducted with reduction followed by increase of input voltage at the rate of 6 V/min. The DC output was connected to full load (electronic load) and it was programmed to unload at brown–out. A resistor of 17 kΩ was also connected at output to discharge the output capacitor of the PFC after brown–out. This resistor represents any auxiliary supply powered from the PFC output.

Measured Brown–Out Threshold	69.9 VAC
Measured Brown–In Threshold	78.1 VAC

Note: *Operation at low input voltages results in higher power dissipation in many components on the board. Forced air cooling is necessary during this test.*

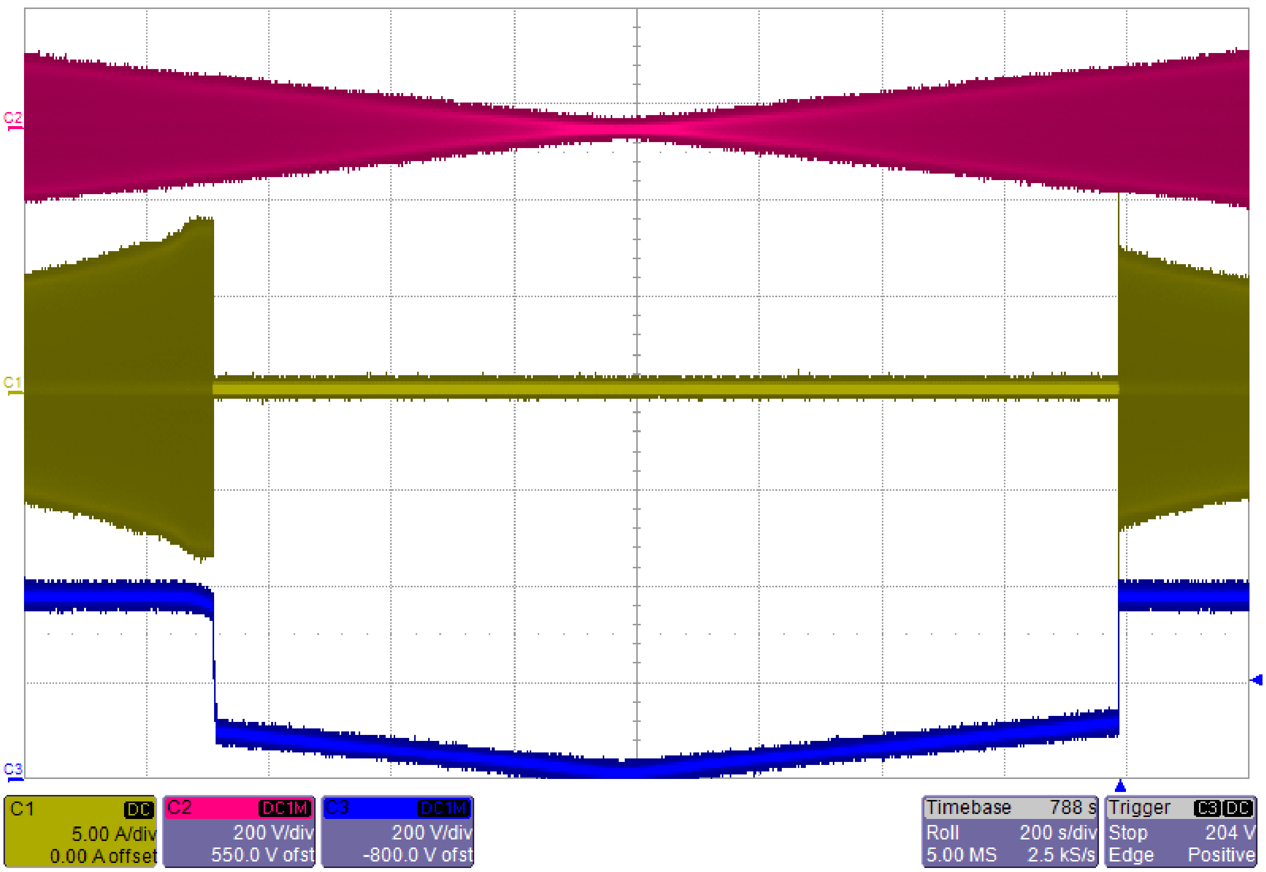

Figure 49 – Brown–Out Followed by Brown–In at 100% Load.
Top: Input Voltage, 200 V / div.
Middle: Input Current, 5 A, 200 s / div.
Bottom: Output Voltage, 200 V / div.

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10.18 Drain Voltage and Current

The drain current was measured at Jumper JP4 location by replacing JP4 with a very short wire loop in order to insert the current probe. The drain voltage was measured at the Drain and Source pins of IC U1. Do not make the wire loop very large since the added inductance at the drain node can cause very large inductance spike and lead to very high Vds voltage that could damage U1, therefore, we do not recommend breaking JP4 to measure the drain–source current. However, the drain–source current can be obtained from the inductor L5 current through some calculations. Please see Appendix C for output inductor current measurement setup and calculations.

10.18.1 Dain Voltage and Current at 115 VAC Input and Full Load

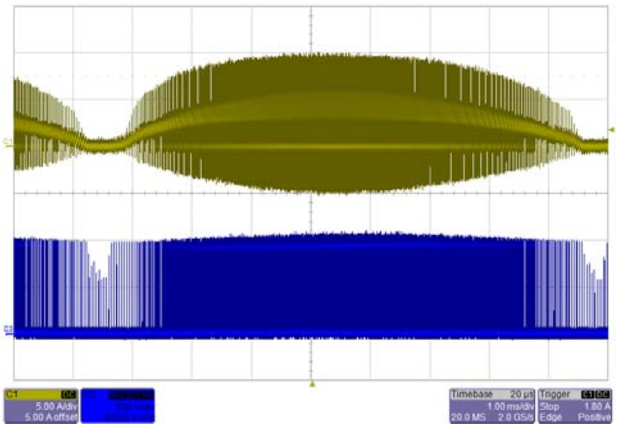

Figure 50 – Input Voltage 115 VAC, 100% Load.
Top: Drain Current, 5 A, 1 ms / div.
Bottom: Drain Voltage, 200 V / div.

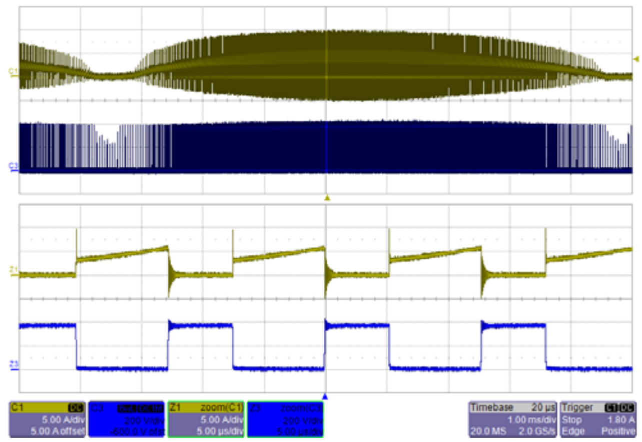

Figure 51 – Input Voltage 115 VAC, 100% Load.
Top: Drain Current, 5 A, 1 ms / div.
Bottom: Drain Voltage, 200 V / div.
Zoom Top: Drain Current, 5 A, 5 μs / div.
Zoom Bottom: Drain Voltage, 200 V / div.

10.18.2 Drain Voltage and Current at 230 VAC Input and Full Load

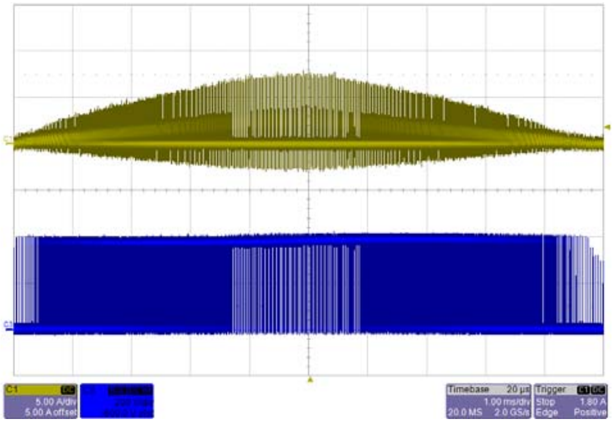

Figure 52 – Input Voltage 230 VAC, 100% Load.
Top: Drain Current, 5 A, 1 ms / div.
Bottom: Drain Voltage, 200 V / div.

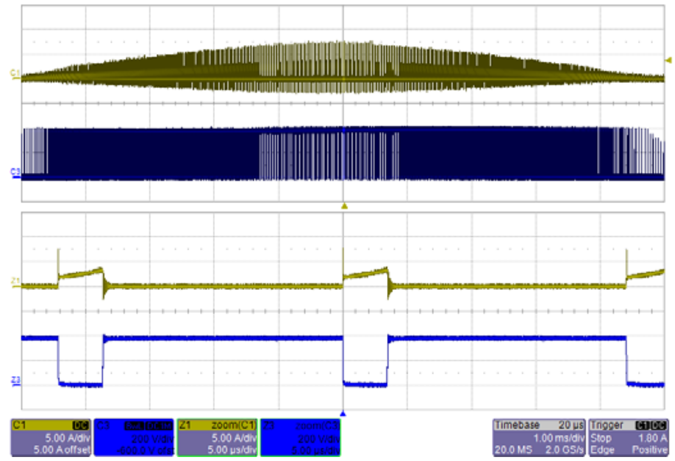

Figure 53 – Input Voltage 230 VAC, 100% Load.
Top: Drain Current, 5 A, 1 ms / div.
Bottom: Drain Voltage, 200 V / div.
Zoom Top: Drain Current, 5 A, 5 μs / div.
Zoom Bottom: Drain Voltage, 200 V / div.

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10.19 Output Ripple Measurements

10.19.1 Ripple Measurement Technique

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

The 4987BA probe adapter is affixed with one capacitor 0.02 μF/1 kV ceramic disc type tied in parallel across the probe tip.

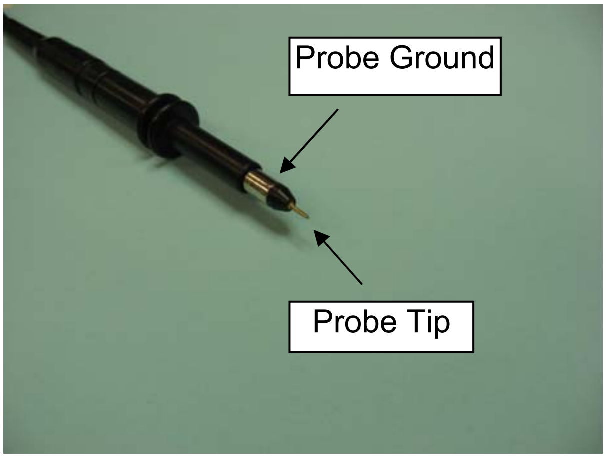

Figure 54 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

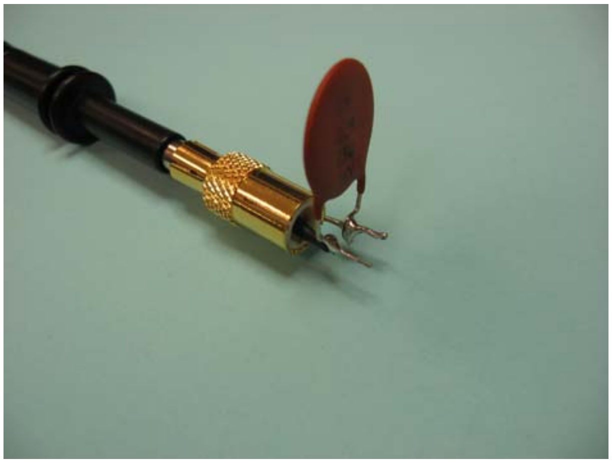

Figure 55 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. Modified with wires for ripple measurement, and one parallel decoupling capacitor added.)

10.19.2 Measurement Results

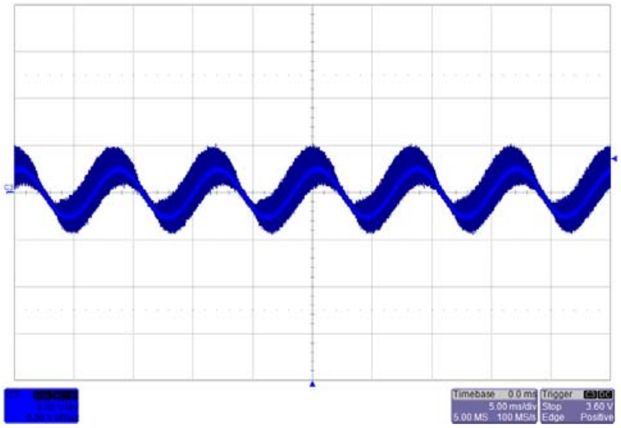

Figure 56 – Ripple, 90 VAC, 50% Load.
5 ms, 5 V / div.

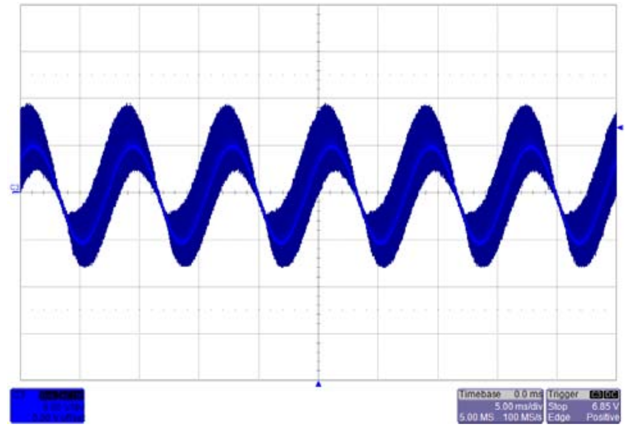

Figure 57 – Ripple, 90 VAC, 100% Load.
5 ms, 5 V / div.

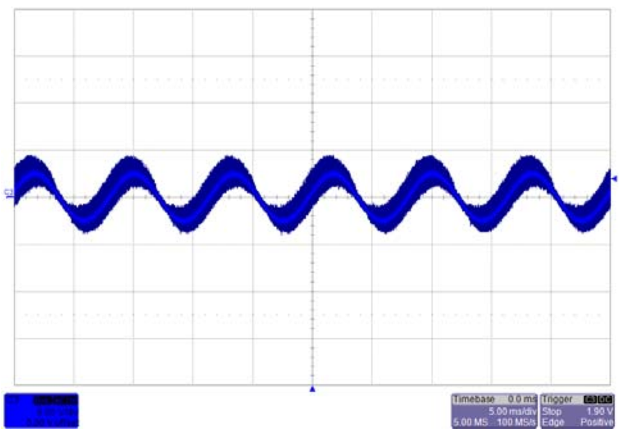

Figure 58 – Ripple, 115 VAC, 50% Load.
5 ms, 5 V / div.

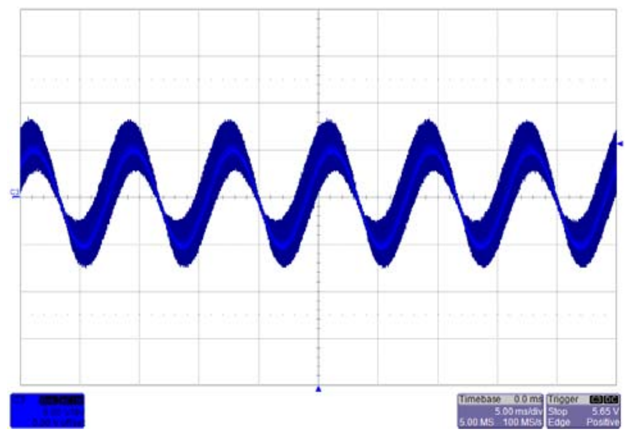

Figure 59 – Ripple, 115 VAC, 100% Load.
5 ms, 5 V / div.

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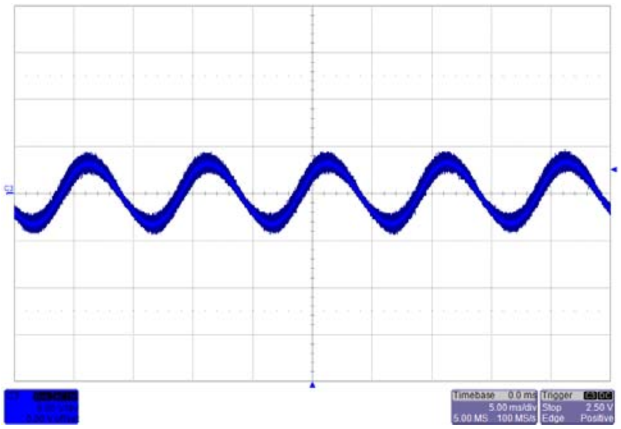

Figure 60 – Ripple, 230 VAC, 50% Load.
5 ms, 5 V / div.

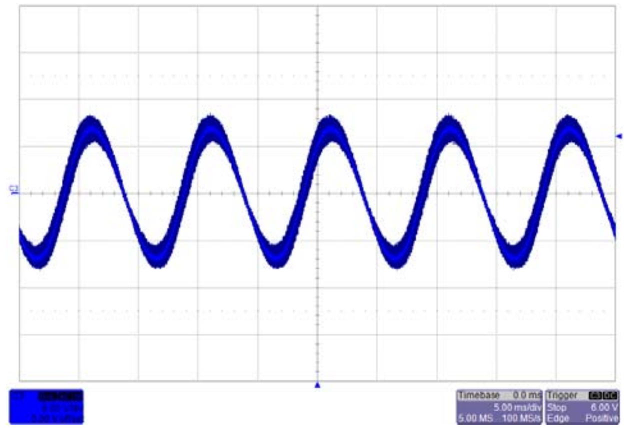

Figure 61 – Ripple, 230 VAC, 100% Load.
5 ms, 5 V / div.

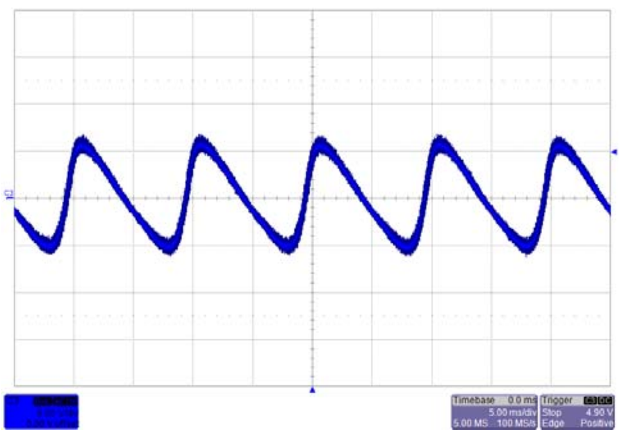

Figure 62 – Ripple, 264 VAC, 50% Load.
5 ms, 5 V / div.

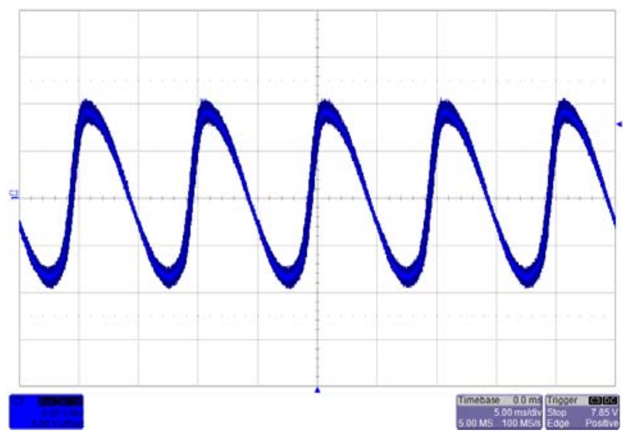

Figure 63 – Ripple, 264 VAC, 100% Load.
5 ms, 5 V / div.

11 Gain–Phase Measurement Procedure and Results

- The PFC stage is supplied form an adjustable DC source for this test. Connect the circuit as shown in Figure 64. Open the top end of the feedback divider network and insert a 100Ω–2W resistor in series as shown. The signal injected in the loop for gain–phase measurement will be injected across this resistor.
- Nodes A and B (two ends of the injection resistor) are connected to Channel 1 and Channel 2 of the frequency response analyzer using high voltage x100 attenuator probes. GND leads of both probes are connected to output return as shown.
- The signal to be injected is isolated using the Bode–Box injection transformer model – 200–000 from Venable Industries.

Test Procedure:

- Adjust the input voltage to 150 VDC and confirm that the PFC output voltage is within regulation limits.
- Inject a signal from the frequency response analyzer.
- The injected signal can be seen in the output voltage ripple of the PFC.
- Plot the gain phase pot by sweeping the injected signal frequency from 3 Hz to 90 Hz

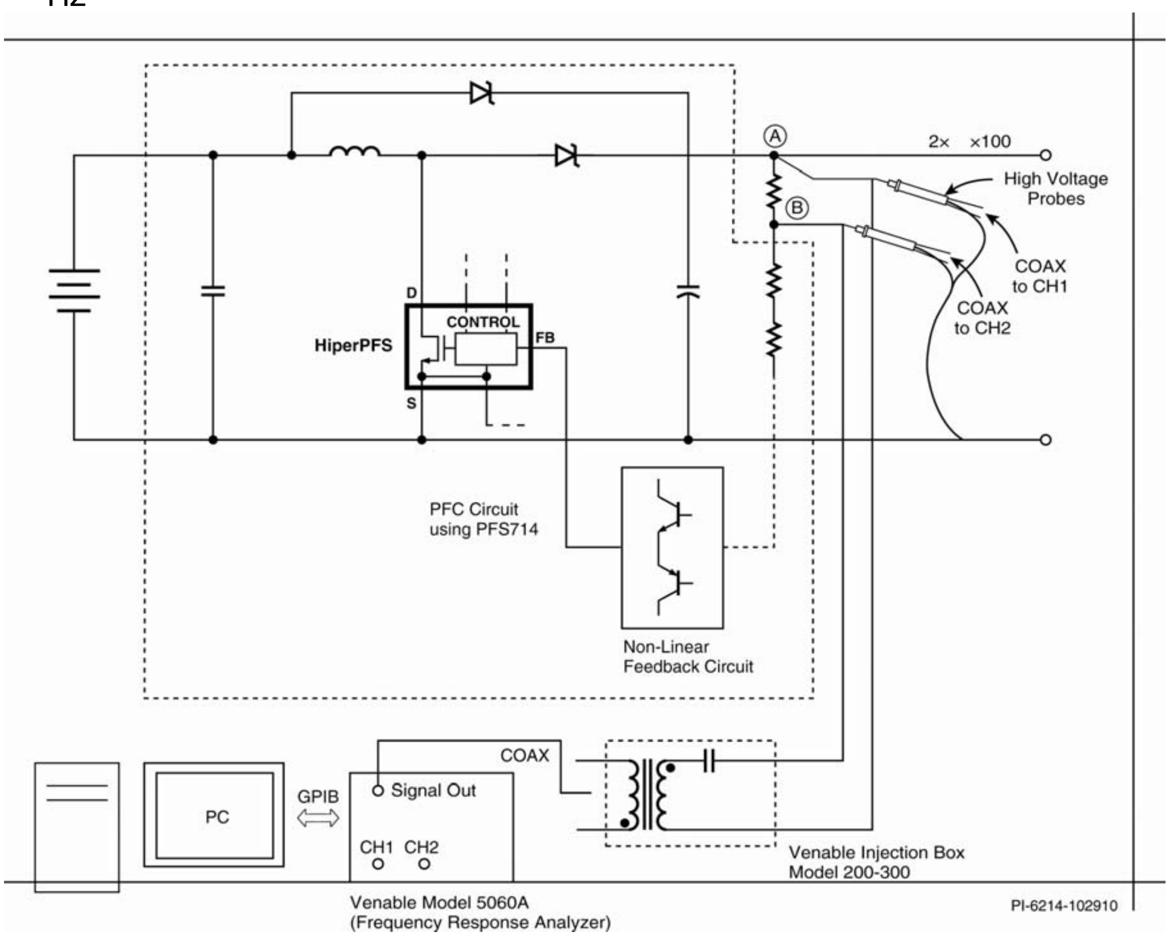

Figure 64 – System Test Setup for Loop Gain–Phase Measurement.

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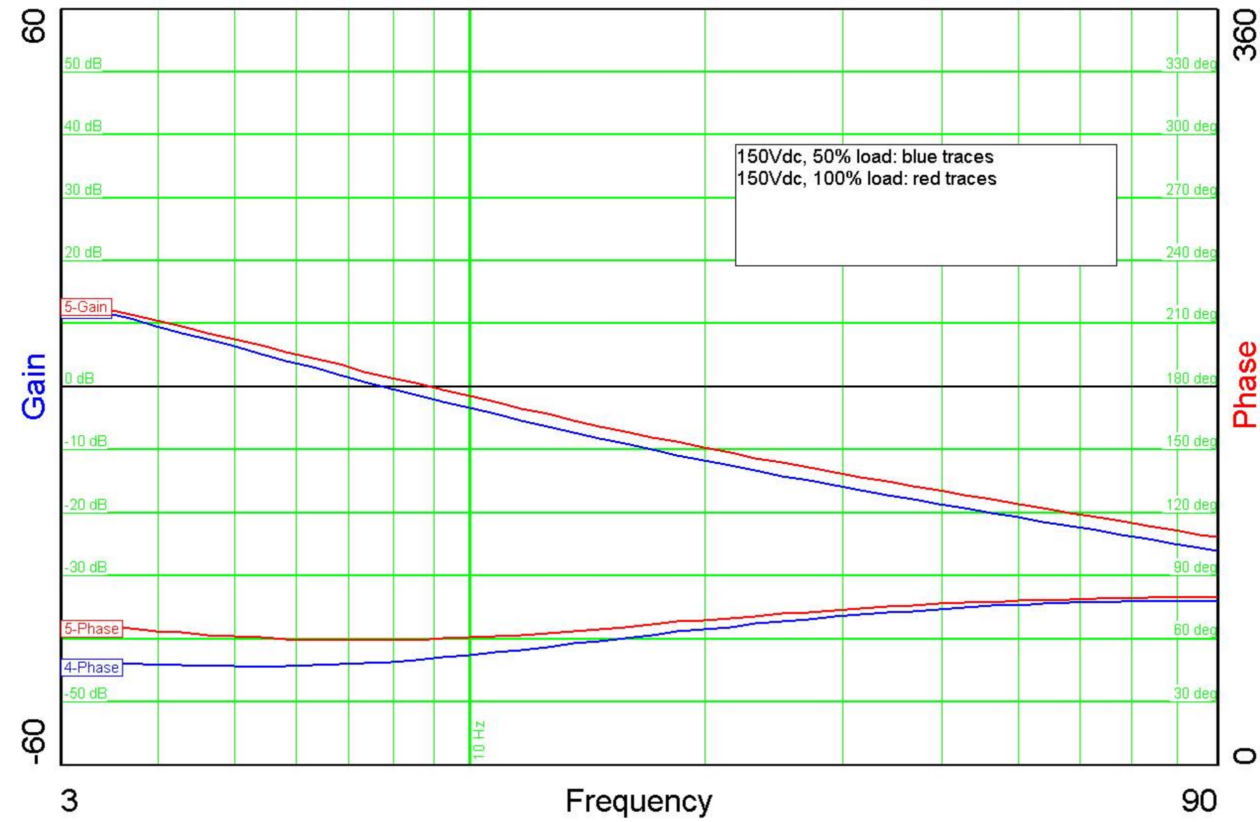

Figure 65 – Bode Plot with 150 VDC, 50% and 100% Load.

Note: phase margin is greater than 45 deg.

12 Line Surge Test

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Results (Pass/Fail # Strikes)
C.M.		**(12Ω source)**		**10 Strikes each Level**
+500	230	L1 to PE	90	Pass
–500	230	L1 to PE	270	Pass
+500	230	L2 to PE	270	Pass
–500	230	L2 to PE	90	Pass
+500	230	L1, L2 to PE	90[1]	Pass
–500	230	L1, L2 to PE	90	Pass
D.M.		**(2Ω source)**		
+500	230	L1 to L2	90[2]	Pass
–500	230	L1 to L2	270	Pass
C.M.		**(12Ω source)**		
+1000	230	L1 to PE	90	Pass
–1000	230	L1 to PE	270	Pass
+1000	230	L2 to PE	270	Pass
–1000	230	L2 to PE	90	Pass
+1000	230	L1, L2 to PE	90[1]	Pass
–1000	230	L1, L2 to PE	90	Pass
D.M.		**(2Ω source)**		
+1000	230	L1 to L2	90[2]	Pass
–1000	230	L1 to L2	270	Pass
C.M.		**(12Ω source)**		**10 Strikes each Level**
+1500	230	L1 to PE	90	Pass
–1500	230	L1 to PE	270	Pass
+1500	230	L2 to PE	270	Pass
–1500	230	L2 to PE	90	Pass
+1500	230	L1, L2 to PE	90[1]	Pass
–1500	230	L1, L2 to PE	90	Pass
C.M.		**(12Ω source)**		**10 Strikes each Level**
+2000	230	L1 to PE	90	Pass
–2000	230	L1 to PE	270	Pass
+2000	230	L2 to PE	270	Pass
–2000	230	L2 to PE	90	Pass
+2000	230	L1, L2 to PE	90[1]	Pass
–2000	230	L1, L2 to PE	90	Pass

[1] Note: 0° and 270° phase angle [relative to L1] was not tested; however, negative voltage polarity was performed at 90° phase angle for worst case total negative pulse on alternate phase [neutral].

[2] Note: 0° and 270° phase angle [relative to L1] was not tested on both polarities; however, negative voltage polarity was performed at 270° phase angle for worst case total negative pulse on alternate phase [neutral].

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13 EMI Scans

13.1 EMI Test Set-up

Use a plexi-glass board with complete copper coated on one side, connect the copper side of the board to test point TP8 with a wire clip. A RD-91 board was used here to provide V_{CC} input to RD-236 board. Both boards should sit on top of the plexi-glass board. Connect TP1/TP2 & TP6/TP7 test point pairs from RD-236 board to J1/J2 & J3/J4 test point pairs of the RD-91 board respectively. Connect the load to J2 2-pin header. All connections should be made as short as possible. See Figure 66 for set-up.

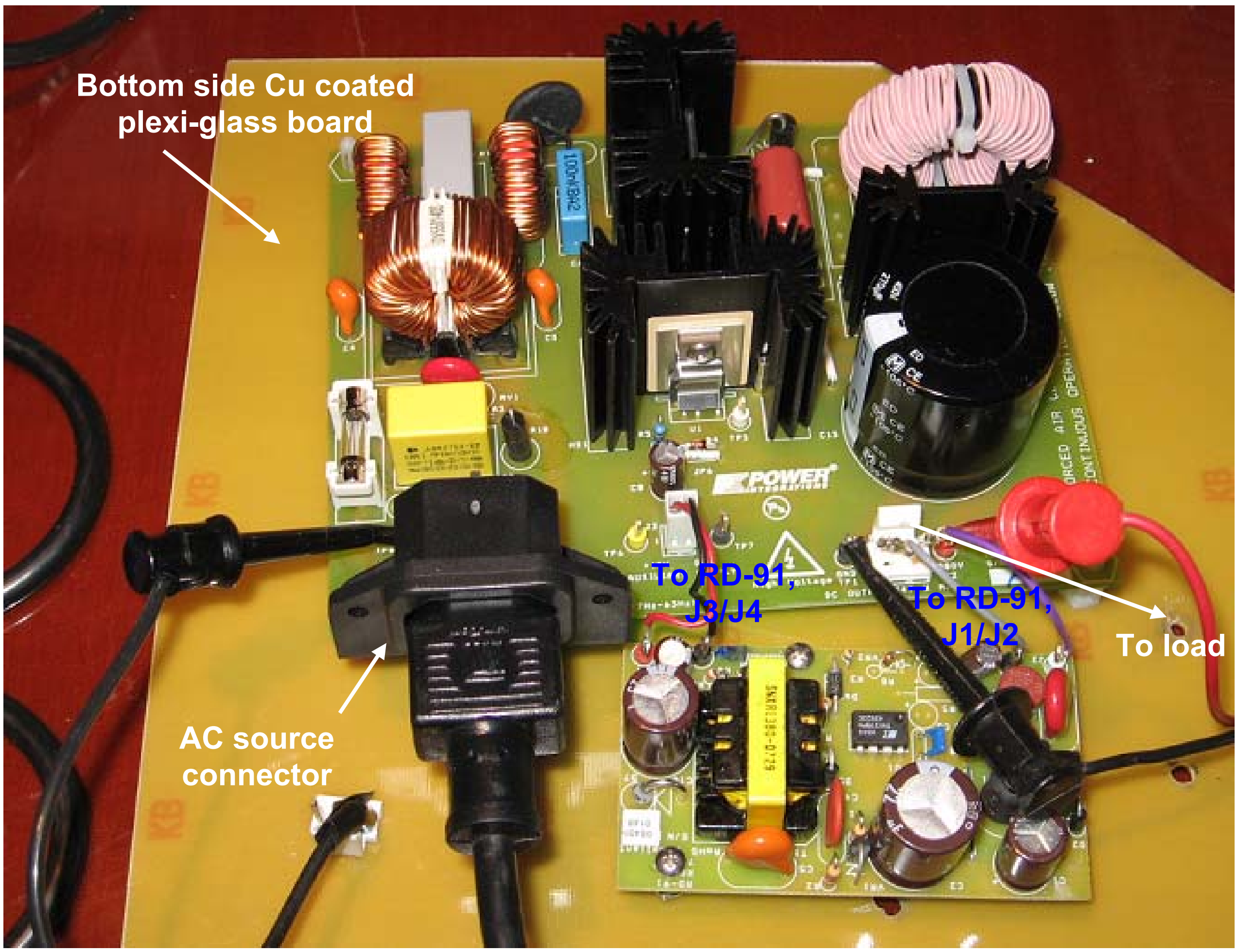

Figure 66 – EMI Test Set-up.

13.2 EMI Scans

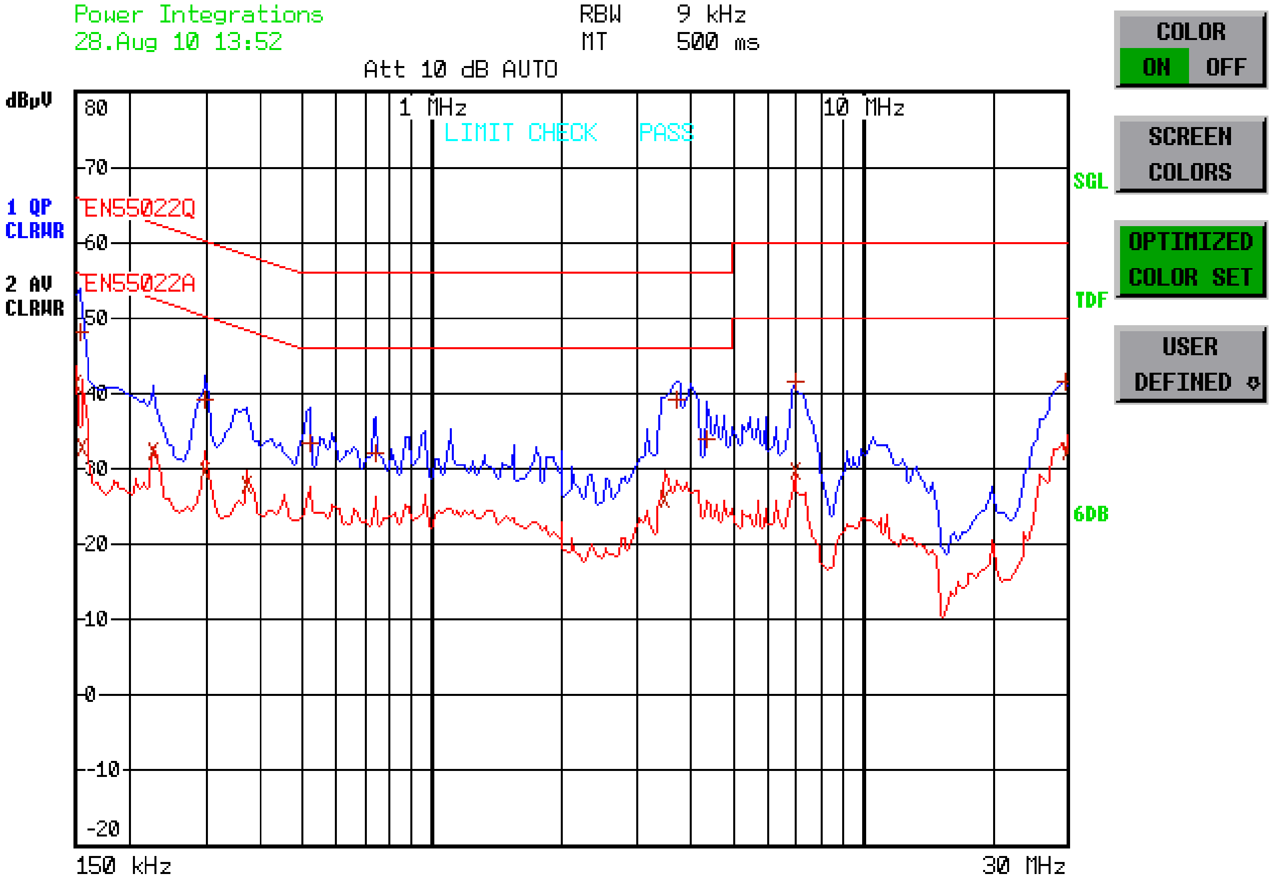

Figure 67 – 115 VAC, 100% Load.

Trace1:	EN55022Q
Trace2:	EN55022A
Trace3:	---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	150 kHz	41.38	L1 gnd	-14.61
1	Quasi Peak	153 kHz	48.13	L1 gnd	-17.70
2	Average	156.06 kHz	32.78	L1 gnd	-22.88
2	Average	227.349951585 kHz	32.24	N gnd	-20.30
1	Quasi Peak	299.983432899 kHz	39.09	N gnd	-21.14
2	Average	299.983432899 kHz	29.86	N gnd	-20.38
2	Average	372.991693411 kHz	27.77	N gnd	-20.66
1	Quasi Peak	522.278418129 kHz	33.32	N gnd	-22.67
1	Quasi Peak	745.942190883 kHz	32.10	N gnd	-23.90
2	Average	3.49557455365 MHz	26.18	N gnd	-19.81
1	Quasi Peak	3.70953168093 MHz	39.12	N gnd	-16.87
1	Quasi Peak	4.34630759308 MHz	33.84	N gnd	-22.15
1	Quasi Peak	6.99076303039 MHz	41.60	L1 gnd	-18.39
2	Average	6.99076303039 MHz	29.64	L1 gnd	-20.35
1	Quasi Peak	29.6713372241 MHz	41.47	L1 gnd	-18.52
2	Average	30 MHz	32.41	L1 gnd	-17.59

Figure 68 – 115 VAC, 100% Load EMI Measurement Results.

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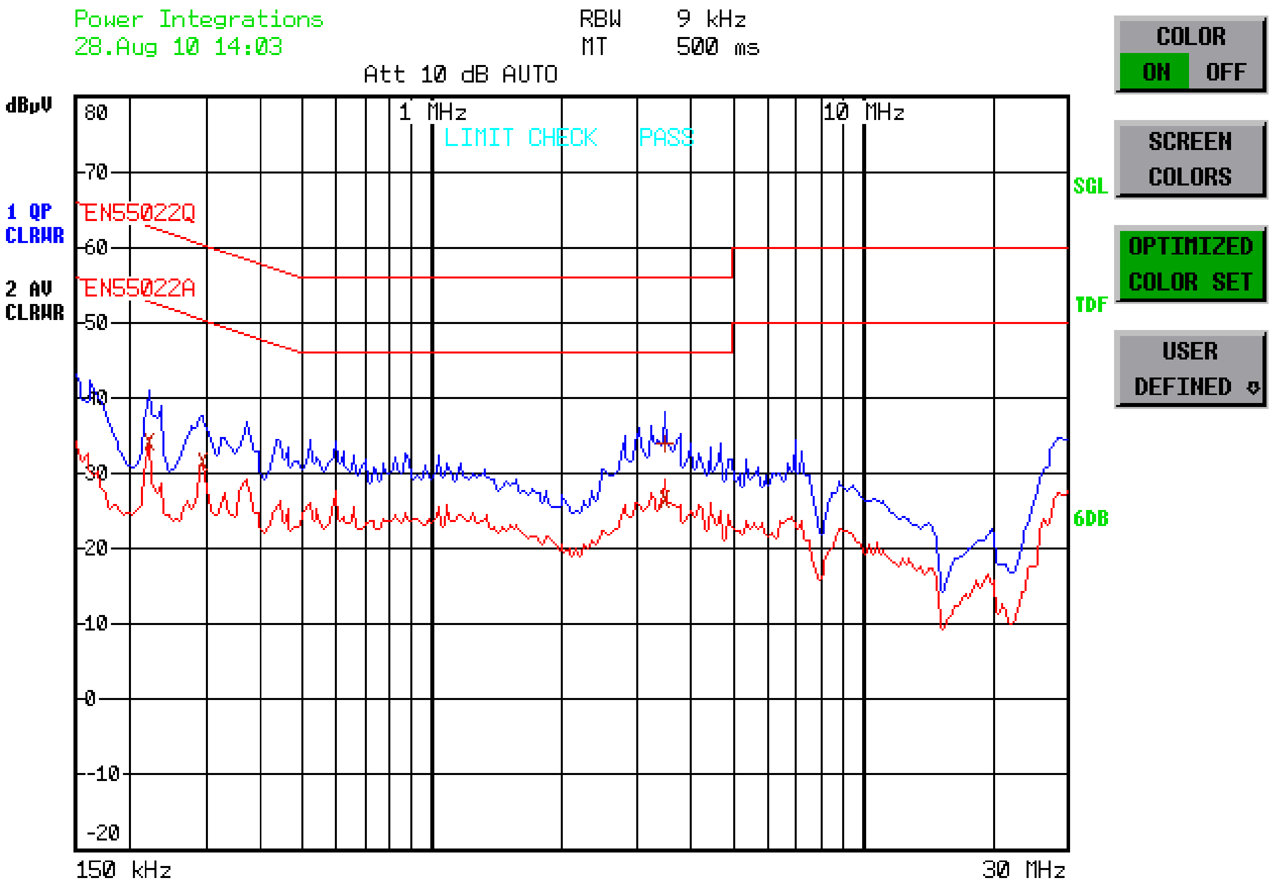

Figure 69 – 230 VAC, 100% Load.

Trace1:	EN55022Q		
Trace2:	EN55022A		
Trace3:	---		
TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2 Average	222.892109397 kHz	34.13 N gnd	-18.57
2 Average	294.101404803 kHz	31.65 N gnd	-18.75
1 Quasi Peak	3.49557455365 MHz	33.89 N gnd	-22.11
2 Average	3.49557455365 MHz	26.64 N gnd	-19.35

Figure 70– 230 VAC, 100% Load EMI Measurement Results

14 Appendix A – Efficiency with Other Diodes and Core Materials

Use of Silicon Carbide Schottky diodes for PFC output can provide higher efficiency. Graph below shows efficiency improvement due to use of C3D06060A instead of the ultrafast STTH8S06D diode.

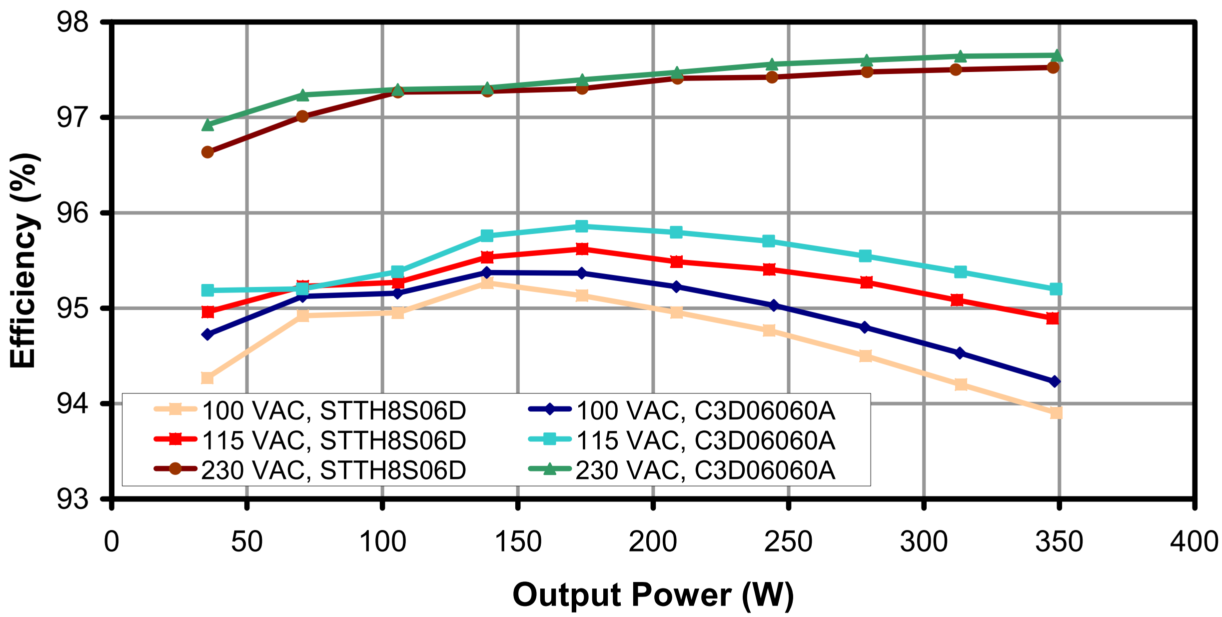

Figure 71 – Efficiency, Silicon Carbide Schottky C3D06060A vs. Ultra Fast STTH8S06D (Reference) Diode.

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Choice of inductor material and inductor design affects PFC efficiency at light load. At lighter load levels, the PFC runs in discontinuous mode for significant portion of the input waveform which increases core losses. The example below shows effect of change of core material.
77324 is Magnetics Inc. Kool-Mu Material
55324 is Magnetics Inc. MPP Material
58324 is Magnetics Inc. High flux Material

Material choice is often a price / performance tradeoff.

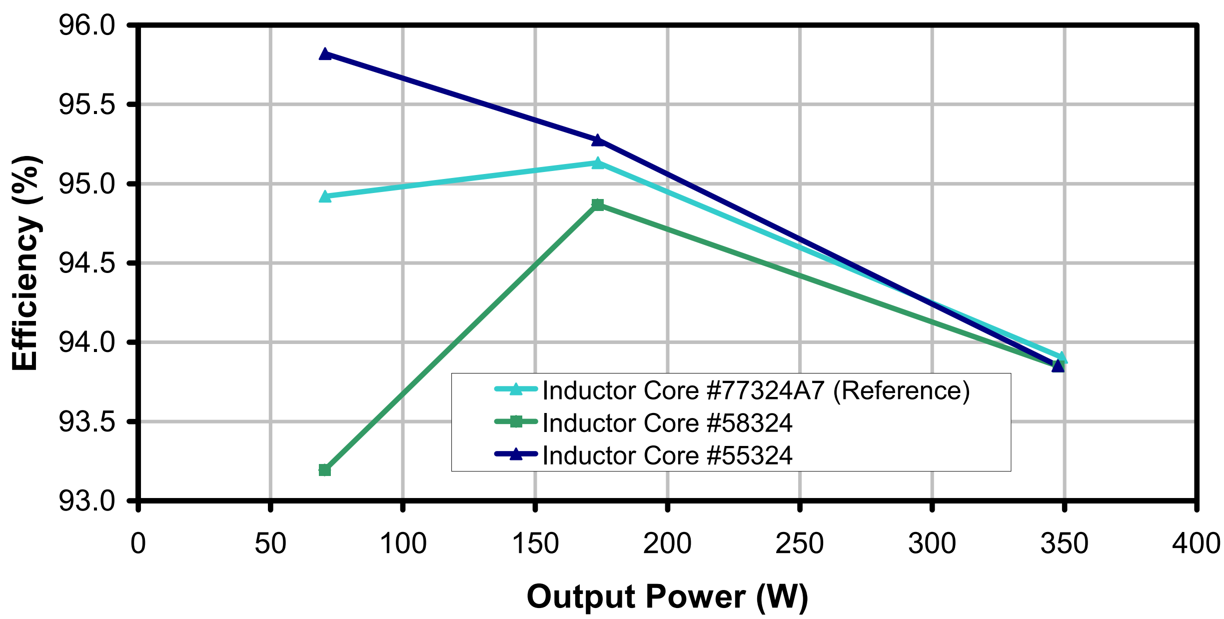

Figure 72 – Efficiency with Other Inductor Cores at 100 VAC.

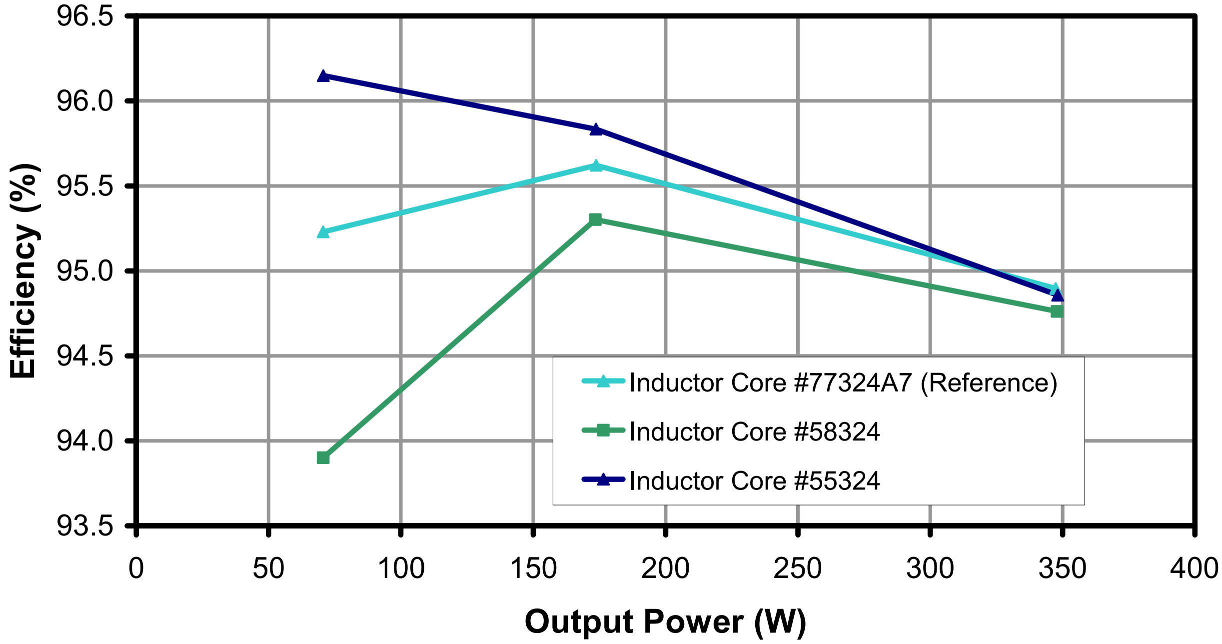

Figure 73 – Efficiency with Other Inductor Cores at 115 VAC.

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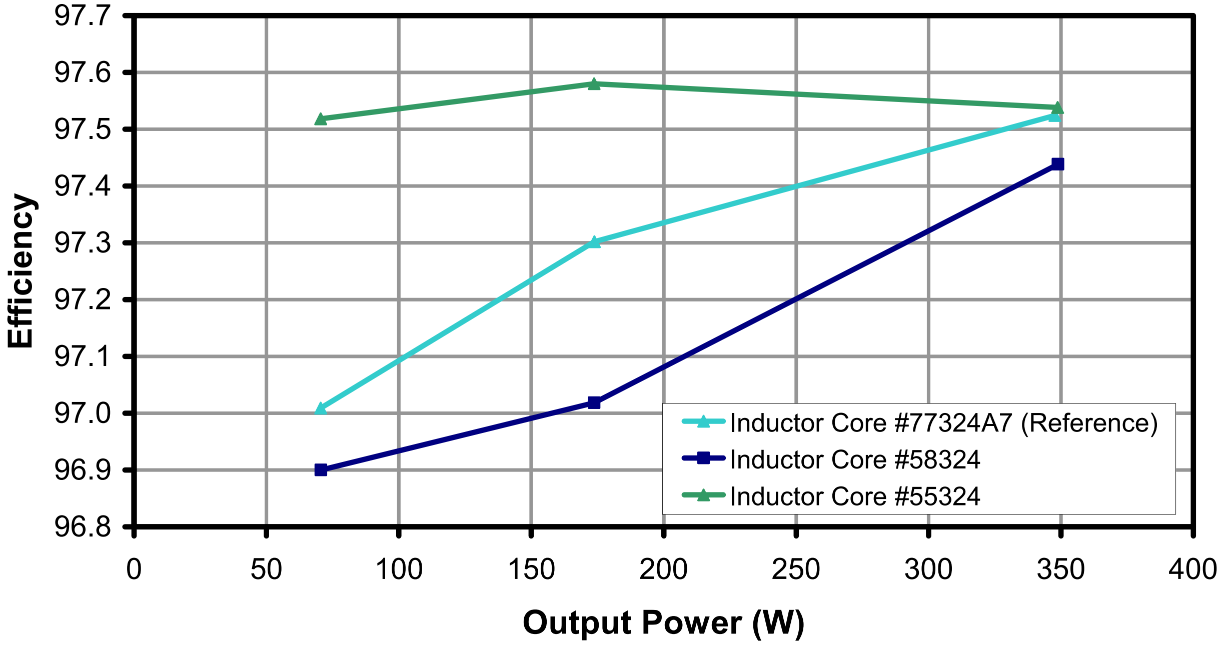

Figure 74 – Efficiency with Other Inductor Cores at 230 VAC.

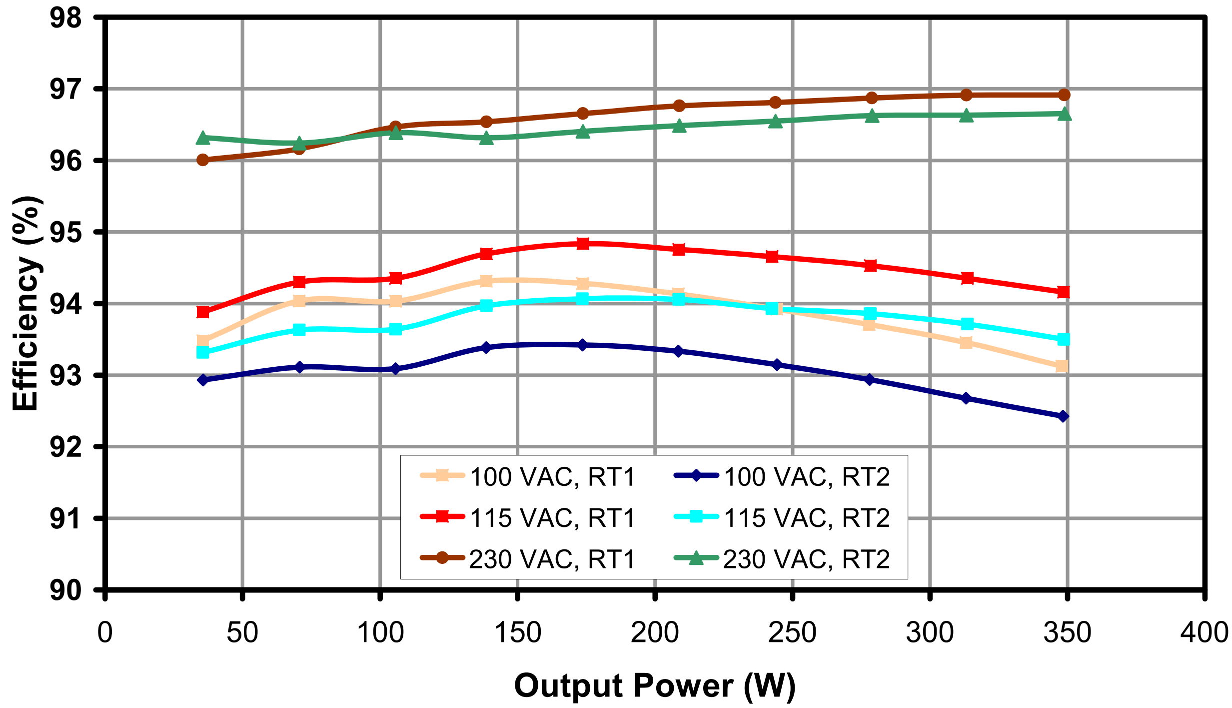

Figure 75 – Efficiency with Thermistor RT1 or RT2 in Circuit vs. Output Power.

Note: this is the PFC efficiency plot with thermistor RT1 in–circuit (RT1 shorting pads open and RT2 pads shorted), and thermistor RT2 in–circuit (RT2 pads open and RT1 pads shorted). The additional voltage drop in series with diode D2 or input line due to thermistor RT1 and RT2 degrade efficiency. By default, RT1 is shorted on the RD–236 board when shipped.

Note: In most applications, a relay will be used to bypass the thermistor RT2 after start up in order to improve system efficiency.

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15 Appendix B – Test Set-up for Efficiency Measurement

RD-236 is designed for continuous operation with full load only for a nominal voltage of 115 VAC. For performance evaluation at input voltage levels below the nominal input voltage, forced air cooling is necessary.

The following setup is recommended for system efficiency, PF and THD measurements. A 4.75” diameter AC fan is placed about 3” away from the right-side edge of the RD-236 bard, in high speed position. Use high resolution meters for output current and output voltage measurements. See figures below for board and fan positions

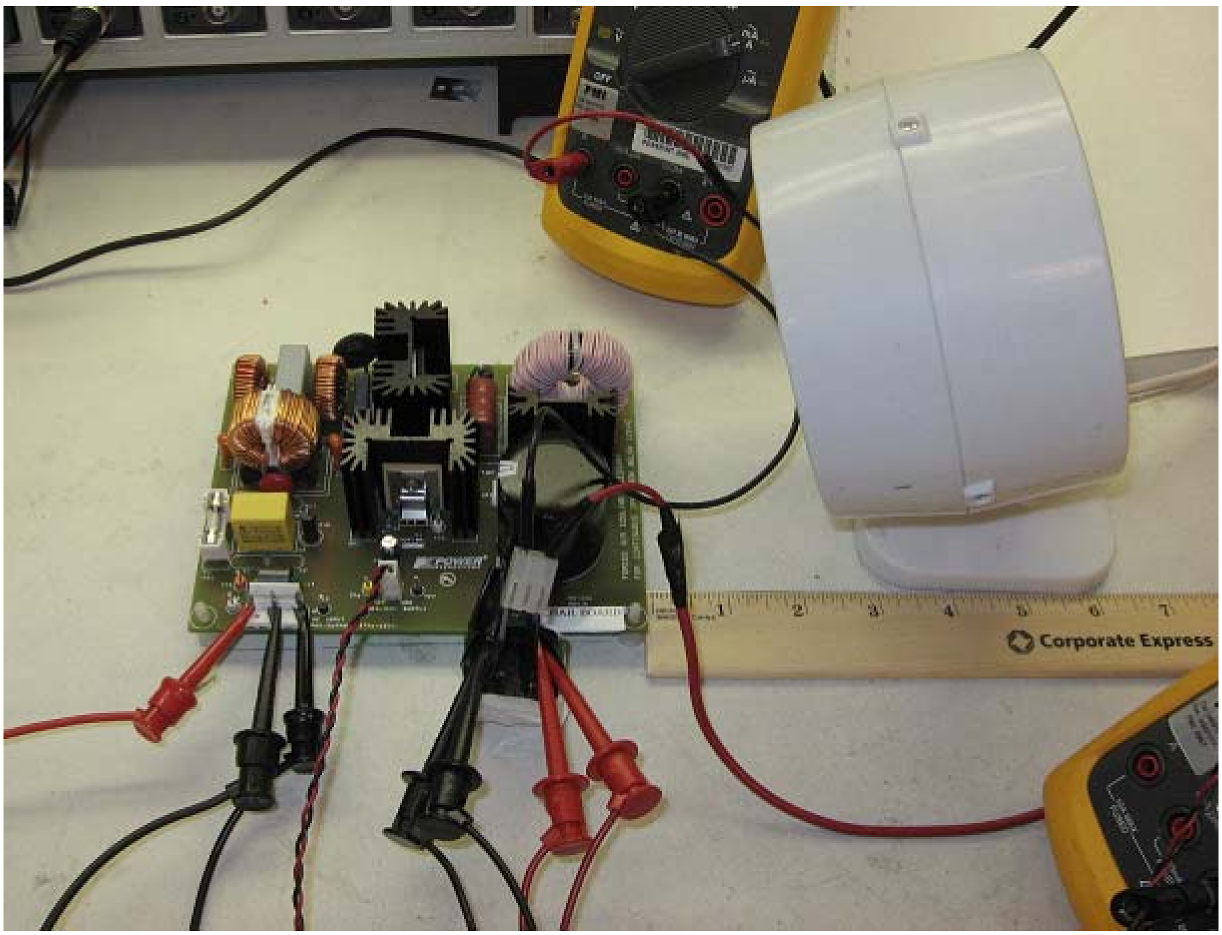

Figure 76 – Front View of the Test Setup for Efficiency, PF and THD Measurements.

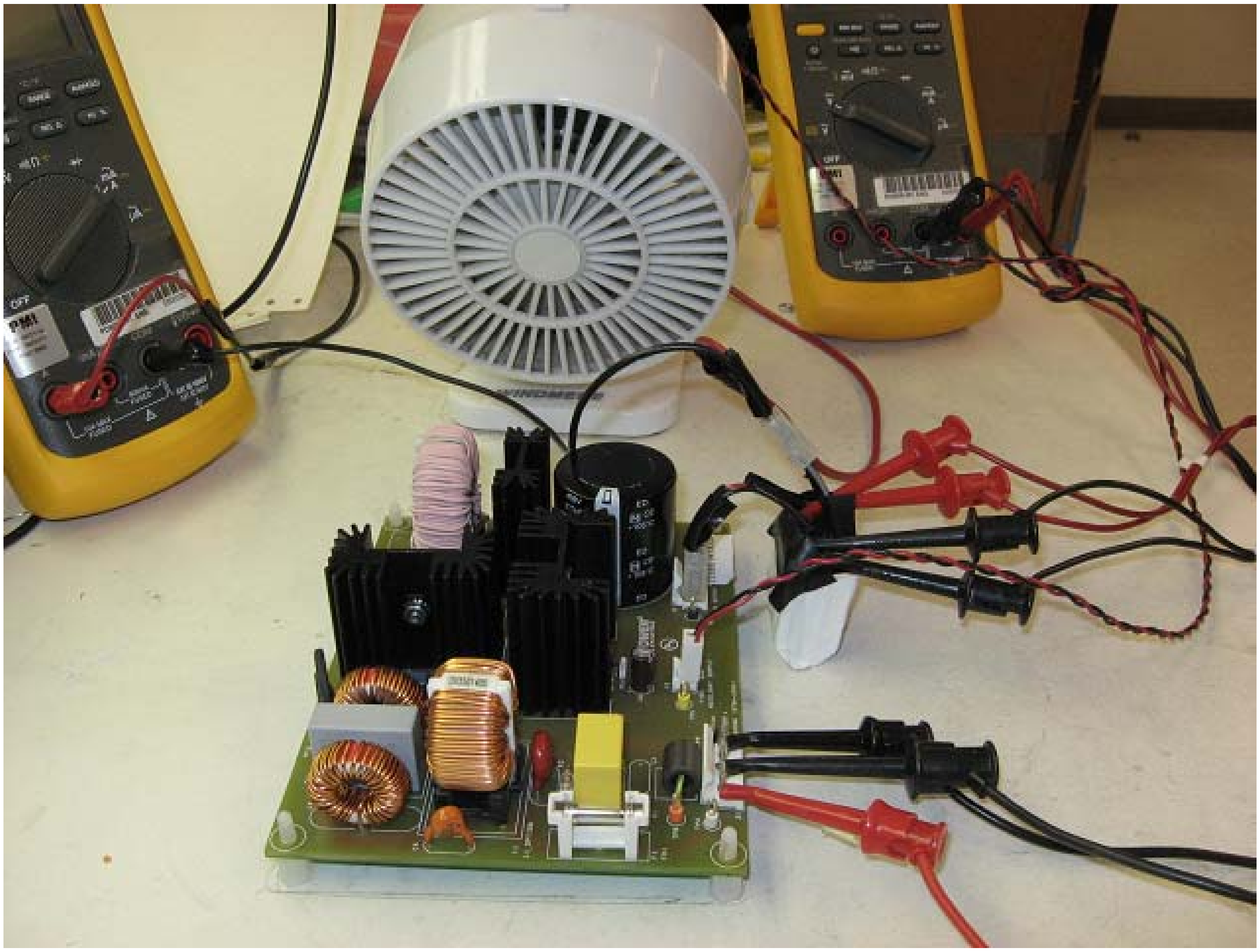

Figure 77 – Side View of the Test Setup for Efficiency, PF and THD Measurements.

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16 Appendix C – Inductor Current Measurement Set-up

The output inductor current can be measured at jumper JP5 location. Simply replace JP5 with a very short wire–loop in order to insert the current probe. Attach the oscilloscope probe directly at the D and S pins of IC U1 at the bottom side of the board, as shown in Figure 79, to measure drain–source voltage. See figure below for set-up.

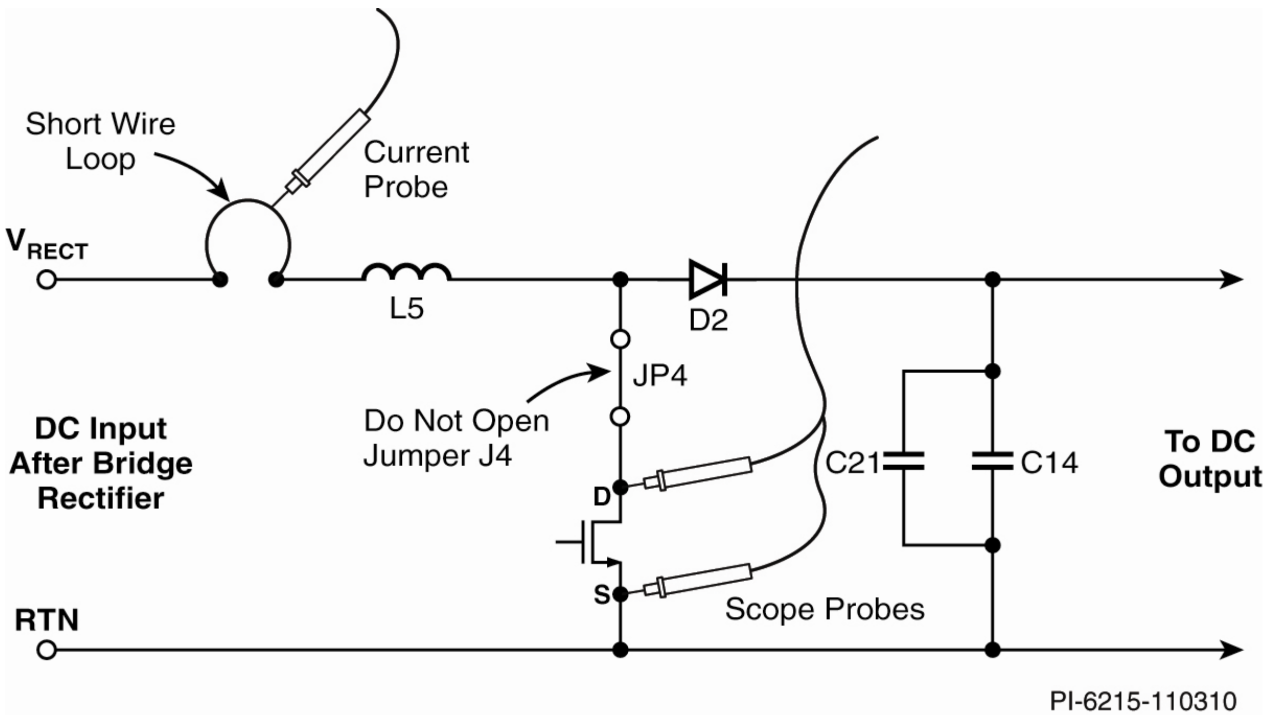

Figure 78 – Current Probe and Scope Probe Jack Insertion Locations.

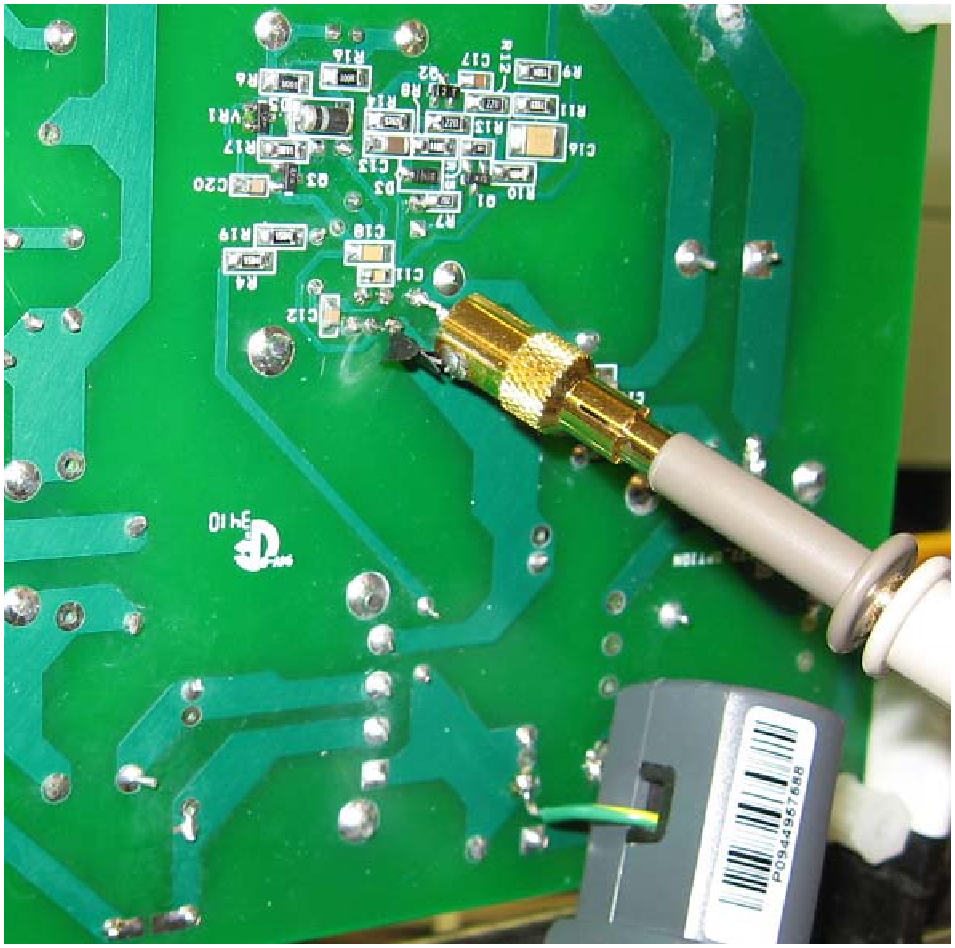

Figure 79 – Inductor Current and Drain Source Voltage Measurements Set-up.

MOSFET drain current is same as inductor current when the MOSFET inside HiperPFS is on. When the MOSFET turns OFF, inductor current is same as diode current. When the MOSFET is ON, the inductor current has a positive slope. When the MOSFET is OFF, the inductor current slope is negative. Information about the drain current and shape of drain current can be obtained from the inductor current waveform. This is a safe and recommended method to measure drain current of the MOSFET.

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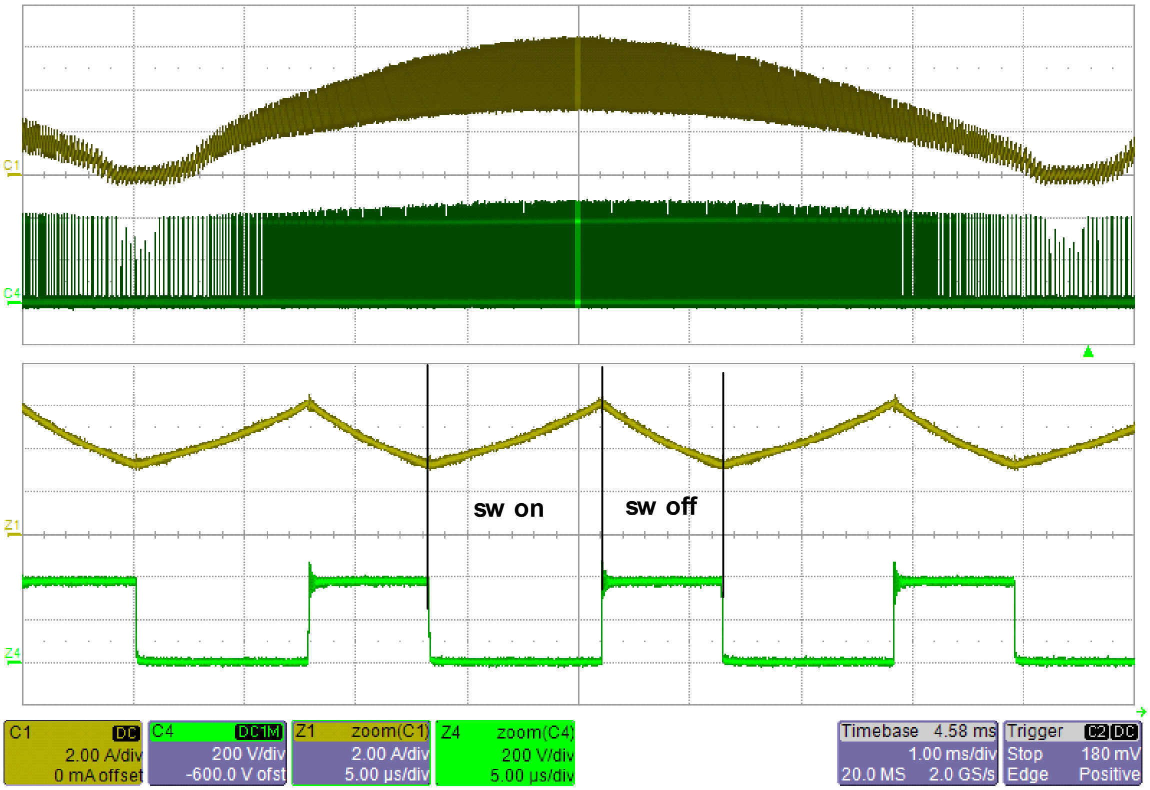

Figure 80 – 115 VAC, 100% Load.
Top: Inductor Current, 2 A / div.
Bottom: Drain Voltage, 200 V / div.
Zoom Top: Inductor Current, 2 A, 5 µs / div.
Zoom Bottom: Drain Voltage, 200 V / div., 5 µs / div.

17 Revision History

Date	Author	Revision	Description and changes	Reviewed
09-Nov-10	EJ	1.0	Initial Release	Apps and Mktg
18-Nov-10	KM	1.1	Minor corrections	Apps and Mktg

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