Design Example Report

Title	***900 W PFC Stage Using HiperPFS™ PFS729EG***
Specification	180 VAC – 264 VAC Input; 380 VDC Output
Application	PFC Front End Stage
Author	Application Engineering Department
Document Number	DER-274
Date	May 12, 2011
Revision	1.0

Summary and Features

- Low component count, high performance PFC
- EN61000-3-2 Class-D compliance with low component count
- High PFC efficiency enables 80 Plus 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 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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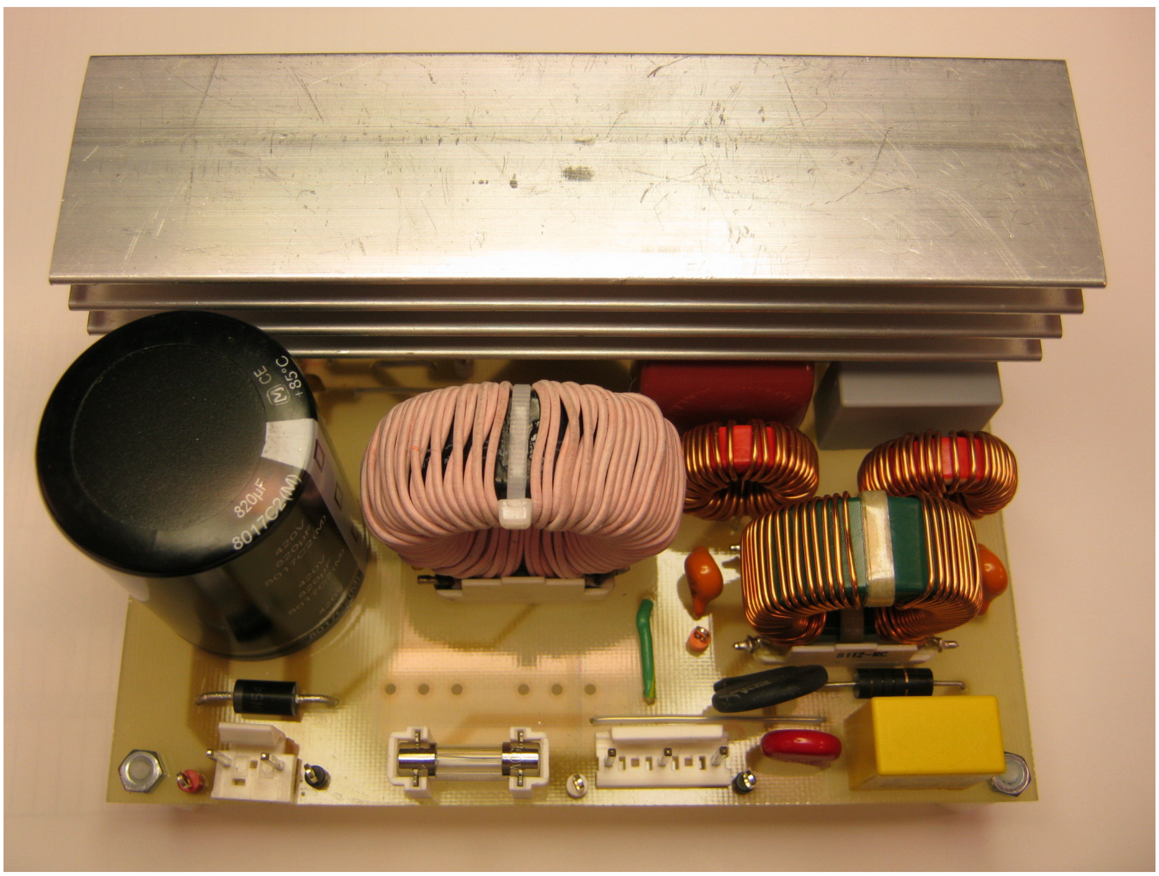
1 Introduction

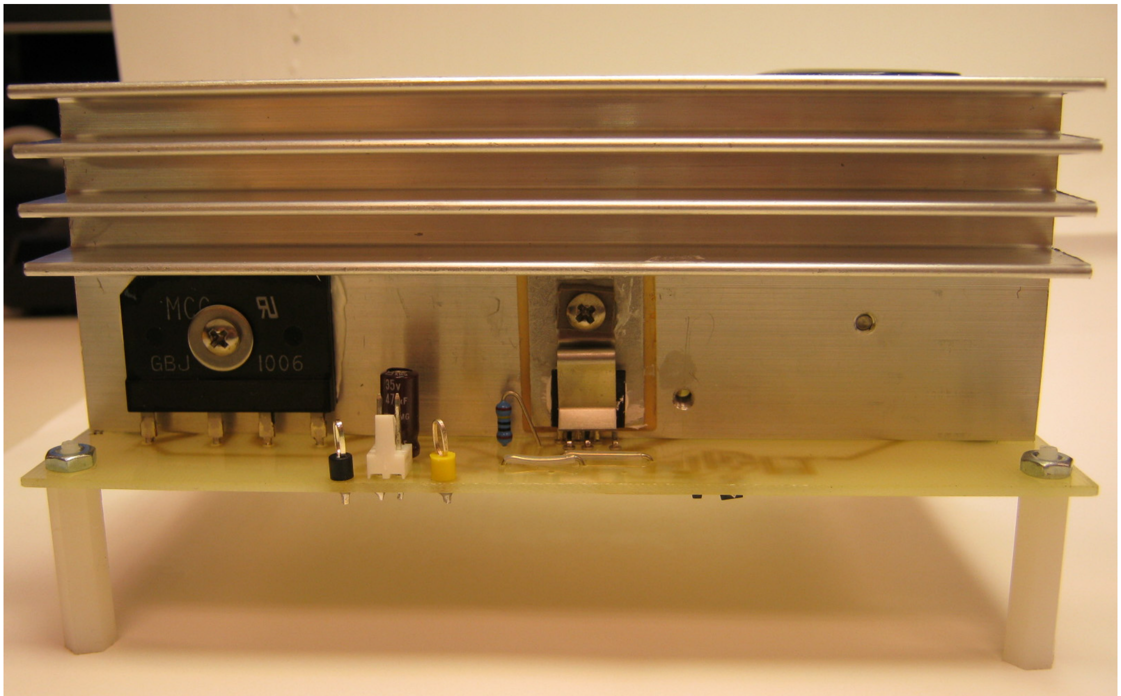
This document is an engineering report describing a PFC power supply utilizing a HiperPFS PFS729EG integrated PFC controller. This power supply is intended as a general purpose evaluation platform that operates from 180 VAC to 264 VAC input and provides a regulated 380 VDC output voltage and a continuous output power of 900 W.

This power supply can deliver the rated power at 230 VAC or higher input voltages at a room temperature of 25 ºC. For operation at higher ambient temperatures or lower input voltages, use of forced air cooling is recommended.

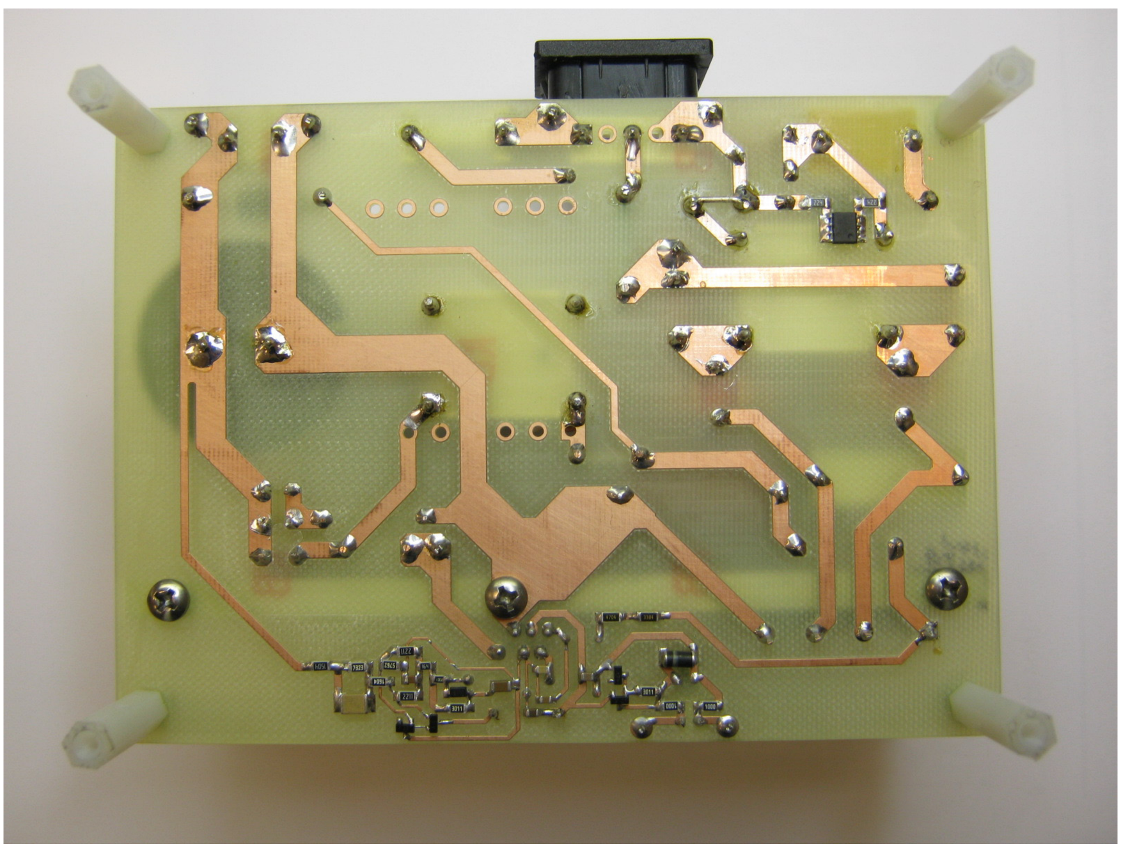
The document contains the power supply specification, schematic, bill of materials, inductor documentation, printed circuit layout, and performance data.



(a) Front View.



(b) Back View.



(c) Bottom View.

Figure 1 – Populated Circuit Board Photograph. (a) Front View; (b) Back View; (c) Bottom View.

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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}	180		264	VAC	3 Wire
Frequency	f_{LINE}	47	50	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}		2.3		A	
Total Output Power						
Continuous Output Power	P_{OUT}		900		W	
Efficiency						
Full Load	η	97			%	Measured at P_{OUT} 25 °C
Minimum efficiency at 20, 50 and 100 % of P_{OUT}	η_{80+}	97			%	Measured at 230 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} < 230 V, sea level
Auxiliary Supply Input						
Auxiliary Supply	V_{AUX}	15		24	V	DC Supply

3 Schematic

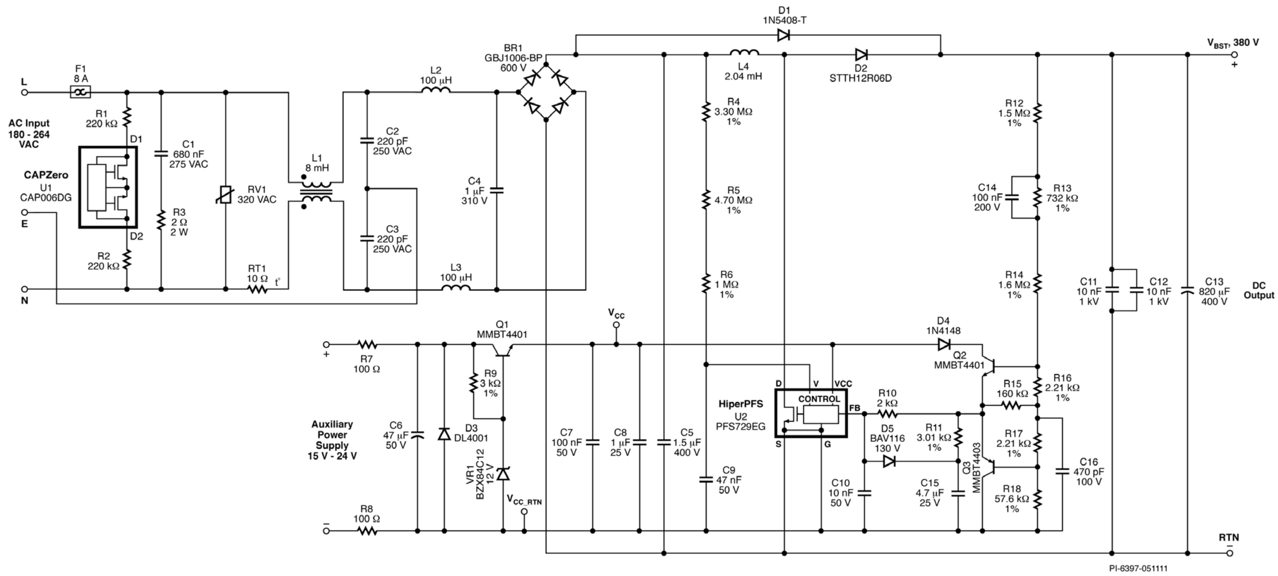

Figure 2 – Schematic.

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4 Circuit Description

This PFC circuit is designed using Power Integration's HiperPFS PFS729EG integrated PFC controller. This design is rated for a continuous output power of 900 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 Filtering 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 C1, C2, C3, and C4 together with inductors L1, L2 and L3 form the EMI filter reducing the common mode and differential mode noise. Resistors R1, R2 and CAPZero, IC U1 are required to discharge the EMI filter capacitors once the circuit is disconnected. High frequency decoupling capacitor C5 after the bridge reduces the loop area of the high frequency loop and helps reduce the noise coupled into the input wires. Resistor R3 connected in series with capacitor C1 provides damping. Metal Oxide Varistor RV1 is placed across AC power lines to provide differential mode surge protection.

4.2 PFS729EG Boost Converter

The boost converter stage consists of inductor L4, diode rectifier D2 and the PFS729EG IC U2. This converter stage works as a variable frequency continuous conduction mode boost converter and controls the input current of the power supply while simultaneously regulating the output DC voltage. Diode D1 prevents a resonant buildup of output voltage at start-up by bypassing inductor L4 while simultaneously charging output capacitor C13. Thermistor RT1 limits the inrush current of the circuit at start-up. In higher performance (efficiency) power supplies, this thermistor is shorted after start-up using a relay. Efficiency measurements should therefore be taken with RT1 shorted to obtain maximum efficiency data. Capacitors C11 and C12 are used for reducing the loop length and area of the output circuit to reduce EMI and overshoot of the voltage across the drain and source of the MOSFET inside U2 at each switching instant.

4.3 Bias Supply Regulator

The PFS729EG IC requires a regulated supply of 12 V for operation. Should this supply exceed 13.4 V, the IC could be damaged. Resistors R7, R8, R9, Zener diode VR1, and transistor Q1 form a shunt regulator that prevents the supply voltage to IC U2 from exceeding 12 V. Capacitors C6, C7 and C8 filter the supply voltage to ensure reliable operation of IC U2. Diode D3 protects the circuit against accidental reversal of polarity of the bias supply.

4.4 Input Feed Forward Sense Circuit

The input voltage of the power supply is sensed by the IC U2 using resistors R4, R5 and R6. The capacitor C9 filters any noise on this signal.

4.5 Output Feedback

Divider network comprising of resistors R12, R13, R14, R16, R17 and R18 are used to scale the output voltage and provide a feedback to the IC U2. Capacitor C14 provides soft-finish to prevent output voltage overshoot at start-up. Capacitor C16 filters out any noise coupled into the feedback divider network. The circuit comprising of diode D4, transistor Q2, Q3 and the resistors R16 and R17 forms a non-linear feedback circuit which improves the transient (load) response by improving the response time of the PFC circuit, under large signal condition (e.g. full to no-load step).

Resistor R10, R11, R15 and capacitors C15 and C10 are required for shaping the loop response of the feedback circuit. The combination of resistor R11 and capacitor C15 provide a low frequency zero. Diode D5 protects against the single point fault condition of C15 short-circuited. Diode D5 ensures that during this single-fault condition, the FEEDBACK pin of IC U2 is pulled below the FB_{OFF} threshold, thereby, protecting the circuit by inhibiting switching.

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5 PCB Layout

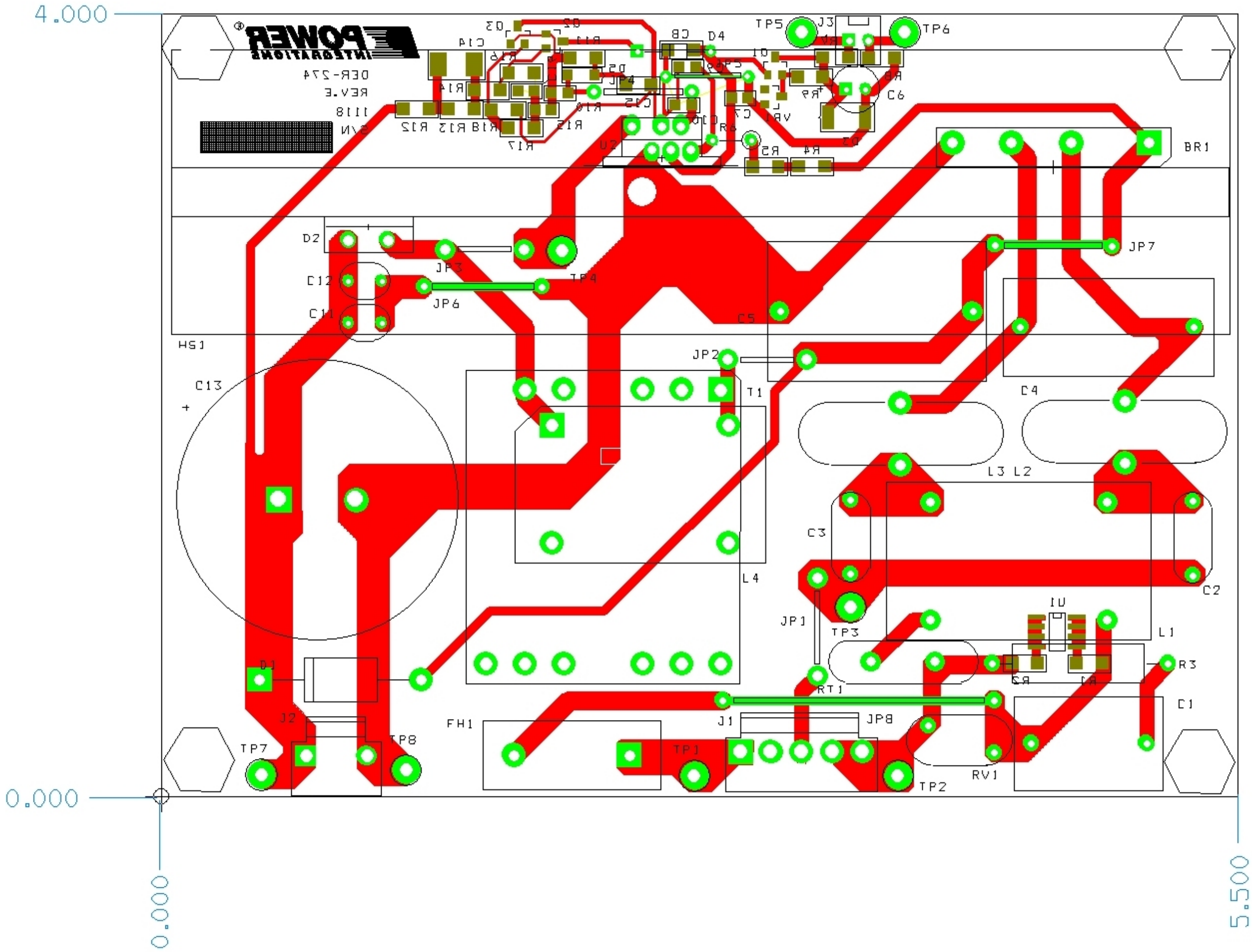

Figure 3 – Printed Circuit Layout (4" x 5.5").

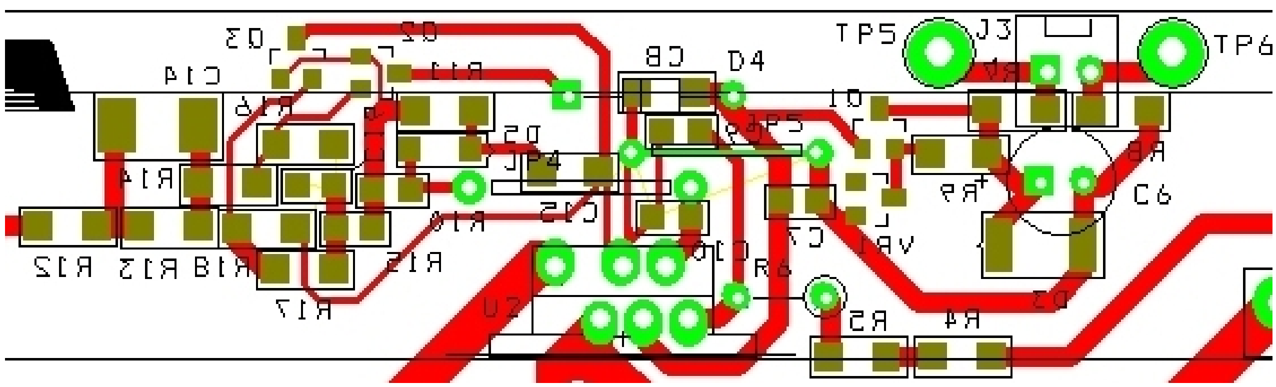

Figure 4 – Zoomed Portion of Printed Circuit Layout Showing HiperPFS.

6 Heat Sink Drawing

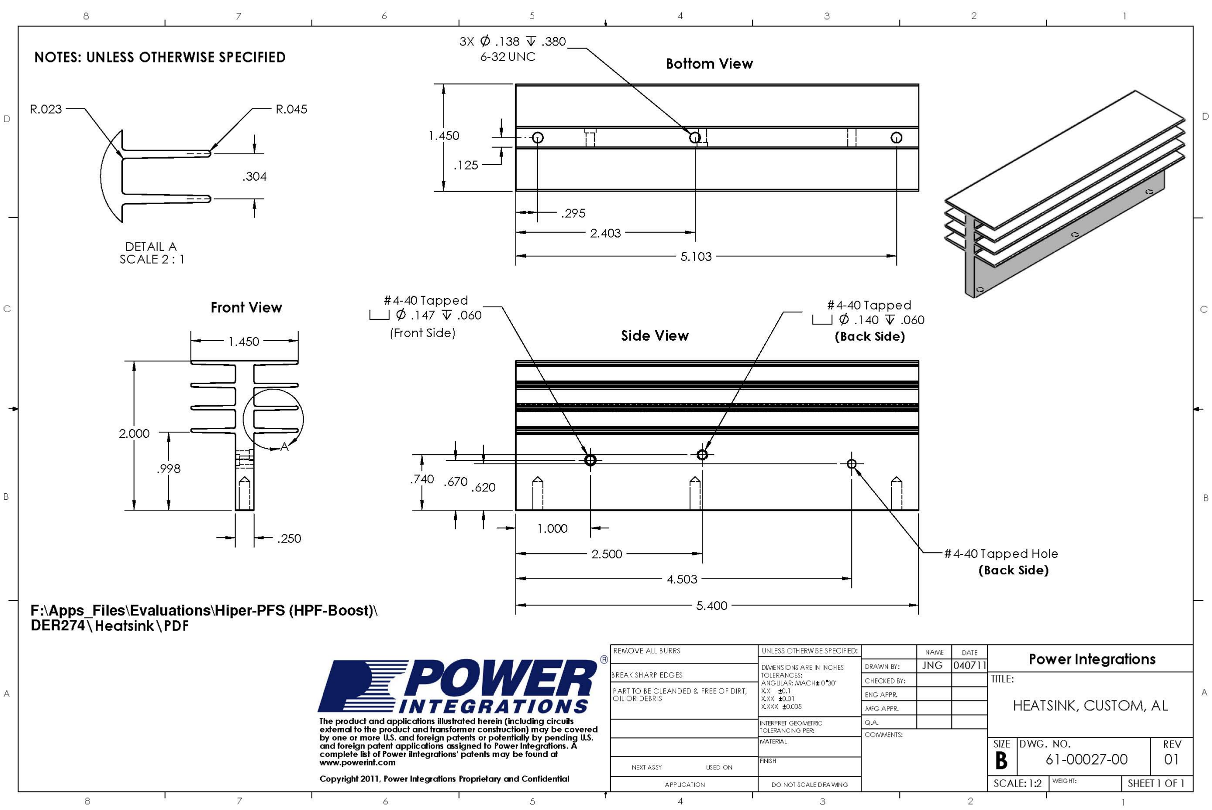

Figure 5 – Heat Sink Drawing.

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7 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 10 A, Bridge Rectifier, GBJ Package	GBJ1006-BP	Micro Commercial
2	1	C1	680 nF, 275 VAC, Film, MPX Series, X2	PX684K3ID6	Carli
3	2	C2 C3	220 pF, Ceramic Y1	440LT33-R	Vishay
4	1	C4	1 μF, 310 VAC, Polyester Film, X2	BFC233820105	BC components
5	1	C5	1.5 μF, 400 V, Polypropylene Film	ECW-F4155JB	Panasonic
6	1	C6	47 μF, 50 V, Electrolytic, (6.3 x 11)	EKMG500ELL470MF11D	Nippon Chemi-Con
7	1	C7	100 nF, 50 V, Ceramic, X7R, 0805	C2012X7R1H104K	TDK
8	1	C8	1 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK
9	1	C9	47 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H473K	Panasonic
10	1	C10	10 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H103K	Panasonic
11	2	C11 C12	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
12	1	C13	820 μF, 420 V, Electrolytic, TS-UQ, (35 x 30)	EET-UQ2S821LA	Panasonic
13	1	C14	100 nF, 200 V, Ceramic, X7R, 1812	18122C104KAT2A	AVX
14	1	C15	4.7 μF, 25 V, Ceramic, X7R, 1206	ECJ-3YB1E475M	Panasonic
15	1	C16	470 pF, 100 V, Ceramic, X7R, 0805	08051C471KAT2A	AVX
16	1	D1	1000 V, 3 A, Recitifier, DO-201AD	1N5408-T	Diodes, Inc.
17	1	D2	600 V, 12 A, Ultrafast Recovery, 45 ns, TO-220AC	STTH12R06D	ST Semi
18	1	D3	50 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4001-13-F	Diodes, Inc
19	1	D4	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
20	1	D5	130 V, 5%, 250 mW, SOD-123	BAV116W-7-F	Diodes Inc
21	1	ESIPCLIP M4 METAL1	Heat sink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk	NP975864	Aavid Thermalloy
22	1	F1	8 A, 250 V, Fast, 5 mm x 20 mm, Cartridge	0217008.HXP	Littelfuse
23	1	FH1	Fuse Holder Open 5 X 20 mm PC MNT	64900001039	Wickmann
24	1	HS1	Heat sink ,Custom, Al		AAVID
25	1	HSPREAD ER_ESIPP FISW1	Heat Spreader, Custom, Al, 3003, 0.030 in Thk	61-00040-00	Custom
26	1	J1	5 Position (1 x 5) header, 0.156 pitch, Vertical	26-64-4050	Molex
27	1	J2	CONN header 3 Position (1x3).156 Vertical TIN	26-64-4030	Molex
28	1	J3	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-23-2021	Molex
29	2	JP1 JP4	Wire Jumper, Insulated, TFE, #22 AWG, 0.5 in	C2004-12-02	Alpha
30	3	JP2 JP3 JP5	Wire Jumper, Insulated, TFE, #18 AWG, 0.4 in	C2052A-12-02	Alpha
31	2	JP6 JP7	Wire Jumper, Insulated, TFE, #22 AWG, 0.6 in	C2004-12-02	Alpha

32	1	JP8	Wire Jumper, Insulated, TFE, #18 AWG, 1.4 in	C2052A-12-02	Alpha
33	1	L1	8 mH, 5.6 A, Common Mode Choke,	8112-RC	JW Miller
34	2	L2 L3	100 μH, 5 A, Inductor TORD HI AMP 100 μH Vertical	7447070	Wurth
35	1	L4	Custom, 900 W PFC Inductor, 2.04 mH, constructed on Lodestone Pacific base PN VTM160-4		Custom
36	4	POST-CRKT_BRD_6-32_HEX1	Post, Circuit Board, Female, Hex, 6-32, snap, 0.375L, Nylon	561-0375A	Eagle Hardware
37	2	Q1 Q2	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401T-7-F	Diodes, Inc.
38	1	Q3	PNP, Small Signal BJT, 40 V, 0.6 A, SOT-23	MMBT4403-7-F	Diodes, Inc.
39	2	R1 R2	220 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ224V	Panasonic
40	1	R3	2 Ω, 1%, 2 W, Wire Wound	WNC2R0FET	Ohmite
41	1	R4	3.30 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF3304	Rohm Semi
42	1	R5	4.70 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF4704	Rohm Semi
43	1	R6	1 MΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-1M00	Yageo
44	2	R7 R8	100 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1000V	Panasonic
45	2	R9 R11	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
46	1	R10	2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ202V	Panasonic
47	1	R12	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
48	1	R13	732 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7323V	Panasonic
49	1	R14	1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1604V	Panasonic
50	1	R15	160 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ164V	Panasonic
51	2	R16 R17	2.21 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2211V	Panasonic
52	1	R18	57.6 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF5762V	Panasonic
53	1	RT1	NTC Thermistor, 10 Ω, 5 A	CL-60	GE Sensing
54	1	RTV1	Thermally Conductive Silicone Grease	120-SA	Wakefield
55	1	RV1	320 V, 23 J, 10 mm, RADIAL	V320LA10P	Littlefuse
56	3	SCREW1 SCREW2 SCREW3	Screw Machine Phil 4-40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners
57	1	T1	Bobbin, PQ35/35, Vertical, 12 pins	BQ35/35-1112CPFR	TDK
58	1	TO-220 PAD1	HEATPAD TO-247 .006" K10	K10-104	Bergquist
59	1	TO-220 PAD2	Thermal Pad TO-220 .009" SP1000	1009-58	Bergquist
60	2	TP1 TP4	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
61	3	TP2 TP6 TP8	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
62	1	TP3	Test Point, ORG, THRU-HOLE MOUNT	5013	Keystone
63	1	TP5	Test Point, YEL, THRU-HOLE MOUNT	5014	Keystone
64	1	TP7	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone

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65	1	U1	CAPZero, SO-8C	CAP006DG	Power Integrations
66	1	U2	HiperPFS, SIP7/6-TH	PFS729EG	Power Integrations
67	1	VR1	12 V, 5%, 225 mW, SOT23	BZX84C12LT1G	On Semi
68	1	WASHER1	Washer Teflon #6, ID 0.156, OD 0.312, Thk 0.031	FWF-6	See Distributor
69	1	WASHER2	Washer, Shoulder, #4, 0.095 Shoulder x 0.117 Dia, Polyphenylene Sulfide PPS	7721-10PPSG	Aavid Thermalloy
70	1	WASHER3	Washer Flat #4 SS	FWSS 004	Building Fasteners
71	1	WASHER4	Washer Flat #4 Zinc, OD 0.219, ID 0.125, Thk 0.032,Yellow Chromate Finish	5205820-2	Tyco
72	1	WASHER5	Washer Nylon Shoulder #4	3049	Keystone

8 Inductor Design Spreadsheet

ACDC_PFS_101210; Rev.1.0; Copyright Power Integrations 2010	INPUT	INFO	OUTPUT	UNITS	ACDC_HiperPFS_101210_Rev1-0.xls; Continuous Mode Boost Converter Design Spreadsheet
Enter Applications Variables					
Input Voltage Range	**High_Line**		**High_Line**		Select Universal or High_Line option
VACMIN			180	V	Minimum AC input voltage
VACMAX			264	V	Maximum AC input voltage
VBROWNIN			175.01		Expected Minimum Brown-in Voltage
VBROWNOUT			158.46	V	Specify brownout voltage.
VO	385			V	Nominal Output voltage
PO	900			W	Nominal Output power
fL			50	Hz	Line frequency
TA Max			40	deg C	Maximum ambient temperature
n	0.97	*Info*	0.97		!!! Info. Efficiency should be between 0.87 and 0.97
KP	0.420		0.42		Ripple to peak inductor current ratio at the peak of VACMIN
VO_MIN			365.75	V	Minimum Output voltage
VO_RIPPLE_MAX			20	V	Maximum Output voltage ripple
tHOLDUP			20	ms	Holdup time
VHOLDUP_MIN			310	V	Minimum Voltage Output can drop to during holdup
I_INRUSH			40	A	Maximum allowable inrush current
Forced Air Cooling	**No**		**No**		Enter "Yes" for Forced air cooling. Otherwise enter "No"
PFS Parameters					
PFS Part Number	**PFS729**		**PFS729**		Selected PFS device
IOCP min			9.30	A	Minimum Current limit
IOCP typ			10.30	A	Typical current limit
IOCP max			11.30	A	Maximum current limit
RDSON			0.40	ohms	Typical RDSon at 100 'C
RV			9.00	Mohms	Line sense resistor
C_VCC			1.00	uF	Supply decoupling capacitor
C_V			47.00	nF	V pin decoupling capacitor
C_FB			10.00	nF	Feedback pin decoupling capacitor
FS_PK			84.38	kHz	Estimated peak frequency of operation
FS_AVG			83.04	kHz	Estimated average frequency of operation
IP			9.22	A	MOSFET peak current
PFS_IRMS			3.67	A	PFS MOSFET RMS current
PCOND_LOSS_PFS			5.38	W	Estimated PFS conduction losses
PSW_LOSS_PFS			4.25	W	Estimated PFS switching losses
PFS_TOTAL			9.64	W	Total Estimated PFS losses
TJ Max			100	deg C	Maximum steady-state junction temperature
Rth-JS			3.00	degC/W	Maximum thermal resistance (Junction to heatsink)

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HEATSINK Theta-CA			3.22	degC/W	Maximum thermal resistance of heatsink
Basic Inductor Calculation					
LPFC			237.36	uH	Value of PFC inductor at peak of VACMIN and Full Load
LPFC (0 Bias)			2037.31	uH	Value of PFC inductor at No load. This is the value measured with LCR meter
LPFC_RMS			5.56	A	Inductor RMS current (calculated at VACMIN and Full Load)
Inductor Construction Parameters					
Core Type	**Sendust**		**Sendust**		Enter "Sendust", "Pow Iron" or "Ferrite"
Core Material	**Auto**		**125u**		Select from 60u, 75u, 90u or 125 u for Sendust cores. Fixed at PC44 or equivalent for Ferrite cores. Fixed at 52 material for Pow Iron cores.
Core Geometry	**Auto**		**TOROID**		Select from Toroid or EE for Sendust cores and from EE, or PQ for Ferrite cores
Core	**Auto**		**77254 (OD=40.8)**		Core part number
AE			107.2	mm^2	Core cross sectional area
LE			98.2	mm	Core mean path length
AL			171	nH/t^2	Core AL value
VE			10050	mm^3	Core volume
HT			15.37	mm	Core height/Height of window
MLT			54	cm	Mean length per turn
BW			N/A	mm	Bobbin width
NL			109		Inductor turns
LG			N/A	mm	Gap length (Ferrite cores only)
ILRMS			5.56	A	Inductor RMS current
Wire type	**LITZ**				Select between "Litz" or "Regular" for double coated magnet wire
AWG			40	AWG	Inductor wire gauge
Filar			250		Inductor wire number of parallel strands
OD			0.079	mm	Outer diameter of single strand of wire
AC Resistance Ratio			1.22		Ratio of AC resistance to the DC resistance (using Dowell curves)
J			4.57	A/mm^2	Estimated current density of wires. It is recommended that 4 < J < 6
BM_TARGET			N/A	Gauss	Target flux density at VACMIN (Ferrite cores only)
BM			2582	Gauss	Maximum operating flux density
BP			6627	Gauss	Peak Flux density (Estimated at VBROWNOUT)
LPFC_CORE_LOSS			2.07	W	Estimated Inductor core Loss
LPFC_COPPER_LOSS			2.35	W	Estimated Inductor copper losses
LPFC_TOTAL LOSS			4.42	W	Total estimated Inductor Losses
Critical Parameters					
IRMS			5.15	A	AC input RMS current
IO_AVG			2.34	A	Output average current
Output Diode					
Part Number	**Auto**		**STTH12R06**		PFC Diode Part Number

Type			ULTRAFAST		Diode Type - Special - Diodes specially catered for PFC applications, SiC - Silicon Carbide type, UF - Ultrafast recovery type
Manufacturer			ST		Diode Manufacturer
VRRM			600	V	Diode rated reverse voltage
IF			12	A	Diode rated forward current
TRR			25	ns	Diode Reverse recovery time
VF			1.1	V	Diode rated forward voltage drop
PCOND_DIODE			2.57	W	Estimated Diode conduction losses
PSW_DIODE			3.28	W	Estimated Diode switching losses
P_DIODE			5.85	W	Total estimated Diode losses
TJ Max			125	deg C	Maximum Operating temperature
Rth-JS			1.70	degC/W	Maximum thermal resistance (Junction to heatsink)
HEATSINK Theta-CA			12.33	degC/W	Maximum thermal resistance of heatsink
Output Capacitor					
CO	**Auto**		**820.00**	uF	Minimum value of Output capacitance
VO_RIPPLE_EXPECTED			9.4	V	Expected ripple voltage on Output with selected Output capacitor
T_HOLDUP_EXPECTED			21.5	ms	Expected holdup time with selected Output capacitor
ESR_LF			0.20	ohms	
ESR_HF			0.07	ohms	
IC_RMS_LF			1.65	A	Low Frequency Capacitor RMS current
IC_RMS_HF			2.93	A	High Frequency Capacitor RMS current
CO_LF_LOSS			0.55	W	Estimated Low Frequency ESR loss in Output capacitor
CO_HF_LOSS			0.61	W	Estimated High frequency ESR loss in Output capacitor
Total CO LOSS			1.16	W	Total estimated losses in Output Capacitor
Input Bridge and Fuse					
I^2t Rating			57.58	A^2s	Minimum I^2t rating for fuse
Fuse Current rating			7.26	A	Minimum Current rating of fuse
VF			0.90	V	Input bridge Diode forward Diode drop
IAVG			4.52	A	Input average current at 70 VAC.
PIV_INPUT BRIDGE			375	V	Peak inverse voltage of input bridge
PCOND_LOSS_BRIDGE			8.35	W	Estimated Bridge Diode conduction loss
CIN			1.00	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
RT			6.44	ohms	Input Thermistor value
D_Precharge			1N5407		Recommended precharge Diode
Feedback Components					
R2			1.54	Mohms	Feedback network, first high voltage divider resistor
R3			1.54	Mohms	Feedback network, second high voltage divider resistor
R4			698.00	kohms	Feedback network, third high voltage divider resistor
C2			100.00	nF	Feedback network, loop speedup capacitor
R5			2.20	kohms	Feedback component, NPN transistor bias resistor

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R6			2.20	kohms	Feedback component, PNP transistor bias resistor
R7			57.60	kohms	Feedback network, lower divider resistor
C3			470.00	pF	Feedback component- noise suppression capacitor
R8			160.00	kohms	Feedback network - pole setting resistor
R9			2.67	kohms	Feedback network - zero setting resistor
R10			10.00	kohms	Feedback pin filter resistor
C4			10.00	uF	Feedback network - compensation capacitor
D3			1N4148		Feedback network reverse blocking Diode
D4			1N4001		Feedback network - capacitor failure detection Diode
Q1			2N4401		Feedback network - speedup circuit NPN transistor
Q2			2N4403		Feedback network - speedup circuit PNP transistor
Loss Budget (Estimated at VACMIN)					
PFS Losses			9.64	W	Total estimated losses in PFS
Boost diode Losses			5.85	W	Total estimated losses in Output Diode
Input Bridge losses			8.35	W	Total estimated losses in input bridge module
Inductor losses			4.42	W	Total estimated losses in PFC choke
Output Capacitor Loss			1.16	W	Total estimated losses in Output capacitor
Total losses			29.43	W	Overall loss estimate
Efficiency			0.97		Estimated efficiency at VACMIN. Verify efficiency at other line voltages

9 Inductor Specification

9.1 Electrical Diagram

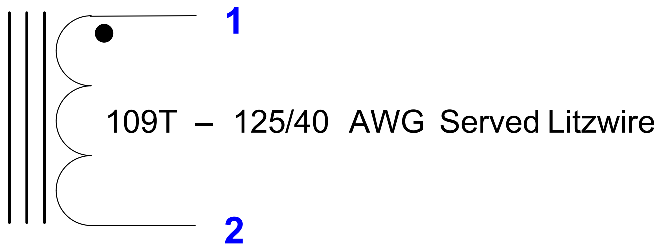

Figure 6 – Inductor Electrical Diagram.

9.2 Electrical Specifications

Primary Inductance	Pins 1-2 measured at 100 kHz, 0.4 VRMS	2.04 mH ±8%

9.3 Materials:

Item	Description
[1]	Core: Magnetics Inc, Mfg: 0077254A7 PI P/ N 32-00246-00.
[2]	Magnet wire: 125/40 Served – Litz wire.
[3]	Base: Toroid mounting base, Lodestone Pacific, P/N VTM160-4, or similar. See Figure 2. 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.

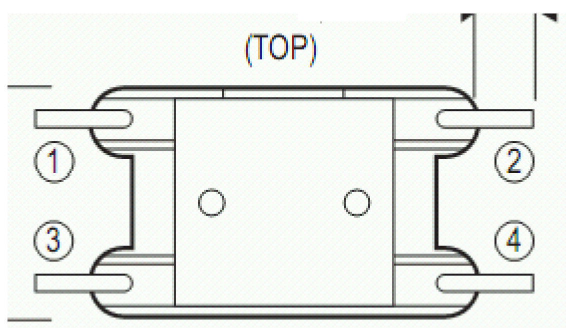

Figure 7 – Top View of Toroid Mounting Base Item [3].

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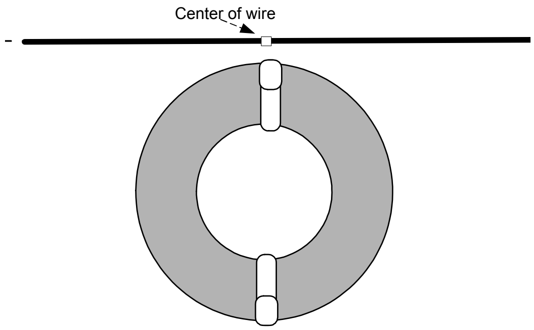
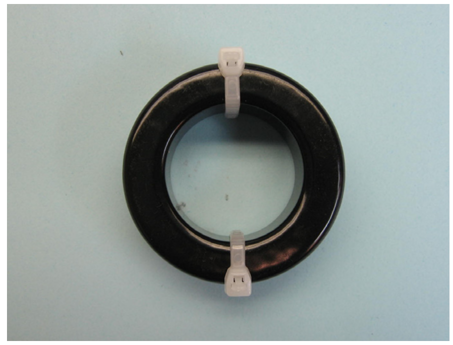
9.4 Inductor Winding Instruction

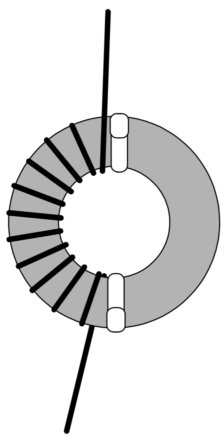
Note: Colors used in diagrams used to denote winding layers.

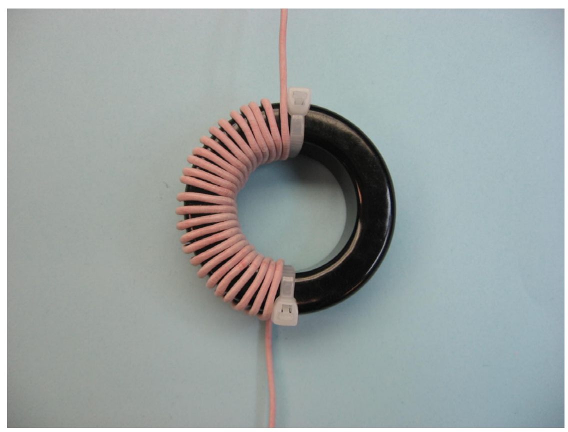
- Insert 2 dividers item [5] in the core item [1] to divide into 2 sections equally. See picture below. Take about 15 ft. of wire item [2]. Align center of wire with 1 divider.



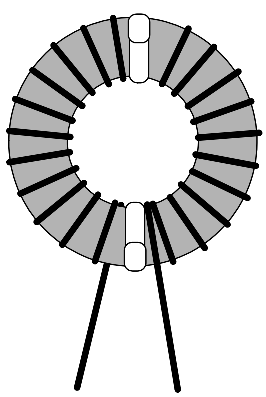


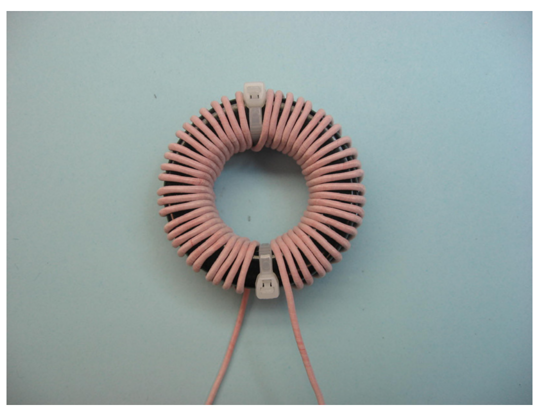
- Start winding on the left section with 23 turns of wire item [2], for the 1st layer, spread wire evenly and ensure that turns do not overlap.



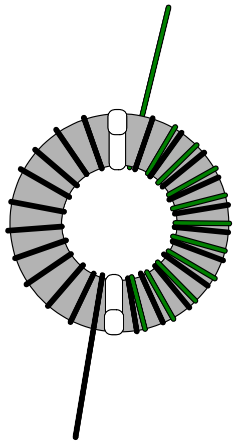


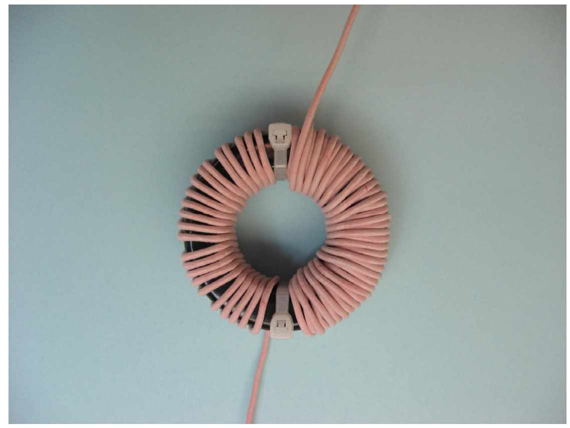
- Wind a further 23 turns on the right section.



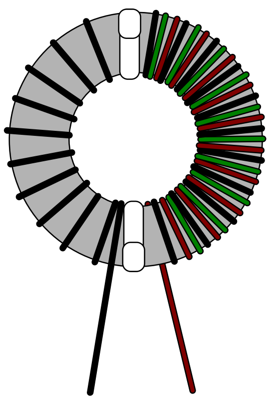


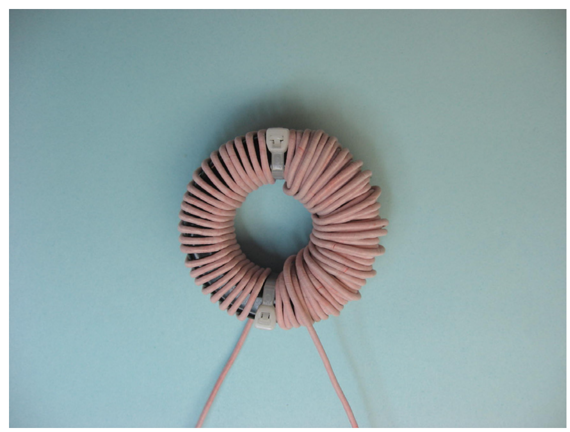
- Continue winding on the right section for the 2nd layer 18 turns, spread wire evenly and ensure that turns do not overlap.



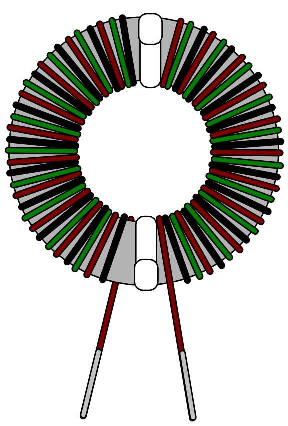


- Continue winding on the right section on the 3rd layer 13 turns, spread wire evenly and ensure that turns do not overlap.





- Wind the same as above for the 2nd and 3rd layer on the left section. Third layer will have 14 turns to complete 109 turns total.



- Solder the leads to the pin 1 and 2 of mounting base item [3].
  Secure the inductor to the base by using high temperature epoxy item [4].

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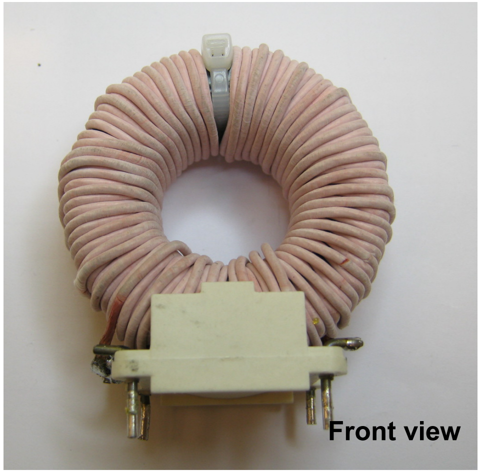
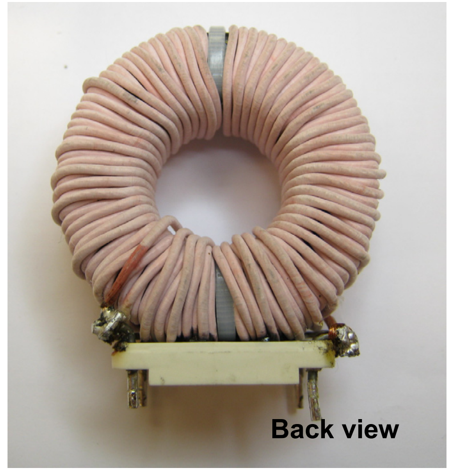

Front view


Back view

10 Performance Data

All measurements performed at room temperature, 50 Hz input frequency

All performance data is with Thermistor's RT1 shorted to represent the high performance configuration which uses RT1 to limit inrush current and shorts thermistor RT1 after startup to improve operating efficiency.

10.1 Efficiency (with RT1 shorted)

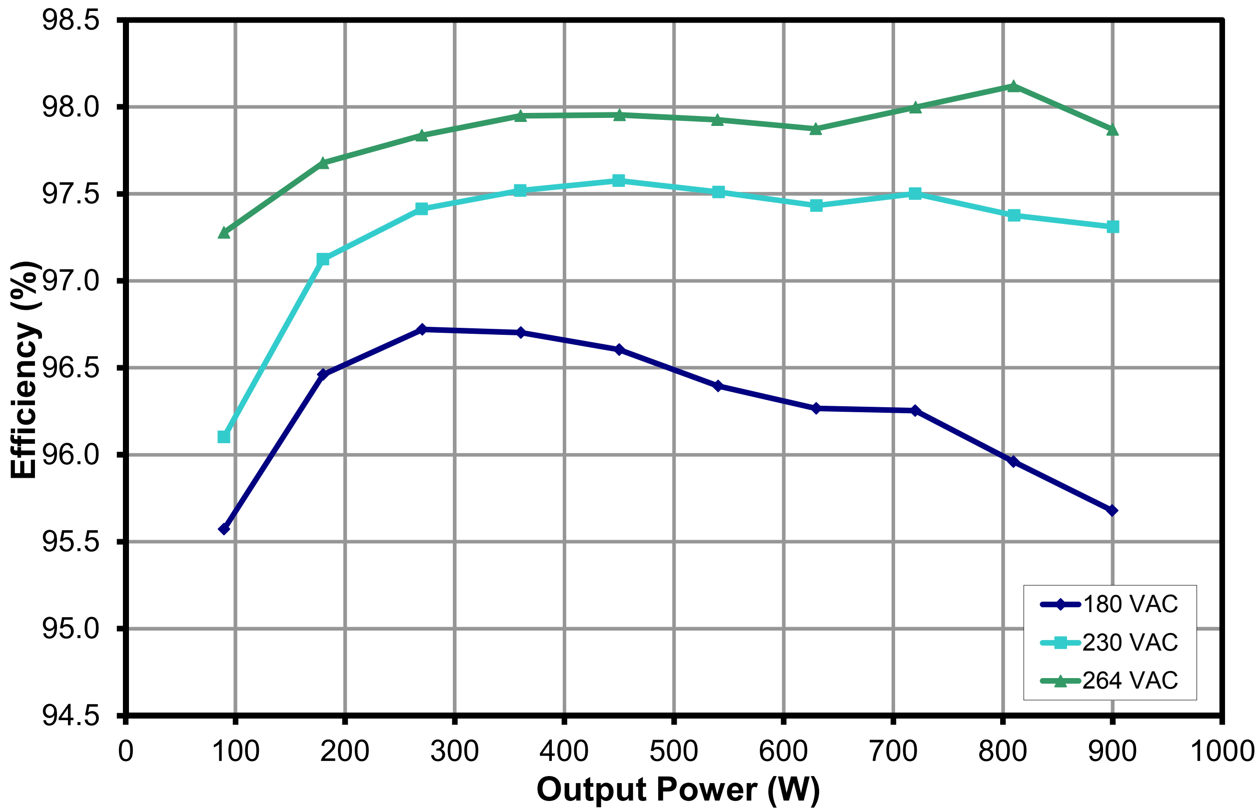


Figure 8 – Efficiency vs. Output Power, Room Temperature, 50 Hz.

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10.2 Input Power Factor

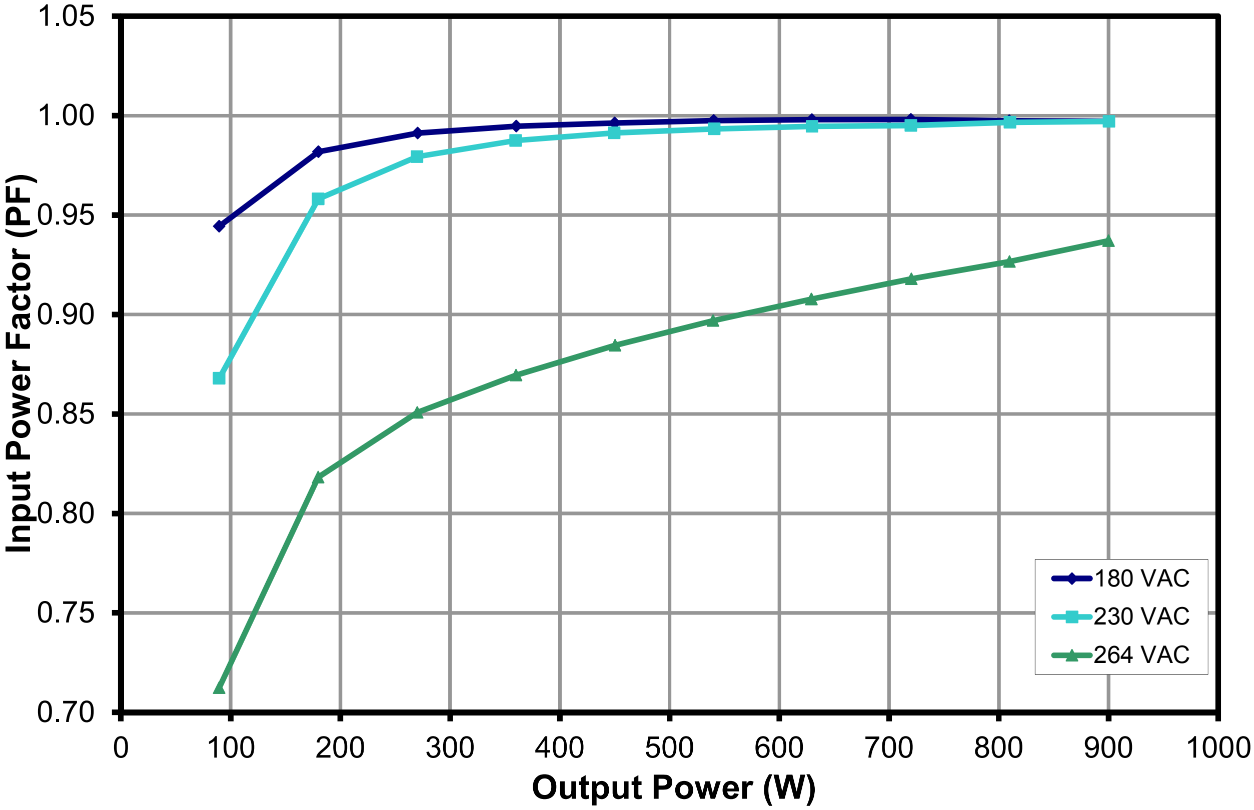

Figure 9 – Input Power Factor vs. Output Power, Room Temperature; 50 Hz**.**

10.3 Regulation

10.3.1 Load

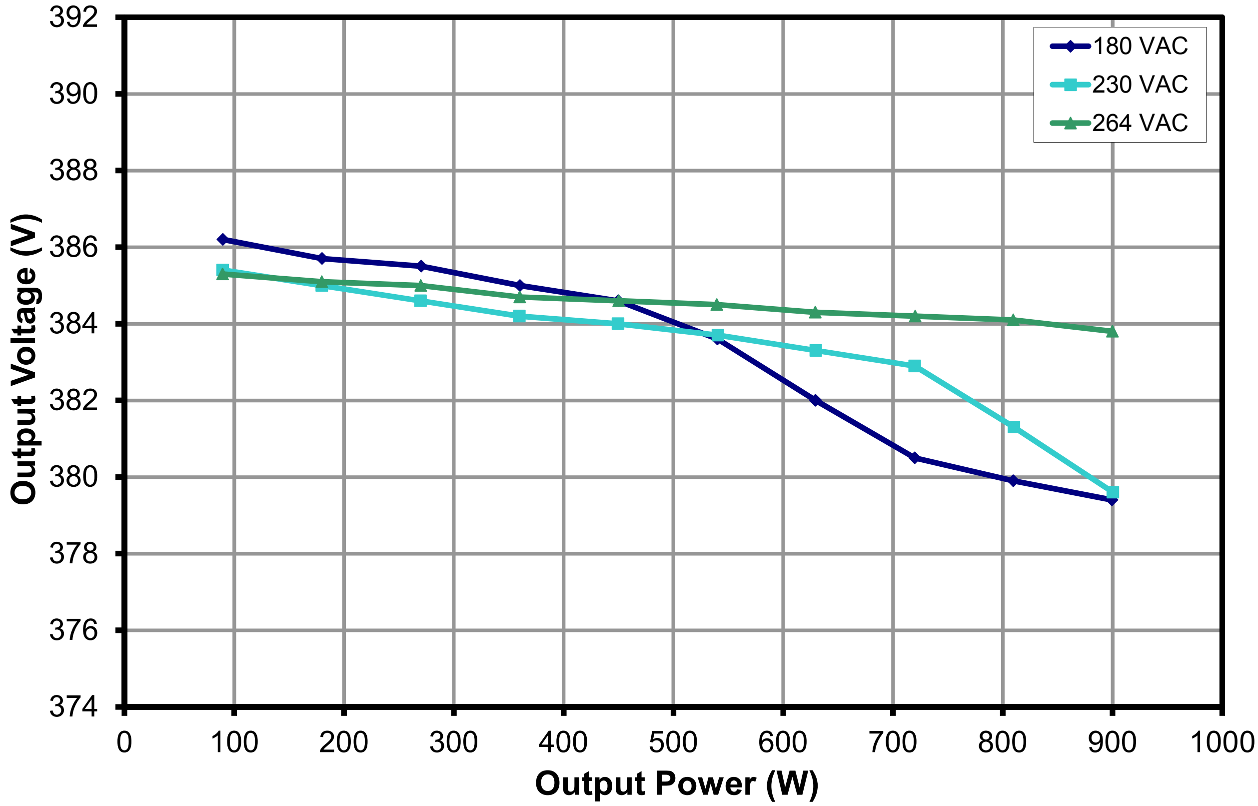

Figure 10 – Load Regulation, Room Temperature.

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10.3.2 Line

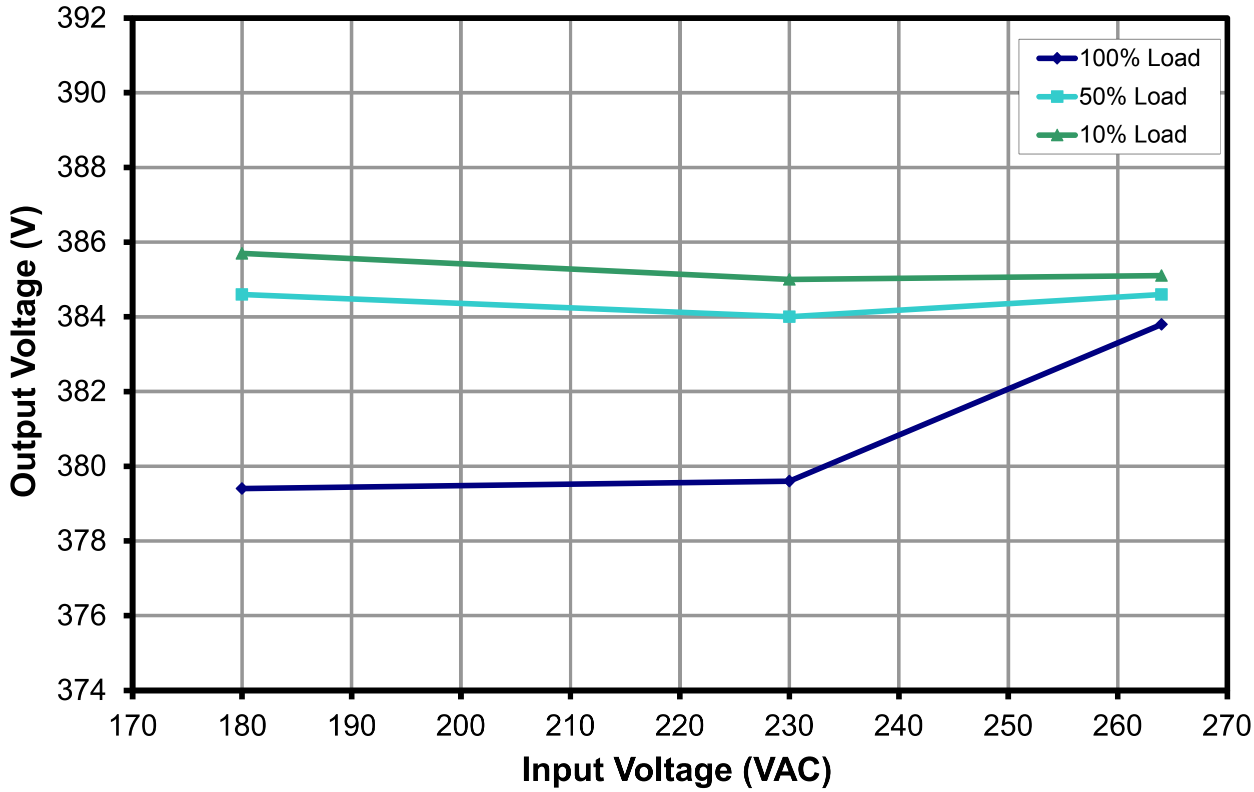

Figure 11 – Line Regulation, Room Temperature.

10.4 Input Current Harmonic Distortion (IEC 61000-3-2 Class-D)

Measured at 230 VAC Input 50 Hz

10.4.1 50% Load at Output

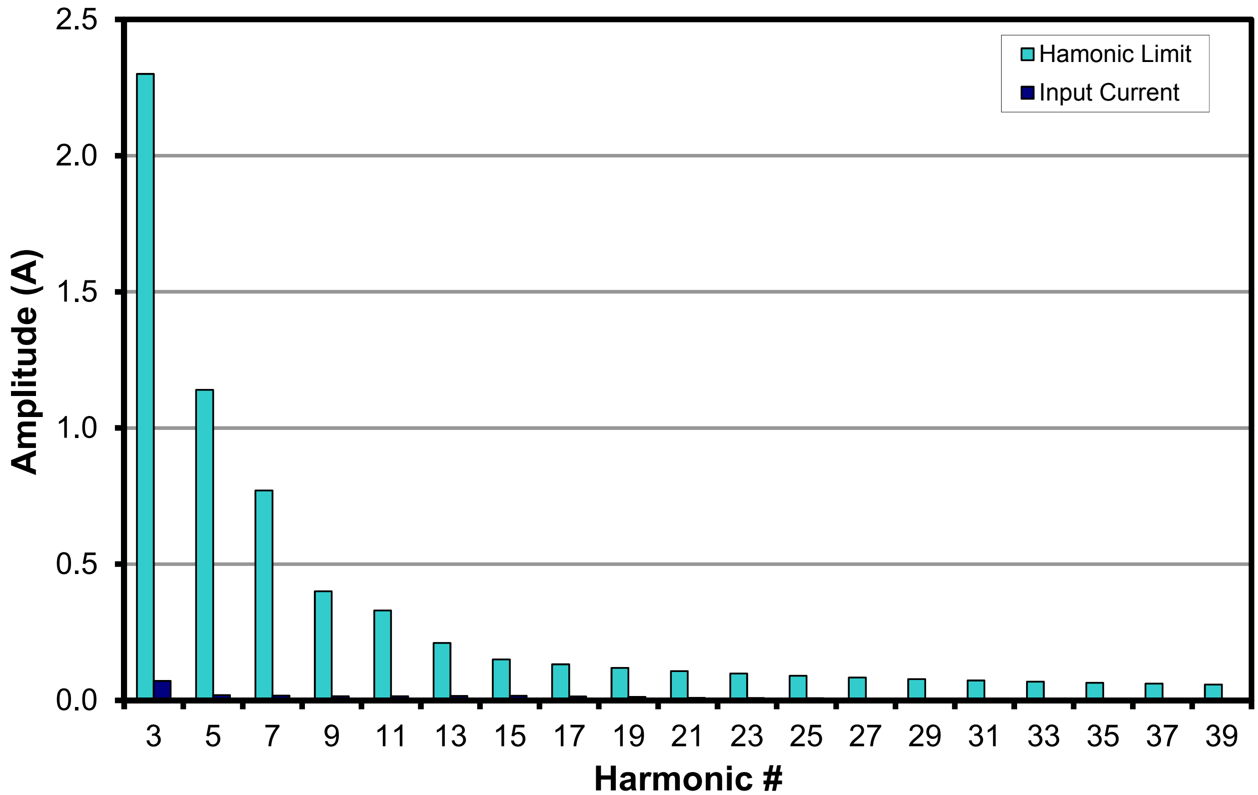

Figure 12 – Amplitude of Input Current Harmonics for 50% Load at 230 VAC Input.

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10.4.2 100% Load at Output

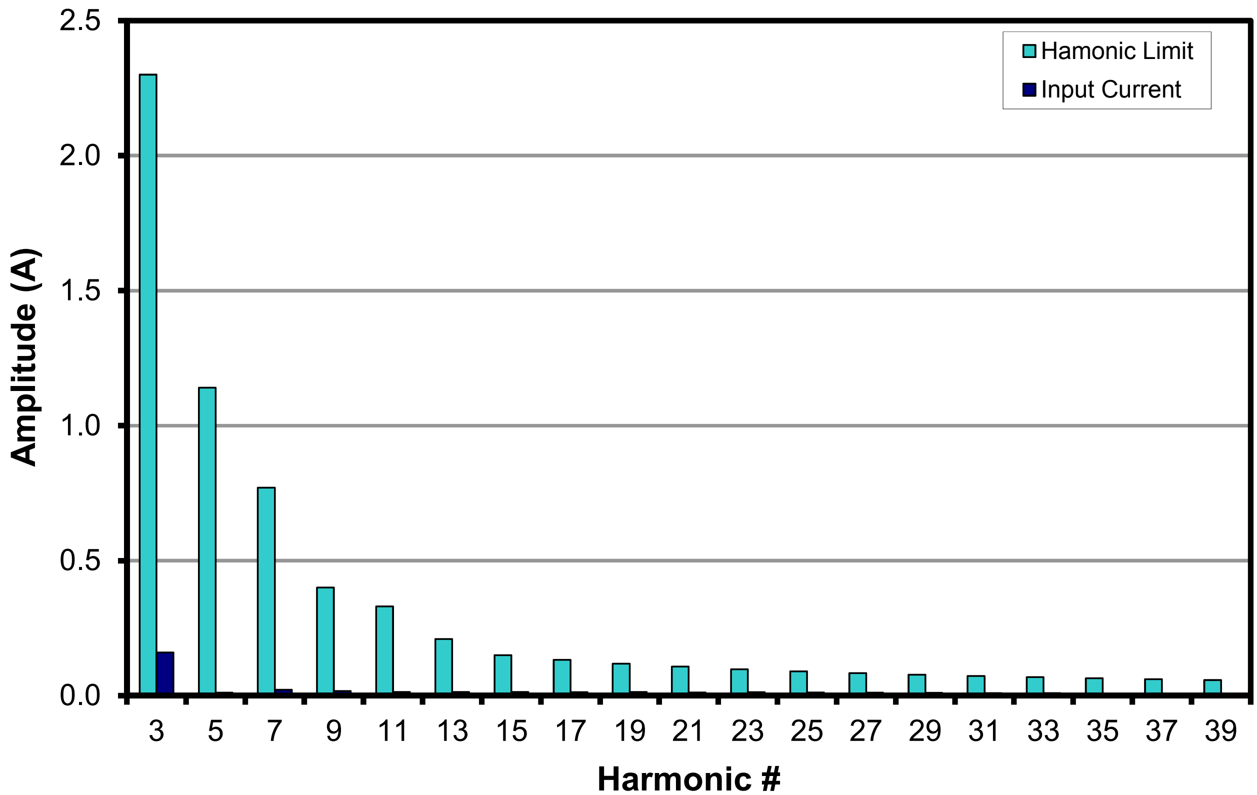

Figure 13 – Amplitude of Input Current Harmonics for 100% Load at 230 VAC Input.

11 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 (ºC) 230 VAC
X1 Capacitor 680 nF, C1	29.3
DC Capacitor after BR 1.5 μF, C5	55.4
Output Capacitor 820 μF, C13	38.4
X2 Capacitor 1 μF, C4	42.4
Output Diode, D2	75.0
CM Inductor 8 mH, L1	58.1
DM Inductor 100 μH, L2	53.9
DM Inductor 100 μH, L3	66.1
Output Inductor, L4	77.4
Bridge Rectifier, BR1	81.0
eSIP, U2	86.0
Heat Sink (Top Surface)	29.0
Ambient Temperature	24.2

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

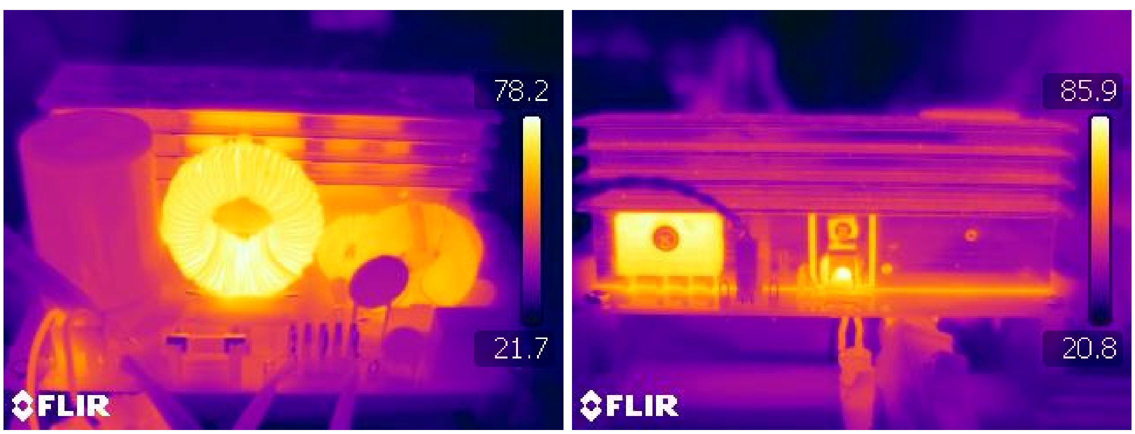

Figure 14 – Infra-Red Image of the Front and Back Side of the Board at Thermal Equilibrium. 230 VAC, Full Load, No Forced-Air Flow, 24 ºC Ambient.

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12 Waveforms

12.1 Input Current at 230 VAC and 50 Hz

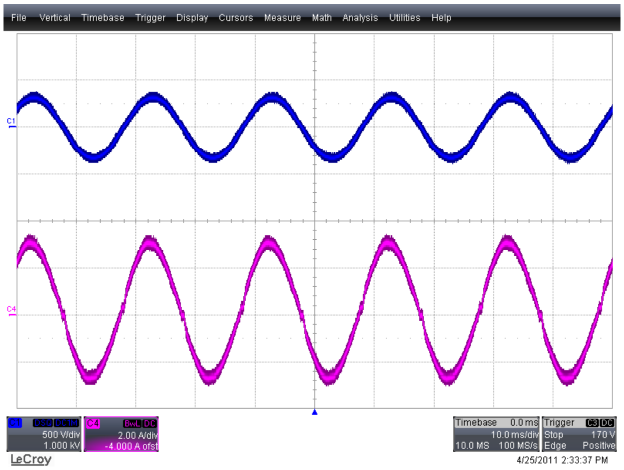

Figure 15 – 230 VAC, 50% Load.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 2 A, 10 ms / div.

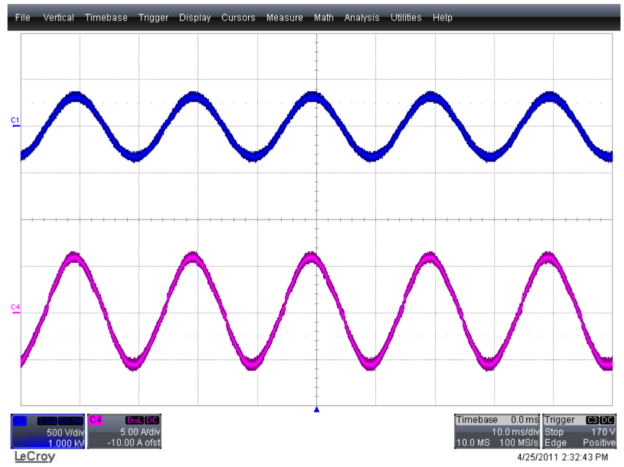

Figure 16 – 230 VAC, 100% Load.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 5 A, 10 ms / div.

12.2 *Start-up at 180 VAC and 50 Hz*

Load in CC mode during turn-on of PFC

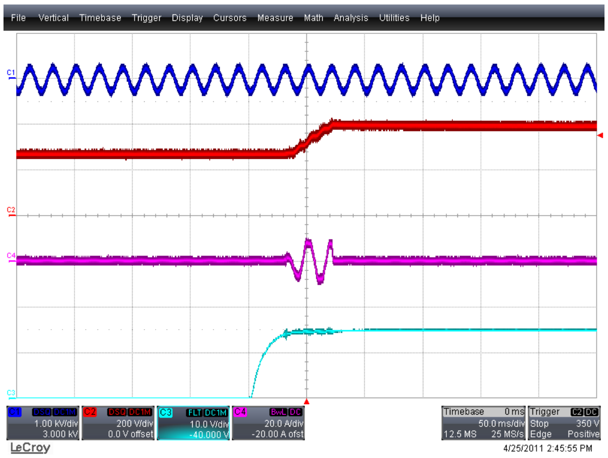

Figure 17 – 180 VAC, No-load.
Upper: V_{IN}, 1000 V / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div.
Lower: V_{CC}, 10 V, 50 ms / div.

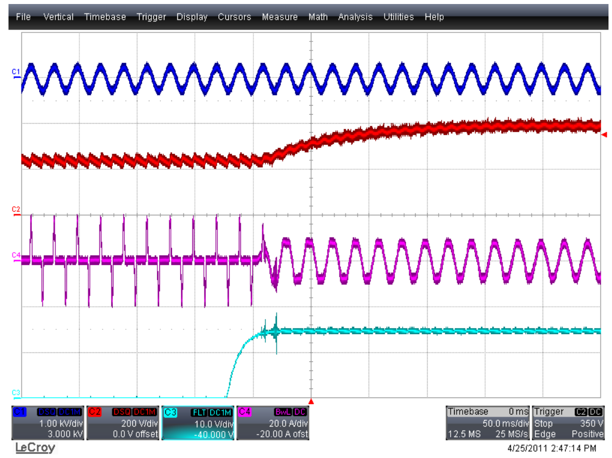

Figure 18 – 180 VAC, Full Load.
Upper: V_{IN}, 1000 V / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div.
Lower: V_{CC}, 10 V, 50 ms / div.

12.3 *Start-up at 230 VAC and 50 Hz*

Load in CC mode during turn-on of PFC

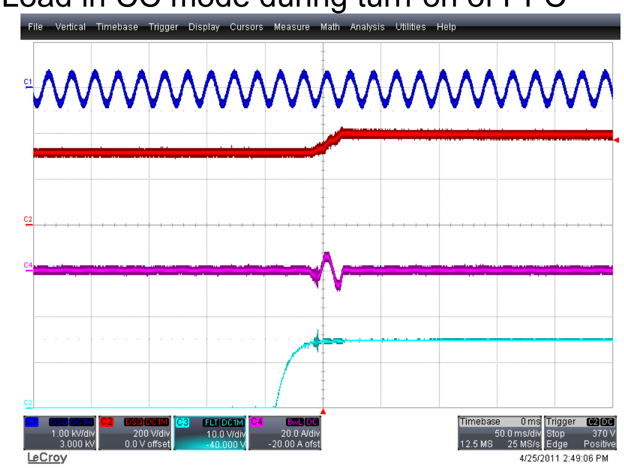

Figure 19 – 230 VAC, No-load.
Upper: V_{IN}, 1 kV / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div.
Lower: V_{CC}, 10 V, 50 ms / div.

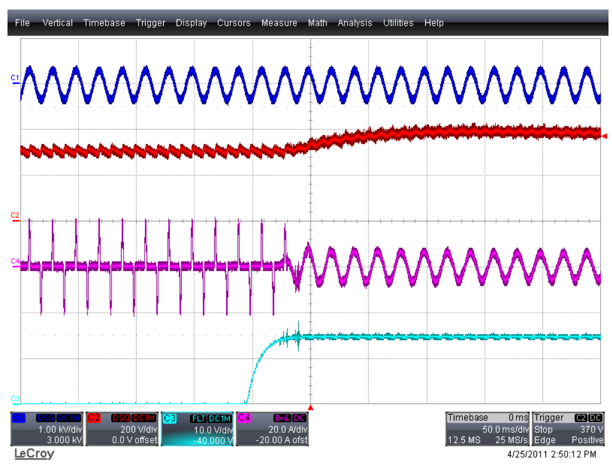

Figure 20 – 230 VAC, Full Load.
Upper: V_{IN}, 1 kV / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div.
Lower: V_{CC}, 10 V, 50 ms / div.

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12.4 Start-up at 264 VAC and 50 Hz

Load in CC mode during turn-on of PFC

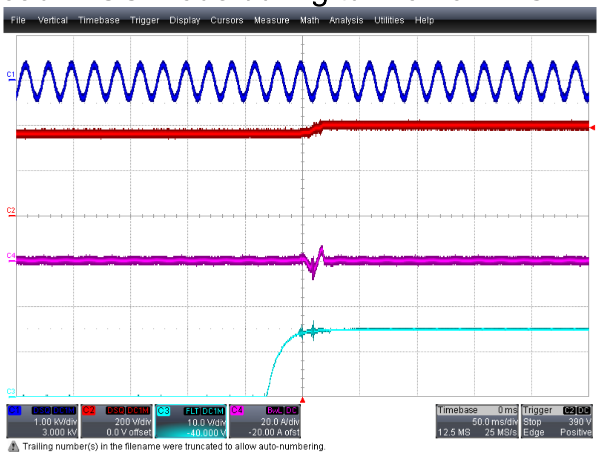

Figure 21 – 264 VAC, No-load.
Upper: V_{IN}, 1 kV / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div.
Lower: V_{CC}, 10 V, 50 ms / div.

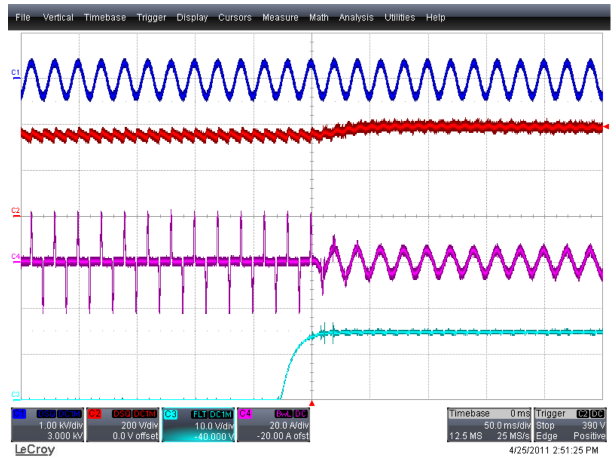

Figure 22 – 264 VAC, Full Load.
Upper: V_{IN}, 1 kV / div.
Second: V_{OUT}, 200 V / div.
Third: I_{IN}, 20 A / div
Lower: V_{CC}, 10 V, 50 ms / div.

12.5 Load Transient Response (180 VAC, 50 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.

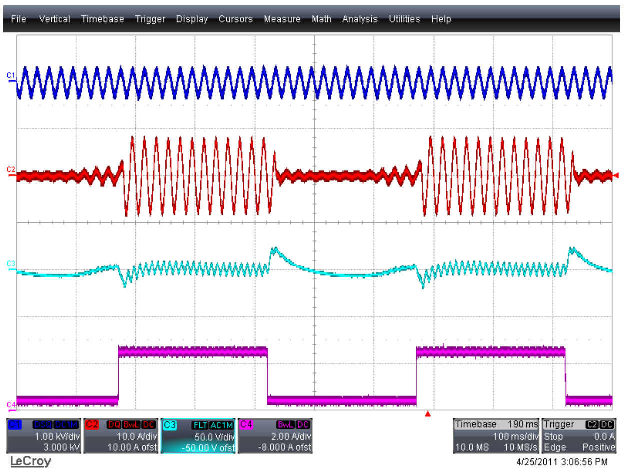

Figure 23 – Transient Response, 180 VAC, 10-100-10% Load Step.
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled), 50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

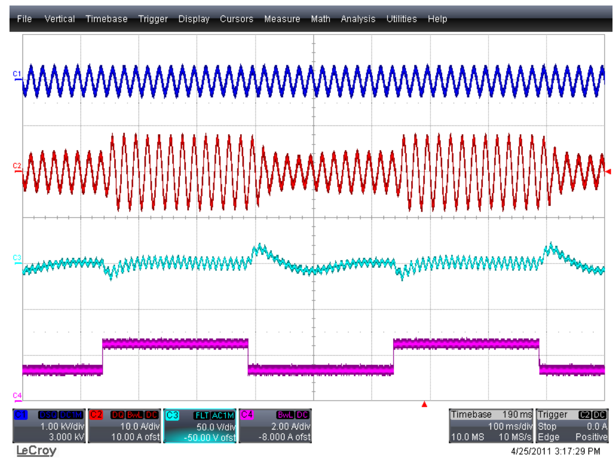

Figure 24 – Transient Response, 180 VAC, 50-100-50% Load Step
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled), 50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

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12.6 Load Transient Response (230 VAC, 50 Hz)

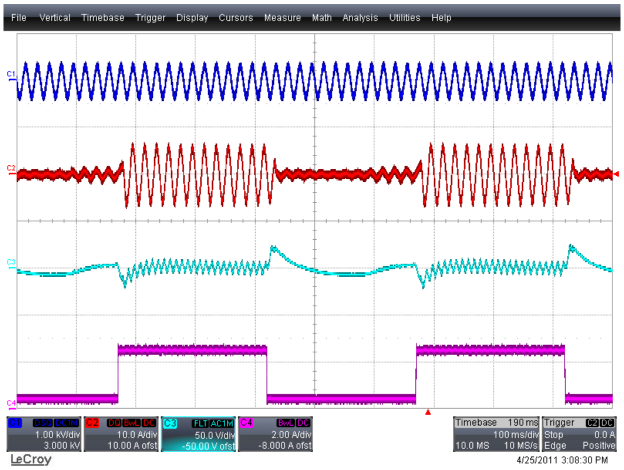

Figure 25 – Transient Response, 230 VAC,
10-100-10% Load Step.
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled), 50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

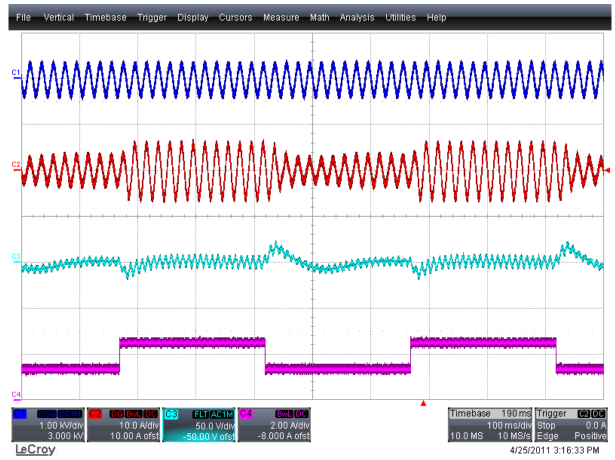

Figure 26 – Transient Response, 230 VAC,
50-100-50% Load Step.
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled), 50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

12.7 Load Transient Response (264 VAC, 50 Hz)

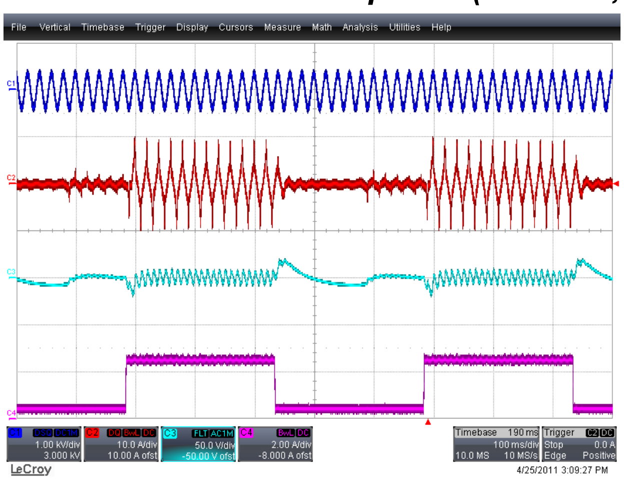

Figure 27 – Transient Response, 264 VAC,
10-100-10% Load Step.
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled), 50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

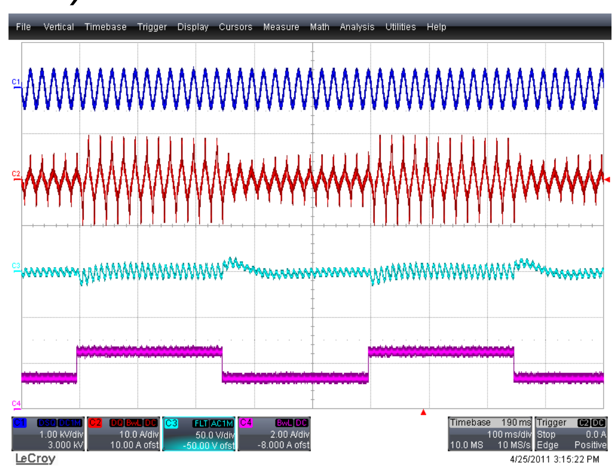

Figure 28 – Transient Response, 264 VAC,
50-100-50% Load Step.
Upper: V_{IN}, 1 kV / div.
Second: I_{IN}, 10 A / div.
Third: V_{OUT} (AC Coupled),50 V / div.
Lower: I_{LOAD} 2 A, 100 ms / div.

12.8 1000 ms Line Dropout (230 VAC / 50 Hz)

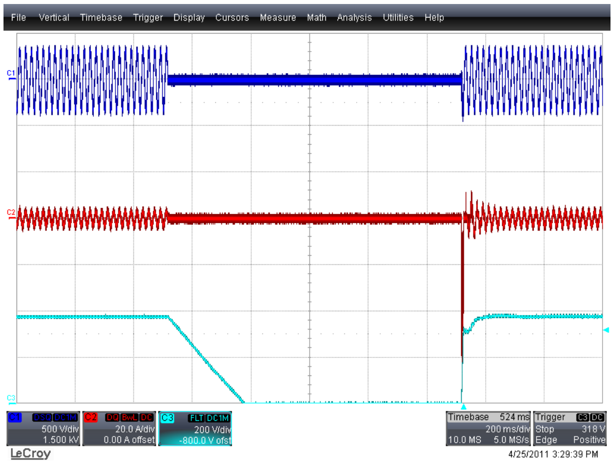

Figure 29 – Line Dropout 230 VAC, 1000 ms.
50% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 20 A / div.
Lower: V_{OUT}, 200 V, 200 ms / div.

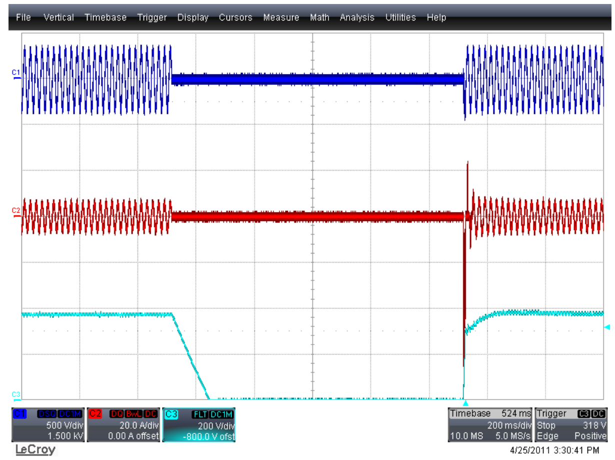

Figure 30 – Line Dropout 230 VAC, 1000 ms.
100% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 20 A / div.
Lower: V_{OUT}, 200 V, 200 ms / div.

12.9 One Cycle Line Dropout (230 VAC / 50 Hz 0 Degree and 90 Degree)

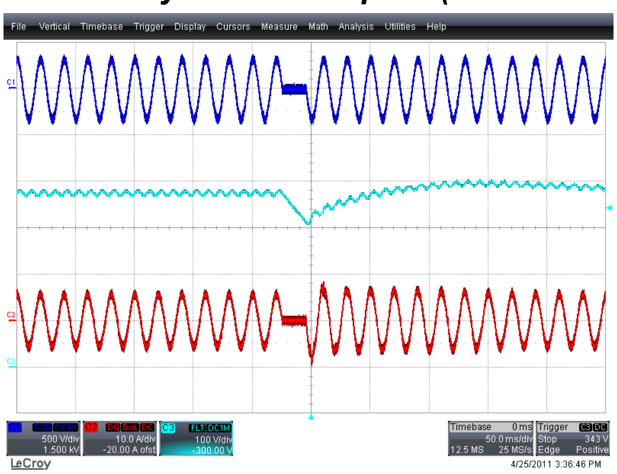

Figure 31 – Line Dropout 230 VAC, 50 Hz.
0 Degree.
Upper: V_{IN}, 500 V / div.
Middle: V_{OUT}, 100 V /div.
Lower: I_{IN}, 10 A, 50 ms / div.

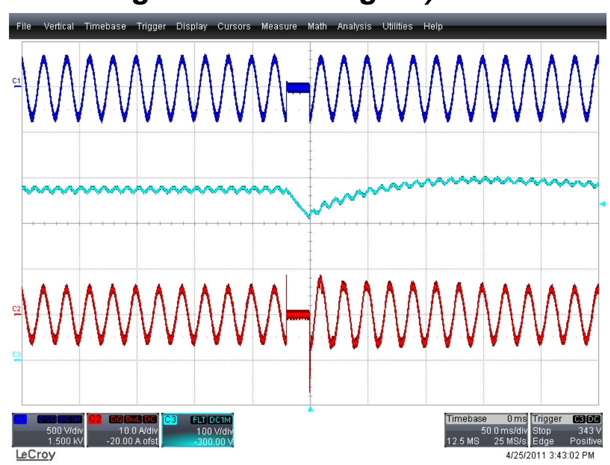

Figure 32 – Line Dropout 230 VAC, 50 Hz.
90 Degree.
Upper: V_{IN}, 500 V / div.
Middle: V_{OUT}, 100 V / div.
Lower: I_{IN}, 10 A, 50 ms /div.

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12.10 *Line Sag (230 VAC – 180 VAC – 230 VAC, 50 Hz)*

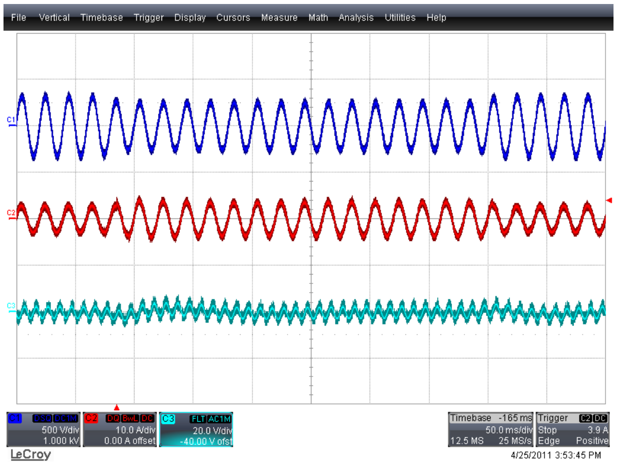

Figure 33 – Line Sag 230 VAC, 50% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 10 A, 50 ms / div.
Lower: V_{OUT} (AC Coupled), 20 V / div.

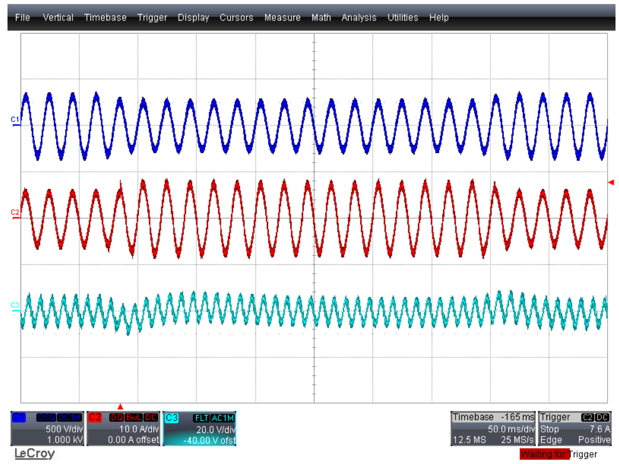

Figure 34 – Line Sag 230 VAC, 100% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 10 A, 50 ms / div.
Lower: V_{OUT} (AC Coupled), 20 V / div.

12.11 *Line Surge (264 VAC – 293 VAC – 264 VAC, 50 Hz)*

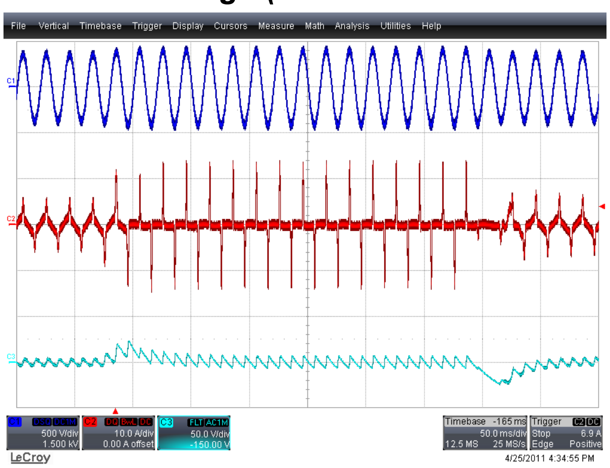

Figure 35 – Line Surge 264 VAC, 50% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 10 A, 50 ms / div.
Lower: V_{OUT} (AC Coupled), 50 V / div.

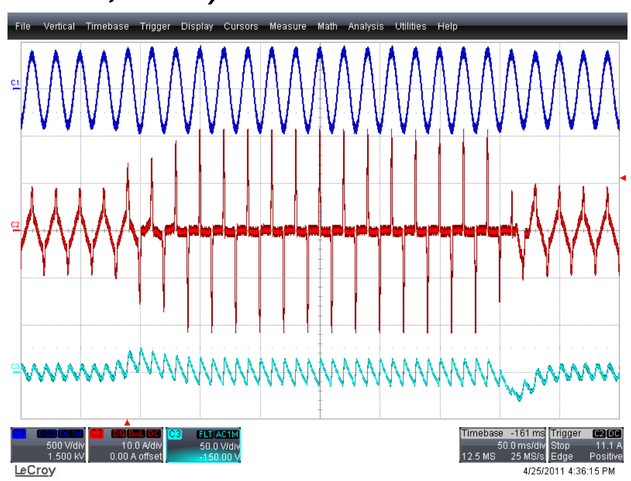

Figure 36 – Line Surge 264 VAC, 100% Load.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 10 A, 50 ms / div.
Lower: V_{OUT} (AC Coupled), 50 V / div.

12.12 Brown-In and Brown-Out at 6 V per Minute Rate

Test conducted with reduction followed by increase of input voltage at the rate of 6 V per minute. The DC output was maximally loaded (electronic load) and it was programmed to unload at brown-out. A resistor of 17 kΩ was also connected at the 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: 151 VAC
Measured Brown-In Threshold: 177 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.*

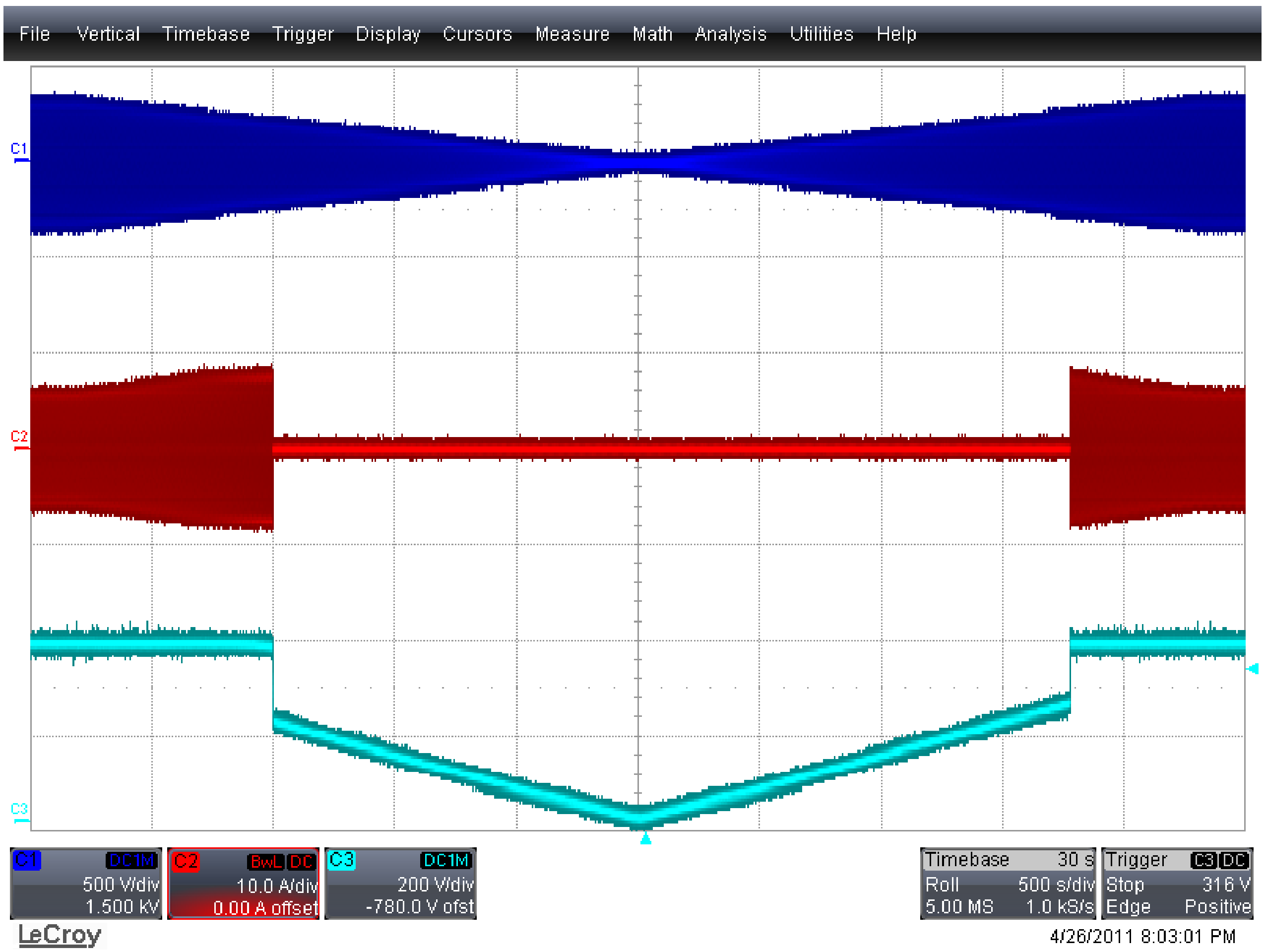

Figure 37 – Brown-in and Brown-out Waveforms.
Upper: V_{IN}, 500 V / div.
Middle: I_{IN}, 10 A, 500 s / div.
Lower: V_{OUT}, 200 V / div.

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12.13 Drain Voltage and Current

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

The drain current was measured at jumper JP3 location by replacing JP3 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 U2. Do not make the wire loop very large since the added inductance at the drain node can cause very large inductance induced voltage spikes and lead to very high VDS voltage that could damage U2.

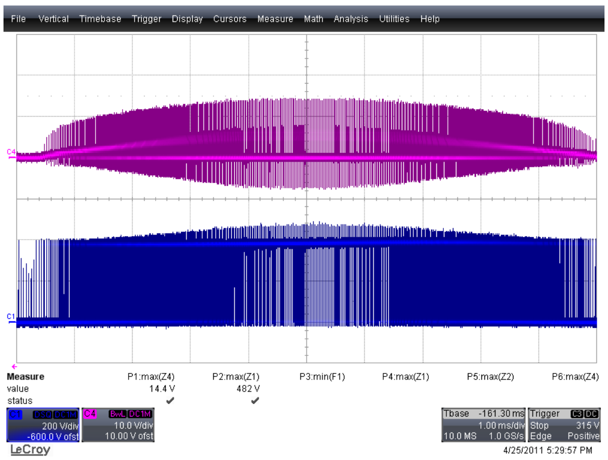

Figure 38 – Input Voltage 230 VAC, 100% Load.
Upper: I_{DRAIN}, 10 A, 1 ms / div.
Lower: V_{DRAIN}, 200 V / div.

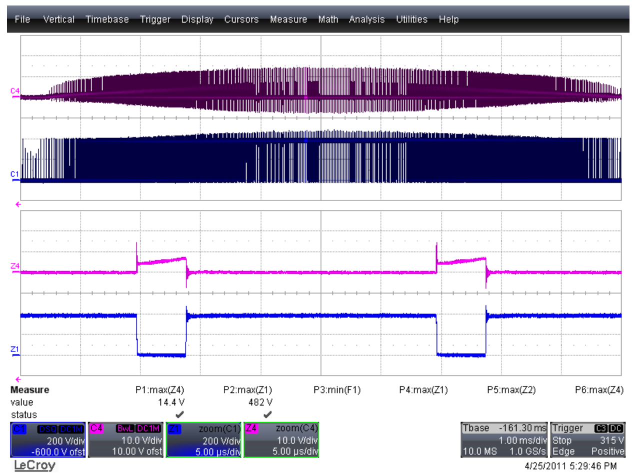

Figure 39 – Input Voltage 230 VAC, 100% Load.
Upper: I_{DRAIN}, 10 A, 1 ms / div.
Lower: V_{DRAIN}, 200 V / div.
Zoom Upper: I_{DRAIN}, 10 A, 5 µs / div.
Zoom Lower: V_{DRAIN}, 200 V / div.

12.14 Output Ripple Measurements

12.14.1 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 one capacitor 0.02 μF/1 kV ceramic disc type tied in parallel across the probe tip.

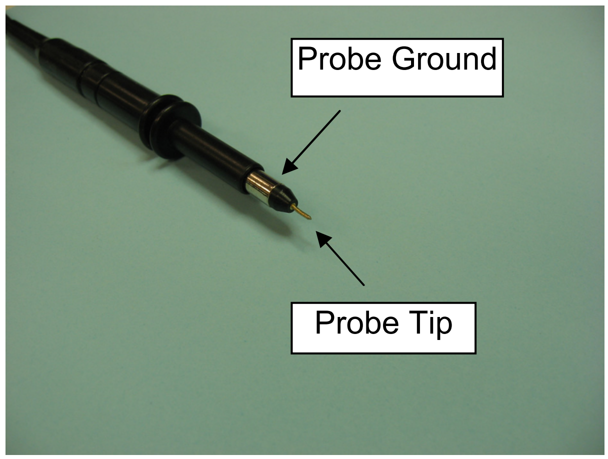

Figure 40 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed.)

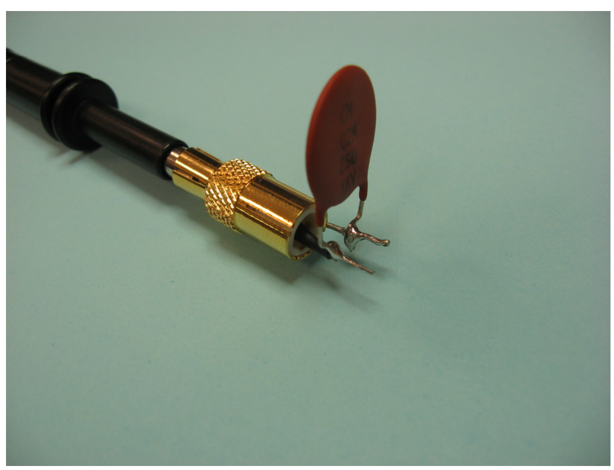

Figure 41 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter (Modified with wires for ripple measurement, and one parallel decoupling capacitor added.)

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12.14.2 Measurement Results

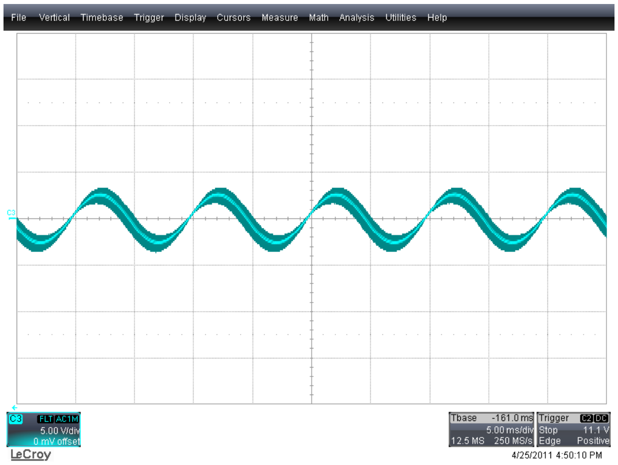

Figure 42 – Ripple, 180 VAC, 50% Load.
5 ms, 5 V / div.

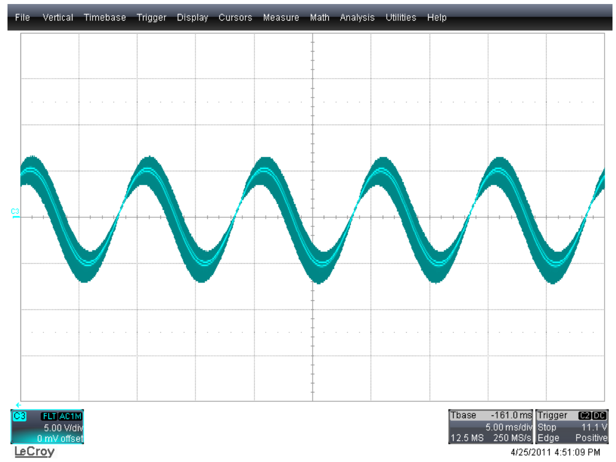

Figure 43 – Ripple, 180 VAC, 100% Load.
5 ms, 5 V / div.

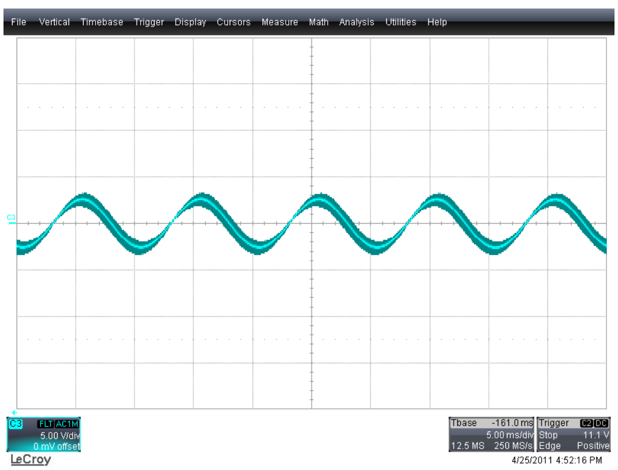

Figure 44 – Ripple, 230 VAC, 50% Load.
5 ms, 5 V / div.

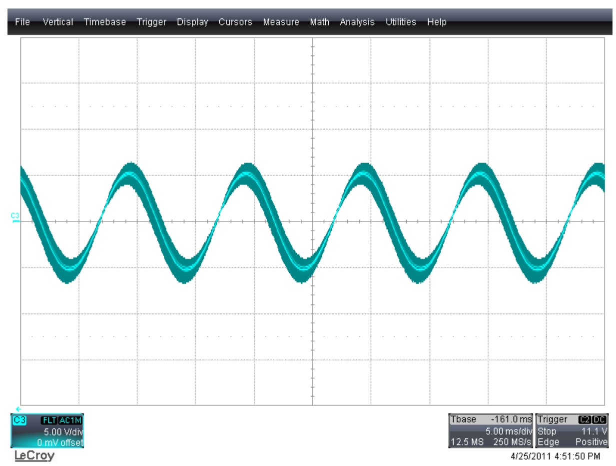

Figure 45 – Ripple, 230 VAC, 100% Load.
5 ms, 5 V / div.

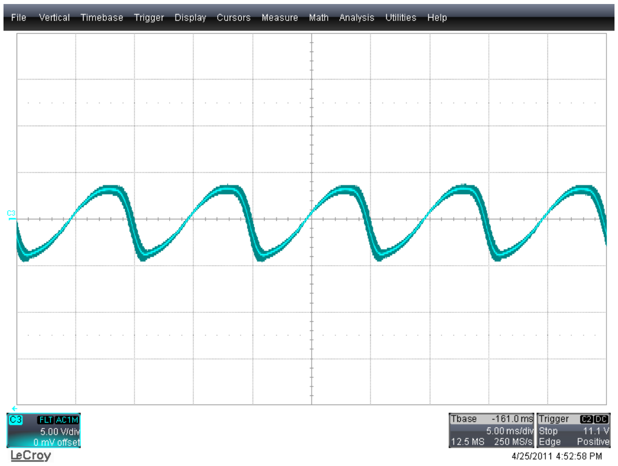

Figure 46 – Ripple, 264 VAC, 50% Load.
5 ms, 5 V / div.

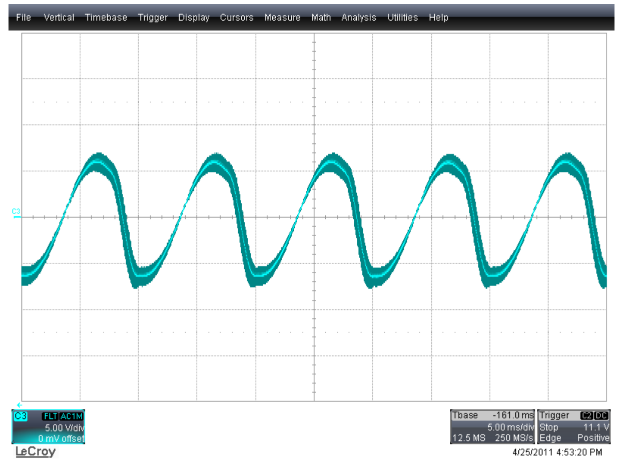

Figure 47 – Ripple, 264 VAC, 100% Load.
5 ms, 5 V / div.

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13 Control Loop Measurements

- The PFC stage was supplied form an adjustable DC source for this test. Connect the circuit as shown in Figure 47. Open the top end of the feedback divider network and insert a 100 Ω, 2 W 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 255 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 plot by sweeping the injected signal frequency from 3 Hz to 90 Hz.

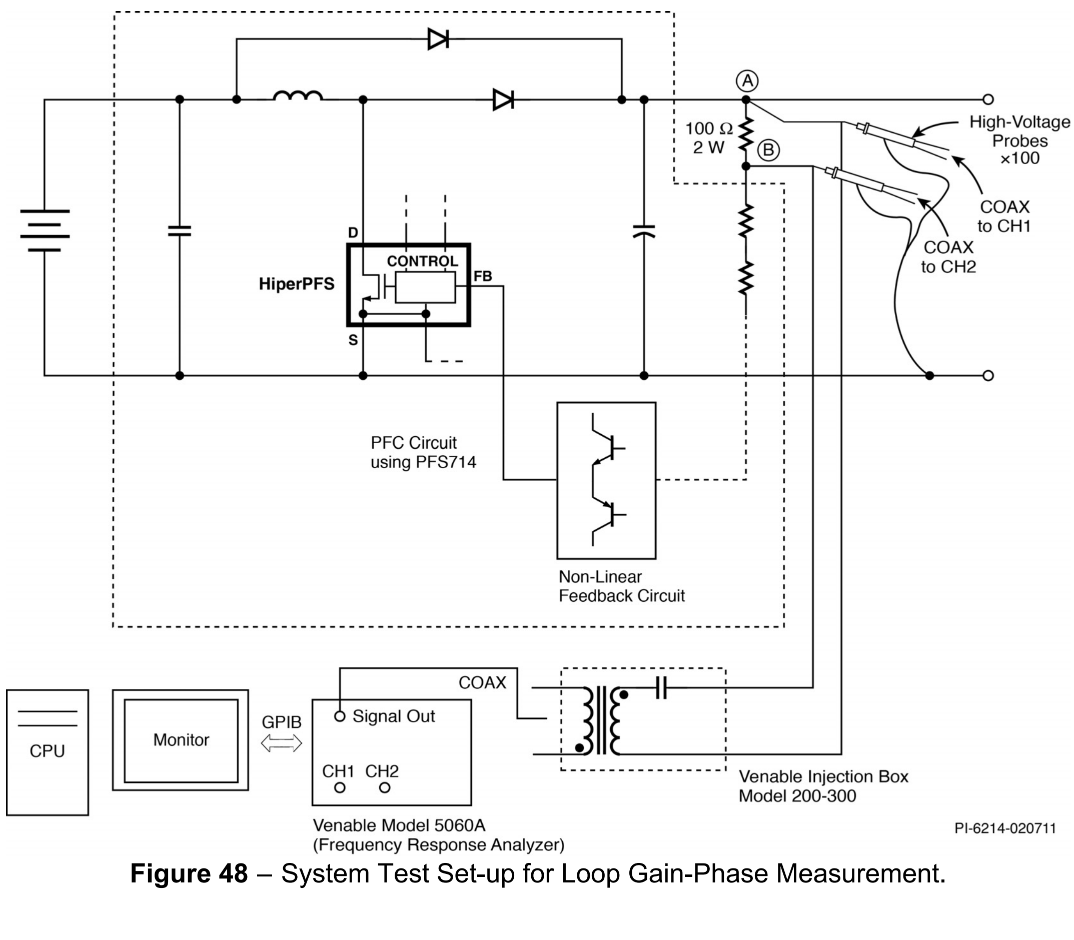

Figure 48 – System Test Set-up for Loop Gain-Phase Measurement.

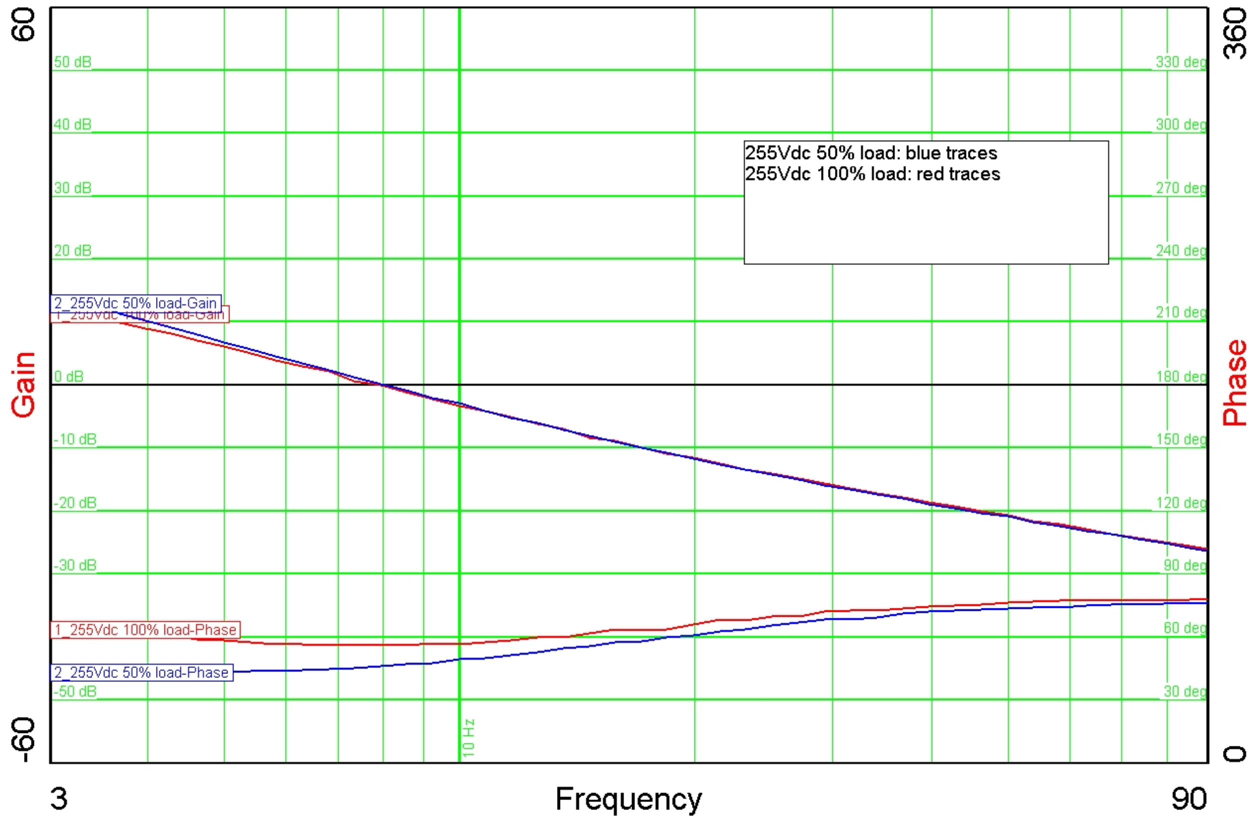

Figure 49 – Bode Plot with 255 VDC, 50% and 100% Load.

Note: Phase margin is greater than 45 degrees.

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14 Line Surge

Differential input line 1.2 / 50 μs surge testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 230 VAC / 50 Hz. Output was loaded at full load and operation was verified following each surge event.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail; # strikes)
C.M.		**(12 Ω 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.		**(2 Ω source)**		
+500	230	L1 to L2	90[2]	Pass
-500	230	L1 to L2	270	Pass
C.M.		**(12 Ω 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.		**(2 Ω source)**		
+1000	230	L1 to L2	90[2]	Pass
-1000	230	L1 to L2	270	Pass
C.M.		**(12 Ω 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.		**(12 Ω 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].
Unit passes under all test conditions.

15 EMI Scans

15.1 EMI Test Set-up

Use a plexi-glass board with complete laminated copper on one side. Connect the copper side of the board to test point TP3 with a wire clip. The RD-91 board was used here to provide V_{CC} input to the DUT board. Both boards should sit on top of the plexi-glass board. Connect TP7/TP8 and TP5/TP6 test point pairs from DUT board to J1/J2 and 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 set-up picture below.

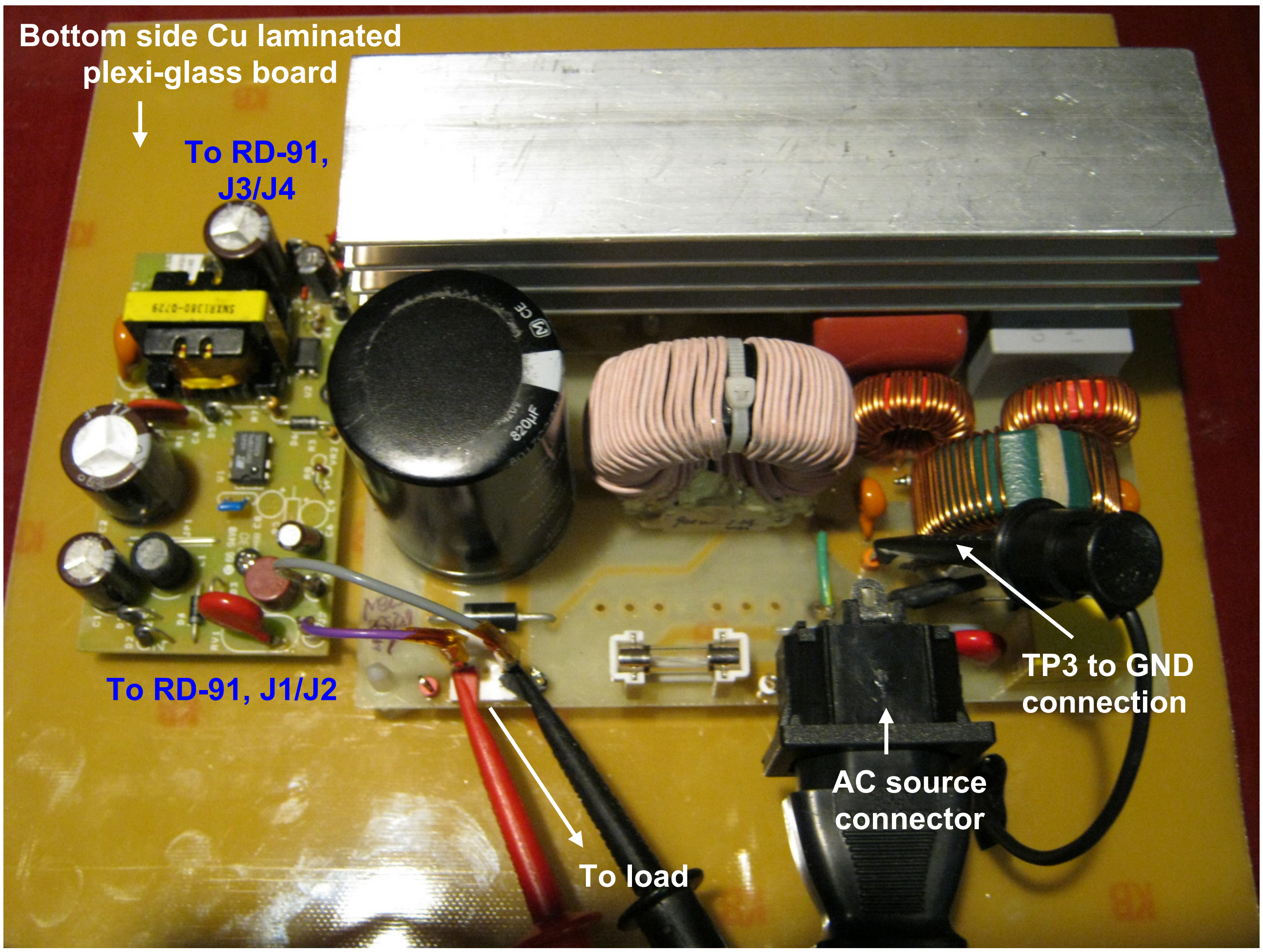

Figure 50 – EMI Test Set-up.

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15.2 EMI Scans

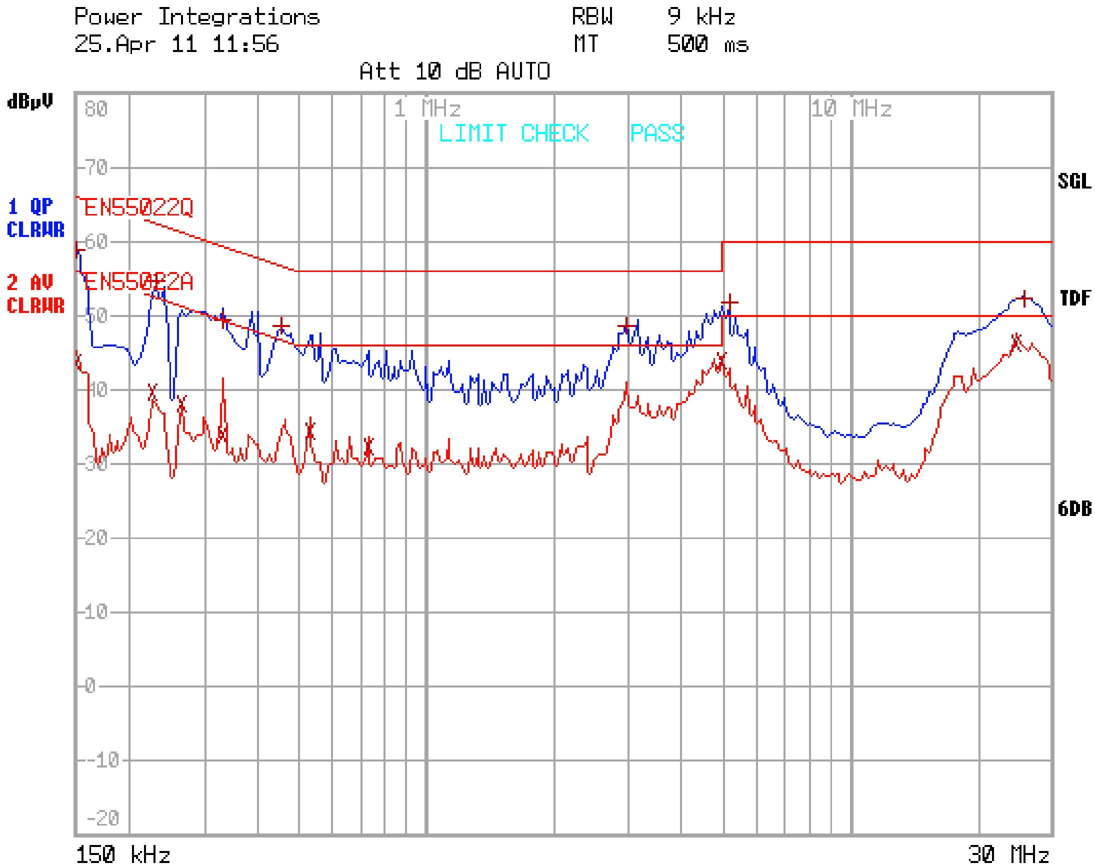

Figure 51 – 230 VAC, 100% Load.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55022Q
Trace2: EN55022A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
1	Quasi Peak	150 kHz	58.84	N gnd	-7.15
2	Average	150 kHz	43.67	N gnd	-12.32
2	Average	227.349951585 kHz	39.63	N gnd	-12.91
1	Quasi Peak	231.896950616 kHz	54.64	N gnd	-7.73
2	Average	266.376703545 kHz	38.03	N gnd	-13.20
1	Quasi Peak	331.205949542 kHz	49.52	N gnd	-9.89
2	Average	331.205949542 kHz	34.05	N gnd	-15.36
1	Quasi Peak	454.674792973 kHz	48.64	N gnd	-8.14
2	Average	532.723986492 kHz	34.46	L1 gnd	-11.54
2	Average	731.315873414 kHz	32.32	L1 gnd	-13.67
1	Quasi Peak	2.98343922331 MHz	48.76	N gnd	-7.24
2	Average	4.99254123937 MHz	43.79	L1 gnd	-2.20
1	Quasi Peak	5.19423990544 MHz	51.88	L1 gnd	-8.11
2	Average	24.8276476678 MHz	46.15	L1 gnd	-3.84
1	Quasi Peak	25.8306846336 MHz	52.29	L1 gnd	-7.70

Figure 52 – 230 VAC, 100% Load EMI Measurement Results.

16 Revision History

Date	Author	Revision	Description & changes	Reviewed
12-May-11	NZ	1.0	Initial Release	Apps & Mktg

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