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Title	<i>Reference Design Report for a High Performance 347 W PFC Stage Using HiperPFS™ PFS714EG</i>
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

PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <<http://www.powerint.com/ip.htm>>.

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Important Note:

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



1 Introduction

This document is an engineering report describing a 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 °C. 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.

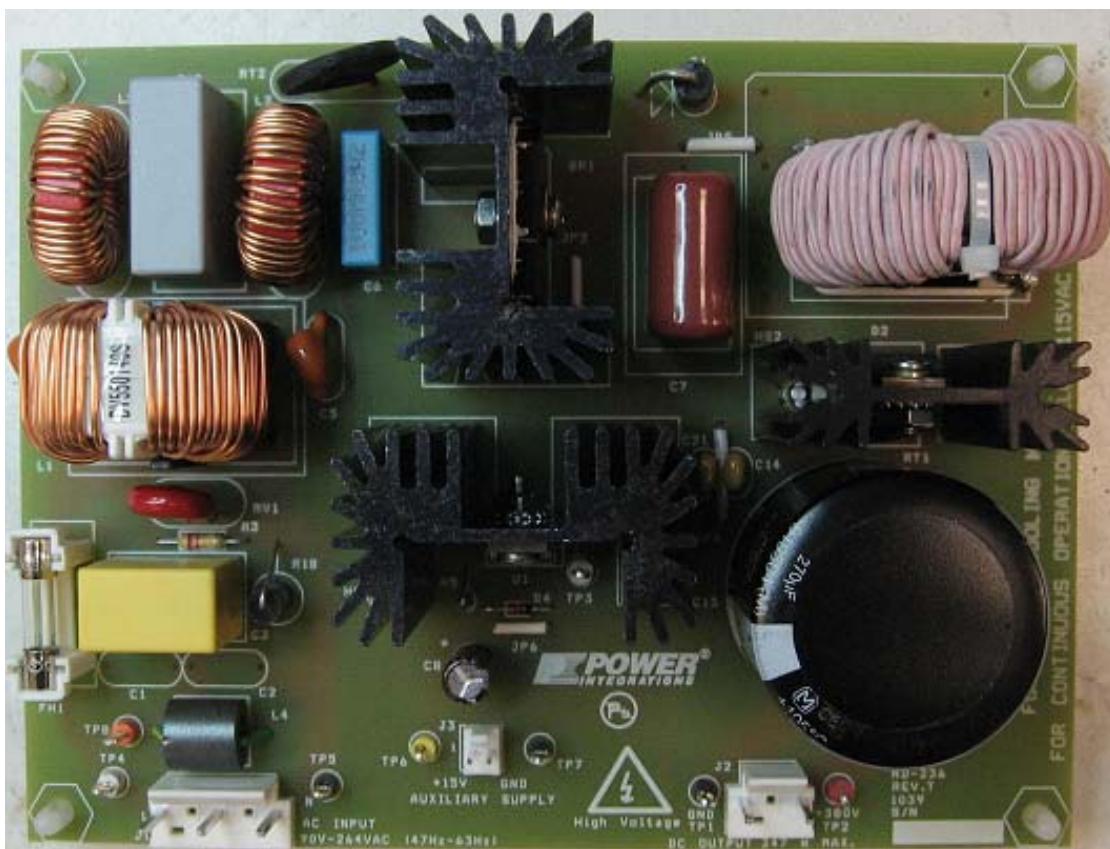


Figure 1 – Populated Circuit Board Photograph.

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 Frequency	V_{IN} f_{LINE}	90 47	50/60	264 64	VAC Hz	3 Wire
Output Output Voltage Output Ripple Voltage p-p Output Current	V_{OUT} V_{RIPPLE} I_{OUT}	370	380	390 30	V V A	20 MHz bandwidth
Total Output Power Continuous Output Power	P_{OUT}		347		W	
Efficiency Full Load Minimum efficiency at 20, 50 and 100 % of P_{OUT}	η η_{80+}	94			%	Measured at P_{OUT} 25 °C Measured at 115 VAC Input
Environmental Line Surge Differential Mode (L1-L2) Common mode (L1/L2-PE)			1 2		kV kV	1.2/50 μ s surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω 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



3 Schematic

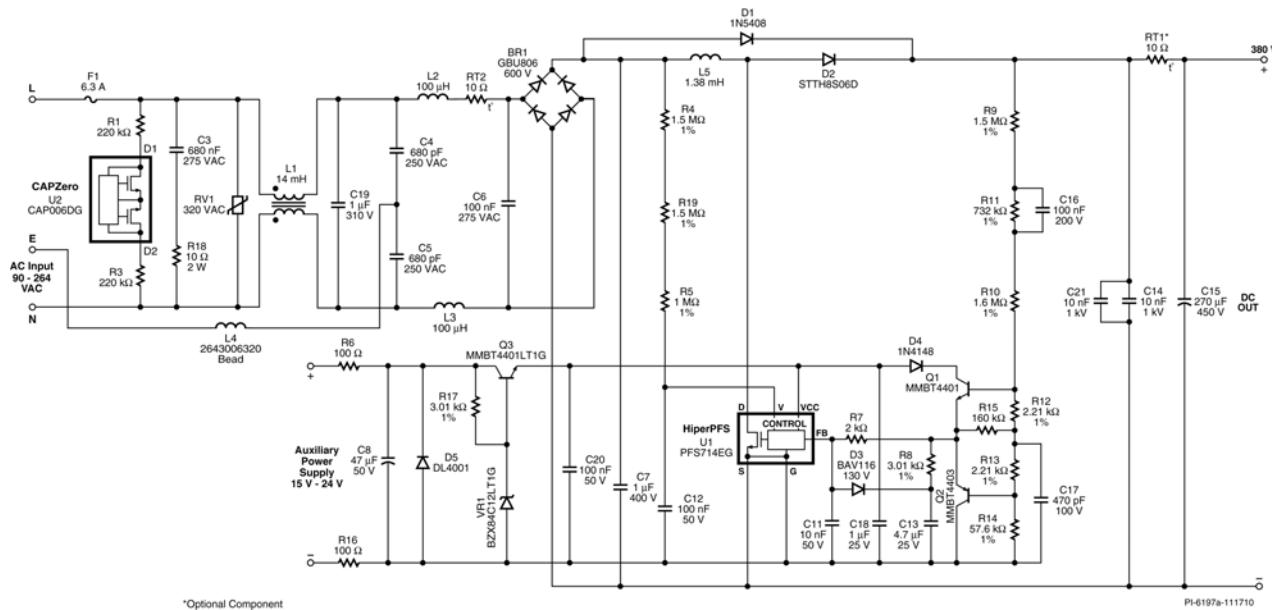


Figure 2 – Schematic.



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.



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

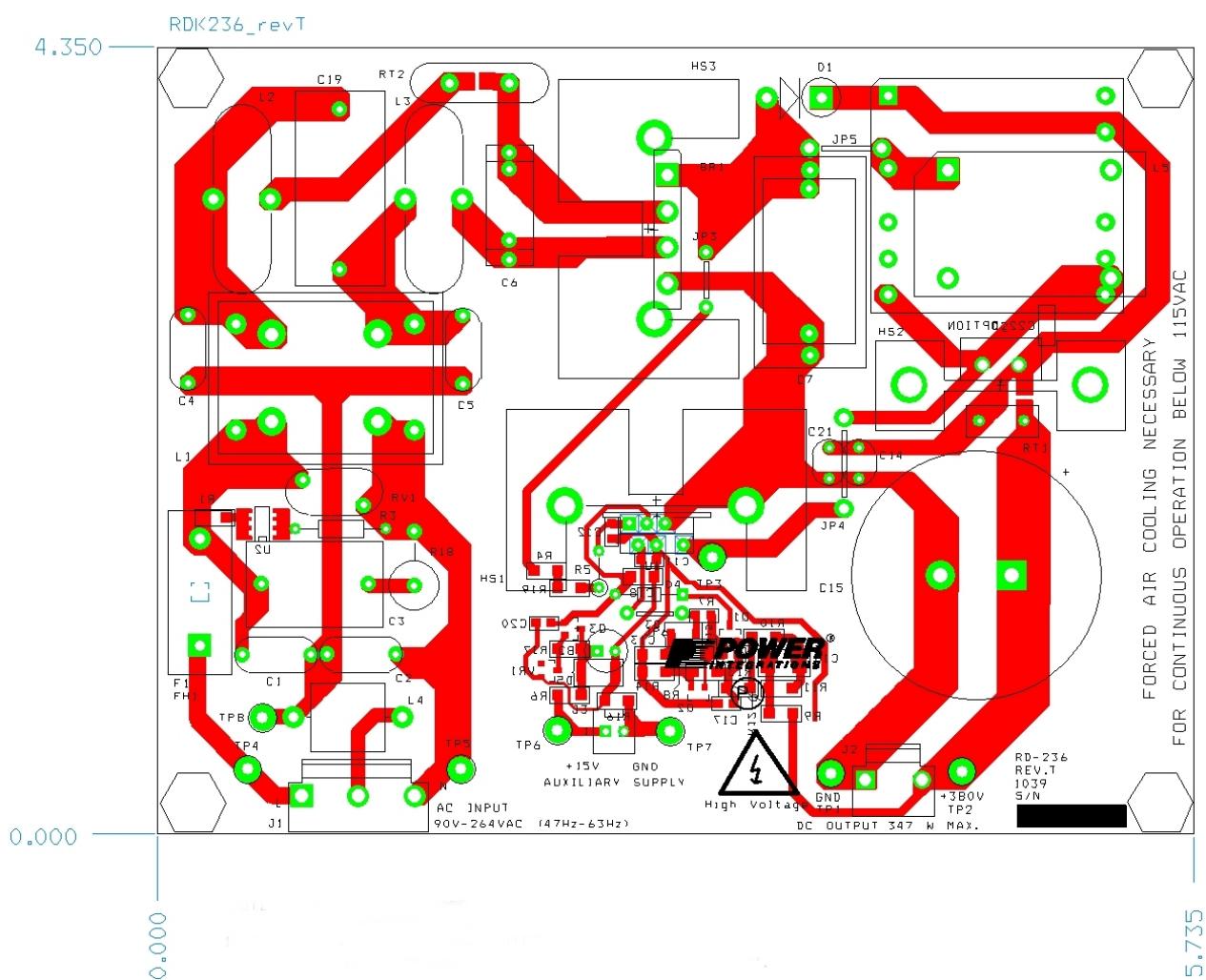


Figure 3 – Printed Circuit Layout.



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	1812C104KAT2A	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 Thermalloy
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 Thermalloy
26	1	HSPREADER ESIPP FISW1	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, 5 A, 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



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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	



7 Inductor Specification

7.1 Electrical Diagram

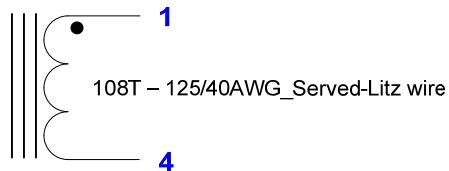


Figure 4 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 1–4 measured at kHz, 0.4 V RMS	1.38 mH, $\pm 8\%$
--------------------	-------------------------------------	--------------------

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.

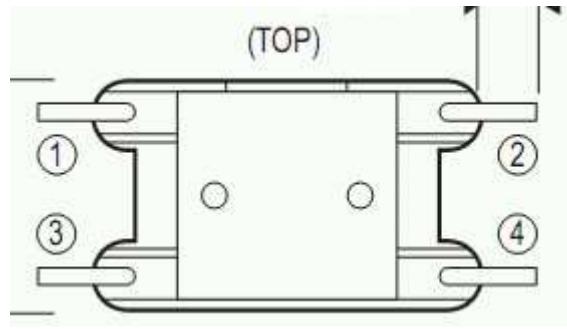
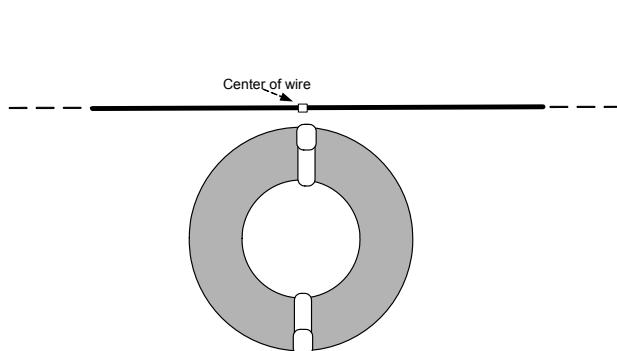


Figure 5 – Top View of Toroid Mounting Base Item [3]

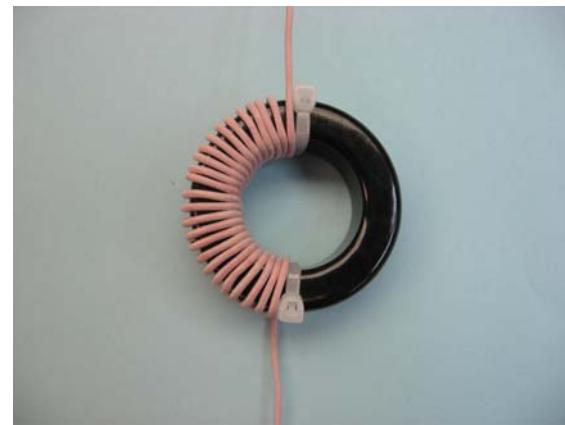
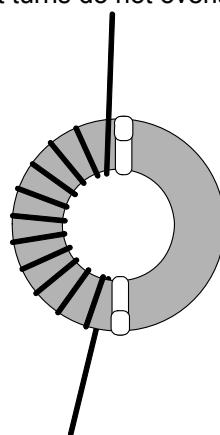


7.4 Inductor Winding Instruction

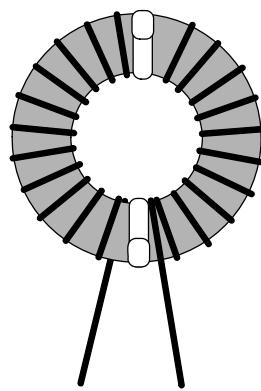
- Insert 2 dividers item [5] in the core item [1] to divide into 2 sections equally. See picture beside. Take about 15ft of wire item [2]. Align center of wire with 1 divider.



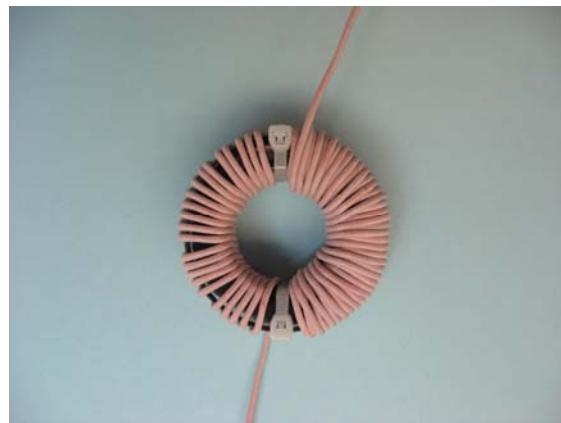
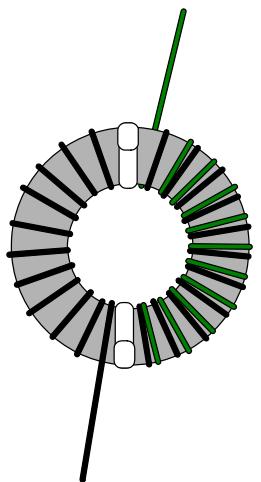
- Start winding on the left section with 23 turns of wire item [2], for the 1st layer, spread wire evenly and ensure that turns do not overlap.



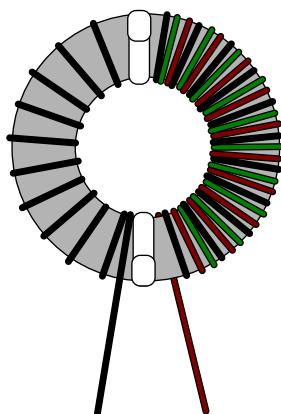
- Also wind another 23 turns on the right section.



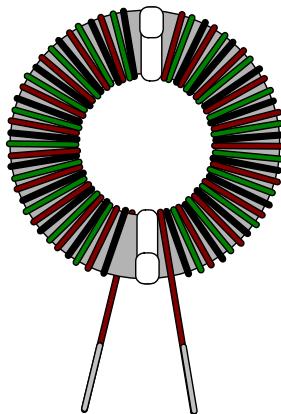
- Continue winding on the right section for the 2nd layer 18 turns, spread wire evenly and ensure that turns do not overlap.



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

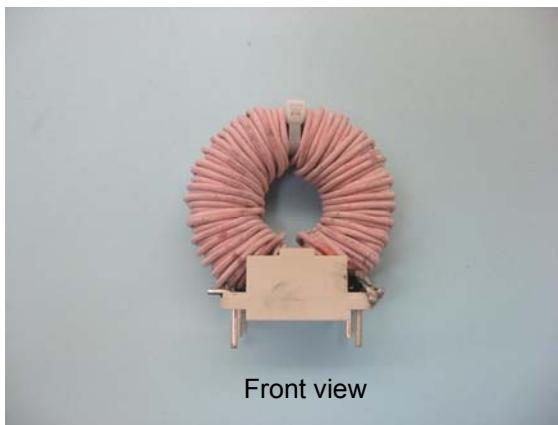


- Wind the same as above for the 2nd and 3rd layer on the left section.



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





Front view



Back view

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

Figure 6 – Finished Inductor

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)

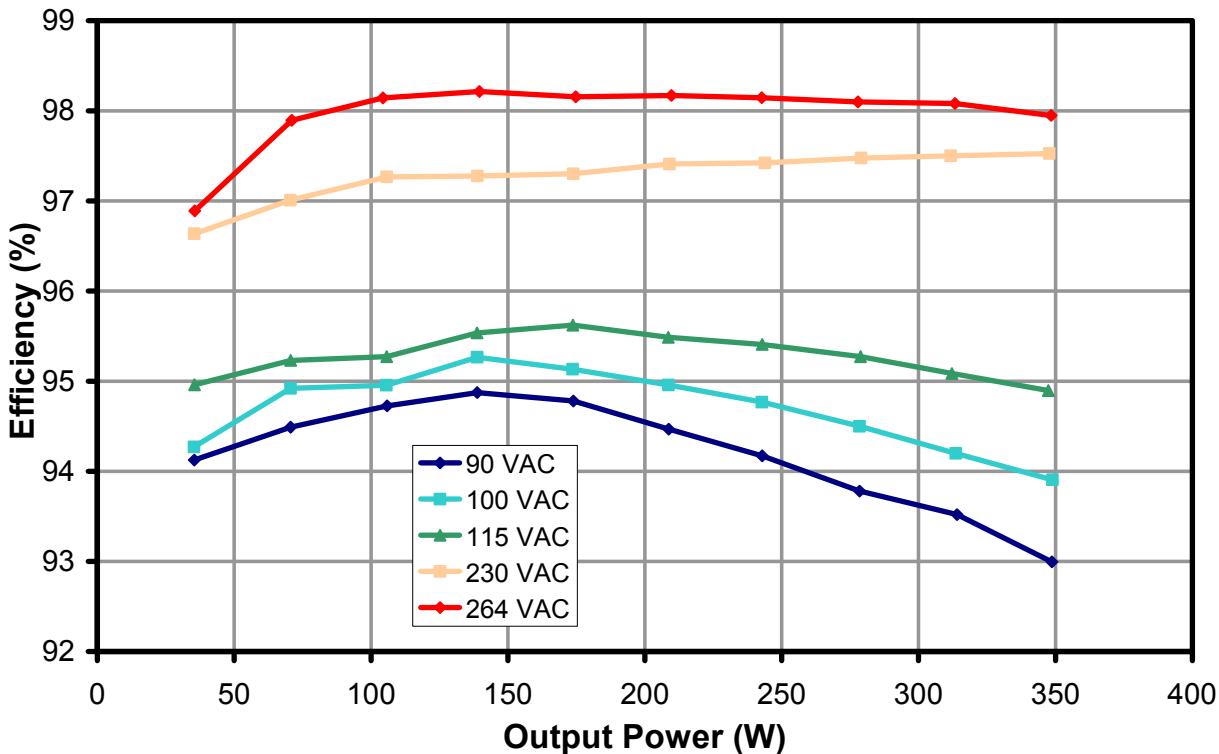


Figure 7 – Efficiency vs. Output Power.



8.2 Input Power Factor

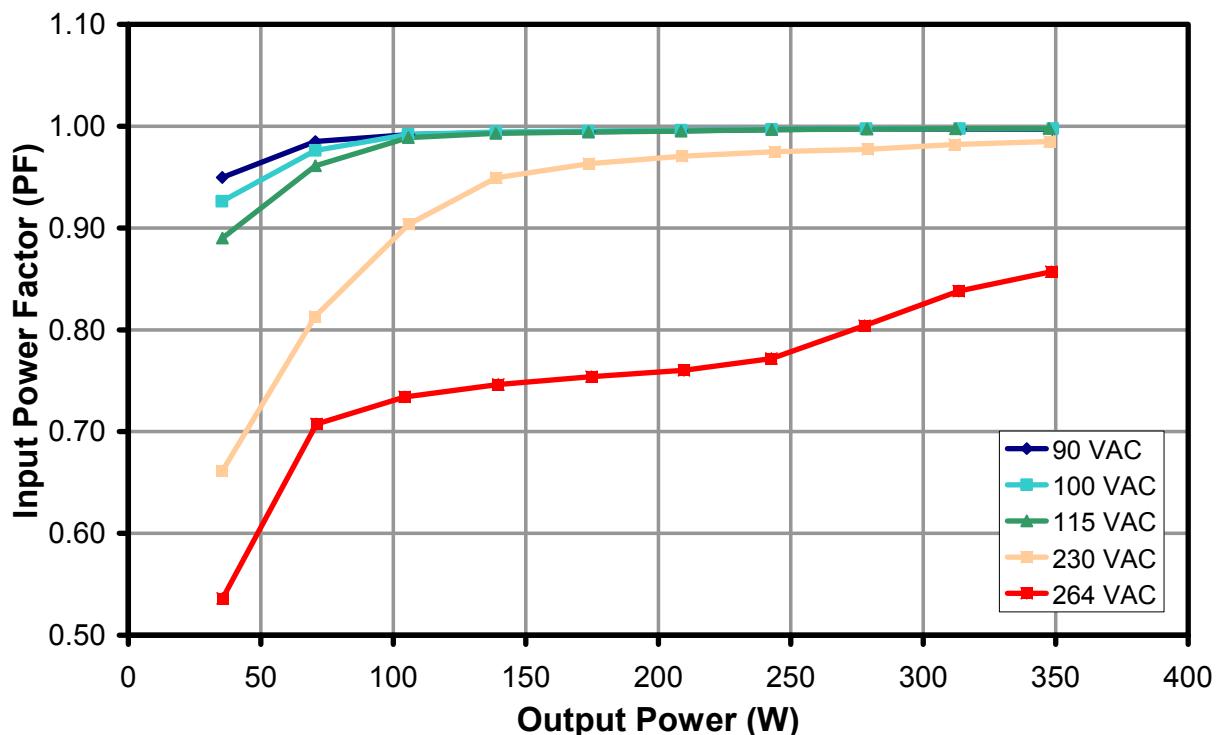


Figure 8 – Input Power Factor vs. Output Power.

8.3 Regulation

8.3.1 Load

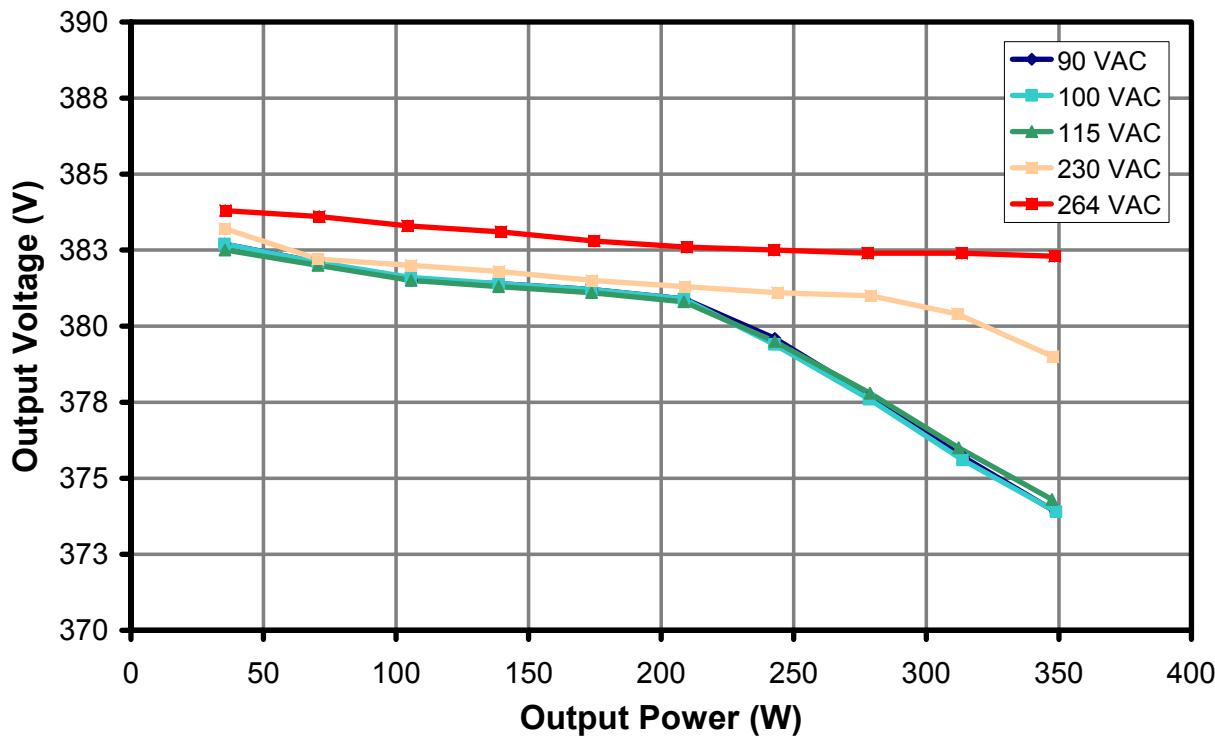


Figure 9 – Load Regulation.

8.3.2 Line

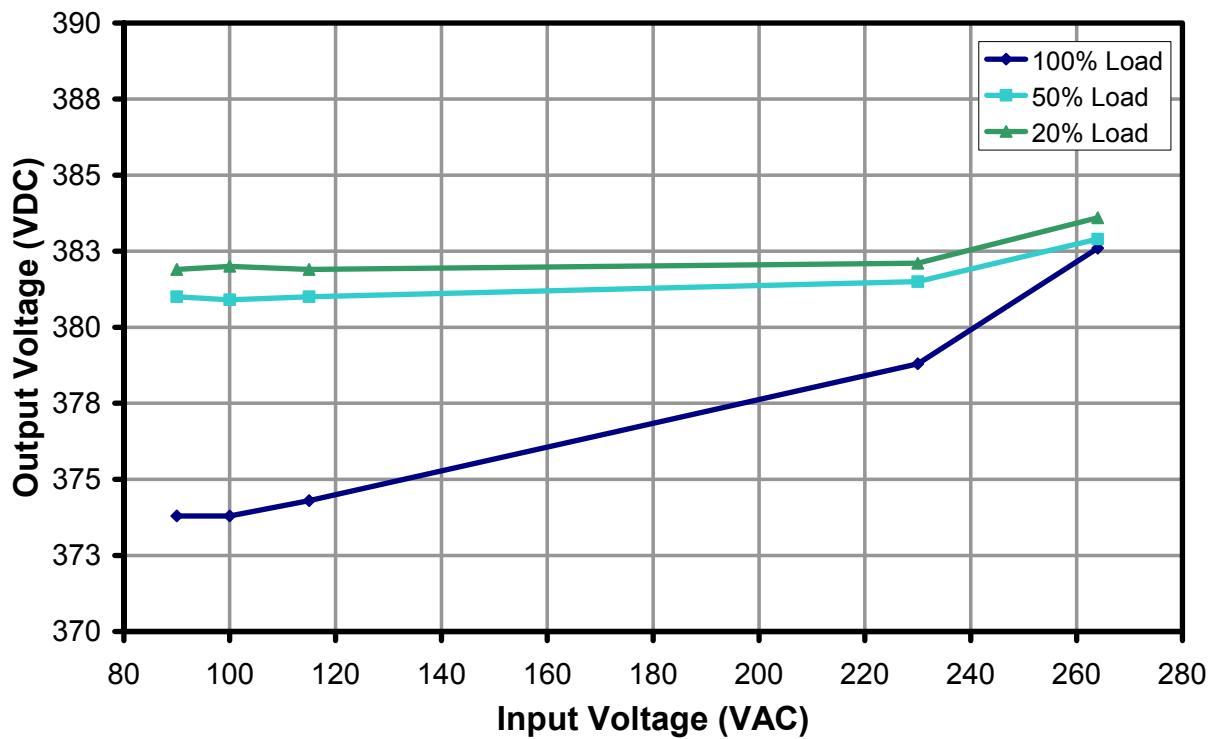


Figure 10 – Line Regulation.

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

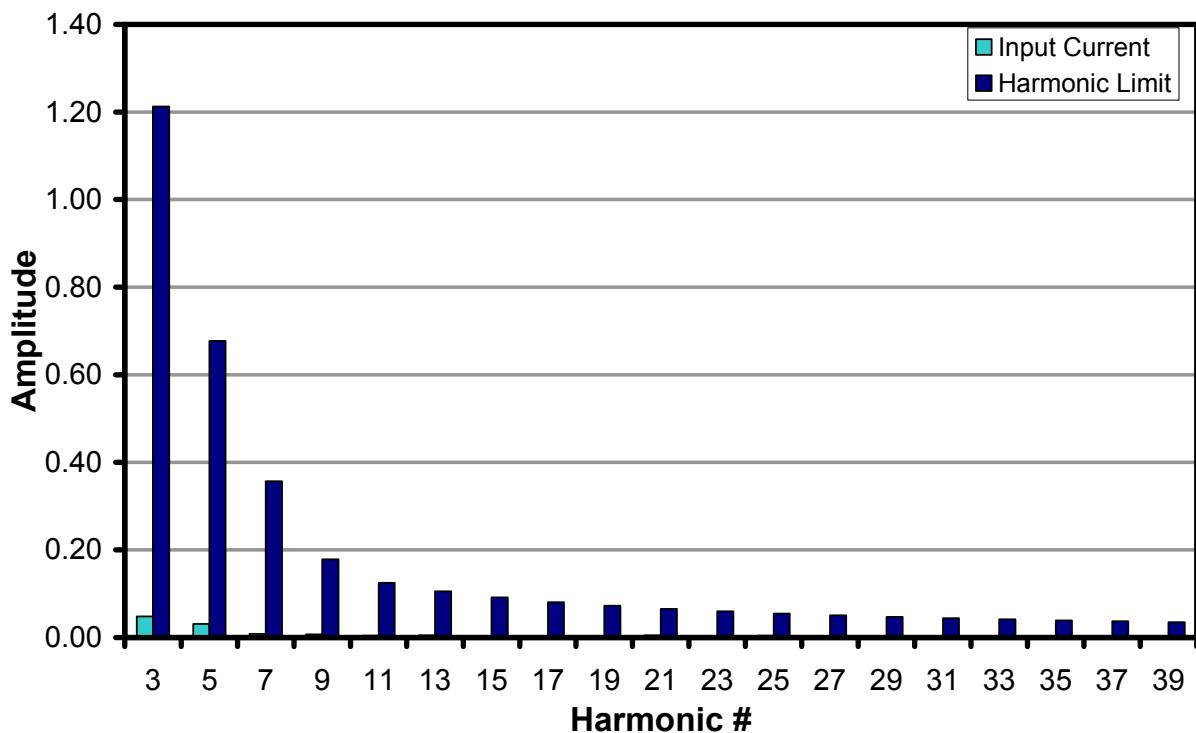


Figure 11 – Amplitude of Input Current Harmonics for 50% Load at 230 VAC Input.



8.4.2 100% Load at Output

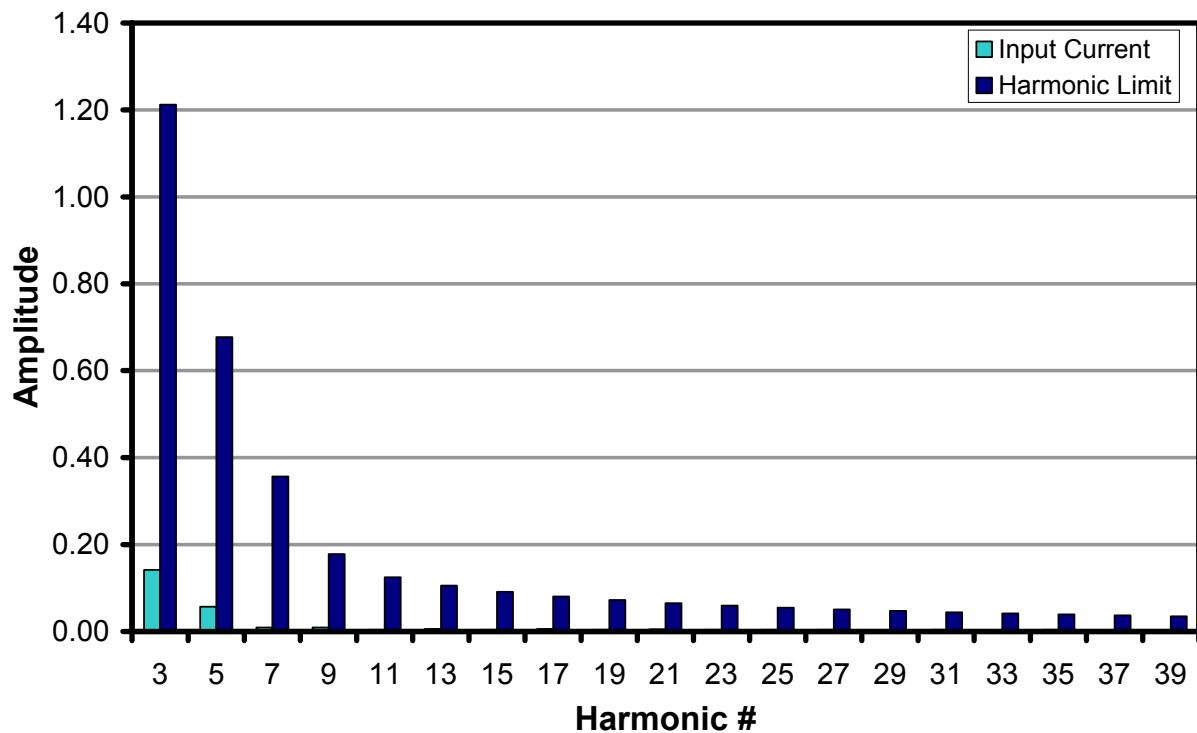


Figure 12 – Amplitude of Input Current Harmonics for 100% Load at 230 VAC Input.

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 (° 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.



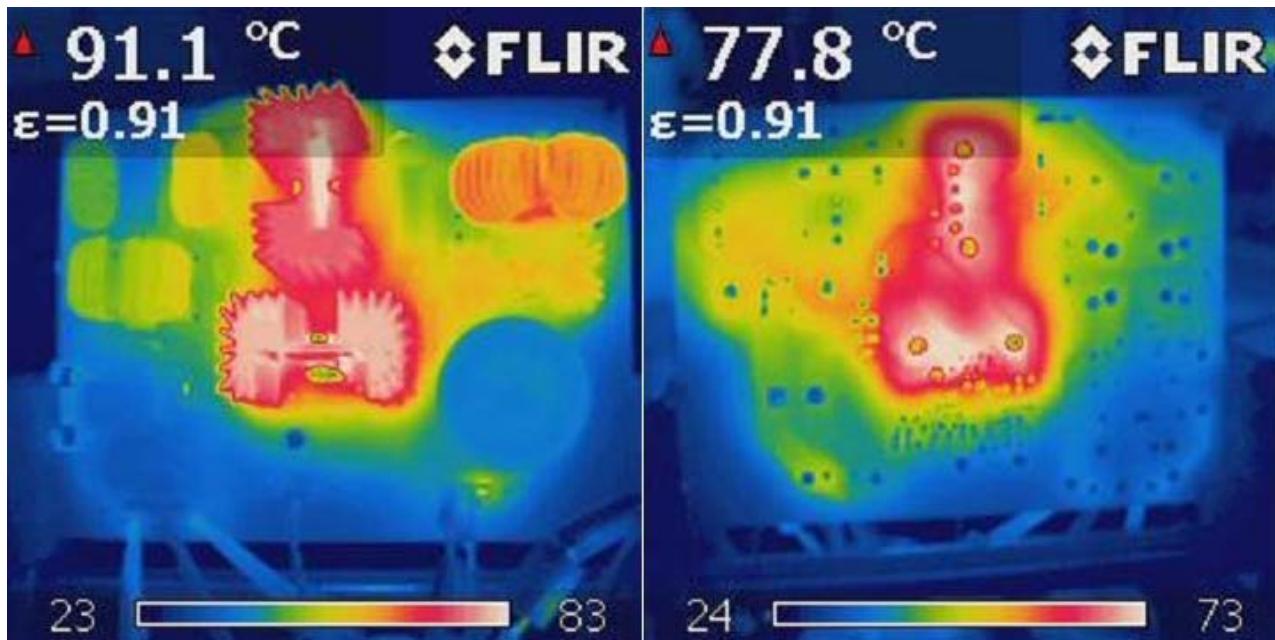


Figure 13 – Infrared Image of the Top and Bottom Side of the Board at Thermal Equilibrium. 115 VAC, Full Load, No Forced-Air Flow, 25°C Ambient.

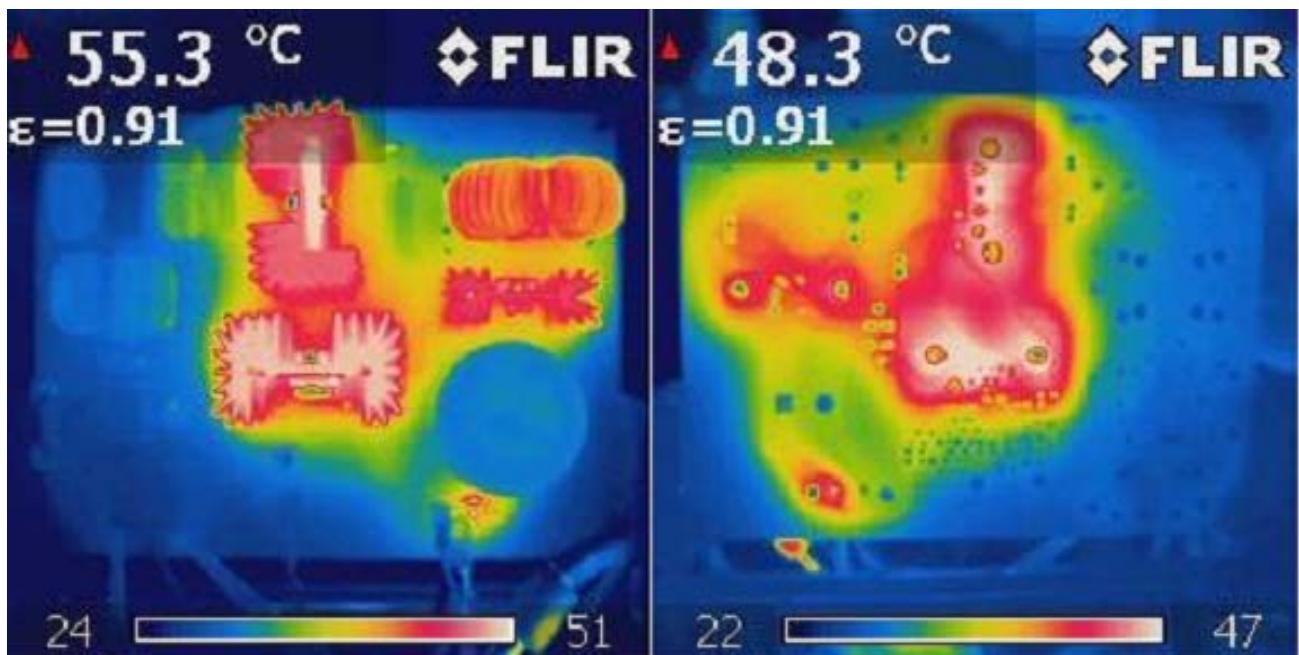


Figure 14 – Infrared Image of the Top and Bottom Sides of the Board at Thermal Equilibrium. 230 VAC, Full Load, No Forced-Air Flow, 25°C Ambient.

10 Waveforms

10.1 Input Current at 115 VAC and 60 Hz

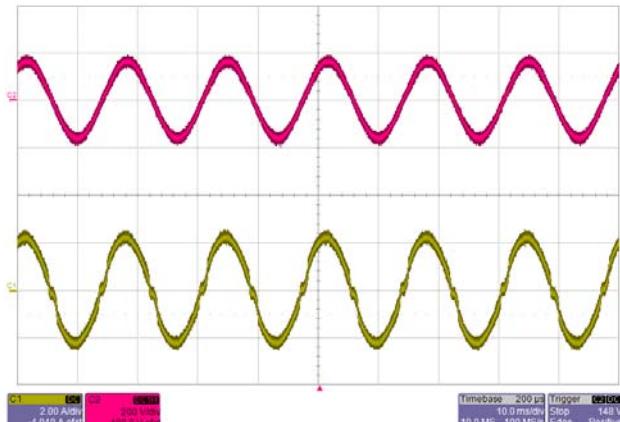


Figure 15 – 115 VAC, 50% Load.

Top: V_{IN} , 200 V / div.
Bottom: I_{IN} , 2 A, 10 ms / div.

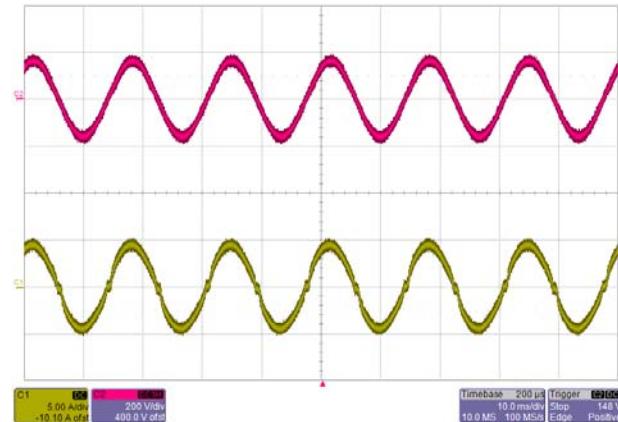


Figure 16 – 115 VAC, 100% Load.

Top: V_{IN} , 200 V / div.
Bottom: I_{IN} , 5 A, 10 ms / div.

10.2 Input Current at 230 VAC and 50 Hz

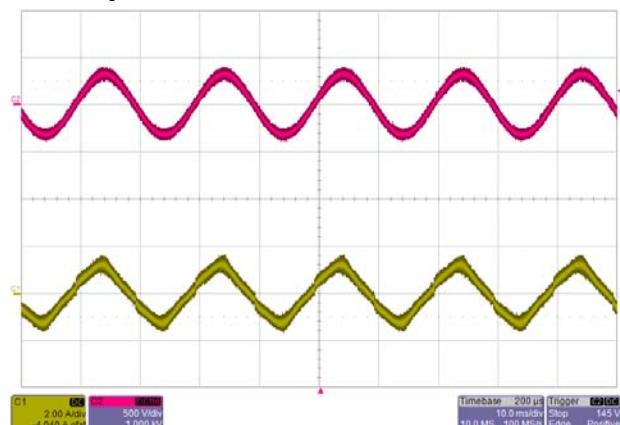


Figure 17 – 230 VAC, 50% Load.

Top: V_{IN} , 500 V / div.
Bottom: I_{IN} , 2 A, 10 ms / div.

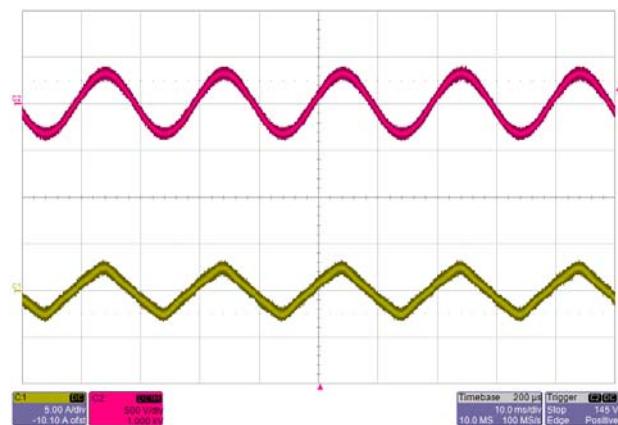


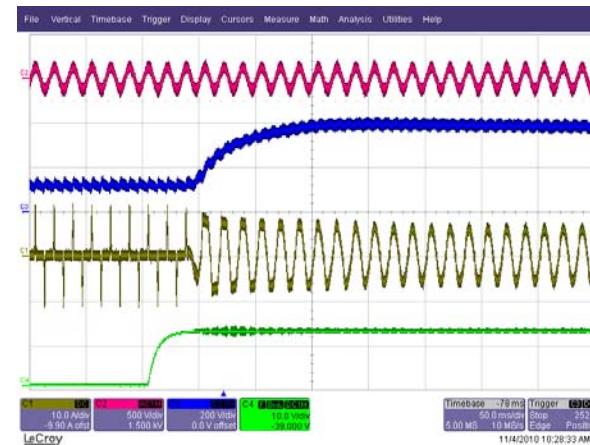
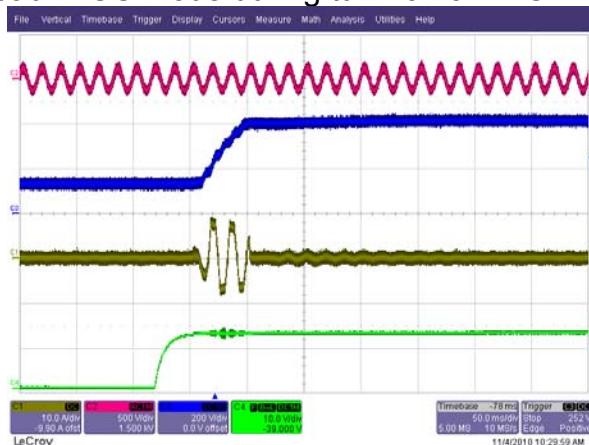
Figure 18 – 230 VAC, 100% Load.

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



10.4 Start-up at 115 VAC and 60 Hz

Load in CC mode during turn-on of PFC

