Title	***Reference Design Report for a 150 W Power Factor Corrected LLC Power Supply Using HiperPFS™ (PFS708EG), HiperLCS™ (LCS702HG), Qspeed™ (LQA05TC600), LinkSwith™-TN (LNK302DG), and CAPZero™ (CAP002DG)***
Specification	90 VAC – 265 VAC Input; 150 W (48 V at 0 - 3.125 A) Output
Application	LED Streetlight
Author	Applications Engineering Department
Document Number	RDR-292
Date	December 29, 2011
Revision	5.0

Summary and Features

- Integrated PFC stage
- Integrated LLC stage
- Continuous mode PFC using small Sendust toroidal core and standard magnet wire
- High frequency (250 kHz) LLC for small transformer size.
- Tight LLC dead-time control
- >95% full load PFC efficiency at 115 VAC
- >95% full load LLC efficiency
- System efficiency 91% / 93% at 115 VAC / 230 VAC
- >0.9 power factor at 50% and 100% Load
- Cost reduction possible if 0.9 PF not needed at 50% load

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

1 Introduction

This engineering report describes a 48 V, 150 W reference design power supply for 90-265 VAC LED street lights and also serves as a general purpose evaluation board for the combination of the PFS power factor stage with an LCS output stage.

The design is based on the PFS708EG and LQA05TC600 for the PFC front end, with a LNK302 utilized in a non-isolated flyback bias supply. An LCS702HG is used in the LLC output stage.

Figure 1 – RD-292 Photograph, Top View.

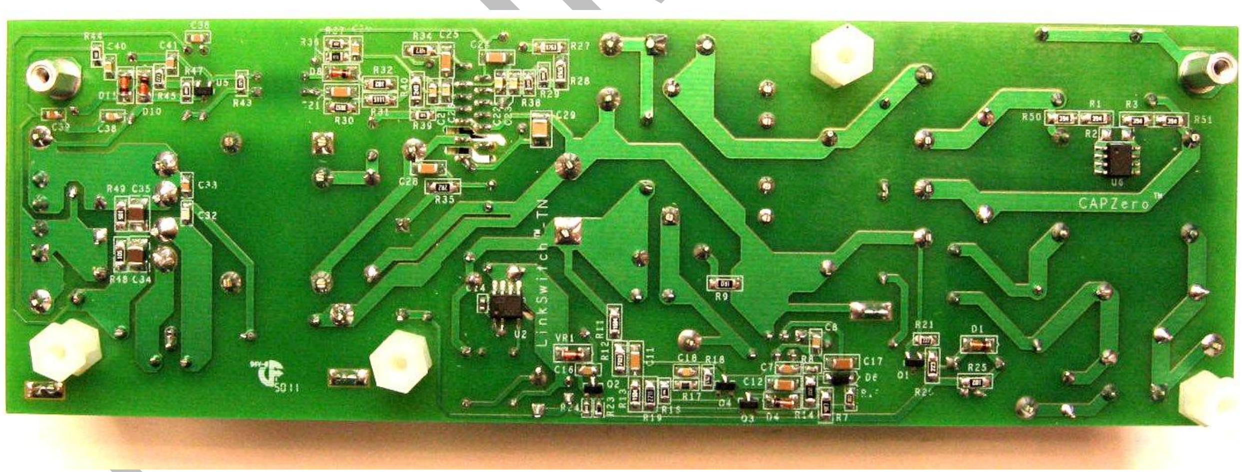

Figure 2 – RD-292 Photograph, Bottom View.

The circuit shown in this report is optimized for >0.9 power factor, 90-230 VAC, at both 100% load and 50% load. If >0.9 power factor is not required for 50% load, the circuit can be cost reduced by downsizing common mode filter L1 and PFC input capacitor C6. Contact Power Integrations for more details.

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This power supply is designed to be mounted inside a grounded enclosure for streetlight service, with the input AC safety ground connected to the chassis. EMI and line surge tests should be performed with the supply screwed down to a ground plane with the input AC safety ground connected to this plane. See set-up photographs in sections 13.1 and 15.1.

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		265	VAC	3 Wire input.
Frequency	f_{LINE}	47	50/60	64	Hz	
Power Factor	**PF**	0.97				Full load, 230 VAC
Main Converter Output						
Output Voltage	V_{LG}	45.6	48	50.4	V	48 VDC ± 5%
Output Ripple	$V_{RIPPLE(LG)}$			150	mV P-P	20 MHz bandwidth
Output Current	I_{LG}	0.00	3.13	3.13	A	Supply is protected for no-load condition
Total Output Power						
Continuous Output Power	P_{OUT}		150		W	
Peak Output Power	$P_{OUT(PK)}$			N/A	W	
Efficiency						
Total system at Full Load	η_{Main}	91 93			%	Measured at 115 VAC, Full Load Measured at 230 VAC, Full Load
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Surge						1.2/50 µs surge, IEC 1000-4-5,
Differential		2			kV	Differential Mode: 2 Ω
Common Mode		4			kV	Common Mode: 12 Ω
100 kHz Ring Wave		4			kV	500 A short circuit current
Ambient Temperature	T_{AMB}	0		60	°C	See thermal section for conditions

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3 Schematic

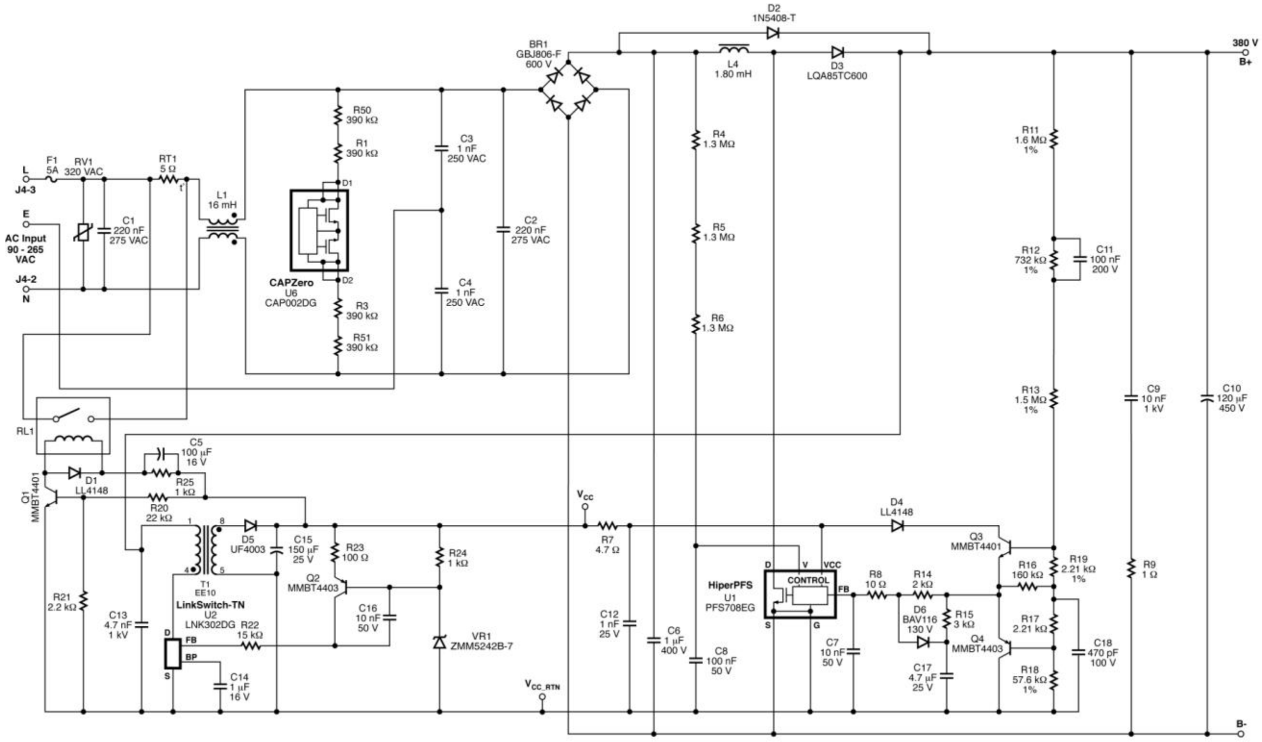

Figure 3 – Schematic RD-292 Streetlight Power Supply Application Circuit - Input Filter, PFC Power Stage, and Bias Supply.

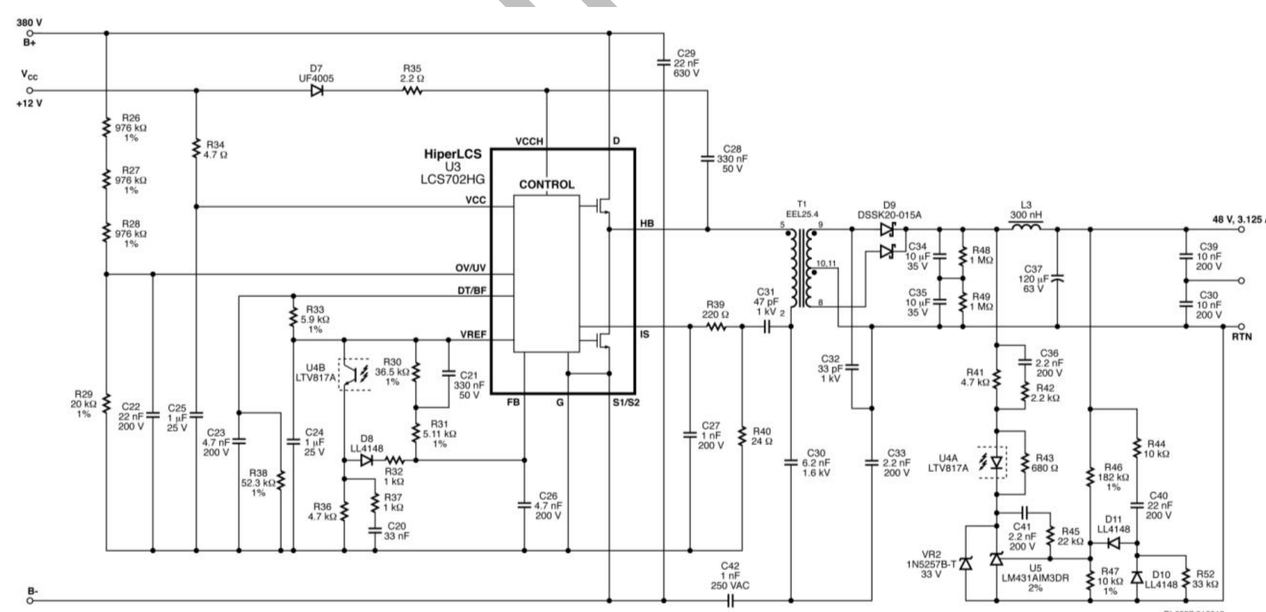

Figure 4 – Schematic of RD-292 Streetlight Power Supply Application Circuit, LLC Stage.

4 Circuit Description

The circuit shown in Figures 3 and 4 utilizes the PFS708BG, the LQA05TC600, the LCS702HG, the LNK302D, and the CAP002DG (optional) in a 48V, 150 W power factor corrected LLC power supply intended to power an LED streetlight.

4.1 Input Filter / Boost Converter/Bias Supply

The schematic in Figure 3 shows the input EMI filter, PFC stage, and primary bias supply/start-up circuit. The power factor corrector utilizes the PFS708EG and the LQA05TC600. The bias supply is a non-isolated flyback using the LNK302DG.The CAP002DG is used to discharge X capacitors C1 and C2 in applications where low-load efficiency is of paramount importance.

4.1.1 EMI Filtering

Capacitors C3 and C4 are used to control common mode noise. Inductor L1 controls EMI at low frequencies and the mid-band (~10 MHz), respectively. Capacitors C1 and C2 together with leakage reactance of inductor L1 provide differential mode EMI filtering. To meet safety requirements resistors R1-3 and R50 discharge these capacitors when AC is removed. For higher efficiency, a CAPZero IC (U6) can be used to discharge C1 and C2. If U6 is used, resistor R2 should be omitted. The primary heat sink for U1, U3, D3 and BR1 is connected to primary return to eliminate the heat sink as a source of radiated/capacitively coupled noise.

4.1.2 Inrush limiting

Thermistor RT1 provides inrush limiting. It is shorted by relay RL1 during normal operation, gated by activation of the internal bias supply (see components Q1, R21-22), increasing efficiency by approximately 1 - 1.5%.

4.1.3 Main PFC Stage

Components C6, C10, L4, U1, and D3 form a boost power factor correction circuit. Components Q3-4, D4, and R16 form a non-linear feedback sense circuit (R11-13, R17-19, C11, and C18) to drive the U1 feedback pin. This configuration achieves extremely fast transient response while simultaneously enabling a slow feedback loop to achieve a low Gain-BW product. A Qspeed ultrafast soft recovery diode was selected for D3 as a lower cost alternative to a silicon carbide diode.

Capacitor C8 provides local bypassing for U1. Components R7 and C12 filter the VCC supply for U10. Diode D2 charges the PFC output capacitor (C10) when AC is first applied. This routes the inrush current around the PFC inductor L4, preventing it from saturating and causing stress to U1 when the PFC stage begins to operate. It also routes the bulk of the inrush current away from PFC rectifier D3. Capacitor C9 and R9 are used to shrink the high frequency loop around components U1, D3 and C10 to reduce EMI. A resistor in series with C9 damps mid-band EMI peaks. The incoming AC is rectified by BR1 and filtered by C6. Capacitor C6 was selected as a low-loss polypropylene type to provide the high instantaneous current through L4 during U1 on-time.

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4.1.4 Primary Bias Supply/Startup

Components U2, T1, D5, C14-16, R22-R24, Q2, and VR1 comprise a simple low power non-isolated flyback supply to provide auxiliary power. Transformer T1 is very small, utilizing an EE10 core. Careful transformer design allows operation without a drain snubber for U2. Components Q2, VR1 R22-24, and C16 comprise the voltage sense, error amplifier, and feedback for U2. Capacitor C13 provides local high-voltage bypassing for U2.

Transistor Q1 switches on relay RL1 when the primary bias supply reaches regulation, shorting out thermistor RT1.

4.2 LLC Converter

The schematic in Figures 4 depicts a 48 V, 150 W LLC DC-DC converter implemented using the LCS702HG.

4.3 Primary

Integrated circuit U3 incorporates the control circuitry, drivers and output MOSFETs necessary for an LLC resonant half-bridge (HB) converter. The HB output of U3 drives output transformer T2 via a blocking/resonating capacitor (C30). This capacitor was rated for the operating ripple current and to withstand the high voltages present during fault conditions.

Transformer T2 was designed for a leakage inductance of 50 μH. This, along with resonating capacitor C30, sets the primary series resonant frequency at ~283 kHz according to the equation:

$$f_R = \frac{1}{6.28\sqrt{L_L \times C_R}}$$

Where f_R is the series resonant frequency in Hertz, L_L is the transformer leakage inductance in Henries, and C_R is the value of the resonating capacitor (C30) in Farads.

The transformer turns ratio was set by adjusting the primary turns such that the operating frequency at nominal input voltage and full load is close to, but slightly less than, the previously described resonant frequency.

An operating frequency of 250 kHz was found to be a good compromise between transformer size, output filter capacitance (enabling ceramic capacitors), and efficiency.

The number of secondary winding turns was chosen to provide a good compromise between core and copper losses. AWG #44 Litz wire was used for the primary and AWG #42 Litz wire, for the secondary, this combination providing high-efficiency at the operating frequency (~250 kHz). The number of strands within each gauge of Litz wire was chosen as a balance between winding fit and copper losses.

The core material selected was NC-2H (from Nicera). This material yielded acceptable (low-loss) performance however selecting a material more suited for high-frequency operation, such as PC95 (from TDK), would further reduce core loss and increase efficiency.

Components D7, R35, and C28 comprise the bootstrap circuit to supply the internal high-side driver of U1.

Components C25 and R34, provide filtering and bypassing of the +12 V input which is the V_{CC} supply for U3. *Note: V_{CC} voltage of >15 V may damage U3.*

Voltage divider R26-29 sets the high-voltage turn-on, turn-off, and overvoltage thresholds of U3. The voltage divider values are chosen to set the LLC turn-on point at 360 VDC and the turn-off point at 285 VDC, with an input overvoltage turn-off point at 473 VDC. Built-in hysteresis sets the input undervoltage turn-off point at 280 VDC.

Capacitor C29 is a high-frequency bypass capacitor for the +380 V input, connected with short traces between the D and S1/S2 pins of U3.

Capacitor C31 forms a current divider with C30, and is used to sample a portion of the primary current. Resistor R40 senses this current, and the resulting signal is filtered by R39 and C27. Capacitor C31 should be rated for the peak voltage present during fault conditions, and should use a stable, low-loss dielectric such as metalized film, SL ceramic, or NPO/COG ceramic. The capacitor used in the RD-292 is a ceramic disc with "SL" temperature characteristic, commonly used in the drivers for CCFL tubes. The values chosen set the 1 cycle (fast) current limit at 5.5 A, and the 7-cycle (slow) current limit at 3 A, according to the equation:

$$I_{CL} = \frac{0.5}{\left(\frac{C31}{C30 + C31}\right) \times R40}$$

I_{CL} is the 7-cycle current limit in Amperes, R40 is the current limit resistor in Ohms, and C30 and C31 are the values of the resonating and current sampling capacitors in nanofarads, respectively. For the one-cycle current limit, substitute 0.9 V for 0.5 V in the above equation.

Resistor R39 and capacitor C27 filter primary current signal to the IS pin. Resistor R39 is set to 220 Ω, the minimum recommended value. The value of C27 is set to 1 nF to avoid nuisance tripping due to noise, but not so high as to substantially affect the current limit set values as calculated above. These components should be placed close to the IS pin for maximum effectiveness. The IS pin can tolerate negative currents, the current sense does not require a complicated rectification scheme.

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The Thevenin equivalent combination of R33 and R38 sets the dead-time at 290 ns and maximum operating frequency for U1 at 934 kHz. The F_{MAX} input of U1 is filtered by C23. The combination of R33 and R138 also selects burst mode “2” for U3. This sets the lower and upper burst threshold frequencies at 366 kHz and 427 kHz, respectively.

The FEEDBACK pin has an approximate characteristic of 2.6 kHz per μA into the FEEDBACK pin. As the current into the FEEDBACK pin increases so does the operating frequency of U3, reducing the output voltage. The series combination of R30 and R31 sets the minimum operating frequency for U3, at ~187 kHz. This value was set to be lower than the frequency required for regulation a full load and minimum bulk capacitor voltage. Resistor R30 is bypassed by C21 to provide output soft start during start-up by initially allowing a higher current to flow into the FEEDBACK pin when the feedback loop is open. This causes the switching frequency to start high and then decrease until the output voltage reaches regulation. Resistor R31 is typically set at the same value as the combination of R33 and R38 so that the initial frequency at soft-start is equal to the maximum switching frequency as set by R33 and R38. If the value of R31 is less than this, it will cause a delay before switching occurs when the input voltage is applied.

Optocoupler U4 drives the U3 FEEDBACK pin through R32 which limits the maximum optocoupler current into the FEEDBACK pin. Capacitor C26 filters the FEEDBACK pin. Resistor R36 loads the optocoupler output to force it to run at a relatively high quiescent current, increasing its gain. Resistors R32 and R36 also improve large signal step response and burst mode output ripple. Diode D8 isolates R36 from the F_{MAX}/soft start network.

4.4 Output Rectification

The output of transformer T1 is rectified and filtered by D9 and C34-35. These capacitors are X5R dielectric, carefully chosen for output ripple current rating. Standard Z5U capacitors will *not* work in this application. Output Rectifier D9 is a 150 V Schottky rectifier chosen for high efficiency, Intertwining the transformer secondary halves (see transformer construction details in section 8) reduces leakage inductance between the two secondary halves, reducing the worst-case PIV and allowing use of a 150V Schottky diode with consequent higher efficiency. Additional output filtering is provided by L3 and C37. Capacitor C37 also damps the LLC output impedance peak at ~30 kHz caused by the LLC “virtual” output series R-L and ceramic output capacitors C34 and C35. It also improves the response to fast, high amplitude load steps. Resistors R48-49 force equal voltage across C34 and C35 by swamping out the effects of any internal or external leakage currents.

Resistors R46 and R47, along with the U5 reference voltage, set the output voltage of the supply. Error amplifier U5 drives the feedback optocoupler U4 via R41. Zener diode VR2 clamps the voltage across U5 to a value below its maximum 35 V rating. Components C20, C36, and C41, R37, R42, R45, and R41 determine the gain-phase characteristics of the supply. These values were chosen to provide stable operation at nominal and extreme load/input voltage combinations. Resistor R43 allows the minimum required operating current to flow in U5 when no current flow occurs in the LED of optocoupler U4. Components C40, R44 and D10-11 are a soft finish network used to eliminate output overshoot at turn-on.

4.5 Secondary EMI Components

Capacitor C74 is a Y1 capacitor that provides common mode filtering for frequencies up to ~15 MHz. Capacitors C94 and C95 are connected from the +48 V output and return to chassis ground through an aluminum spacer. These capacitors suppress common mode mid-to-high frequencies.

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5 PCB Layout

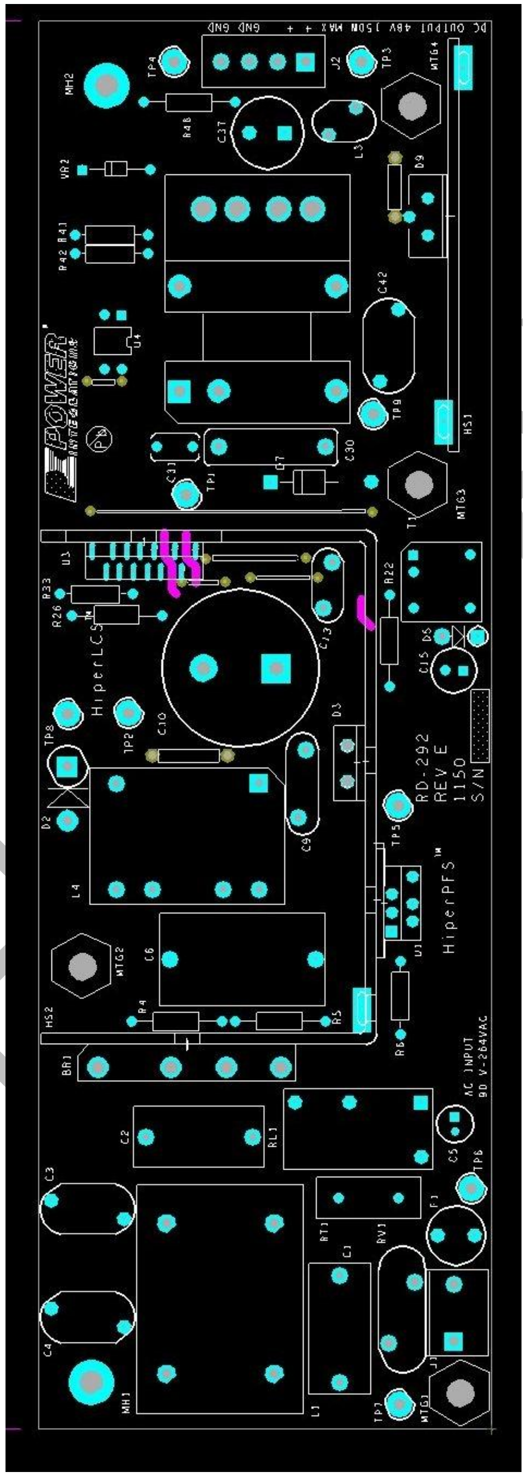

Figure 5 – Printed Circuit Layout, Top Side.

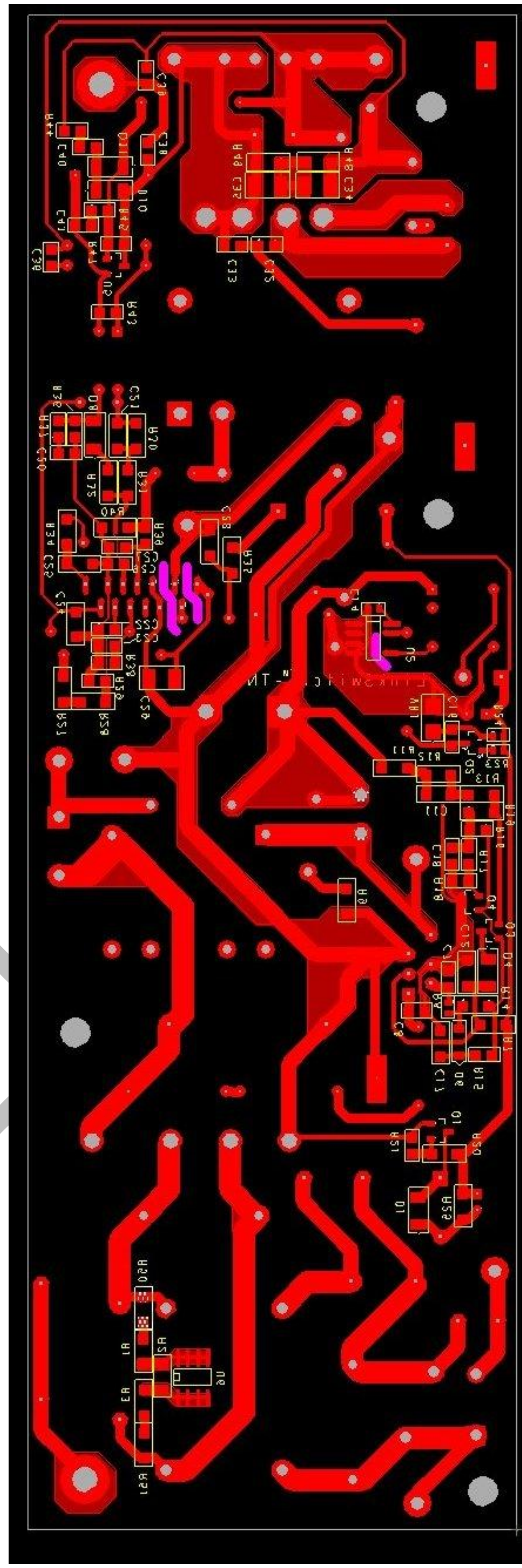

Figure 6 – Printed Circuit Layout, Bottom Side.

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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, GBJ Package	GBJ806-F	Diodes, Inc.
2	2	C1 C2	220 nF, 275 VAC, Film, X2	ECQ-U2A224ML	Panasonic
3	3	C3 C4 C42	1 nF, Ceramic, Y1	440LD10-R	Vishay
4	1	C5	100 μF, 16 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG160ELL101ME11D	Nippon Chemi-Con
5	1	C6	1 μF, 400 V, Polypropylene Film	ECW-F4105JL	Panasonic
6	2	C7 C16	10 nF, 50 V, Ceramic, X7R, 0805	C0805C103K5RACTU	Kemet
7	1	C8	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
8	1	C9	10 nF, 1000 V, Disc Ceramic	S103K75Y5PN83K0R	Vishay
9	1	C10	120 μF, 450 V, Electrolytic, (22 x 430)	EET-ED2W121BA	Panasonic
10	1	C11	100 nF, 200 V, Ceramic, X7R, 1206	C1206C104K2RACTU	Kemet
11	3	C12 C24 C25	1 μF, 25 V, Ceramic, X7R, 1206	HMK316B7105KL-T	Taiyo Yuden
12	1	C13	4.7 nF, 1 kV, Thru Hole, Disc Ceramic	562R5GAD47	Vishay
13	1	C14	1 μF, 16 V, Ceramic, X5R, 0603	GRM188R61C105KA93D	Murata
14	1	C15	150 μF, 25 V, Electrolytic, Low ESR, 180 mΩ, (6.3 x 15)	ELXZ250ELL151MF15D	Nippon Chemi-Con
15	1	C17	4.7 μF, 25 V, Ceramic, X7R, 1206	ECJ-3YB1E475M	Panasonic
16	1	C18	470 pF, 100 V, Ceramic, X7R, 0805	08051C471KAT2A	AVX
17	1	C20	33 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H333K	Panasonic
18	2	C21 C28	330 nF, 50 V, Ceramic, X7R, 1206	12065C334KAT2A	AVX
19	2	C22 C40	22 nF, 200 V, Ceramic, X7R, 0805	08052C223KAT2A	AVX
20	2	C23 C26	4.7 nF, 200 V, Ceramic, X7R, 0805	08052C472KAT2A	AVX
21	1	C27	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
22	1	C29	22 nF, 630 V, Ceramic, X7R, 1210	GRM32QR72J223KW01L	Murata
23	1	C30	6.2 nF, 1600 V, Film	B32672L1622J000	Epcos
24	1	C31	47 pF, 1 kV, Disc Ceramic	DEA1X3A470JC1B	Murata
25	1	C32	33 pF, 1000 V, Ceramic, COG, 0805	0805AA330KAT1A	AVX
26	3	C33 C36 C41	2.2 nF, 200 V, Ceramic, X7R, 0805	08052C222KAT2A	AVX
27	2	C34 C35	10 μF, 35 V, Ceramic, X5R, 1210	GMK325BJ106KN-T	Taiyo Yuden
28	1	C37	120 μF, 63 V, Electrolytic, Gen. Purpose, (10 x 16)	EKZE630ELL121MJ16S	United Chemi-con
29	2	C38 C39	10 nF, 200 V, Ceramic, X7R, 0805	08052C103KAT2A	AVX
30	5	D1 D4 D8 D10 D11	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diodes, Inc.
31	1	D2	1000 V, 3 A, Recitifier, DO-201AD	1N5408-T	Diodes, Inc.
32	1	D3	600 V, 5 A, TO-220AC	LQA05TC600	Power Integrations
33	1	D5	200 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4003-E3	Vishay
34	1	D6	130 V, 5%, 250 mW, SOD-123	BAV116W-7-F	Diodes, Inc.
35	1	D7	600 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4005-E3	Vishay
36	1	D9	150 V, 20 A, Schottky, TO-220AB	DSSK 20-015A	IXYS
37	2	ESIPCLIP M4 METAL1 ESIPCLIP M4 METAL2	Heat sink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk	NP975864	Aavid Thermalloy
38	1	F1	5 A, 250V, Slow, TR5	37215000411	Wickman
39	1	HS1	Heat sink, RDK292-Diode, Alum 1.300 H x 2.270 W x 0.062" Thk"	61-00071-01	Custom
40	1	HS2	Heat sink, RDK292-eSIP,Alum 1.85 L x 2.840 W x 0.062" Thk"		Custom
41	1	HSPREADER_ESIPPFISW1	Heat Spreader, Custom, Al, 3003, 0.030 Thk"	61-00040-00	Custom

42	1	J1	3 Position (1 x 3) header, 0.156 pitch, Vertical	B3P-VH	JST
43	1	J2	4 Position (1 x 4) header, 0.156 pitch, Vertical	26-48-1045	Molex
44	1	L1	16 mH, 2 A, Common Mode Choke	ELF-22V020C	Panasonic
45	1	L3	Custom, 300 nH, ±15%, constructed on Micrometals T30-26 toroidal core		Power Integrations
46	1	L4	Custom, 1.8 mH, constructed on VTM-1050-10 base		Custom
47	4	MTG1 MTG2 MTG3 MTG4	Post, Circuit Board, Female, Hex, 6-32, snap, 0.375L, Nylon	561-0375A	Eagle Hardware
48	5	NUT1 NUT2 NUT3 NUT4 NUT5	Nut, Hex, Kep 4-40, S ZN Cr3 plateing RoHS	4CKNTZR	Any RoHS Compliant Mfg.
49	2	Q1 Q3	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401T-7-F	Diodes, Inc.
50	2	Q2 Q4	PNP, Small Signal BJT, 40 V, 0.6 A, SOT-23	MMBT4403-7-F	Diodes, Inc.
51	4	R1 R3 R50 R51	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
52	3	R4 R5 R6	1.3 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-1M3	Yageo
53	2	R7 R34	4.7 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ4R7V	Panasonic
54	1	R8	10 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ100V	Panasonic
55	1	R9	1 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ1R0V	Panasonic
56	1	R11	1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1604V	Panasonic
57	1	R12	732 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7323V	Panasonic
58	1	R13	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
59	1	R14	2 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ202V	Panasonic
60	1	R15	3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
61	1	R16	160 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ164V	Panasonic
62	1	R17	2.21 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2211V	Panasonic
63	1	R18	57.6 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5762V	Panasonic
64	1	R19	2.21 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2211V	Panasonic
65	1	R20	22 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ223V	Panasonic
66	1	R21	2.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ222V	Panasonic
67	1	R22	15 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-15K	Yageo
68	1	R23	100 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ101V	Panasonic
69	1	R24	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
70	2	R25 R32	1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ102V	Panasonic
71	1	R26	976 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-976K	Yageo
72	2	R27 R28	976 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF9763V	Panasonic
73	1	R29	20 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2002V	Panasonic
74	1	R30	36.5 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3652V	Panasonic
75	1	R31	5.11 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF5111V	Panasonic
76	1	R33	5.9 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-5K90	Yageo
77	1	R35	2.2 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ2R2V	Panasonic
78	1	R36	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
79	1	R37	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
80	1	R38	52.3 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5232V	Panasonic
81	1	R39	220 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ221V	Panasonic
82	1	R40	24 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ240V	Panasonic
83	1	R41	10 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-10K	Yageo
84	1	R42	2.2 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2K2	Yageo
85	1	R43	680 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ681V	Panasonic
86	1	R44	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
87	1	R45	22 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ223V	Panasonic
88	1	R46	182 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-182K	Yageo

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89	1	R47	10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
90	2	R48 R49	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
91	1	R52	33 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ333V	Panasonic
92	1	RL1	SPST-NO, 5 A 12 VDC, PC MNT	G6B-1114P-US-DC12	OMRON
93	1	RT1	NTC Thermistor, 5 Ohms, 4.7 A	CL-150	Thermometrics
94	5	RTV1 RTV2 RTV3 RTV4 RTV5	Thermally conductive Silicone Grease	120-SA	Wakefield
95	1	RV1	320 V, 80 J, 14 mm, RADIAL	V320LA20AP	Littlefuse
96	3	SCREW1 SCREW2 SCREW3	Screw Machine Phil 4-40 X 5/16 SS	PMSSS 440 0031 PH	Building Fasteners
97	2	SCREW4 SCREW5	Screw Machine Phil 4-40 X 3/8 SS	PMSSS 440 0038 PH	Building Fasteners
98	2	SCREW6 SCREW7	Screw Machine Phil 4-40 X 1/4 SS	PMSSS 440 0025 PH	Building Fasteners
99	2	STDOFF1 STDOFF2	Standoff Hex, 4-40, 0.375 L	1892	Keystone Elect
100	1	T1	Custom Transformer, LinkSwitch, EE10, Vertical, pins 3, 6 & 7 removed		Custom
101	1	T2	Custom Transformer, LLC, 48V, EEL25.4, Vertical		Custom
102	1	TO-220 PAD3	THERMAL PAD TO-118, TO-220, TO-247, .006 K10"	SPK10-0.006-00-90	Bergquist
103	1	TO-220 PAD1	HEATPAD TO-247 .006" K10	K10-104	Bergquist
104	1	TP1	Test Point, WHT,THRU-HOLE MOUNT	5012	Keystone
105	5	TP2 TP4 TP6 TP7 TP9	Test Point, BLK,THRU-HOLE MOUNT	5011	Keystone
106	2	TP3 TP8	Test Point, RED,THRU-HOLE MOUNT	5010	Keystone
107	1	TP5	Test Point, YEL,THRU-HOLE MOUNT	5014	Keystone
108	1	U1	HiperPFS, eSIP7/6-TH	PFS708EG	Power Integrations
109	1	U2	LinkSwitch-TN, SO-8	LNK302DG	Power Integrations
110	1	U3	HiperLCS, ESIP16/13	LCS702HG	Power Integrations
111	1	U4	Optocoupler, 35 V, CTR 80-160%, 4-DIP	LTV-817A	Liteon
112	1	U5	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semic
113	1	U6	CAPZero, SO-8C	CAP002DG	Power Integrations
114	1	VR1	12 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5242B-7	Diodes, Inc.
115	1	VR2	33 V, 5%, 500 mW, DO-35	1N5257B-T	Diodes, Inc.
116	2	WASHER1 WASHER3	Washer,Shoulder, #4, 0.095 Shoulder x 0.117 Dia , Polyphenylene Sulfide PPS	7721-10PPSG	Aavid Thermalloy
117	1	WASHER2	Washer Teflon #6, ID 0.156, OD 0.312, Thk 0.031	FWF-6	See Distributor
118	5	WASHER4 WASHER5 WASHER6 WASHER7 WASHER8	Washer FLAT #4 SS	FWSS 004	Building Fasteners

7 Magnetics

7.1 PFC Choke (L2) Specification

7.1.1 Electrical Diagram

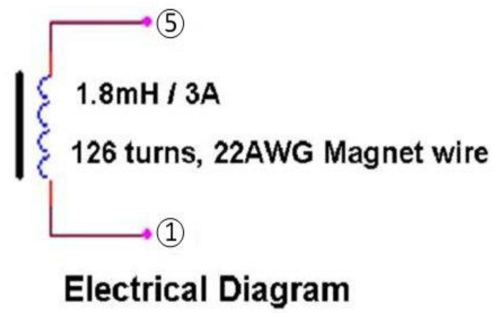

Figure 7 – Transformer Electrical Diagram.

7.1.2 Electrical Specifications

Inductance	Pins 1-5 measured at 100 kHz, 0.4 V_{RMS}	1.8 mH, ±8%

7.1.3 Materials

Item	Description
[1]	Core: Chang Sung, Inc.: Sendust core: CS270090; Alternate: Magnetics Inc., Mfg: 77934-A7.
[2]	Magnet wire: 22AWG insulated magnet wire. VTM1050-1D.
[3]	Base: Toroid mounting base, Lodestone Pacific, P/N VTM160-4, or similar. See Figure 2. PI P/N: 76-00019-00.
[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.

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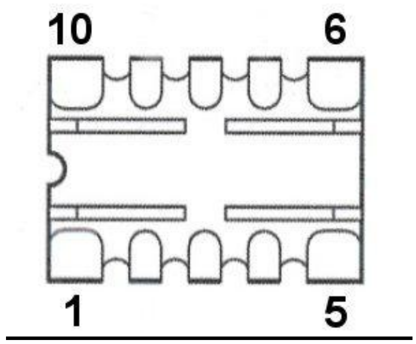
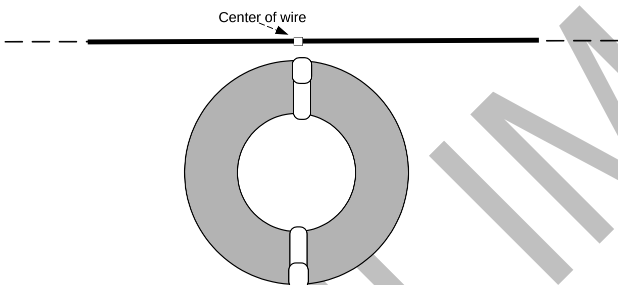
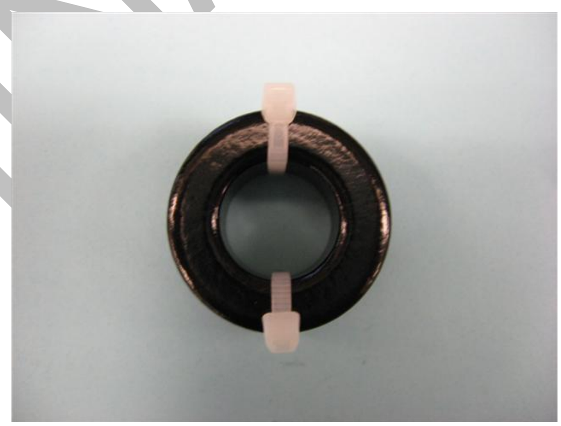


Figure 8 – Top View of Toroid mounting Base Item [3].

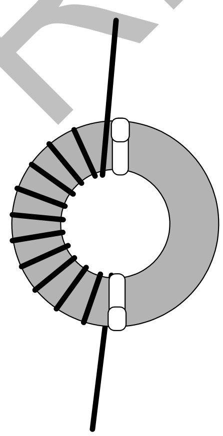
7.1.4 Winding Instructions

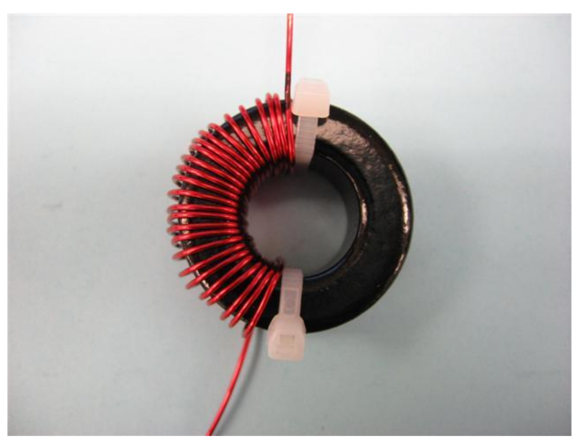
- Insert 2 dividers item [5] in the core item [1] to divide into 2 sections equally. See Photo. Superglue dividers in place if necessary to prevent slipping.
- Take approximately 17ft of wire item [2]. Align center of wire with 1 divider. This location on the inductor is your 'top' reference point.



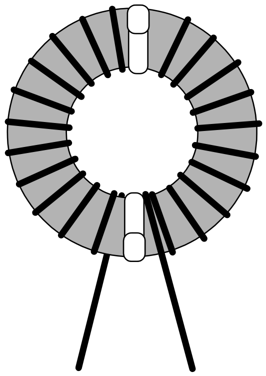


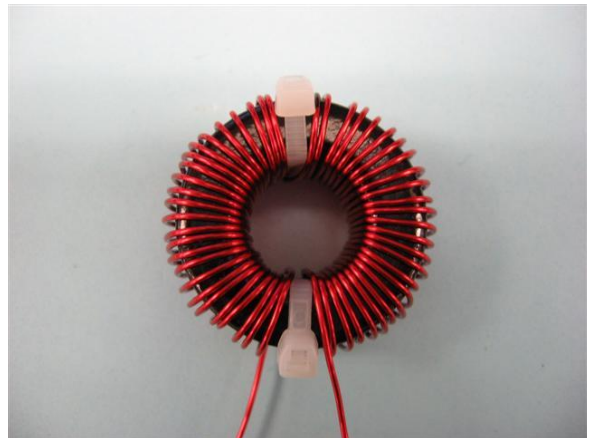
- Start winding on the left section with approximately 24 turns of wire item [2], for the 1st layer, wind wire laminar fashion and ensure that turns do not overlap.
-



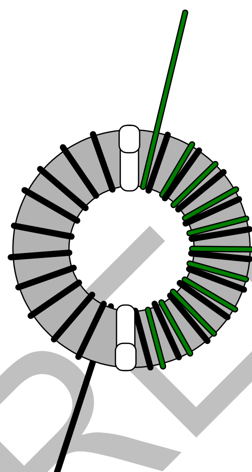


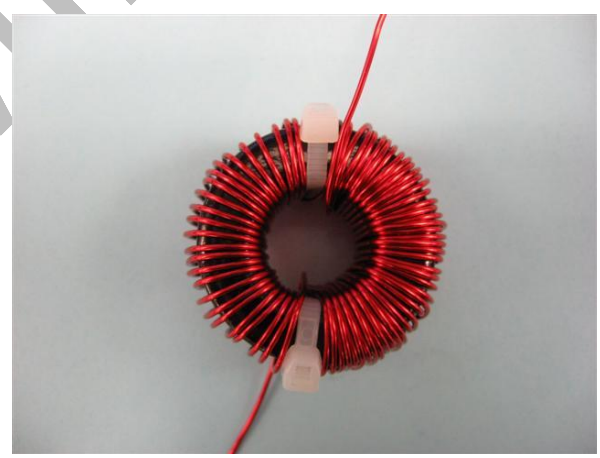
- Next, wind another 24 turns on the right hand side of the core.





- Continue winding on the right hand side for the 2nd layer approximately 22 turns, spread wire evenly and try to ensure that turns do not overlap.





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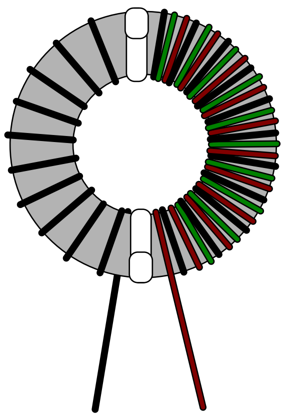
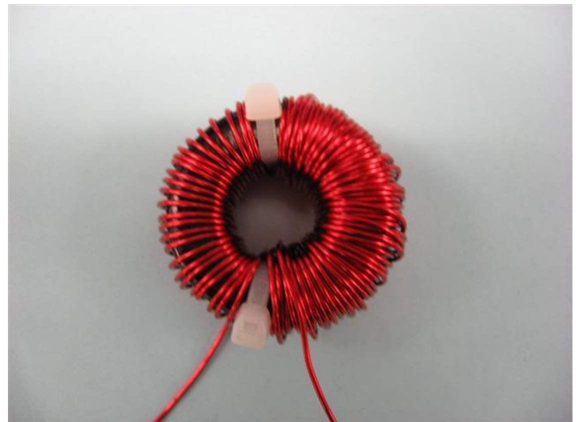
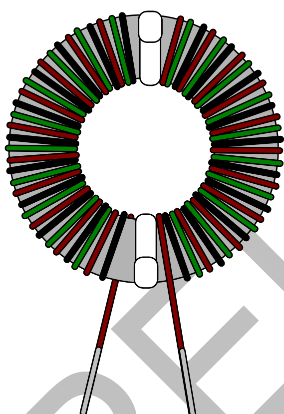
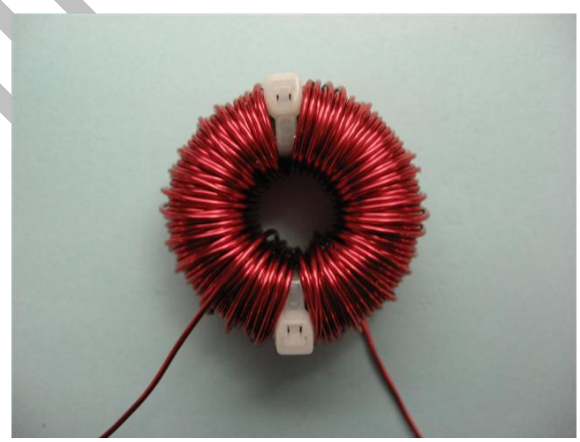
- Continue winding on the right section on the 3rd layer the remaining [approximately 17] turns, distributing wire evenly and try to ensure that turns do not overlap.



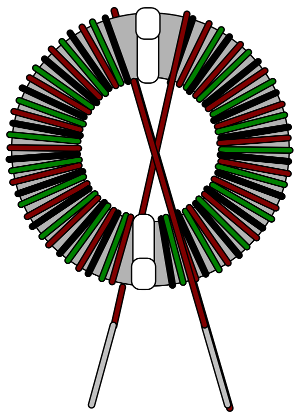


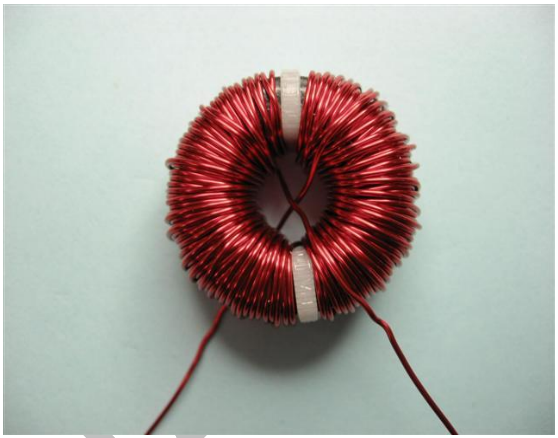
- Wind the same as above for the 2nd and 3rd layers on the left section. Inductor leads will finish at the 'bottom' of the inductor after all turns are wound.



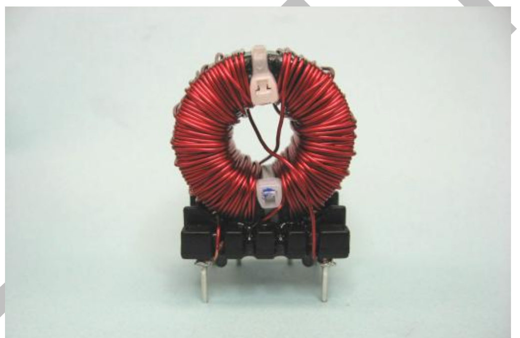


- Invert toroid with 'top' side down for mounting.

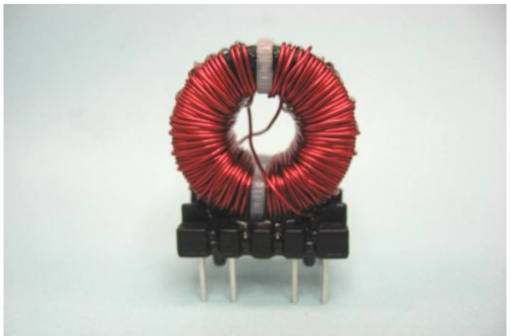




- Remove pins 2, 3, 4, and 8 on base (item [3]).
- Place wound toroid into the mount with 'top' side down
- Solder the leads to pins 1 and 5 of mounting base item [3].
  Secure the 'top' side of the inductor to the base by using High Temperature Epoxy item [4].



Front view



Back view

Figure 9 – Front and Back Views of Finished PFC Inductor

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7.2 LLC Transformer (T2) Specification

7.2.1 Electrical Diagram

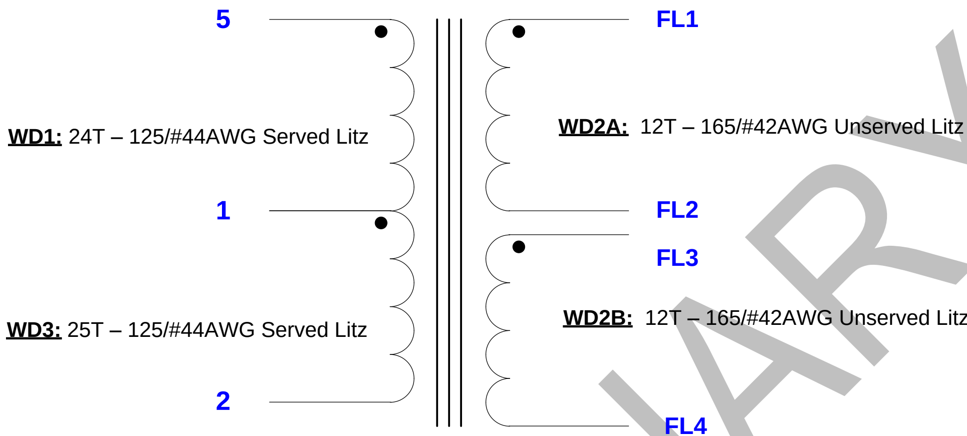

Figure 9 – PFC Electrical Diagram.

7.2.2 Electrical Specification

Electrical Strength	1 second, 60 Hz, from pins 1-6 to FL1, Fl2, FL3, FL4.	3000 VAC
Primary Inductance	Pins 2-5, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	340 μH, ±10%
Resonant Frequency	Pins 2-5, all other windings open	1800 kHz (Min)
Primary Leakage Inductance	Pins 2-5, with FL1, FL2, FL3, FL4 shorted, measured at 100 kHz, 0.4 V_{RMS}	50 μH ±5%

7.2.3 Materials

Item	Description
[1]	Core Pair: EEL25.4 Nippon Ceramic FEEL25.4-NC-2H, ungapped.
[2]	Bobbin: EEL25 Vertical, 3 chamber, 5 pins, PI P/N 25-00960-05.
[3]	Bobbin EEL25 Cover, PI P/N 25-00961-00.
[4]	Tape: Polyester Film, 3M 1350F-1 or equivalent, 7.0 mm wide.
[5]	Litz wire: 165/#42 Single Coated, Unserved.
[6]	Litz wire: 125/#44 Single Coated, Served.
[7]	Transformer Varnish: Dolph BC-359 or equivalent.

7.2.4 Build Diagram

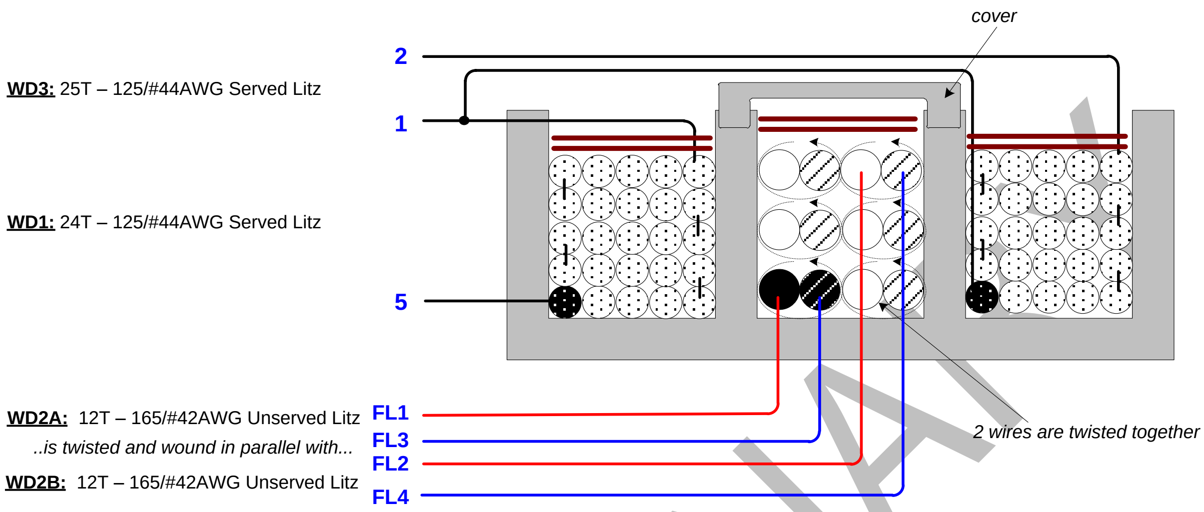

Figure 10 – PFC Choke Build Diagram.

7.2.5 Winding Instructions

Secondary wire preparation	Prepare 2 strands of wire item [5] 26" length, tin ends, and label one strand to distinguish from other and designate it as FL1, FL2. Other strand will be designated as FL3 and FL4. Twist these 2 strands together ~60 twists evenly along length leaving 1" free at each end. See pictures below.
WD1 (Primary)	Place the bobbin item [2] on the mandrel with pin side on the left side. Starting on pin 5, wind 24 turns of served Litz wire [6] in 5 layers, and finish on pin 1. Secure winding with one turn of tape [4].
WD2A & WD2B (Secondary)	Using unserved Litz assembly prepared in step 1, start with FL1 and FL3 inserted into hole 1 and hole 4 of bobbin [2] bottom flange (see illustration). Tightly wind 12 turns in bobbin center chamber. Finish with FL2 in Hole 3 of bobbin bottom flange, and FL4 in hole 1. Secure winding with one turn of tape [4].
Bobbin Cover	Slide bobbin cover [3] into grooves in bobbin flanges as shown, with closed end of cover pointed to pin 1-5 side of bobbin see illustration. Make sure cover is securely seated.
WD 3 (Primary)	Start on pin 1 of bobbin [2], wind 25 turns of served Litz wire [6], finishing on pin 2. Secure and insulate winding start lead using tape [4] per illustration. Secure winding with one turn of tape [4].
Finish	Grind core halves [1] for inductance of 340 µH ±10%. Assemble and secure core halves. Tin all secondary wires to ~ ¼" from bobbin holes per illustration, and trim to ½". Dip varnish [7].

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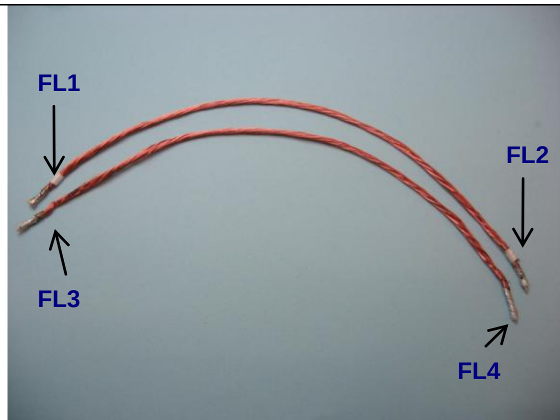
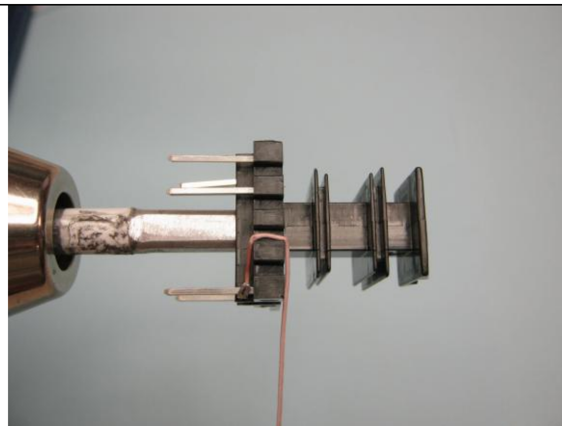
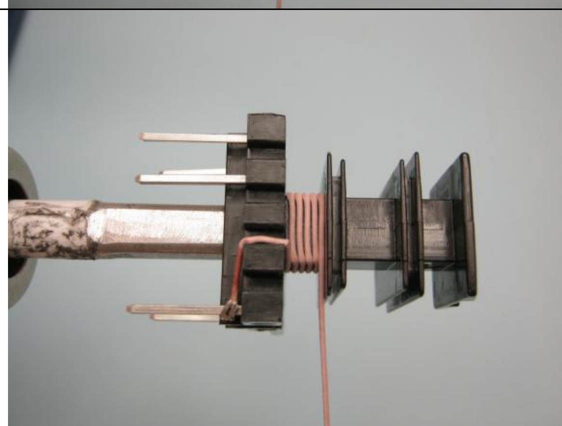
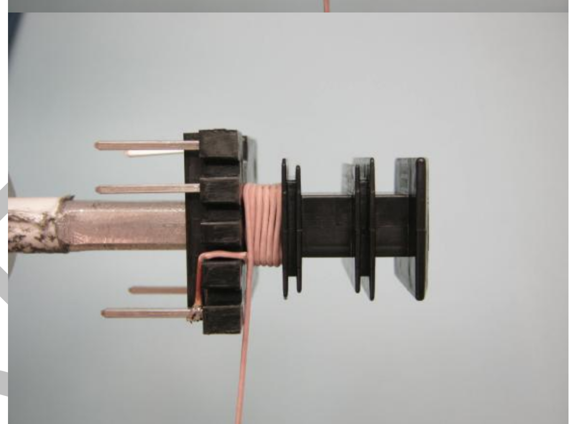
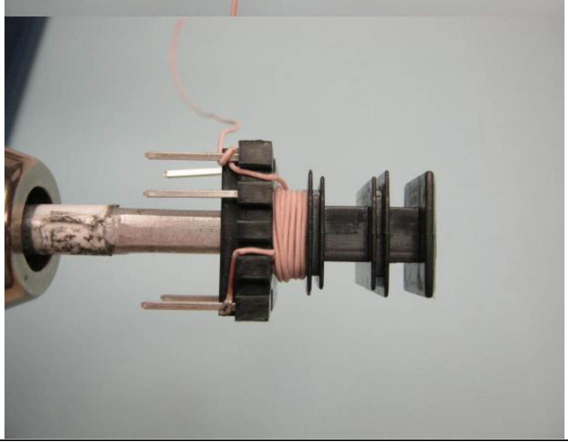
7.2.6 Winding Illustrations

Secondary Wire Preparation		Make 2 strands of wire item [5] 26” length, tin ends, label one cable to distinguish from other and designate it as FL1, FL2. Other strand will be designated as FL3 and FL4. Twist these 2 cables together ~60 twists evenly along length leaving 1” free at each end. See pictures below.  Video 1.wmv
WD1 (Primary)		Place the bobbin item [2] on the mandrel with pin side on the left side. Starting on pin 5**.**

		
WD1 (Primary) (Cont'd)	  	Wind 24 turns of served Litz wire [6] in 5 layers, and finish on pin 1. Secure winding with one turn of tape [4].

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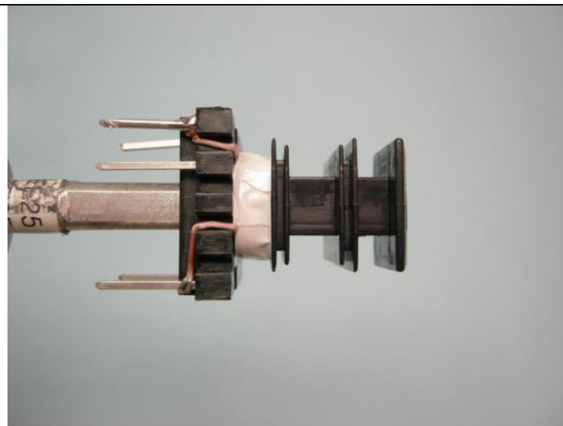
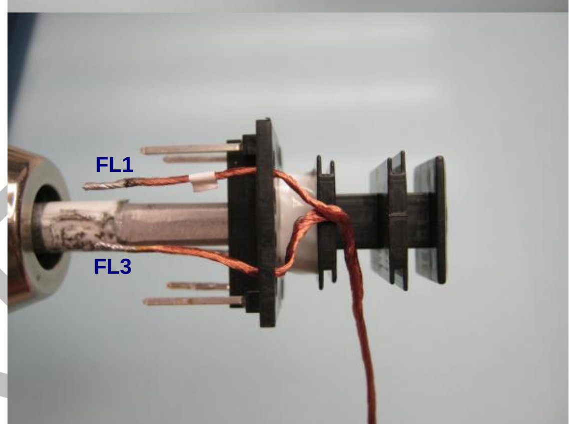
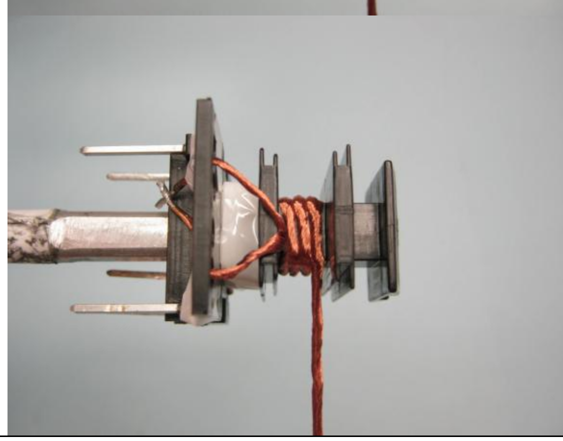
<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>WD2A & WD2B
(Secondary)</td><td>



</td><td>Using unserved Litz assembly prepared in step 1, start with FL1 and FL3 inserted into Hole 2 and hole 4 of bobbin [2] bottom flange (see illustration). Tightly wind 12 turns in bobbin center chamber. Finish with FL2 in hole 3 of bobbin bottom flange, and FL4 in hole 1. Secure winding with one turn of tape [4].</td></tr>
</table>

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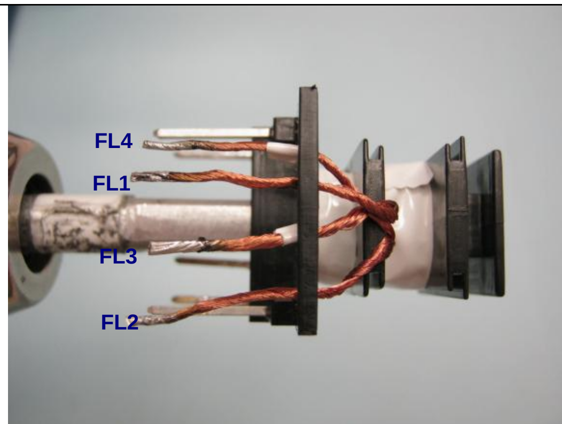
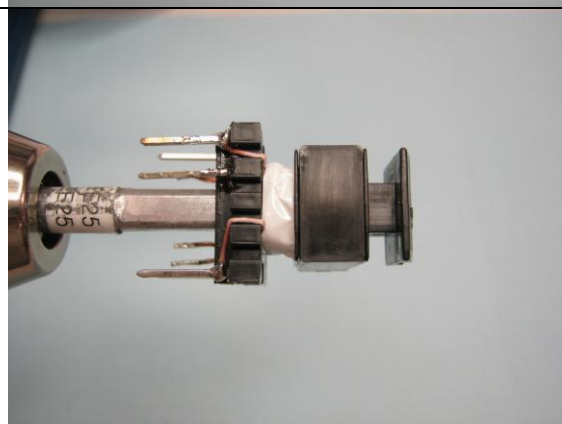
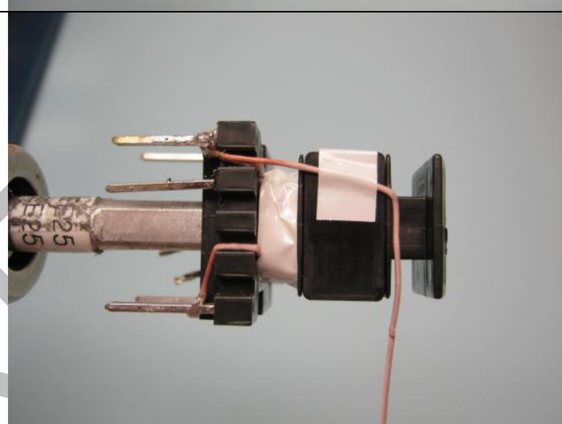
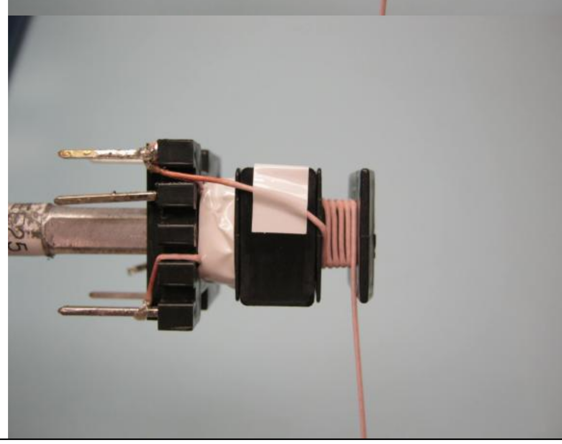
<tr><td></td><td>
</td><td></td></tr>
<tr><td>Bobbin Cover</td><td></td><td>Slide bobbin cover [3] into grooves in bobbin flanges as shown, with closed end of cover pointed to Pin 1-5 side of bobbin, see illustration. Make sure cover is securely seated.</td></tr>
<tr><td>WD 3
(Primary)</td><td>
</td><td>Start on pin 1 of bobbin [2], wind 25 turns of served Litz wire [6] in 5 layers, finish on pin 2.
Secure and insulate winding start lead using tape [4] per illustration. Secure winding with one turn of tape [4].</td></tr>
</table>

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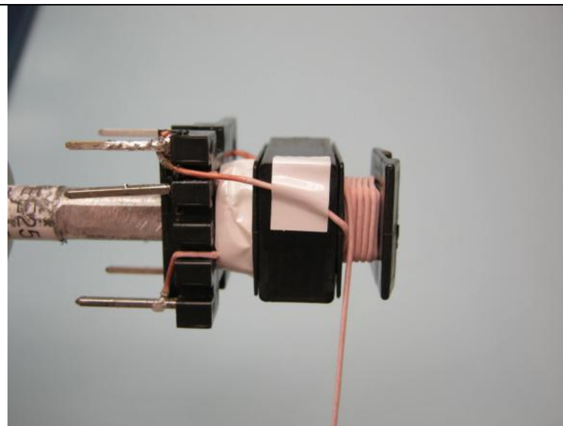
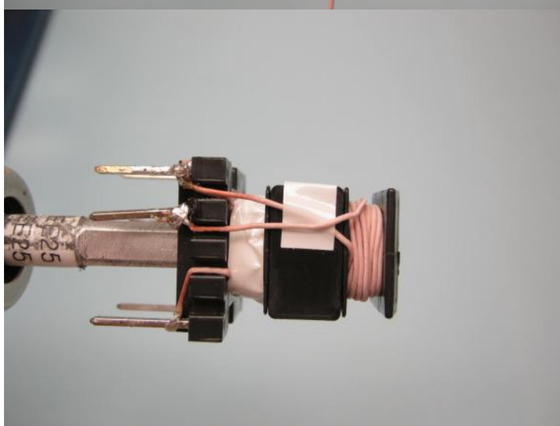
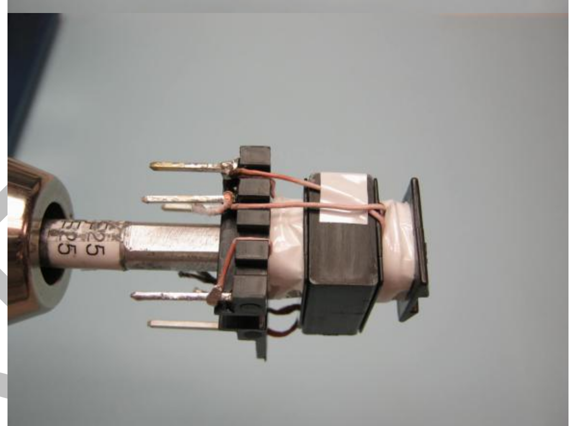
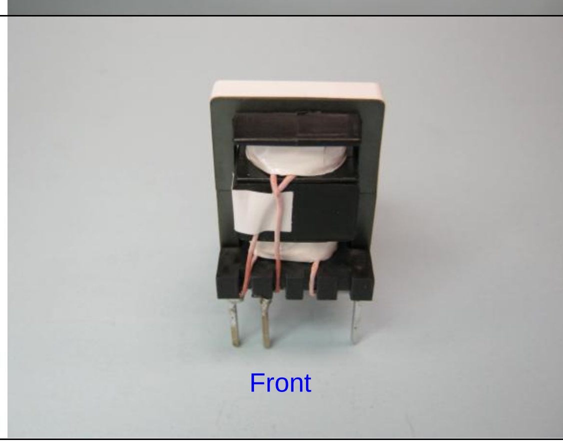
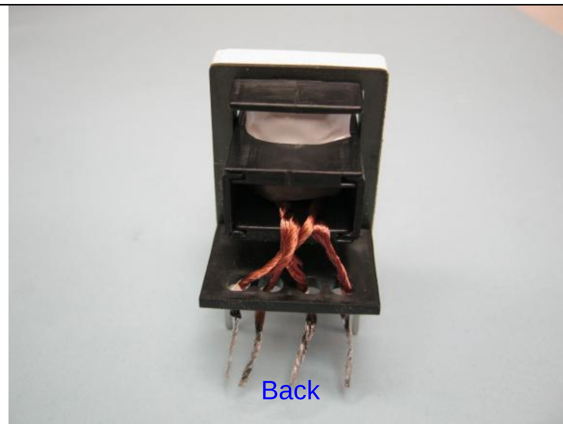
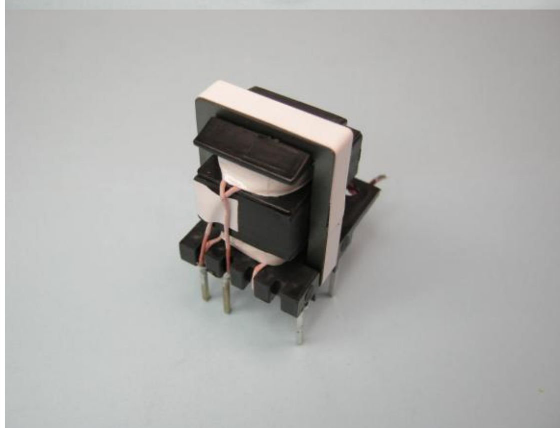
	  	
Finish		Grind core halves [1] for inductance of 340 μH ±10%. Assemble and secure core halves. Tin all secondary wires to ~ ¼” from bobbin holes per illustration, and trim to ½”. Dip varnish [7].

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7.3 Bias Transformer

7.3.1 Electrical Diagram

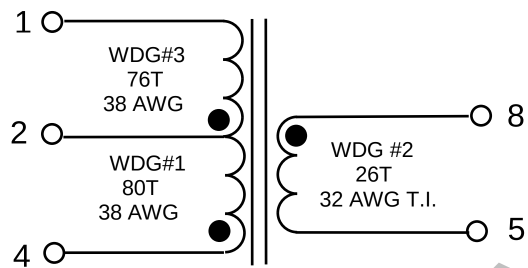

Figure 11 – Transformer Electrical Diagram.

7.3.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-4 to pins 5-8	500V
Primary Inductance	Pins 1-4, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	1880 μH ±10%
Resonant Frequency	Pins 1-4, all other windings open	1000 kHz (Min.)
Primary Leakage Inductance	Pins 1-4, with pins 5-8 shorted, measured at 100 kHz, 0.4 V_{RMS}	20 μH ±10%

7.3.3 Materials List

Item	Description
[1]	Core: EE10, TDK PC40 material or equivalent. Gap for inductance coefficient (A_L) of 77 nH/T².
[2]	Bobbin, EE10 vertical, 8 Pin. TDK BE10-118CPSFR, Taiwan Shulin TF-10, or equiv.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 7.1 mm wide.
[4]	Wire, Magnet #38 AWG, solderable double coated.
[5]	Wire, Triple Insulated, Furukawa TEX-E or equivalent, #32 AWG.
[6]	Transformer Varnish, Dolph BC-359 or equivalent

7.3.4 Transformer Build Diagram

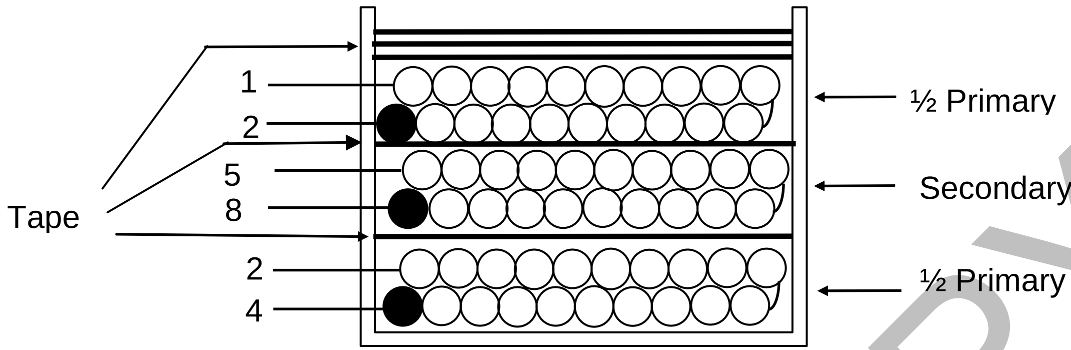

Figure 12 – Bias Transformer Build Diagram.

7.3.5 Transformer Build Instructions

General note	For the purpose of these instructions, bobbin is oriented on winder such that pin side is on the left side (see illustration). Winding direction as shown is counter-clockwise.
WD1 (1/2 Primary)	Starting at pin 4, wind 80 turns of wire (Item [4]) in two layers. Finish at pin 2.
Tape	Use 1 layer of tape (Item [3]) for insulation.
WD2 (Secondary)	Starting at pin 8, wind 26 turns of triple insulated wire (Item [5]) in two layers. Finish at pin 5.
Tape	Use 1 layer of tape (Item [3]) for insulation.
WD3 (1/2 Primary)	Starting at pin 2, wind 76 turns of wire (Item [4]) in two layers. Finish at pin 1.
Tape	Use 3 layer of tape (Item [3]) for finish wrap.
Assembly	Grind core halves for specified primary inductance, insert bobbin, and secure core halves. Remove pin 3, 6, 7. Dip Varnish [6].

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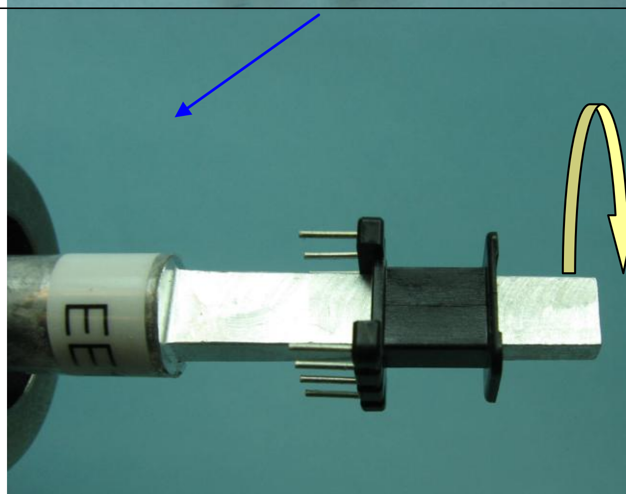
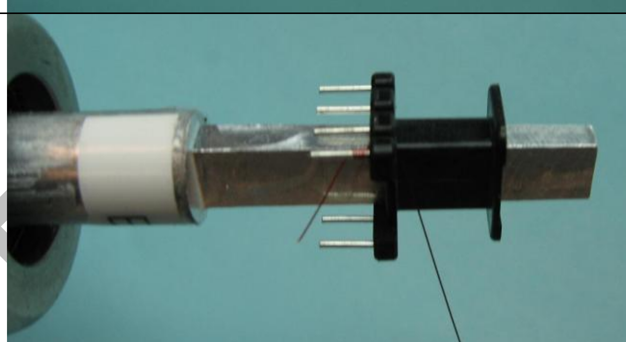
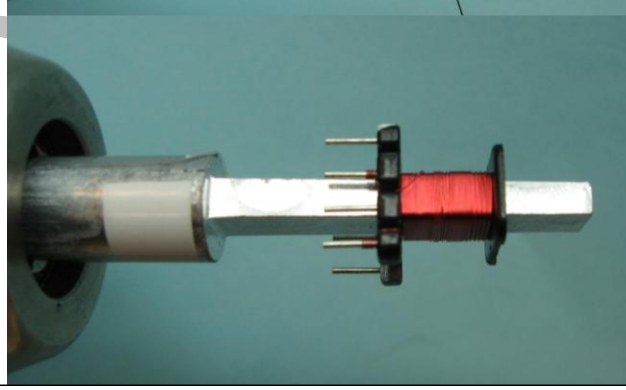
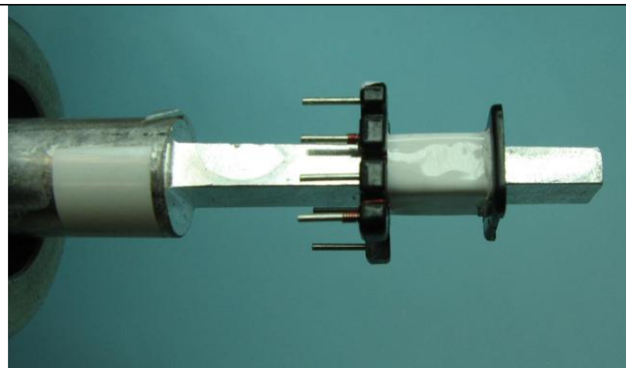
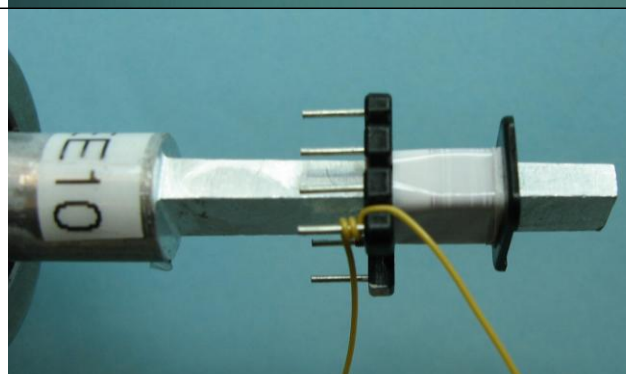
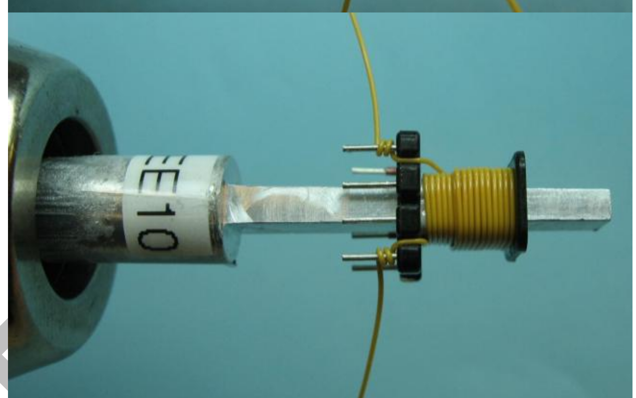
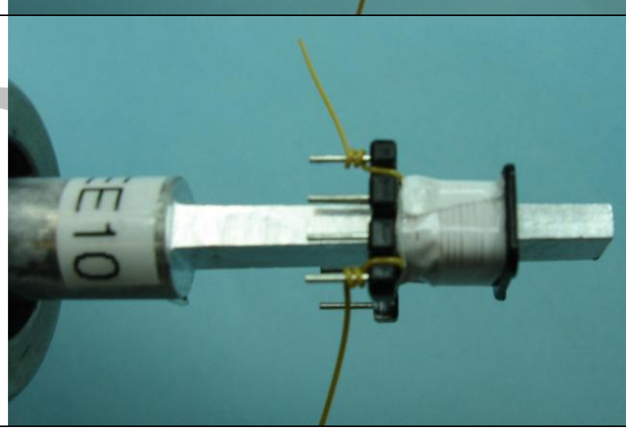
7.3.6 Transformer Build Illustrations

Bobbin Preparation		
General Note		For the purpose of these instructions, Bobbin is oriented on winder such that pin side is on the left side (see illustration). Winding direction as shown is counter-clockwise.
WD1 (1/2 Primary)	 	Starting at Pin 4, wind 80 turns of wire (Item [4]) in two layers. Finish at Pin 2.

Tape		Apply one layer of tape (item [3]) for insulation.
WD2 (Secondary)	 	Starting at Pin 8, wind 26 turns of triple insulated wire (Item [5]) in two layers. Finish at Pin 5.
Tape		Use 1 layer of tape (Item [3]) for insulation.

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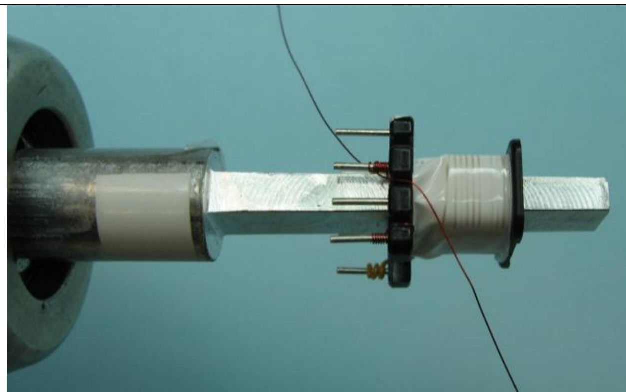
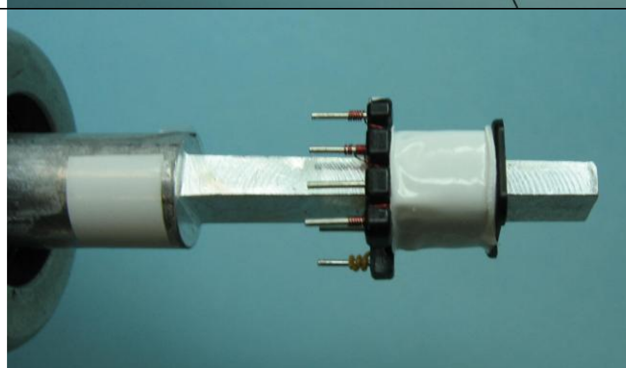
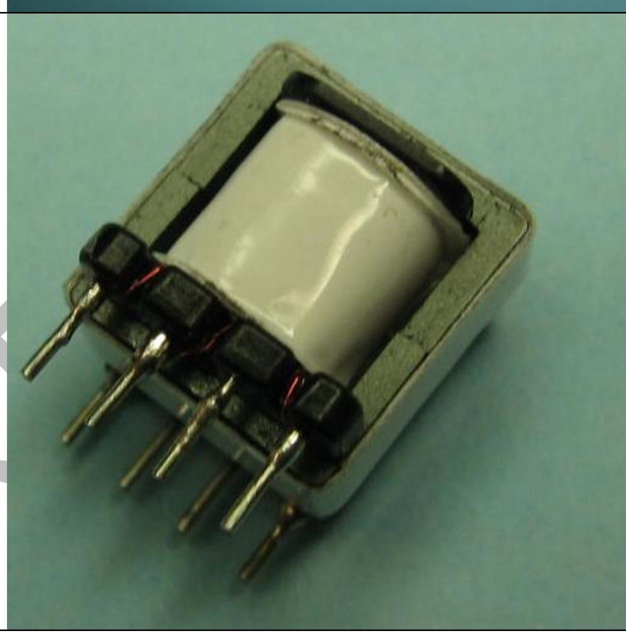
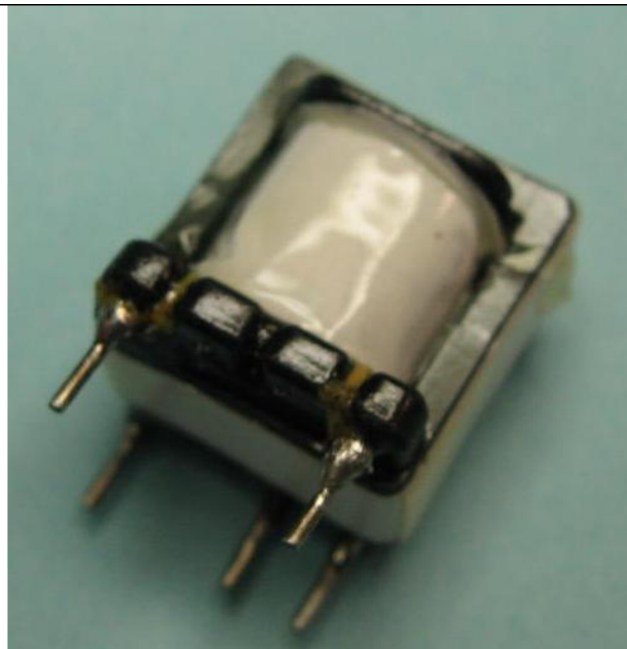
WD3 (1/2 Primary)		Starting at Pin 2, wind 76 turns of wire (Item [4]) in two layers. Finish at Pin 1.
Tape		Use 3 layer of tape (Item [3]) for finish wrap.
Assembly		Grind core halves for specified primary inductance, insert bobbin, and secure core halves. Remove Pin 3, 6, 7. Dip Varnish [6].

		Finished Transformer Note that Pins 3, 6, 7 are removed.

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7.4 Output Inductor

7.4.1 Electrical Diagram

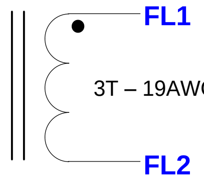

Figure 13 – Inductor Electrical Diagram.

7.4.2 Electrical Specifications

Inductance	Pins FL1-FL2, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	300 nH, ±15%

7.4.3 Material List

Item	Description
[1]	Powdered Iron Toroidal Core: Micrometals T30-26.
[2]	Magnet wire: 19 AWG Solderable Double Coated.

7.4.4 Construction Details

Figure 14 – Finished Part, Front View. Tin Leads to within ~ 1/8“ of Toroid Body

8 LLC Transformer Design Spreadsheet

HiperLCS_120611; Rev.1.2; Copyright Power Integrations 2011	INPUTS	INFO	INFO	OUTPUTS	OUTPUTS	UNITS	HiperLCS_120611_Rev1-2.xls; HiperLCS Half-Bridge, Continuous mode LLC Resonant Converter Design Spreadsheet
Enter Input Parameters							
Vbulk_nom	380			380	380	V	Nominal LLC input voltage
Vbrownout				280	280	V	Brownout threshold voltage. HiperLCS will shut down if voltage drops below this value. Allowable value is between 65% and 76% of Vbulk_nom. Set to 65% for max holdup time
Vbrownin				353	353	V	Startup threshold on bulk capacitor
VOV_shut				465	465	V	OV protection on bulk voltage
VOV_restart				448	448	V	Restart voltage after OV protection.
CBULK	120.00			120	120	uF	Minimum value of bulk cap to meet holdup time requirement; Adjust holdup time and Vbrownout to change bulk cap value
tHOLDUP				25.5	25.5	ms	Bulk capacitor hold up time
Enter LLC (secondary) outputs							**The spreadsheet assumes AC stacking of the secondaries**
VO1	48.00			48.00	48.0	V	Main Output Voltage. Spreadsheet assumes that this is the regulated output
IO1	3.13			3.13	3.1	A	Main output maximum current
VD1	0.70			0.70	0.70	V	Forward voltage of diode in Main output
PO1				150	150	W	Output Power from first LLC output
VO2				0.00	0.0	V	Second Output Voltage
IO2				0.00	0.0	A	Second output current
VD2				0.70	0.70	V	Forward voltage of diode used in second output
PO2				0.00	0.00	W	Output Power from second LLC output
P_LLC				150	150	W	Specified LLC output power
LCS Device Selection							
Device	**LCS702**			**LCS702**	**LCS702**		LCS Device
RDS-ON (MAX)				1.39	1.39	ohms	RDS-ON (max) of selected device
Coss				250	250	pF	Equivalent Coss of selected device
Cpri				40	40	pF	Stray Capacitance at transformer primary
Pcond_loss				1.5	1.5	W	Conduction loss at nominal line and full load
Tmax-hs				90	90	deg C	Maximum heatsink temperature
Theta J-HS				9.1	9.1	deg C/W	Thermal resistance junction to heatsink (with grease and no insulator)
Expected Junction temperature				104	104	deg C	Expected Junction temperature
Ta max				50	50	deg C	Expected max ambient temperature
Theta HS-A				26	26	deg C/W	Required thermal resistance heatsink to ambient
LLC Resonant Parameter and Transformer Calculations (generates red curve)							
Vres_target				395	395	V	Desired Input voltage at which power train operates at resonance. If greater than Vbulk_nom, LLC operates below resonance at VBULK.
Po				152	152	W	LLC output power including diode loss
Vo				48.70	48.70	V	Main Output voltage (includes diode

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							drop) for calculating Nsec and turns ratio
f_target				250	250	kHz	Desired switching frequency at Vbulk_nom. 66 kHz to 300 kHz, recommended 180-250 kHz
Lpar				229	229	uH	Parallel inductance. (Lpar = Lopen - Lres for integrated transformer; Lpar = Lmag for non-integrated low-leakage transformer)
Lpri	280.00			280	280	uH	Primary open circuit inductance for integrated transformer; for low-leakage transformer it is sum of primary inductance and series inductor. If left blank, auto-calculation shows value necessary for slight loss of ZVS at ~80% of Vnom
Lres	51.00			51.0	51.0	uH	Series inductance or primary leakage inductance of integrated transformer; if left blank auto-calculation is for K=4
Kratio				4.5	4.5		Ratio of Lpar to Lres. Maintain value of K such that 2.1 < K < 11. Preferred Lres is such that K<7.
Cres	6.20			6.2	6.2	nF	Series resonant capacitor. Red background cells produce red graph. If Lpar, Lres, Cres, and n_RATIO_red_graph are left blank, they will be auto-calculated
Lsec				14.100	14.100	uH	Secondary side inductance of one phase of main output; measure and enter value, or adjust value until f_predicted matches what is measured ;
m				94	94	%	Leakage distribution factor (primary to secondary). >50% signifies most of the leakage is in primary side. Gap physically under secondary yields >50%, requiring fewer primary turns.
n_eq				4.03	4.03		Turns ratio of LLC equivalent circuit ideal transformer
Npri	49.0			49.0	49.0		Primary number of turns; if input is blank, default value is auto-calculation so that f_predicted = f_target and m=50%
Nsec	12.0			12.0	12.0		Secondary number of turns (each phase of Main output). Default value is estimate to maintain BAC<=200 mT, using selected core (below)
f_predicted				262	262	kHz	Expected frequency at nominal input voltage and full load; Heavily influenced by n_eq and primary turns
f_res				283	283	kHz	Series resonant frequency (defined by series inductance Lres and C)
f_brownout				187	187	kHz	Expected switching frequency at Vbrownout, full load. Set HiperLCS minimum frequency to this value.
f_par				121	121	kHz	Parallel resonant frequency (defined by Lpar + Lres and C)
f_inversion				166	166	kHz	LLC full load gain inversion frequency. Operation below this frequency results in operation in gain inversion region.
Vinversion				240	240	V	LLC full load gain inversion point input voltage
Vres_expected				393	393	V	Expected value of input voltage at which LLC operates at resonance.
RMS Currents and Voltages							

IRMS_LLC_Primary			1.04	1.04	A	Primary winding RMS current at full load, Vbulk_nom and f_predicted
Winding 1 (Lower secondary Voltage) RMS current			2.4	2.4	A	Winding 1 (Lower secondary Voltage) RMS current
Lower Secondary Voltage Capacitor RMS current			1.4	1.4	A	Lower Secondary Voltage Capacitor RMS current
Winding 2 (Higher secondary Voltage) RMS current			0.0	0.0	A	Winding 2 (Higher secondary Voltage) RMS current
Higher Secondary Voltage Capacitor RMS current			0.0	0.0	A	Higher Secondary Voltage Capacitor RMS current
Cres_Vrms			102	102	V	Resonant capacitor AC RMS Voltage at full load and nominal input voltage
Virtual Transformer Trial - (generates blue curve)						
New primary turns			49.0	49.0		Trial transformer primary turns; default value is from resonant section
New secondary turns			12.0	12.0		Trial transformer secondary turns; default value is from resonant section
New Lpri			280	280	uH	Trial transformer open circuit inductance; default value is from resonant section
New Cres			6.2	6.2	nF	Trial value of series capacitor (if left blank calculated value chosen so f_res same as in main resonant section above
New estimated Lres			51.0	51.0	uH	Trial transformer estimated Lres
New estimated Lpar			229	229	uH	Estimated value of Lpar for trial transformer
New estimated Lsec			14.100	14.100	uH	Estimated value of secondary leakage inductance
New Kratio			4.5	4.5		Ratio of Lpar to Lres for trial transformer
New equivalent circuit transformer turns ratio			4.03	4.03		Estimated effective transformer turns ratio
V powertrain inversion new			240	240	V	Input voltage at LLC full load gain inversion point
f_res_trial			283	283	kHz	New Series resonant frequency
f_predicted_trial			262	262	kHz	New nominal operating frequency
IRMS_LLC_Primary			1.04	1.04	A	Primary winding RMS current at full load and nominal input voltage (Vbulk) and f_predicted_trial
Winding 1 (Lower secondary Voltage) RMS current			2.4	2.4	A	RMS current through Output 1 winding, assuming half sinusoidal waveshape
Lower Secondary Voltage Capacitor RMS current			1.4	1.4	A	Lower Secondary Voltage Capacitor RMS current
Winding 2 (Higher secondary Voltage) RMS current			2.4	2.4	A	RMS current through Output 2 winding; Output 1 winding is AC stacked on top of Output 2 winding
Higher Secondary Voltage Capacitor RMS current			0.0	0.0	A	Higher Secondary Voltage Capacitor RMS current
Vres_expected_trial			393	393	V	Expected value of input voltage at which LLC operates at resonance.
Transformer Core Calculations (Calculates From Resonant Parameter Section)						
Transformer Core	**Auto**		**EEL25**	**EEL25**		**Transformer Core**
Ae			0.40	0.40	cm^2	Enter transformer core cross-sectional area
Ve			3.01	3.01	cm^3	Enter the volume of core
Aw			107.9	107.9	mm^2	Area of window
Bw			22.0	22.0	mm	Total Width of Bobbin
Loss density			200.0	200.0	mW/cm^3	Enter the loss per unit volume at the switching frequency and BAC (Units same as kW/m^3)
MLT			3.1	3.1	cm	Mean length per turn

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Nchambers		2	2		Number of Bobbin chambers
Wsep		3.0	3.0	mm	Winding separator distance (will result in loss of winding area)
Ploss		0.6	0.6	W	Estimated core loss
Bpkfmin		134	134	mT	First Quadrant peak flux density at minimum frequency.
BAC		192	192	mT	AC peak to peak flux density (calculated at f_predicted, Vbulk at full load)
Primary Winding					
Npri		49.0	49.0		Number of primary turns; determined in LLC resonant section
Primary gauge		44	44	AWG	Individual wire strand gauge used for primary winding
Equivalent Primary Metric Wire gauge		0.050	0.050	mm	Equivalent diameter of wire in metric units
Primary litz strands	125	125	125		Number of strands in Litz wire; for non-litz primary winding, set to 1
Primary Winding Allocation Factor		50	50	%	Primary window allocation factor - percentage of winding space allocated to primary
AW_P		47	47	mm^2	Winding window area for primary
Fill Factor		43%	43%	%	% Fill factor for primary winding (typical max fill is 60%)
Resistivity_25 C_Primary		75.42	75.42	m-ohm/m	Resistivity in milli-ohms per meter
Primary DCR 25 C		114.42	114.42	m-ohm	Estimated resistance at 25 C
Primary DCR 100 C		153.32	153.32	m-ohm	Estimated resistance at 100 C (approximately 33% higher than at 25 C)
Primary RMS current		1.04	1.04	A	Measured RMS current through the primary winding
ACR_Trf_Primary		245.31	245.31	m-ohm	Measured AC resistance (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature
Primary copper loss		0.27	0.27	W	Total primary winding copper loss at 85 C
Secondary Winding 1 (Lower secondary voltage OR Single output)					**Note - Power loss calculations are for each winding half of secondary**
Output Voltage		48.00	48.00	V	Output Voltage (assumes AC stacked windings)
Sec 1 Turns		12.00	12.00		Secondary winding turns (each phase)
Sec 1 RMS current (total, AC+DC)		2.4	2.4	A	RMS current through Output 1 winding, assuming half sinusoidal waveshape
Winding current (DC component)		1.56	1.56	A	DC component of winding current
Winding current (AC RMS component)		1.85	1.85	A	AC component of winding current
Sec 1 Wire gauge	42	42	42	AWG	Individual wire strand gauge used for secondary winding
Equivalent secondary 1 Metric Wire gauge		0.060	0.060	mm	Equivalent diameter of wire in metric units
Sec 1 litz strands	165	165	165		Number of strands used in Litz wire; for non-litz non-integrated transformer set to 1
Resistivity_25 C_sec1		35.93	35.93	m-ohm/m	Resistivity in milli-ohms per meter
DCR_25C_Sec1		13.35	13.35	m-ohm	Estimated resistance per phase at 25 C (for reference)
DCR_100C_Sec1		17.89	17.89	m-ohm	Estimated resistance per phase at 100 C (approximately 33% higher than at 25 C)
DCR_Ploss_Sec1		0.35	0.35	W	Estimated Power loss due to DC resistance (both secondary phases)

ACR_Sec1		28.62	28.62	m-ohm	Measured AC resistance per phase (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature. Default value of ACR is twice the DCR value at 100 C
ACR_Ploss_Sec1		0.20	0.20	W	Estimated AC copper loss (both secondary phases)
Total winding 1 Copper Losses		0.55	0.55	W	Total (AC + DC) winding copper loss for both secondary phases
Capacitor RMS current		1.4	1.4	A	Output capacitor RMS current
Co1		1.3	1.3	uF	Secondary 1 output capacitor
Capacitor ripple voltage		3.0	3.0	%	Peak to Peak ripple voltage on secondary 1 output capacitor
Output rectifier RMS Current		2.4	2.4	A	Schottky losses are a stronger function of load DC current. Sync Rectifier losses are a function of RMS current
Secondary Winding 2 (Higher secondary voltage)					**Note - Power loss calculations are for each winding half of secondary**
Output Voltage		0.00	0.00	V	Output Voltage (assumes AC stacked windings)
Sec 2 Turns		0.00	0.00		Secondary winding turns (each phase) AC stacked on top of secondary winding 1
Sec 2 RMS current (total, AC+DC)		2.4	2.4	A	RMS current through Output 2 winding; Output 1 winding is AC stacked on top of Output 2 winding
Winding current (DC component)		0.0	0.0	A	DC component of winding current
Winding current (AC RMS component)		0.0	0.0	A	AC component of winding current
Sec 2 Wire gauge		42	42	AWG	Individual wire strand gauge used for secondary winding
Equivalent secondary 2 Metric Wire gauge		0.060	0.060	mm	Equivalent diameter of wire in metric units
Sec 2 litz strands		0	0		Number of strands used in Litz wire; for non-litz non-integrated transformer set to 1
Resistivity_25 C_sec2		59292.53	59292.53	m-ohm/m	Resistivity in milli-ohms per meter
Transformer Secondary MLT		3.10	3.10	cm	Mean length per turn
DCR_25C_Sec2		0.00	0.00	m-ohm	Estimated resistance per phase at 25 C (for reference)
DCR_100C_Sec2		0.00	0.00	m-ohm	Estimated resistance per phase at 100 C (approximately 33% higher than at 25 C)
DCR_Ploss_Sec1		0.00	0.00	W	Estimated Power loss due to DC resistance (both secondary halves)
ACR_Sec2		0.00	0.00	m-ohm	Measured AC resistance per phase (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature. Default value of ACR is twice the DCR value at 100 C
ACR_Ploss_Sec2		0.00	0.00	W	Estimated AC copper loss (both secondary halves)
Total winding 2 Copper Losses		0.00	0.00	W	Total (AC + DC) winding copper loss for both secondary halves
Capacitor RMS current		0.0	0.0	A	Output capacitor RMS current
Co2		N/A	N/A	uF	Secondary 2 output capacitor
Capacitor ripple voltage		N/A	N/A	%	Peak to Peak ripple voltage on secondary 1 output capacitor
Output rectifier RMS Current		0.0	0.0	A	Schottky losses are a stronger function of load DC current. Sync Rectifier losses are a function of RMS current
Transformer Loss Calculations					**Does not include fringing flux loss from gap**

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Primary copper loss (from Primary section)				0.27	0.27	W	Total primary winding copper loss at 85 C
Secondary copper Loss				0.55	0.55	W	Total copper loss in secondary winding
Transformer total copper loss				0.81	0.81	W	Total copper loss in transformer (primary + secondary)
AW_S				46.59	46.59	mm^2	Area of window for secondary winding
Secondary Fill Factor				40%	40%	%	% Fill factor for secondary windings; typical max fill is 60% for served and 75% for unserved Litz
Signal Pins Resistor Values							
f_min				187	187	kHz	Minimum frequency when optocoupler is cut-off. Only change this variable based on actual bench measurements
Dead Time	290			290	290	ns	Dead time
Burst Mode	**Auto**			**2**	**2**		Select Burst Mode: 1, 2, and 3 have hysteresis and have different frequency thresholds
f_max				934	934	kHz	Max internal clock frequency, dependent on dead-time setting. Is also start-up frequency
f_burst_start				366.2	366	kHz	Lower threshold frequency of burst mode, provides hysteresis. This is switching frequency at restart after a bursting off-period
f_burst_stop				427.2	427	kHz	Upper threshold frequency of burst mode; This is switching frequency at which a bursting off-period stops
DT/BF pin upper divider resistor				5.84	5.84	k-ohms	Resistor from DT/BF pin to VREF pin
DT/BF pin lower divider resistor				52.6	53	k-ohms	Resistor from DT/BF pin to G pin
Rstart				5.09	5.09	k-ohms	Start-up resistor - resistor in series with soft-start capacitor; equivalent resistance from FB to VREF pins at startup. Use default value unless additional start-up delay is desired.
Start up delay				0.0	0.0	ms	Start-up delay; delay before switching begins. Reduce R_START to increase delay
Rfmin				36.8	36.8	k-ohms	Resistor from VREF pin to FB pin, to set min operating frequency; This resistor plus Rstart determine f_MIN. Includes 7% HiperLCS frequency tolerance to ensure f_min is below f_brownout
C_softstart	0.22			0.22	0.22	uF	Soft start capacitor. Recommended values are between 0.1 uF and 0.47 uF
Ropto				1.0	1.0	k-ohms	Resistor in series with opto emitter
OV/UV pin lower resistor	20.00			20.0	20.0	k-ohm	Lower resistor in OV/UV pin divider
OV/UV pin upper resistor				2.92	2.92	M-ohm	Total upper resistance in OV/UV pin divider
LLC Capacitive Divider Current Sense Circuit							
Slow current limit				2.92	2.92	A	8-cycle current limit - check positive half-cycles during brownout and startup
Fast current limit				5.26	5.26	A	1-cycle current limit - check positive half-cycles during startup
LLC sense capacitor				47	47	pF	HV sense capacitor, forms current divider with main resonant capacitor
RLLC sense resistor				22.8	22.8	ohms	LLC current sense resistor, senses current in sense capacitor
IS pin current limit resistor				220	220	ohms	Limits current from sense resistor into IS pin when voltage on sense R is < -

				0.5V
IS pin noise filter capacitor	1.0	1.0	nF	IS pin bypass capacitor; forms a pole with IS pin current limit capacitor
IS pin noise filter pole frequency	724	724	kHz	This pole attenuates IS pin signal
Loss Budget				
LCS device Conduction loss	1.5	1.5	W	Conduction loss at nominal line and full load
Output diode Loss	2.2	2.2	W	Estimated diode losses
Transformer estimated total copper loss	0.81	0.81	W	Total copper loss in transformer (primary + secondary)
Transformer estimated total core loss	0.6	0.6	W	Estimated core loss
Total transformer losses	1.4	1.4	W	Total transformer losses
Total estimated losses	5.1	5.1	W	Total losses in LLC stage
Estimated Efficiency	97%	97%	%	Estimated efficiency
PIN	155	155	W	LLC input power
Secondary Turns and Voltage Centering Calculator				**This is to help you choose the secondary turns - Outputs not connected to any other part of spreadsheet**
V1	48.00	48.00	V	Target regulated output voltage Vo1. Change to see effect on slave output
V1d1	0.70	0.70	V	Diode drop voltage for Vo1
N1	12.00	12.00		Total number of turns for Vo1
V1_Actaul	48.00	48.00	V	Expected output
V2	0.00	0.00	V	Target output voltage Vo2
V2d2	0.70	0.70	V	Diode drop voltage for Vo2
N2	0.00	0.00		Total number of turns for Vo2
V2_Actual	-0.70	-0.70	V	Expected output voltage
Separate Series Inductor (For Non-Integrated Transformer Only)				**Not applicable if using integrated magnetics - not connected to any other part of spreadsheet**
Lsep	51.00	51.00	uH	Desired inductance of separate inductor
Ae_Ind	0.53	0.53	cm^2	Inductor core cross-sectional area
Inductor turns	10	10		Number of primary turns
BP_fnom	152	152	mT	AC flux for core loss calculations (at f_predicted and full load)
Expected peak primary current	2.9	2.9	A	Expected peak primary current
BP_fmin	284	284	mT	Peak flux density, calculated at minimum frequency fmin
Inductor Litz gauge	44	44	AWG	Individual wire strand gauge used for primary winding
Equivalent Inductor Metric Wire gauge	0.050	0.050	mm	Equivalent diameter of wire in metric units
Inductor litz strands	125	125.00		Number of strands used in Litz wire
Inductor parallel wires	1	1		Number of parallel individual wires to make up Litz wire
Resistivity_25 C_Sep_Ind	75.4	75.4	m-ohm/m	Resistivity in milli-ohms per meter
Inductor MLT	7.00	7.00	cm	Mean length per turn
Inductor DCR 25 C	52.8	52.8	m-ohm	Estimated resistance at 25 C (for reference)
Inductor DCR 100 C	70.7	70.7	m-ohm	Estimated resistance at 100 C (approximately 33% higher than at 25 C)
ACR_Sep_Inductor	113.2	113.2	m-ohm	Measured AC resistance (at 100 kHz, room temperature), multiply by 1.33 to approximate 100 C winding temperature
Inductor copper loss	0.12	0.12	W	Total primary winding copper loss at 85 C
Feedback section				

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VMAIN	**Auto**	48.00	48.0		Output voltage rail that optocoupler LED is connected to
ITL431_BIAS		1	1.0	mA	Minimum operating current in TL431 cathode
VF_MIN		1.1	1.1	V	Maximum Optocoupler LED forward voltage at IOPTO_BJTMAX (max current)
VCE_SAT		0.3	0.3	V	Optocoupler transistor saturation voltage
CTR_MIN		0.8	0.8		Optocoupler minimum CTR at VCE_SAT and at IOPTO_BJT_MAX
VTL431_SAT		2.5	2.5	V	TL431 minimum cathode voltage when saturated
RLED_SHUNT		1.1	1.1	k-ohms	Resistor across optocoupler LED to ensure minimum TL431 bias current is met
ROPTO_LOAD		4.70	4.70	k-ohms	Resistor from optocoupler emitter to ground, sets load current
IFMAX		382.98	382.98	uA	FB pin current when switching at FMAX (e.g. startup) - Sameer should we show this?
IOPTO_BJT_MAX		0.99	0.99	mA	Optocoupler transistor maximum current - when bursting at FMAX (e.g. startup)
RLED_SERIES_MAX		17.86	17.86	k-ohms	Maximum value of gain setting resistor, in series with optocoupler LED, to ensure optocoupler can deliver IOPTO_BJT_MAX. Includes - 10% tolerance factor.

9 Bias Transformer Design Spreadsheet

ACDC_LinkSwitch-TN_Flyback_103007; Rev.1.9; Copyright Power Integrations 2007	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**ACDC_LinkSwitch-TN Flyback_103007; Copyright Power Integrations 2007**
ENTER APPLICATION VARIABLES					
VACMIN	85			Volts	Minimum AC Input Voltage
VACMAX	280			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	12.60			Volts	Output Voltage (main) (For CC designs enter upper CV tolerance limit)
IO	0.05			Amps	Power Supply Output Current (For CC designs enter upper CC tolerance limit)
CC Threshold Voltage	0.00			Volts	Voltage drop across sense resistor.
Output Cable Resistance			0.17	Ohms	Enter the resistance of the output cable (if used)
PO			0.63	Watts	Output Power (VO x IO + CC dissipation)
Feedback Type	OPTO		Opto		Choose 'BIAS' for Bias winding feedback and 'OPTO' for Optocoupler feedback from the 'Feedback Type' drop down box at the top of this spreadsheet
Add Bias Winding	NO		No		Choose 'YES' in the 'Bias Winding' drop down box at the top of this spreadsheet to add a Bias winding. Choose 'NO' to continue design without a Bias winding. Addition of Bias winding can lower no load consumption
n			0.6		Efficiency Estimate at output terminals.
Z			0.5		Loss Allocation Factor (suggest 0.5 for CC=0 V, 0.75 for CC=1 V)
tC	2.90			mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	100.00			uFarads	Input Capacitance
Input Rectification Type	F		***F***		Choose H for Half Wave Rectifier and F for Full Wave Rectification from the 'Rectification' drop down box at the top of this spreadsheet
ENTER LinkSwitch-TN VARIABLES					
LinkSwitch-TN	**LNK302**		**LNK302**		User selection for LinkSwitch-TN. Ordering info - Suffix P/G indicates DIP 8 package; suffix D indicates SO8 package; second suffix N indicates lead free RoHS compliance
Chosen Device		*LNK302*			
ILIMITMIN			*0.126*	Amps	Minimum Current Limit
ILIMITMAX			*0.146*	Amps	Maximum Current Limit
fSmin			*62000*	Hertz	Minimum Device Switching Frequency
I^2fmin			984.312	A^2Hz	I^2f (product of current limit squared and frequency is trimmed for tighter tolerance)
VOR			80	Volts	Reflected Output Voltage
VDS			10	Volts	LinkSwitch-TN on-state Drain to Source Voltage

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VD			0.7	Volts	Output Winding Diode Forward Voltage Drop
KP			4.72		Ripple to Peak Current Ratio (0.6 < KP < 6.0).
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EE10**		**EE10**		User-Selected transformer core
Core		*EE10*		*P/N:*	PC40EE10-Z
Bobbin		*EE10_BOBBIN*		*P/N:*	EE10_BOBBIN
AE			0.121	cm^2	Core Effective Cross Sectional Area
LE			2.61	cm	Core Effective Path Length
AL			850	nH/T^2	Ungapped Core Effective Inductance
BW			6.6	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	3.00		3		Number of Primary Layers
NS			26		Number of Secondary Turns
NB			N/A		Bias winding not used
VB			N/A	Volts	Bias winding not used
PIVB			N/A	Volts	N/A - Bias Winding not in use
DC INPUT VOLTAGE PARAMETERS					
VMIN			120	Volts	Minimum DC Input Voltage
VMAX			396	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.13		Maximum Duty Cycle
IAVG			0.01	Amps	Average Primary Current
IP			0.13	Amps	Minimum Peak Primary Current
IR			0.13	Amps	Primary Ripple Current
IRMS			0.03	Amps	Primary RMS Current
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1879	uHenries	Typical Primary Inductance. +/- 10%
LP_TOLERANCE			10	%	Primary inductance tolerance
NP			156		Primary Winding Number of Turns
ALG			77	nH/T^2	Gapped Core Effective Inductance
BM			1449	Gauss	Maximum Operating Flux Density, BM<1500 is recommended
BAC			725	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1459		Relative Permeability of Ungapped Core
LG			0.18	mm	Gap Length (Lg > 0.1 mm)
BWE			19.8	mm	Effective Bobbin Width
OD			0.13	mm	Maximum Primary Wire Diameter including insulation
INS			0.03	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.10	mm	Bare conductor diameter
AWG			39	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			13	Cmils	Bare conductor effective area in circular mils
CMA			467	Cmils/Amp	Primary Winding Current Capacity (150 < CMA < 500)
TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					
ISP			0.76	Amps	Peak Secondary Current
ISRMS			0.19	Amps	Secondary RMS Current
IRIPPLE			0.18	Amps	Output Capacitor RMS Ripple

					Current
CMS			38	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			34	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.16	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.25	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			0.05	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN			584	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			78	Volts	Output Rectifier Maximum Peak Inverse Voltage
FEEDBACK COMPONENTS					
Recommended Bias Diode			1N4003 - 1N4007		Recommended diode is 1N4003. Place diode on return leg of bias winding for optimal EMI. See LinkSwitch-TN Design Guide
R1			500 - 1000	ohms	CV bias resistor for CV/CC circuit. See LinkSwitch-TN Design Guide
R2			200 - 820	ohms	Resistor to set CC linearity for CV/CC circuit. See LinkSwitch-TN Design Guide
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1			12.60	Volts	Main Output Voltage (if unused, defaults to single output design)
IO1			0.05	Amps	Output DC Current
PO1			0.63	Watts	Output Power
VD1			0.70	Volts	Output Diode Forward Voltage Drop
NS1			26.00		Output Winding Number of Turns
ISRMS1			0.19	Amps	Output Winding RMS Current
IRIPPLE1			0.18	Amps	Output Capacitor RMS Ripple Current
PIVS1			78.43	Volts	Output Rectifier Maximum Peak Inverse Voltage
Recommended Diodes			MUR110, UF4002, SB1100		Recommended Diodes for this output
Pre-Load Resistor			4	k-Ohms	Recommended value of pre-load resistor
CMS1			38.28	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			34.00	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1			0.16	mm	Minimum Bare Conductor Diameter
ODS1			0.25	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output					
VO2				Volts	Output Voltage
IO2				Amps	Output DC Current
PO2			0.00	Watts	Output Power
VD2			0.70	Volts	Output Diode Forward Voltage Drop
NS2			1.37		Output Winding Number of Turns
ISRMS2			0.00	Amps	Output Winding RMS Current
IRIPPLE2			0.00	Amps	Output Capacitor RMS Ripple

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					Current
PIVS2			3.46	Volts	Output Rectifier Maximum Peak Inverse Voltage
Recommended Diode					Recommended Diodes for this output
CMS2			0.00	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS2			N/A	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS2			N/A	mm	Minimum Bare Conductor Diameter
ODS2			N/A	mm	Maximum Outside Diameter for Triple Insulated Wire
3rd output					
VO3				Volts	Output Voltage
IO3				Amps	Output DC Current
PO3			0.00	Watts	Output Power
VD3			0.70	Volts	Output Diode Forward Voltage Drop
NS3			1.37		Output Winding Number of Turns
ISRMS3			0.00	Amps	Output Winding RMS Current
IRIPPLE3			0.00	Amps	Output Capacitor RMS Ripple Current
PIVS3			3.46	Volts	Output Rectifier Maximum Peak Inverse Voltage
Recommended Diode					Recommended Diodes for this output
CMS3			0.00	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS3			N/A	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS3			N/A	mm	Minimum Bare Conductor Diameter
ODS3			N/A	mm	Maximum Outside Diameter for Triple Insulated Wire
Total power			0.63	Watts	Total Output Power

10 Power Factor Controller Design Spreadsheet

ACDC_PFS_041411; Rev.1.1; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNITS	ACDC_HiperPFS_041411_Rev1-1.xls; Continuous Mode Boost Converter Design Spreadsheet
Enter Applications Variables					**Design Title**
Input Voltage Range	**Universal**		**Universal**		Select Universal or High_Line option
VACMIN			90	V	Minimum AC input voltage
VACMAX			265	V	Maximum AC input voltage
VBROWNIN			77.77		Expected Minimum Brown-in Voltage
VBROWNOUT			70.42	V	Specify brownout voltage.
VO	380.00		380.00	V	Nominal Output voltage
PO	157.00		157.00	W	Nominal Output power
fL			50	Hz	Line frequency
TA Max	50.00		50	deg C	Maximum ambient temperature
n	0.950		0.95		Enter the efficiency estimate for the boost converter at VACMIN
KP	0.445		0.445		Ripple to peak inductor current ratio at the peak of VACMIN
VO_MIN			361	V	Minimum Output voltage
VO_RIPPLE_MAX			20	V	Maximum Output voltage ripple
tHOLDUP	18.00		18	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	**Auto**		**PFS708**		Selected PFS device
IOCP min			5.50	A	Minimum Current limit
IOCP typ			5.85	A	Typical current limit
IOCP max			6.20	A	Maximum current limit
RDSON			0.73	ohms	Typical RDSon at 100 'C
RV			4.00	Mohms	Line sense resistor
C_VCC			1.00	uF	Supply decoupling capacitor
C_V			100.00	nF	V pin decoupling capacitor
C_FB			10.00	nF	Feedback pin decoupling capacitor
FS_PK			72.7	kHz	Estimated frequency of operation at crest of input voltage (at VACMIN)
FS_AVG			59.2	kHz	Estimated average frequency of operation over line cycle (at VACMIN)
IP			3.34	A	MOSFET peak current
PFS_IRMS			1.74	A	PFS MOSFET RMS current
PCOND_LOSS_PFS			2.21	W	Estimated PFS conduction losses
PSW_LOSS_PFS			1.07	W	Estimated PFS switching losses
PFS_TOTAL			3.28	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)
HEATSINK Theta-CA			12.25	degC/W	Maximum thermal resistance of heatsink
Basic Inductor Calculation					
LPFC			705	uH	Value of PFC inductor at peak of VACMIN and Full Load
LPFC (0 Bias)			1820	uH	Value of PFC inductor at No load. This

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					is the value measured with LCR meter
LPFC_RMS			2.07	A	Inductor RMS current (calculated at VACMIN and Full Load)
LP_TOL			10	%	Tolerance of PFC Inductor Value
Inductor Construction Parameters					
Core Type	**Sendust**		**Sendust**		Enter "Sendust", "Pow Iron" or "Ferrite"
Core Material	**90u**		**90u**		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	**TOROID**		**TOROID**		Select from Toroid or EE for Sendust cores and from EE, or PQ for Ferrite cores
Core	**77934(OD=27.7)**		**77934(OD=27.7)**		Core part number
AE			65.4	mm^2	Core cross sectional area
LE			63.5	mm	Core mean path length
AL			116	nH/t^2	Core AL value
VE			4150	mm^3	Core volume
HT			11.94	mm	Core height/Height of window
MLT			41	cm	Mean length per turn
BW			N/A	mm	Bobbin width
NL			125		Inductor turns
LG			N/A	mm	Gap length (Ferrite cores only)
ILRMS			2.07	A	Inductor RMS current
Wire type	**regular**		**regular**		Select between "Litz" or "Regular" for double coated magnet wire
AWG	22	*Info*	22	AWG	!!! Info. Selected wire gauge is too thick and may cause increased proximity losses. Selecta thinner wire gauge
Filar	1		1		Inductor wire number of parallel strands
OD			0.643	mm	Outer diameter of single strand of wire
AC Resistance Ratio			3.42		Ratio of AC resistance to the DC resistance (using Dowell curves)
J		*Warning*	6.38	A/mm^2	!!! Warning Current density is too high and may cause heating in the inductor wire. Reduce J
BM_TARGET			N/A	Gauss	Target flux density at VACMIN (Ferrite cores only)
BM			2892	Gauss	Maximum operating flux density
BP			1793	Gauss	Peak Flux density (Estimated at VBROWNOUT)
LPFC_CORE_LOSS			1.33	W	Estimated Inductor core Loss
LPFC_COPPER_LOSS			1.39	W	Estimated Inductor copper losses
LPFC_TOTAL LOSS			2.73	W	Total estimated Inductor Losses
Critical Parameters					
IRMS			1.84	A	AC input RMS current
IO_AVG			0.41	A	Output average current
Output Diode (DO)					
Part Number	**LQA05TC600**		**LQA05TC600**		PFC Diode Part Number
Type			SPECIAL		Diode Type - Special - Diodes specially catered for PFC applications, SiC - Silicon Carbide type, UF - Ultrafast recovery type
Manufacturer			Qspeed		Diode Manufacturer
VRRM			600	V	Diode rated reverse voltage
IF			5	A	Diode rated forward current
TRR			24	ns	Diode Reverse recovery time

VF			1.1	V	Diode rated forward voltage drop
PCOND_DIODE			0.45	W	Estimated Diode conduction losses
PSW_DIODE			0.71	W	Estimated Diode switching losses
P_DIODE			1.16	W	Total estimated Diode losses
TJ Max			125	deg C	Maximum steady-state operating temperature
Rth-JS			2.90	degC/W	Maximum thermal resistance (Junction to heatsink)
HEATSINK Theta-CA			61.21	degC/W	Maximum thermal resistance of heatsink
Output Capacitor					
CO	**120**		**120.00**	uF	Minimum value of Output capacitance
VO_RIPPLE_EXPECTED			11.5	V	Expected ripple voltage on Output with selected Output capacitor
T_HOLDUP_EXPECTED			18.5	ms	Expected holdup time with selected Output capacitor
ESR_LF			1.38	ohms	
ESR_HF			0.553	ohms	
IC_RMS_LF			0.29	A	Low Frequency Capacitor RMS current
IC_RMS_HF			0.83	A	High Frequency Capacitor RMS current
CO_LF_LOSS			0.12	W	Estimated Low Frequency ESR loss in Output capacitor
CO_HF_LOSS			0.38	W	Estimated High frequency ESR loss in Output capacitor
Total CO LOSS			0.50	W	Total estimated losses in Output Capacitor
Input Bridge (BR1) and Fuse (F1)					
I^2t Rating			8.43	A^2s	Minimum I^2t rating for fuse
Fuse Current rating			2.85	A	Minimum Current rating of fuse
VF			0.90	V	Input bridge Diode forward Diode drop
IAVG			1.77	A	Input average current at 70 VAC.
PIV_INPUT BRIDGE			375	V	Peak inverse voltage of input bridge
PCOND_LOSS_BRIDGE			2.98	W	Estimated Bridge Diode conduction loss
CIN			0.47	uF	Input capacitor. Use metallized polypropylene or film foil type with high ripple current rating
RT			8.54	ohms	Input Thermistor value
D_Precharge			1N5407		Recommended precharge Diode
Feedback Components					
R2			1.50	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
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			2.21	kohms	Feedback network - zero setting resistor

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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			3.28	W	Total estimated losses in PFS
Boost diode Losses			1.16	W	Total estimated losses in Output Diode
Input Bridge losses			2.98	W	Total estimated losses in input bridge module
Inductor losses			2.73	W	Total estimated losses in PFC choke
Output Capacitor Loss			0.50	W	Total estimated losses in Output capacitor
Total losses			10.65	W	Overall loss estimate
Efficiency			0.94		Estimated efficiency at VACMIN. Verify efficiency at other line voltages

Note: There is a warning in the spreadsheet for current density in PFC choke. Whenever such a warning is issued, thermal performance of the PFC Choke should be checked while operating continuously at the lowest input voltage. In this design, it was found that the temperature rise of the choke was within acceptable limits when operating continuously at 90 VAC and full load (see Page 80 and Figure 52).

11 RD-292 Performance Data

All measurements were taken at room temperature and 60 Hz input frequency unless otherwise specified, Output voltage measurements were taken at the output connectors.

11.1 LLC Stage Efficiency

To make this measurement, the LLC stage was supplied by connecting an external 380 VDC supply across bulk capacitor C23. The efficiency includes the losses from the bias supply.

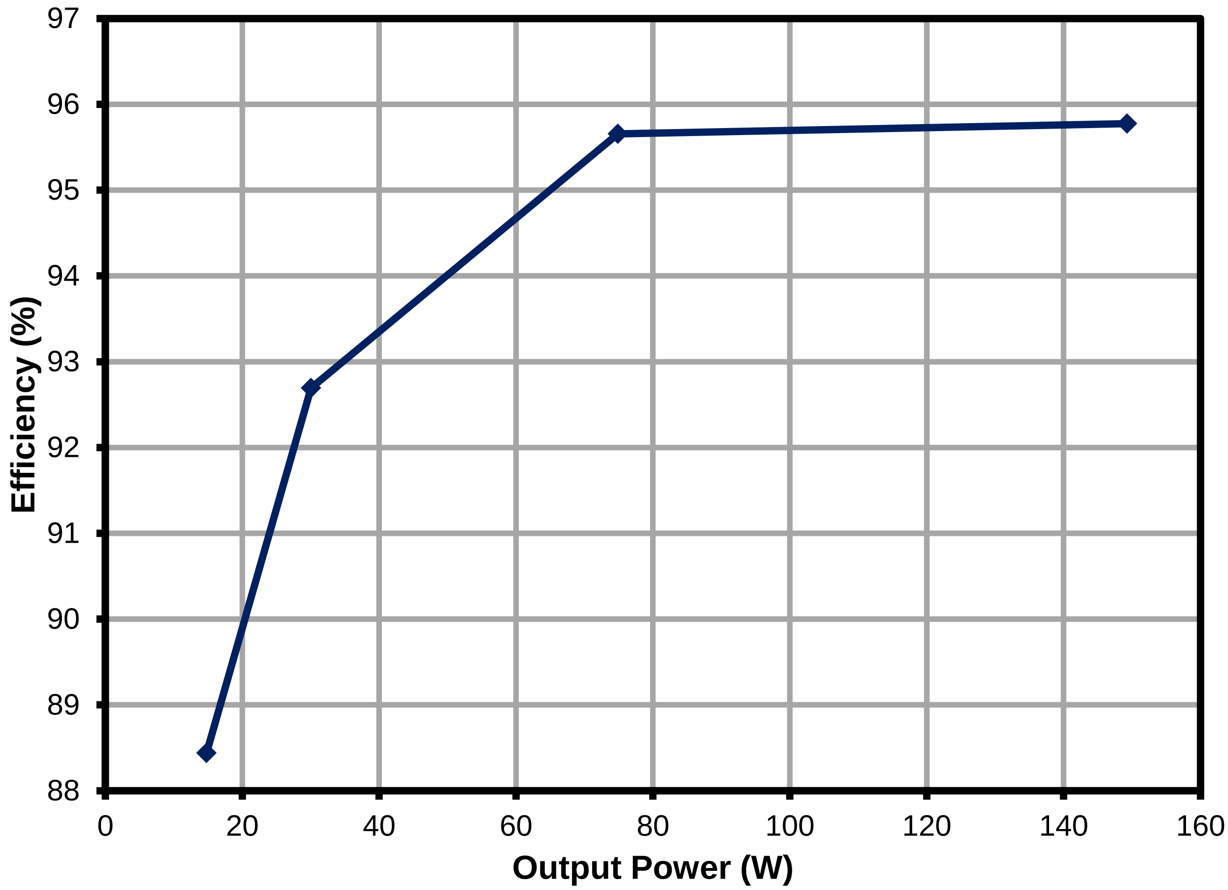

Figure 15 – LLC Stage Efficiency vs. Load, 380 VDC Input.

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11.2 Total Efficiency

Figures below show the total supply efficiency (PFC and LLC stages). AC input was supplied using a sine wave source.

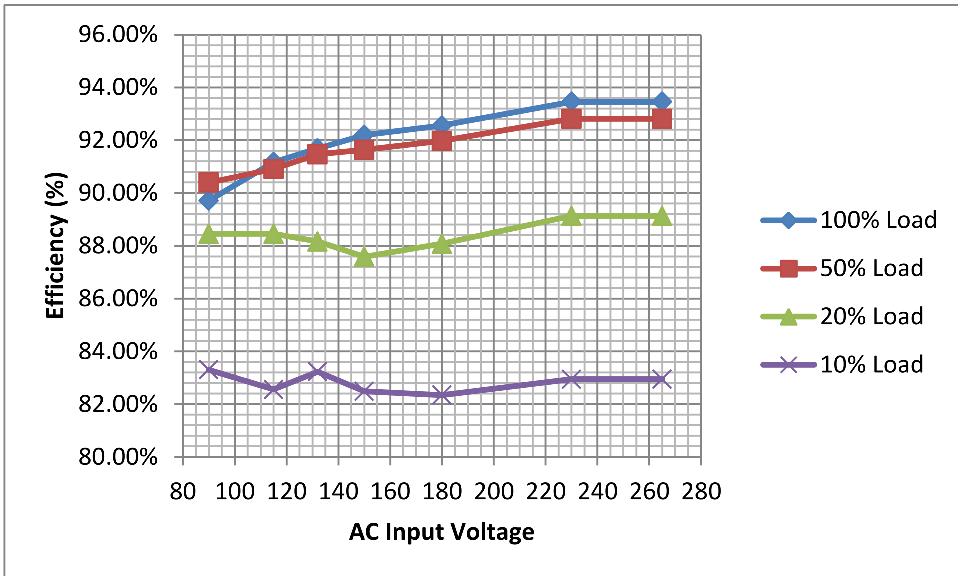

Figure 16 – Total Efficiency vs. Output Power.

11.3 No-Load Power

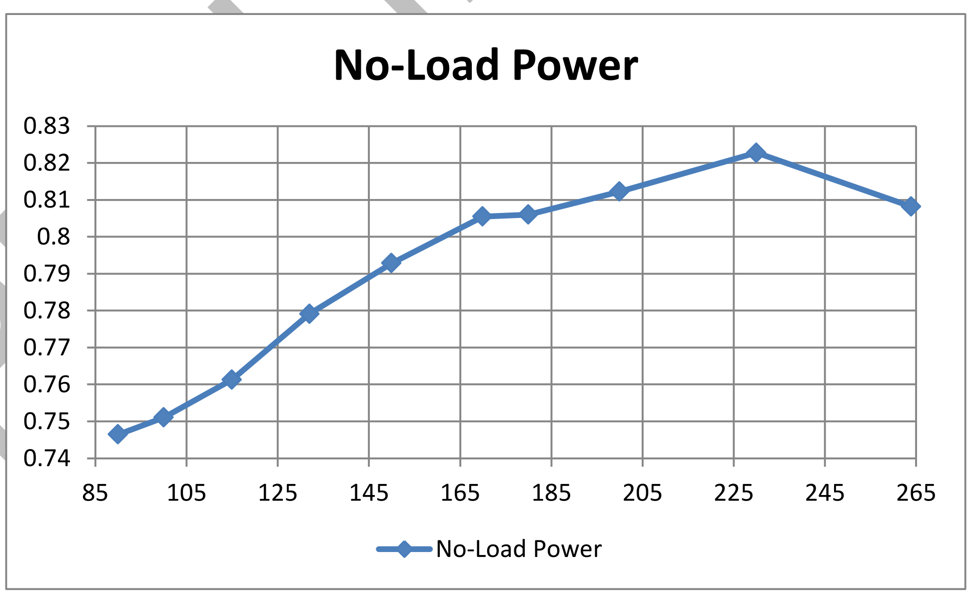

Figure 17 – No-Load Input Power.

11.4 Power Factor

Power factor measurements were made using a sine wave AC source.

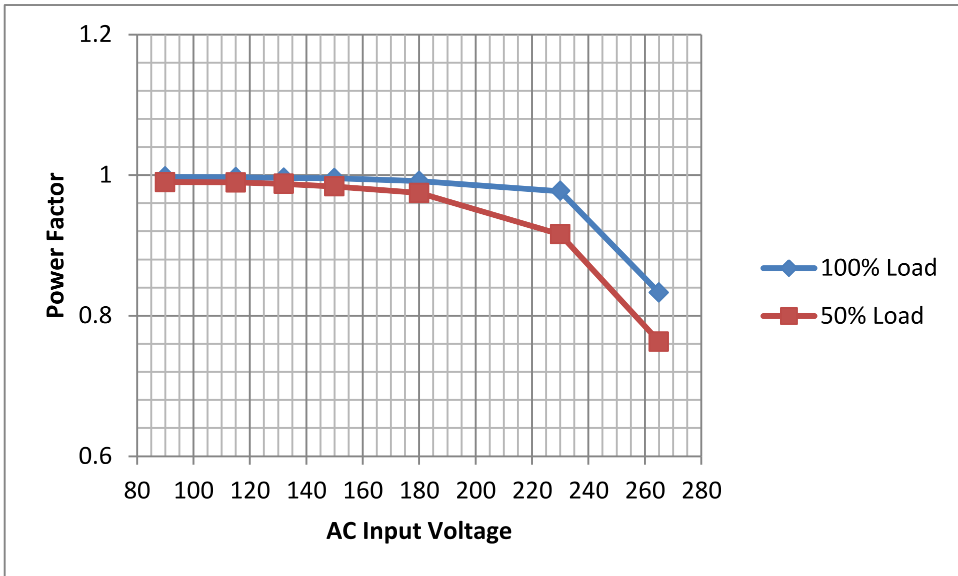

Figure 18 – Power Factor vs. Input Voltage, 50% and 100% Load.

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11.5 THD

THD measurements were taken a 100% and 50% load using a sine wave source and a Yokogawa WT210 power analyzer with harmonic measurement option.

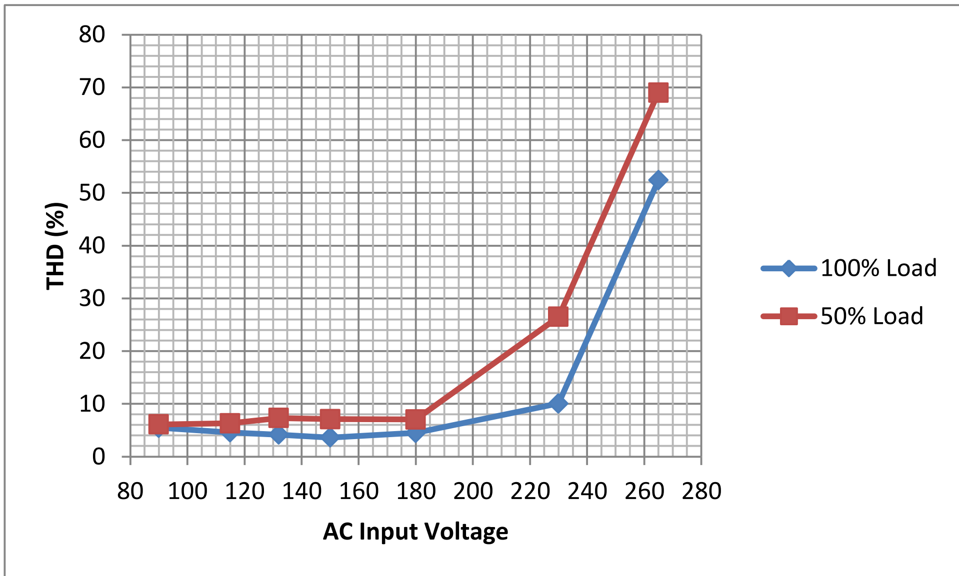

Figure 19 – THD vs. Input Voltage, 50% and 100% Load.

11.6 Output Regulation

The PFC regulates the LLC and standby supply input voltage under normal conditions so the outputs will not be affected by the AC input voltage. Variations due to temperature and component tolerances are not represented. The 48 V output varies by less than 1% over a load range of 10% to 100% load.

11.6.1 Output Line Regulation

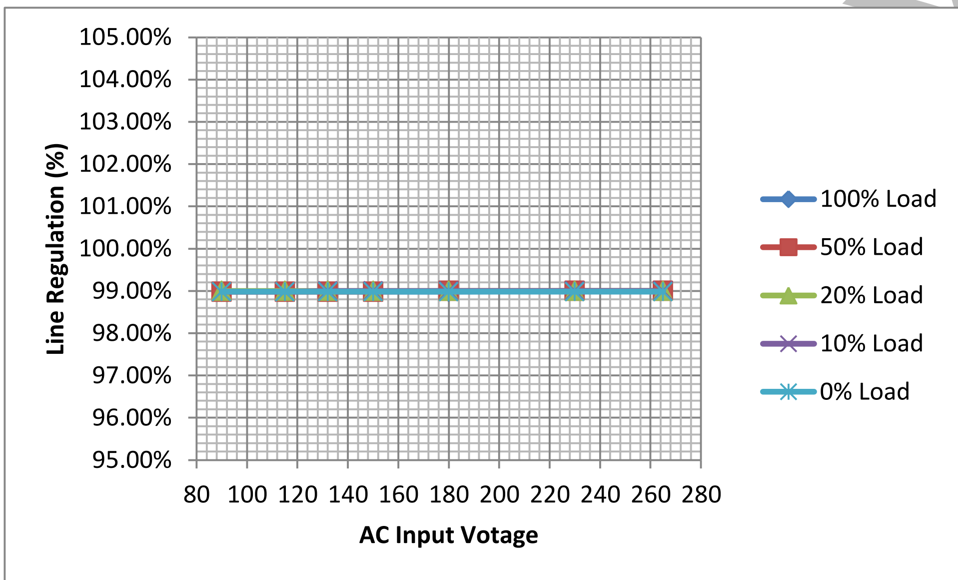

Figure 20 – Output Voltage vs. Input Line Voltage (Line Regulation).

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11.6.2 Output Load Regulation

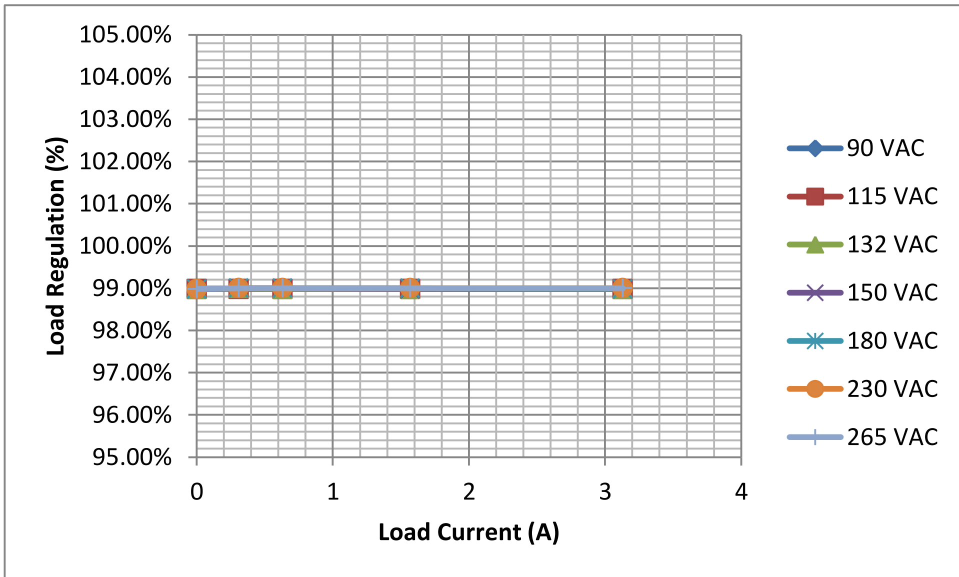

Figure 21 – Output Voltage vs. Output Load Current (Load Regulation).

12 Input Current Harmonics vs. EN 61000-3-2 Class C Limits

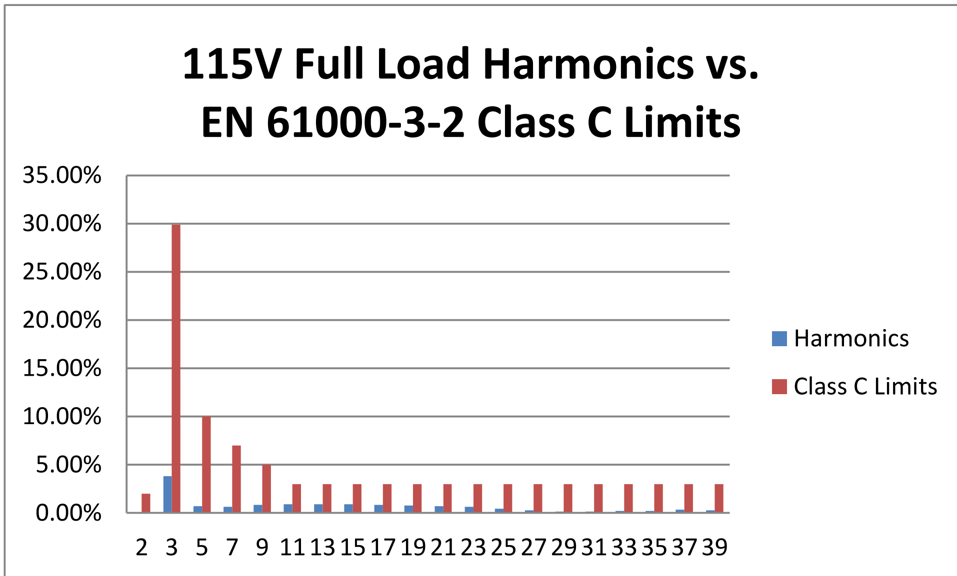

Figure 22 – AC Input Harmonics vs. EN 61000-3-2 Class C Limits, 115 VAC, 60 Hz, 100% Load.

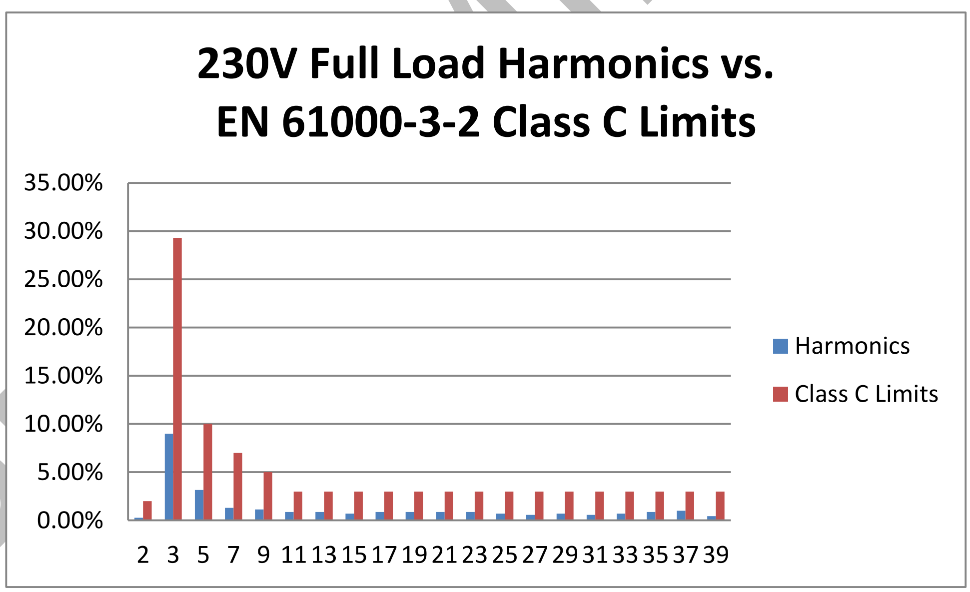

Figure 23 – AC Input Harmonics vs. EN 61000-3-2 Class C Limits, 230 VAC, 60 Hz, 100% Load.

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13 Waveforms

13.1 Input Voltage and Current

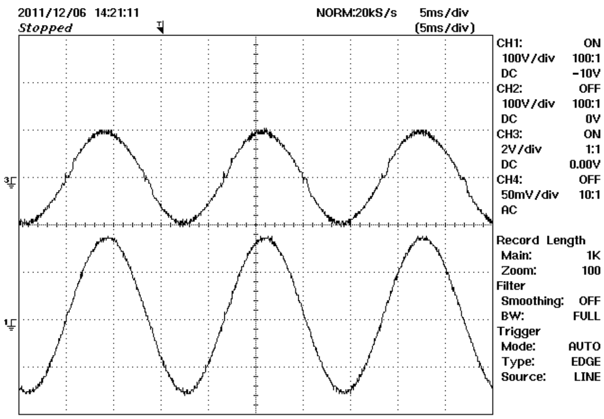

Figure 24 – 115 VAC, 150 W Load.
Upper: Input Current, 2 A / div.
Lower: Input Voltage, 100 V, 5 ms / div.

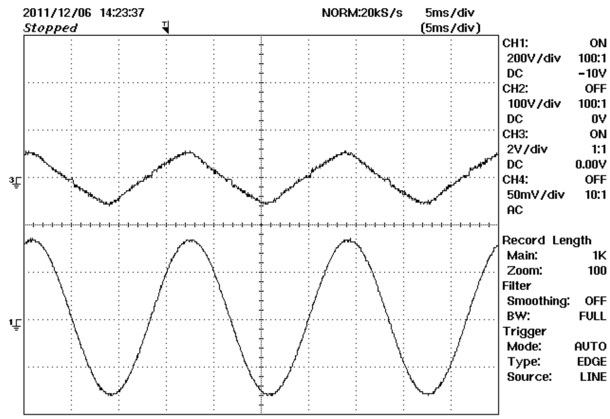

Figure 25 – 230 VAC, 150 W Load.
Upper: Input Current, 2 A / div.
Lower: Input Voltage, 200 V, 5 ms / div.

13.2 LLC Primary Voltage and Current

The LLC stage current was measured by replacing jumper JP26 with a current sensing loop that measures the LLC transformer (T3) primary current. The primary voltage waveform was measured at the hot side of ferrite bead inductor L6.

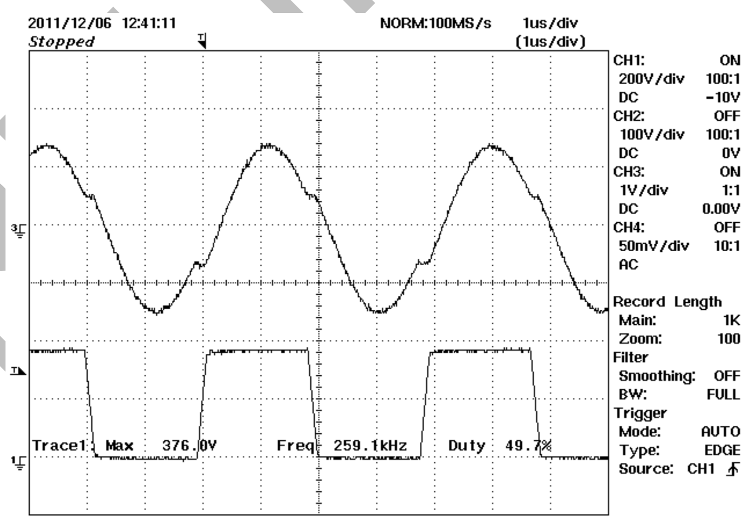

Figure 26 – LLC Stage Primary Voltage and Current.
Upper: Current, 1 A / div.
Lower: Voltage, 200 V, 1 μs / div.

13.3 PFC Switch Voltage and Current - Normal Operation

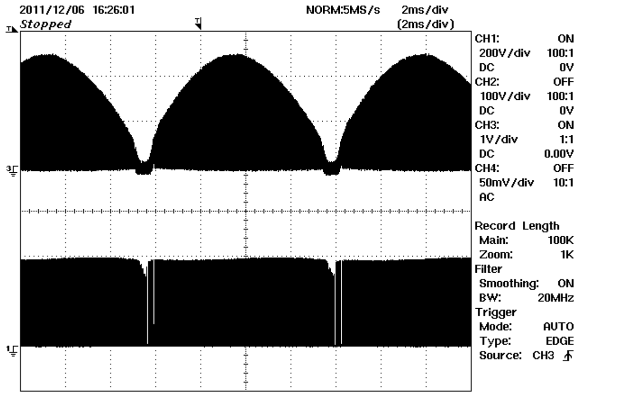

Figure 27 – PFC Stage Drain Voltage and Current, Full Load, 115 VAC
Upper: Drain Current, 1 A / div.
Lower: Drain Voltage, 200 V, 2 ms / div.

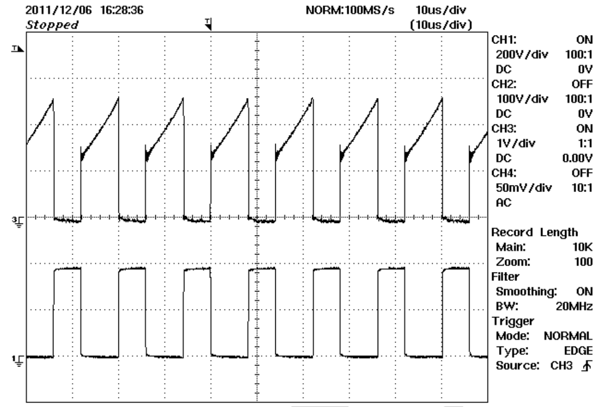

Figure 28 – PFC Stage Drain Voltage and Current, Full Load, 115 VAC.
Upper: Drain Current, 1 A / div.
Lower: Drain Voltage, 200 V, 10 μs / div.

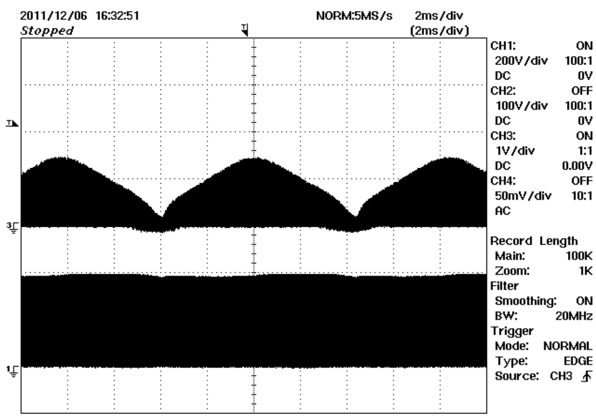

Figure 29 – PFC Stage Drain Voltage and Current, Full Load, 230 VAC.
Upper: Drain Current, 1 A / div.
Lower: Drain Voltage, 200 V, 2 ms / div.

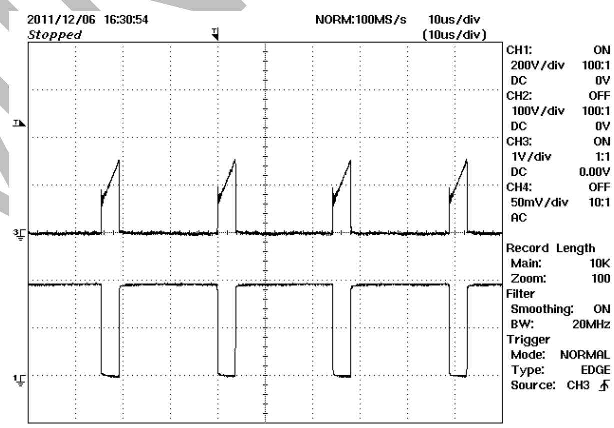

Figure 30 – PFC Stage Drain Voltage and Current, Full Load, 230 VAC.
Upper: Drain Current, 1 A / div.
Lower: Drain Voltage, 200 V, 10 μs / div.

13.4 AC Input Current and PFC Output Voltage during Start-up

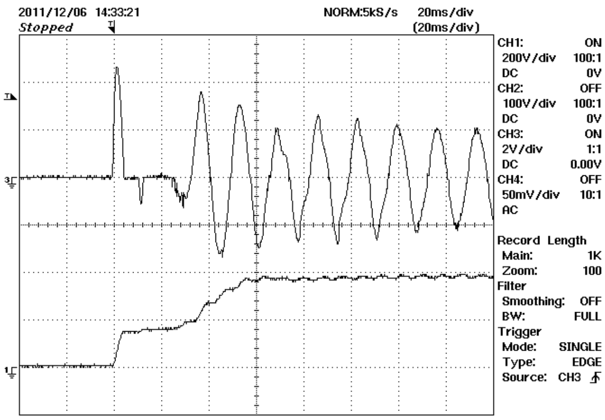

Figure 31 – AC Input Current vs. PFC Output Voltage at Startup, Full Load, 115 VAC.
Upper: AC Input Current, 2 A / div.
Lower: PFC Voltage, 200 V, 20 ms / div

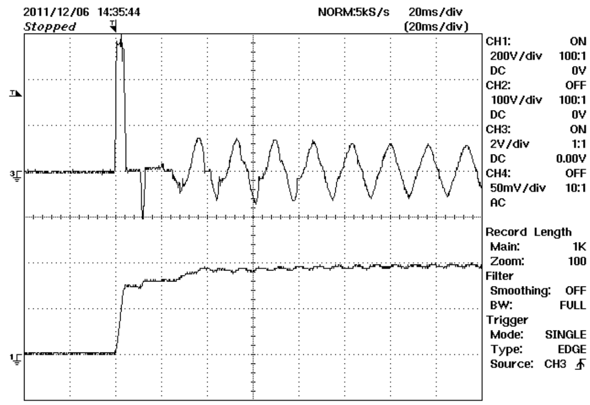

Figure 32 – AC Input Current vs. PFC Output Voltage at Startup, Full Load, 230 VAC.
Upper: AC Input Current, 2 A / div.
Lower: PFC Voltage, 200 V, 20 ms / div.

13.5 Bias Supply Drain Waveforms

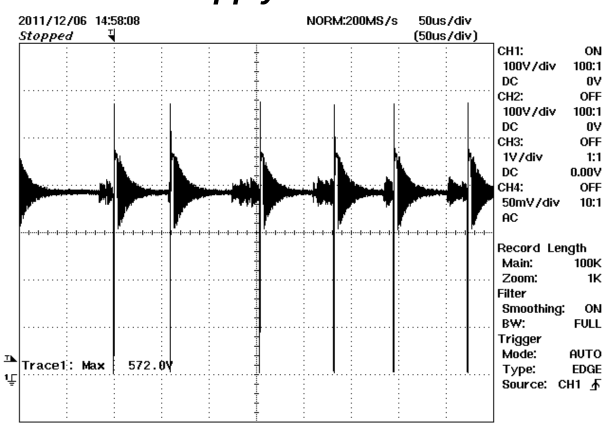

Figure 33 – Bias Supply LNK302 Drain Voltage, 100 V, 50 µs / div.

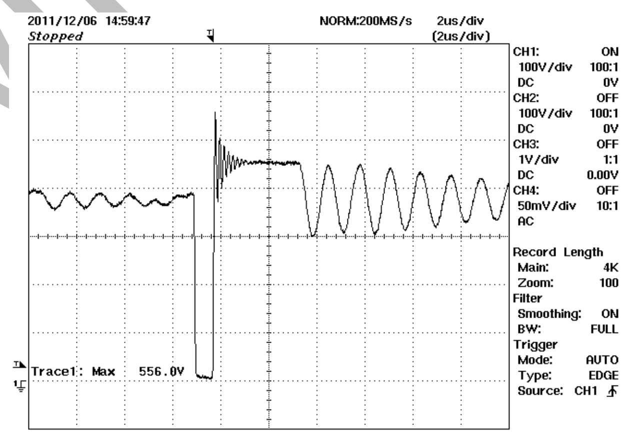

Figure 34 – Bias Supply LNK302 Drain Voltage, 100 V, 2 µs / div.

13.6 LLC Start-up

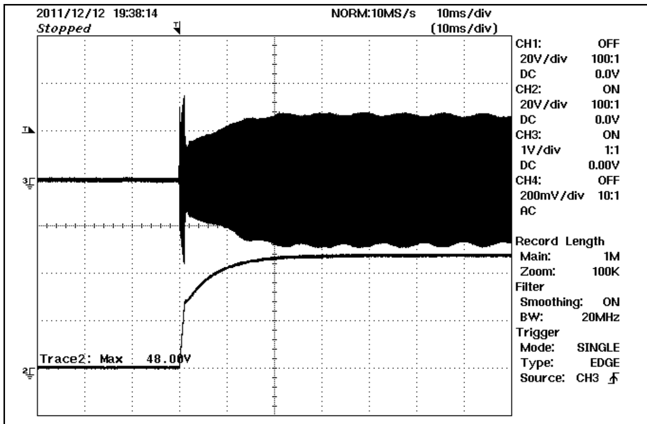

Figure 35 – LLC Startup. 115 VAC, 100% Load.
Upper: LLC Primary Current, 1 A / div.
Lower: LLC Output Voltage, 20 V,
2 ms / div.

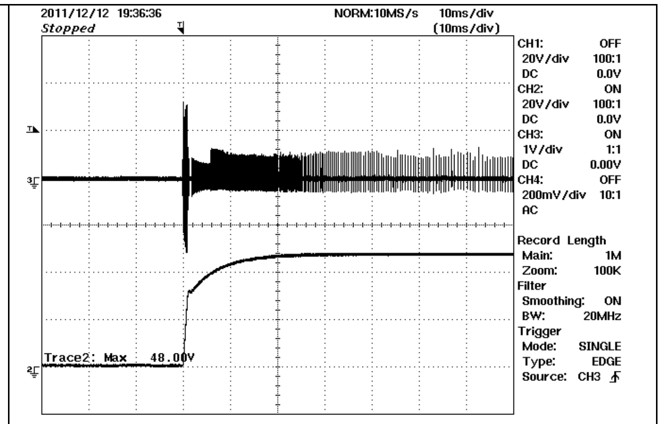

Figure 36 – LLC Startup. 115 VAC, 0% Load.
Upper: LLC Primary Current, 1 A / div.
Lower: LLC Output Voltage, 20 V,
5 ms / div.

13.7 LLC Brownout

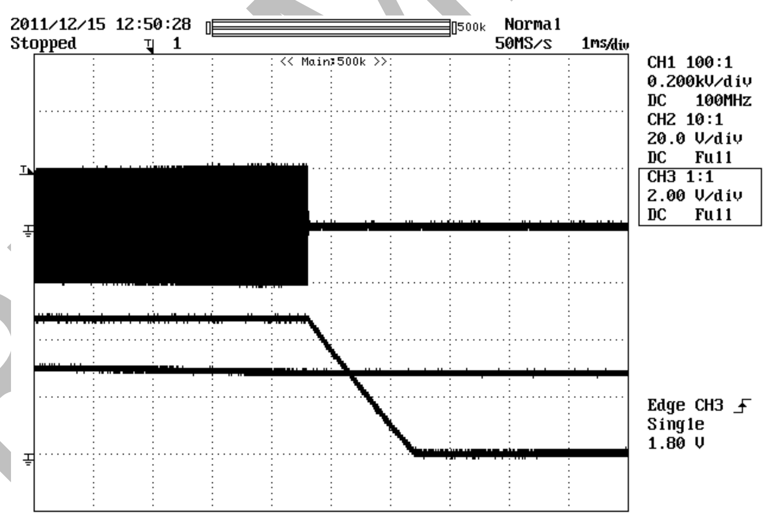

Figure 37 – LLC Brown-out.
Upper: Primary Current, 2 A / div.
Middle: Output Voltage, 20 V / div.
Lower: B+ Voltage, 200 V, 1 ms / div

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13.8 LLC Output Short-Circuit

The figure below shows the effect of an output short circuit on the LLC primary current. A mercury displacement relay was used to short the output to get a fast, bounce-free connection.

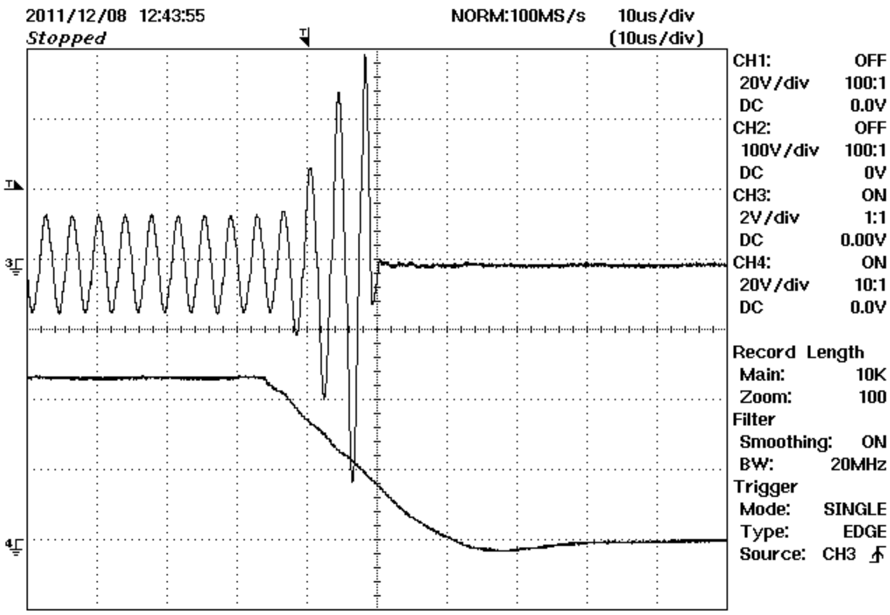

Figure 38 – Output Short Circuit Test.
Upper: LLC Primary Current, 2 A / div.
Lower: 48 V Output, 20 V, 10 µs / div.

13.9 *Output Ripple Measurements*

13.9.1 Ripple Measurement Technique

For DC output ripple measurements, use a modified oscilloscope test probe to reduce spurious signals. Details of the probe modification are provided in figures below.

Tie two capacitors in parallel across the probe tip of the 4987BA probe adapter. Use a 0.1 μF / 50 V ceramic capacitor and 1.0 μF / 100 V aluminum electrolytic capacitor. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs.

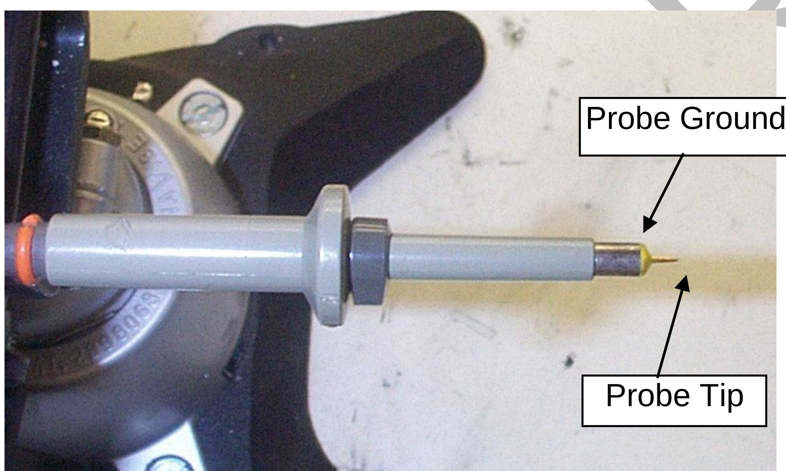

Figure 39 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

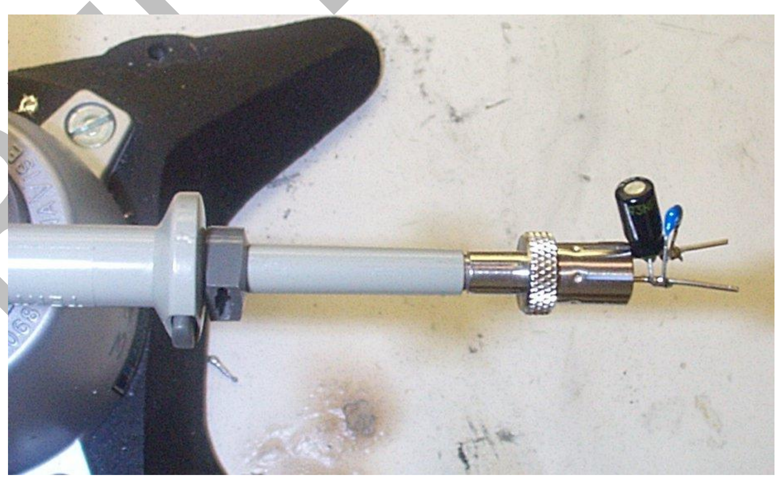

Figure 40 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).

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13.9.2 Full Load Output Ripple Results

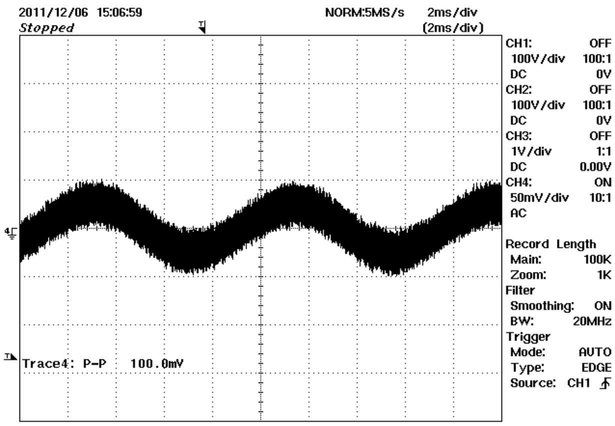

Figure 41 – 48 V Output Ripple, 100 mV, 2 ms / div.

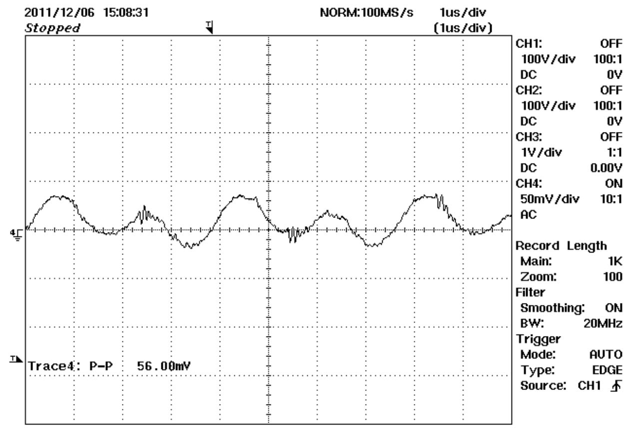

Figure 42 – 48 V Output Ripple, 100 mV, 5 µs / div.

13.9.3 No-Load Ripple Results

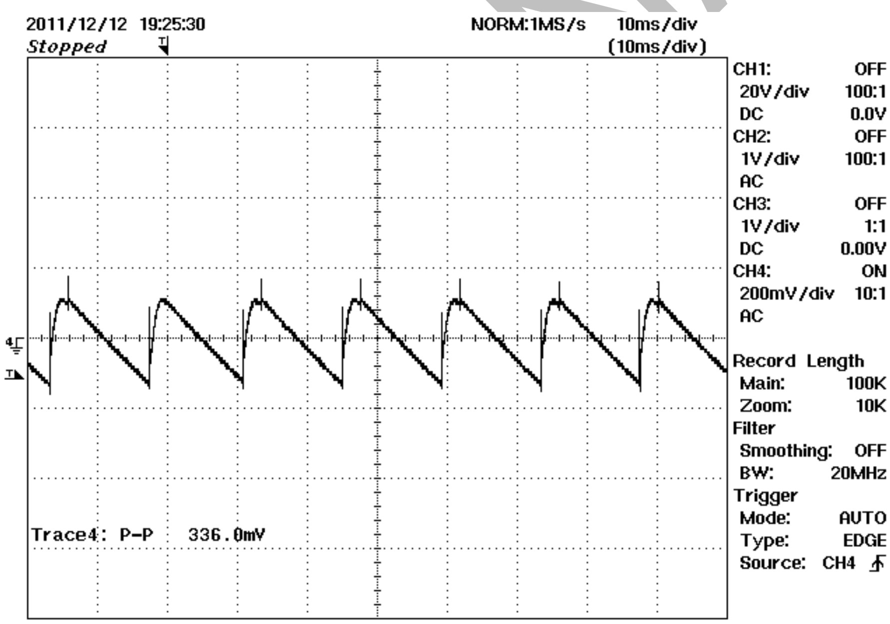

Figure 43 – 48 V No-Load Output Ripple, 200 mV, 10 ms / div.

13.10 Output Load Step Response

The figures below show transient response with a 75%-100%-75% load step for the 48 V output. The oscilloscope was triggered using the rising edge of the load step, and averaging was used to cancel out ripple components asynchronous to the load step in order to better ascertain the load step response.

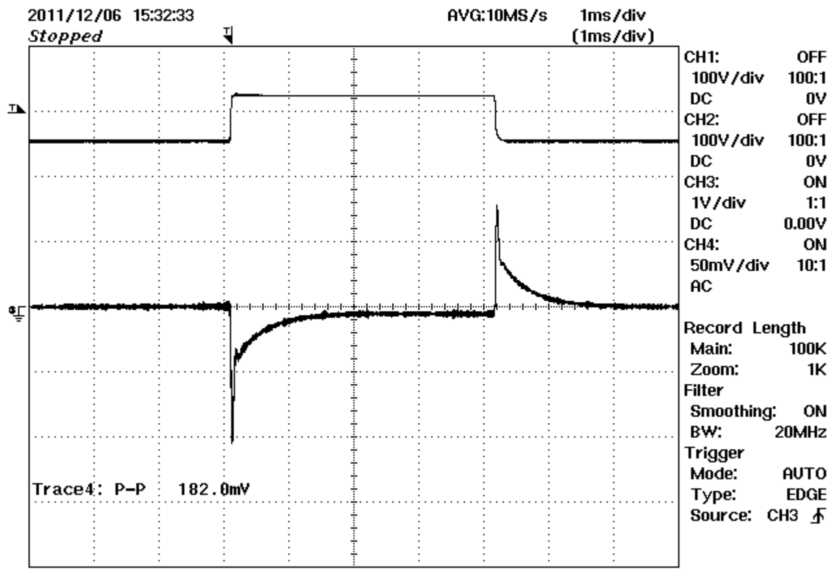

Figure 44 – Output Transient Response 3.13 A – 2.3 A – 3.13 A Load Step.
Upper: Output Load Step, 1 A / div.
Lower: 48 V Transient Response, 100 mV /,1 ms / div.

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13.10.1 100% to 0% Load Step

Figure 45 shows the response of the supply to a 100% to 0% load step. The LLC supply enters burst mode to maintain regulation.

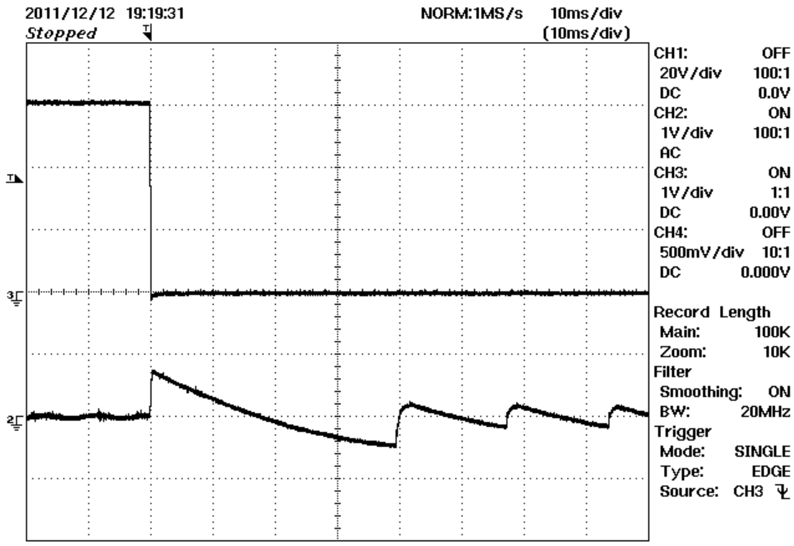

Figure 45 – Output Transient Response 3.13 A – 0 A Load Step.
500 mV, 10 ms / div.

13.10.2 0% to 100% Load Step

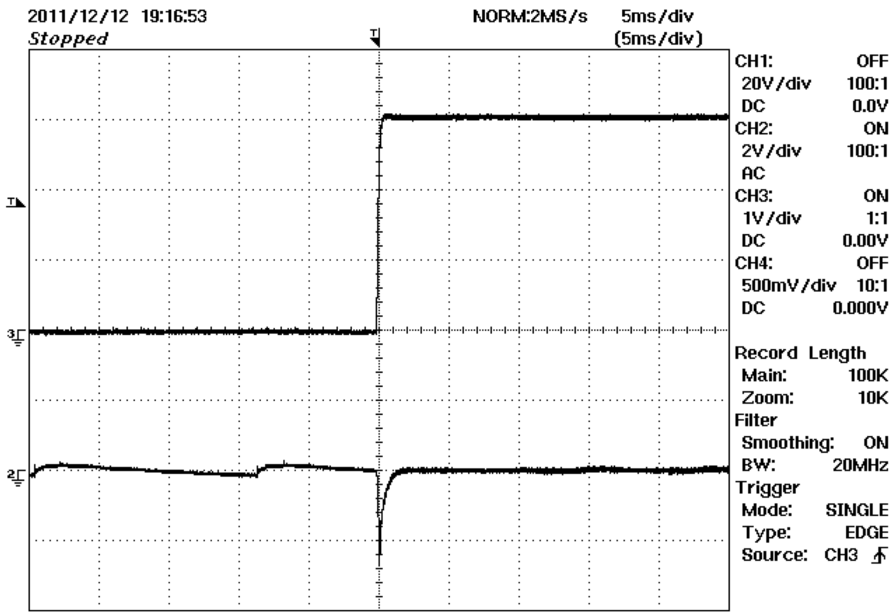

Figure 46 – Output Transient Response 0 A – 3.13 A Load Step.
1 V, 5 ms / div.

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13.10.3 Temperature Profiles

The board was operated at room temperature in a vertical orientation as shown below. For each test condition the unit was allowed to thermally stabilize (>1 hr) before measurements were made.

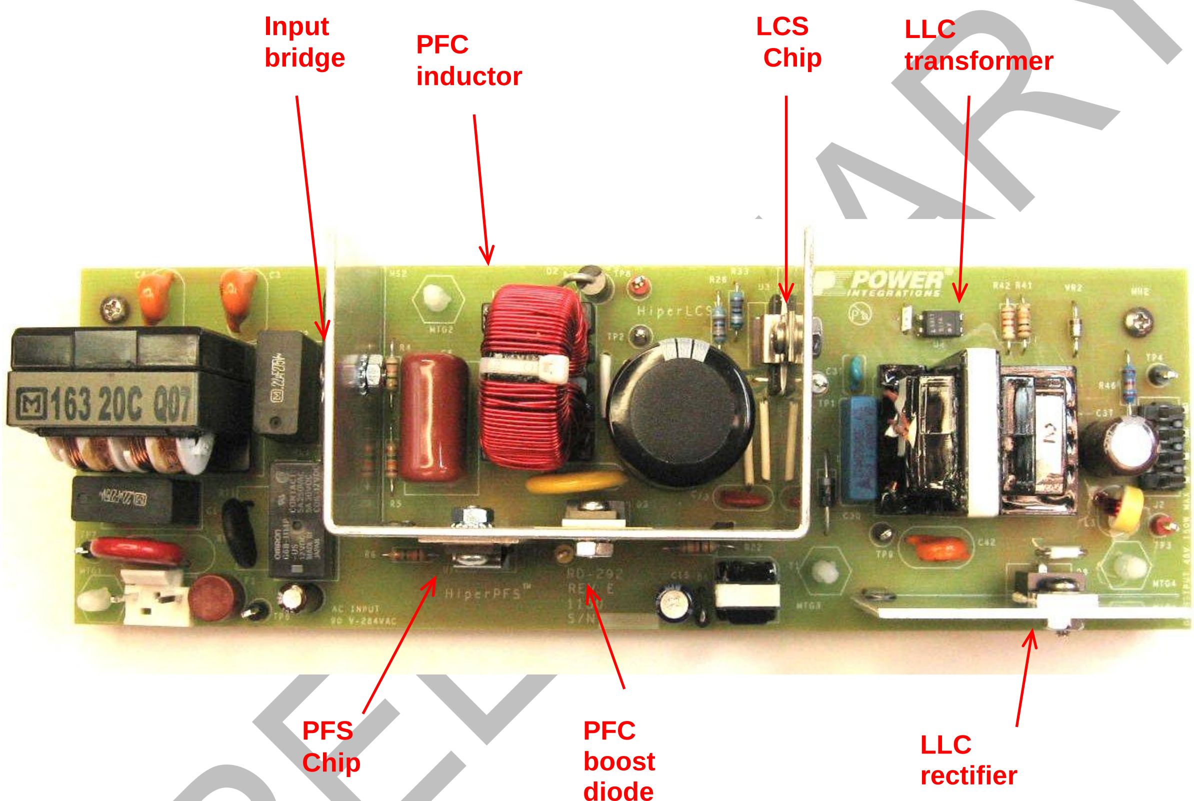

Figure 47 – Photograph of Board Used for Thermal Testing.

13.11 Thermal Results Summary

13.11.1 Testing Conditions

Thermal Measurement data is presented below. The unit was allowed to thermally stabilize (>1 hour in all cases) before gathering data.

13.11.2 90 VAC, 60 Hz, 150 W Output

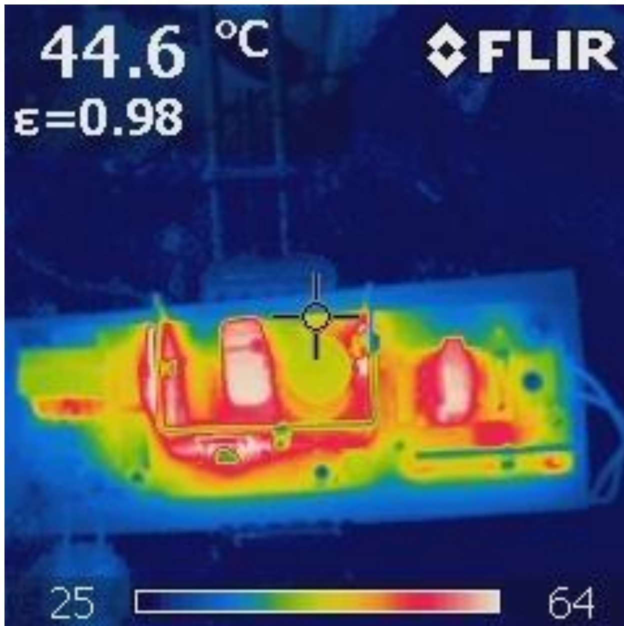

Figure 48 – Overall Thermal Profile, Room Temperature, 90 VAC, 60 Hz, 150 W Load (1 hr).

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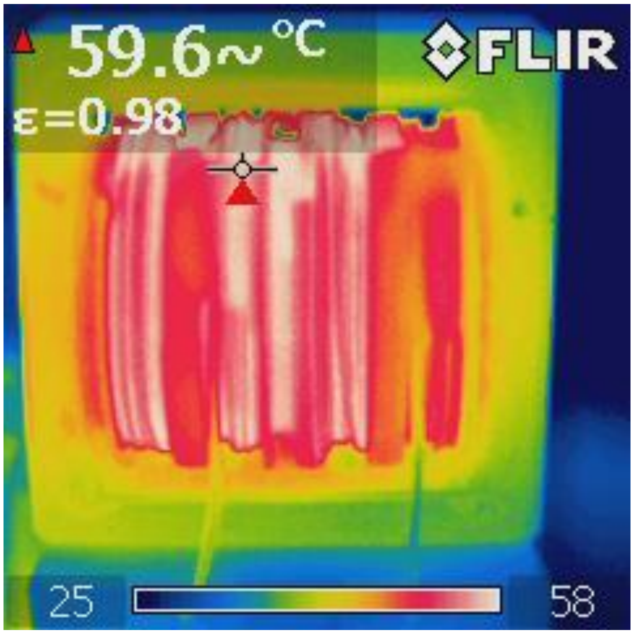

Figure 49 – Input Common Mode Choke Temperature, 90 VAC, Full load.

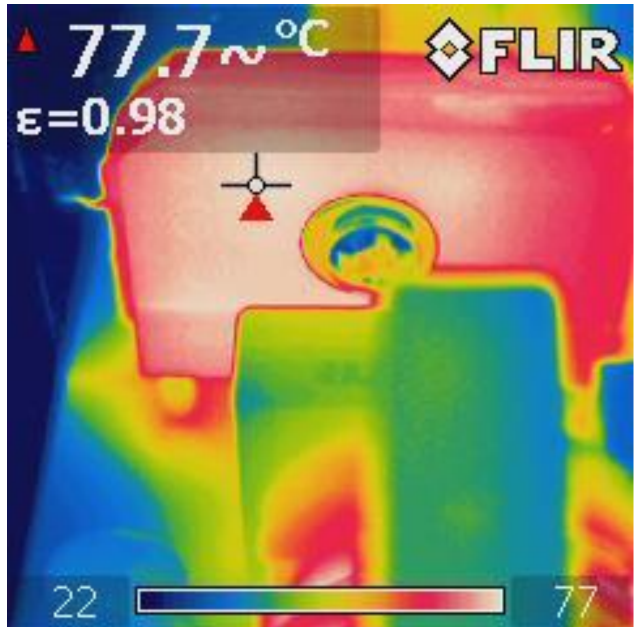

Figure 50 – Diode Bridge Case Temperature, 90 VAC, Full load.

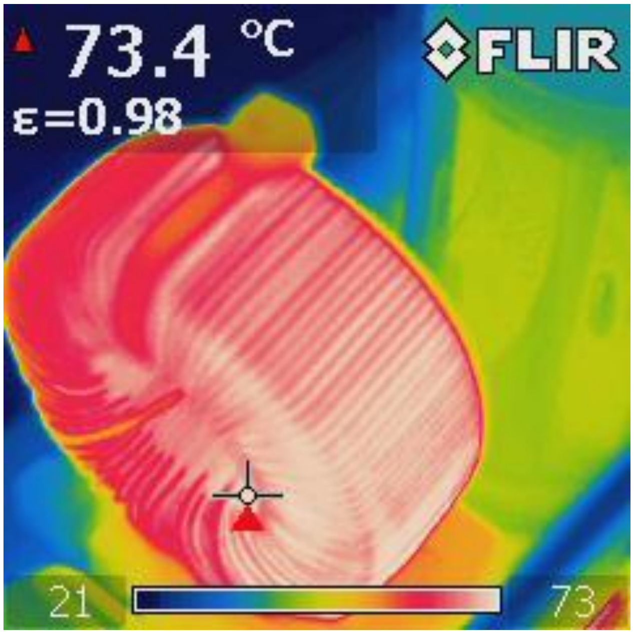

Figure 51 – PFC Choke Temperature, 90 VAC, Full Load.

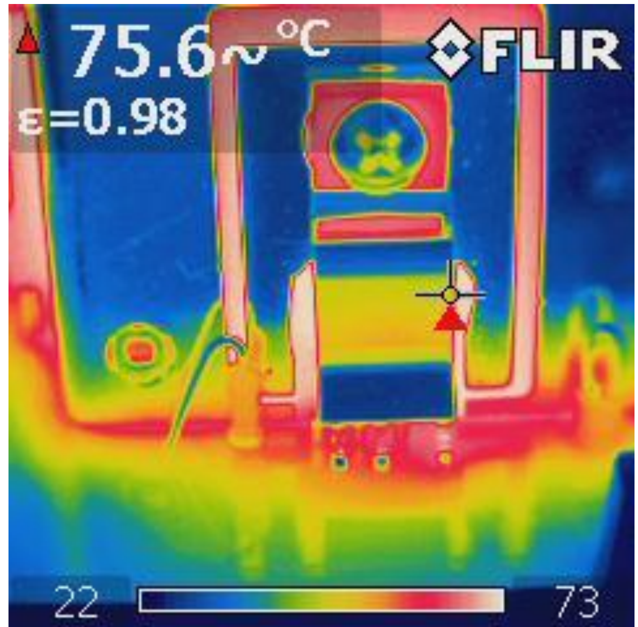

Figure 52 – PFS Chip Case Temperature, 90 VAC, Full Load.

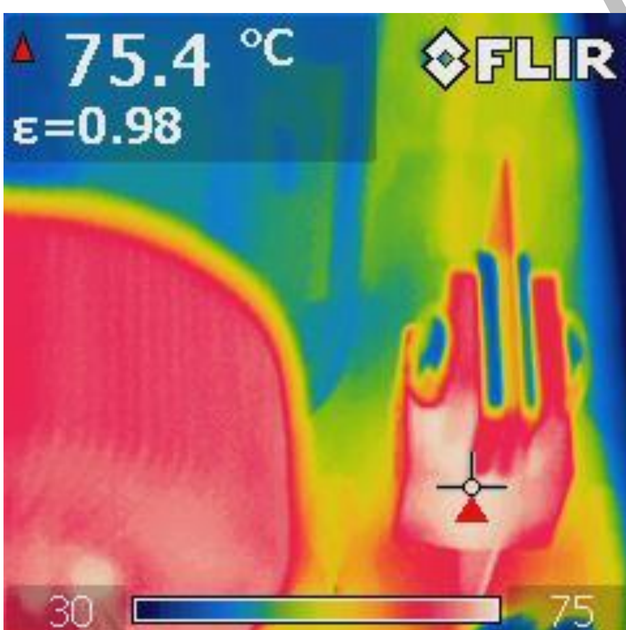

Figure 53 – PFC Output Rectifier Case Temperature, 115 VAC, Full Load.

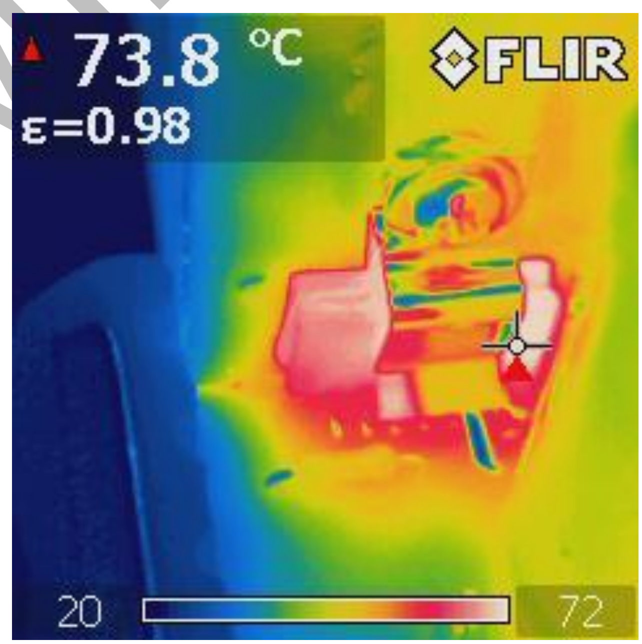

Figure 54 – LCS Chip Case Temperature, 90 VAC, Full Load.

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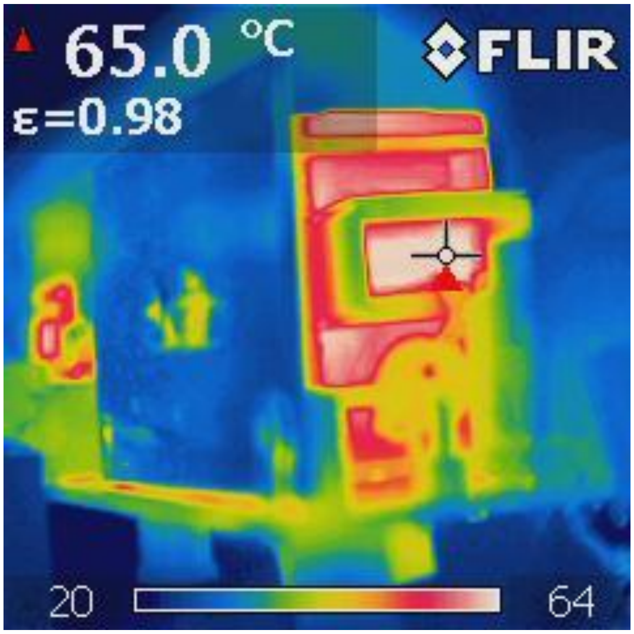

Figure 55 – LLC Transformer Hot Spot Temperature, 90 VAC, Full Load.

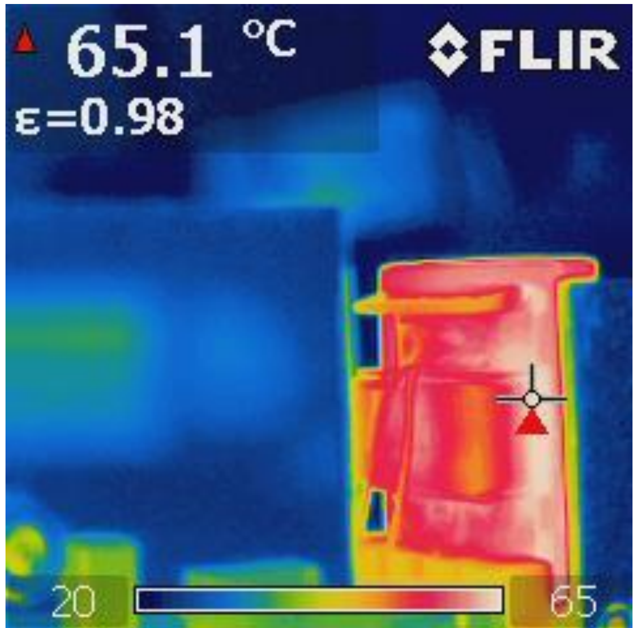

Figure 56 – LLC Transformer Hot Spot Temperature, 90 VAC, Full Load.

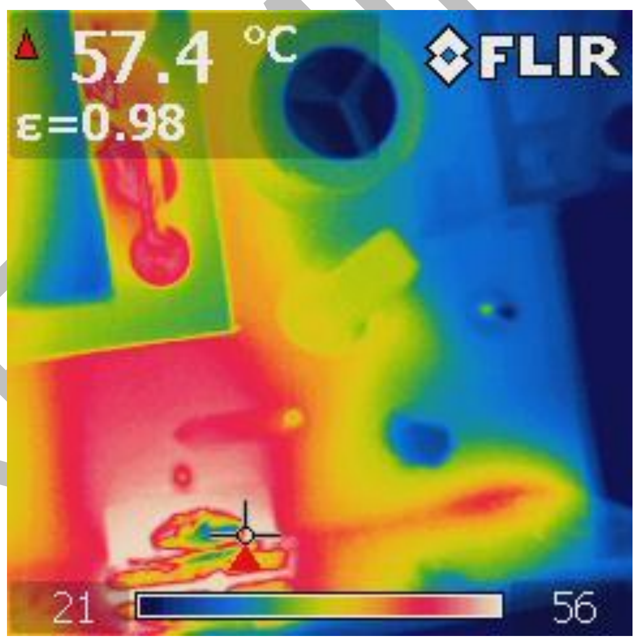

Figure 57 – LLC Output Diode CaseTemperature, 90 VAC, Full Load (Viewed from Above).

13.11.3 115 VAC, 60 Hz, 150 W Output

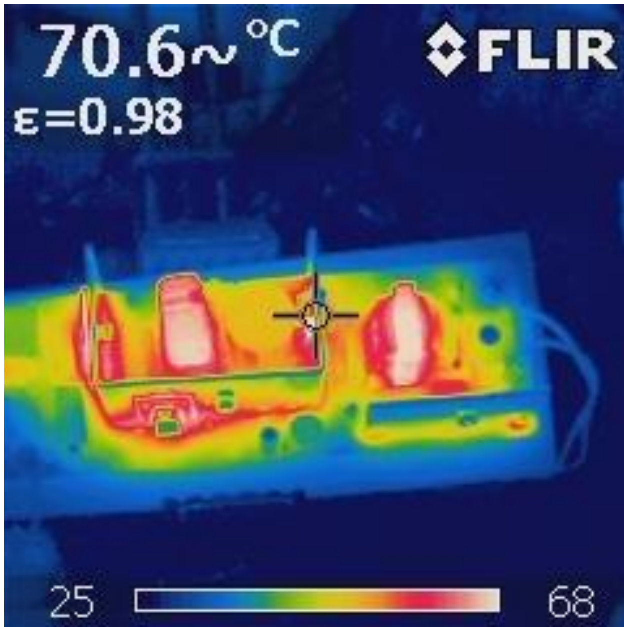

Figure 58 – Overall Thermal Profile. Room Temperature, 115 VAC, 60 Hz, 150 W Load (1 hr).

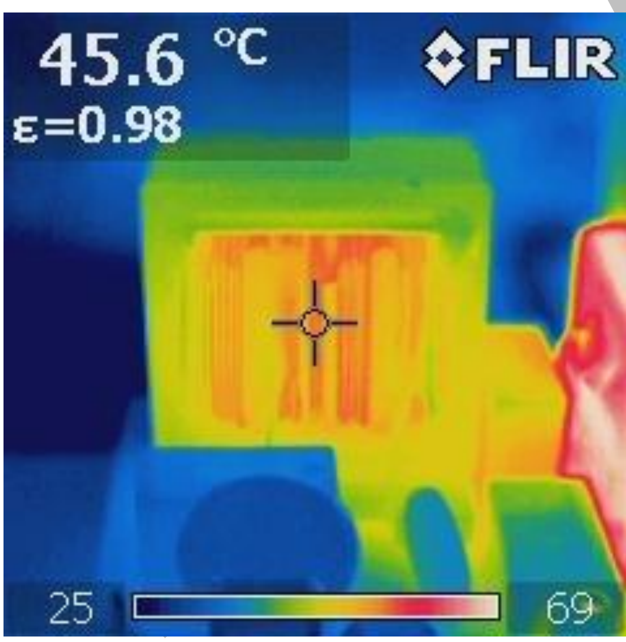

Figure 59 – Input Common Mode Choke Temperature, 115 VAC, Full Load.

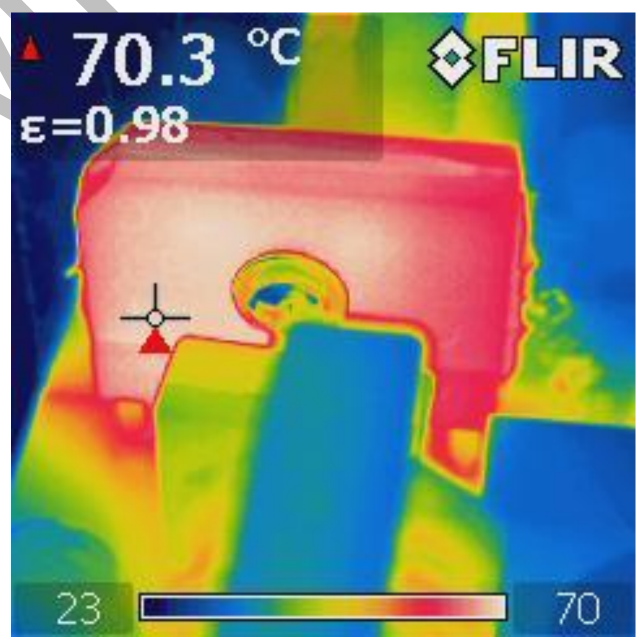

Figure 60 – Diode Bridge Case Temperature, 115 VAC, Full Load.

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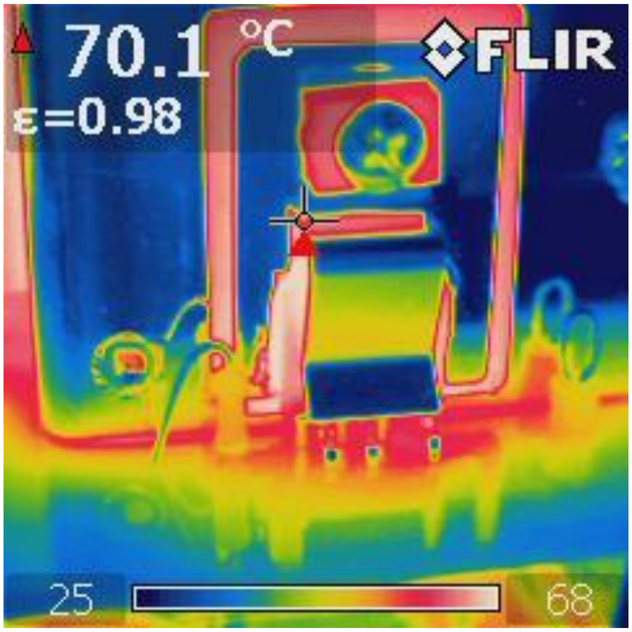

Figure 61 – PFS Chip CaseTemperature, 115 VAC, Full Load.

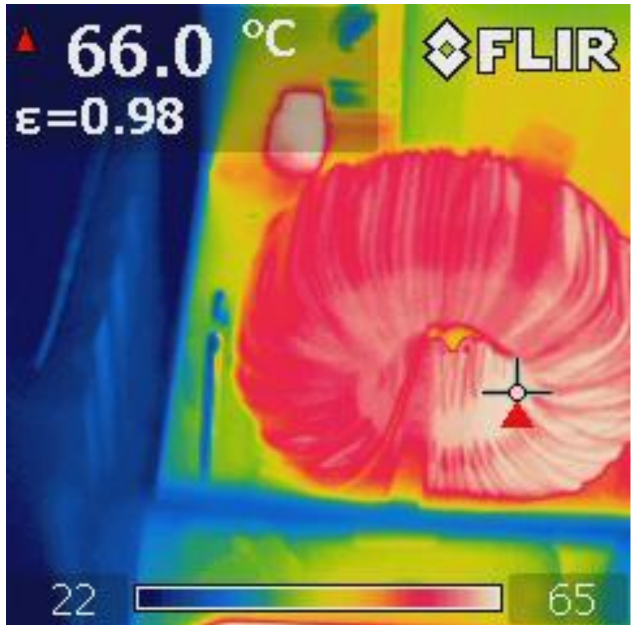

Figure 62 – PFC Choke Temperature, 115 VAC, Full Load.

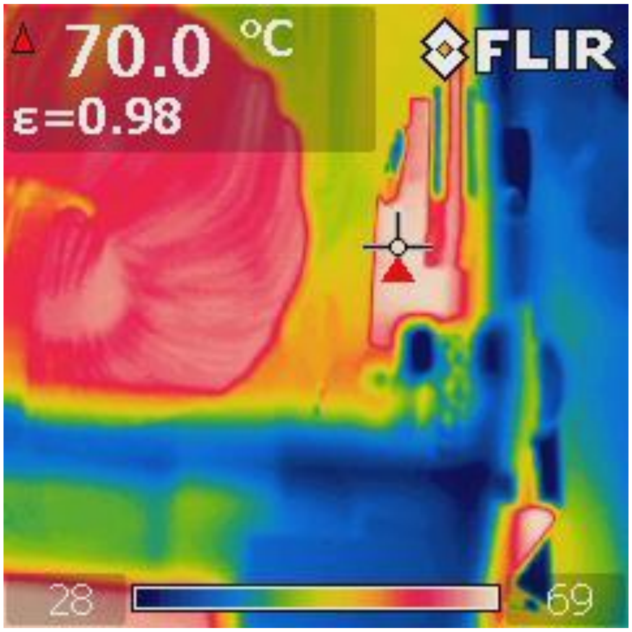

Figure 63 – PFC Output Rectifier Case Temperature, 115 VAC, Full Load.

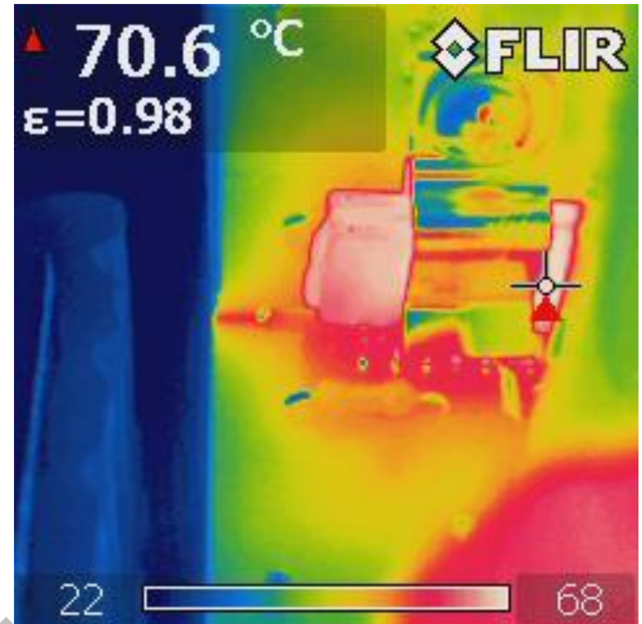

Figure 64 – LCS Chip Case Temperature, 115 VAC, Full Load.

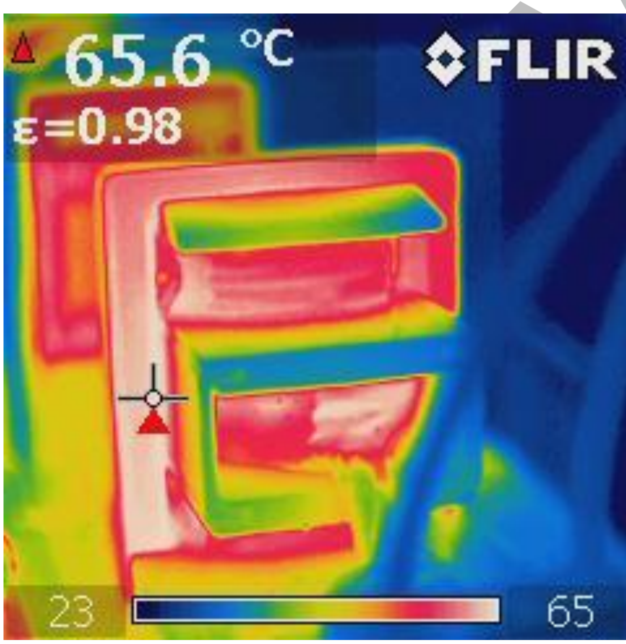

Figure 65 – LLC Transformer Secondary Side Hot Spot Temperature, 115 VAC, Full Load.

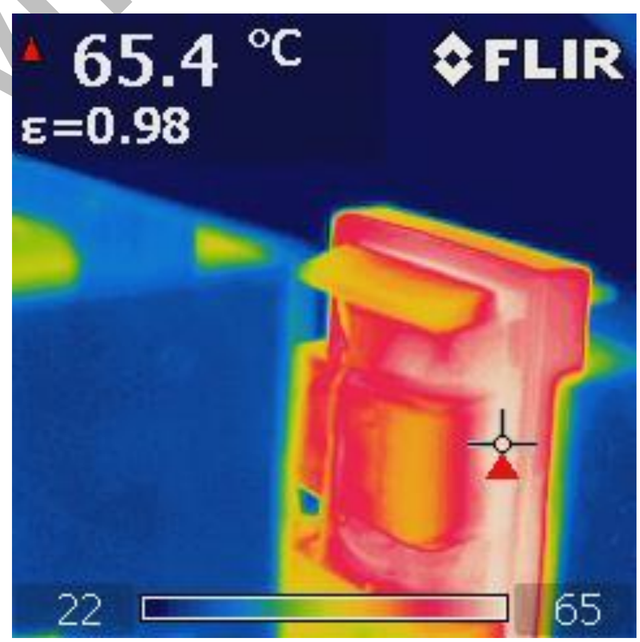

Figure 66 – LLC Transformer Primary Side Hot Spot Temperature, 115 VAC, Full Load.

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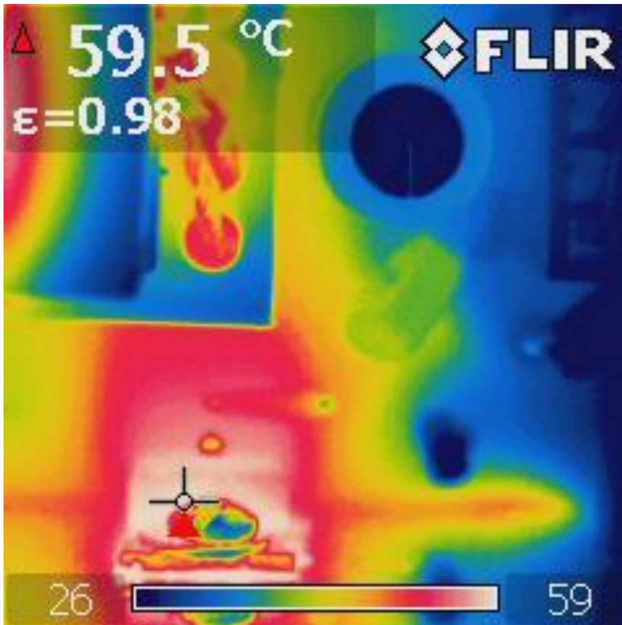

Figure 67 – LLC Output Rectifier Case Temperature, 115 VAC, Full Load (Viewed from Above).

13.11.4 230 VAC, 150 W, Room Temperature

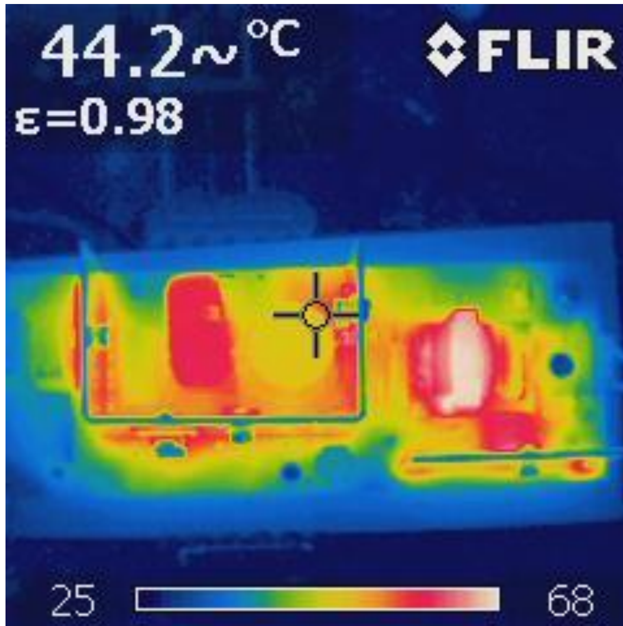

Figure 68 – Overall Temperature Profile, 230 VAC, Full Load.

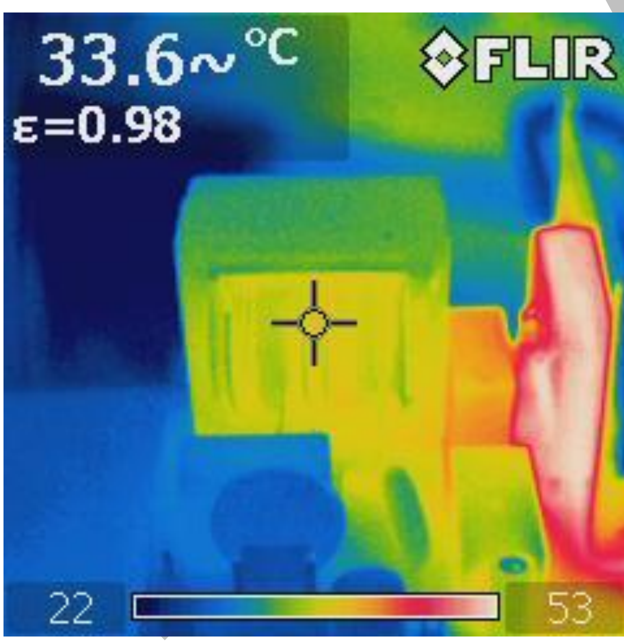

Figure 69 – Input Common Mode FilterTemperature, 230 VAC, Full Load.

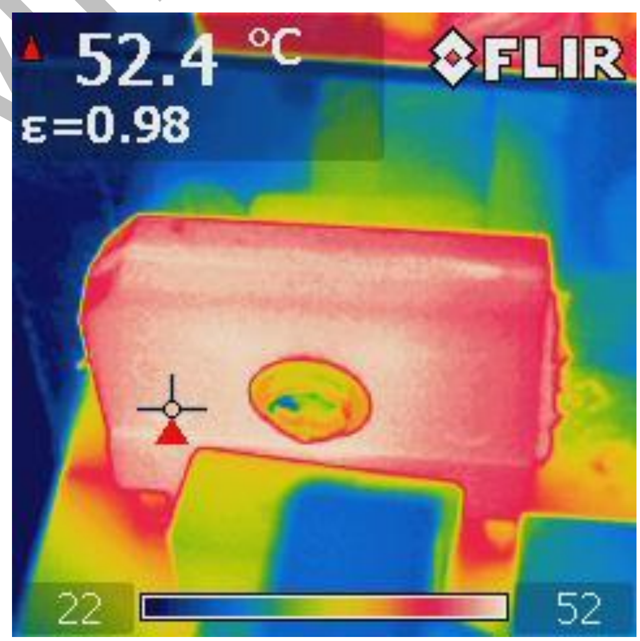

Figure 70 – Bridge Rectifier Case Temperature, 230 VAC, Full Load.

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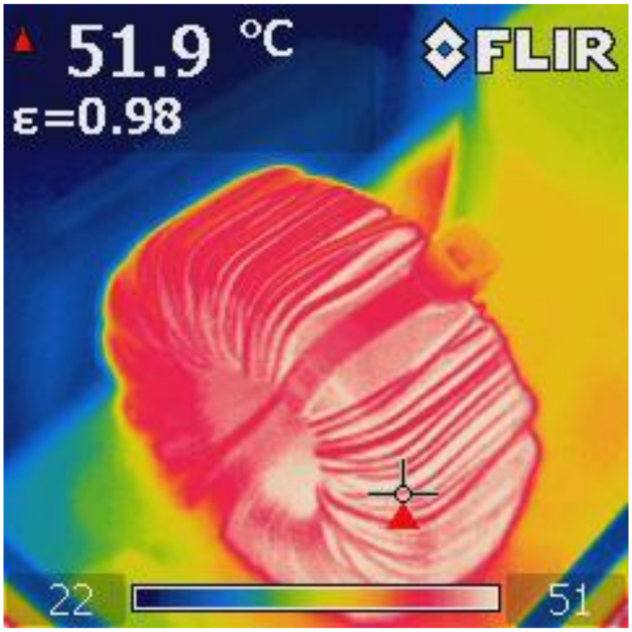

Figure 71 – PFC ChokeTemperature, 230 VAC, Full Load.

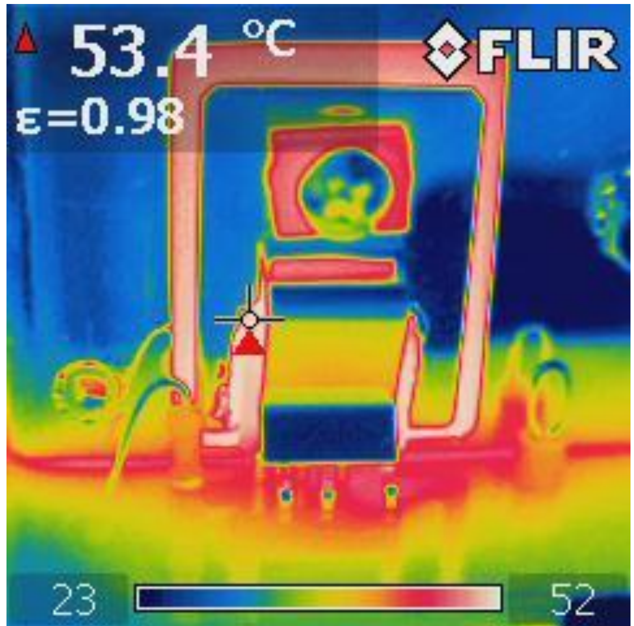

Figure 72 – PFS Chip Case Temperature, 230 VAC, Full Load.

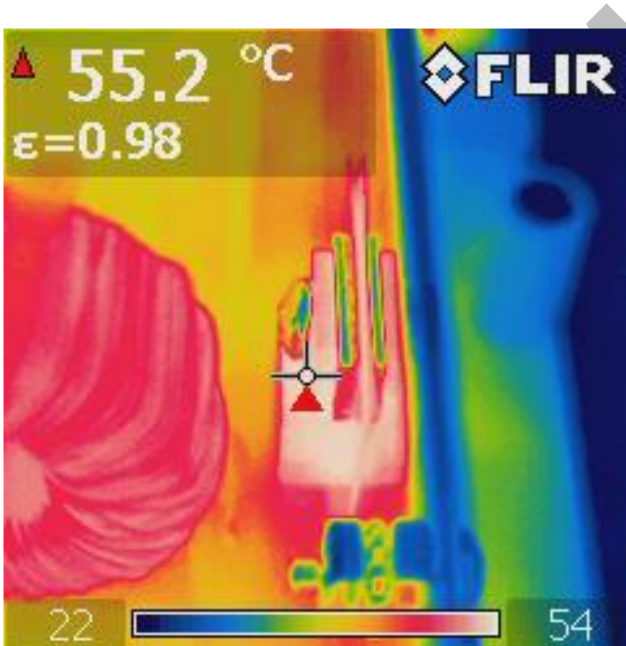

Figure 73 – PFC Output Rectifier Case Temperature, 115 VAC, Full Load.

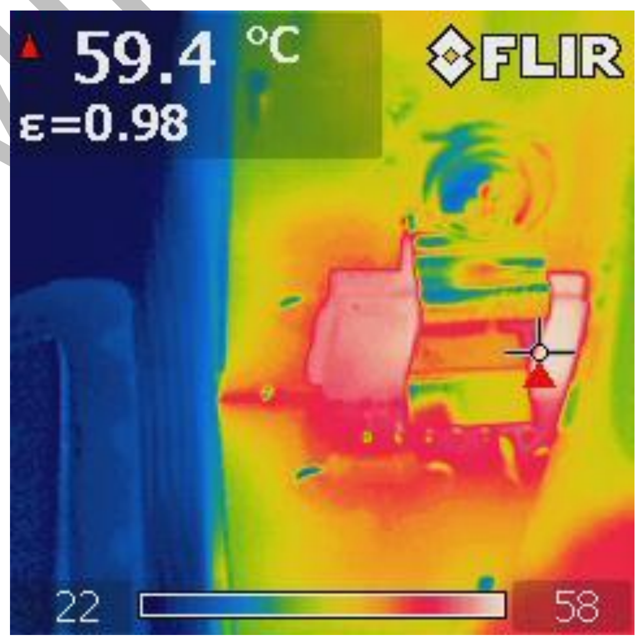

Figure 74 – Hiper LCS CaseTemperature, 115 VAC, Full Load.

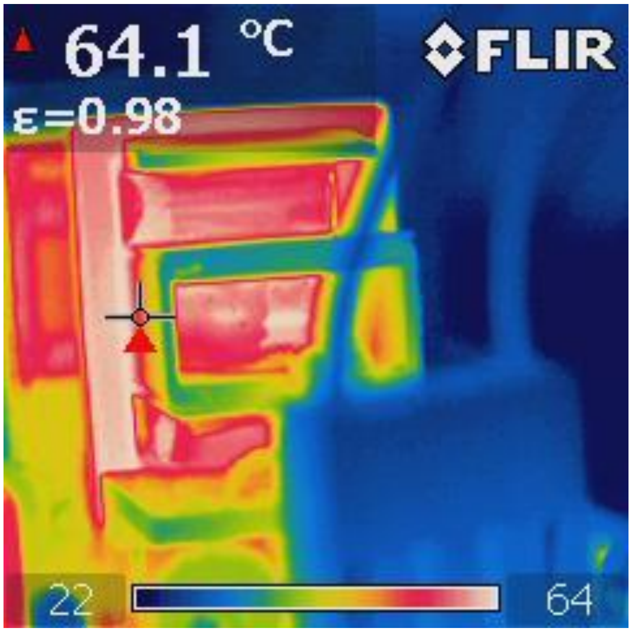

Figure 75 – LLC Output Transformer Secondary Side Hot Spot Temperature, 230 VAC, Full Load.

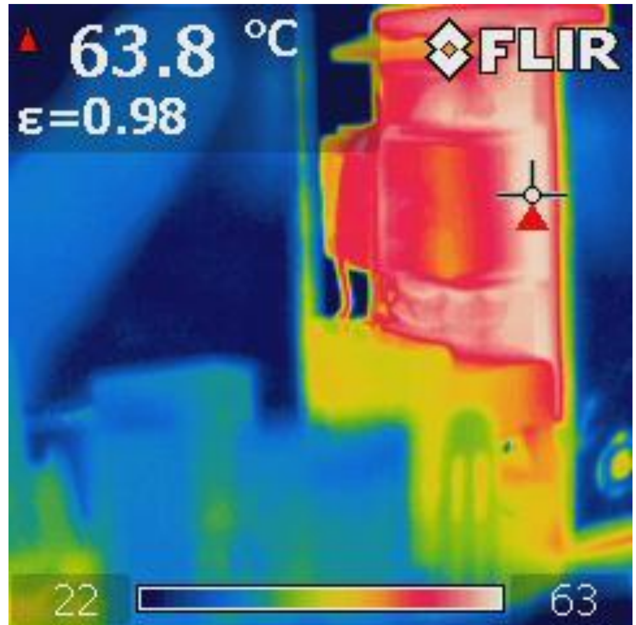

Figure 76 – LLC Output Transformer Primary Side Hot Spot Temperature, 230 VAC, Full Load.

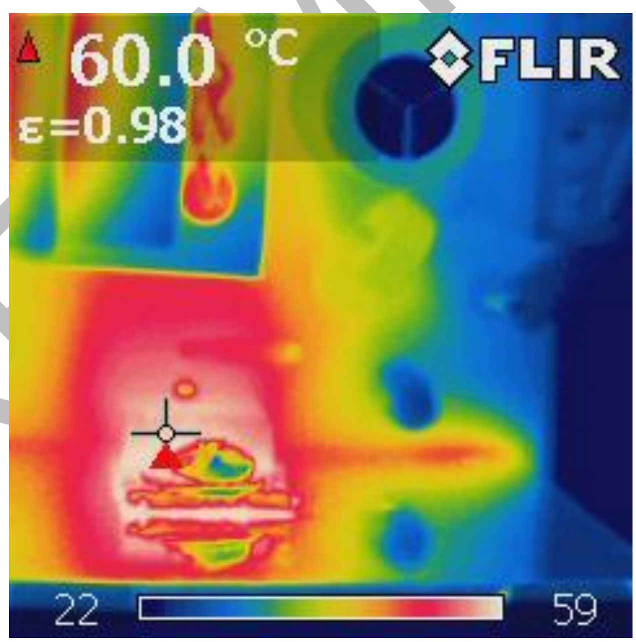

Figure 77 – LLC Output Rectifier Case Temperature, 230 VAC, Full Load (Viewed from Above).

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14 Conducted EMI

14.1 EMI Set-up

14.1.1 Power Supply Preparation for EMI Test

The picture below shows the power supply set-up for EMI and surge testing. The supply is attached to a ground plane approximately the size of the power supply A piece of single-sided copper clad printed circuit material was used in this case, but a piece of aluminum sheet would also work. The supply is attached to the ground plane in two places using ¼" 4-40 screws. Attachments points are the metal spacers marked as MH1 and MH2 on the top silk screen. An IEC AC connector was hard-wired to the power supply AC input, with the safety ground connected to the ground plane. A Fair-Rite 2643250302 ferrite bead was placed over the safety ground connection, and can be seen in the illustration below. This bead gives additional margin at ~20 MHz.

Figure 78 – RD-292 Set-up for EMI and Surge Testing.

14.1.2 EMI Test Set-up

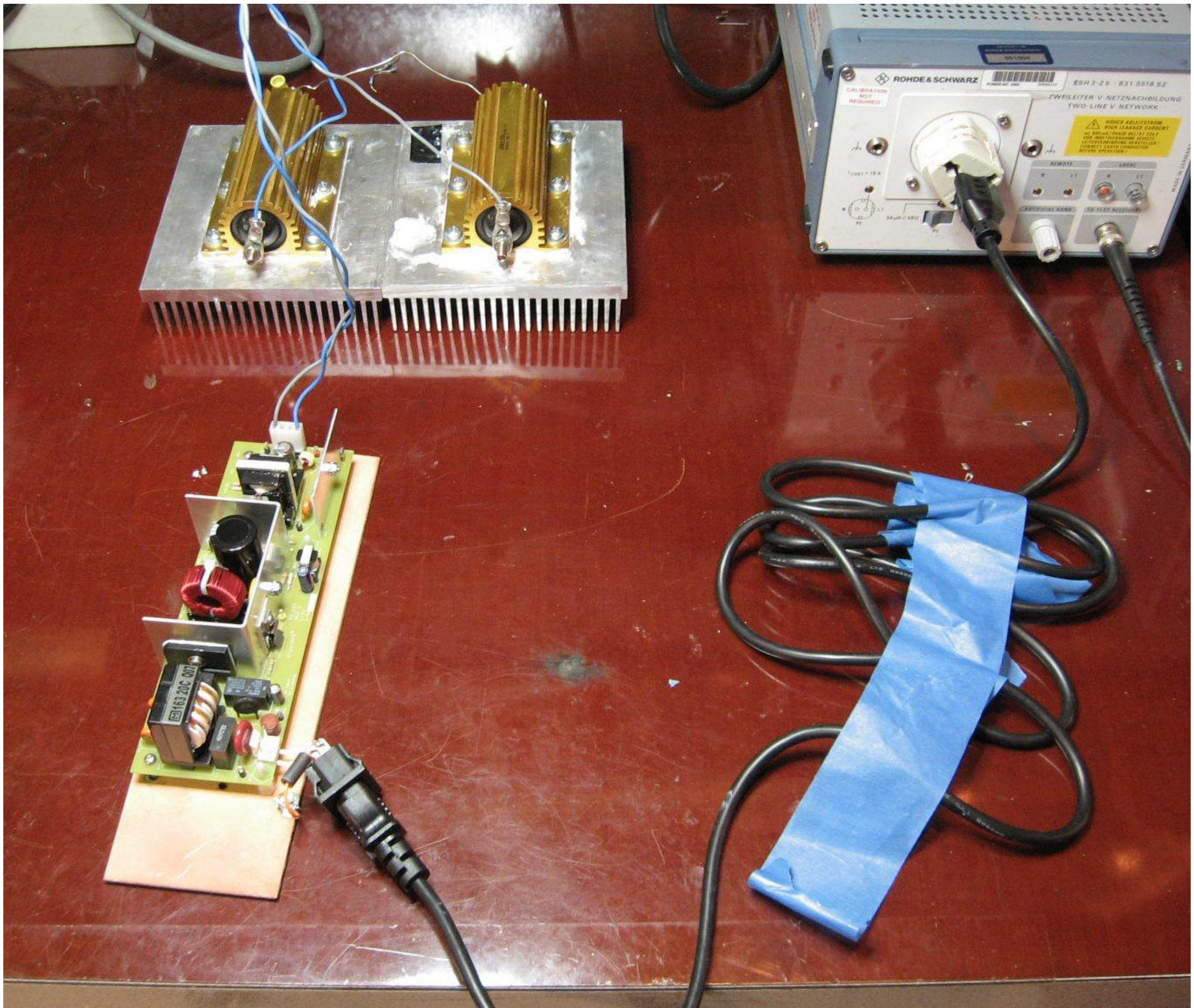

Figure 79 – EMI Room Set-up.

Conducted EMI tests were performed with a 16 Ω resistive load on the 48 V main output. The unit was attached to a metallic ground plane, which in turn was hard wired to the AC cord ground. The resistive load was left floating.

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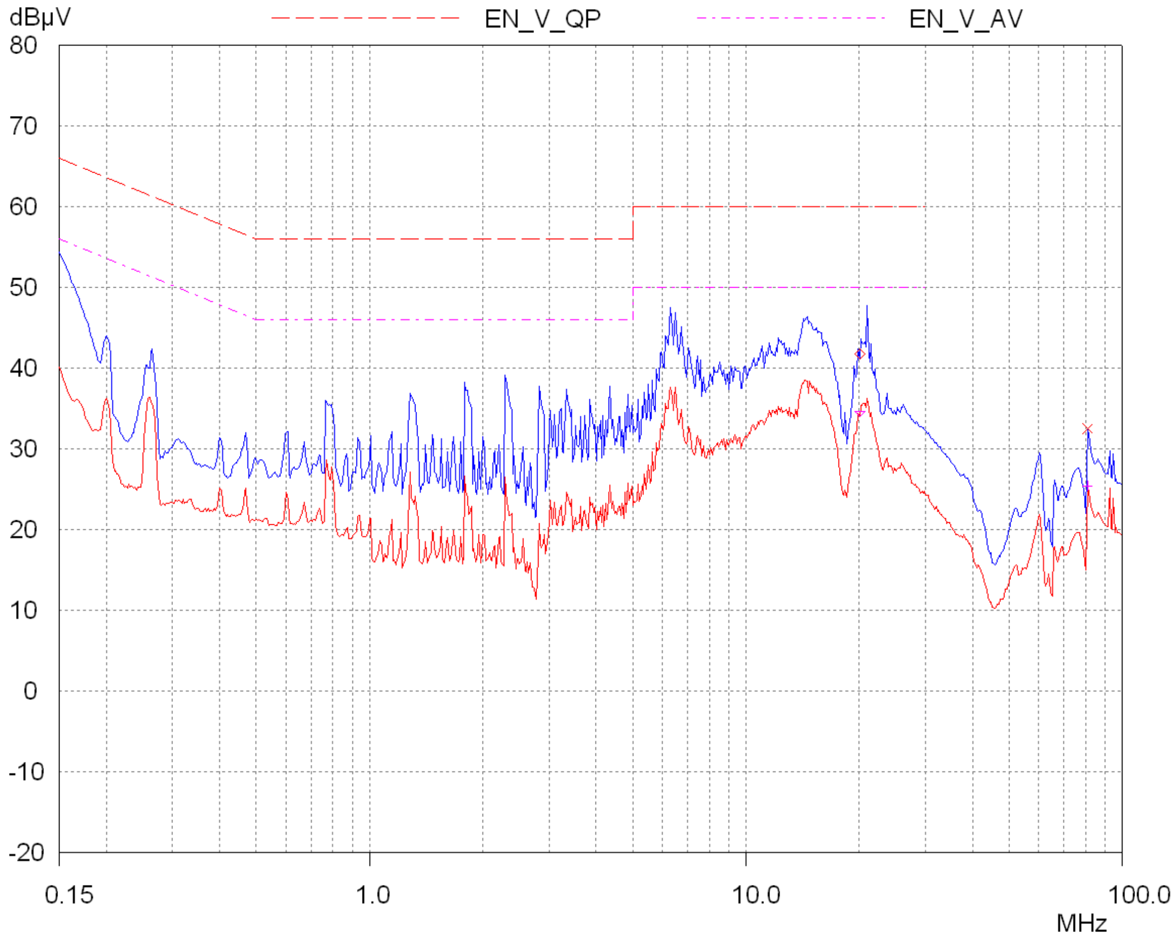

Figure 80 – Conducted EMI, 115 VAC.

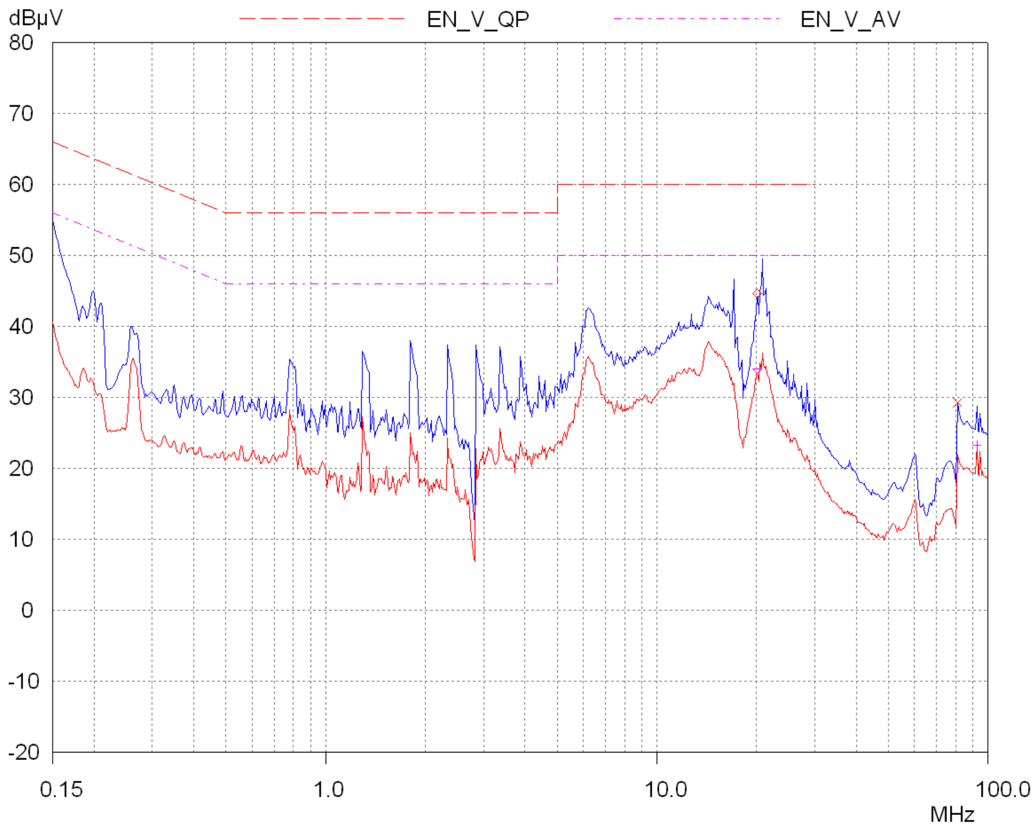

Figure 81 – Conducted EMI, 230 VAC.

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15 Gain-Phase Measurement

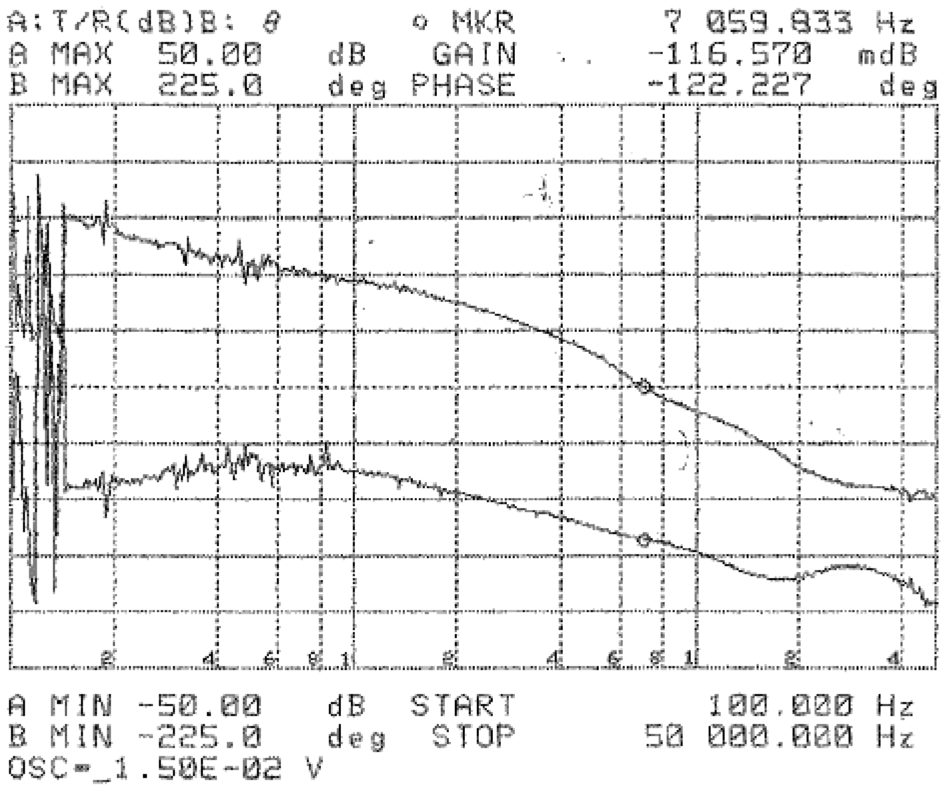

Figure 83 – RD-292 LLC Gain-Phase Measurement, Full Load Gain Crossover Frequency – 7.06 kHz, Phase Margin, 57.8º.

16 Input Surge Testing

16.1 Surge Test Set-up

The set-up for surge testing identical to that of EMI testing, with the UUT mounted on a ground plane as shown below, with a 16 Ω floating resistive load. An LED in series with a 680 Ω resistor and a 39 V, 1 W Zener diode was used to monitor the output, in order to detect dropouts/loss of function. The Zener diode provides extra sensitivity for dropout testing, as the LED will shut off in response to a partial loss of output voltage.

The UUT was tested using a Key Tek EMC Pro Plus surge tester. The power supply was configured on a ground plane as shown in Figure 84, with a floating 16 Ω resistive load. Results of common mode and differential mode surge testing are shown below. A test failure was defined as a non-recoverable output interruption requiring supply repair or recycling AC input voltage.

Figure 82 – RD-292 Set-up for Surge Testing.

16.2 Differential Mode Surge, 1.2/50 μsec

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (º)	Generator Impedance (Ω)	Number of Strikes	Test Result
115 VAC	+2	90	2	10	PASS
115 VAC	-2	90	2	10	PASS
115 VAC	+2	270	2	10	PASS
115 VAC	-2	270	2	10	PASS
115 VAC	+2	0	2	10	PASS
115 VAC	-2	0	2	10	PASS

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (º)	Generator Impedance (Ω)	Number of Strikes	Test Result
230 VAC	+2	90	2	10	PASS
230 VAC	-2	90	2	10	PASS
230 VAC	+2	270	2	10	PASS
230 VAC	-2	270	2	10	PASS
230 VAC	+2	0	2	10	PASS
230 VAC	-2	0	2	10	PASS

16.3 Common Mode Surge, 1.2/50 μsec

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (º)	Generator Impedance (Ω)	Number of Strikes	Test Result
115	+4	90	12	10	PASS
115	-4	90	12	10	PASS
115	+4	270	12	10	PASS
115	-4	270	12	10	PASS
115	+4	0	12	10	PASS
115	-4	0	12	10	PASS

AC Input Voltage (VAC)	Surge Voltage (kV)	Phase Angle (º)	Generator Impedance (Ω)	Number of Strikes	Test Result
230	+4	90	12	10	PASS
230	-4	90	12	10	PASS
230	+4	270	12	10	PASS
230	-4	270	12	10	PASS
230	+4	0	12	10	PASS
230	-4	0	12	10	PASS

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17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
21-Sep-11	RH	1.0	Initial Release	
25-Oct-11	RH	2.0	Added Figures	
07-Dec-11	RH	3.0	Extensive Changes	
22-Dec-11	RH	4.0	Update Schematic and BOM	
29-Dec-11	RJ	5.0	Minor description edits and note below HiperPFS spreadsheet	

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