Design Example Report

Title	***300 W Non-PFC Stage Forward Power Supply Using HiperTFS™-2 TFS7707H***
Specification	90 VAC – 132 VAC Input; 61 V / 4.59 A Main Output (CV/CC) and 5 V / 4 A Standby Output
Application	Battery Charger
Author	Applications Engineering Department
Document Number	DER-472
Date	November 19, 2015
Revision	1.2

Summary and Features

- Integrated forward power stage and flyback standby for a very low component count design
- 90-132 VAC voltage doubler input (no PFC)
- 132 kHz forward stage for small magnetics size
- >88% full load efficiency

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5245 Hellyer Avenue, San Jose, CA 95138 USA.
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Important Notes:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. All testing should be performed using an isolation transformer to provide the AC input to the prototype board.

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1 Introduction

This engineering report describes a 61 V (nominal), 280 W reference design for a power supply operating from 90 VAC to 132 VAC. A 5 V, 4 A standby output is also provided. The power supply main output is designed with a constant voltage / constant current characteristic for use in battery charger applications.

The design is based on the TFS7707H operating from doubled mains, with no PFC input stage. It can run at maximum power without fan at 115 VAC, room temperature, but will require forced air for low line and/or elevated ambient temperatures.

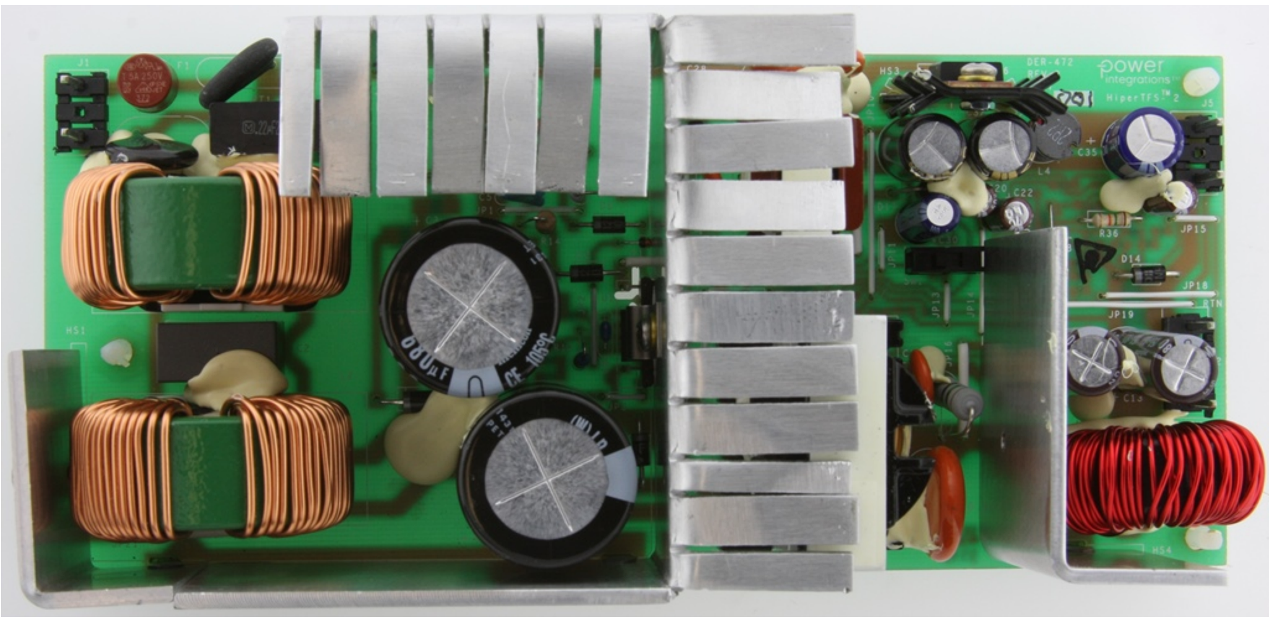

Figure 1 – DER-472 Photograph, Top View.

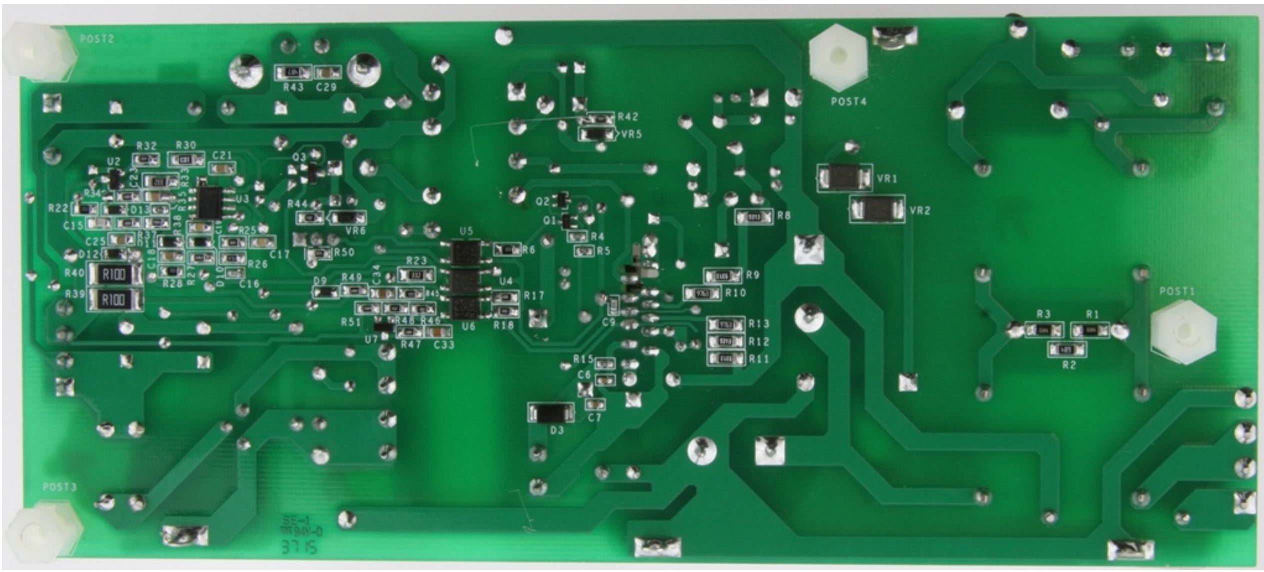

Figure 2 – DER-472 Photograph, Bottom View.

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2 Power Supply Specification

The table below represents the specification for the design detailed in this report. Actual performance is listed in the results section. Detailed customer specification is shown below.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		132	VAC	2 Wire Input.
Frequency	f_{LINE}	47	50/60	64	Hz	
Main Converter Output						
Output Voltage	V_{OUT}	0		61	V	61 VDC (nominal – otherwise defined by battery load).
Output Current	I_{OUT}		4.59		A	Nominal Current Limit Setting for Design.
Standby Converter Output						
Output Voltage	V_{OUT}	4.75	5.00	5.25	V	5 VDC ±5%
Output Current	I_{OUT}	0		4	A	
Output Ripple (optional)				50	mV P-P	20 MHz BW
Total Output Power						
Continuous Output Power	P_{OUT}		300		W	61 V / 4.59 A + 5 V / 4 A
Peak Output Power	$P_{OUT(PK)}$			N/A	W	
Efficiency						
Total system at Full Load	η_{Main}	85	88		%	Measured at 115 VAC, Full Load.
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Ambient Temperature	T_{AMB}	0	25		^{o}C	See Thermal Section for Conditions.

3 Schematic

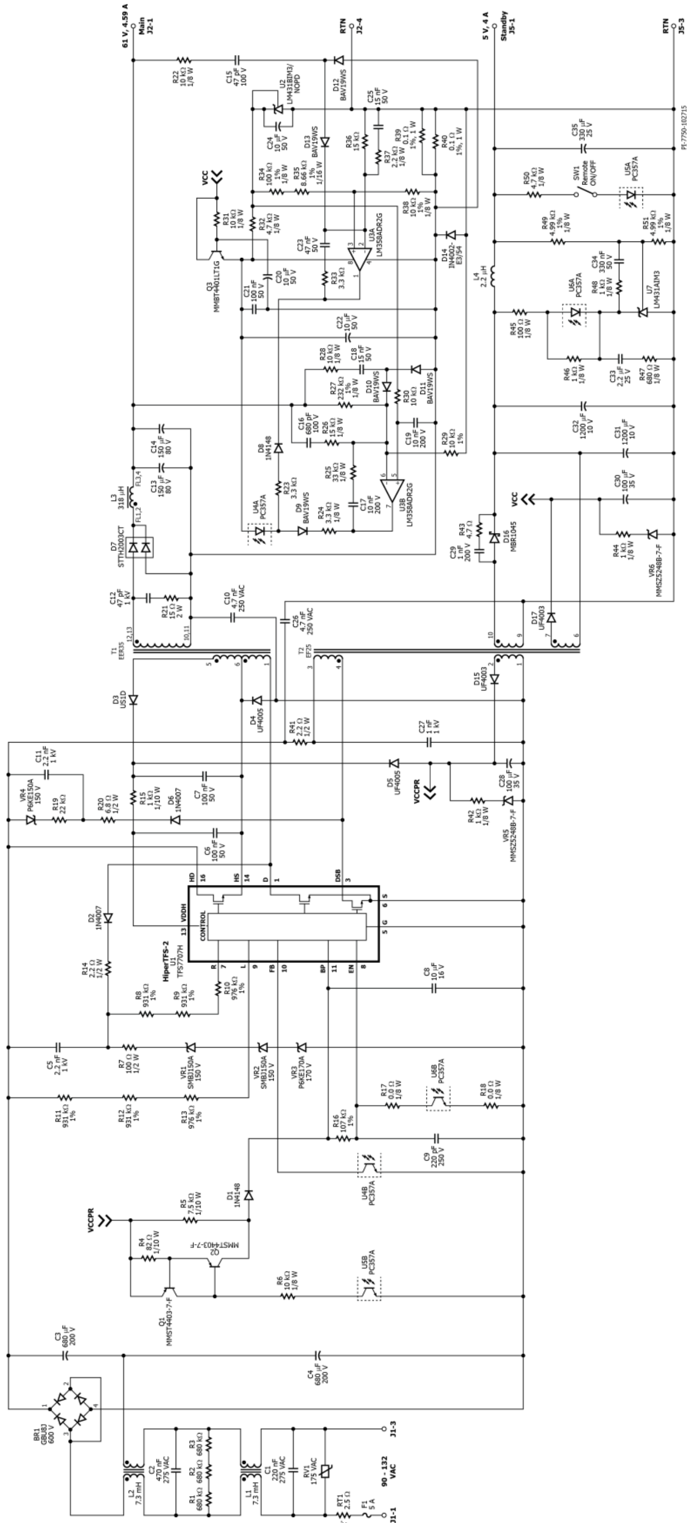

Figure 3 – Schematic - Forward Battery Charger Application Circuit - Input Filter, FWD Stage, Bias Supplies and Output Voltage/Current Control.

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4 Circuit Description

4.1 General Topology

The schematic in Figure 3 shows a 2-switch forward power supply with flyback standby utilizing the TFS7707H, powered via a voltage doubler. The secondary control circuitry provides CV/CC control for use in battery charger applications

4.2 EMI Filtering / Voltage Doubler

Capacitors C1 and C2 are used to control differential mode noise. Resistors R1-3 discharge C1 and C2 when AC power is removed. Inductors L1 and L2 primarily control common mode EMI, and to some extent, differential mode EMI. The heat sink for U1 is connected to primary return to eliminate the heat sink as a source of radiated/capacitive coupled noise. Thermistor RT1 provides inrush limiting. Capacitors C10 and C26 filter common mode EMI. Capacitors C3 and C4, along with BR1, form a voltage doubler to provide a ~250-380 VDC B+ supply from the 90-132 VAC input. Capacitor C27 provides local HV bypassing for the 5V standby converter.

4.3 Primary Bias Supply

The standby supply utilizes built-in capability of the U1 HiperTFS-2 device. Components D15 and C28 provide a 15 V (nominal) flyback bias supply for U1 generated from a primary-referred winding on standby transformer T2. Components D17 and C30 generate a 12 V bias supply for the secondary control circuitry via a secondary-referred winding on T2. Components R42, R44, and VR5-6 clamp the primary and secondary VCC output voltages when the 5 V standby supply is heavily loaded. Components Q3, R31, and C20 comprise a "capacitor multiplier" circuit to provide extra ripple filtering for the secondary VCC supply.

4.4 Main Forward Converter / Standby

The schematic in Figures 3 depicts a 61 V, 280 W Forward DC-DC converter with constant voltage/ constant current output implemented using the TFS7707H.

Integrated circuit U1 incorporates the control circuitry, drivers and output MOSFETs necessary for a 2-switch forward converter and a flyback standby converter.

Components D6, C11, R19-20, and VR4 form a turn-off clamping circuit that limits the standby drain voltage of U1. Zener VR4 provides a defined clamp voltage and maintains a maximum voltage (150 V) on clamp capacitor C11 for higher light/no-load efficiency.

Diode D5 provides initial biasing for the main converter high-side driver in U1. Subsequent power is supplied by a winding on T1, rectified and filtered by D3, C6-7 and R15.

The low-side drain of the main output forward converter is clamped by D2, R7, R14, C5, and VR1-3. This clamping scheme is described as “clamp to ground” and enables a wider operating duty cycle for the main forward converter. This in turn allows the turns ratio of main transformer T1 to be dropped (lower peak output voltage), enabling use of lower voltage rating (lower voltage drop) components for forward output rectifier and catch diode D7. The high-side drain is clamped by D5.

Most of the leakage and magnetizing energy associated with the main and standby converters is returned back to the B+ supply due to the slow recovery aspect of blocking diodes D2 and D6. During the main converter off-time, the main transformer is reset by a substantially higher voltage than V_{IN}, hence the main converter can operate above 50% duty cycle, lowering RMS switch currents without penalizing holdup time. Use of a clamp to ground snubber for the main converter instead of the usual clamp to rail scheme allows this advantage to be exploited even further.

The BYPASS (BP) pin along with C8 provides a decoupled regulated 5.85 V for the HiperTFS-2 controller. The value for C8 (10 μF) also selects the operating frequency of the main converter at 132 kHz. At start-up the bypass capacitor is charged from a current source internal to U1. When the BP pin voltage reaches 5.8 V, the standby converter can begin switching and both the secondary and primary-side bias voltages will begin to rise.

Output of the primary bias winding is used to supply power via resistor R5 to the HiperTFS BP pin during standby-only operation. Additional current is provided via current source Q1-2, R4, R6, and D1 by the primary bias supply when remote-on switch SW1 activates U5A and U5B. The value of R4 is selected to satisfy the maximum current requirement of U1. The value of R5 is selected to maintain the minimum 700 μA required into BP pin to inhibit the internal HiperTFS-2 high voltage current source and thus reduce no-load consumption when the main converter is turned off.

The ENABLE (EN) pin is the feedback pin for the flyback standby controller section. Prior to start-up a resistor (R16) connected from EN to BP can be detected by the controller to select the internal current limit for standby section. The circuit presented here uses a 107 kΩ resistor (R16) at the EN pin for a standby I_{LIM} of 750 mA (nominal). A capacitor (C9) is placed between EN and G to filter high frequency noise and help prevent pulse bunching, especially at maximum output power.

The FEEDBACK (FB) pin has no pull-up resistor to the BP pin, selecting the minimum primary current limit option for the U1 main forward converter. The FB pin provides feedback for the main converter. An increase in current sinking from FB pin to ground will reduce the operating duty cycle.

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Capacitor C6 is the filtering and charge storage capacitor for the U1 high-side driver. During start-up the high-side MOSFET HS pin of U1 is briefly pulled to Source for 12 ms to precharge C6 using an internal current source. The nominal voltage on C6 during normal operation is shunt regulated to approximately 12 V. Components D3, C7, and R15 provide an efficient alternate source of current from a winding on main transformer T1 to power the high-side driver of U1, so that the internal high voltage supply for the high-side driver is turned off. This increases efficiency at light load and prevents main converter from pulse skipping, especially at light output loads.

Resistors R8-10 are used to translate the maximum available OFF time reset voltage into a current for the R pin and compare with the L pin current to compute the maximum allowable duty cycle to prevent saturation and to also determine the maximum allowable duty factor as a function of peak on-time flux.

The LINE-SENSE (L) pin provides an input bulk voltage line-sense function. This information is used by the under-voltage and over-voltage detection circuits for both the Main and standby sections. This pin can also be pulled down to Source to implement a remote-ON/OFF for both the standby and main supplies simultaneously. Resistors R11-R13 are used to translate the input voltage into a current for the L pin.

Components R50, SW1, and U5 (on the standby converter secondary output) provide remote start. When SW1 is closed, the output transistor of U5 turns on current source Q1-2 on the primary side of the supply, providing operating current to the main converter via the BP pin of U1. Opening SW1 turns off U5, shutting down the main converter function of U1.

4.5 Output Rectification

The output of transformer T1 is rectified and filtered by D7, L3, and C13-14. Output rectifier D7 is a 300 V rectifier chosen for high efficiency. A snubber consisting of R21 and C12 helps limit the peak voltage excursion on the output rectifier.

4.6 Output Current and Voltage Control

Output current is sensed via resistors R39 and R40. These resistors are clamped by diode D14 to avoid damage to the current control circuitry during an output short-circuit. Components R32 and U2 provide a voltage reference for current sense and voltage sense amplifiers U3A and U3B. The reference voltage for current sense amplifier U3A is divided down by R34-35 and R38. The default current limit setting is 4.589 A, as programmed by R39-40, R34-35, and R38. Voltage from the current sense resistors is applied to the inverting input of U3A via R36. Opamp U3A drives optocoupler U4 through D8 and R23. Components R23, R33, R36, R37, C23, and C25 are used for frequency compensation of the current loop.

Opamp U3B is used for output constant voltage control when the current limit is not engaged. Resistors R27 and R29 sense the output voltage. A reference voltage is applied to the non-inverting input of U3B from U2 via R30 and C19. Opamp U3B drives optocoupler U4 via D9 and R24. Components R24-26 and C16-C17 all affect the frequency compensation of the voltage control loop.

Networks R28, C18, and D10-D11, along with R22, C15, and D12-D13, are used as soft-finish networks to reduce output voltage and/or output current overshoot during startup. Capacitor C15 on the current soft finish network has been reduced to a very small placeholder value (47 pF) in order to disable the current soft-finish function for this design. The networks can be eliminated if main output start-up overshoot is not a concern.

4.7 Standby Output

A 5 V, 4 A standby output is provided via a triple insulated winding on standby transformer T2. This winding is rectified and filtered by D16, and C31-32. Components L4 and C35 provide additional filtering to remove high frequency ripple and noise. Snubber C29 and R43 helps limit the peak voltage excursion on D16. The 5 V output is divided down by R49 and R51, and is applied to the reference input of error amplifier U7, which controls the standby section of U1 via R45 and U6. Resistor R46 provides bias current to U7, while C33 and R47 comprise a soft-finish network to eliminate output voltage overshoot at start-up. Components R45, R48, and C34 compensate the standby control loop.

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5 PCB Layout

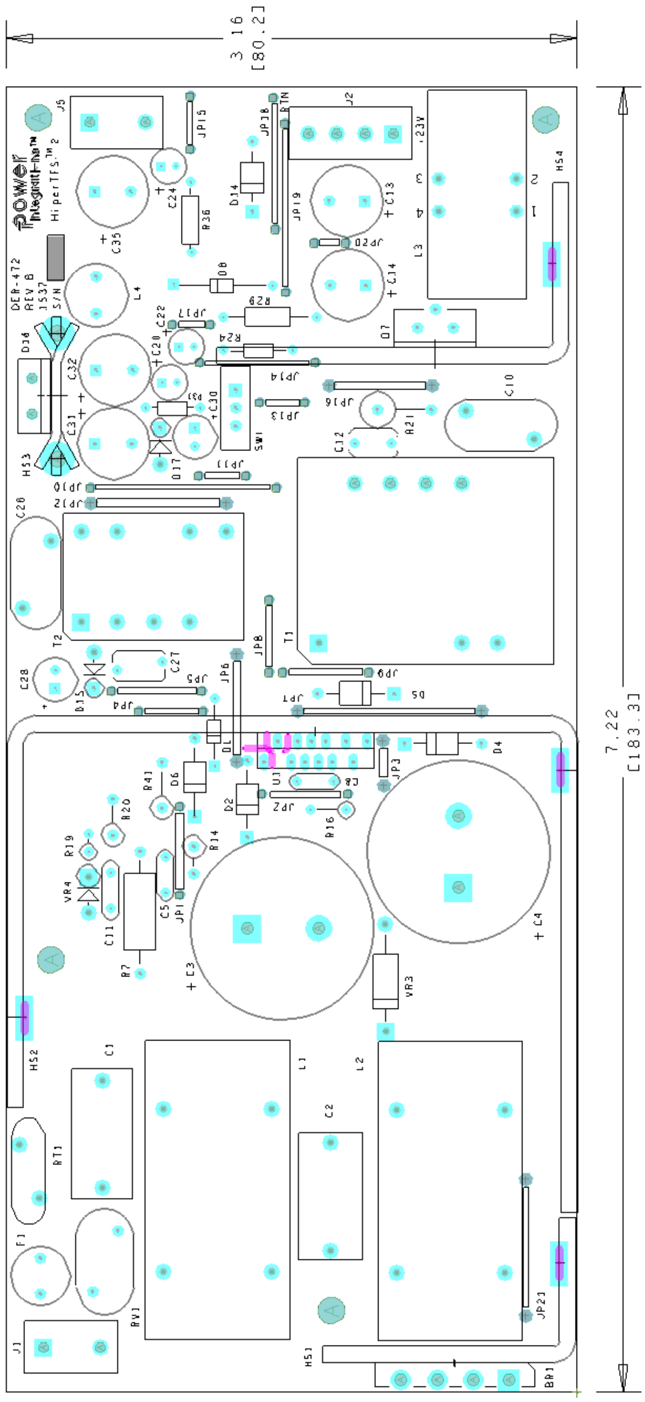

Figure 4 – Printed Circuit Layout, Showing Top Side Components.

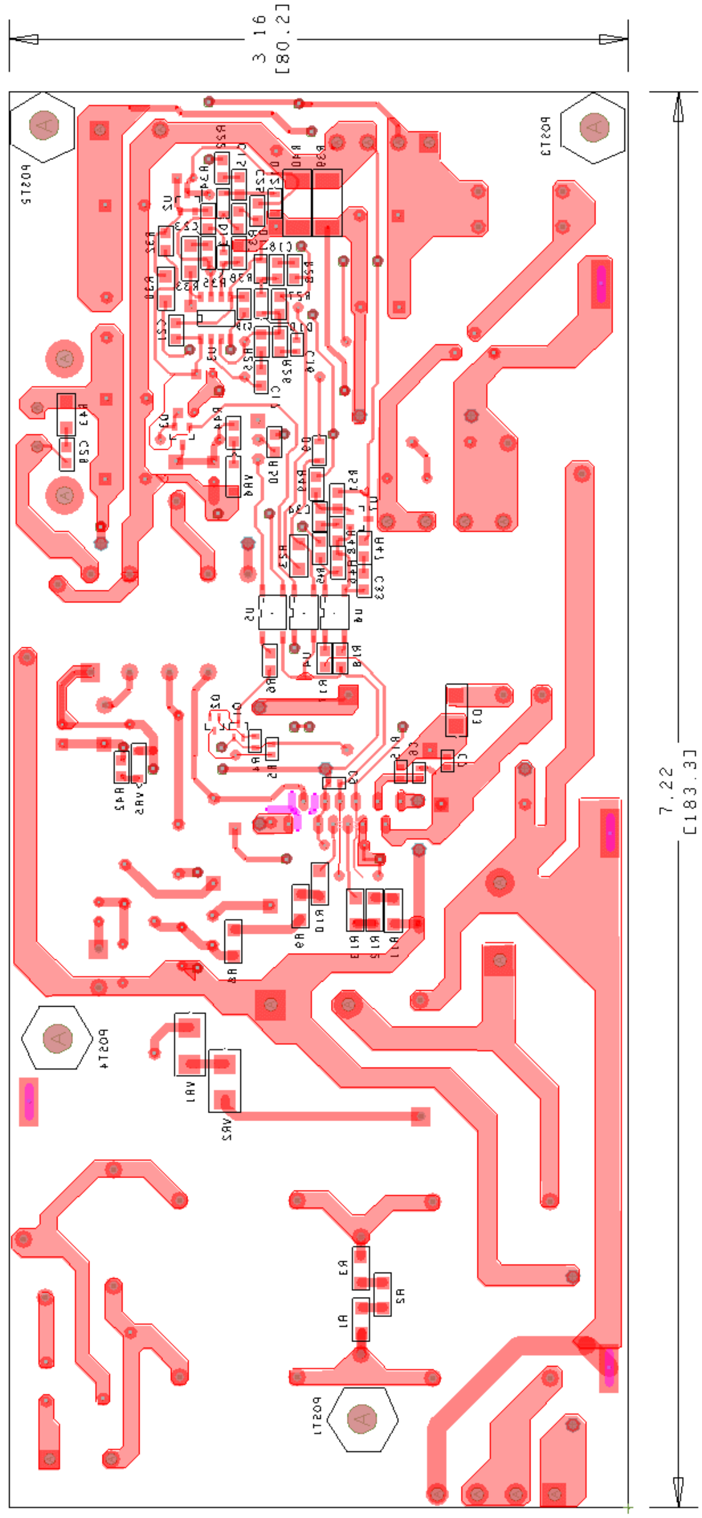

Figure 5 – Printed Circuit Layout, Bottom Side Traces and Components.

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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, GBU Case	GBU8J-BP	Micro Commercial
2	1	C1	220 nF, 275 VAC, Film, X2	ECQ-U2A224ML	Panasonic
3	1	C2	470 nF, 275 VAC, Film, X2	80-R46KI347050P1M	Kemet
4	2	C3 C4	680 μF, 200 V, Electrolytic, (25 x 40)	LGY2D681MELA	Nichicon
5	1	C5	2.2 nF, 1 KV, Ceramic, SL, 0.2" L.S.	DEBB33A222KA2B	Murata
6	2	C6 C7	100 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H104K	TDK
7	1	C8	10 μF, 16 V, Ceramic, X5R	FK24X5R1C106K	TDK
8	1	C9	220 pF, 250 V, Ceramic, COG, 0603	C1608C0G2E221J	TDK
9	2	C10 C26	4.7 nF, Ceramic, Y1	440LD47-R	Vishay
10	1	C11	2.2 nF, 1 kV, Disc Ceramic	NCD222K1KVY5FF	NIC
11	1	C12	47 pF, 1 kV, Disc Ceramic	561R10TCCQ47	Vishay
12	2	C13 C14	150 μF, 80 V, Electrolytic, Gen. Purpose, (10 x 33)	UPJ1K151MPD	Nichicon
13	1	C15	47 pF, 100 V, Ceramic, COG, 0805	08051A470JAT2A	Kemet
14	1	C16	680 pF 100 V, Ceramic, NPO, 0603	CGA3E2C0G2A681J	TDK
15	2	C17 C19	10 nF, 200 V, Ceramic, X7R, 0805	08052C103KAT2A	AVX
16	2	C18 C25	15 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB153	Yageo
17	3	C20 C22 C24	10 μF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG500ELL100ME11D	Nippon Chemi-Con
18	1	C21	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
19	1	C23	47 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H473KA01L	Murata
20	1	C27	1.0 nF, 1 kV, Disc Ceramic	562R10TSD10	Vishay
21	2	C28 C30	100 μF, 35 V, Electrolytic, Low ESR, 180 mΩ, (6.3 x 15)	ELXZ350ELL101MF15D	Nippon Chemi-Con
22	1	C29	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
23	2	C31 C32	1200 μF, 10 V, Electrolytic, Radial	EEU-FM1A122	Panasonic
24	1	C33	2.2 μF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
25	1	C34	330 nF, 50 V, Ceramic, X7R, 0805	GRM219R71H334KA88	Murata
26	1	C35	330 μF, 25 V, Electrolytic, Low ESR, 90 mΩ, (10 x 12.5)	ELXZ250ELL331MJC5S	Nippon Chemi-Con
27	2	D1 D8	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
28	2	D2 D6	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
29	1	D3	Diode Ultrafast, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
30	2	D4 D5	600 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4005-E3	Vishay
31	1	D7	300 V, 10 A, Diode ARRAY, GP, 35 ns, TO-220AB	STTH2003CT	ST Micro
32	5	D9 D10 D11 D12 D13	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
33	1	D14	100 V, 1 A, Rectifier, DO-41	1N4002-E3/54	Vishay
34	2	D15 D17	200 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4003-E3	Vishay
35	1	D16	45 V, 10 A, Schottky, TO-220AC	MBR1045	Vishay
36	1	ESIP CLIP1	Heat Sink Hardware, Edge Clip, 12.40 mm x 6.50 mm	TRK-24	Kang Tang
37	1	F1	5 A, 250 V, Slow, TR5	37215000411	Wickman
38	1	HOTMELT _V1	Adhesive, Hot Melt, VO	3748 VO-TC	3M
39	1	HS1	FAB, Heat Sink, BRIDGE, DER-472		Custom
40	1	HS2	FAB, Heat Sink, eSIP, DER-472		Custom
41	1	HS3	Heat Sink, TO-220, Copper base, staggered, Vertical	6025DG	Aavid Thermalloy
42	1	HS4	FAB, Heat Sink, DIODE, DER-472		Custom
43	2	J1 J5	3 Position (1 x 3) header, 0.156 pitch, Vertical	26-48-1031	Molex
44	1	J2	4 Position (1 x 4) header, 0.156 pitch, Vertical	26-48-1045	Molex

45	4	JP1 JP2 JP8 JP9	Wire Jumper, Insulated, #24 AWG, 0.5 in	C2003A-12-02	Gen Cable
46	5	JP3 JP11 JP13 JP15 JP17	Wire Jumper, Insulated, #24 AWG, 0.3 in	C2003A-12-02	Gen Cable
47	1	JP4	Wire Jumper, Insulated, #24 AWG, 0.4 in	C2003A-12-02	Gen Cable
48	1	JP5	Wire Jumper, Insulated, #24 AWG, 0.6 in	C2003A-12-02	Gen Cable
49	2	JP6 JP16	Wire Jumper, Insulated, TFE, #18 AWG, 0.6 in	C2052A-12-02	Alpha
50	1	JP7	Wire Jumper, Insulated, TFE, #18 AWG, 1.1 in	C2052A-12-02	Alpha
51	1	JP10	Wire Jumper, Insulated, #24 AWG, 1.1 in	C2003A-12-02	Gen Cable
52	2	JP12 JP21	Wire Jumper, Insulated, TFE, #18 AWG, 0.8 in	C2052A-12-02	Alpha
53	1	JP14	Wire Jumper, Insulated, #24 AWG, 0.7 in	C2003A-12-02	Gen Cable
54	1	JP18	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
55	1	JP19	Wire Jumper, Insulated, #24 AWG, 1.0 in	C2003A-12-02	Gen Cable
56	1	JP20	Wire Jumper, Insulated, #24 AWG, 0.2 in	C2003A-12-02	Gen Cable
57	2	L1 L2	7.3 mH, 9.3 A, Common Mode Choke with header (1.65" W x .80" T x 1.65" H)	CMT-8118	Triad Magnetics
58	1	L3	318 μH, Inductor Toroidal		
59	1	L4	2.2 μH, 6.0 A	RFB0807-2R2L	Coilcraft
60	4	POST1 POST2 POST3 POST4	Post, Circuit Board, Female, Hex, 6-32, snap, 0.375L, Nylon	561-0375A	Eagle Hardware
61	2	Q1 Q2	PNP, Small Signal BJT, 40 V, 0.6 A, SC70-3, SOT-323	MMST4403-7-F	Diodes, Inc.
62	1	Q3	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401LT1G	Diodes, Inc.
63	3	R1 R2 R3	680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
64	1	R4	82 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ820V	Panasonic
65	1	R5	7.5 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ752V	Panasonic
66	3	R6 R22 R28	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
67	1	R7	100 Ω, 5%, 1/2 W, Carbon Film	CF12JT100R	Stackpole
68	4	R8 R9 R11 R12	931 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF9313V	Panasonic
69	2	R10 R13	976 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF9763V	Panasonic
70	1	R14	2.2 Ω, 5%, 1/2 W, Carbon Film	CFR-50JB-2R2	Yageo
71	1	R15	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
72	1	R16	107 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-107K	Yageo
73	2	R17 R18	0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
74	1	R19	22 k, 5%, 1/4 W, Carbon Film	CFR-25JB-22K	Yageo
75	1	R20	6.8 Ω, 5%, 1/2 W, Carbon Film	CFR-50JB-6R8	Yageo
76	1	R21	15 Ω, 5%, 2 W, Metal Oxide	RSF200JB-15R	Yageo
77	2	R23 R33	3.3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ332V	Panasonic
78	1	R24	3.3 kΩ, 5%, 1/8 W, Carbon Film	CF18JT3K30	Stackpole
79	1	R25	33 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ333V	Panasonic
80	1	R26	15 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ153V	Panasonic
81	1	R27	232 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2323V	Panasonic
82	1	R29	10.0 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-10K0	Yageo
83	1	R30	10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
84	1	R31	10 kΩ, 5%, 1/8 W, Carbon Film	CF18JT10K0	Stackpole
85	2	R32 R50	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
86	1	R34	100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
87	1	R35	8.66 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF8661V	Panasonic
88	1	R36	15 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-15K	Yageo
89	1	R37	2.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ222V	Panasonic
90	1	R38	10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic
91	2	R39 R40	0.1 Ω, 1%, 1 W, Thick Film, 2512	RL2512FK-070R1L	Yageo
92	1	R41	2.2 Ω, 5%, 1/2 W, Metal Film, Fusible/Flame Proof	NFR25H0002208JR500	Vishay

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93	4	R42 R44 R46 R48	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
94	1	R43	4.7 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ4R7V	Panasonic
95	1	R45	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
96	1	R47	680 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ681V	Panasonic
97	2	R49 R51	4.99 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4991V	Panasonic
98	1	RT1	NTC Thermistor, 2.5 Ohms, 7 A	SL15 2R507	Ametherm
99	2	RTV1 RTV2	Thermally conductive Silicone Grease	120-SA	Wakefield
100	1	RV1	175 V, 70 J, 14 mm, RADIAL	ERZ-V14D271	Panasonic
101	1	SCREW1	SCREW MACHINE PHIL 4-40 X 1/4 SS	PMSSS 440 0025 PH	Building Fasteners
102	1	SCREW2	SCREW MACHINE PHIL 4-40X 3/16 SS	67413609	MSC Industrial
103	1	SCREW3	SCREW MACHINE PHIL 4-40 X 5/16 SS	PMSSS 440 0031 PH	Building Fasteners
104	2	SPACER_CER1 SPACER_CER2	SPACER RND, Steatite C220 Ceramic	CER-2	Richco
105	1	SW1	SWITCH SLIDE SPDT 30 V. 2 A PC MNT	EG1218	E-Switch
106	1	T1	Transformer, EER35, Vertical, 14 pins		Custom
107	1	T2	Transformer, EF25/13/7, Vertical, 10 pins		Custom
108	1	TO-220 PAD1	THERMAL PAD TO-220 .009" SP1000	1009-58	Bergquist
109	1	U1	HiperTFS-2, ESIP16/12	TFS7707H	Power Integrations
110	1	U2	IC, REG ZENER SHUNT ADJ SOT-23	LM431BIM3/NOPB	National Semi
111	1	U3	DUAL Op Amp, LM358ADR2G, Single Supply, SOIC-8	LM358ADR2G	ON Semi
112	3	U4 U5 U6	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N1TJ00F	Sharp
113	1	U7	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semi
114	2	VR1 VR2	150 V, 5 W, 5%, DO214AA (SMB)	SMBJ150A	Littlefuse
115	1	VR3	170 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE170A	Littlefuse
116	1	VR4	150 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE150A	Littlefuse
117	2	VR5 VR6	Diode Zener 18 V 500 MW SOD123	MMSZ5248B-7-F	Diodes, Inc.
118	1	WASHER1	WASHER FLAT #4 SS	FWSS 004	Building Fasteners
119	2	WASHER2 WASHER4	WASHER FLAT #4 Zinc, OD 0.219, ID 0.125, Thk 0.032, Yellow Chromate Finish	5205820-2	Tyco
120	1	WASHER3	Washer, Shoulder, #4, 0.032 Shoulder x 0.116" Dia, Polyphenylene Sulfide PPS	7721-7PPSG	Aavid Thermalloy

7 Magnetics

7.1 Transformer (T1) Specification

7.1.1 Electrical Diagram

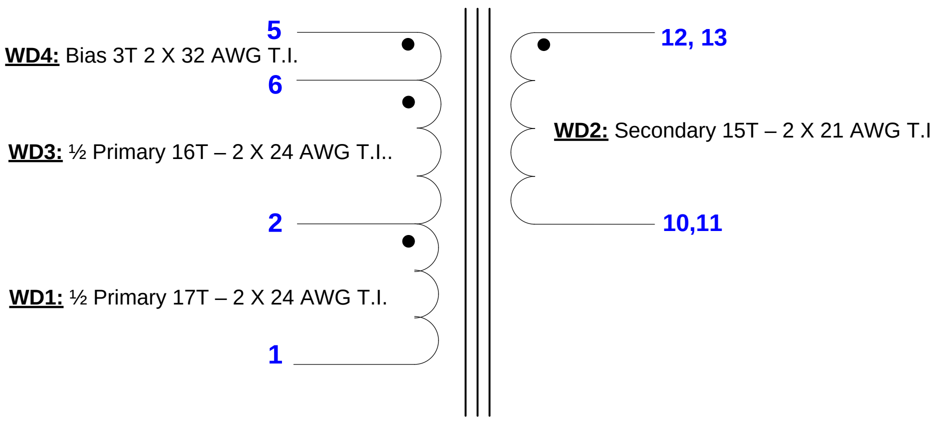

Figure 5 – Main Forward Transformer Schematic.

7.1.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-6 to 10-13.	3000 VAC
Primary Inductance	Pins 1-6 all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	1.75 mH ±10%
Resonant Frequency	Pins 1-6, all other windings open.	450 kHz (Min.)
Primary Leakage Inductance	Pins 1-6, with pins 10-13 shorted, measured at 100 kHz, 0.4 V_{RMS}.	2 µH (Max.)

7.1.3 Material List

Item	Description
[1]	Core Pair EER35: TDK PC95 or equivalent.
[2]	Bobbin: EER35 Vertical, 14 pins, PI Part # 25-00029-00.
[3]	Wire, Triple Insulated, #24 AWG – Furukawa Tex-E or equivalent.
[4]	Wire, Triple Insulated, #21 AWG – Furukawa Tex-E or equivalent.
[5]	Wire, Triple Insulated, #32 AWG – Furukawa Tex-E or equivalent.
[6]	Tape: Polyester Film, 3M 1350F-1 or equivalent, 26 mm wide.
[7]	Tape: Polyester Film, 3M 74 or equivalent, 11 mm wide.
[8]	Tape: Copper Foil, 3M 1194 or equivalent, 13 mm wide.
[9]	Varnish: Dolph BC-359, or equivalent.

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7.1.4 Build Diagram

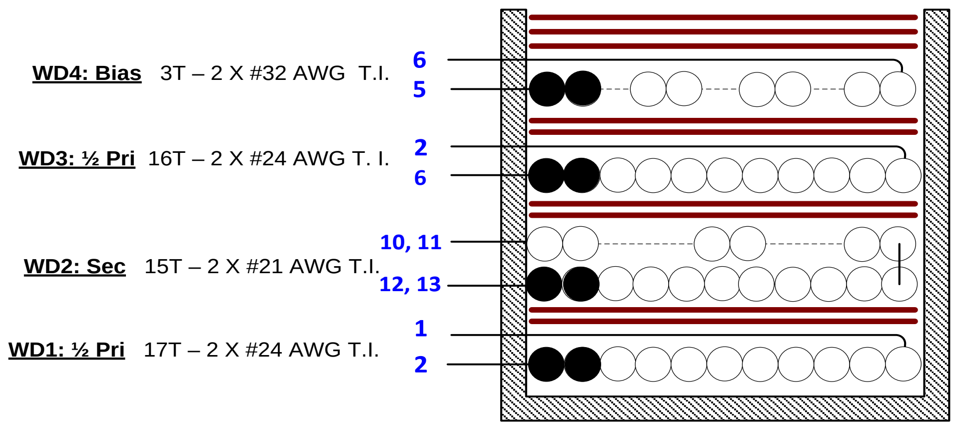
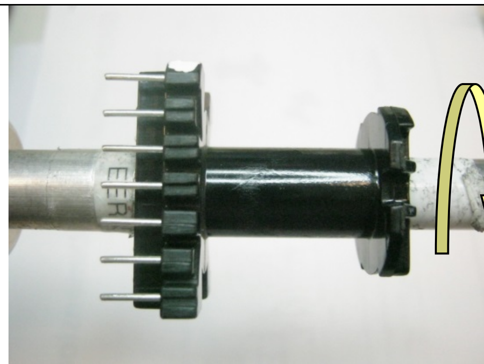
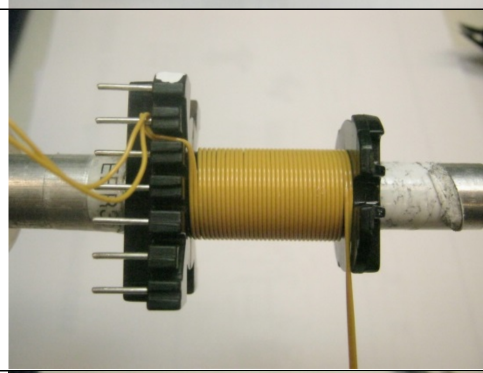
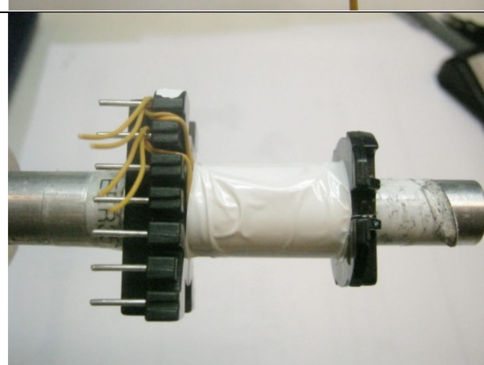
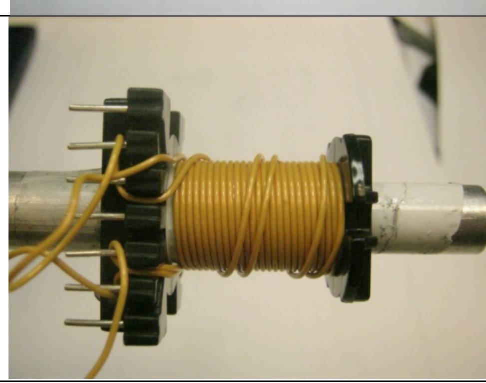


Figure 6 – Transformer Build Diagram.

7.1.5 Winding Instructions

General note	For the purpose of these instructions, bobbin is oriented on winder such that pins 1-7 are on the left side (see illustration). Winding direction as shown is clockwise.
WD1: ½ Primary	Starting on pin 2, wind 17 bifilar turns of triple insulated wire item [3] in 1 layer, finish on pin 1.
Insulation	Apply 2 layers of tape item [6].
WD2: Secondary	Starting at pins 12 and 13, wind 12 bifilar turns of triple insulated wire item [4] in one layer. Wind remaining 3 turns back evenly across bobbin width, finishing at pins 10 and 11.
Insulation	Apply 2 layers of tape item [6].
WD3: ½ Primary	Starting on pin 6, wind 16 bifilar turns of triple insulated wire item [3] in 1 layer, and finish on pin 2.
Insulation	Apply 2 layers of tape item [6].
WD4: Bias	Starting at pin 5, wind 3 bifilar turns of triple insulated wire [5] finish on pin 6.
Insulation	Apply 3 layers of tape item [6].
Core Gapping	Apply tape shim gap item [7] to mating faces of **one** core half as shown. Polish core faces against flat surface to remove air bubbles from tape and assure minimum possible gap.
Assembly (1)	Assemble gapped and ungapped core halves in bobbin, secure with tape. Using copper tape item [8], apply an outside flux band centered in the bobbin window as shown in illustration. Overlap and solder ends of band to form a shorted turn. Attach wire item [5] to copper band and terminate to pin 7.
Assembly (2)	Apply 1 layer of tape item [6] around transformer as shown to insulate flux band. Remove pins 3, 4, 8, 9, and 14. Cut pin 2 short. Dip varnish [9].

7.1.6 Winding Illustrations

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pins 1-5 are on the left side (see illustration). Winding direction as shown is clockwise.
WD1: 1st Primary		Starting on pin 2, wind 17 bifilar turns of triple insulated wire item [3] in 1 layer, finish on pin 1.
Insulation		Apply 2 layers of tape item [6].
WD2: Secondary		Starting at pins 12 & 13, wind 12 bifilar turns of triple insulated wire item [4] in one layer. Wind remaining 3 turns back evenly across bobbin width, finishing at pins 10 & 11.

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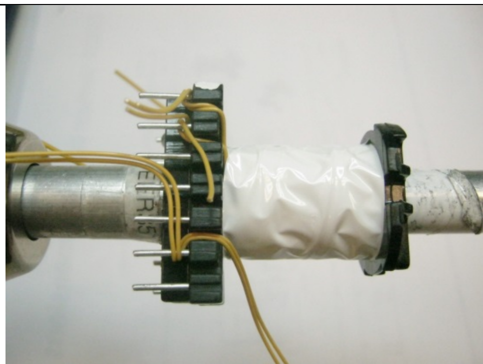
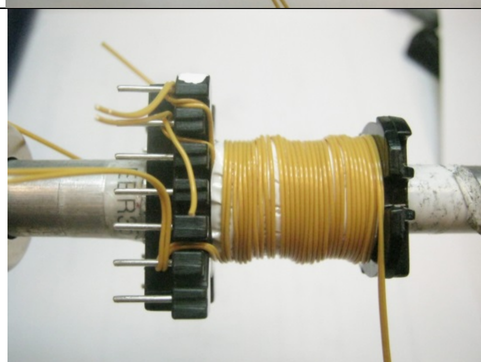
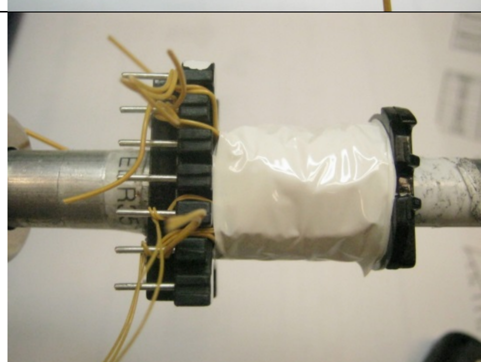
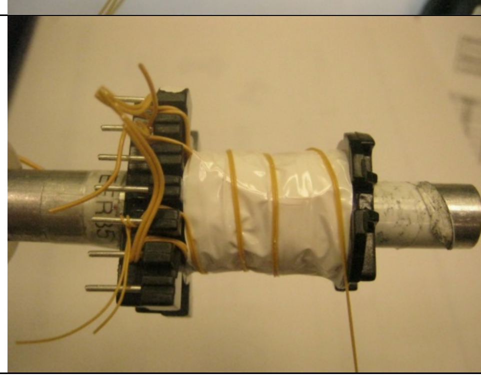
Insulation		Apply 2 layers of tape item [6].
WD3: ½ Primary		Starting on pin 6, wind 16 bifilar turns of triple insulated wire item [3] in 1 layer, and finish on pin 2.
Insulation		Apply 2 layers of tape item [6].
WD4: Bias		Starting at pin 5, wind 3 bifilar turns of triple insulated wire [5] finish on pin 6.

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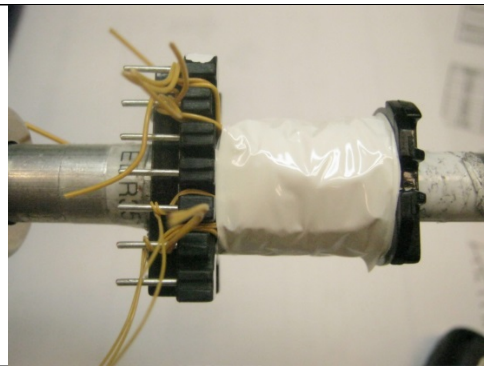
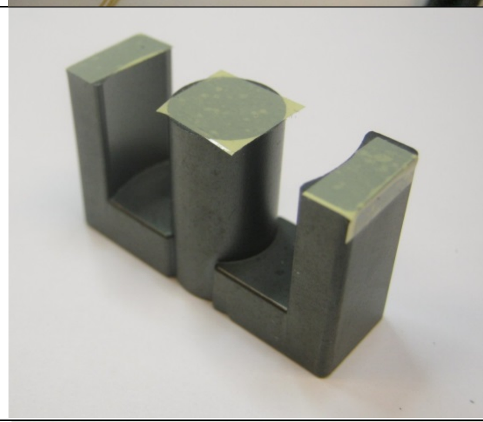
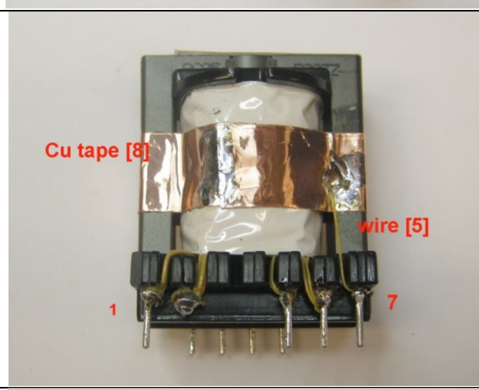
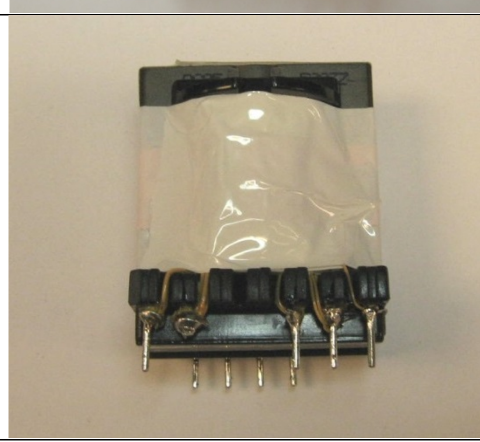
Insulation		Apply 3 layers of tape item [6].
Core Gapping		Apply tape shim gap item [7] to mating faces of **one** core half as shown. Polish core faces against flat surface to remove air bubbles from tape and assure minimum possible gap.
Assembly (1)		Assemble gapped and ungapped core halves in bobbin, secure with tape. Using copper tape item [8], apply an outside flux band centered in the bobbin window as shown in illustration. Overlap and solder ends of band to form a shorted turn. Attach wire item [5] to copper band and terminate to pin 7.
Assembly (2)		Apply 1 layer of tape item [6] around transformer as shown to insulate flux band. Remove pins 3, 4, 8, 9, and 14. Cut pin 2 short. Dip varnish [9].

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7.2 Standby Transformer (T2) Specification

7.2.1 Electrical Diagram

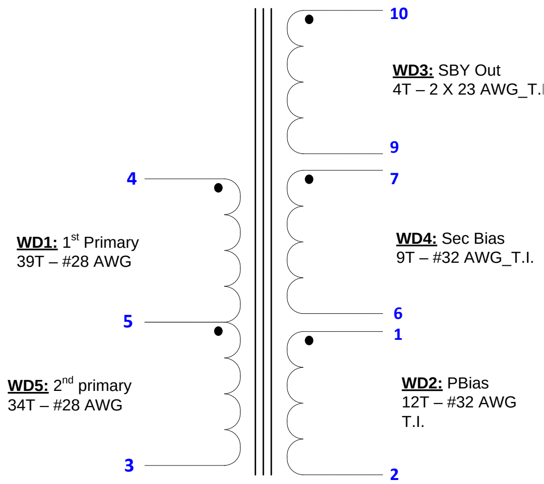

Figure 7 – Transformer Electrical Diagram.

7.2.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-5 to 6-10.	3000 V
Primary Inductance	Pins 4-3, all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	1074 μH ±10%
Resonant Frequency	Pins 4-3, all other windings open.	600 kHz (Min.)
Primary Leakage Inductance	Pins 4-3, with pins 9-10 shorted, measured at 100 kHz, 0.4 V_{RMS}.	30 μH (Max.)

7.2.3 Material List

Item	Description
[1]	Core: EF25, TDK PC44 material or equivalent. Gap for inductance coefficient (A_L) of 202 nH/T².
[2]	Bobbin, EF25, Vertical, 10 Pins (5/5), PI Part # 25-00012-00.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 16.4 mm wide.
[4]	Tape, Polyester film, 3M 1350F-1 or equivalent, 14.9 mm wide.
[5]	Tape, Polyester web, 3M 44 or equivalent, 1.5 mm wide.
[6]	Wire, Magnet #28 AWG, solderable double coated.
[7]	Wire, Triple Insulated, Furukawa TEX-E or equivalent, #23 AWG.
[8]	Wire, Triple Insulated, Furukawa TEX-E or equivalent, #32 AWG.
[9]	Transformer Varnish, Dolph BC-359 or equivalent.

7.2.4 Build Diagram

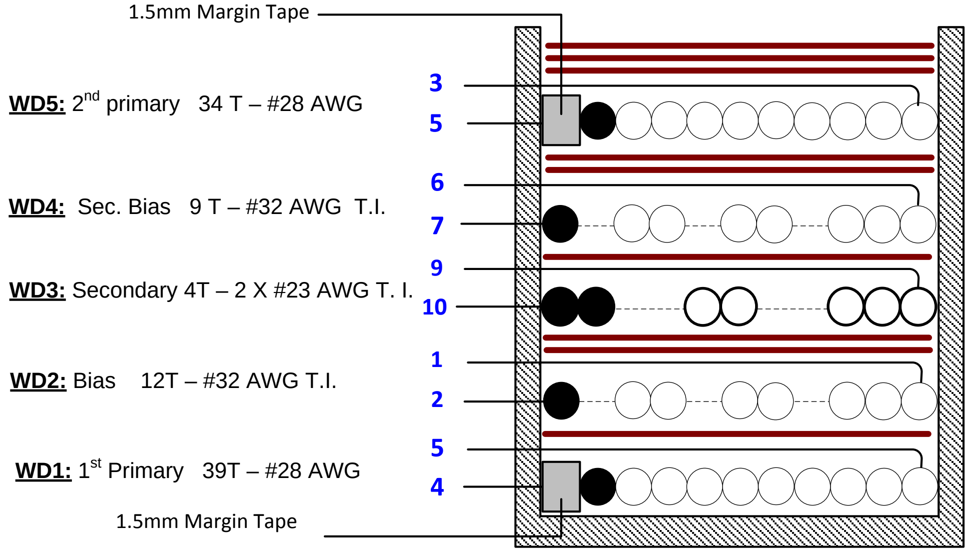

Figure 8 – Transformer Build Diagram.

7.2.5 Winding Instructions

General Note	For the purpose of these instructions, bobbin is oriented on winder such that pins 1-5 are on the left side (see illustration). Winding direction as shown is clockwise.
Margin	Apply 1.5 mm margin on pins side of bobbin using tape [5]. Match height of WDG 1
WD1: 1st Primary	Starting at pin 4, wind 39 turns of wire item [6] in 1 layer. Finish at pin 5.
Insulation	Use 1 layer of tape item [3] for insulation.
WD2: Primary Bias	Starting at pin 2, wind 12 turns of triple insulated wire item [8] in one layer. Finish at pin 1.
Insulation	Use 2 layers of tape item [3] for insulation.
WD3: Secondary	Starting at pin 10, wind 4 bifilar turns of triple insulated wire item [4] in one layer. Finish at pin 9.
Insulation	Use 1 layer of tape item [3] for insulation.
WD4: Secondary Bias	Starting at pin 7, wind 9 turns of triple insulated wire item [8] in one layer. Finish at pin 6.
Insulation	Use 2 layers of tape item [3] for insulation.
Margin	Apply 1.5 mm margin on pins side of bobbin using tape [5]. Match height of WDG 5.
WD5: 2nd Primary	Starting at pin 5, wind 34 turns of wire item [6] in 1 layer. Finish at pin 3.
Insulation	Use 3 layers of tape item [3] to secure the windings.
Assembly	Grind core halves for specified primary inductance. Wrap one core half with 2 layers of tape item [4] as shown in Figure 11. Insert this core in pin side of bobbin. Secure core halves with tape. Remove pin 8, cut pin 5 short. Dip varnish item [9].

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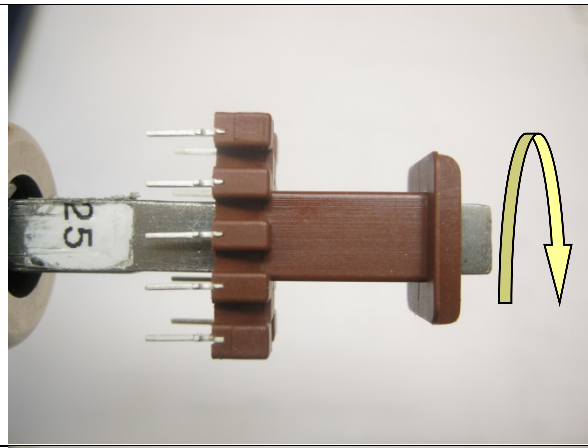
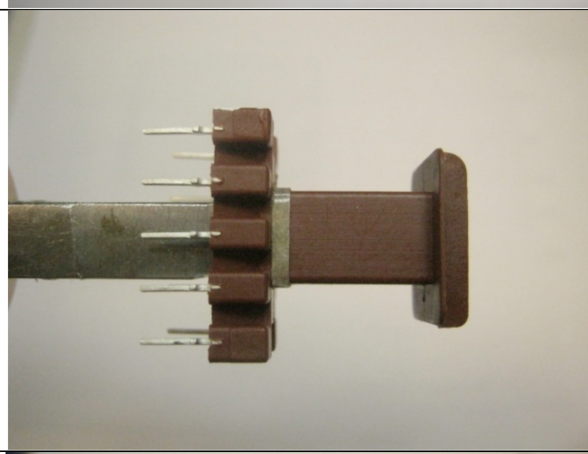
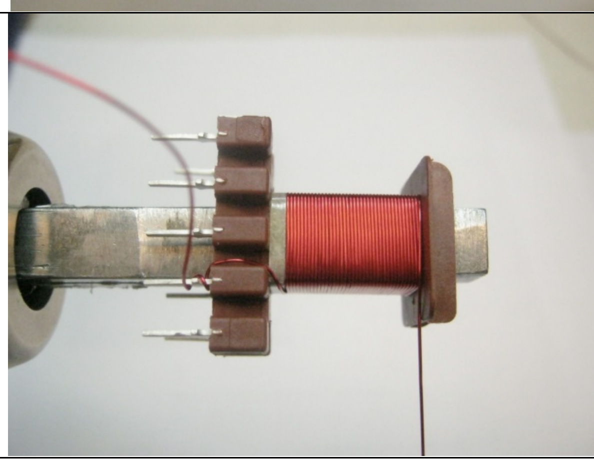
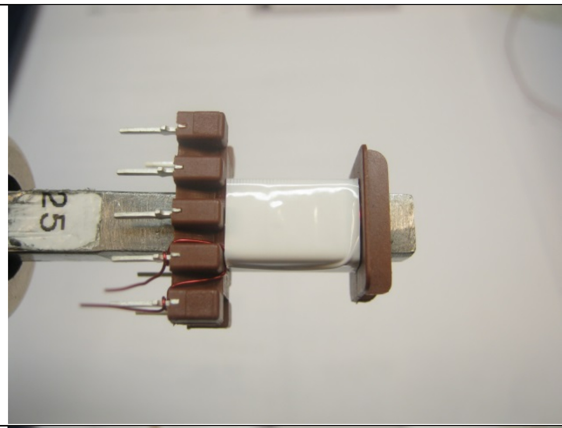
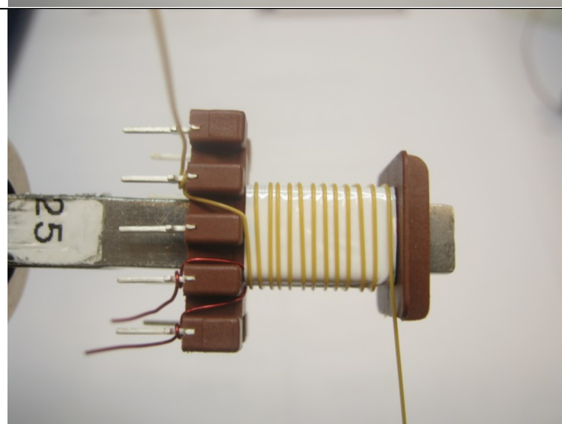
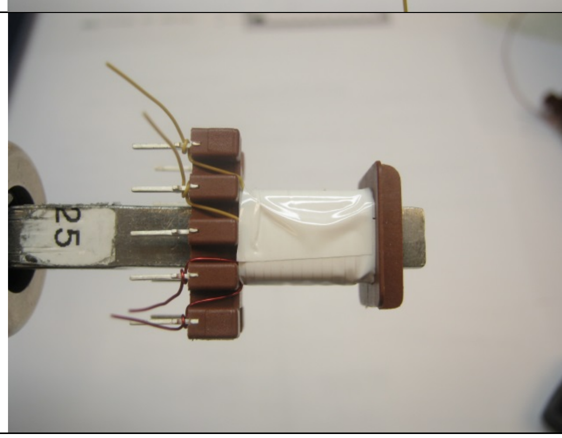
7.2.6 Winding Illustrations

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pins 1-5 are on the left side (see illustration). Winding direction as shown is clockwise.
Margin		Apply 1.5 mm margin on pins side of bobbin using tape [5]. Match height of WDG 1 & 2.
WD1: 1st Primary		Starting at pin 4, wind 39 turns of wire item [6] in 1 layer. Finish at pin 5.

Insulation		Use 1 layer of tape item [3] for insulation.
WD2: Primary Bias		Starting at pin 2, wind 12 turns of triple insulated wire item [8] in one layer. Finish at pin 1.
Insulation		Use 2 layers of tape item [3] for insulation.

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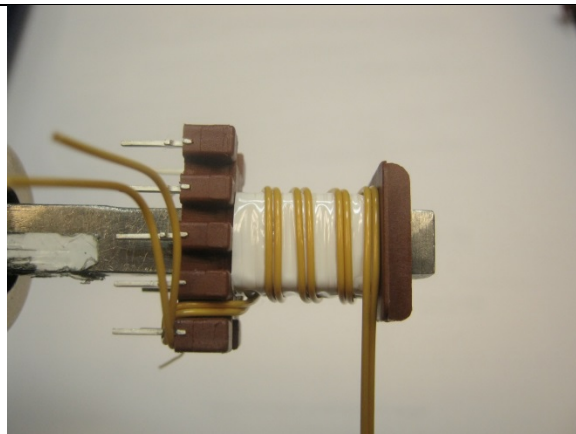
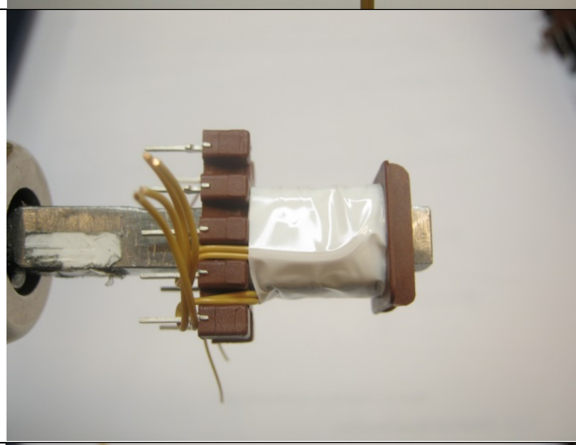
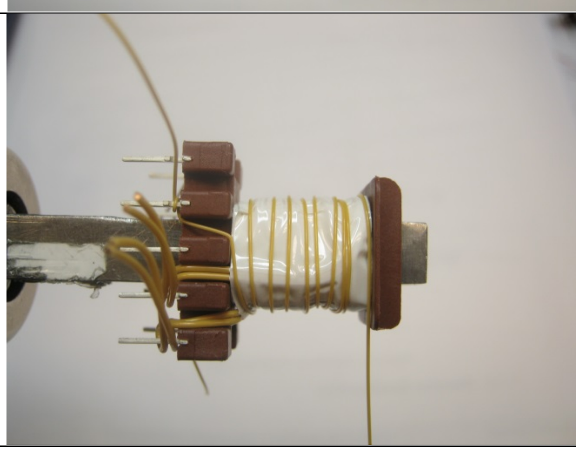
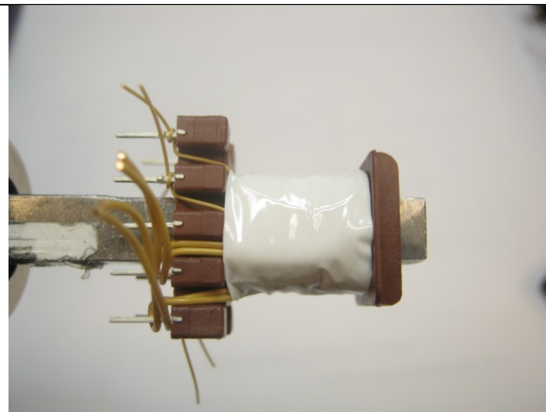
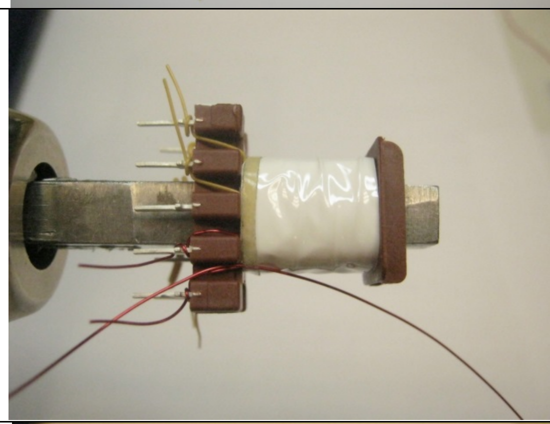
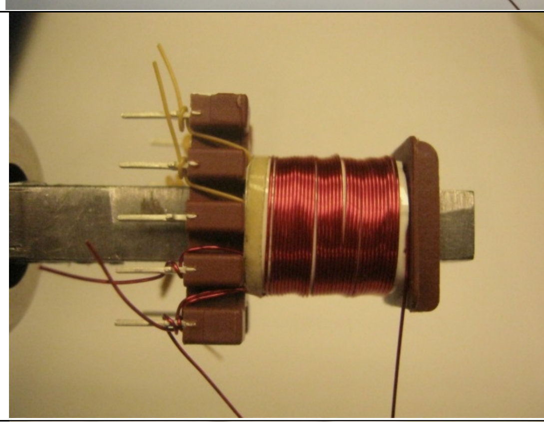
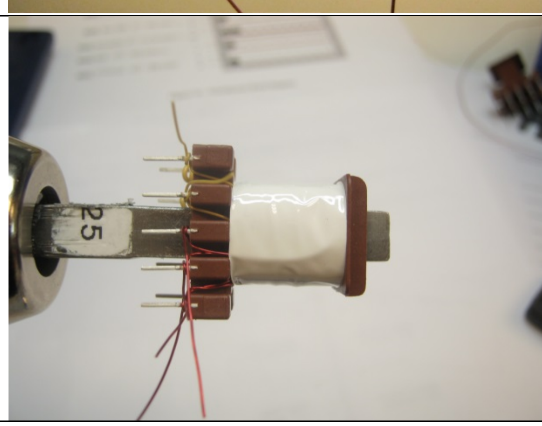
WD3: Secondary		Starting at pin 10, wind 4 bifilar turns of triple insulated wire item [4] in one layer. Finish at pin 9.
Insulation		Use 1 layer of tape item [3] for insulation.
WD4: Secondary Bias		Starting at pin 7, wind 9 turns of triple insulated wire item [8] in one layer. Finish at pin 6.

Insulation		Use 2 layers of tape item [3] for insulation.
Margin		Apply 1.5 mm margin on pins side of bobbin using tape [5]. Match height of WDG 5.
WD5: 2nd Primary		Starting at pin 5, wind 34 turns of wire item [6] in 1 layer. Finish at pin 3.
Insulation		Use 3 layers of tape item [3] to secure the windings.

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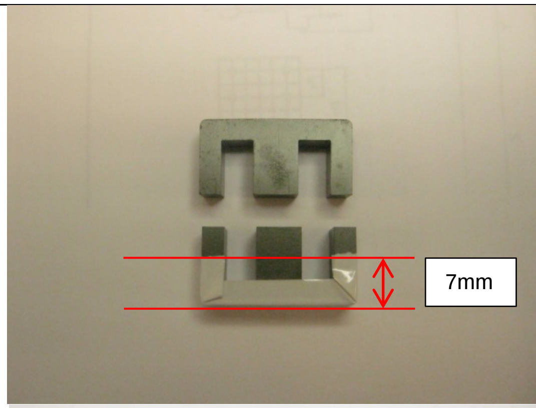
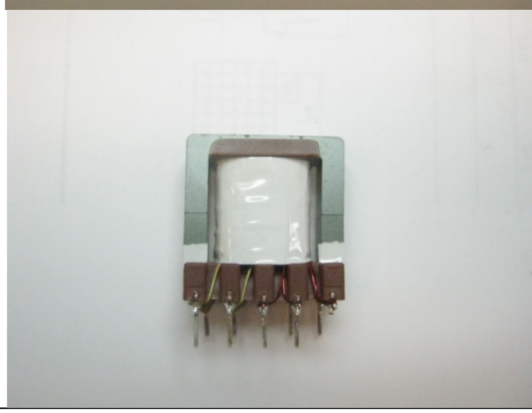
Assembly		Grind core halves for specified primary inductance. Wrap one core half with 2 layers of tape item [4] as shown in Figure 11. Insert this core in pin side of bobbin. Secure core halves with tape. Remove pin 8, cut pin 5 short. Dip varnish item [9].

7.3 Output Choke

7.3.1 Schematic

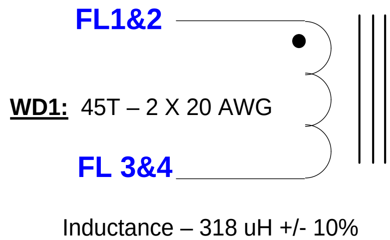


Figure 9 – Output Choke Schematic.

7.3.2 Material List

	Description
[1]	Core: Sendust Toroid 125µ, 27.7 mm diameter, Mag-Inc 77930-A7 or equivalent.
[4]	Wire, Magnet, #20 AWG, solderable double coated.

7.3.3 Winding Illustration

Figure 10 – Finished Output Choke.

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8 Transformer/Inductor Design Spreadsheet

The main transformer design shown in this spreadsheet was refined by measuring the actual minimum B+ value at 90 VAC, 100% load (measured at the bottom of the ripple trough) and entering it as the VMIN value in the "Input Voltage and UV/OV" section of the spreadsheet.

HiperTFS2_Two-switch_Forward_041114; Rev.2.0; Copyright Power Integrations 2013	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**HiperTFS2_041114_Rev2-0.xls; Two-switch Forward Transformer Design Spreadsheet**
Hiper-TFS MAIN OUTPUT (TWO-SWITCH FORWARD STAGE)					
OUTPUT VOLTAGE AND CURRENT					
VMAIN	61.00		61.00	V	Main output voltage
IMAIN	4.59		4.59	A	Main output current
VOUT2			0.00	V	Output2 voltage - enter zero or leave blank if none
IOUT2			0.00	A	Output2 current - enter zero or leave blank if none
Post Regulated Output					
Post Regulator	**NONE**		NONE		Select post regulator from Mag-Amp, Buck, or NONE
V_SOURCE	**NONE**		NONE	V	Select source of input voltage for post regulator. Enter None if Post regulator not used.
VOUT3			0.00	V	Enter post regulator output voltage. Enter zero or leave blank if none
IOUT3			0.00	A	Enter post regulator output current. Enter zero or leave blank if none
n_PR			1.00		Enter post regulator efficiency (Buck only)
Coupled Inductor (Low Power) derived output					
VOUT4			0.00	V	Output choke derived (low power) output voltage (typically -12 V)
IOUT4			0.00	A	Output choke derived (low power) output current
System Power					
POUT(Main)			280.0	W	Total output power (Main converter)
POUT_PEAK(Main)	280.0		280.0	W	Peak Output power (Main converter). If there is no peak power requirement enter value equal to continuous power
POUT(Standby)			20.3	W	Continuous output power from Standby power supply
POUT_PEAK(Standby)			20.3	W	Peak output power from Standby section below
POUT(System Total)			**300.3**	**W**	**Total system continuous output power**
POUT_PEAK(System Total)			300.3	W	Total system peak output power
INPUT VOLTAGE AND UV/OV					
CIN_MIN			253	uF	Minimum Input Capacitance to meet holdup time. To increase CMIN, increase T_HOLDUP
T_HOLDUP			20.0	ms	Holdup time
CIN_ACTUAL	**330**		330	uF	Select Actual Bulk Capacitor
CIN_ESR			0.25	Ω	Bulk capacitor ESR
IRMS_CIN			1.13	A	RMS current through bulk capacitor
PLOSS_CIN			0.32	W	Bulk capacitor ESR losses
VMIN	220		220	V	Minimum input voltage to guarantee output regulation at full load
VNOM	322		322	V	Nominal input voltage
VMAX			392	V	Maximum DC input voltage

RR			3.32	MΩ	R pin resistor
RL			3.32	MΩ	Line Sense resistor value (L-pin) - goal seek (VUV OFF) for std 1% resistor series
UV and OV thresholds					
Clamp Section					
Clamp Selection	**CLAMP TO GND**				Select either "CLAMP TO RAIL" (default) or "CLAMP TO GND"
VCLAMP			530	V	Asymmetric Clamp Zener Voltage
VDSOP			530	V	Estimated Maximum Hiper-TFS Drain voltage (at VOVOFF_MAX)
DUTY CYCLE VALUES (REGULATION)					
DVMIN			0.67		Duty cycle at minimum DC input voltage
DVNOM_GOAL			0.46		Target duty cycle at nominal input voltage (VNOM)
DVNOM			0.45		Duty cycle at nominal DC input voltage
DVMAX			0.37		Duty cycle at maximum DC input voltage
DOVOFF MIN			0.37		Duty cycle at over-voltage DC input voltage (DOVOFF_MIN)
Maximum Duty Cycle values					
DMAX_UVOFF_MIN			0.78		Max duty cycle clamp at VUVOFF_MIN
DMAX_VMIN			0.71		Max duty clamp cycle at VMIN
DMAX_VNOM			0.56		Max duty clamp cycle at VNOM
DMAX_VMAX			0.46		Max duty clamp cycle at VMAX
DMAX_OVOFFMIN			0.46		Max duty clamp cycle at VOVOFF_MAX
DEVICE VARIABLES					
Device	**TFS7707**		TFS7707		Selected HiperTFS device
Select Frequency mode	**Auto**		132	kHz	Select Frequency mode.
ILIMIT_MIN			4.36	A	Device current limit (Minimum)
ILIMIT_TYP			4.69	A	Device current limit (Typical)
ILIMIT_MAX			5.02	A	Device current limit (Maximum)
fSMIN			124,000	Hz	Device switching frequency (Minimum)
fS			132,000	Hz	Device switching frequency (Typical)
fSMAX			140,000	Hz	Device switching frequency (Maximum)
KI	0.7		0.7		Select Current limit factor (KI=1.0 for default ILIMIT, or select KI=0.9 or KI=0.7)
R(FB)			1740	kΩ	Feedback Pin Resistor value
ILIMIT SELECT			3.05	A	Selected current limit
RDS(ON)			2.54	Ω	Sum of Rds(on) of high and low-side MOSFETs at 100°C
VDS			4.51	V	HiperTFS full-load average on-state Drain to Source Voltage (sum for both MOSFETs)
Main MOSFET losses					
MAIN TRANSFORMER					
Transformer core selection					
Core Type	**EER35**		EER35		Selected core type
AE			1.07	cm^2	Core effective cross sectional area
LE			9.08	cm	Core Effective Path Length
AL			2770	nH/T^2	Ungapped Core Effective Inductance
BW			26.1	mm	Bobbin Physical Winding Width
B_HT			5.52	mm	Height of bobbin (to calculate fit)
B_WA			1.44	cm^2	Bobbin Winding area
M			4.5	mm	Bobbin safety margin tape width (2 * M = Total Margin)
Primary Inductance					
LMAG_MAX			9.1	mH	Max LMAG to hit min zero-load resonant frequency, calculated from C_PRI. Do not exceed.
LMAG	4.4		4.4	mH	Actual magnetizing inductance (measured) of transformer

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GAP		Warning	-0.02	mm	Warning: Inductance is higher than zero gap inductance. Decrease LMAG
FRES_SYS	173		173	kHz	Total XFMR + system resonant frequency; enter value along with actual LMAG
C_SYS			192	pF	Estimated total XFMR + Sys parasitic cap reflected to primary, calc'd from LMAG and FRES
Diode Vf Selection					
Turns					
NMAIN	15.0		15	turns	Main rounded turns
NS2			N/A	turns	2nd output number of turns
VOUT2 ACTUAL			0.0	V	Approximate Output2 voltage with NS2 = 0 turns (AC stacked secondary). VDMAIN and VDOUT2 affect this.
NP			33	turns	Primary rounded turns. NMAIN and DVNOM_GOAL affect this.
HI SIDE BIAS WINDING (optional)	**Yes**		Yes		Can be used to eliminate pulse skipping at light load 132 kHz when zero transformer gap; better efficiency than adding gap
VBIAS			17.0	V	DC bias voltage from main transformer optional aux winding
NBIAS	3		3	turns	VBias rounded turns
VBIAS_ACTUAL			19.3	V	Approximate Forward Bias Winding Voltage at VMIN with NB = 3 turns
Flux calculations					
BM_MAX			1916	Gauss	Peak positive flux density at nominal switching frequency
BM PK-PK			2903	Gauss	Peak-peak flux density at nominal conditions. Used to calculate core losses
BP_MAX			2565	Gauss	Max transient positive flux density at Vmax (limited by DVMAX clamp)
BP PK-PK			3886	Gauss	Max transient peak-peak flux density at Vmax (limited by DVMAX clamp)
TRANSFORMER LOSSES AND FIT ESTIMATE					
Core loss					
Core material	**PC95**		PC95		Core material
core_loss_multiplier			23.97		Core Loss coefficient
f_coeff			1.56		Core Loss Frequency co-efficient
BAC_coeff			2.89		Core Loss AC flux density co-efficient
specific core loss			182	mW/cc	Core loss per unit volume
core volume			9.72	cm^3	Volume of core
core loss			1.77	W	Core loss
Primary Winding Fit and losses					
L	2.00		2.0	layers	Transformer primary layers (split primary recommended)
OD_PRI			0.63	mm	Primary winding diameter
FILAR_PRI			1.0	strands	Number of parallel strands of wire (primary)
MLT_PRI			6.14	cm	Mean length per turn
DCR_PRI			143	mΩ	DC resistance of primary winding
PCOND_PRI			0.31	W	Conduction loss in primary winding
FILL_PRI			7	%	Fill factor (primary only)
Secondary Winding 1 (lower winding when AC stacked)					
VOUT			61.0	V	Specified voltage for this winding
NS1			15.0	turns	Number of turns
IRMS_SEC1			3.8	A	RMS current through winding
Foil/Wire	**WIRE**		WIRE	foil/wire	Select FOIL or WIRE for winding
OD/Thickness			0.36576	mm	Wire diameter or Foil thickness
FILAR_SEC1			2.00	strands	Number of parallel strands (wire selection only)
SEC1_WIDTH			N/A	mm	Foil Width (Applicable if FOIL winding

					used)
SEC1_MLT			6.14	cm	Mean length per turn
DCR_SEC1			96.86	mΩ	DC resistance of secondary winding
PCOND_SEC1			1.38	W	Conduction loss in secondary winding
FILL_SEC1			2	%	Fill factor (secondary 1 only)
Secondary Winding 2 (upper winding when AC stacked)					
VOUT			0.0	V	Specified voltage for this winding
NS2			0.0	turns	Number of turns
IRMS_SEC2			0.0	A	RMS current through winding
Foil/Wire	**FOIL**		FOIL	foil/wire	Select FOIL or WIRE for winding
OD/Thickness			0.125	mm	Wire diameter or Foil thickness
FILAR_SEC2			N/A	strands	Number of parallel strands (wire selection only)
SEC2_WIDTH			18.0	mm	Foil Width (Applicable if FOIL winding used)
SEC2_MLT			6.14	cm	Mean length per turn
DCR_SEC2			0.00	mΩ	DC resistance of secondary winding
PCOND_SEC2			0.00	W	Conduction loss in secondary winding
FILL_SEC2			0	%	Fill factor (secondary 1 only)
Fill Factor and losses of main transformer					
FILL_TOTAL			9	%	Total transformer fill factor
TOTAL_CU_LOSS			1.69	W	Total copper losses in transformer
TOTAL_CORE_LOSS			1.77	W	Total core losses in transformer
TOTAL_TRF_LOSS			3.46	W	Total losses in transformer
CURRENT WAVESHAPE PARAMETERS					
IP			2.79	A	Peak primary current at Full Load, VNOM
IP_PEAK			2.79	A	Peak primary current at Peak Load and VNOM
IPRMS(NOM)			1.49	A	Primary RMS current at Full Load, VNOM
IMAG			0.25	A	Peak magnetizing current at VMIN
OUTPUT INDUCTOR					
KDI_ACTUAL			0.44		Current ripple factor of combined Main and Output2 outputs
Turns					
POWDER TURNS MULTIPLIER	3.00		3.0		Powder only. Multiplier factor between main number of turns in transformer and inductor (default value = 3 for 66kHz or 4 for 132kHz).
NMAIN_INDUCTOR			45.0	turns	Main output inductor number of turns - affected by powder turns multiplier or ferrite Target BM
NOUT2_INDUCTOR				turns	Output 2 inductor number of turns
NOUT4_INDUCTOR			N/A	turns	Output 4 number of turns (low power)
Inductance and flux					
LMAIN_ACTUAL			144.9	uH	Estimated inductance of main output at full load
LOUT_2			0.0	uH	Estimated inductance of auxiliary output at full load
BM_IND			2412	gauss	DC component of flux density
BAC_IND			498	gauss	AC component of flux density
Core Selection					
Core Type	**Kool Mu 125u**		Kool Mu 125u		Select core type
Core	**Auto**		77930(O.D)=27.7		Output choke core size - verify on bench
AE			65.4	mm^2	Core Effective Cross Sectional Area
LE			63.5	mm	Core Effective Path Length
AL			157.0	nH/T^2	Ungapped Core Effective Inductance
BW			44.3	mm	Bobbin Physical Winding Width
VE			4150	mm^3	Volume of core
Powder cores (Sendust and Powdered Iron) Cores					
MUR			125		Relative permeability of material at 0 bias

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H			34.7	AT/cm	Magnetic field strength
MUR_RATIO			0.46		Ratio of permeability at full load divided by initial permeability
LMAIN_0bias			317.9	uH	Estimated inductance of main output with 0 DC bias
Ferrite Cores					
LG			N/A	mm	Gap length of inductor cores
Target BM			N/A	Gauss	Target maximum flux density
Choke wires					
Total number of layers			1.80	layers	Total number of layers for chosen toroid
IRMS_MAIN			4.59	A	RMS current through main inductor windings
IRMS_AUX			0.00	A	RMS current through aux winding
AWG_MAIN	20.00		20	AWG	Main inductor winding wire gauge
OD_MAIN			0.88	mm	Main winding wire gauge outer diameter
FILAR_MAIN			2	strands	Number of parallel strands for main output
RDC_MAIN			28.88	mΩ	Resistance of wire for main inductor winding
AC Resistance Ratio (Main)			11.79		Ratio of total resistance (AC + DC) to the DC resistance (using Dowell curves)
CMA_MAIN			445	CMA	Cir mils per amp for main inductor winding
J_MAIN			7.57	A/mm^2	Current density in main inductor winding
AWG_AUX			0	AWG	Aux winding wire gauge
OD_AUX			N/A	mm	Auxiliary winding wire gauge outer diameter
FILAR_AUX			2	strands	Number of parallel strands for aux output
RDC_AUX			0.00	mΩ	Resistance of wire for aux inductor winding
AC Resistance Ratio (Aux)			0.00		Ratio of total resistance (AC + DC) to the DC resistance (using Dowell curves)
CMA_AUX		Info	0	CMA	!!! Info. Low CMA may cause overheating. Verify acceptable temperature rise
J_AUX			0.00	A/mm^2	Current density in auxiliary winding
Choke Losses					
PCOPPER_MAIN			0.61	W	Copper loss in main inductor winding
PCOPPER_AUX			0.00	W	Copper loss in aux inductor windings
PCORE			1.28	W	Total core loss
PTOTAL_IND			1.89	W	Total losses in output choke
SECONDARY OUTPUT DIODE PARAMETERS					
Main Output					
ISFWDRMS			3.77	A	Full load forward diode RMS current at nominal input voltage
ISCATCHRMS			4.14	A	Freewheeling diode RMS current at nominal input voltage
IDAVMAINF			3.07	A	Worst case average current of forward rectifier at VMIN (single device rating)
IDAVMAINC			2.89	A	Worst case average current of freewheeling diode at VMAX(single device rating)
IRMSMAIN			0.58	A	Maximum RMS current, Main output capacitor
PD_LOSS_MAIN			2.30	W	Conduction loss of forward diode
Second Output					
ISFWD2RMS			0.00	A	Full load forward diode RMS current at nominal input voltage
ISCATCH2RMS			0.00	A	Freewheeling diode RMS current at nominal input voltage
IDAVOUT2F			0.00	A	Worst case average current of forward rectifier at VMIN (single device rating)

IDAVOUT2C			0.00	A	Worst case average current of freewheeling diode at VMAX(single device rating)
IRMSOUT2			0.00	A	Maximum RMS current, Main output capacitor
PD_LOSS_OUT2			0.00	W	Conduction loss of forward diode
Diode Derating					
VPIVMAINF	0.80		301.1	V	Main Forward Diode peak-inverse voltage (at VDSOP), including derating
VPIVMAINC	0.80		222.9	V	Main Catch Diode peak-inverse voltage (at VOVOFF_MAX), including derating
VPIVOUT2F	1.00		0.0	V	Output2 Forward Diode peak-inverse voltage (at VDSOP), including derating
VPIVOUT2C	1.00		0.0	V	Output2 Catch Diode peak-inverse voltage (at VOVOFF_MAX), including derating
VPIVB	1.00		48.2	V	Bias output rectifier peak-inverse voltage (at VDSOP), including derating
Hiper-TFS STANDBY SECTION (FLYBACK STAGE)					
ENTER APPLICATION VARIABLES					
VACMIN			85	V	Minimum AC Input Voltage
VACMAX	132		132	V	Maximum AC Input Voltage
fL			50	Hz	AC Mains Frequency
VO_SB			5.0	V	Output Voltage (at continuous power)
IO_SB	4.00		4.00	A	Power Supply Output Current (corresponding to peak power)
IO_SB_PK			4.00	A	Peak output current
POUT_SB			20.00	W	Continuous Output Power
POUT_SB_TOTAL			20.32	W	Total Standby power (Includes Bias winding power)
POUT_SB_PK			20.32	W	Peak Standby Output Power
n			0.70		Efficiency Estimate at output terminals. Under 0.7 if no better data available
Z			0.50		Z Factor. Ratio of secondary side losses to the total losses in the power supply. Use 0.5 if no better data available
tC			3.00	ms	Bridge Rectifier Conduction Time Estimate
ENTER Hiper-TFS STANDBY VARIABLES					
Select Current Limit	**INC**		Increased Current Limit		Enter "LOW" for low current limit, "RED" for reduced current limit (sealed adapters), "STD" for standard current limit or "INC" for increased current limit (peak or higher power applications)
ILIM_MIN			0.70	A	Minimum Current Limit
ILIM_TYP			0.75	A	Typical Current Limit
ILIM_MAX			0.80	A	Maximum Current Limit
R(EN)			107	kΩ	Enable pin resistor
fSmin			124,000	Hz	Minimum Device Switching Frequency
I^2fmin			66.8	A^2kHz	I^2f (product of current limit squared and frequency is trimmed for tighter tolerance)
VOR			100	V	Reflected Output Voltage (VOR < 135 V Recommended)
VDS			10.0	V	Hiper-TFS Standby On State Drain to Source Voltage
VD_SB			0.5	V	Output Winding Diode Forward Voltage Drop
KP			0.51		Ripple to Peak Current Ratio (KP < 6)
KP_TRANSIENT			0.27		Transient Ripple to Peak Current Ratio. Ensure KP_TRANSIENT > 0.25
ENTER BIAS WINDING VARIABLES					
VB			16.0	V	Bias Winding Voltage
IB			20.0	mA	Bias winding Load current

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PB			0.32	W	Bias winding power
VDB			0.70	V	Bias Winding Diode Forward Voltage Drop
NB			12.1	turns	Bias Winding Number of Turns
VZOV			22	V	Over Voltage Protection zener diode voltage.
UVLO VARIABLES					
RLS			3.32	MΩ	Line sense resistor (from Main converter section)
V_UV_ACTUAL			85	V	Typical DC start-up voltage
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EF25**		**EF25**		Enter Transformer Core
AE			0.518	cm^2	Core Effective Cross Sectional Area
LE			5.78	cm	Core Effective Path Length
AL			2000	nH/T^2	Ungapped Core Effective Inductance
BW			15.6	mm	Bobbin Physical Winding Width
M	1.50		1.5	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2.00		2		Number of Primary Layers
NS_SB	4		4		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN_SB			113	V	Minimum DC Input Voltage
VMAX_SB			187	V	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX_SB			0.49		Duty Ratio at full load, minimum primary inductance and minimum input voltage
IAVG			0.28	A	Average Primary Current
IP_SB			0.70	A	Minimum Peak Primary Current
IR_SB			0.35	A	Primary Ripple Current
IRMS_SB			0.43	A	Primary RMS Current
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP_SB			1074	uH	Typical Primary Inductance. +/- 10% to ensure a minimum primary inductance of 976 uH
LP_TOLERANCE			10	%	Primary inductance tolerance
NP_SB			73	turns	Primary Winding Number of Turns
ALG			203	nH/T^2	Gapped Core Effective Inductance
BM			2287	Gauss	Maximum Operating Flux Density, BM<3000 is recommended
BAC			579	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1776		Relative Permeability of Ungapped Core
LG			0.29	mm	Gap Length (Lg > 0.1 mm)
BWE			25.2	mm	Effective Bobbin Width
OD			0.35	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.29	mm	Bare conductor diameter
AWG			29	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			128	Cmils	Bare conductor effective area in circular mils
CMA			299	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					
ISP			12.7	A	Peak Secondary Current
ISRMS			7.91	A	Secondary RMS Current
IRIPPLE			6.83	A	Output Capacitor RMS Ripple Current
CMS			1583	Cmils	Secondary Bare Conductor minimum

					circular mils
AWGS			18	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
VOLTAGE STRESS PARAMETERS					
VDRAIN			417	V	Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)
PIVS			15	V	Output Rectifier Maximum Peak Inverse Voltage
Forward DC-DC System efficiency					
P_MOSFET_MAIN_TOTAL			7.17	W	HiperTFS losses
P_XFMR_LOSS			3.5	W	Main transformer losses
P_MAIN_OUT_DIODE			2.3	W	Output diode losses
P_CIN_ESR			0.32	W	Bulk capacitor ESR losses
P_IND_MAIN			1.9	W	Output choke losses
OTHER_LOSSES			0.13	W	Other losses (includes PCB traces, clamp loss, magamp loss etc.)
EFFICIENCY_STDBY			70.0%		Estimated efficiency of flyback power supply
EFFICIENCY_MAIN			94.6%		Estimated Forward efficiency
EFFICIENCY_SYSTEM			92.4%		Estimated System efficiency (forward + standby)
Other Losses					
Detailed Mosfet Loss Information					

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9 Heat Sinks

9.1 Main Primary Heat Sink

9.1.1 Primary Heat Sink Sheet Metal

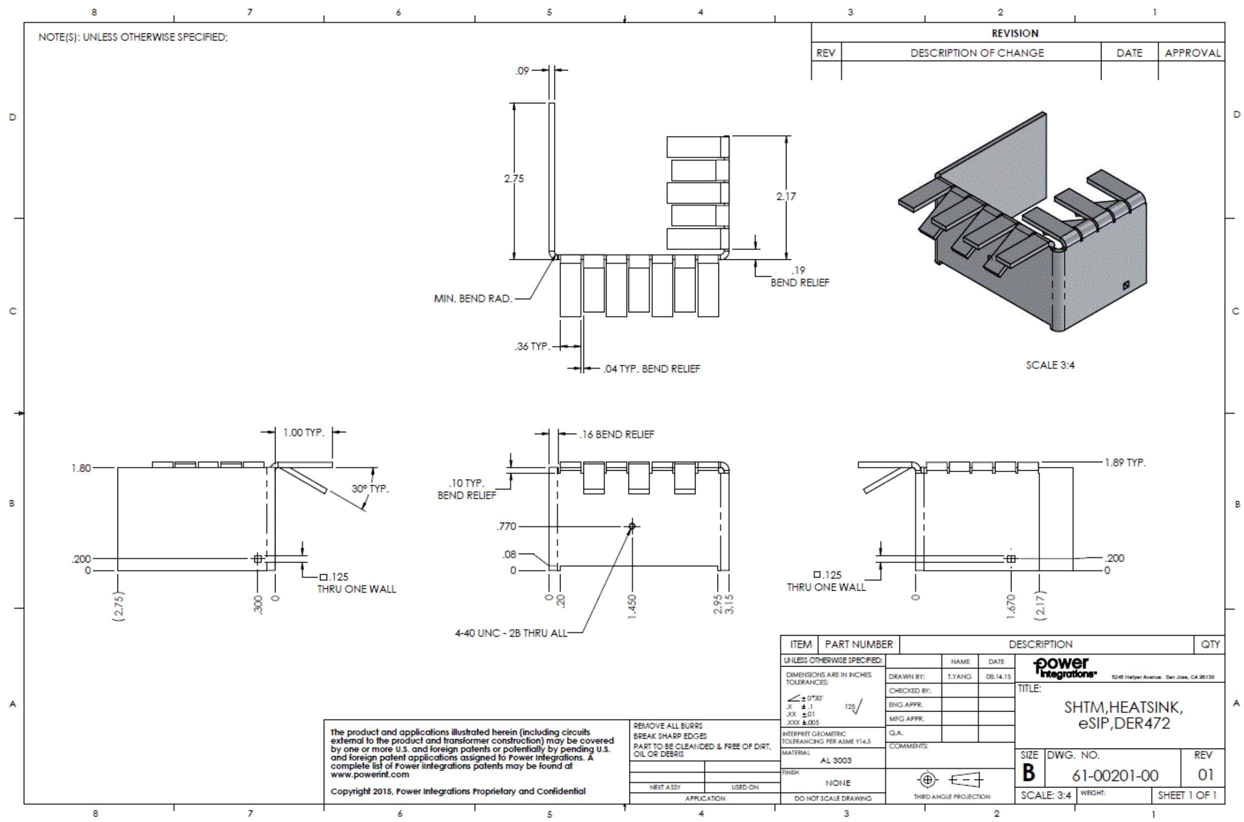

Figure 11 – DER-472 Primary Heat Sink Sheet Metal Drawing.

9.1.2 Finished Primary Heat Sink with Hardware

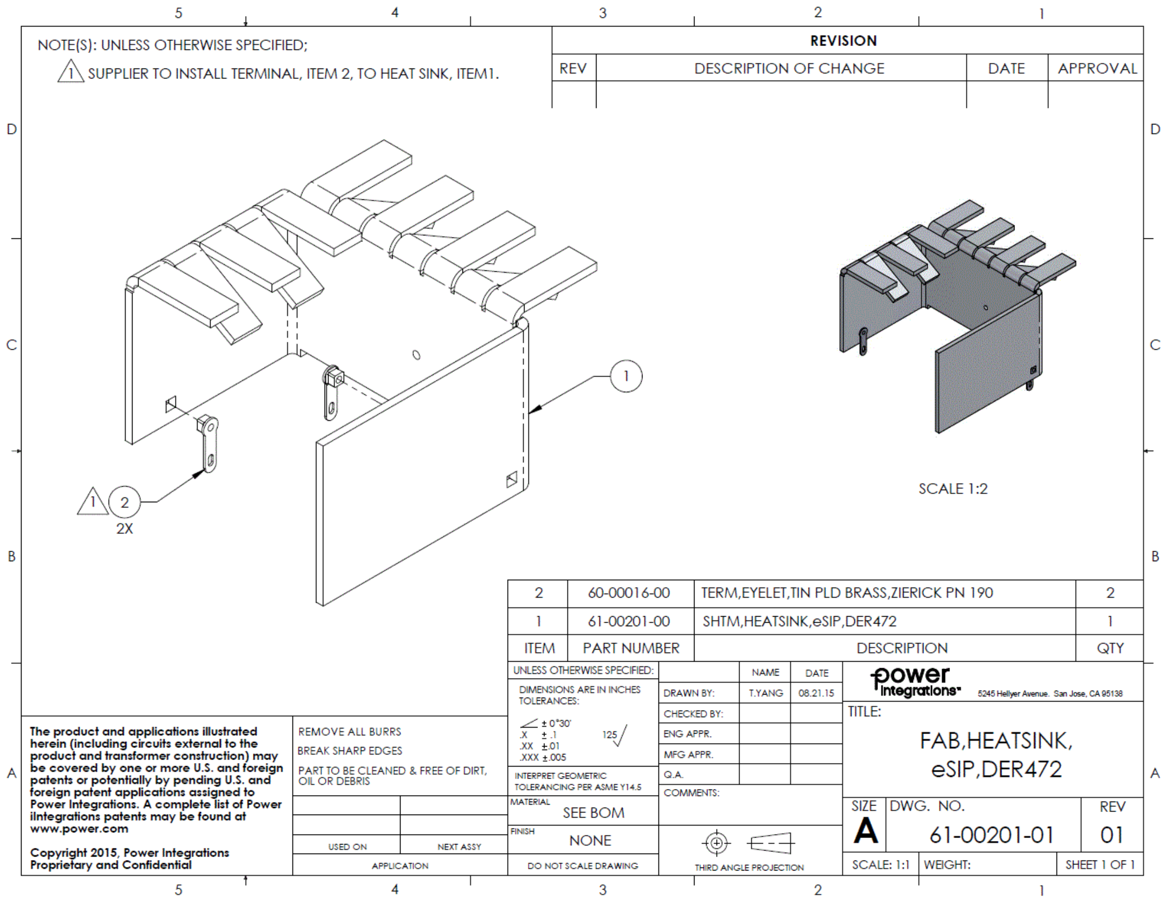

Figure 12 – DER-472 – Finished Primary Heat Sink with Hardware.

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9.1.3 Primary Heat Sink Assembly

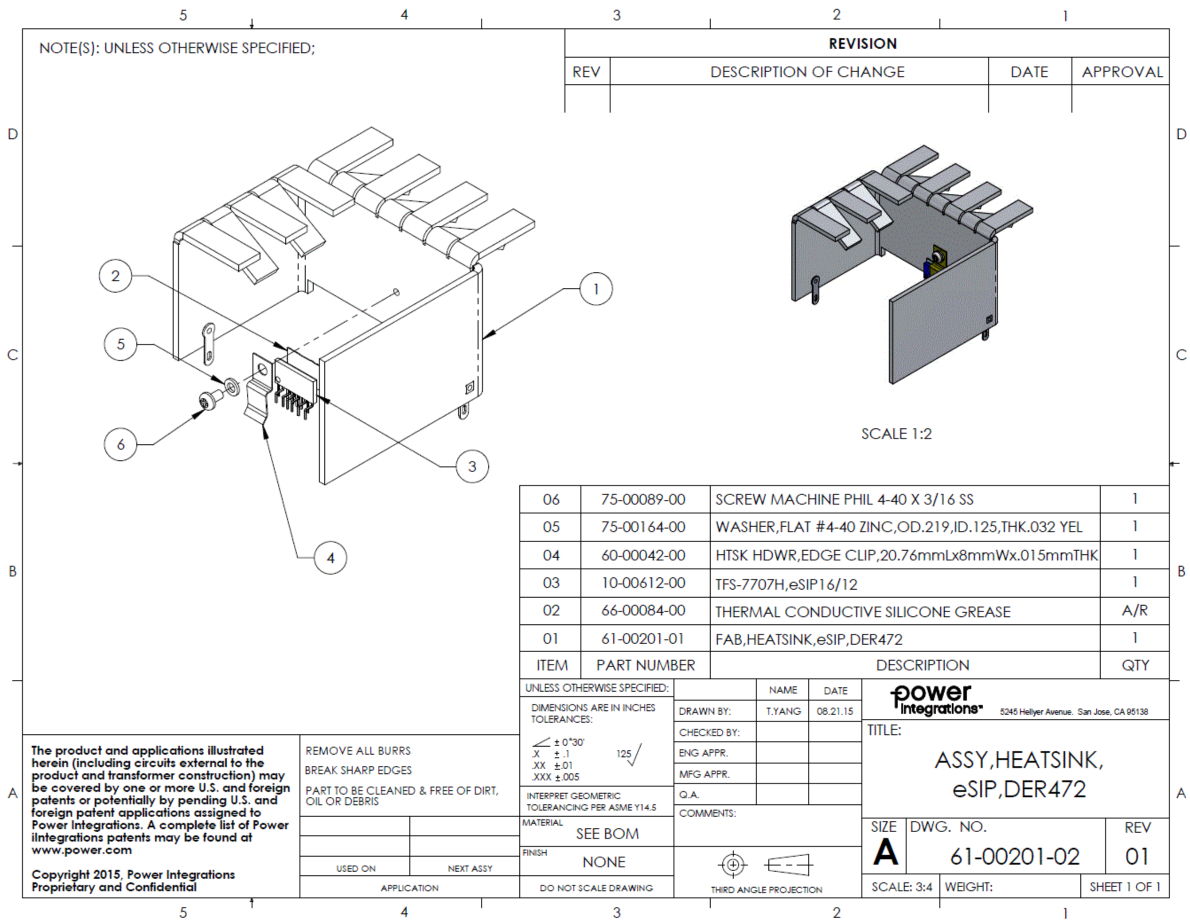

Figure 13 – Primary Heat Sink Assembly

9.2 Diode Bridge Heat Sink

9.2.1 Diode Bridge Heat Sink Sheet Metal

Figure 14 – DER-472 Diode Bridge Heat Sink Sheet Metal Drawing.

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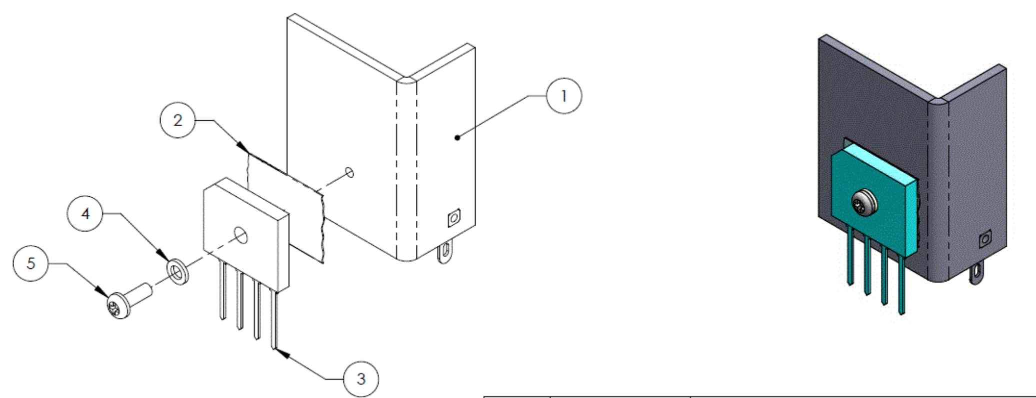
9.2.2 Completed Diode Bridge Heat Sink with Hardware

Figure 15 – DER-472 Finished Diode Bridge Heat Sink with Hardware.

9.2.3 Diode Bridge Heat Sink Assembly

NOTE(S): UNLESS OTHERWISE SPECIFIED;

REVISION			
REV	DESCRIPTION OF CHANGE	DATE	APPROVAL
02	UPDATE ASSY-HS DESIGN CHANGED	08.18.15	R.H.



ITEM	PART NUMBER	DESCRIPTION	QTY
05	75-00002-00	SCREW MACHINE PHIL 4-40 X 5/16 SS	1
04	75-00164-00	WASHER,FLAT #4-40 ZINC,OD.219,ID.125,THK.032 YEL	1
03	15-00720-00	600V,8A,BRIDGE RECTIFIED,GBU CASE	1
02	66-00084-00	THERMAL CONDUCTIVE SILICONE GREASE	A/R
01	61-00193-01	FAB,HEATSINK,BRIDGE,DER472	1

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REMOVE ALL BURRS
BREAK SHARP EDGES
PART TO BE CLEANED & FREE OF DIRT, OIL OR DEBRIS

USED ON | NEXT ASSY | APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
∠ ± 0°30'
.X ± .1
.XX ± .01
.XXX ± .005
125 √
INTERPRET GEOMETRIC TOLERANCING PER ASME Y14.5
MATERIAL: SEE BOM
FINISH: NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN BY:	T.YANG	03.04.15
CHECKED BY:		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
THIRD ANGLE PROJECTION

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TITLE: ASSY,HEATSINK, BRIDGE,DER472
SIZE: A | DWG. NO. 61-00193-02 | REV 02
SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

Figure 16 – DER-472 Diode Bridge Heat Sink Assembly.

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9.3 Output Rectifier Heat Sink

9.3.1 Output Rectifier Heat Sink Sheet Metal Drawing

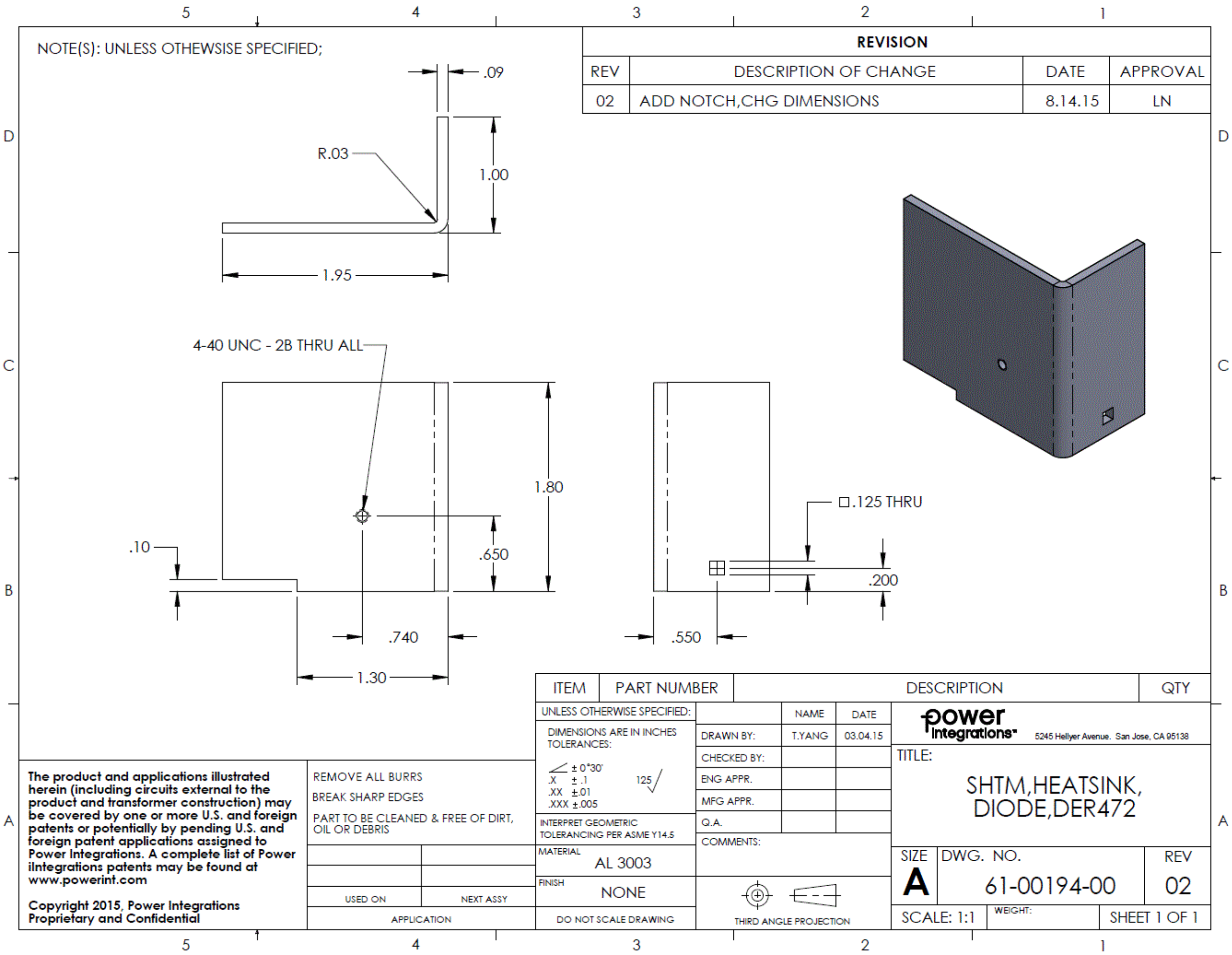

Figure 17 – DER-472 Output Rectifier Heat Sink Sheet Metal Drawing.

9.3.2 Finished Output Rectifier Heat Sink with Hardware

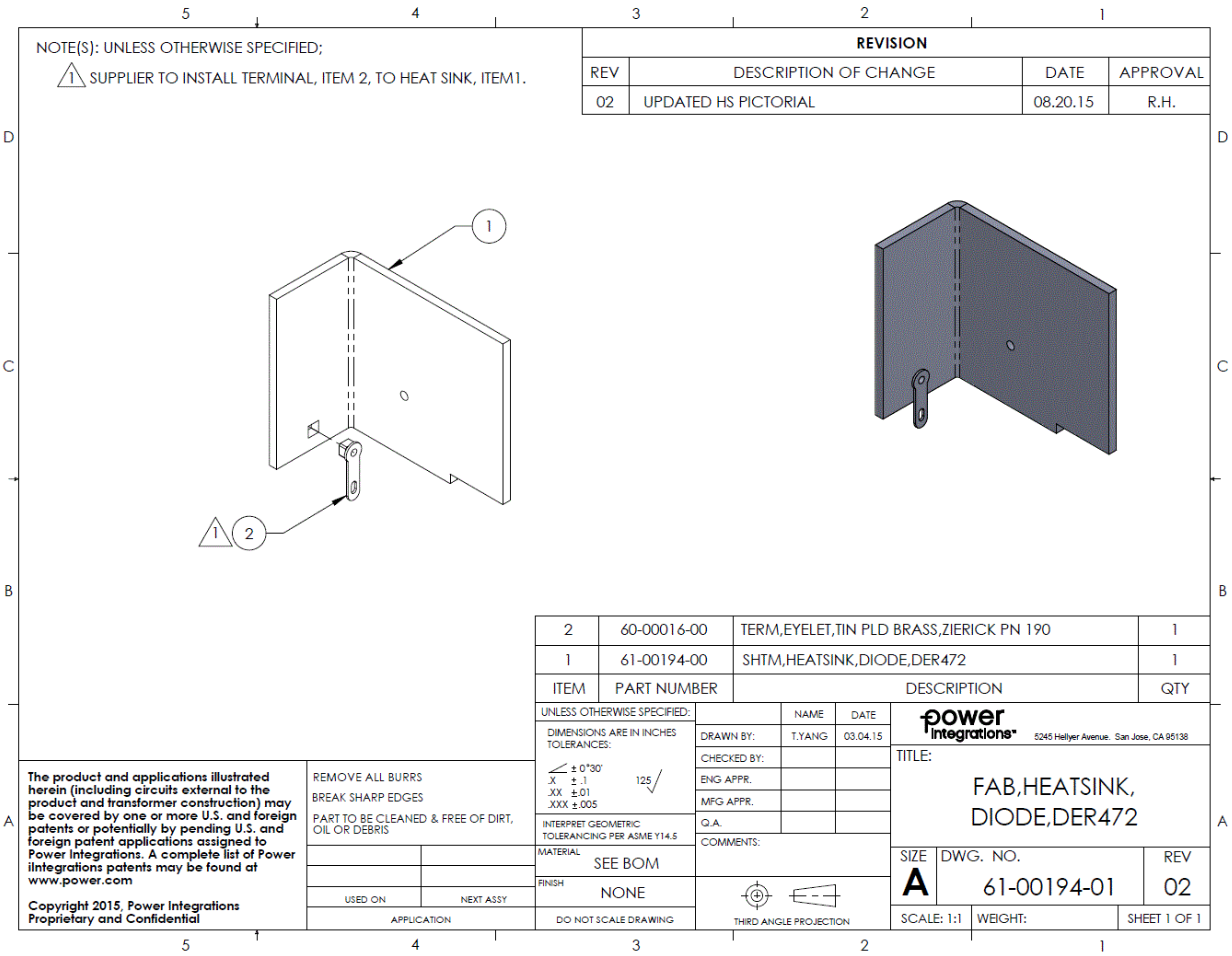

Figure 18 – DER-472 Output Rectifier Heat Sink with Hardware.

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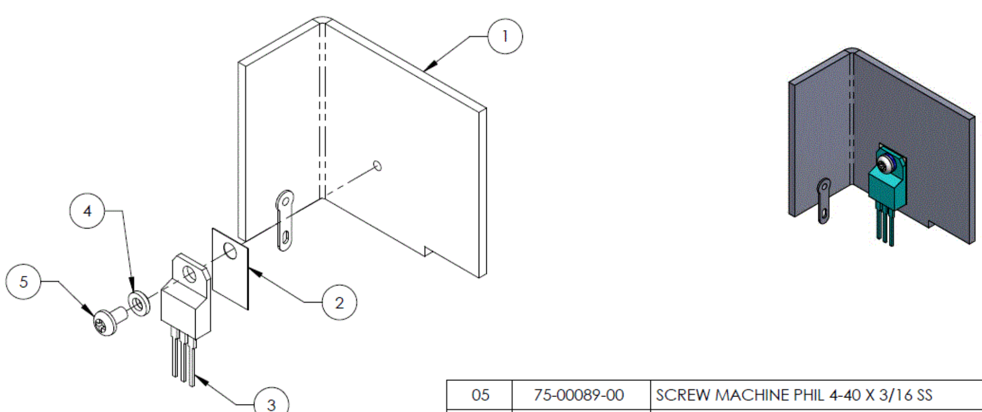
9.3.3 Output Rectifier Heat Sink Assembly

NOTE(S): UNLESS OTHERWISE SPECIFIED;

REVISION			
REV	DESCRIPTION OF CHANGE	DATE	APPROVAL
02	UPDATE HS,CHG ITEMS 2-4 P/N	08.25.15	R.H.



ITEM	PART NUMBER	DESCRIPTION	QTY
05	75-00089-00	SCREW MACHINE PHIL 4-40 X 3/16 SS	1
04	75-00152-00	WSHR,SHLDR #4-40 .032 SHLDRX.116 DIA,PPS	1
03	15-01131-00	300V,10A,DIODE ARRAY,GP,35ns,TO220AB	1
02	66-00079-00	THERMAL PAD TO-220,.009" SP1000	1
01	61-00194-01	FAB,HEATSINK,DIODE,DER472	1

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REMOVE ALL BURRS
BREAK SHARP EDGES
PART TO BE CLEANED & FREE OF DIRT, OIL OR DEBRIS

USED ON | NEXT ASSY
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
∠ ±0°30'
.X ±.1
.XX ±.01
.XXX ±.005
125
INTERPRET GEOMETRIC TOLERANCING PER ASME Y14.5
MATERIAL: SEE BOM
FINISH: NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN BY:	T.YANG	03.04.15
CHECKED BY:		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
THIRD ANGLE PROJECTION

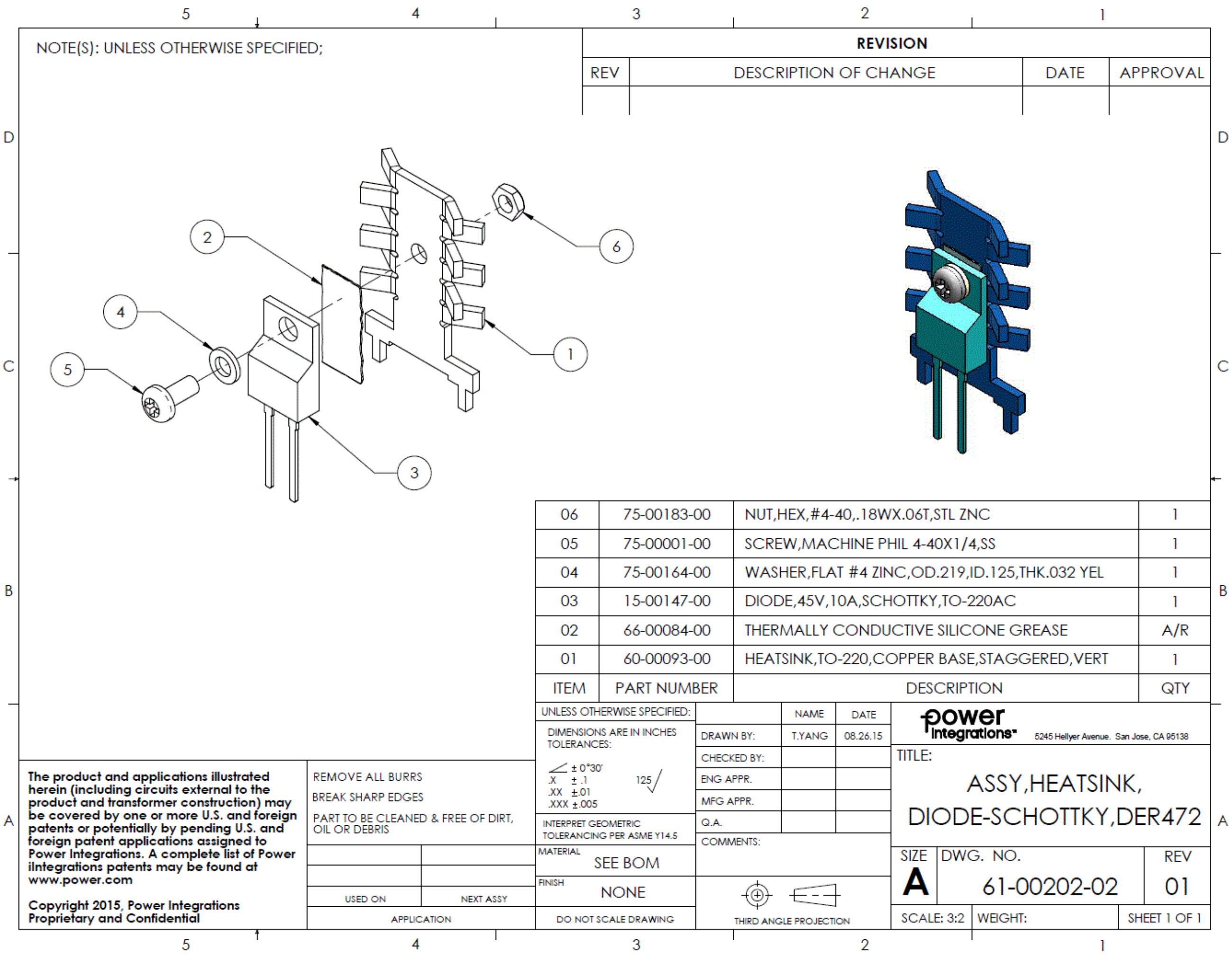
power integrations 5245 Hellyer Avenue, San Jose, CA 95138

TITLE: ASSY,HEATSINK, DIODE,DER472

SIZE: A | DWG. NO.: 61-00194-02 | REV: 02
SCALE: 1:1 | WEIGHT: | SHEET 1 OF 1

Figure 19 – Output Rectifier Heat Sink Assembly.

9.4 *Standby Output Rectifier Heat Sink Assembly*



ITEM	PART NUMBER	DESCRIPTION	QTY
06	75-00183-00	NUT,HEX,#4-40,.18WX.06T,STL ZNC	1
05	75-00001-00	SCREW,MACHINE PHIL 4-40X1/4,SS	1
04	75-00164-00	WASHER,FLAT #4 ZINC,OD.219,ID.125,THK.032 YEL	1
03	15-00147-00	DIODE,45V,10A,SCHOTTKY,TO-220AC	1
02	66-00084-00	THERMALLY CONDUCTIVE SILICONE GREASE	A/R
01	60-00093-00	HEATSINK,TO-220,COPPER BASE,STAGGERED,VERT	1

Figure 20 – DER-472 Standby Output Rectifier Heat Sink Assembly.

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10 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.

10.1 Output Load Considerations for Testing a CV/CC Supply in Battery Charger Applications

Since this power supply has a constant voltage/constant current output and normally operates in CC mode in its intended application (battery charging), some care must be taken in selecting the type/s of output load for testing.

The default setting for most electronic loads is constant current. This setting can be used in testing a CV/CC supply in the CV portion of its load range below the power supply current limit set point. Once the current limit of the DUT is reached, a constant current load will cause the output voltage of the DUT to immediately collapse to the minimum voltage capability of the electronic load.

To test a CV/CC supply in both its CV and CC regions (an example - obtaining a V-I characteristic curve that spans both the CV and CC regions of operation), an electronic load set for constant resistance can be used. However, in an application where the control loop is strongly affected by the output impedance, use of a CR load will give results for loop compensation that are overly optimistic and will likely oscillate when tested with an actual low impedance battery load. For final characterization and tuning the output control loops, a constant voltage load should be used.

Having said this, many electronic loads incorporate a constant voltage setting, but the output impedance of the load in this setting may not be sufficiently low to successfully emulate a real-world battery (impedance on the order of tens of milliohms). Simulating this impedance can be crucial in properly setting the compensation of the current control loop in order to prevent oscillation in a real-life application.

10.2 Efficiency

To make this measurement, the supply was powered with an AC source. The figure shown includes the efficiency of the main forward stage combined with that of the standby/bias flyback supply.

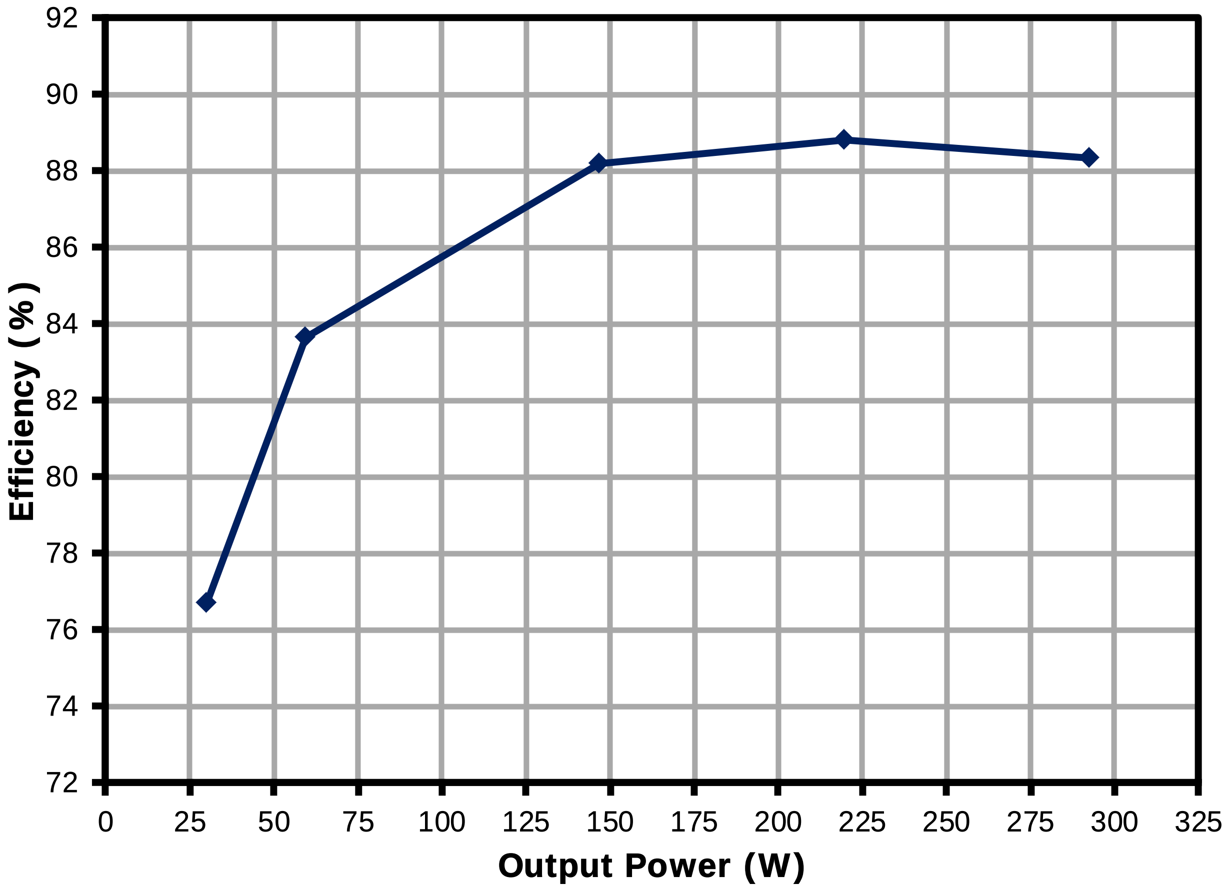

Figure 21 – Efficiency vs. Output Power, 115 VAC Input.

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10.3 No-Load Input Power

No-load input power was measured with no-load on the main and standby outputs and with the main enable switch turned off, such that only the standby supply remained active.

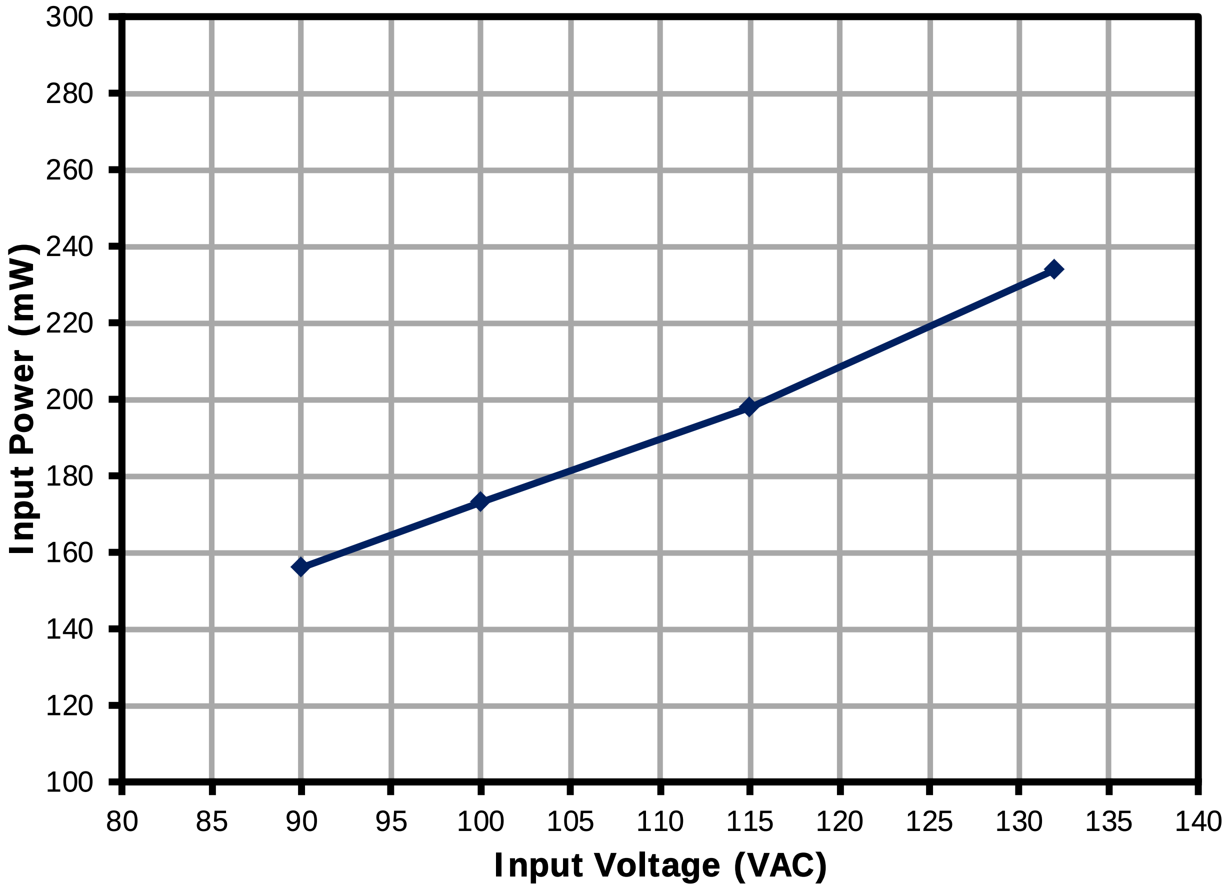

Figure 22 – No-Load Input Power vs. Input Voltage.

10.4 Main Output V-I Characteristic

The main output V-I characteristic showing the transition from constant voltage mode to constant current mode was measured using a Chroma electronic load set for constant resistance. This setting allows proper operation of the DUT in both CV and CC mode. The measurements cut off at 3.2 V, as this is the minimum load voltage attainable by the electronic load in CR mode.

10.4.1 Main Output V-I Characteristic, Constant Resistance Load

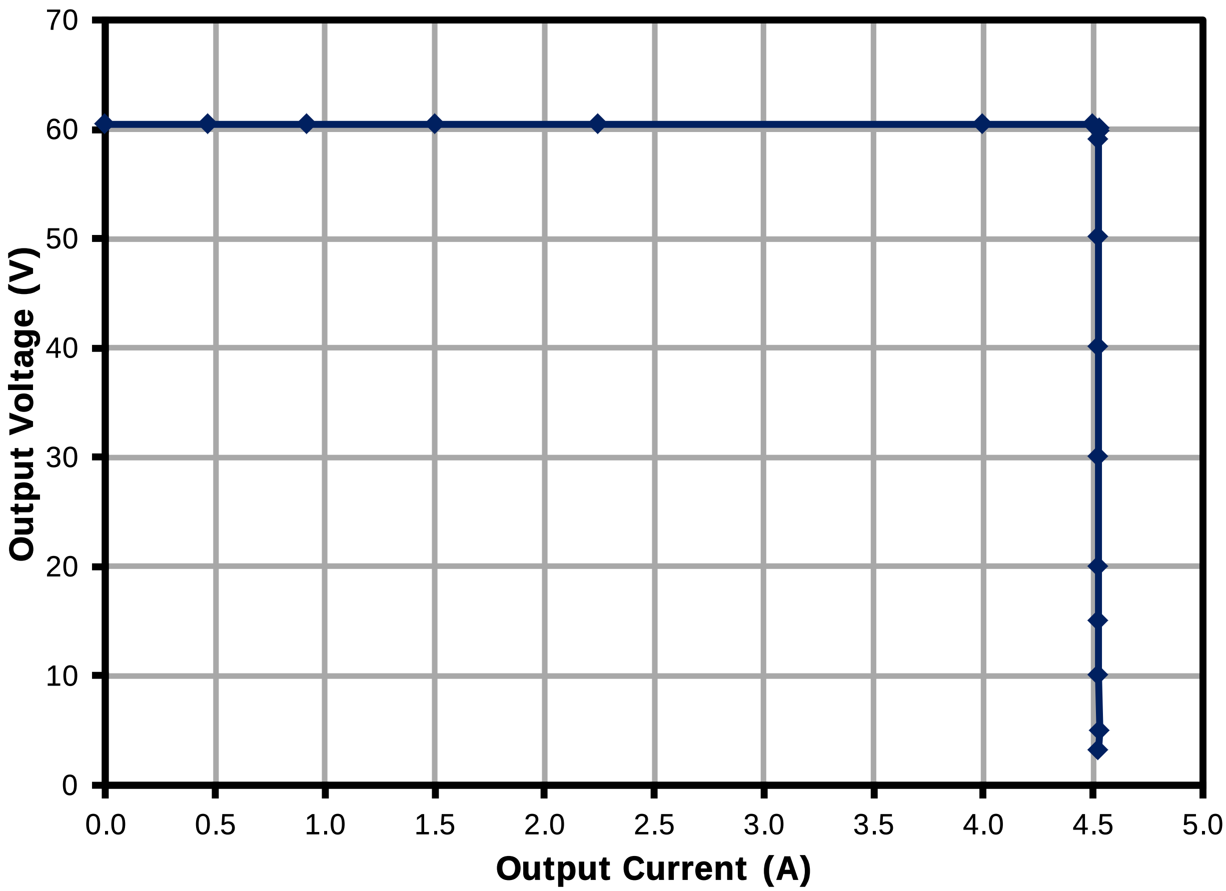

Figure 23 – V-I Characteristic with CR Load.

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10.4.2 Main Output V-I Characteristic, Constant Voltage Load

The main output V-I characteristic in constant current mode was measured using a Chroma electronic load set for constant voltage mode. The minimum operating voltage of the load in CV mode is ~0.37 V.

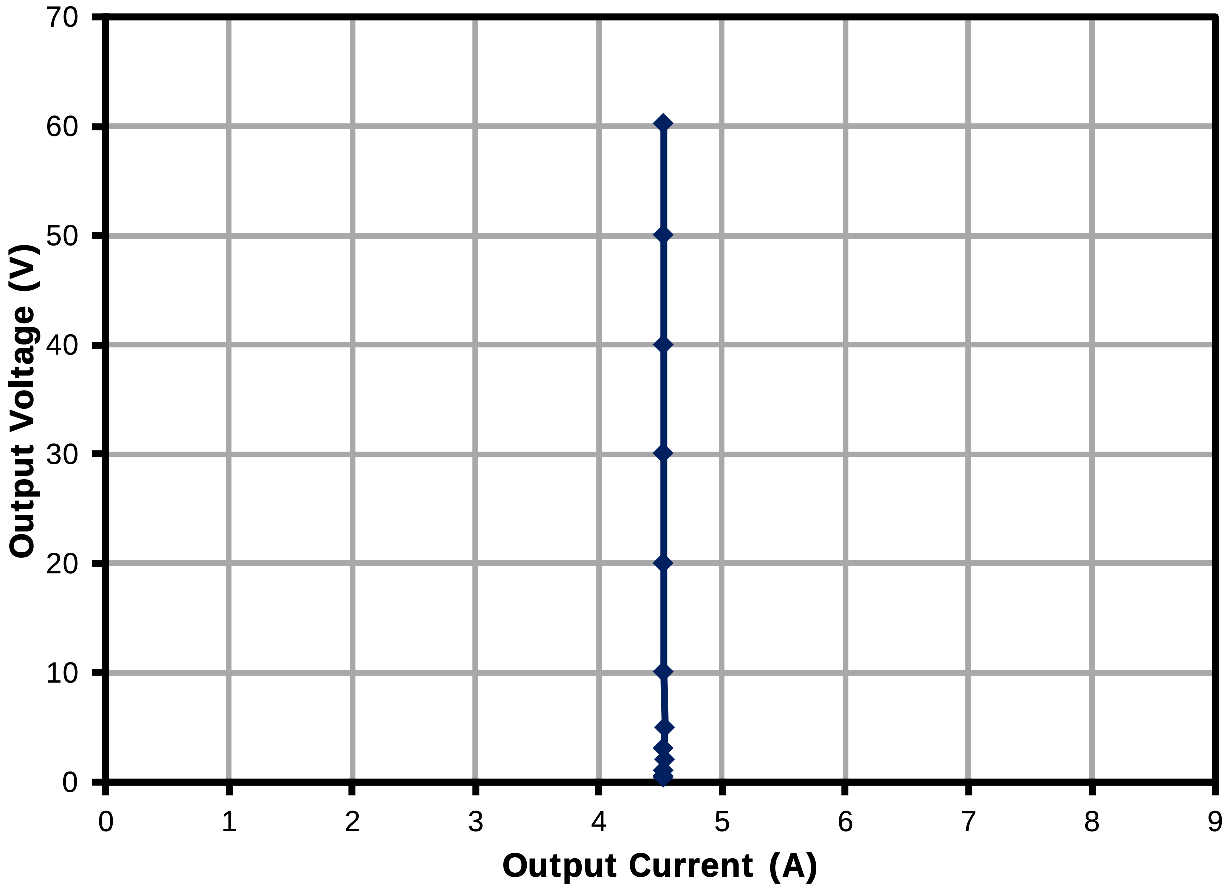

Figure 24 – V-I Characteristic with CV Load**.**

11 Waveforms

11.1 Primary Voltage and Current, Main and Standby Converters

The main stage primary current was measured by inserting a current sensing loop in series with the "HS" pin of U1.

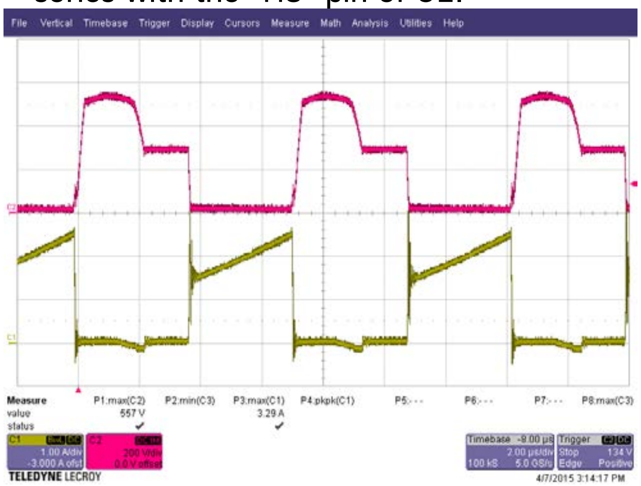

Figure 25 – Main Stage Primary Voltage and Current, 115 VAC Input, 100% Load.
Upper: D Pin Voltage, 200 V/div.
Lower: I_{DRAIN}, 1 A / div. 2 µs / div.

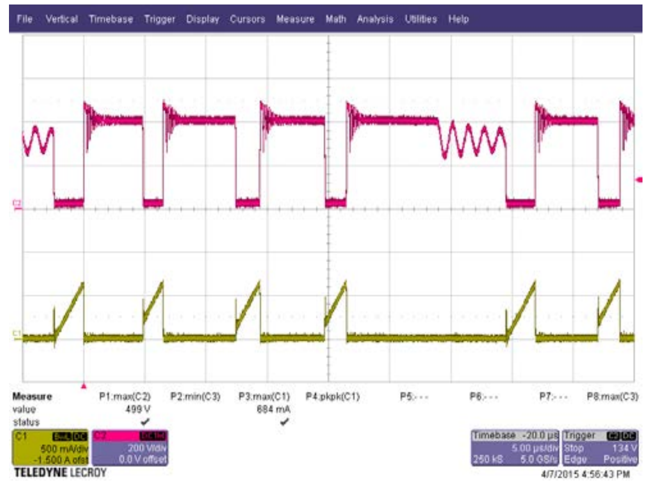

Figure 26 – Standby Primary Voltage and Current, 115 VAC Input, 100% Load.
Upper: DSB Pin Voltage, 200 V / div.
Lower: I_{DRAIN}, 0.5 A /, 5 µs / div.

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11.2 Output Rectifier Peak Reverse Voltage

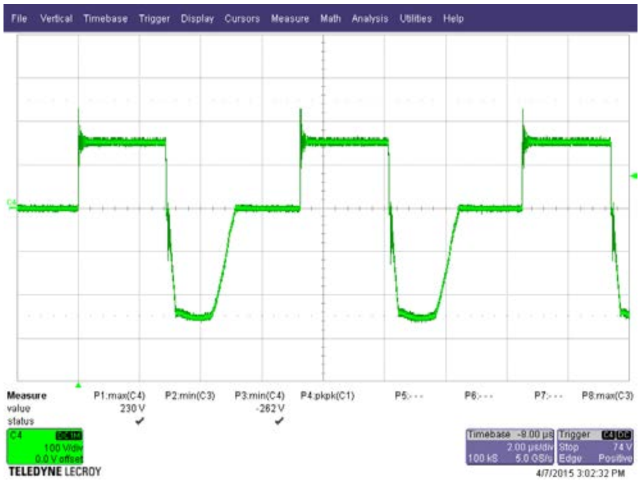

Figure 27 – Output Forward Rectifier (D19) Reverse Voltage, 132 VAC input, 100% Load. 100 V, 2 µs / div.

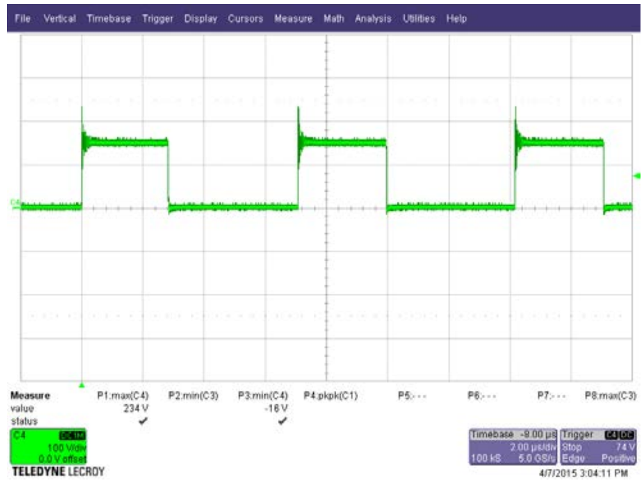

Figure 28 – Output Catch Rectifier (D19) Reverse Voltage, 132 VAC, 100% Load. 100 V, 2 µs / div.

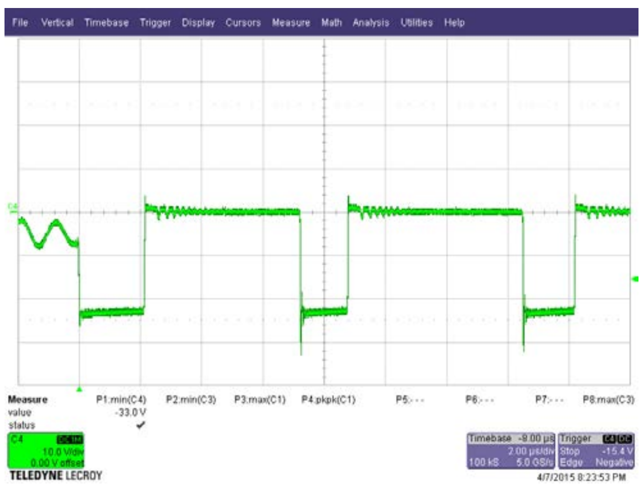

Figure 29 – Standby Output Rectifier (D18) Reverse Voltage, 132 VAC, 100% Load. 10 V, 2 µs / div.

11.3 Main Start-up Output Voltage / Current and Transformer Primary Current Using Constant Voltage and Constant Voltage Output Loads

11.3.1 Main and Standby Start-Up, Supply Started via AC Input

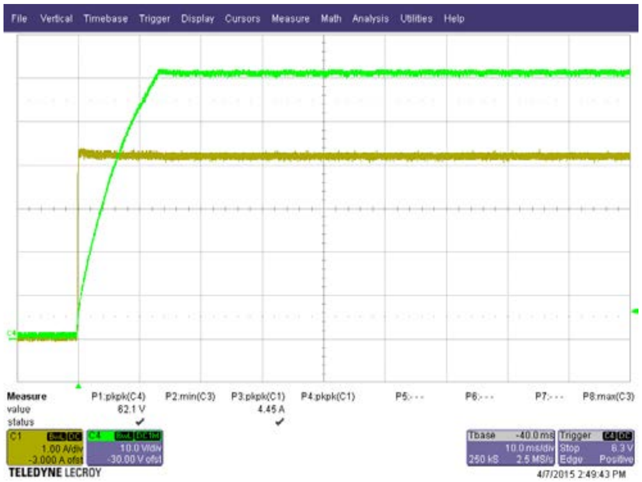

Figure 30 – Main Output Start-up, Constant Voltage Mode, 115 VAC, Chroma CC Load, ~4.2 A Setting.
Upper: Main V_{OUT}, 10 V / div.
Lower: Main I_{OUT}, 1 A, 10 ms / div.

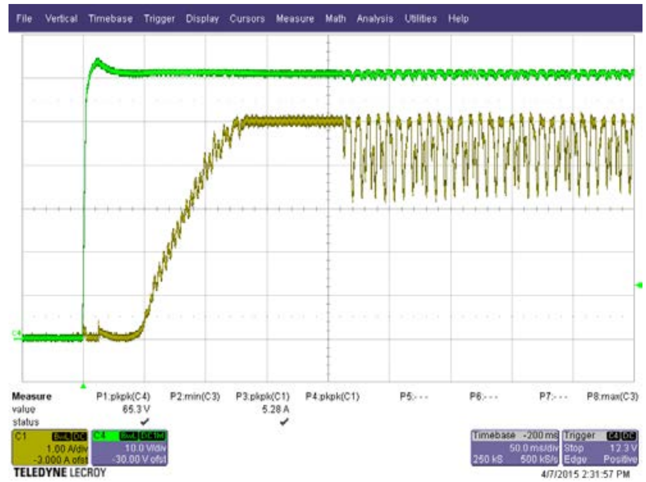

Figure 31 – Main Output Start-up, Constant Current Mode, 115 VAC, Chroma CV Load, 60 V Setting.
Upper: Main V_{OUT}, 10 V / div.
Lower: Main I_{OUT}, 1 A, 50 ms / div.

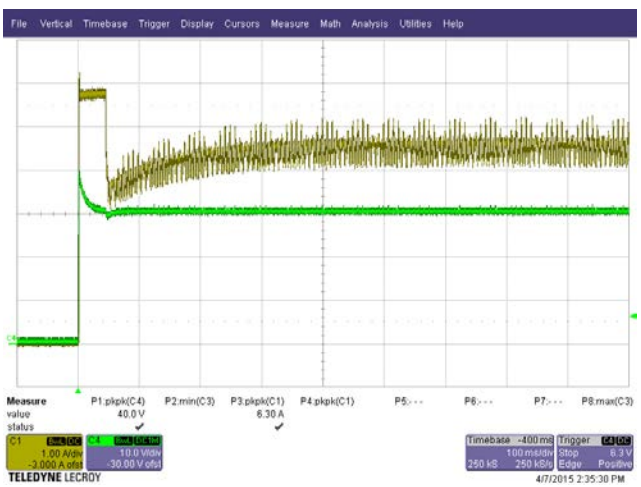

Figure 32 – Main Output Start-up, Constant Current Mode, 115 VAC, Chroma CV Load, 30 V Setting.
Upper: Main I_{OUT}, 1 A / div.
Lower: Main V_{OUT}, 10 V, 100 ms / div.

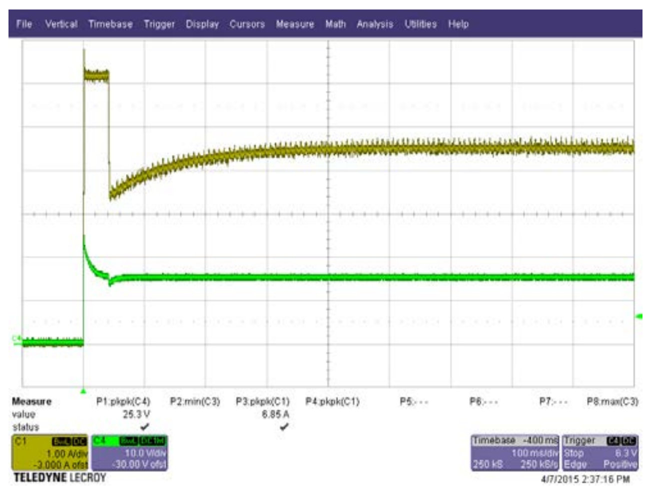

Figure 33 – Main Output Start-up, Constant Current Mode. 115 VAC, Chroma CV Load, 15 V Setting.
Upper: Main I_{OUT}, 1 A / div.
Lower: Main V_{OUT} 10 V, 100 ms / div.

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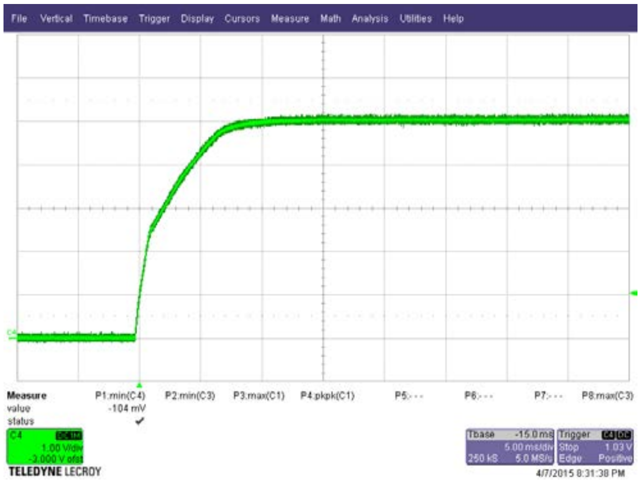

Figure 34 – Standby Start-up, 100% Load, 115 VAC Input, 1 V / 5 ms / div.

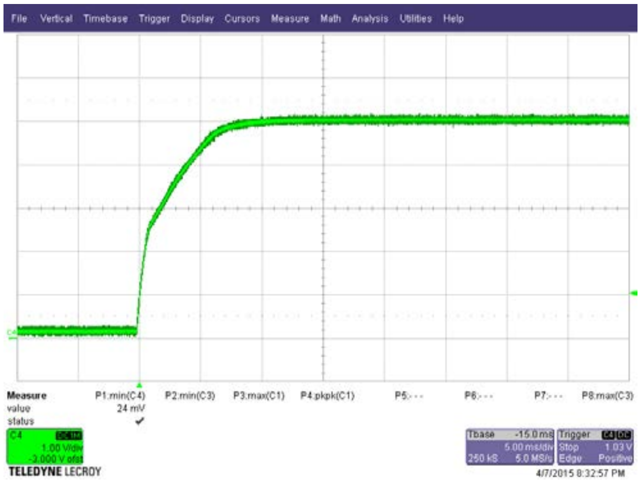

Figure 35 – Standby Start-up, No-Load, 115 VAC Input, 1 V / 5 ms / div.

11.3.2 Main Output Start-Up Using Enable Switch

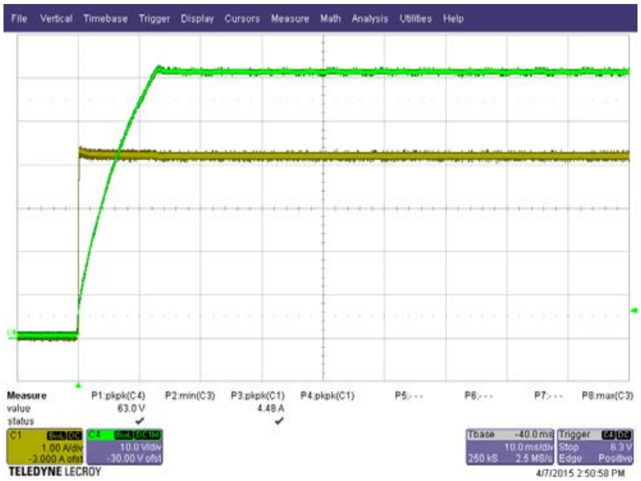

Figure 36 – Main Output Start-up, Constant Voltage Mode, 115 VAC, Chroma CC Load, ~4.2 A Setting.
Upper: Main V_{OUT}, 10 V / div.
Lower: Main I_{OUT}, 1 A, 10 ms / div.

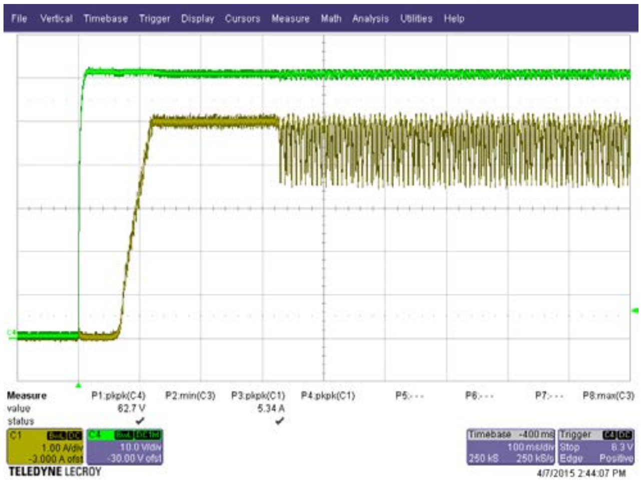

Figure 37 – Main Output Start-up, Constant Current Mode, 115 VAC, Chroma CV Load, 60 V Setting.
Upper: Main V_{OUT}, 10 V / div.
Lower: Main I_{OUT}, 1 A, 100 ms / div.

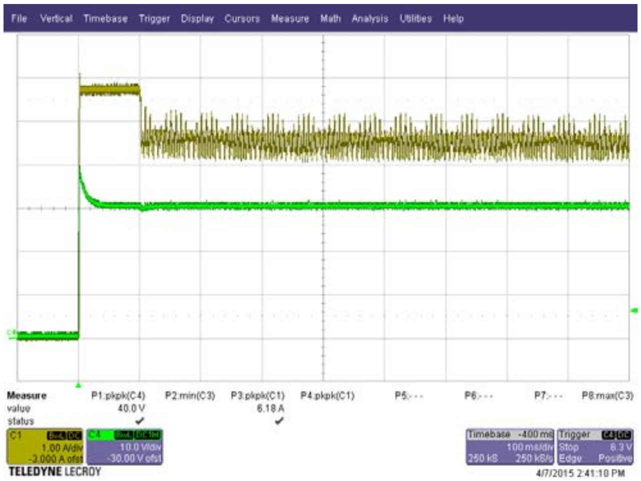

Figure 38 – Main Output Start-up, Constant Current Mode, 115 VAC, Chroma CV Load, 30 V Setting.
Upper: Main I_{OUT}, 1 A / div.
Lower: Main V_{OUT}, 10 V, 100 ms / div.

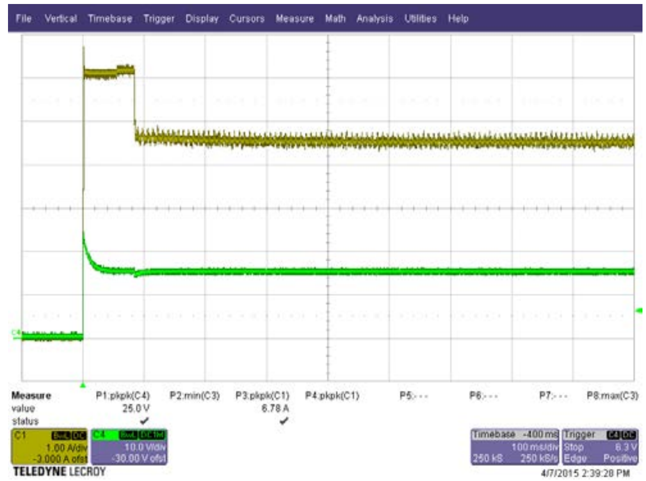

Figure 39 – Main Output Start-up, Constant Current Mode, 115 VAC, Chroma CV Load, 15 V Setting.
Upper: Main I_{OUT}, 1 A / div.
Lower: Main V_{OUT} 10 V, 100 ms / div.

11.4 Load Transient Response, Voltage Mode 50% -75% -50% Load Step

32 cycles of averaging were used on load transient waveforms to filter out ripple and better view actual output voltage excursion due to load transient.

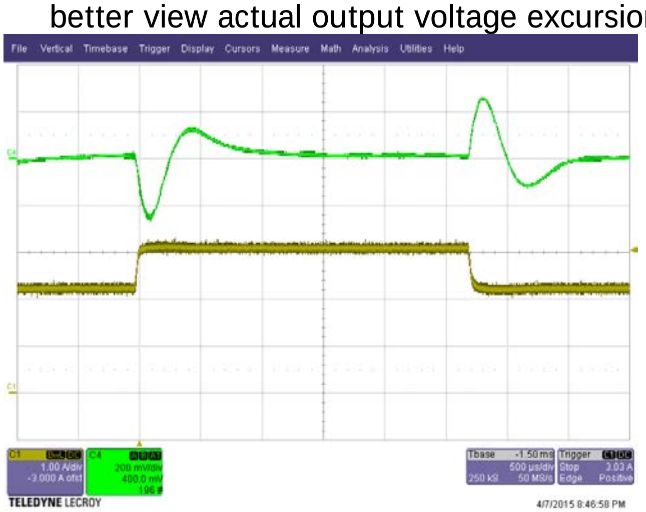

Figure 40 – Main Output Transient Response, CV Mode, 50%-75%-50% Load Step, 115 VAC Input.
Upper: V_{OUT}, 200 mV / div.
Lower: Main Output I_{LOAD}, 1 A, 500 μs / div.

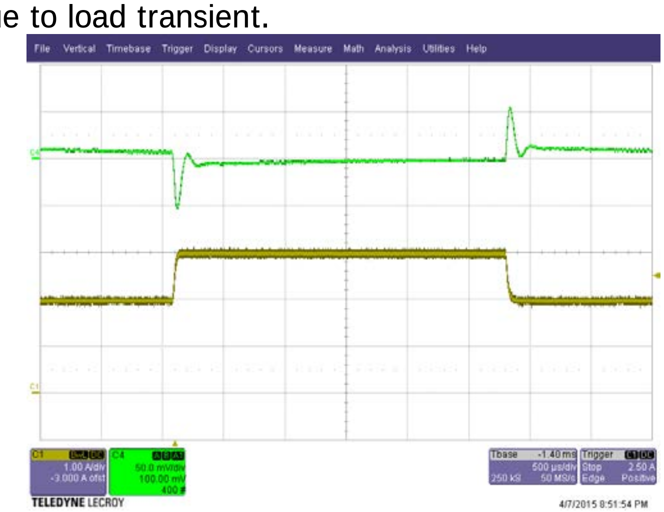

Figure 41 – Standby Output Transient Response, CV Mode, 50%-75%-50% Load Step, 115 VAC Input.
Upper: V_{OUT}, 50 mV / div.
Lower: Main Output I_{LOAD}, 1 A, 500 μs / div.

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11.5 Output Ripple Measurements

11.5.1 Ripple Measurement Technique

For DC output ripple measurements a modified oscilloscope test probe is used to reduce spurious signals. Details of the probe modification are provided in the 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.

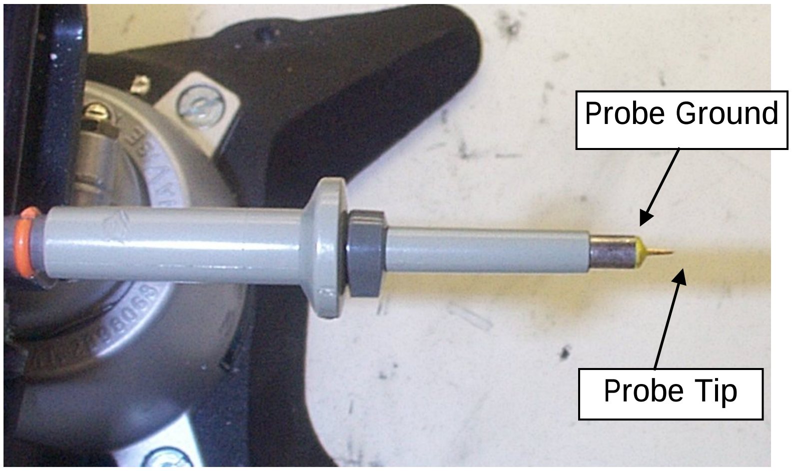

Figure 42 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

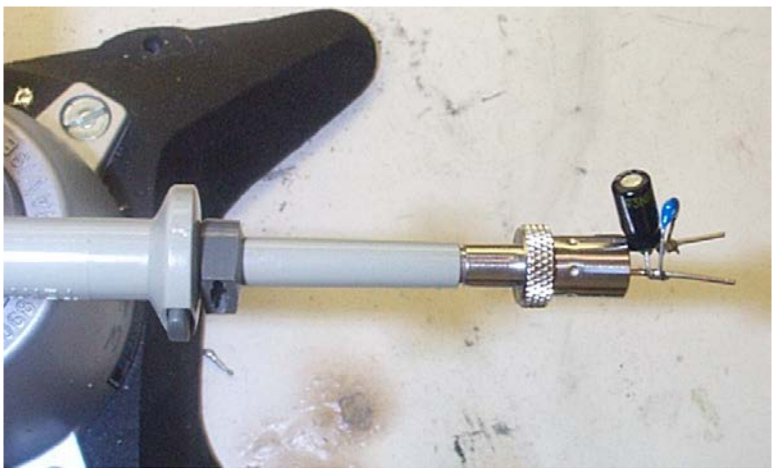

Figure 43 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).

11.5.2 Output Ripple Measurements

Measurements were taken for output ripple voltage with the main supply operating in constant voltage mode with a constant current load, and for both output ripple voltage and current with the main supply operating in CC mode. CC mode measurements were taken using a Chroma electronic load set in CV mode at 60 V, 30 V, and 15 V CV settings. Output ripple voltage/current measurements were made using AC coupled voltage and/or current probes.

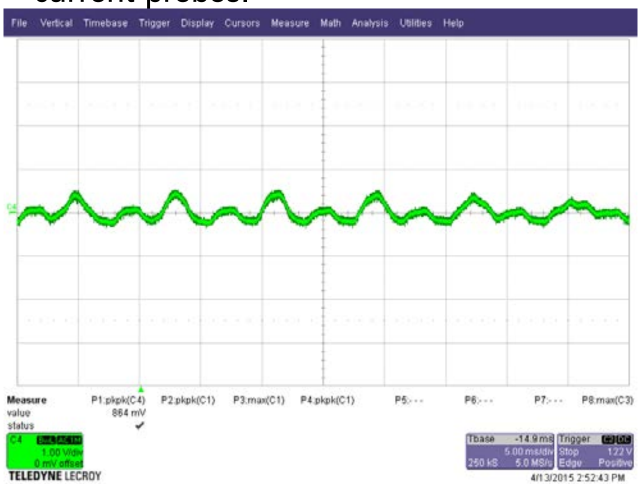

Figure 44 – Main Output Voltage Ripple, 115 VAC, CV Mode, 100% Load Using Chroma CC Load – 1 V, 5 ms / div.

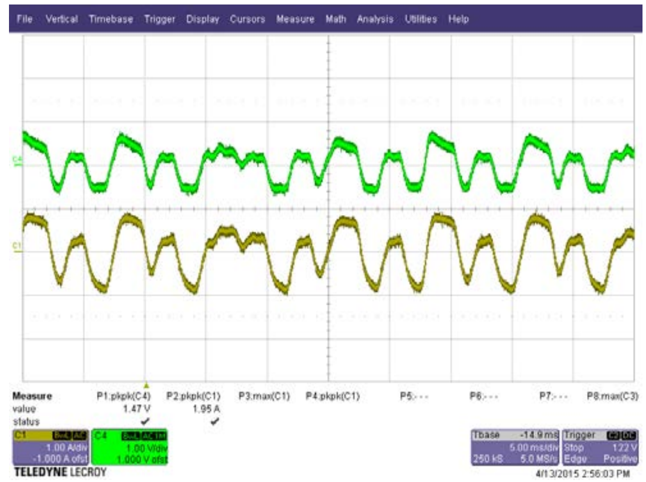

Figure 45 – Output Voltage and Current Ripple in Constant Current Mode, 115 VAC, Chroma CV Load, 60 V Setting.
Upper: Main Output V_{RIPPLE}, 1 V / div.
Lower: I_{OUT} Ripple, 1 A, 5 ms / div.

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Figure 46 – Main Output Voltage and Current Ripple in Constant Current Mode, 115 VAC, Chroma CV Load, 30 V Setting. Upper: Main Output V_{RIPPLE}, 1 V / div. Lower:, I_{OUT} Ripple, 1 A, 5 ms /div.

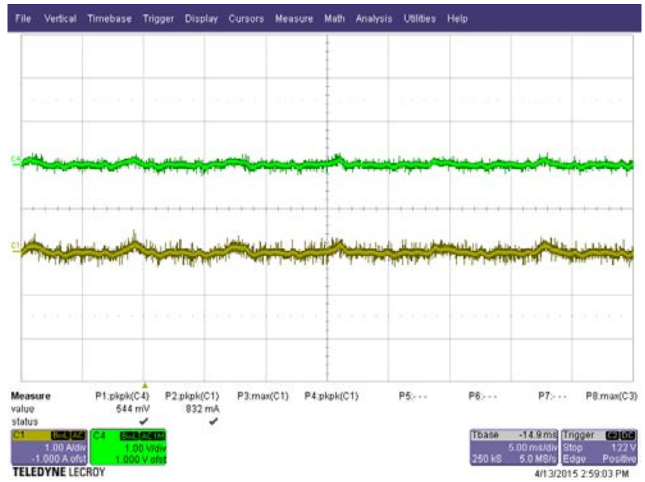

Figure 47 – Main Output Voltage and Current Ripple in Constant Current Mode, 115 VAC, Chroma CV Load, 15 V Setting. Upper: Main Output V_{RIPPLE}, 1 V / div. Lower: I_{OUT} Ripple, 1 A, 5 ms /div.

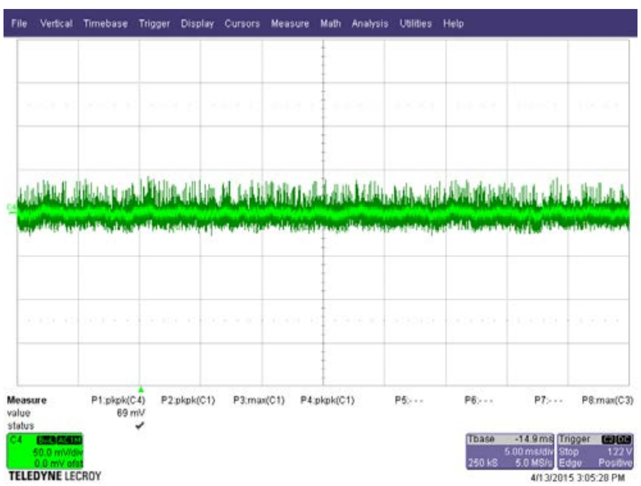

Figure 48 – Standby Output Voltage Ripple, 100% Load, 115 VAC with 100% Load on Main Output – 50 mV, 5 ms / div.

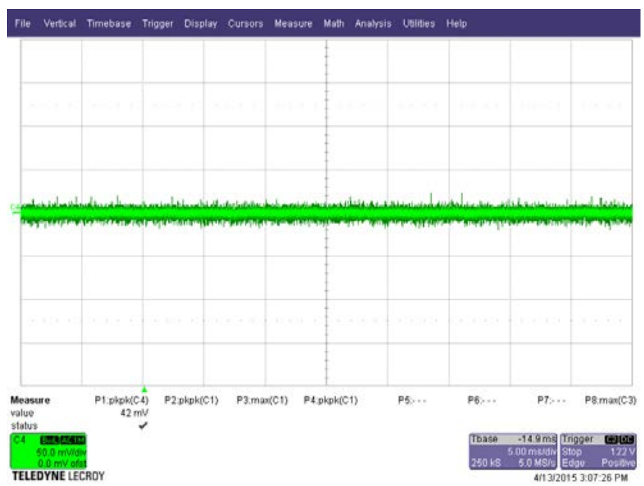

Figure 49 – Standby Output Voltage Ripple, 100% Load, 115 VAC, Main Output Disabled with ON/OFF Switch – 50 mV, 5 ms / div.

12 Temperature Profiles

The board was operated at room temperature, with output set at maximum using a Chroma electronic load with constant resistance for the main output and constant current mode for the standby output. The constant resistance load for the main output allows the main load to be set for maximum power output without having the main output drift into current limit and collapsing the output voltage, as can happen when a constant current load is used. The unit was allowed to thermally stabilize (~1 hr) before measurements were made.

12.1 Spot Temperature Measurements

Position	Temperature (°C)
	115 VAC
T1 (Main)	80.4 Outside / 95.7 (Inner Hot Spot)
T2 (SBY)	62.5
BR1	65
L6 (CM)	49
L8 (CM)	49.4
L3 (Main)	55.7
R47 (Main Sec Snubber)	65.1
U1	92.9
D19 Main (FWD/CTH)	84.4
D18 SBY Rect	75
Ambient	25

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12.1.1 115 VAC, 60 Hz, 100% Load Overall Temperature Profile

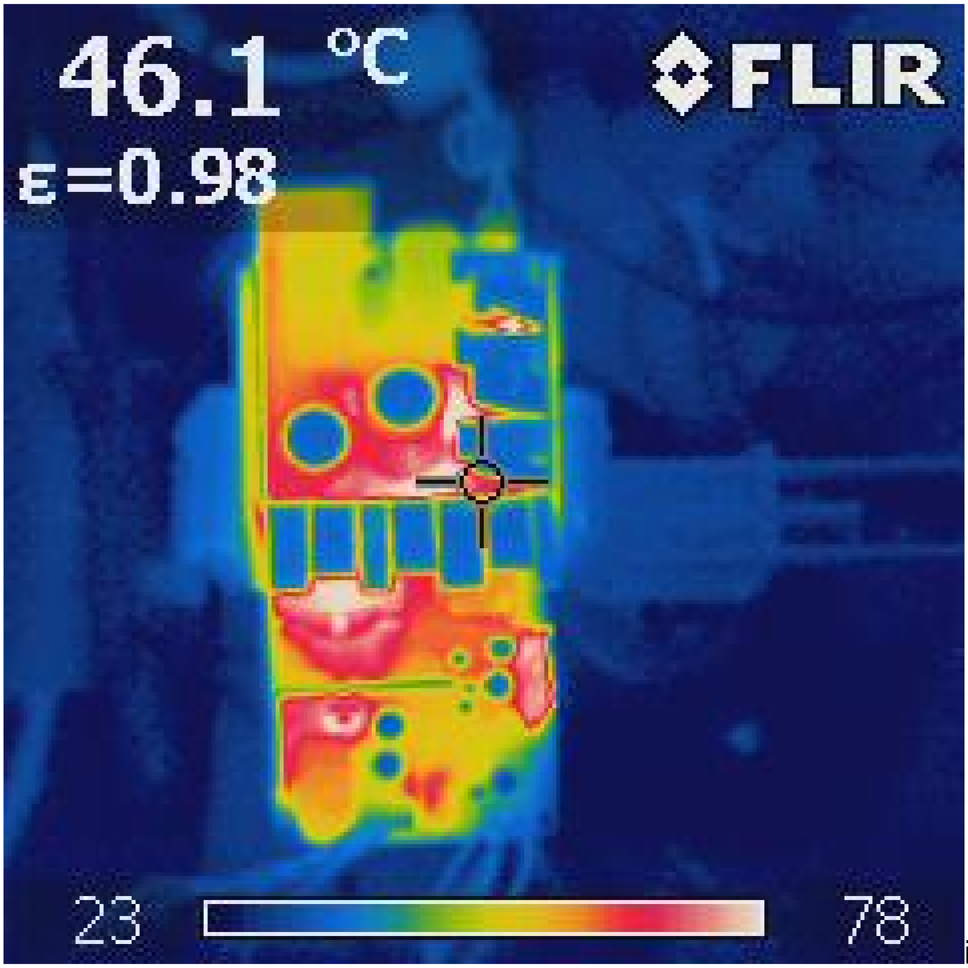

Figure 50 – Top View Thermal Picture, 115 VAC.

13 Gain-Phase

13.1 Main Output Constant Voltage Mode Gain-Phase

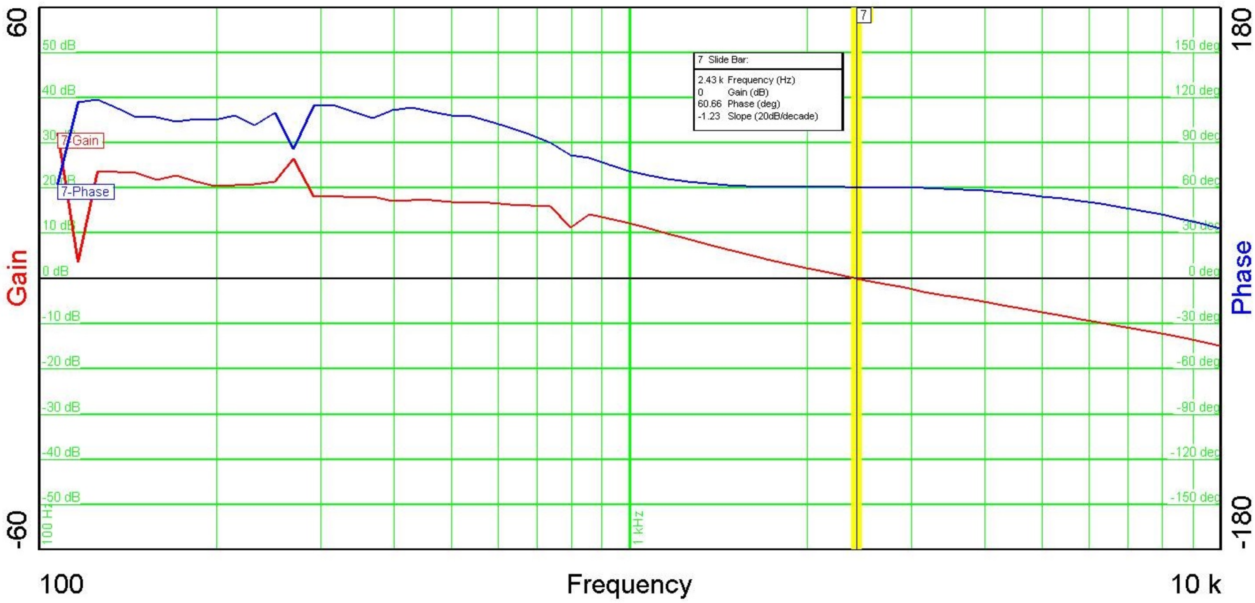

Figure 51 – Main Output Voltage Mode Gain-Phase Plot with Chroma CC Load - Gain Crossover is 2.43 kHz, Phase Margin is 60.7°.

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13.2 Main Output Constant Current Mode Gain-Phase

Gain-phase was tested using a Chroma electronic load set to constant voltage mode at three set points - 60 V, 30 V, and 15 V, obtaining the gain-phase measurements for three widely separated points on the V-I characteristic curve. Using a CV load maximizes the CC loop gain (worst case for control loop) and simulates operating while charging a low impedance load like a battery. Using the constant resistance setting for the electronic load will yield overly optimistic results for gain-phase measurements and for determining component values for frequency compensation.

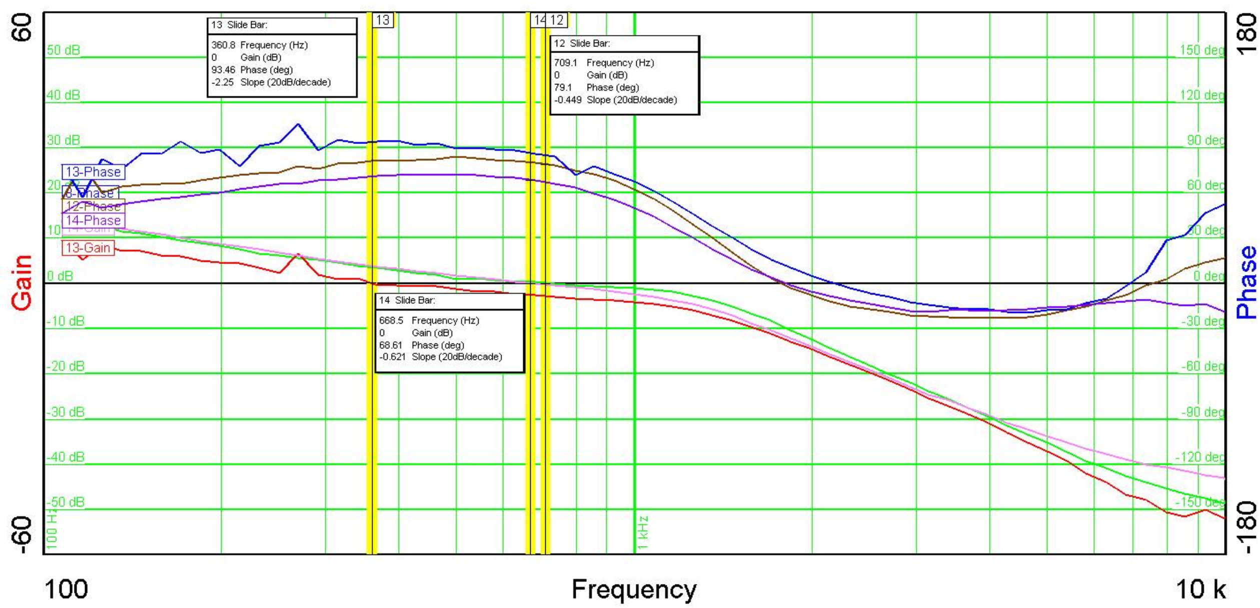

Figure 52 – Main Output Gain-Phase, Constant Current Output, Chroma Constant Voltage Load.
Red/Blue – 60 V Gain and Phase Crossover Frequency – 361 Hz, Phase Margin – 93°.
Brown/Green – 30 V Gain and Phase Crossover Frequency – 709 Hz, Phase Margin – 79°.
Pink/Purple – 15 V Gain and Phase Crossover Frequency – 668 Hz, Phase Margin – 69°.

14 Conducted EMI

Conducted EMI tests were performed using floating resistive loads (13 Ω main, 1.25 ohms standby).

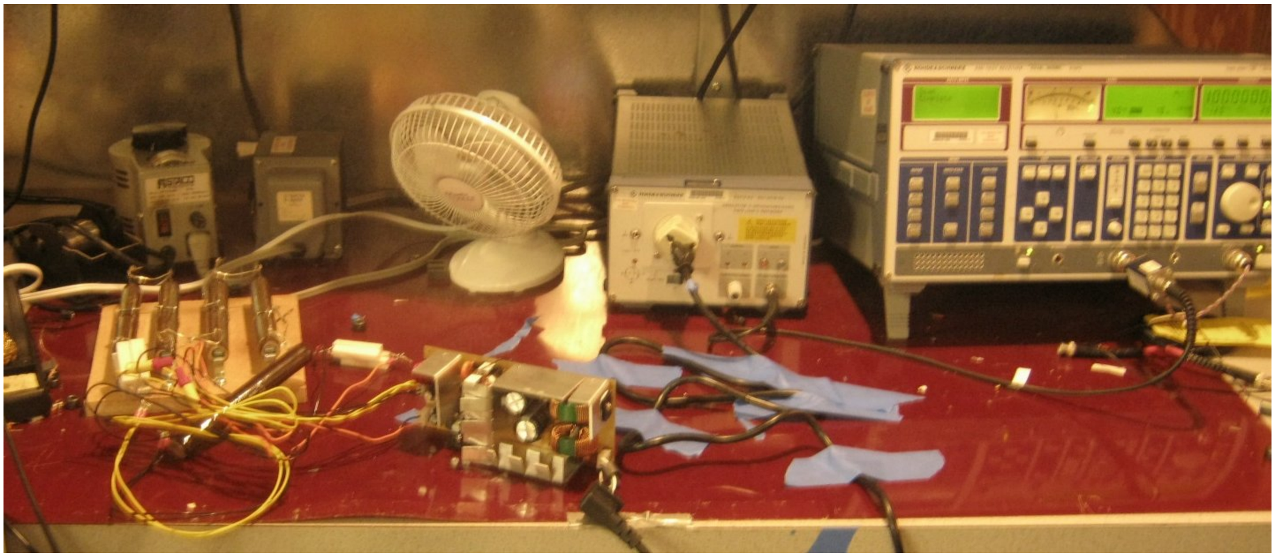

Figure 53 – EMI Set-up with Floating Resistive Load.

A supplemental common mode choke was added to the AC input cable harness of the supply as shown in the figure below. This choke consisted of 4 turns on a Fair-Rite 5943000201 toroidal bead. In practice, this choke would be wound into the AC input cord inside the power supply enclosure

Figure 54 – Supplemental CM Choke (4T on Fair-Rite 5943000201).

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14.1 Conducted EMI Scan

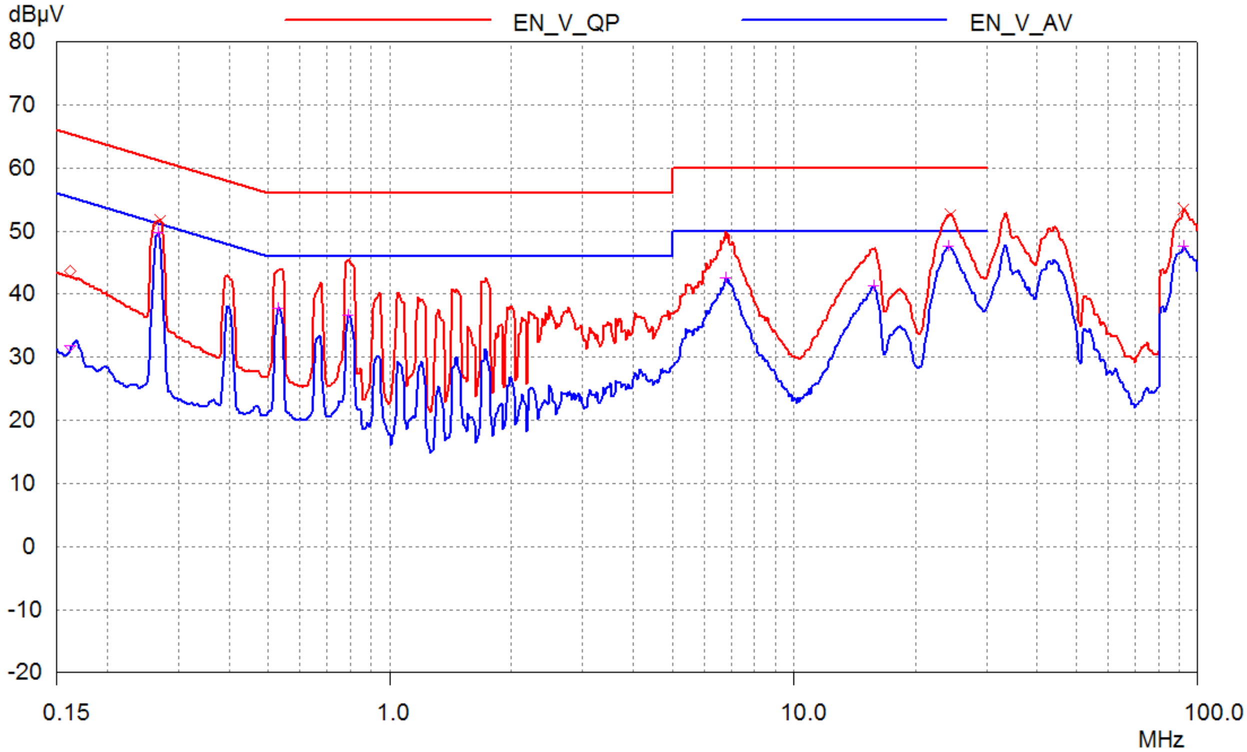

Figure 55 – Conducted EMI, 115 VAC, 13 Ω (Main) and 1.25 Ω (Standby) Floating Resistive Loads.

15 Revision History

Date	Author	Revision	Description & changes	Reviewed
30-Oct-15	RH	1.0	Initial Release.	Apps & Mktg
12-Nov-15	RH	1.1	Updated Circuit Description Text.	
19-Nov-15	RH	1.2	Updated Circuit Description Text.	

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WORLD HEADQUARTERS
5245 Hellyer Avenue
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Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@power.com

GERMANY
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@power.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
e-mail: chinasales@power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@power.com

UK
Cambridge Semiconductor,
a Power Integrations company
Westbrook Centre, Block 5,
2nd Floor
Milton Road
Cambridge CB4 1YG
Phone: +44 (0) 1223-446483
e-mail: eurosales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
Fax: +86-755-8672-8690
e-mail: chinasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI)
Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@power.com