Design Example Report

Title	***106 W High Line Input Non-PFC CV/CC Flyback Charger Supply Using TOPSwitch™-JX TOP267EG***
Specification	165 VAC – 264 VAC Input; 59 V, 1.8 A Main Output
Application	Battery Charger
Author	Applications Engineering Department
Document Number	DER-583
Date	December 20, 2016
Revision	1.1

Summary and Features

- High power flyback design with low component count
- 165 VAC to 264 VAC universal input (no PFC)
- 66 kHz operation for high efficiency
- High full load efficiency (89% at 230 V)
- Wide output range 59 V – 1.5 V

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Important Notes:
The output voltage of this supply is close to the SELV limit, so any final application must employ an output connector that prevents consumer contact with output voltage. The transformer does not meet safety standards for creepage, which also makes it imperative to prevent customer access to output voltage. For transformer design options that meet creepage requirements, please contact Power integrations.

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1 Introduction

This engineering report describes a 59 V (nominal), 106 W flyback reference design for a power supply operating from 165 VAC to 264 VAC. The power supply output is designed with a constant voltage / constant current characteristic for use in battery charger applications. The charging circuit is optimized for a lead-acid battery. At charging currents below ~0.5 A, the output voltage switches from the 59 V charging voltage to a float voltage of 56 V to maintain battery charge without overcharging. This is a standard feature for chargers intended for lead-acid batteries.

The design is based on the TOP267EG with no PFC input stage. It is designed to operate in a fan-cooled enclosure. The design utilizes an air diverter to direct cooling air across the primary heat sink. This minimizes the heat sink size (and device size) required for TOPSwitch U1. The diverter can be seen in the Figure 1 photograph.

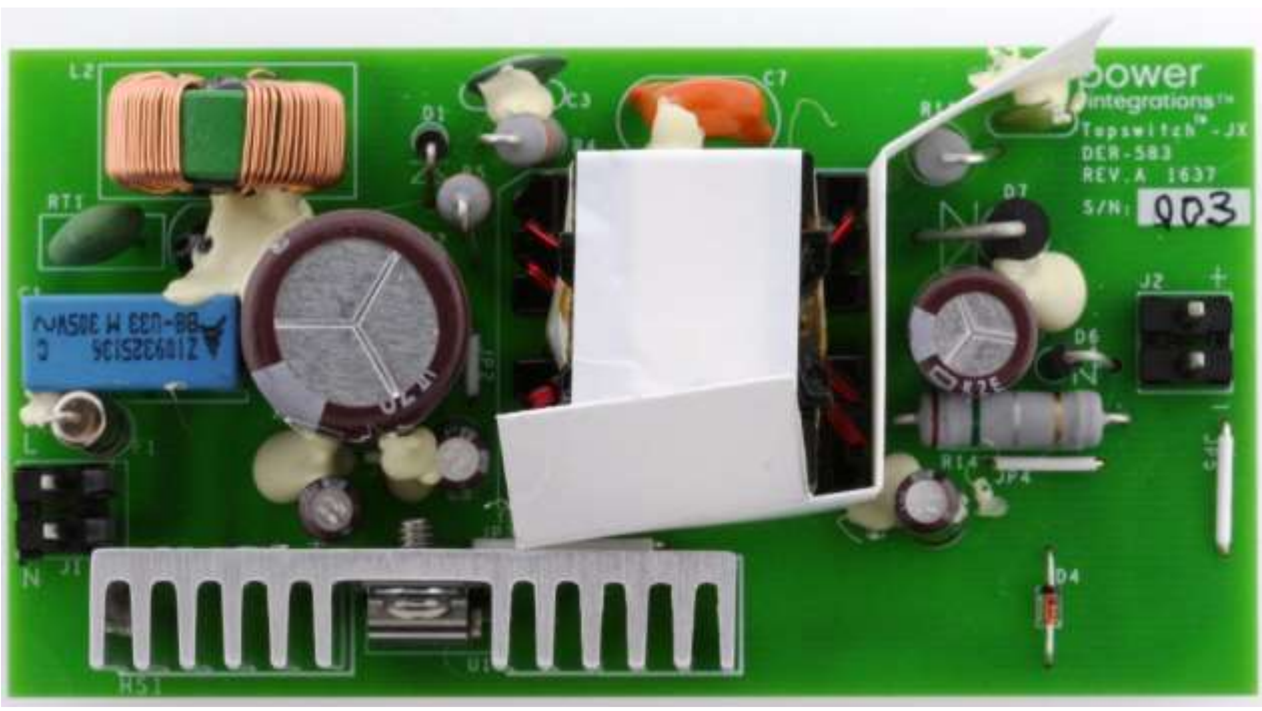

Figure 1 – Photograph, Top View, Showing Air Diverter.

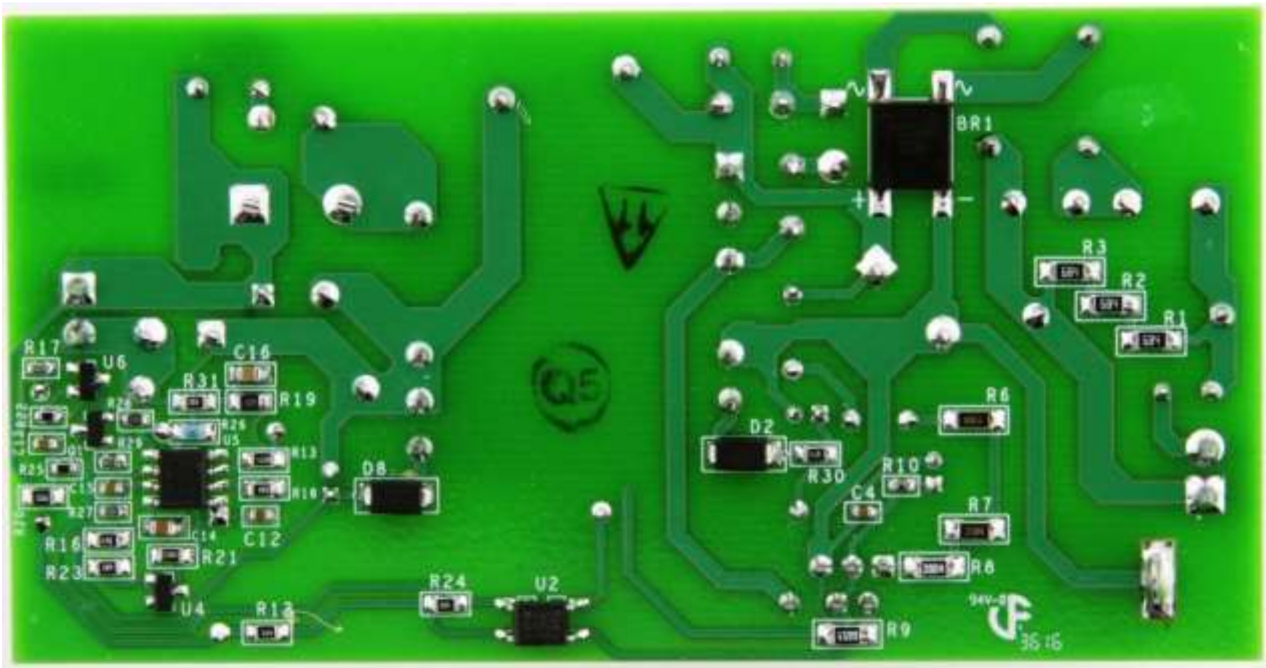

Figure 2 – Photograph, Bottom View.

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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.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	165		264	VAC	2 Wire Input. Must Operate at 150 VAC.
Frequency	f_{LINE}	47	50/60	64	Hz	
Main Converter Output						
Output Voltage	V_{OUT}	4		59	V	59 VDC (Nominal – Otherwise Defined by Battery Load).
Output Current	I_{OUT}		1.8		A	Nominal Current Limit Setting for Design.
Total Output Power						
Continuous Output Power	P_{OUT}		106		W	
Peak Output Power	$P_{OUT(PK)}$			N/A	W	
Efficiency						
Total system at Full Load	η_{Main}		89		%	Measured at 230 VAC, Full Load.
Environmental						
Conducted EMI						
Safety						
Ambient Temperature	T_{AMB}	0	25	65	°C	Fan Cooling, No Shutdown at 165 VAC, 65 ºC Ambient, Max Load.

3 Schematic

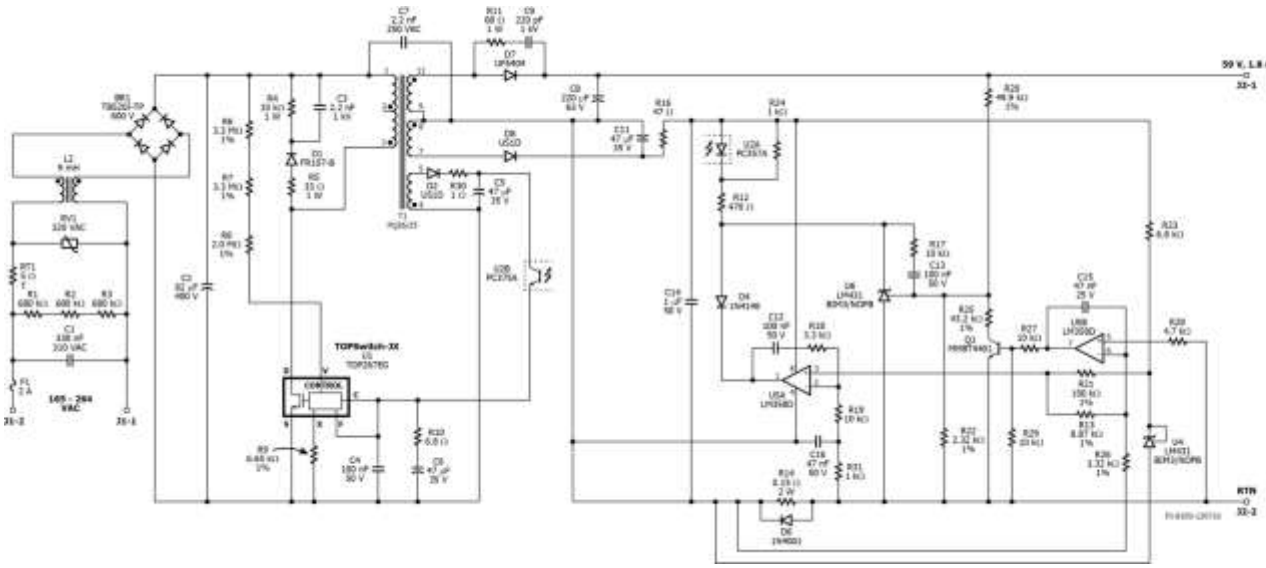

Figure 3 – Schematic - Flyback Battery Charger Application Circuit - Input Filter, DC/DC Stage, Output Voltage / Current Control.

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4 Circuit Description

4.1 General Topology

The schematic in Figure 3 shows a 59 V, 106 W high line input flyback power supply utilizing the TOP267EG. The secondary control circuitry provides CV/CC control for use in battery charger applications. The supply is designed to operate in a fan-cooled enclosure.

4.2 EMI Filtering / Rectification

Capacitor C1 is used to control differential mode noise. Resistors R1-3 discharge C1 when AC power is removed. Inductor L2 primarily controls 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. Capacitor C7 filters common mode EMI. Capacitor C2 and BR1 provide a ~231-370 VDC B+ supply from the 165 VAC to 264 VAC input. The supply is designed to operate under brownout conditions as low as 150 V after starting up at 165 V.

4.3 Main Flyback Converter

The schematic in Figure 3 depicts a 59 V, 106 W flyback DC-DC converter with constant voltage/ constant current output implemented using the TOP267EG. For greater detail on TOPSwitch-JX operation, consult the data sheet at www.power.com .

Integrated circuit U1 incorporates the control circuitry, drivers and output power MOSFETs necessary for a flyback converter.

Components D1, C3, and R4-5 form a turn-off clamping circuit that limits the peak drain voltage of U1.

Resistors R6-8 set the start-up voltage for U1 at _ VDC. Resistor R9 scales the U1 current limit to 100% of rated value. The F pin of U1 is connected to the control pin to set the nominal operating frequency to 66 kHz.

Primary bias is provided from a winding on T1 rectified and filtered by D2, R30, and C5. The winding is phased for “forward mode” so that the primary bias voltage does not collapse when the supply is operating in constant current mode with reduced output voltage.

Components C4, C6, and R10 act as bypass, start-up energy storage, and compensation for U1.

4.4 Output Rectification

The output of transformer T1 is rectified and filtered by D7 and C8. Output rectifier D7 is a 400 V ultrafast rectifier. A snubber consisting of R11 and C9 helps limit the peak voltage excursion on the output rectifier. A forward biased winding referred to secondary return is used to power the secondary CVCC circuitry. This winding is rectified and filtered by D8 and C11.

4.5 Output Current and Voltage Control

Output current is sensed via resistor R14. This resistor is clamped by diode D6 to avoid damage to the current control circuitry during an output short-circuit. Components R23 and U4 provide a voltage reference for current sense amplifiers U5A and U5B. The reference voltage for current sense amplifier U5A is divided down by R13 and R21. The nominal current limit setting is 1.8 A, as programmed by R13, R21, and R26. The inverting input of U5A is referenced to ground via R19 and R31. Opamp U5A drives optocoupler U2 through D4 and R12. Components R12, R18-19, R31, C12, and C16 are used for frequency compensation of the current loop.

Programmable shunt regulator U6 is used for output constant voltage control when the current limit is not engaged. Resistors R20, R22, and R25 sense the output voltage. Regulator U6 drives optocoupler U2 via R12. Components R12, R17 and C13 affect the frequency compensation of the voltage control loop.

Opamp U5B is used to sense the output current via R14 and R13, R21, and R26. When the output current falls below 0.5 A, opamp U5B is used as a comparator to switch off transistor Q1 via resistor R27 and R29, isolating R25 and causing the output voltage to fall to a “float” voltage of 56 V. Capacitor C15 prevents U5B from oscillating during switching transitions.

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5 PCB Layout

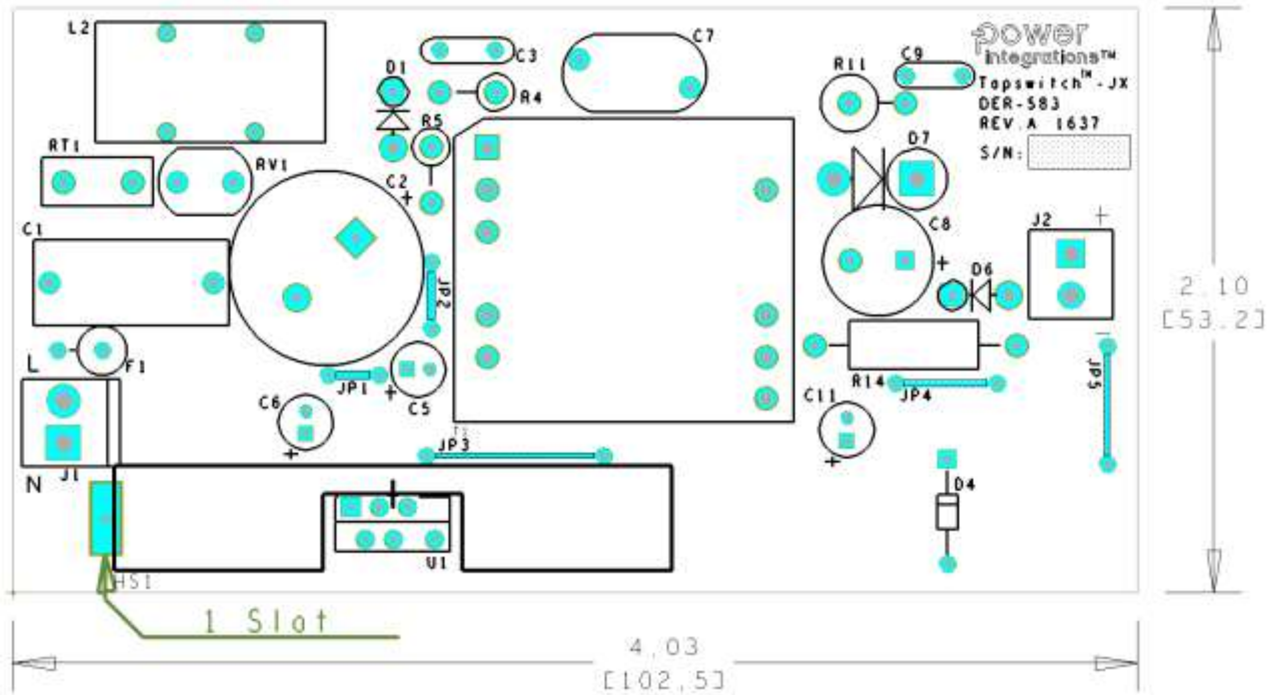

Figure 4 – Printed Circuit Layout, Showing Top Side Components.

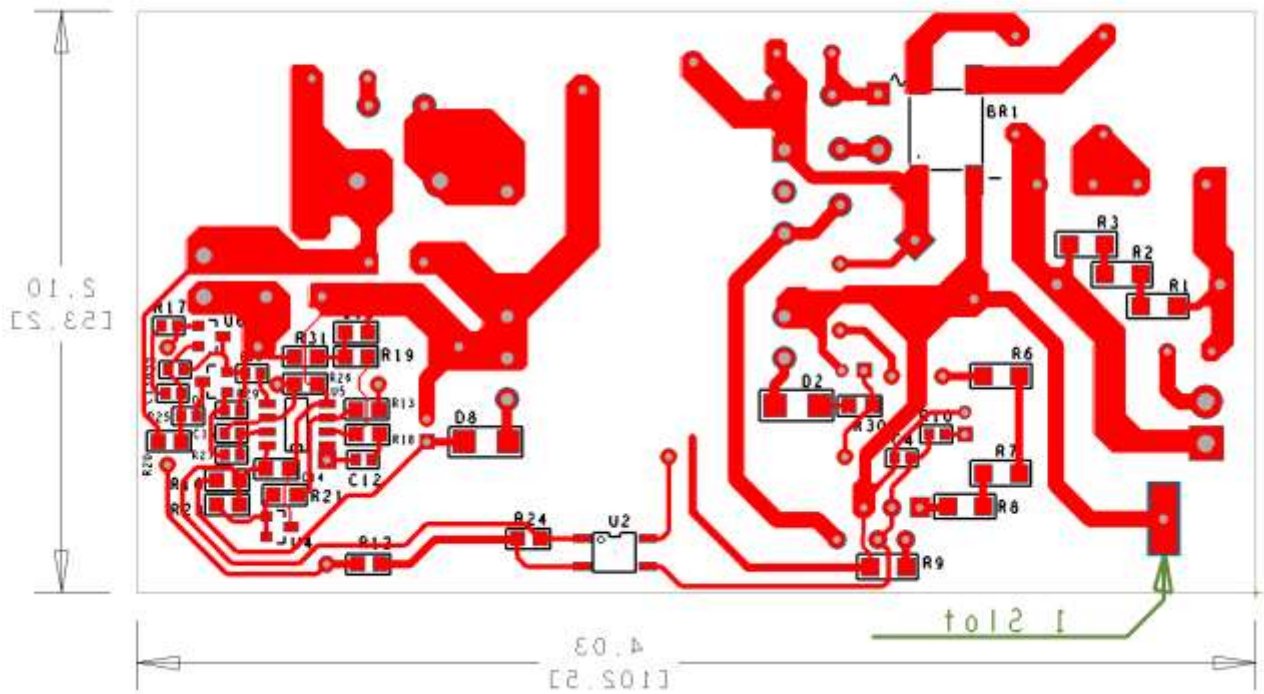

Figure 5 – Printed Circuit Layout, Bottom Side Traces and Components.

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6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	ADF1	AirDeflector,DER-583		Custom
2	1	BR1	BRIDGE RECT, 2 A 600 V, TBS-1,	TBS20J-TP	Micro Commercial
3	1	C1	330 nF, 310 VAC, Film, X2	B32922C3334M	Epcos
4	1	C2	82 μF, 400 V, Electrolytic, (18 x 25)	EKXG401ELL820MM25S	United Chemi-Con
5	1	C3	2.2 nF, 1 kV, Disc Ceramic	NCD222K1KVY5FF	NIC
6	3	C4 C12 C13	100 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H104K	TDK
7	3	C5 C6 C11	47 F, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG350ELL470ME11D	Nippon Chemi-Con
8	1	C7	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
9	1	C8	220 F, 63 V, Electrolytic, Gen. Purpose, (10 x 25)	EKZE630ELL221MJ25S	United Chemi-con
10	1	C9	220 pF, 1 kV, Disc Ceramic	NCD221K1KVY5FF	NIC
11	1	C14	1 F,50 V, Ceramic, X7R, 0805	C2012X7R1H105M	TDK
12	1	C15	47 nF 25 V, Ceramic, X7R, 0603	CC0603KRX7R8BB473	Yago
13	1	C16	47 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H473KA01L	Murata
14	1	D1	1000 V, 1 A, Fast Recovery Diode, DO-41	FR107-B	Rectron
15	2	D2 D8	Diode Ultrafast, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
16	1	D4	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
17	1	D6	DIODE, GEN PURP, 50 V, 1 A, DO204AL	1N4001-E3/54	Vishay
18	1	D7	400 V, 3 A, Ultrafast Recovery, 75 ns, DO-201AD	UF5404-E3	Vishay
19	1	ESIPCLIP M4 METAL1	Heat sink Hardware, Edge Clip, 20.76 mm L x 8 mm W x 0.015 mm Thk	NP975864	Aavid Thermalloy
20	1	F1	FUSE, GLASS, 2 A,SloBlo, 250 VAC, 125 VDC, 2AG	0230002.HXP	Littlefuse
21	1	HOTMELT	Adhesive, Hot Melt, VO	3748 VO-TC	3M
22	1	HS1	MACH, Heat sink, DER569		Custom
23	1	J1	Header, 2 Position (1 x 2), 0.156 pitch, Vertical, friction lock	0026481025	Molex
24	1	J2	2 Position (1 x 2) header, 0.156 pitch, Vertical	26-48-1021	Molex
25	1	JP1	Wire Jumper, Insulated, TFE, #22 AWG, 0.2 in	C2004-12-02	Alpha
26	1	JP2	Wire Jumper, Insulated, TFE, #22 AWG, 0.3 in	C2004-12-02	Alpha
27	1	JP3	Wire Jumper, Insulated, TFE, #22 AWG, 0.7 in	C2004-12-02	Alpha
28	1	JP4	Wire Jumper, Insulated, TFE, #22 AWG, 0.4 in	C2004-12-02	Alpha
29	1	JP5	Wire Jumper, Insulated, TFE, #22 AWG, 0.5 in	C2004-12-02	Alpha
30	1	L2	9 mH, 2 A, Common Mode Choke	T18107V-902S P.I. Custom	Fontaine Tech
31	1	Q1	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401LT1G	Diodes, Inc.
32	3	R1 R2 R3	RES, 680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
33	1	R4	RES, 33 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-33K	Yageo
34	1	R5	RES, 33 Ω, 5%, 1 W, Metal Oxide	RSF100JB-33R	Yageo
35	2	R6 R7	RES, 3.30 MΩ, 1%, 1/4 W, Thick Film, 1206	KTR18EZPF3304	Rohm
36	1	R8	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
37	1	R9	RES, 6.65 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF6651V	Panasonic
38	1	R10	RES, 6.8 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ6R8V	Panasonic
39	1	R11	RES, 68 Ω, 5%, 1 W, Metal Oxide	RSF100JB-68R	Yageo
40	1	R12	RES, 470 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ471V	Panasonic
41	1	R13	RES, 8.87 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF8871V	Panasonic
42	1	R14	RES, 0.15 Ω, 5%, 2 W, Metal Oxide	MO200J0R15B	Synton-Tech
43	1	R16	RES, 47 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ470V	Panasonic
44	3	R17 R27 R29	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
45	1	R18	RES, 3.3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ332V	Panasonic
46	1	R19	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
47	1	R20	RES, 49.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4992V	Panasonic

48	1	R21	RES, 100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
49	1	R22	RES, 2.32 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2321V	Panasonic
50	1	R23	RES, 6.8 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ682V	Panasonic
51	2	R24 R31	RES, 1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
52	1	R25	RES, 43.2 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4322V	Panasonic
53	1	R26	RES, 3.32 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3321V	Panasonic
54	1	R28	RES, 4.7 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
55	1	R30	RES, 1 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ1R0V	Panasonic
56	1	RT1	TKS Thermistor, 5 Ω, 3 A	SCK08053MSY	Thinking Elect.
57	1	RTV1	Thermally conductive Silicone Grease	120-SA	Wakefield
58	1	RV1	320 VAC, 32 J, 7 mm, RADIAL	ERZ-V07D511	Panasonic
59	1	SCREW1	SCREW MACHINE PHIL 4-40 X 1/4 SS	PMSSS 440 0025 PH	Building Fasteners
60	1	T1	Custom Transformer wound on Bobbin, PQ26/25, Vertical, 12 pins		
61	1	U1	TOPSwitch-JX, eSIP-7F	TOP267EG	Power Integrations
62	1	U2	Optoisolator, Transistor Output, 3750 Vrms, 1 Channel, 4-Mini-Flat	PC357N1J000F	Sharp
63	2	U4 U6	IC, REG ZENER SHUNT ADJ SOT-23	LM431BIM3/NOPB	National Semi
64	1	U5	DUAL Op Amp, Single Supply, SOIC-8	LM358D	TI
65	1	WASHER1	WASHER FLAT #4 SS	FWSS 004	Building Fasteners

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7 Magnetics

7.1 Transformer (T1) Specification

7.1.1 Electrical Diagram

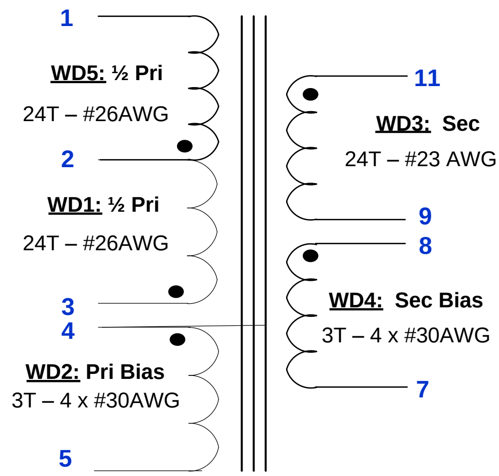

Figure 6 – Transformer Schematic.

7.1.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-6 to 7-12.	3000 VAC
Primary Inductance	Pins 1-3 all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	652 μH ± 10%
Resonant Frequency	Pins 1-3, all other windings open.	1.5 MHz (Min.)
Primary Leakage Inductance	Pins 1-3, with pins 7-12 shorted, measured at 100 kHz, 0.4 V_{RMS}.	8 μH (Max.)

7.1.3 Material List

Item	Description
[1]	Core Pair PQ26/25: TDK PC44 or equivalent. Gap for A_L of 283 nH/T^2.
[2]	Bobbin: PQ26/25 Vertical, 12 Pins, PI Part # 25-00055-00.
[3]	Wire, Magnet Solderable Double Coated, #26 AWG.
[4]	Wire, Magnet Solderable Double Coated, #23 AWG.
[5]	Wire, Magnet, Solderable Double Coated, #30 AWG.
[6]	Tape: Polyester Film, 3M 1350F-1 or Equivalent, 13.5 mm Wide.
[7]	Tape: Polyester Film, 3M 1350F-1 or Equivalent, 10.0 mm Wide.
[8]	Tape: Polyester Web, 3M 44 or Equivalent, 1.5 mm Wide.
[9]	Tape: Copper Foil, 3M 1194 or Equivalent, 8 mm Wide.
[10]	Varnish: Dolph BC-359, or Equivalent.

7.1.4 Build Diagram

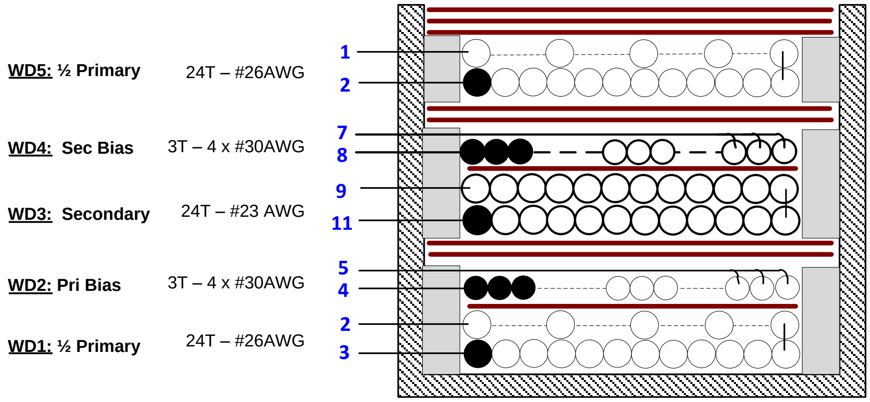

Figure 7 – Transformer Build Diagram.

7.1.5 Winding Instructions

General Note	For the purpose of these instructions, bobbin is oriented on winder such that pins are on the left side (see illustration). Winding direction as shown is clockwise.
Margin	Apply 1.5 mm margin on both sides of bobbin using item [8] match height of first primary and bias winding.
WD1: ½ Primary	Starting on pin 3, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 2.
Insulation	Apply 1 layer of tape item [7].
WD2: Bias	Starting at pin 4, wind 3 quad-filar turns of wire [5] spaced evenly across bobbin window. Finish on pin 5.
Insulation	Apply 2 layers of tape item [6].
Margin	Apply1.5 mm margin on both sides of bobbin using item [8] match height of secondary and bias winding.
WD3: Secondary	Starting at pin 11, wind 24 turns of wire item [4] in two layers, finishing at pin 9.
Insulation	Apply 1 layer of tape item [7].
WD4: Secondary Bias	Starting at pin 8, wind 3 quad-filar turns of wire [5] spaced evenly across bobbin window. Finish on pin 7.
Insulation	Apply 2 layers of tape item [6].
Margin	Apply 1.5 mm margin on both sides of bobbin using item [8] match height of first primary
WD5: ½ Primary	Starting on pin 2, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 1.
Finish Wrap	Apply 3 layers of tape item [6].
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 [5] to copper band and terminate to pin 4.
Assembly (2)	Apply 1 layer of tape item [7] around transformer as shown to insulate flux band. Remove pins 6 and 10, cut pin 2 short. Dip varnish [9].

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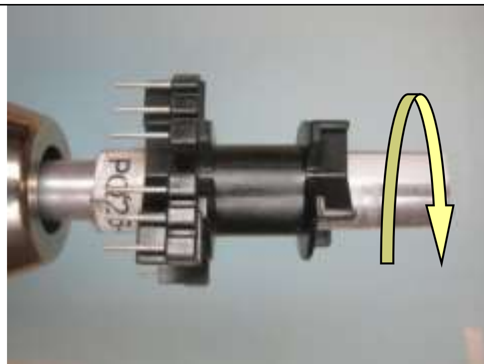
7.1.6 Winding Illustrations

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pins are on the left side (see illustration). Winding direction as shown is clockwise.
Margin		Apply 1.5 mm margin on both sides of bobbin using item [8] match height of first primary and bias winding.
WD1: ½ Primary	 	Starting on pin 3, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 2.

		
Insulation		Apply 1 layer of tape item [7].
WD2: Bias	 	Starting at pin 4, wind 3 quad -filar turns of wire [5] spaced evenly across bobbin window. Finish on pin 5.

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	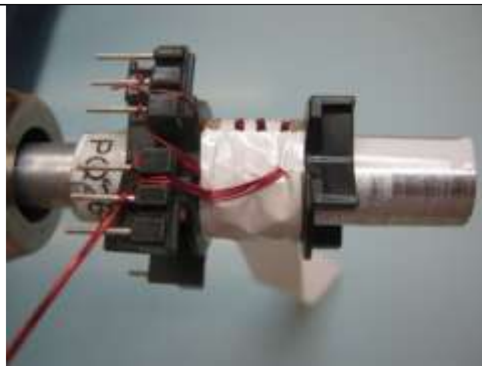	
Insulation		Apply 2 layers of tape item [6].
WD3: Secondary	 	Starting at pin 8, wind 3 quad-filar turns of wire [5] spaced evenly across bobbin window. Finish on pin 7.

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Insulation		Apply 1 layer of tape item [7].
WD4: Secondary Bias	 	Starting at pin 8, wind 3 quad-filar turns of wire [5] spaced evenly across bobbin window. Finish on pin 7.

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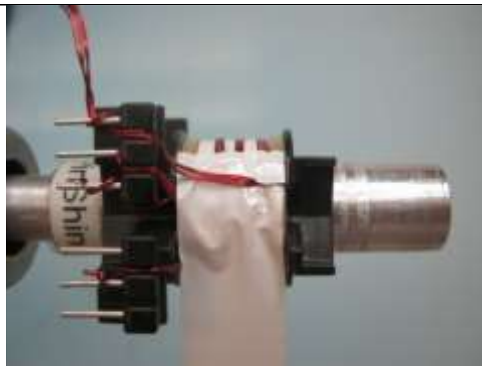
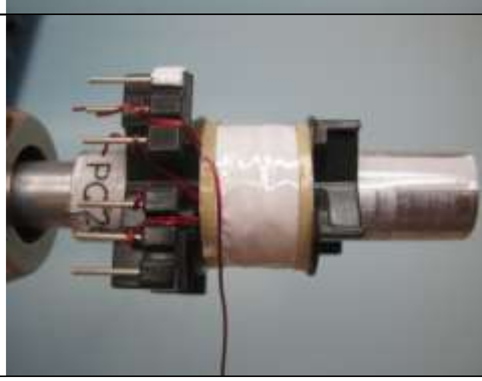
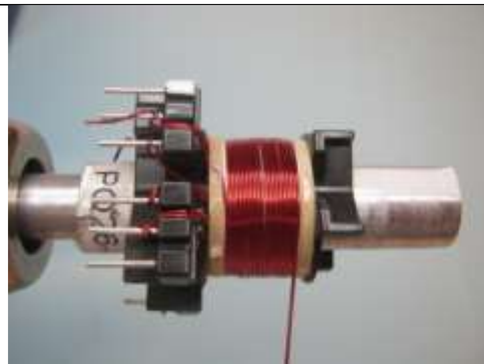
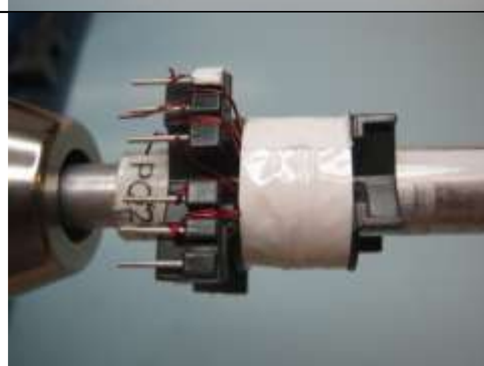
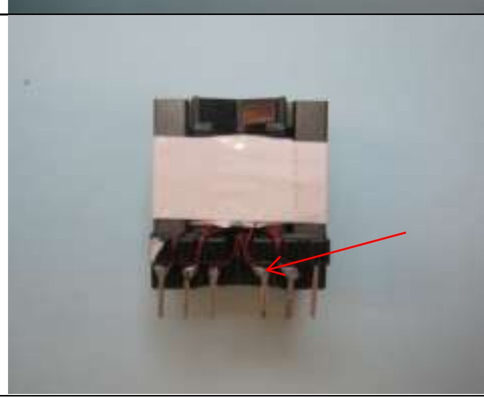
		
Insulation		Apply 2 layers of tape item [6].
		
WD5: ½ Primary		Starting on pin 2, wind 20 turns of wire item [3] in 1 layer, wind remaining four turns evenly back across bobbin, finish on pin 1.

	 	
Finish Wrap		Apply 3 layers of tape item [6].
Assembly (1)		Assemble gapped and un gapped 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 [5] to copper band and terminate to pin 4.

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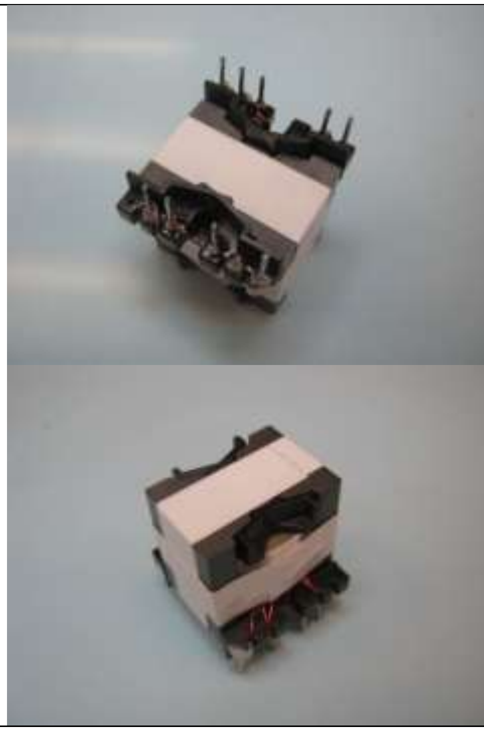
Assembly (2)		Apply 1 layer of tape item [7] around transformer as shown to insulate flux band. Remove pins 6 and 10, cut pin 2 short. Dip varnish [9].

8 Transformer Design Spreadsheet

ACDC_TOPSwitchJX_ 032514; Rev.1.6; Copyright Power Integrations 2014	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**TOP_JX_032514: TOPSwitch-JX Continuous/Discontinuous Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
VACMIN	150			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	59.00			Volts	Output Voltage (main)
PO_AVG	106.00	Warning		Watts	!!! For low line (VMIN < 200 VDC) designs: Reduce PO_AVG<103 W (or use larger device)
PO_PEAK		**Warning**	106.00	Watts	!!! Peak Output Power is too great! PO_PEAK<103 W (Or choose a larger device)
Heatsink Type	**External**		External		Heatsink Type
Enclosure	**Open Frame**				Open Frame enclosure assumes sufficient airflow, while Adapter means a sealed enclosure.
n	0.87			%/100	Efficiency Estimate
Z	0.50				Loss allocation factor
VB	12			Volts	Bias Voltage - Verify that VB is > 8 V at no load and VMAX
tC	3.00			ms	Bridge Rectifier Conduction Time Estimate
CIN	82.0		82.0	uFarads	Input Filter Capacitor
ENTER TOPSWITCH-JX VARIABLES					
TOPSwitch-JX	**TOP267E**			Universal / Peak	115 Doubled/230V
Chosen Device		TOP267E	Power Out	103 W / 103 W	137W
KI	1.00				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN_EXT			2.800	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX_EXT			3.311	Amps	Use 1% resistor in setting external ILIMIT. Includes tolerance over temperature. See Fig 37 of datasheet
Frequency (F)=132kHz, (H)=66kHz	**H**		H		Select 'H' for Half frequency - 66kHz, or 'F' for Full frequency - 132kHz
fS			66000	Hertz	TOPSwitch-JX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			59400	Hertz	TOPSwitch-JX Minimum Switching Frequency
fSmax			72600	Hertz	TOPSwitch-JX Maximum Switching Frequency
High Line Operating Mode			FF		Full Frequency, Jitter enabled
VOR	120.00			Volts	Reflected Output Voltage
VDS			10.00	Volts	TOPSwitch on-state Drain to Source Voltage
VD	0.50			Volts	Output Winding Diode Forward Voltage Drop
VDB	0.70			Volts	Bias Winding Diode Forward Voltage Drop
KP	0.64				Ripple to Peak Current Ratio (0.3 < KRP < 1.0 : 1.0< KDP<6.0)
PROTECTION FEATURES					
LINE SENSING					V pin functionality
VUV_STARTUP			167.56	Volts	Minimum DC Bus Voltage at which the power supply will start-up
VOV_SHUTDOWN			804	Volts	Typical DC Bus Voltage at which power supply will shut-down (Max)
RLS			7.2	M-ohms	Use two standard, 3.6 M-Ohm, 5% resistors in series for line sense functionality.

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OUTPUT OVERVOLTAGE					
VZ			22	Volts	Zener Diode rated voltage for Output Overvoltage shutdown protection
RZ			5.1	k-ohms	Output OVP resistor. For latching shutdown use 20 ohm resistor instead
OVERLOAD POWER LIMITING					X pin functionality
Overload Current Ratio at VMAX			1.20		Enter the desired margin to current limit at VMAX. A value of 1.2 indicates that the current limit should be 20% higher than peak primary current at VMAX
Overload Current Ratio at VMIN			1.06		Margin to current limit at low line.
ILIMIT_EXT_VMIN			2.55	A	Peak primary Current at VMIN
ILIMIT_EXT_VMAX			2.51	A	Peak Primary Current at VMAX
RIL			6.65	k-ohms	Current limit/Power Limiting resistor.
RPL			N/A	M-ohms	Resistor not required. Use RIL resistor only
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**Custom**		PQ26/25		Core Type
Custom Core (Optional)	**PQ26/25**				If Custom core is used - Enter Part number here
Bobbin		#N/A		P/N:	#N/A
AE	1.2000		1.2000	cm^2	Core Effective Cross Sectional Area
LE	5.4300		5.4300	cm	Core Effective Path Length
AL	6000.0		6000.0	nH/T^2	Ungapped Core Effective Inductance
BW	13.5		13.5	mm	Bobbin Physical Winding Width
M	1.00			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2.00				Number of Primary Layers
NS	24		24		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			156	Volts	Minimum DC Input Voltage
VMAX			375	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.45		Maximum Duty Cycle (calculated at PO_PEAK)
IAVG			0.78	Amps	Average Primary Current (calculated at average output power)
IP			2.55	Amps	Peak Primary Current (calculated at Peak output power)
IR			1.63	Amps	Primary Ripple Current (calculated at average output power)
IRMS			1.21	Amps	Primary RMS Current (calculated at average output power)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			652	uHenries	Primary Inductance
LP Tolerance			10		Tolerance of Primary Inductance
NP			48		Primary Winding Number of Turns
NB			5		Bias Winding Number of Turns
ALG			278	nH/T^2	Gapped Core Effective Inductance
BM			2862	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			4089	Gauss	Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss
BAC			916	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			2161		Relative Permeability of Ungapped Core
LG			0.52	mm	Gap Length (Lg > 0.1 mm)
BWE			23	mm	Effective Bobbin Width
OD			0.48	mm	Maximum Primary Wire Diameter including

					insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.41	mm	Bare conductor diameter
AWG			26	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			256	Cmils	Bare conductor effective area in circular mils
CMA			212	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
Primary Current Density (J)			9.42	Amps/mm^2	Primary Winding Current density (3.8 < J < 9.75)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			5.14	Amps	Peak Secondary Current
ISRMS			2.68	Amps	Secondary RMS Current
IO_PEAK			1.80	Amps	Secondary Peak Output Current
IO			1.80	Amps	Average Power Supply Output Current
IRIPPLE			1.99	Amps	Output Capacitor RMS Ripple Current
CMS			536	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			22	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.65	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.48	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			-0.08	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN			611	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			245	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			52	Volts	Bias Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1			59.00	Volts	Output Voltage
IO1_AVG			1.80	Amps	Average DC Output Current
PO1_AVG			106.00	Watts	Average Output Power
VD1			0.50	Volts	Output Diode Forward Voltage Drop
NS1			24.00		Output Winding Number of Turns
ISRMS1			2.682	Amps	Output Winding RMS Current
IRIPPLE1			1.99	Amps	Output Capacitor RMS Ripple Current
PIVS1			245	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1			536	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			22	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1			0.65	mm	Minimum Bare Conductor Diameter
ODS1			0.48	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output					
VO2				Volts	Output Voltage
IO2_AVG				Amps	Average DC Output Current
PO2_AVG			0.00	Watts	Average Output Power
VD2			0.70	Volts	Output Diode Forward Voltage Drop
NS2			0.28		Output Winding Number of Turns
ISRMS2			0.000	Amps	Output Winding RMS Current
IRIPPLE2			0.00	Amps	Output Capacitor RMS Ripple Current

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PIVS2			2	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS2			0	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_AVG				Amps	Average DC Output Current
PO3_AVG			0.00	Watts	Average Output Power
VD3			0.70	Volts	Output Diode Forward Voltage Drop
NS3			0.28		Output Winding Number of Turns
ISRMS3			0.000	Amps	Output Winding RMS Current
IRIPPLE3			0.00	Amps	Output Capacitor RMS Ripple Current
PIVS3			2	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS3			0	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 Continuous Output Power			106	Watts	Total Continuous Output Power

9 Heat Sinks

9.1 Primary Heat Sink

9.1.1 Primary Heat Sink Sheet Metal

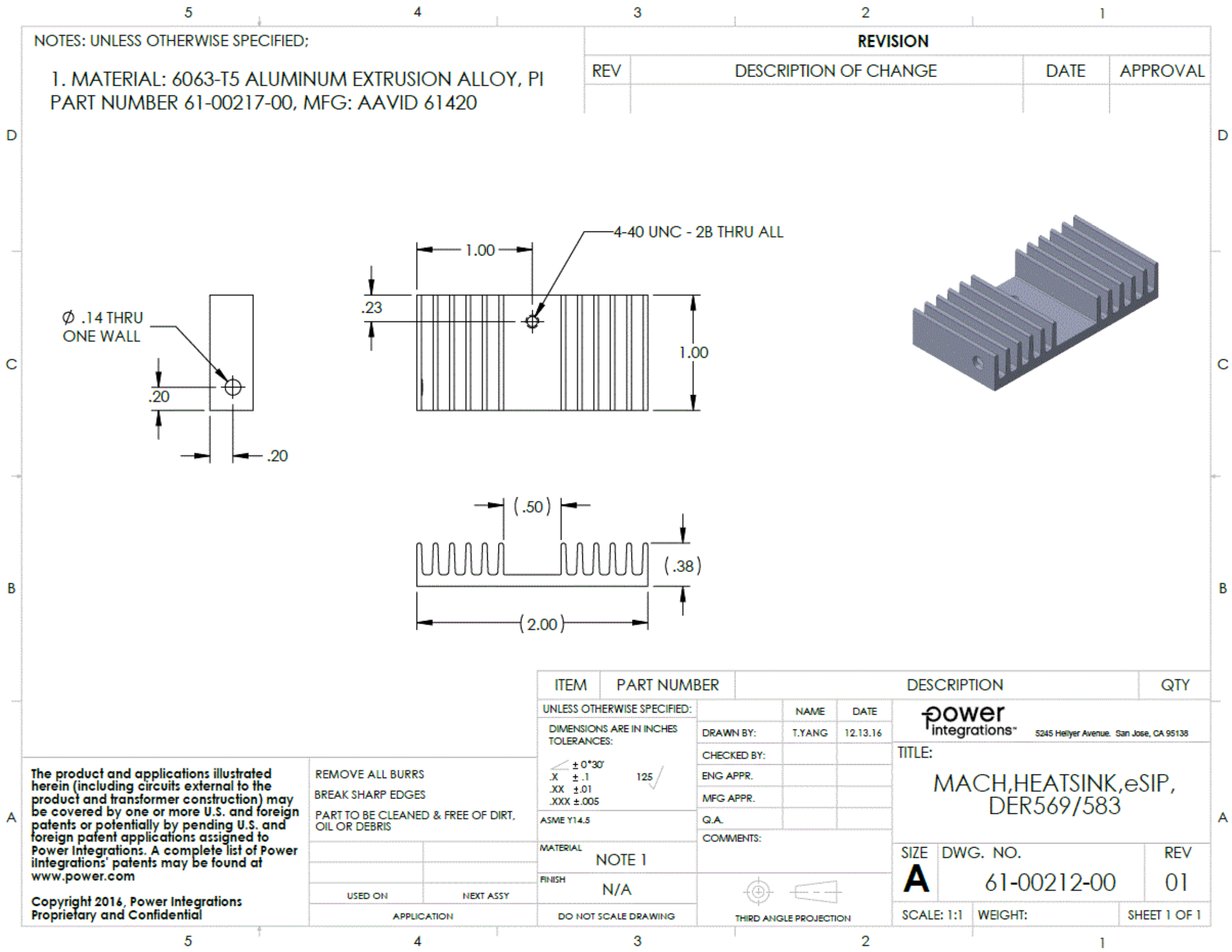

Figure 8 – Primary Heat Sink Sheet Metal Drawing.

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9.1.2 Finished Primary heat Sink

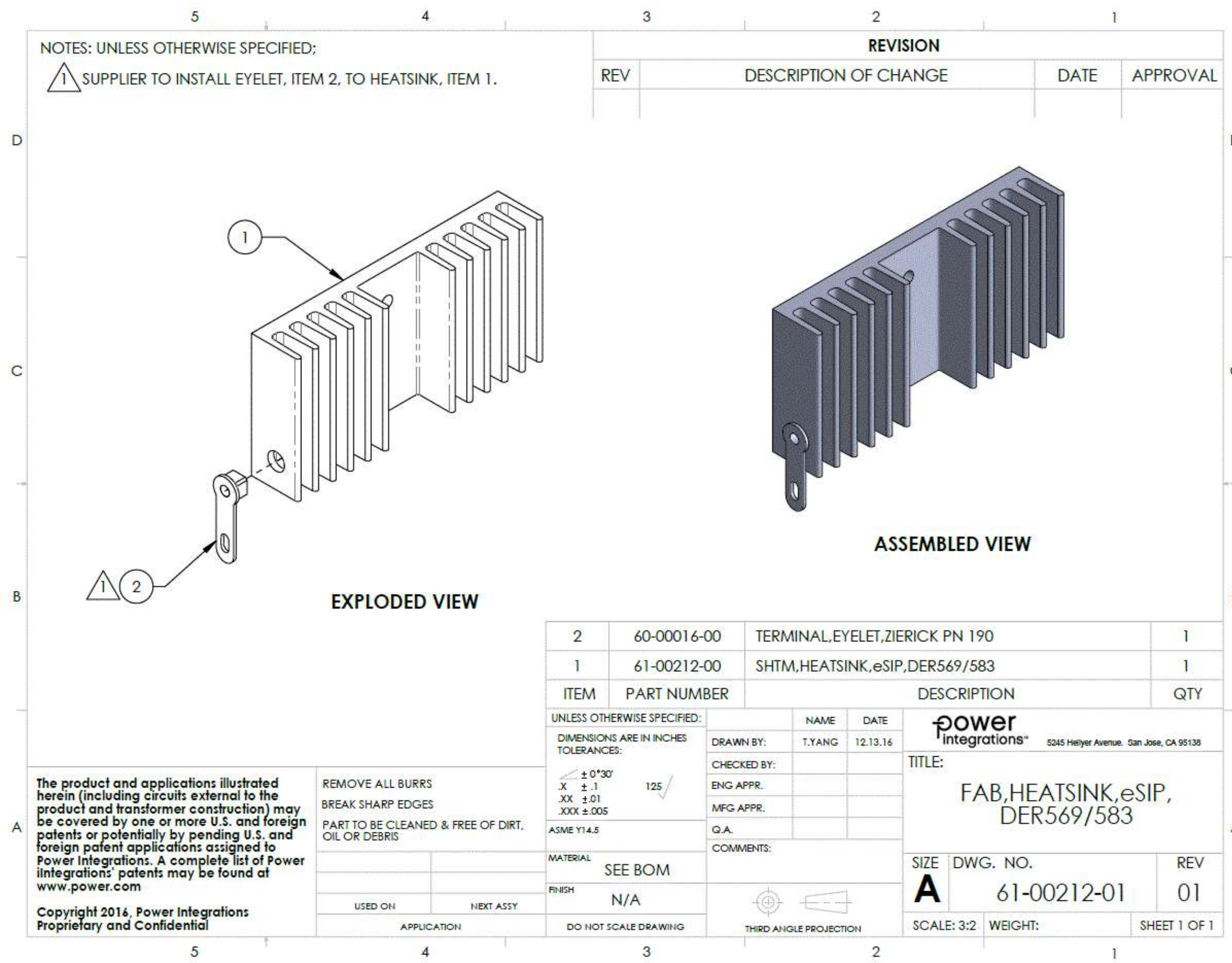

Figure 9 – Finished Primary Heat Sink.

9.1.3 Primary Heat Sink Assembly

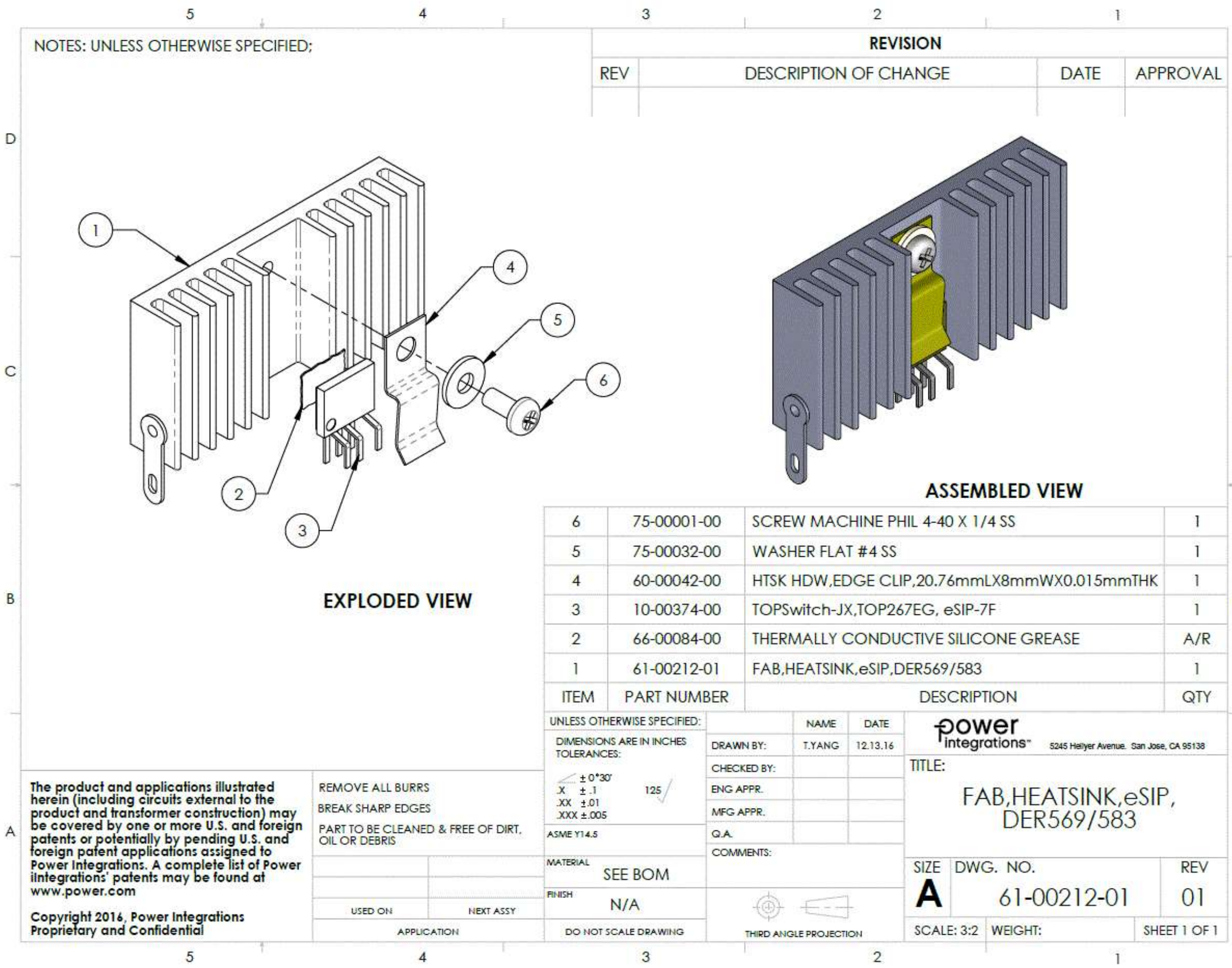

Figure 10 – Primary Heat Sink Assembly.

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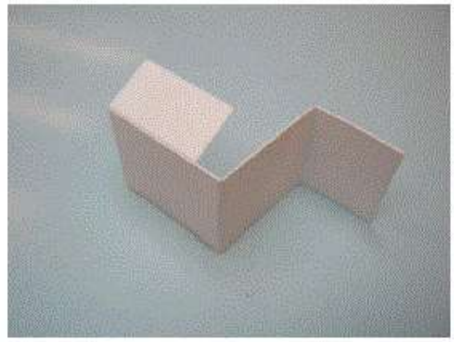
10 Air Diverter

10.1 Air Diverter Drawing



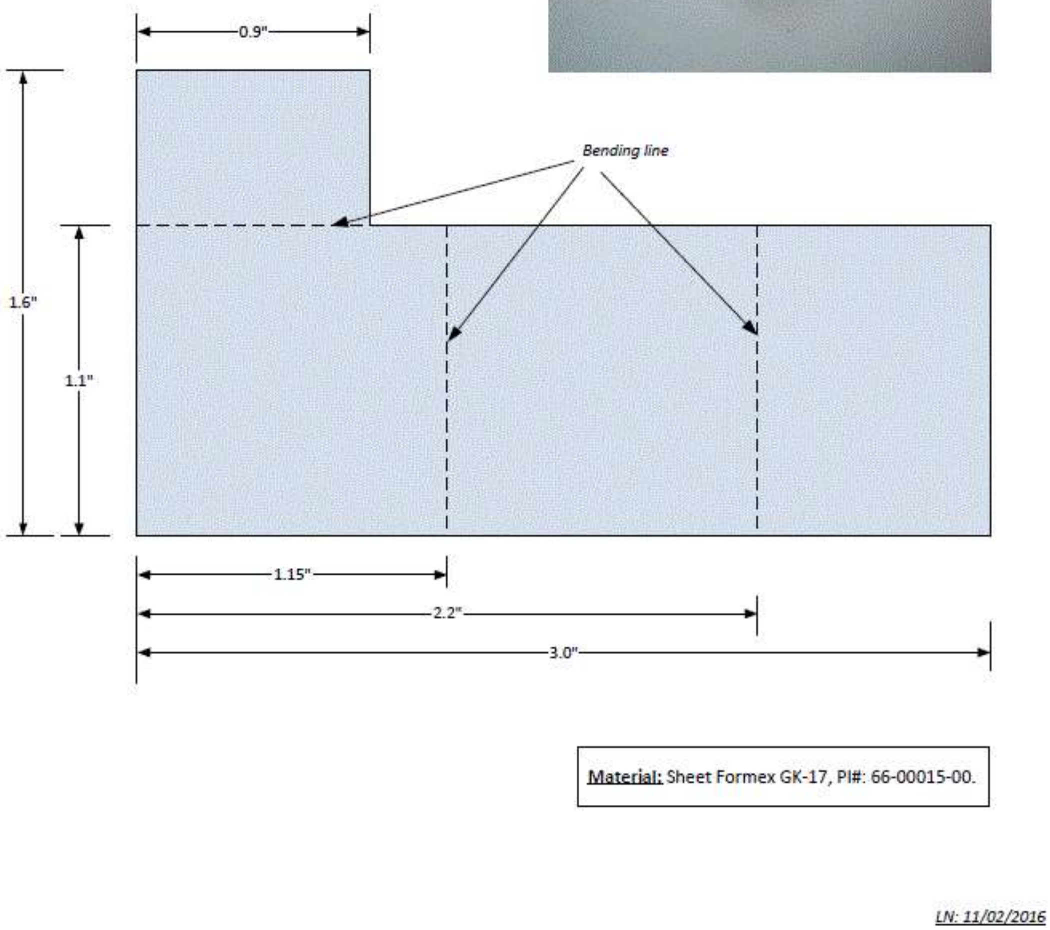


Figure 11 – Air Diverter with Folding Pattern.

11 Performance Data

All measurements were taken at room temperature and 50 Hz (input frequency) unless otherwise specified. Output voltage measurements were taken at the output connectors.

11.1 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.

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11.2 Efficiency

To make this measurement, the supply was powered with an AC source.

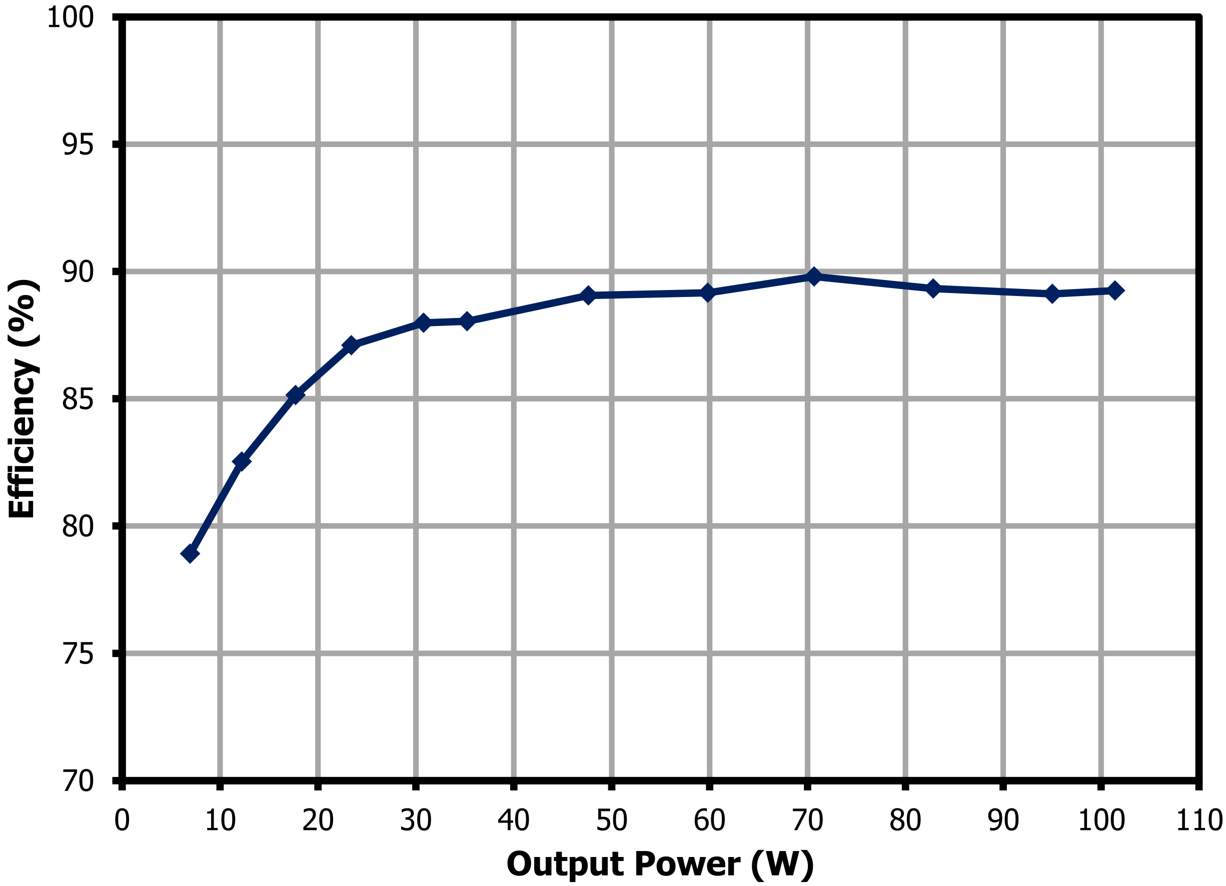

Figure 12 – Efficiency vs. Output Power, 230 VAC Input.

11.3 No-Load Input Power

No-load input power was measured using a Yokogawa WT210 power analyzer. The power meter was set up to record Watt-Hours, with a 20 minute integration time.

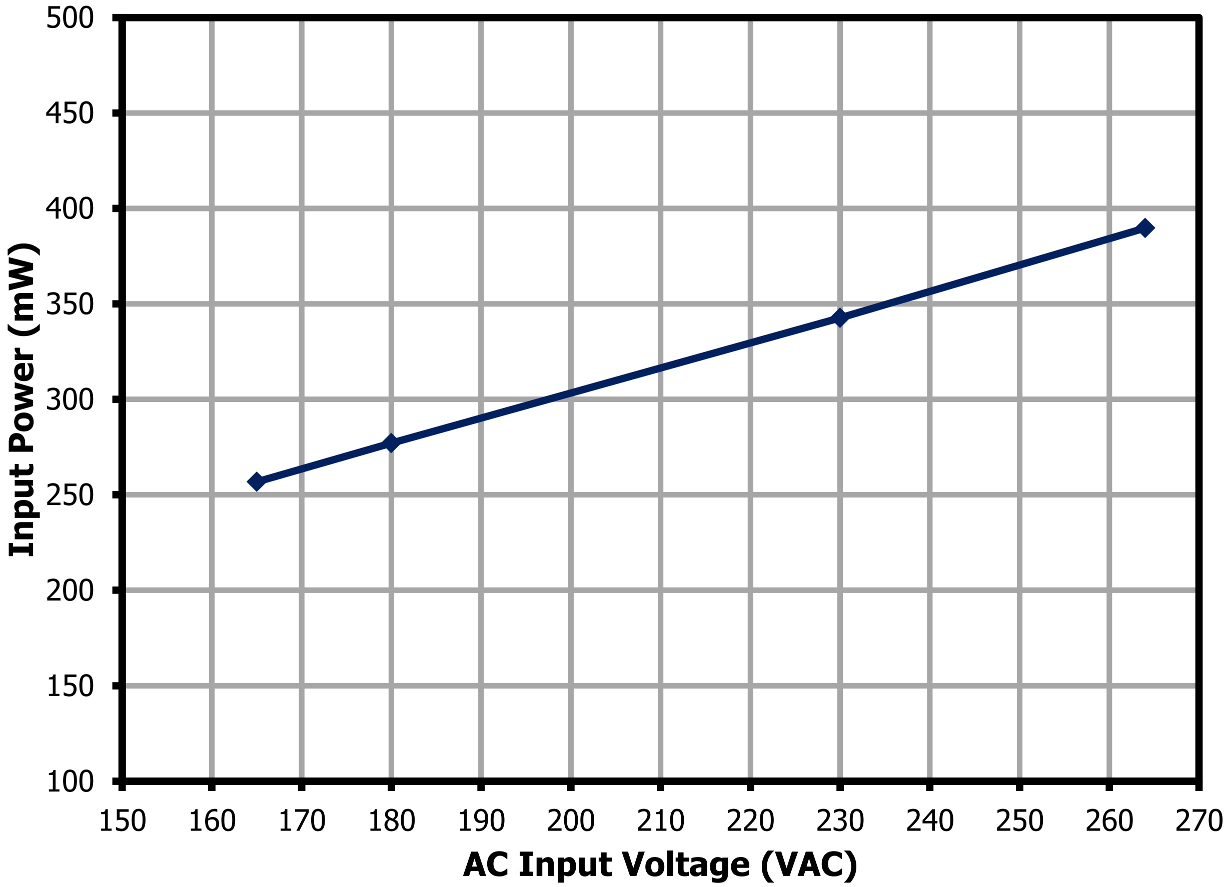

Figure 13 – No-Load Input Power vs. Input Voltage.

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11.4 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 ~1.5 VDC, limited by the capabilities of the electronic load. The rise in output voltage at ~0.5 A is caused by the power supply switching from "float" mode (56 V) to "charging" mode (59 V).

11.4.1 Main Output V-I Characteristic, Constant Resistance Load

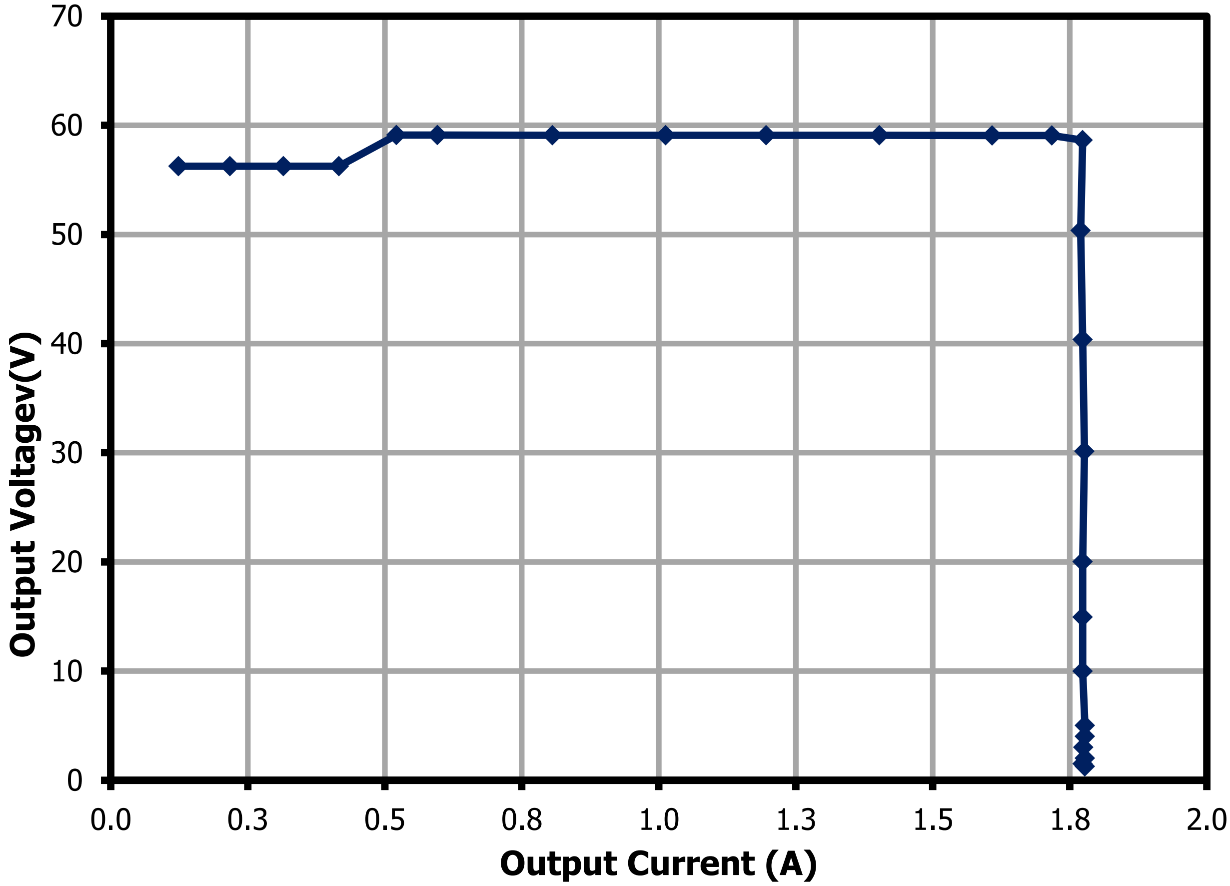

Figure 14 – V-I Characteristic with CR Load.

12 Waveforms

12.1 Primary Voltage and Current

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

Figure 15 – Primary Voltage and Current, 230 VAC Input, 100% Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 1 A / div. 5 μs / div.

12.2 Output Rectifier Peak Reverse Voltage

Figure 16 – Output Rectifier (D3) Reverse Voltage, 230 VAC Input, 100% Load.
100 V, 1 μs / div.

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12.3 Start-up Output Voltage / Current and Using Constant Current and Constant Voltage Output Loads

Figures 17-19 show the power supply output voltage/current start-up profiles. Figure 17 shows the start-up into a constant current load, set to 1.5 A, comfortably below the supply current limit set point. This shows the start-up behavior of the supply in constant voltage mode. Figures 18-19 show the start-up behavior into a constant voltage load, showing the start-up behavior of the supply in constant current mode for two voltage set points.

Figure 17 – Output Start-up, CV Mode, 230 VAC, Chroma CC Load, 1.5 A Setting.
Upper: V_{OUT}, 20 V / div.
Lower: I_{OUT}, 0.5 A, 20 ms / div.

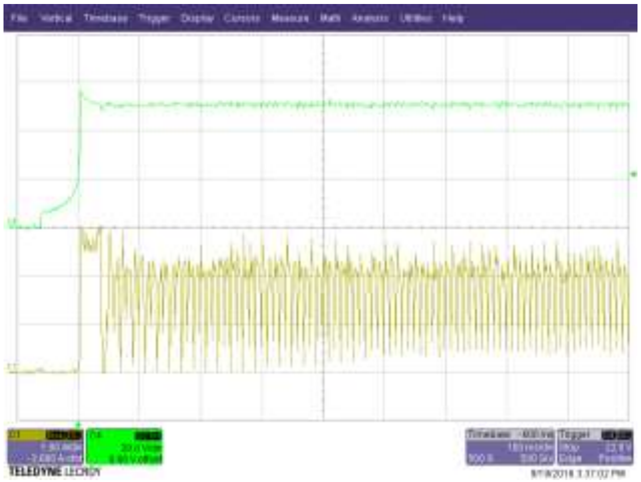

Figure 18 – Output Start-up, CC Mode, 230 VAC, Chroma CV Load, 50 V Setting.
Upper: Main V_{OUT}, 20 V / div.
Lower: Main I_{OUT}, 1 A, 100 ms / div.

Figure 19 – Output Start-up, CC Mode. 230 VAC, Chroma CV Load, 30 V Setting.
Upper: Main V_{OUT}, 20 V / div.
Lower: Main $V_{OUT,}$ 1 A, 100 ms / div.

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

Figure 20 – Output Transient Response, CV Mode, 50%-75%-50% Load Step, 230 VAC Input.
Upper: V_{OUT}, 1 V / div.
Lower: Main Output, I_{LOAD}, 0.5 A, 2 ms / div.

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12.5 Output Ripple Measurements

12.5.1 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 / 100 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.

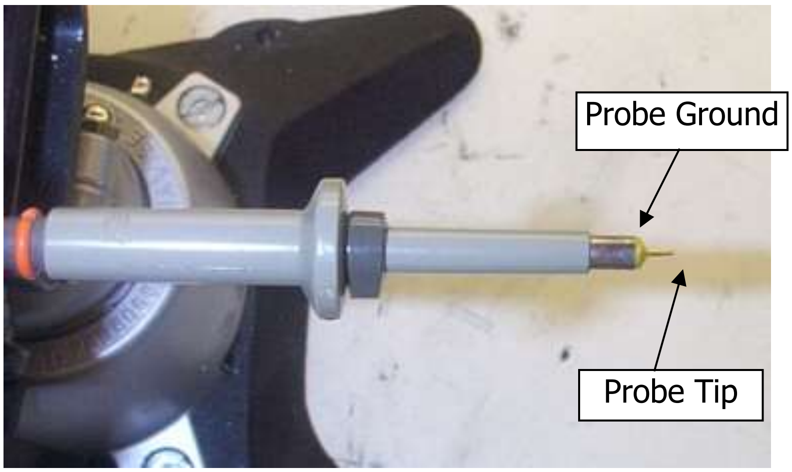

Figure 21 – Oscilloscope Probe Prepared for Ripple Measurement (End Cap and Ground Lead Removed).

Figure 22 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter (Modified with Wires for Probe Ground for Ripple measurement and Two Parallel Decoupling Capacitors Added).

12.5.2 Output Ripple Measurements

Measurements were taken for output ripple voltage and current with the supply operating in constant voltage mode with a constant current load, and for with the supply operating in CC mode. CC mode measurements were taken using a Chroma electronic load set in CV mode at 50 V and 30 V CV settings. Output ripple voltage/current measurements were made using AC coupled voltage and DC coupled current probes.

The 50 Hz ripple is caused by ripple on the secondary bias supply coupling directly into the voltage/current control loops. If the bias supply is regulated to remove the ripple component, the 50 Hz artifact disappears from the output voltage/current ripple waveforms.

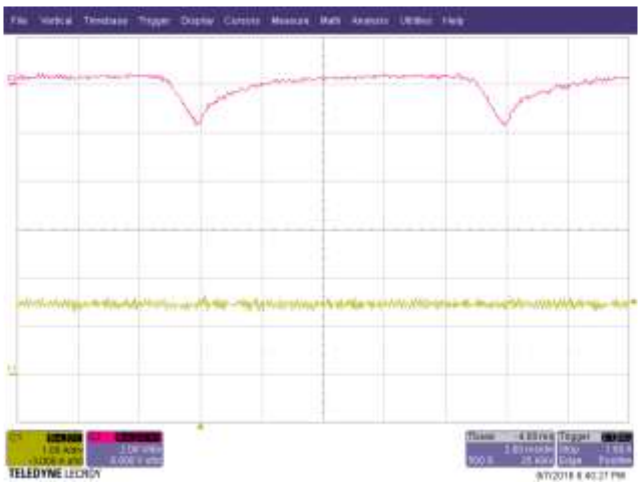

Figure 23 – Main Output Voltage Ripple, 180 VAC, CV Mode, Using Chroma CC Load, 1.5 A Setting.
Upper: $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 2 ms / div.

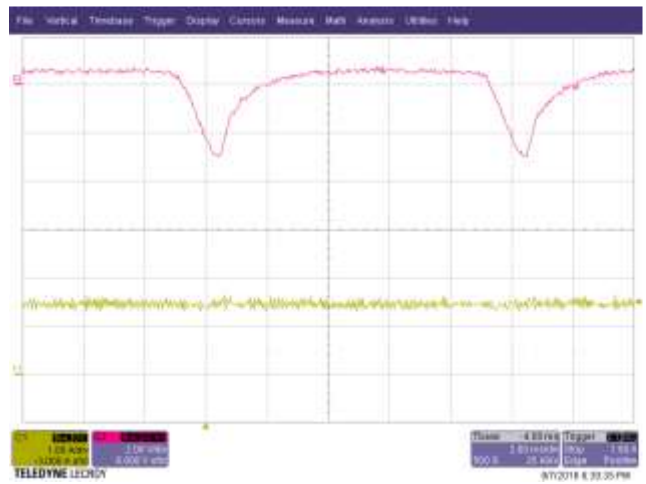

Figure 24 – Output Voltage and Current Ripple in CV Mode, 230 VAC, Chroma CC Load, 1.5 A Setting.
Upper: $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 2 ms / div.

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Figure 25 – Main Output Voltage and Current Ripple in CC Mode, 180 VAC, Chroma CV Load, 57 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.

Figure 26 – Main Output Voltage and Current Ripple in CC Mode, 230 VAC, Chroma CV Load, 57 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.

Figure 27 – Main Output Voltage and Current Ripple in CC Mode, 180 VAC, Chroma CV Load, 30 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.

Figure 28 – Main Output Voltage and Current Ripple in CC Mode, 230 VAC, Chroma CV Load, 30 V Setting.
Upper: Main $V_{OUT(RIPPLE)}$, 2 V / div.
Lower: $I_{OUT(RIPPLE)}$, 1 A, 5 ms /div.

13 Temperature Profiles

One particular requirement for this supply was that the unit not shut down at full load, 65C ambient, 165 VAC input voltage. Monitoring the supply with a thermal camera at room temperature and fan cooling revealed that other than the inrush thermistor (RT1), the hottest component on the board was IC U1. A thermocouple was mounted on this component to monitor the temperature of this part when the unit is placed in a fan-cooled enclosure for thermal testing.

Figure 29 shows the power supply with thermocouple mounted (using thermal epoxy) to measure U1 case temperature. The supply utilizes an air diverter to direct airflow from the fan across the U1 heat sink, reducing the heat sink size (and TOPSwitch size) necessary for supplying the required output power without triggering thermal shutdown

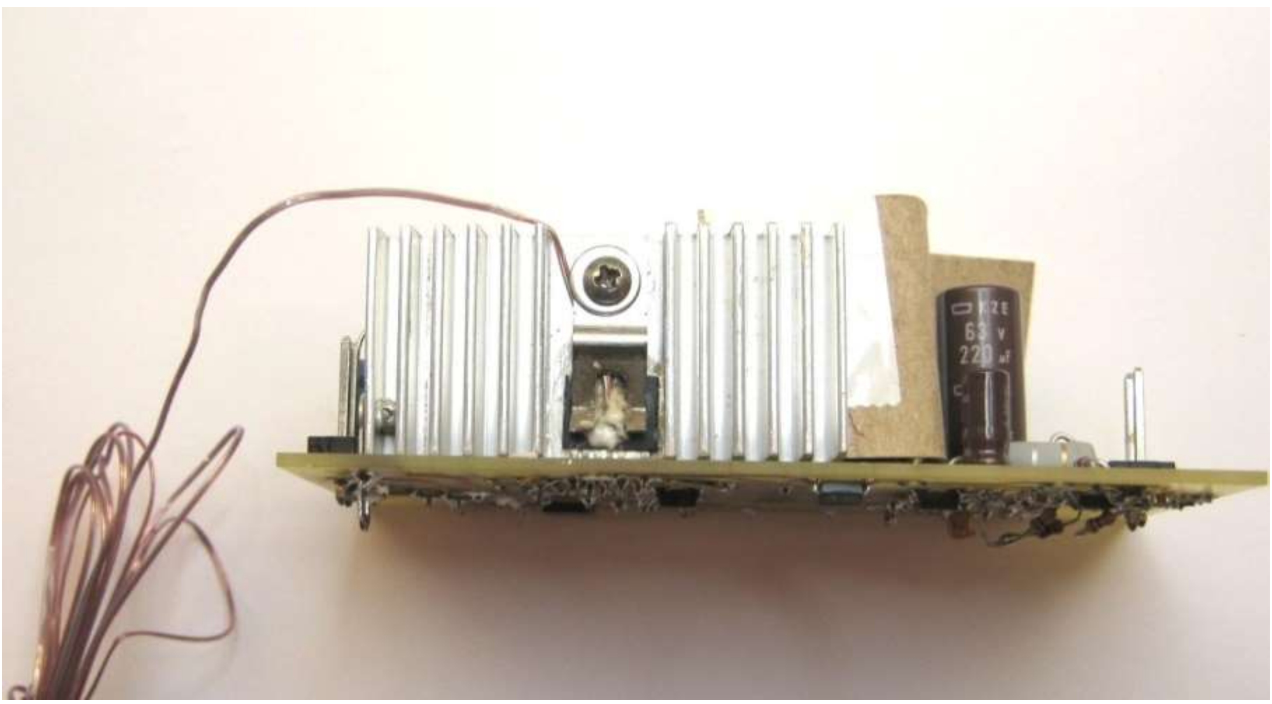

Figure 29 – U1 Thermocouple Placement for Thermal Testing.

Figures 30 and 31 show the supply placed in a cardboard enclosure to simulate an actual plastic enclosure of similar size. A 12 V, 40 mm fan is mounted one end of the enclosure using hot melt glue, oriented to blow into the enclosure.

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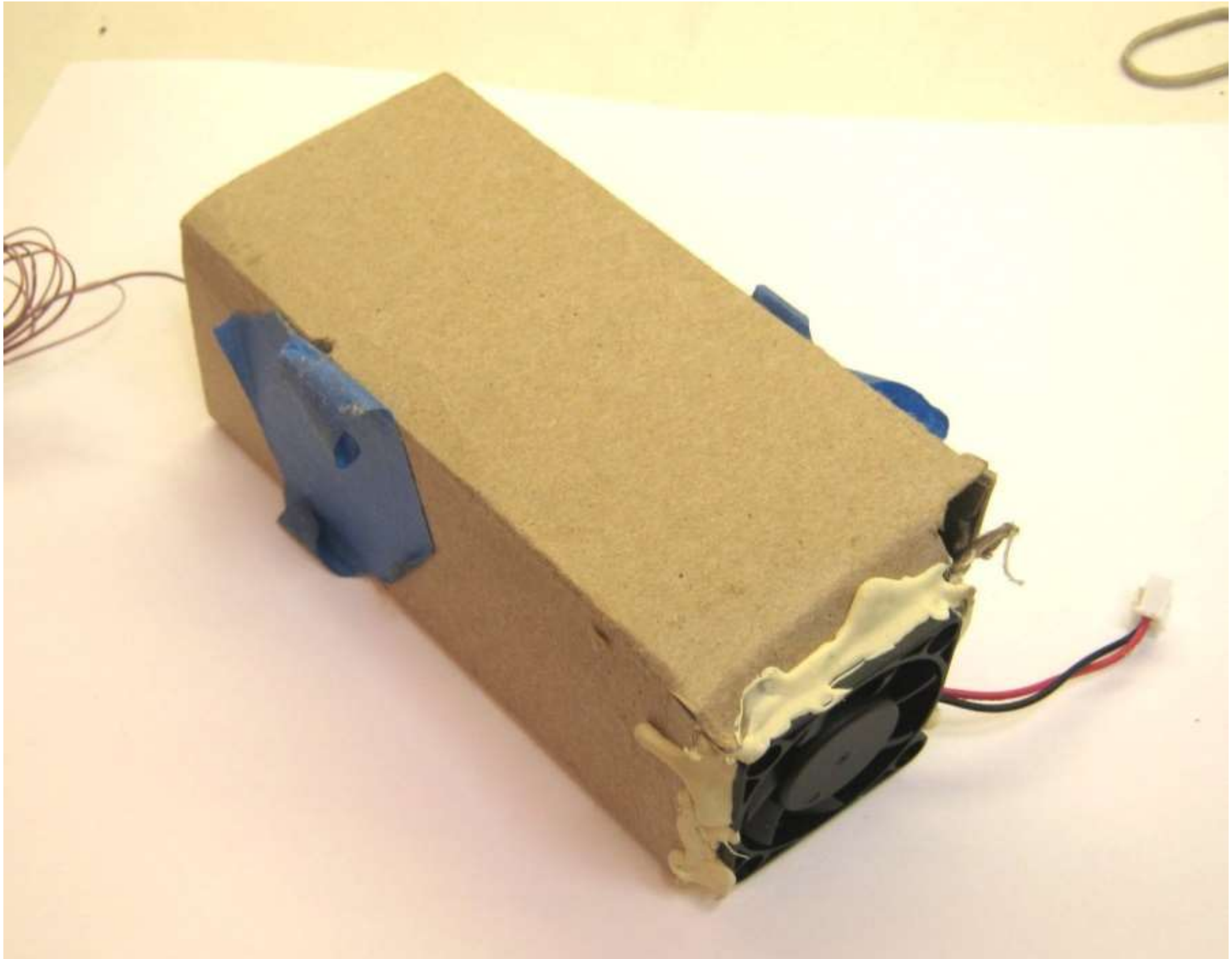

Figure 30 – U1 Enclosure with Fan for Thermal Testing, View 1.

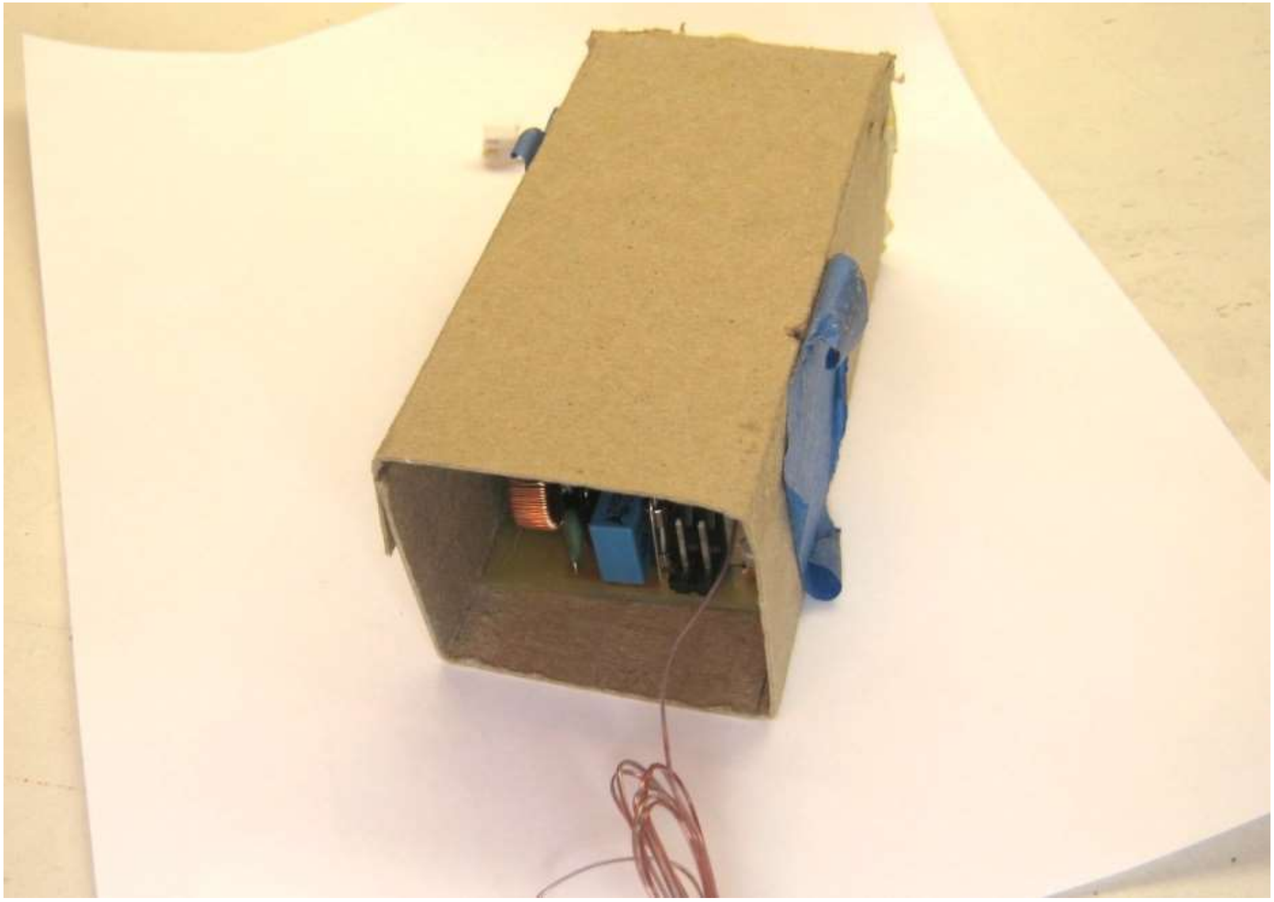

Figure 31 – U1 Enclosure with Fan for Thermal Testing, View 2.

Figure 32 and 33 show an isolation box used in thermal chamber testing. The box is perforated on four sides (2 are shown) to allow its interior to equilibrate with the thermal chamber environment without direct exposure to the air circulation fan in the thermal chamber. A thermocouple is used to monitor the isolation box interior temperature, and the thermal chamber temperature is adjusted for the desired equilibrium temperature inside the box.

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Figure 32 – Isolation Box with Equilibration Holes for Thermal Chamber Testing.

Figure 33 – Isolation Box in Thermal Chamber.

13.1 U1 Temperature Measurements

Position	Temperature (°C)		
	165 VAC	180 VAC	230 VAC
Chamber Ambient	61.5	63.5	64
ISO Box Ambient	65	66	66
U1 Temperature	100	98	93

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13.1.1 165 VAC, 50 Hz, 100% Load Overall Temperature Profile, Room Temperature with Air Flow

Figure 34 – Top View Thermal Picture, 165 VAC.

14 Gain-Phase

14.1 Main Output Constant Voltage Mode Gain-Phase

For these measurements the electronic load was set to constant current mode, with the output current just below the current limit (~1.7 A), in order to determine the characteristics of the voltage regulation loop. Measurements were taken at 180 VAC and 230 VAC.

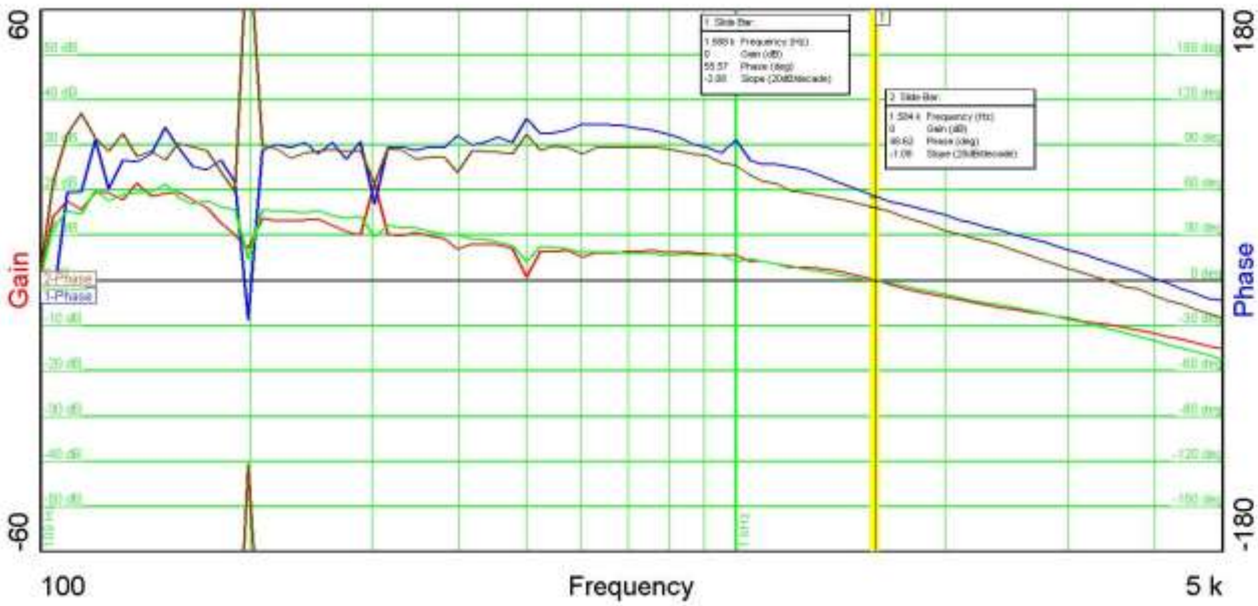

Figure 35 – Main Output Gain-Phase, Voltage Loop, Chroma Constant Current Load Set to 1.7 ADC.
Red/Blu – 230 VAC Gain and Phase Crossover Frequency – 1588 Hz, Phase Margin – 56°.
Grn/Brn – 180 VAC Gain and Phase Crossover Frequency – 1584 Hz, Phase Margin – 48.6°.

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14.2 Main Output Constant Current Mode Gain-Phase

Current loop gain-phase was tested using a Chroma electronic load set to constant voltage mode at three set points - 57 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. Measurements were taken at 180 VAC and 230 VAC for each output voltage setting

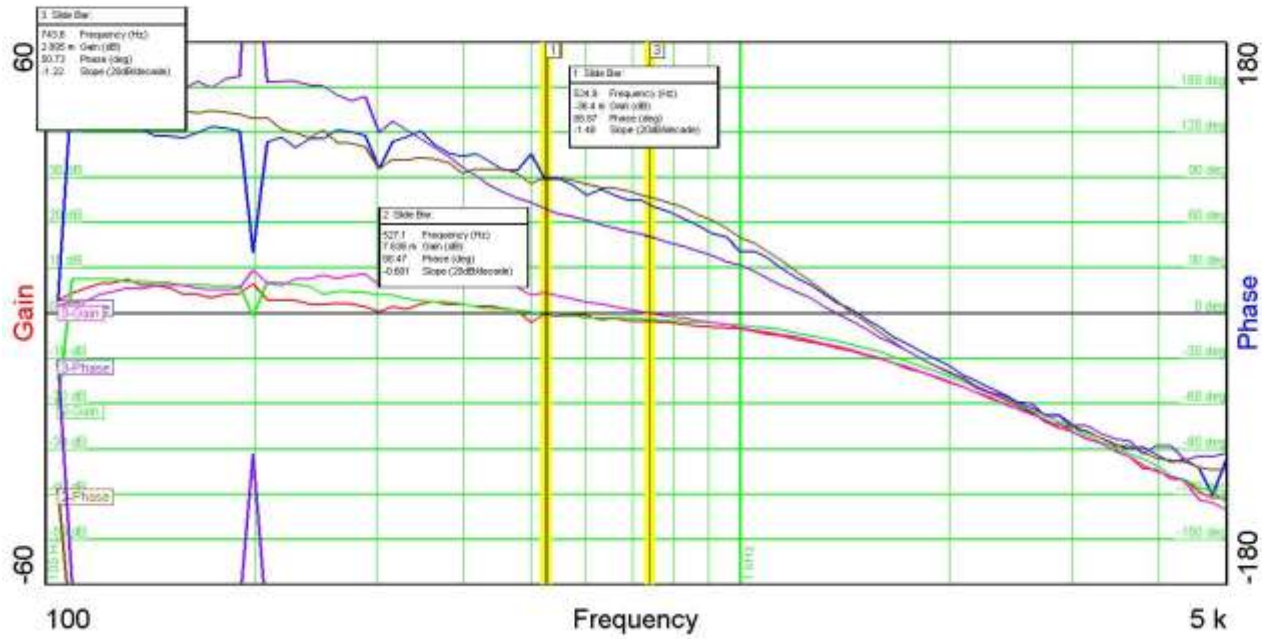

Figure 36 – Main Output Gain-Phase, Current Loop, 230 VAC, Chroma Constant Voltage Load.
Red/Blu – 57 V Output Gain and Phase Crossover Frequency – 525 Hz, Phase Margin – 89°.
Grn/Brn – 30 V Output Gain and Phase Crossover Frequency – 527 Hz, Phase Margin – 90.5°.
Pink/Pur – 15 V Output Gain and Phase Crossover Frequency – 743 Hz, Phase Margin – 50.7°.

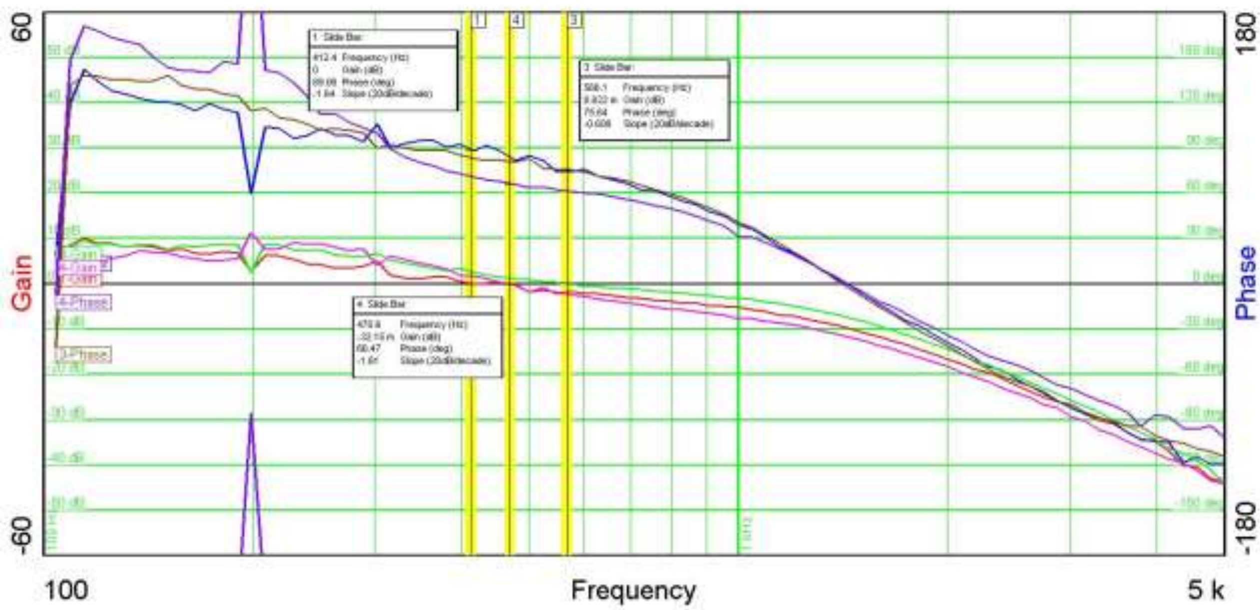

Figure 37 – Main Output Gain-Phase, Current Loop, Chroma Constant Voltage Load 180 VAC Input.
Red/Blu – 57 V Output Gain and Phase Crossover Frequency – 412 Hz, Phase Margin – 89°.
Grn/Brn – 30 V Output Gain and Phase Crossover Frequency – 566 Hz, Phase Margin – 76°.
Pink/Pur – 15 V Output Gain and Phase Crossover Frequency – 471 Hz, Phase Margin – 66.5°.

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15 Conducted EMI

Conducted EMI tests were performed using a 33 Ω floating resistive load. An actual 2-wire input cord was used for EMI measurements.

Figure 38 – EMI Set-up with Floating Resistive Load.

15.1 Conducted EMI Scan

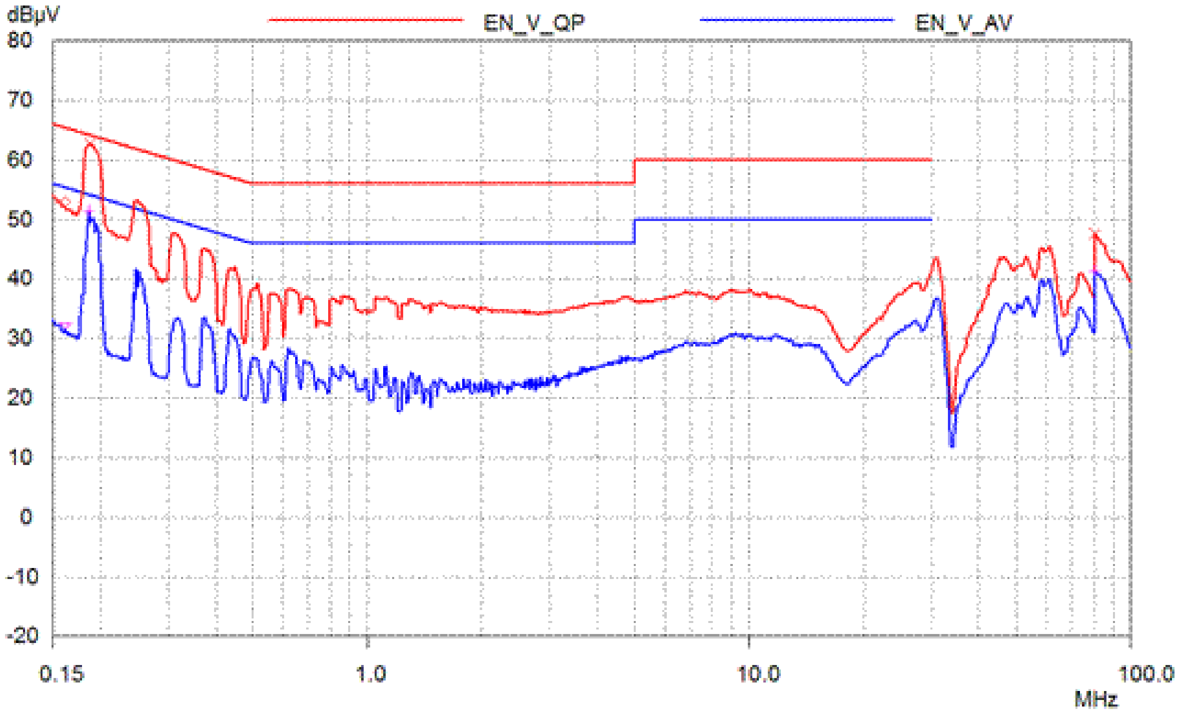

Figure 39 – Conducted EMI, 230 VAC, 33 Ω Floating Resistive Load.

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16 Revision History

Date	Author	Revision	Description & changes	Reviewed
08-Dec-16	RH	1.0	Initial Release.	Apps & Mktg
20-Dec-16	RH	1.1	Updated Heat Sink Drawings	

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