DESIGN EXAMPLE REPORT

Title	***35 W (80 W Peak) Power Supply Using TOP258MN***
Specification	90 – 265 VAC Input; 24 V, 1.46 A (3.33 A_{PEAK}) Output
Application	Inkjet Printer
Author	Applications Engineering Department
Document Number	DER-161
Date	April 21, 2009
Revision	1.1

Summary and Features

- Very high efficiency in standby and sleep modes
  - Enables up to 0.8 W output power for <1 W input power at 230 VAC input
  - Enables up to 2.39 W output power for <3 W input power at 230 VAC input
- Very low no-load input power - <0.225 W at 230 VAC
- Excellent transient load response
- Hysteretic thermal overload protection with automatic recovery
- Time triggered over power protection for the output
- Latching fault protection and fast AC reset

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

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1 Introduction

This engineering report describes an inkjet printer power supply design based on the Power Integrations® TOPSwitch®-HX TOP258MN. This power supply operates from a universal input (90 VAC – 265 VAC) and provides a 24 V, 35 W continuous output. To accommodate peak load power requirements this supply also delivers up to 80 W (peak power) for 40 ms durations, at regular intervals of 1060 ms (a 3.6% duty cycle).

The TOPSwitch-HX, by design, maintains constant efficiency across a very wide load range. This optimizes performance for existing and emerging energy efficiency regulations, such as 1 W standby and 3 W sleep mode requirements. This constant efficiency capability ensures a design based on the TOPSwitch-HX line is optimized for any future energy efficiency regulation changes, without the need for redesign.

This power supply design offers various protection features:

- Output overvoltage protection (OVP) or open-loop fault protection, with latching shutdown and fast AC reset
- Time-triggered latching overload protection with fast AC reset
- Auto-restart during brownout or line sags
- Accurate thermal overload protection with auto recovery using a large hysteresis

This document provides the specifications, schematic, bill of materials, and transformer design and construction details for this power supply. This document includes performance parameters such as regulation, efficiency, stand-by, transient load, power-limiting data, and conducted EMI test results.

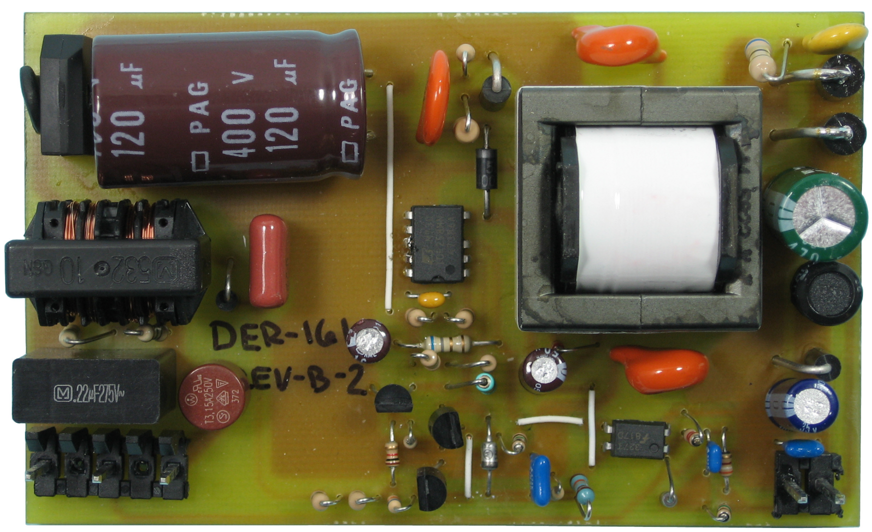

Figure 1 – Top View: 35 W Continuous, 80 W Peak Power Supply with TOP258MN.

2 Power Supply Specifications

Description	Symbol	Min.	Typ.	Max.	Peak	Unit	Notes
Input							
Voltage	V_{IN}	90	115/230	265		VAC	3 Wire, PE
Frequency	f_{LINE}	47	50/60	64		Hz	
Output							
Output Voltage 1	V_{OUT1}	22.2	24	25.6		V	±7 %
Output Ripple Voltage 1	$V_{RIPPLE1}$			400		mV	20 MHz bandwidth
Output Current 1	I_{OUT1}	0	1.458		3.33	A	Peak for 40 ms
Continuous Output Power	P_{OUT}		35			W	
Peak Output Power 2	P_{PEAK}				80	W	40 ms
Efficiency							
Full Load Efficiency		86.9				%	35 W, 115 VAC
Average Efficiency		86.9				%	115 VAC, per CEC
Sleep Mode Efficiency*		79				%	P_{IN}=3 W, 230 VAC
Standby Efficiency*		78					P_{IN}=1 W, 230 VAC
Environmental							
Conducted EMI		Designed to meet EN55022B					RTN connected to PE
Safety		Designed to meet IEC950, Class II					
Ambient Temperature	T_{AMB}	0		40		°C	Power supply ambient
Miscellaneous							
Startup Time				3		s	AC applied to outputs in regulation
Output Rise Time				50		ms	10% to 90% of steady state output
AC Reset Time After Latching Shutdown				3		s	AC input is disconnected and reconnected
Overload Latching Shutdown Time		120				ms	>3.5 A load on 24 V output

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3 Schematic

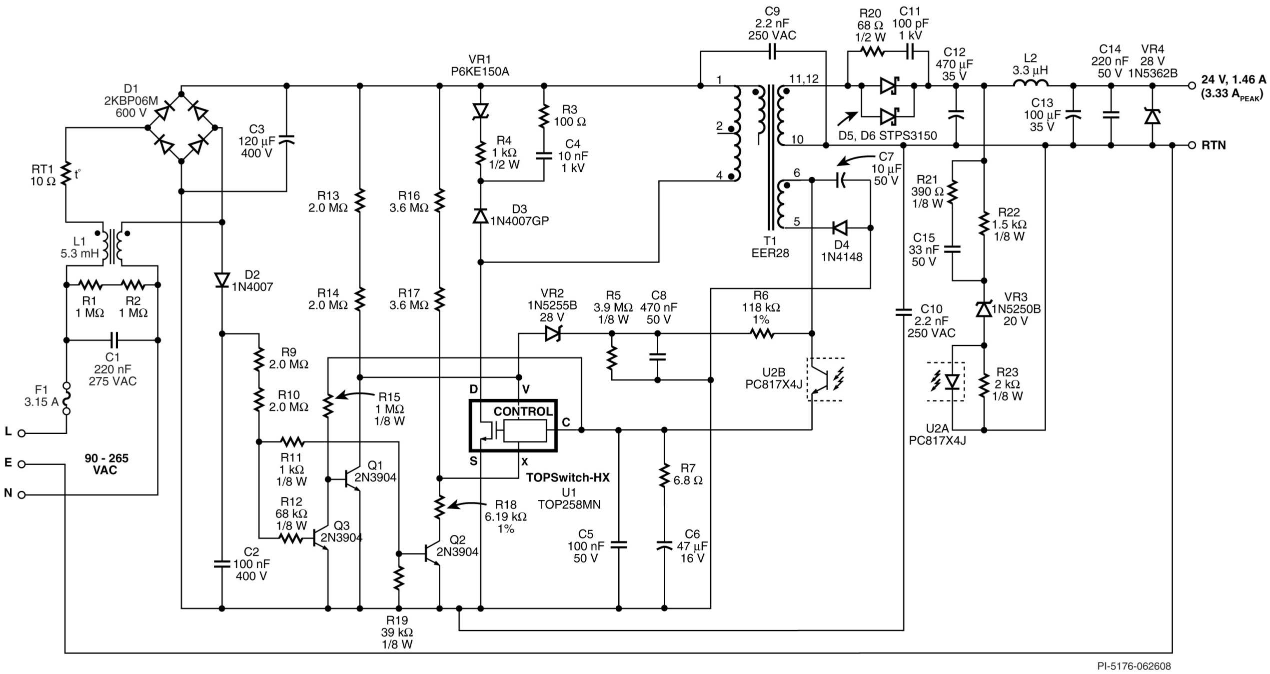

Figure 2 – Schematic.

4 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C1	220 nF, 275 VAC, Film, X2	ECQ-U2A224ML	Panasonic
2	1	C2	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
3	1	C3	120 μF, 400 V, Electrolytic, (18 x 31.5)	YSD2GM121L32B0BA10264	Ltec
4	1	C4	10 nF, 1 kV, Disc Ceramic	562R5HKMS10	Vishay/Sprague
5	1	C5	100 nF, 50 V, Ceramic, Z5U, .2Lead Space	C317C104M5U5TA	Kemet
6	1	C6	47 μF, 16 V, Electrolytic, Gen Purpose, (5 x 11.5)	ECA-1CHG470	Panasonic
7	1	C7	10 μF, 50 V, Electrolytic, Gen Purpose, (5 x 11)	ECA-1HHG100	Panasonic
8	1	C8	470 nF, 50 V, Ceramic, X7R	B37984M5474K000	Epcos
9	2	C9 C10	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
10	1	C11	100 pF, 1 kV, Disc Ceramic	ECC-D3A101JGE	Panasonic - ECG
11	1	C12	470 μF, 35 V, Electrolytic, Very Low ESR, 23 mΩ, (10 x 20)	EKZE350ELL471MJ20S	Nippon Chemi-Con
12	1	C13	100 μF, 35 V, Electrolytic, Low ESR, 180 mΩ, (6.3 x 15)	ELXZ350ELL101MF15D	Nippon Chemi-Con
13	1	C14	220 nF, 50 V, Ceramic, Z5U, 0.2" L.S.	C322C224M5U5CA	Kemet
14	1	C15	33 nF, 50 V, Ceramic, X7R	B37981F5333K000	Epcos
15	1	D1	600 V, 2 A, Bridge Rectifier, Glass Passivated	2KBP06M	Vishay
16	1	D2	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
17	1	D3	1000 V, 1 A, Rectifier, Glass Passivated, 2 us, DO-41	1N4007GP	Vishay
18	1	D4	75 V, 300 mA, Fast Switching, DO-35	1N4148	Vishay
19	2	D5 D6	150 V, 3 A, Schottky, DO-201AD	STPS3150RL	ST
20	1	F1	3.15 A, 250V,Fast, TR5	37013150410	Wickman
21	1	J1	5 Position (1 x 5) header, 0.156 pitch, Vertical	26-48-1055	Molex
22	1	J2	2 Position (1 x 2) header, 0.156 pitch, Vertical	26-48-1021	Molex
23	1	JP1	Wire Jumper, Non-insulated, 22 AWG, 1.1 in	298	Alpha
24	2	JP2 JP4	Wire Jumper, Non-insulated, 22 AWG, 0.3 in	298	Alpha
25	1	JP3	Wire Jumper, Non-insulated, 22 AWG, 0.4 in	298	Alpha
26	1	L1	5.3 mH, 1 A, Common-mode Choke	ELF15N010A	Panasonic
27	1	L2	3.3 μH, 5.5 A	RL622-3R3K-RC	JW Miller
28	3	Q1 Q2 Q3	NPN, Small Signal BJT, 40 V, 0.2 A, TO-92	2N3904RLRAG	On Semiconductor
29	2	R1 R2	1 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-1M0	Yageo
30	1	R3	100 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-100R	Yageo
31	1	R4	1 k Ω, 5%, 1/2 W, Carbon Film	CFR-50JB-1K0	Yageo
32	1	R5	3.9 M Ω, 5%, 1/8 W, Carbon Film	CFR-12JB-3M9	Yageo
33	1	R6	118 k Ω, 1%, 1/4 W, Metal Film	MFR-25FBF-118K	Yageo
34	1	R7	6.8 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-6M8	Yageo
35	4	R9 R10 R13 R14	2.0 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M0	Yageo
36	1	R11	1 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-1K0	Yageo
37	1	R12	68 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-68K	Yageo
38	1	R15	1 MΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-1M0	Yageo
39	2	R16 R17	3.6 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-3M6	Yageo
40	1	R18	6.19 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-6K19	Yageo
41	1	R19	39 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-39K	Yageo
42	1	R20	68 Ω, 5%, 1/2 W, Carbon Film	CFR-50JB-68R	Yageo
43	1	R21	390 Ω, 5%, 1/8 W, Carbon Film	CFR-12JB-390R	Yageo

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44	1	R22	1.5 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-1K5	Yageo
45	1	R23	2 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-2K0	Yageo
46	1	RT1	NTC Thermistor, 10 Ω, 1.7 A	CL-120	Thermometrics
47	1	T1	Bobbin, EER28, Horizontal, In built margins, 12 pins	YW-200-00B	Yih-Hwa Enterprises
48	1	U1	TOPSwitch-HX, TOP258MN, SDIP-10	TOP258 MN	Power Integrations
49	1	U2	Optocoupler, 80 V, CTR 300-600%, 4-DIP	PC817X4J000F	Sharp
50	1	VR1	150 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE150A	LittlelFuse
51	1	VR2	28 V, 5%, 500 mW, DO-35	1N5255B-T	Diodes Inc
52	1	VR3	20 V, 5%, 500 mW, DO-35	1N5250B	Microsemi
53	1	VR4	28 V, 5%, 5 W, DO-41	1N5362B	ON Semiconductor

5 Circuit Operation

5.1 General

This power supply uses a flyback topology to generate an isolated 24 V output which supplies 1.46 A continuously and 3.33 A for short durations (40 ms). The integrated thermal shutdown feature of the TOP258MN (U1) provides protection in case of thermal overload. Zener diode VR2 also provides protection by breaking down under failure conditions (such as an output overvoltage condition), delivering current into the V pin of U1, and causing a latching shutdown. (The value of resistor R6 determines whether the shutdown is latching or non-latching.)

5.2 Energy Efficiency

The EcoSmart® feature of the TOPSwitch-HX family provides constant efficiency over an entire load range. Proprietary Multi-mode Operation automatically accommodates different load conditions and simplifies circuit design by eliminating the need to consider specific operating conditions or load thresholds.

5.3 Startup and Power Down

The line-sensing network formed by D2 and C2 provides input voltage information. Using this network instead of input bulk capacitor C3 provides such information faster, since it removes the large time constant associated with C3. This provides the ability to have advanced power up, power down, and reset behaviors when used with the internal features of U1.

5.3.1 Normal Input Voltage Range

Resistors R13 and R14 control the line voltage at which IC U1 turns on. A current into the V pin exceeding 25 µA corresponds to a voltage greater than the UV threshold and enables U1 to switch. The base of Q1 is pulled low by Q3 during normal operating conditions, keeping Q1 off which allows current from the DC bus to be fed to the V pin of IC U1. This condition corresponds to a voltage of 100 VDC on the DC bus, or the input being approximately 72 VAC.

5.3.2 AC Loss (Power Down)

During power down, the power supply continues to operate until output regulation is lost and does not restart until the UV threshold is exceeded. This prevents output glitches during power down.

5.3.3 Fast AC Reset

Once U1 goes into a latching shutdown, removing the input AC resets the power supply. This is achieved via Q3 and Q1. Once the AC is removed Q3 turns off, which turns Q1 on and pulls the voltage at the V pin below the reset threshold. Applying the AC source again and exceeding the UV threshold restarts the power supply. The X pin remote off feature is used to prevent the output from glitching when AC is removed and latching shutdown is reset while the voltage across C3 is above the UV threshold.

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When AC is removed, Q2 turns off and the X pin of U1 is essentially floating (a small current flows into the X pin through R16 and R17). This puts U1 into remote off mode. The voltage at which this occurs is set by resistor divider R11 and R19 and is below the UV set by R13 and R14.

5.4 EMI Filtering

The three-wire AC supply is connected to the circuit using input connector J1. Fuse F1 provides protection against circuit faults. Thermistor RT1 limits the inrush current drawn by the circuit at start up. X-capacitor C1 reduces differential-mode EMI. Resistors R1 and R2 discharge C1 on AC removal to provide safety against shock hazards at the input. Common-mode inductor L1 filters common-mode EMI and prevents it from coupling back to the AC source.

5.5 TOPSwitch-HX Primary

IC U1 regulates the output using PWM-based voltage mode control. At high loads the controller operates at full switching frequency (66 kHz). The duty cycle is controlled by the control pin current, which regulates the output voltage.

The internal current limit provides cycle-by-cycle peak current limit protection. The TOPSwitch-HX controller has a second current limit comparator to monitor the actual peak drain current (I_P) relative to the programmed current limit ($I_{LIMITEXT}$). The current I_P is held constant once the ratio $I_P/I_{LIMITEXT}$ falls below 55%, at which point the output is regulated through switching frequency modulation (variable frequency PWM control). As the load decreases, the switching frequency decreases, linearly, down to 30 kHz.

Once the switching frequency has reached 30 kHz the controller maintains the switching frequency and reduces I_P to regulate the output (fixed frequency, direct duty cycle PWM control).

As the power drawn by the load decreases and the ratio $I_P/I_{LIMITEXT}$ falls below 25%, the controller enters multi-cycle-modulation mode, providing both excellent efficiency under light load conditions or standby operation, and low no-load input power consumption.

5.6 Primary Clamp

Capacitor C4, resistors R3 and R4, and Zener diode VR1 form an efficient RCDZ clamp circuit. During normal operation C4 absorbs leakage energy and dissipates it through R4. Zener diode VR1 prevents excessive power dissipation under no load and light-load conditions. Resistor R3 damps out high frequency ringing and reduces EMI.

5.7 Output Rectification

Output rectification is provided by diodes D5 and D6. Two diodes were used for better thermal performance. Low-ESR capacitor C12 provides filtering. Inductor L2 and capacitors C13 and C14 form a second-stage filter that significantly attenuates the switching ripple across C12 and ensures a low ripple output. Capacitor C11 and resistor

R20 form the secondary-side snubber network to dampen high-frequency ringing from the transformer windings (leakage inductance) and secondary trace inductances.

5.8 Latching Output Overload Shutdown and Fast AC Reset

This power supply design features time-triggered overload protection, sensed from the primary-side bias winding. During an overload event, the voltage across the bias winding, and therefore across C8, rises. Having this voltage exceed (approximately) 28 V triggers the latching shutdown feature of U1. The values of C8, R5, and R6 determine the delay before triggering.

Once the power supply has been triggered to latch off, cycling the AC input turns it on again immediately.

5.9 Output Power Limiting with Line Voltage

To limit the output power with line voltage, Resistors R16, R17, and R18 reduce the internal current limit through the X pin. Resistors R13 and R14 reduce the maximum duty cycle by providing a current proportional to the increasing line voltage, into the V pin. During normal operation, transistor Q2 is driven into saturation, which connects R18 to the X pin and sets an external current limit.

5.10 Output Over-Voltage Protection (OVP)

Open-loop faults can cause the output voltage to exceed the specified maximum value. A simple TVS (VR4) on the output provides a clamp on the voltage level when this happens. This limits the maximum output voltage before a latching shutdown is triggered. During such an over-voltage event both the output voltage and the bias winding voltage rise. This voltage increase triggers VR2, which causes current to be pushed into the V pin, initiating a latching shutdown.

5.11 Thermal Overload Protection

IC U1 has an integrated, 100% tested, accurate hysteretic thermal overload protection function. If the device junction temperature reaches +142 °C, U1 shuts down. It automatically recovers once the junction temperature decreases by 75 °C.

5.12 Feedback

Output feedback is provided via R21, C15, R22, VR3, U2 and R23. Resistor R22 sets the loop DC gain with R21 and C15 forming a phase boost network. Resistor R23 provides ~0.5 mA bias current for VR3.

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6 PCB Layout

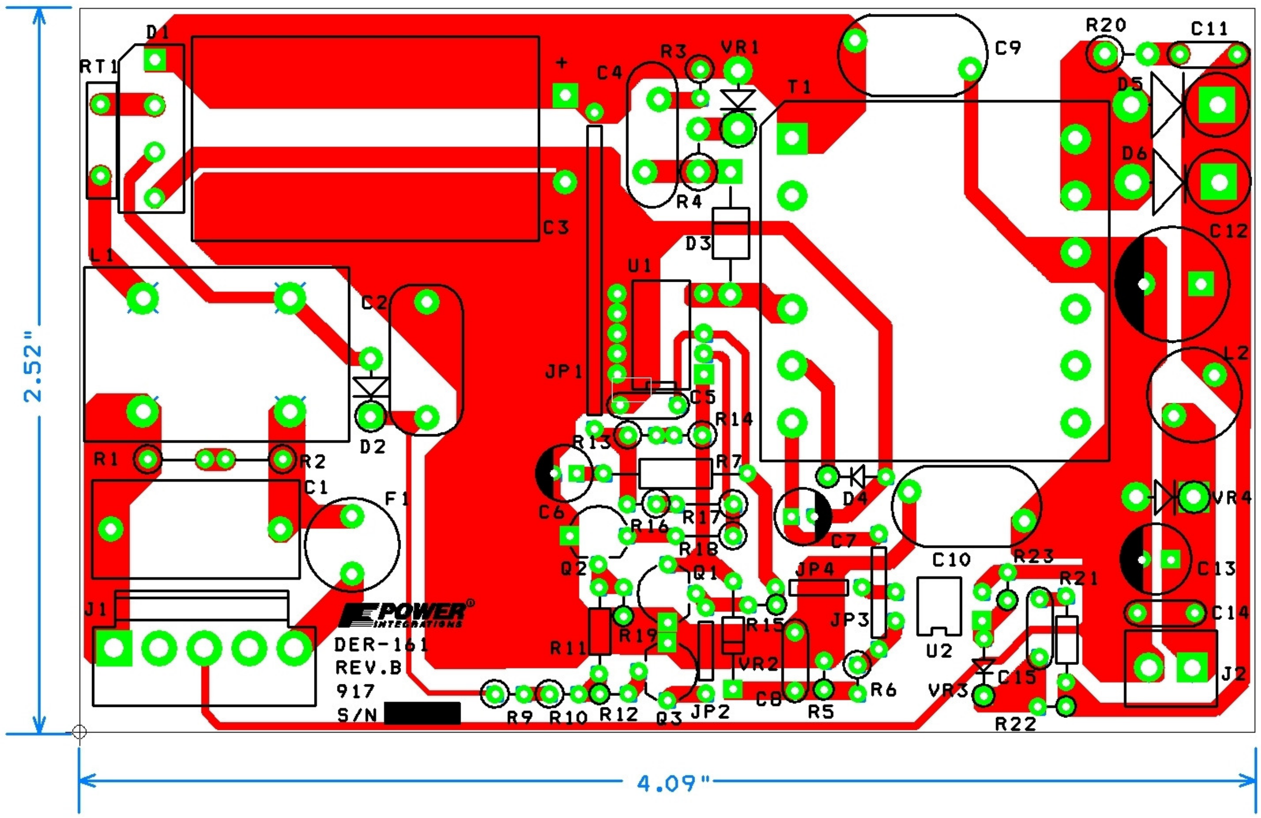

Figure 3 – Printed Circuit Layout.

7 Transformer Specification

7.1 Electrical Diagram

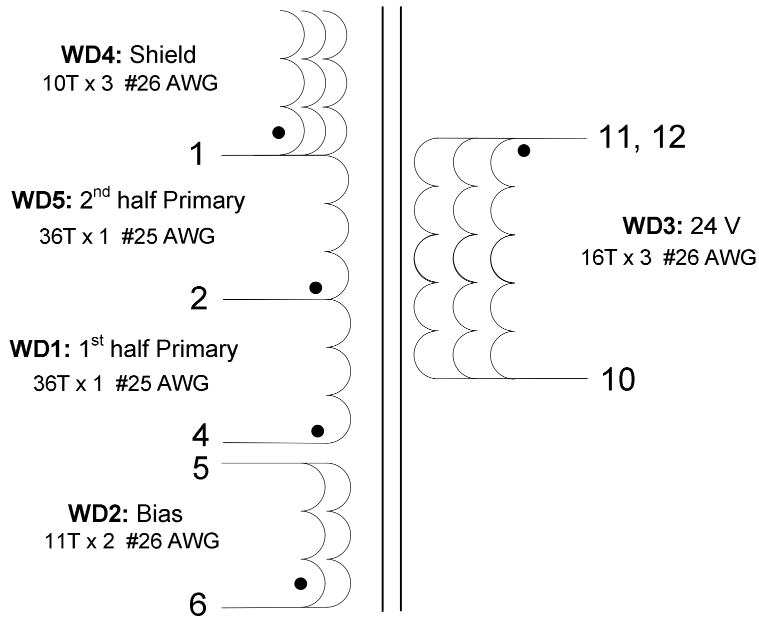

Figure 4 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1 – 4 to pins 10 – 12	3000 VAC
Primary Inductance	Pins 1 - 4, all other windings open, measured at 66 kHz, 0.4 VRMS	705 µH, ±5%
Resonant Frequency	Pins 1 - 4, all other windings open	800 kHz (Min.)
Primary Leakage Inductance	Pins 1 - 4, with pins 6 - 12 shorted, measured at 66 kHz, 0.4 VRMS	14 µH (Max.)

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7.3 Materials

Item	Description
[1]	Core: PC40 EER28, AL=137 nH/T^2
[2]	Bobbin: EER28 Horizontal, (6 + 6 pins)
[3]	Magnet Wire: #25 AWG
[4]	Magnet Wire: #26 AWG
[5]	Magnet Wire: #27 AWG
[6]	Magnet Wire: #29 AWG
[7]	Teflon Tube
[8]	Tape: Margin 3 mm
[9]	Tape: 3M 1298 Polyester Film, 11.2 mm width
[10]	Tape: 3M 1298 Polyester Film, 17.2 mm width
[11]	Varnish

7.4 Transformer Build Diagram

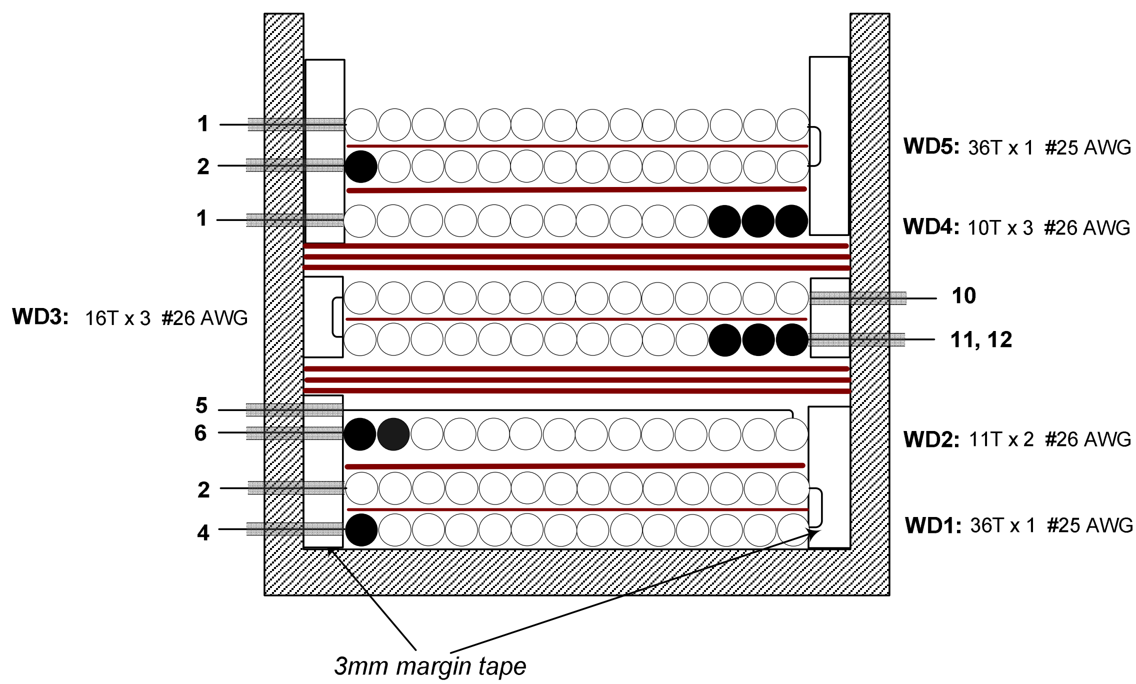

Figure 5 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	The side of the bobbin with a marking dot is defined as the primary side; it orients to the right-hand side. The machine spins clock-wise, looking from the right to the left side, unless otherwise specified.
Teflon Tube	Put Teflon Tube [7] on each wire that connects to the bobbin pins.
Margin Tape	Wind item [8] on both sides of the bobbin to match the height of the first half of the primary and bias windings.
WD#1 First Half Primary	Start on pin 4, wind 36 turns of item [3] from right to left finishing on pin 2.
Insulation	1 Layer of tape [8] for insulation
WD#2 Bias	Start on Pin 6, wind 11 bifilar turns of item [4] from right to left. Wind with tight tension and finish on pin 5.
Insulation	3 Layers of tape [9] for insulation.
Margin Tape	Wind item [7] on both sides of the bobbin to match the height of the secondary windings.
WD#3 24V OP	Start on pin 12 and 11, wind 16 turns trifilar of item [5] from left to right finishing on pin 10.
Insulation	3 Layers of tape [10] for insulation.
Margin Tape	Wind item [8] on both sides of the bobbin to match the height of second half of the primary and shield windings.
WD#4 Shield	Start on Pin 1, reverse wind (anti-clock-wise) 10 turns trifilar of item [6] from right to left. Wind with tight tension. After finishing the 10th turn, cut the finishing wires.
Insulation	1 Layer of tape [10] for insulation.
WD#4 Second Half Primary	Start on pin 2, wind 36 turns of item [3] from right to left finishing on Pin 1.
Insulation	3 Layers of tape [10] for insulation.
Finish	Grind the core [1]. Secure the core with tape. Varnish [11].

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8 Transformer Design Spreadsheet

ACDC_TOPSwitchHX_120407 Rev.1.6; Copyright Power Integrations 2007	INPUT	INFO	OUTPUT	UNIT	TOP_HX_120407: TOPSwitch-HX Continuous/Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					Customer
VACMIN	90			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	24.00			Volts	Output Voltage (main)
PO_AVG	35.00			Watts	Average Output Power
PO_PEAK	80.00		80.00	Watts	Peak Output Power
n	0.85			%/100	Efficiency Estimate
Z	0.50				Loss Allocation Factor
VB	15			Volts	Bias Voltage
tC	3.00			mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	120.0		120	uFarads	Input Filter Capacitor
ENTER TOPSWITCH-HX VARIABLES					
TOPSwitch-HX	**TOP258MN**			Universal / Peak	115 Doubled/230V
Chosen Device		*TOP258MN*	Power Out	35 W / 92 W	48W
KI	1.00				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN_EXT			2.790	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX_EXT			3.210	Amps	Use 1% resistor in setting external ILIMIT
Frequency (F)=132kHz, (H)=66kHz	**H**		H		Only half frequency option available for P, G and M package devices. For full frequency operation choose Y package.
fS			66000	Hertz	TOPSwitch-HX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			59400	Hertz	TOPSwitch-HX Minimum Switching Frequency
fSmax			72600	Hertz	TOPSwitch-HX Maximum Switching Frequency
High Line Operating Mode			FF		Full Frequency, Jitter enabled
VOR	110.00			Volts	Reflected Output Voltage
VDS			10	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	0.37	*Info*			A minimum KP of 0.4 is recommended for Low Line or Universal input supplies.
PROTECTION FEATURES					
LINE SENSING					
VUV_STARTUP			101	Volts	Minimum DC Bus Voltage at which the power supply will start-up
VOV_SHUTDOWN			490	Volts	Typical DC Bus Voltage at which power supply will shut-down (Max)
RLS			4.4	M-ohms	Use two standard, 2.2 M-Ohm, 5% resistors in series for line sense functionality.
OUTPUT OVERVOLTAGE					
VZ			27	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					
Overload Current Ratio at VMAX			1.2		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			1.08		Margin to current limit at low line.
ILIMIT_EXT_VMIN			2.50	A	Peak primary Current at VMIN
ILIMIT_EXT_VMAX			2.04	A	Peak Primary Current at VMAX
RIL			8.34	k-ohms	Current limit/Power Limiting resistor.
RPL			28.13	M-ohms	Power Limiting resistor
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	EER28		EER28		Core Type
Core		*EER28*		*P/N:*	PC40EER28-Z
Bobbin		*EER28_BOBBIN*		*P/N:*	BEER-28-1112CPH
AE			0.821	cm^2	Core Effective Cross Sectional Area
LE			6.4	cm	Core Effective Path Length
AL			2870	nH/T^2	Ungapped Core Effective Inductance
BW	15.8		15.8	mm	Bobbin Physical Winding Width
M	3.00			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	4.00				Number of Primary Layers
NS	16		16		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			72	Volts	Minimum DC Input Voltage
VMAX			375	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.64		Maximum Duty Cycle (calculated at PO_PEAK)
IAVG			0.57	Amps	Average Primary Current (calculated at average output power)
IP			2.50	Amps	Peak Primary Current (calculated at Peak output power)
IR			0.41	Amps	Primary Ripple Current (calculated at average output power)
IRMS			0.72	Amps	Primary RMS Current (calculated at average output power)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			705	uHenries	Primary Inductance
LP Tolerance	5		5		Tolerance of Primary Inductance
NP			72		Primary Winding Number of Turns
NB			10		Bias Winding Number of Turns
ALG			137	nH/T^2	Gapped Core Effective Inductance
BM			2990	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			4026	Gauss	Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss
BAC			553	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1780		Relative Permeability of Ungapped Core
LG			0.72	mm	Gap Length (Lg > 0.1 mm)
BWE			39.2	mm	Effective Bobbin Width
OD			0.55	mm	Maximum Primary Wire Diameter including insulation
INS			0.07	mm	Estimated Total Insulation Thickness (= 2 * film thickness)

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DIA			0.48	mm	Bare conductor diameter
AWG			25	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			323	Cmils	Bare conductor effective area in circular mils
CMA			448	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
Primary Current Density (J)			4.43	Amps/mm^2	Primary Winding Current density (3.8 < J < 9.75)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			11.24	Amps	Peak Secondary Current
ISRMS			2.43	Amps	Secondary RMS Current
IO_PEAK			3.33	Amps	Secondary Peak Output Current
IO			1.46	Amps	Average Power Supply Output Current
IRIPPLE			1.94	Amps	Output Capacitor RMS Ripple Current
CMS			486	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			23	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.58	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.61	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			0.02	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN			593	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			107	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			68	Volts	Bias Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1			24	Volts	Output Voltage
IO1_AVG			1.46	Amps	Average DC Output Current
PO1_AVG			35.00	Watts	Average Output Power
VD1			0.5	Volts	Output Diode Forward Voltage Drop
NS1			16.00		Output Winding Number of Turns
ISRMS1			2.429	Amps	Output Winding RMS Current
IRIPPLE1			1.94	Amps	Output Capacitor RMS Ripple Current
PIVS1			107	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1			486	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			23	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1			0.58	mm	Minimum Bare Conductor Diameter
ODS1			0.61	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			0.7	Volts	Output Diode Forward Voltage Drop
NS2			0.46		Output Winding Number of Turns
ISRMS2			0.000	Amps	Output Winding RMS Current
IRIPPLE2			0.00	Amps	Output Capacitor RMS Ripple Current
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			0.7	Volts	Output Diode Forward Voltage Drop
NS3			0.46		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			35	Watts	Total Continuous Output Power
Negative Output			N/A		If negative output exists enter Output number; e.g. If VO2 is negative output, enter 2

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9 Power Supply Performance Data

All tests were performed at room temperature (+25 °C) and 60 Hz line frequency unless noted otherwise.

9.1 No-load Input Power

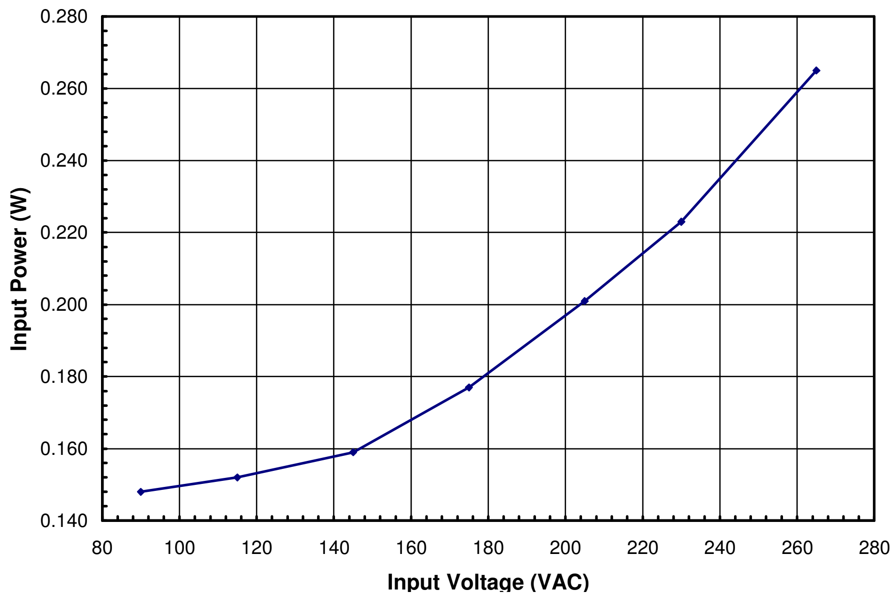

Figure 6 – No Load Power Consumption.

9.2 Full-load Efficiency

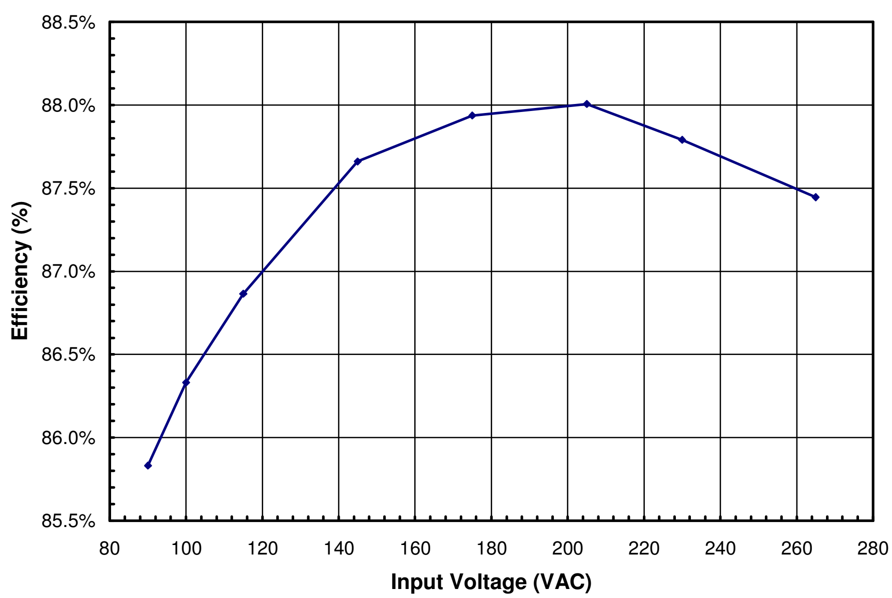

Figure 7 – Efficiency vs. Input Voltage at 35 W Load.

9.3 *Efficiency Table*

The power supply was run at full load for 30 minutes, at room temperature, and allowed to heat up. Efficiency measurements were then taken.

Active-on Efficiency (%)					
V_{IN} (VAC)	**25% Load**	**50% Load**	**75% Load**	**100% Load**	**Average**
115	86.7	87.4	87.1	86.9	87.0
230	85.0	87.1	87.7	87.8	87.0
Sleep Mode					
V_{IN} (VAC)	**P_O (W)**	**P_{IN} (W)**	**Efficiency**	**Notes**	
115	2.55	3.03	84.3 %	Output:23.42 V @ 109 mA	
230	2.39	3.020	79.2 %	Output:23.22 V @ 103 mA	
Standby Mode					
V_{IN} (VAC)	**P_O (W)**	**P_{IN} (W)**	**Efficiency**	**Notes**	
115	0.80	1.02	78.1 %	Output:23.43 V @ 34 mA	
230	0.70	1.00	69.8 %	Output:23.26 V @ 30 mA	
No-Load Input Power					

Table 1 – Efficiency at Distinct Operating Points

Note:

To meet the average active-on efficiency at 115/230 VAC, as defined by the California Energy Commission (CEC) 2008 requirements, a 35 W external power supply must provide a minimum efficiency of 82%. The required minimum efficiency must be calculated using the following equation, using the natural log of the nominal power output:

$$(0.5 + 0.09 * \ln(35)) * 100\% >= 82.0\%$$

This prototype board, as can be seen by the data in Table 1, excels in meeting the efficiency requirement.

To meet the average active-on efficiency and no-load consumption at 115/230 VAC defined by Energy Star Version 2.0 a 35 W external power supply must provide a minimum efficiency of 84.5 % and the no-load consumption must be less than or equal to 300 mW.

$$(0.0626 * \ln(35) + 0.622) * 100\% >= 84.5\%$$

The prototype board, as can be seen by the data in Table 1, excels in meeting the efficiency requirement. Furthermore it can be seen from Figure 6 that the prototype also meets the no-load power consumption goals.

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10 Regulation

10.1 Line Regulation

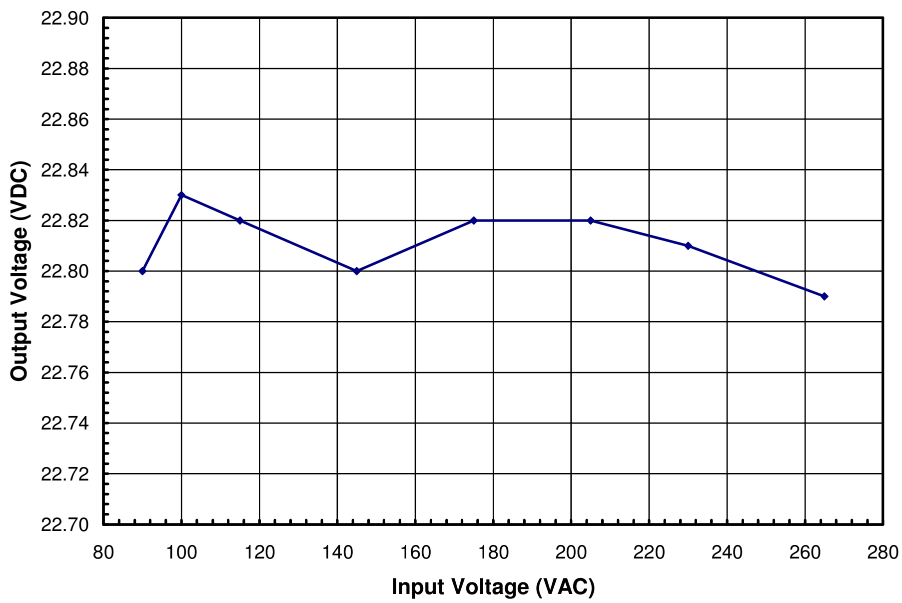

Figure 8 – Output Voltages vs. Line Voltage at 35 W Load.

10.2 Load Regulation

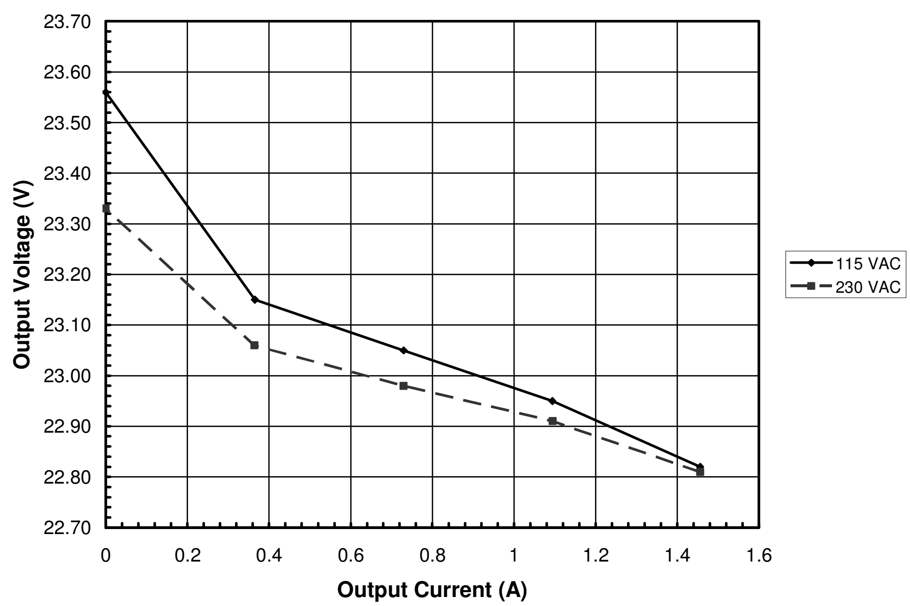

Figure 9 – Load Regulation.

11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

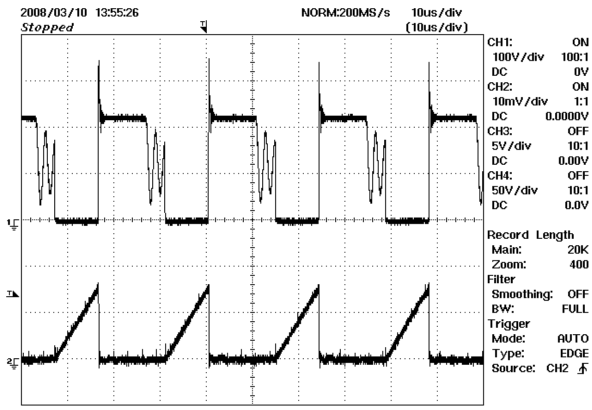

Figure 10 – 90 VAC, 35 W Load.
Upper: V_{DRAIN}, 100 V / div.
Lower: I_{DRAIN}, 0.5 A / div.
Timebase: 10 µs / div.

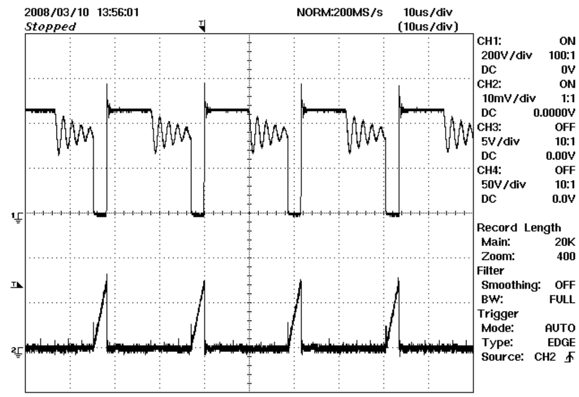

Figure 11 – 265 VAC, 35 W Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.5 A / div.
Timebase: 10 µs / div.

11.2 Output Voltage Start-up Profile

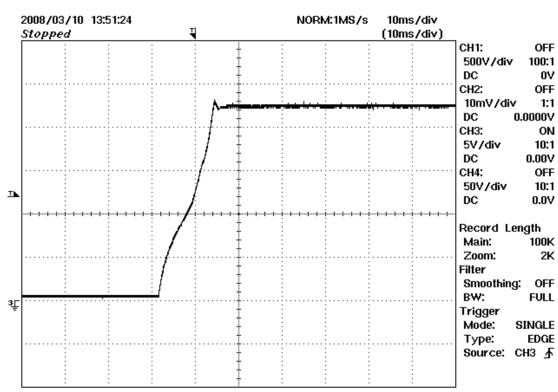

Figure 12 – Start-up Profile, 90 VAC, 35 W Load.
5 V / div, 10 ms / div.

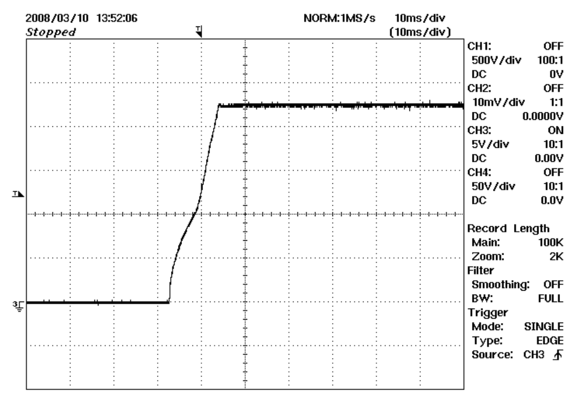

Figure 13 – Start-up Profile, 265 VAC, 35 W Load.
5 V / div, 10 ms / div.

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11.3 Drain Voltage and Current Start-up Profile

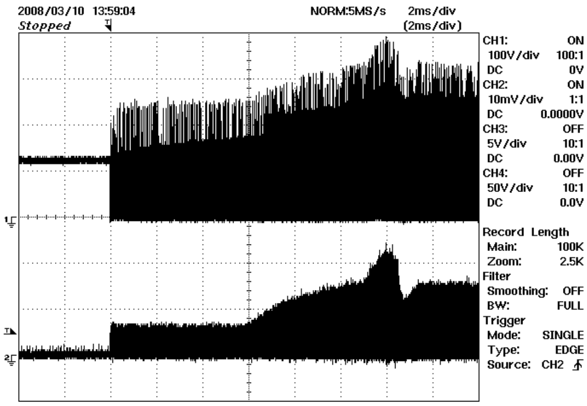

Figure 14 – 90 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 100 V / div.
Lower: I_{DRAIN}, 0.5 A / div.
Timebase: 2 ms / div.

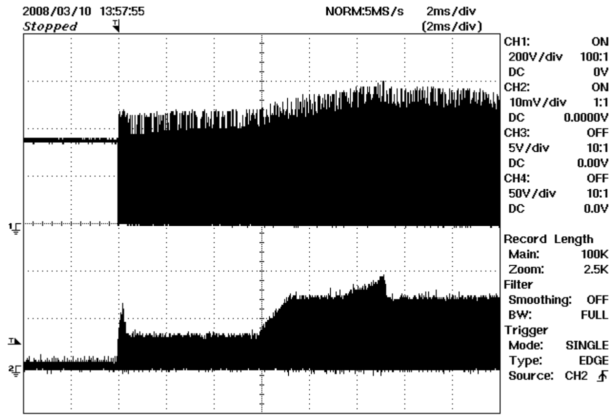

Figure 15 – 265 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.5 A / div.
Timebase: 2 ms / div.

11.4 Load Transient

The following table lists the conditions for the transient load response performance tests. The test was made more severe by omitting any additional capacitive loads across the two outputs at the end of the output cable. Each waveform was captured at the power supply output connector.

Vin (VAC)	TEST #	DUTY RATIO		
		24 V	Peak On	Peak Off
90	1	0.3 W / 80 W	40 ms	1060 ms
265	2	0.3 W / 80 W	40 ms	1060 ms

Table 2 – Summary Transient Load Response Test Conditions.

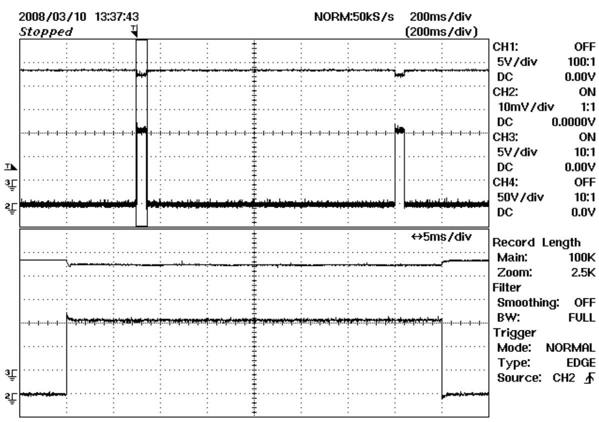

Figure 16 – Transient Response, 90 VAC.
Upper: V_{OUT}, 5 V / div.
Lower: I_{OUT}, 1.0 A / div.
Timebase: 200 ms / div.

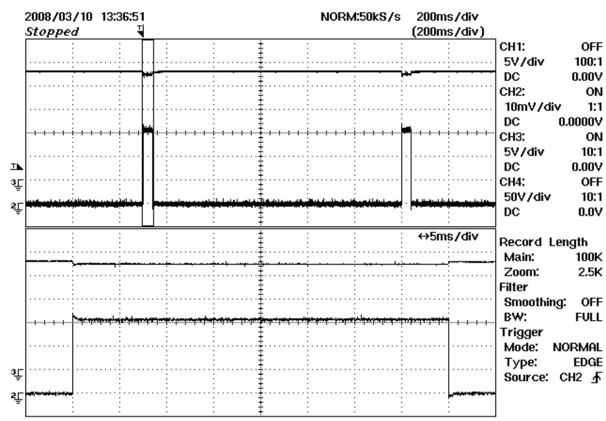

Figure 17 – Transient Response, 265 VAC.
Upper: V_{OUT}, 5 V / div.
Lower: I_{OUT}, 1.0 A / div.
Timebase: 200 ms / div.

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11.5 Latching Overload Protection

In this test the power supply initially runs in standby mode (24 V / 0.01 A). Next the 24 V output is loaded with 3.5 A. After a time greater than 120 ms the power supply latches off.

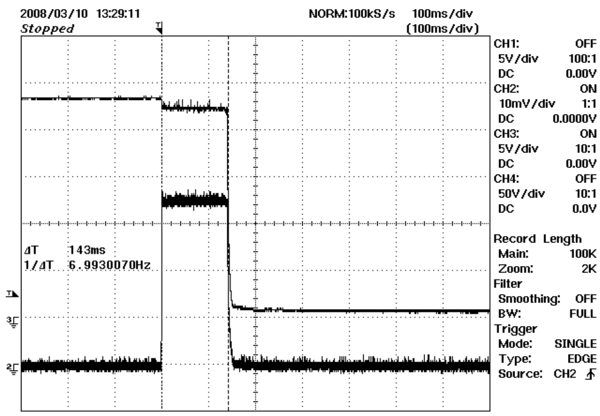

Figure 18 – Overload Protection 90 VAC.
Upper: V_{OUT}, 5 V / div.
Lower: I_{OUT}, 1.0 A / div.
Timebase: 100 ms / div.

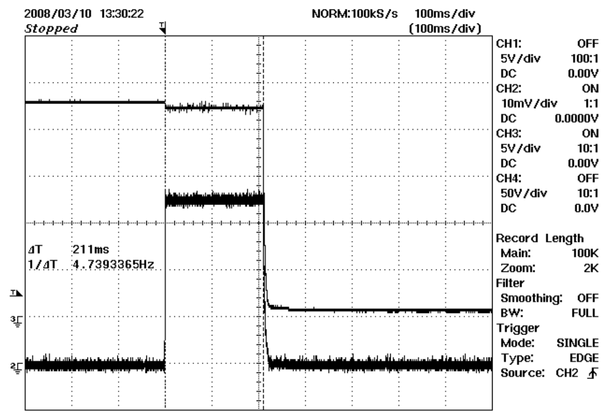

Figure 19 – Overload Protection 265 VAC.
Upper: V_{OUT}, 5 V / div.
Lower: I_{OUT}, 1.0 A / div.
Timebase: 100 ms / div.

11.6 AC Reset

The fast AC reset function test results are shown below. An overload is applied which causes the power supply to latch off. The overload and the AC input are both removed. After approximately three seconds the AC is reapplied and the supply has reset itself, allowing the supply to go through the normal start up process and come into regulation.

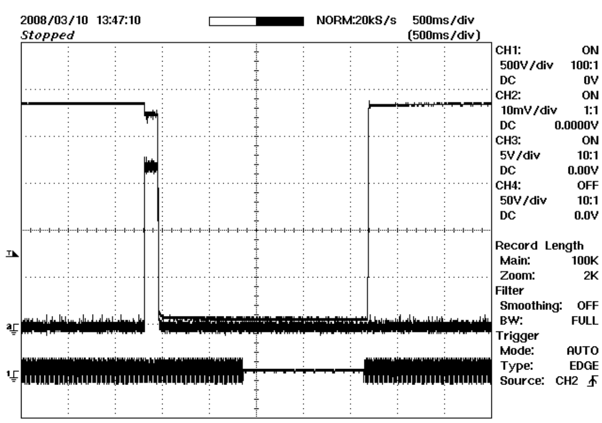

Figure 20 – AC Reset, 90 VAC.
Upper: V_{OUT}, 5 V / div.
Middle: I_{OUT}, 1.0 A / div.
Lower: AC Input, 500 V / div.
Timebase: 500 ms / div.

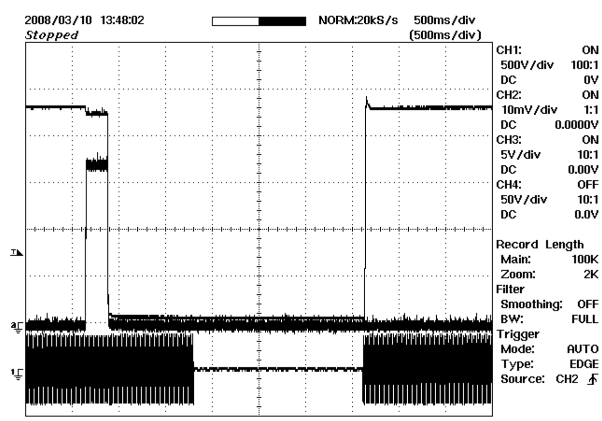

Figure 21 – AC Reset, 265 VAC.
Upper: V_{OUT}, 5 V / div.
Middle: I_{OUT}, 1.0 A / div.
Lower: AC Input, 500 V / div.
Timebase: 500 ms / div.

11.7 AC Line Dropout

The supply maintained output regulation during a half-cycle dropout of the AC supply.

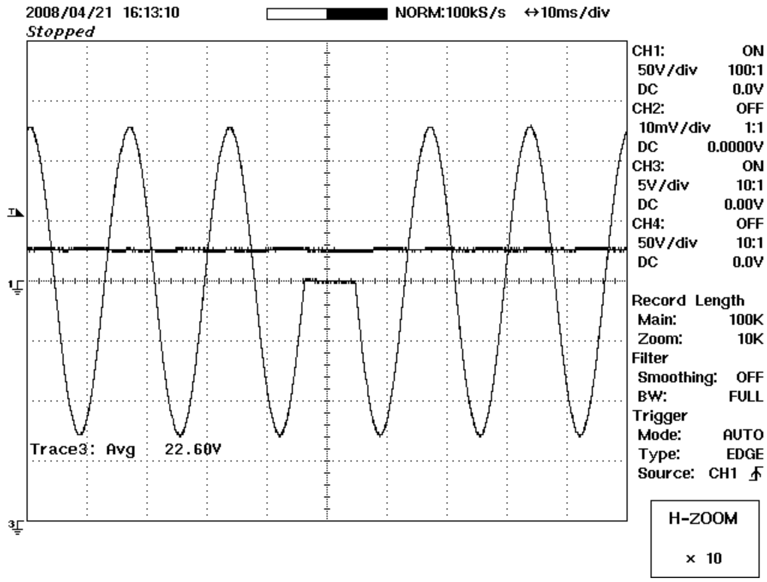

Figure 22 – Line dropout at 90 VAC, 35 W Load. Ch. 1: AC Input, Ch. 2: Output Voltage.

11.8 Open-loop Protection

The emitter of the transistor in optocoupler U2B was opened to simulate a broken control loop. The waveforms were captured at the power supply output under full load.

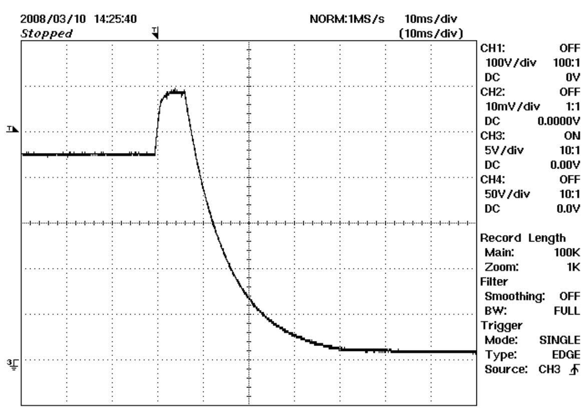

Figure 23 – Overload Protection 90 VAC.
V_{OUT}, 5 V / div.
Timebase: 10 ms / div.

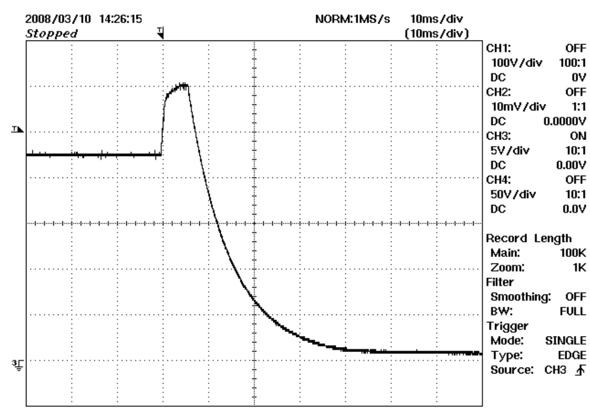

Figure 24 – Overload Protection 265 VAC.
V_{OUT}, 5 V / div.
Timebase: 10 ms / div.

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11.9 Output Noise

11.9.1 Output Noise Measurement Technique

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

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

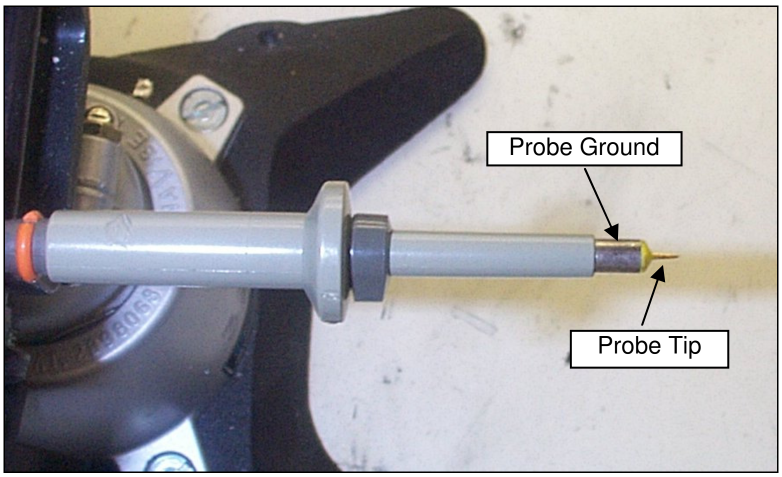

Figure 25 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed).

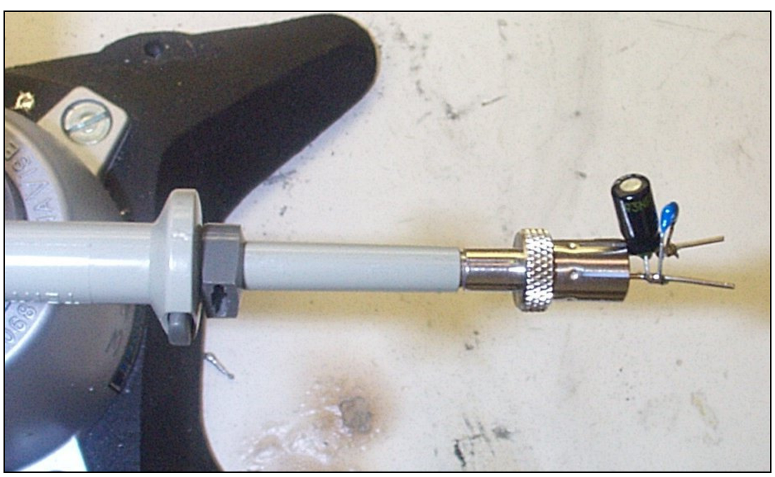

Figure 26 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added.)

11.9.2 Measurement Results

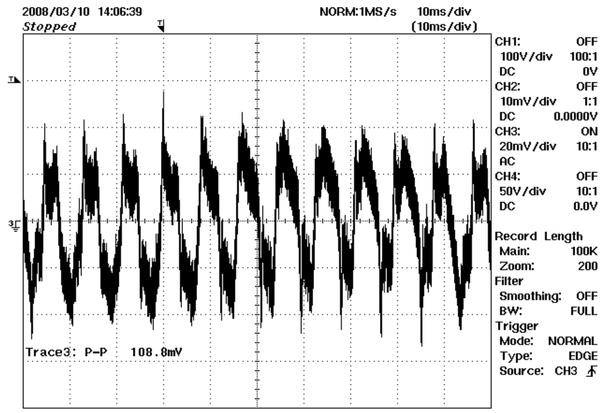

Figure 27 – Ripple, 90 VAC, 35 W Load.
20 mV / div, 10 ms / div.

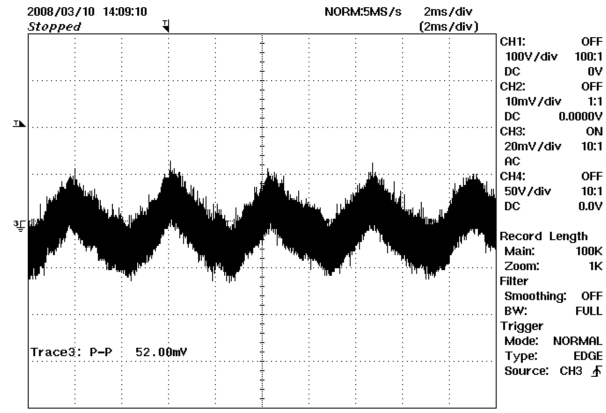

Figure 28 – Ripple, 265 VAC, 35 W Load.
20 mV / div, 2 ms / div.

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12 Control Loop Analysis

The control loop is stable during full load operation. At low line (90 VAC) the supply has a phase margin of approximately 70° and a crossover frequency of approximately 600 Hz. At high line (265 VAC) the supply has a phase margin of approximately 70° with a crossover frequency of approximately 900 Hz.

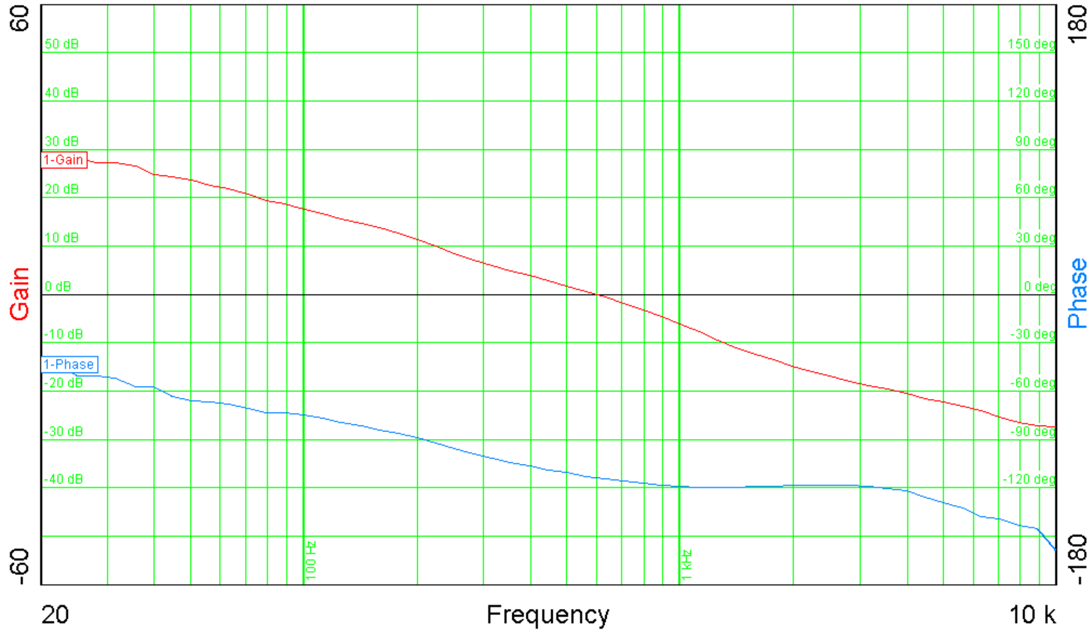

Figure 29 – Control-loop Gain and Phase Plot, Full Load (1.46 A), 90 VAC Input.
Phase Margin: 70º, Crossover Frequency: 600 Hz.

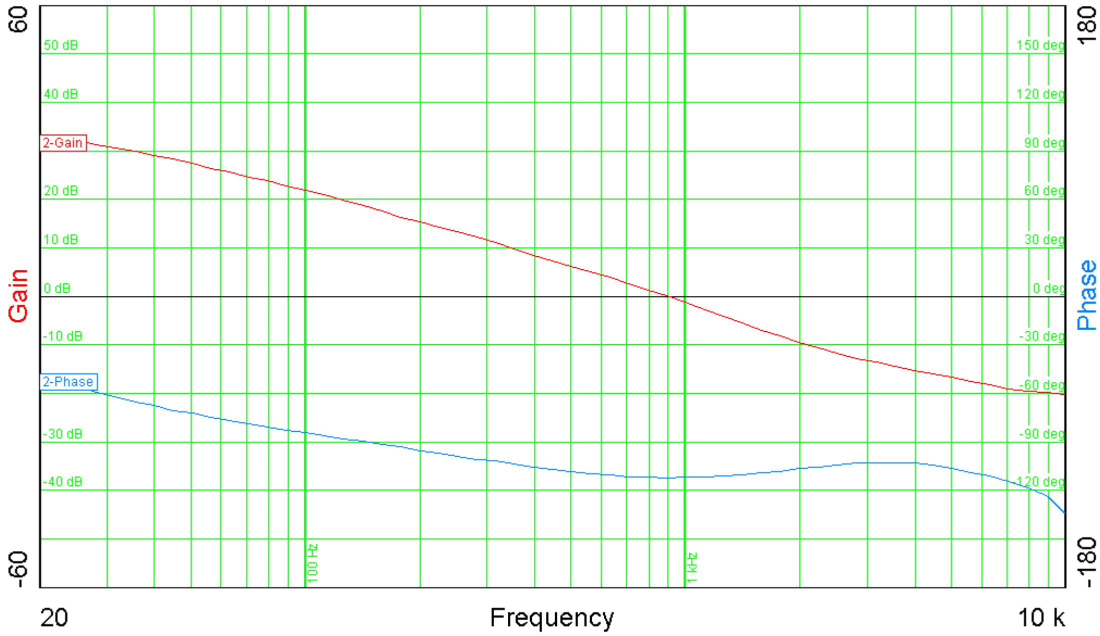

Figure 30 – Control-loop Gain and Phase Plot, Full Load (1.46 A), 265 VAC Input.
Phase Margin: 70º, Crossover Frequency: 900 Hz.

13 Thermal Performance

13.1 Test Results

To accurately test the thermal performance of the power supply, it was placed in a cardboard box to prevent convectional cooling. The box was then placed inside a thermal chamber. The chamber temperature was controlled to maintain a constant temperature inside the box. The supply was operated at its peak output power (3.33 A) using the specified duty cycle of 40 ms peak on-time and 1060 ms off-time.

To measure the device (U1) temperature, a T-type thermocouple was soldered to one of the inner source pins, close to the device plastic case. The output diode (D5) temperature was measured by soldering a T-type thermocouple to the anode, close to the plastic case. The transformer (T1) core temperature was measured by taping a T-type thermocouple firmly to the outer side of the core.

Table 3 – Thermal Performance at 50° C Ambient

Item	**Temperature (°C)**	
	90 VAC	**265 VAC**
Ambient	**50 (°C)**	
U1	114	89
Output Diode D5	98	105
Transformer Core T1	89	91

Table 4 – Thermal Performance at 40° C Ambient

Item	**Temperature (°C)**	
	90 VAC	**265 VAC**
Ambient	**40 (°C)**	
U1	103	78
D5	88	95
T1	79	81

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14 Conducted EMI

14.1 Conducted EMI

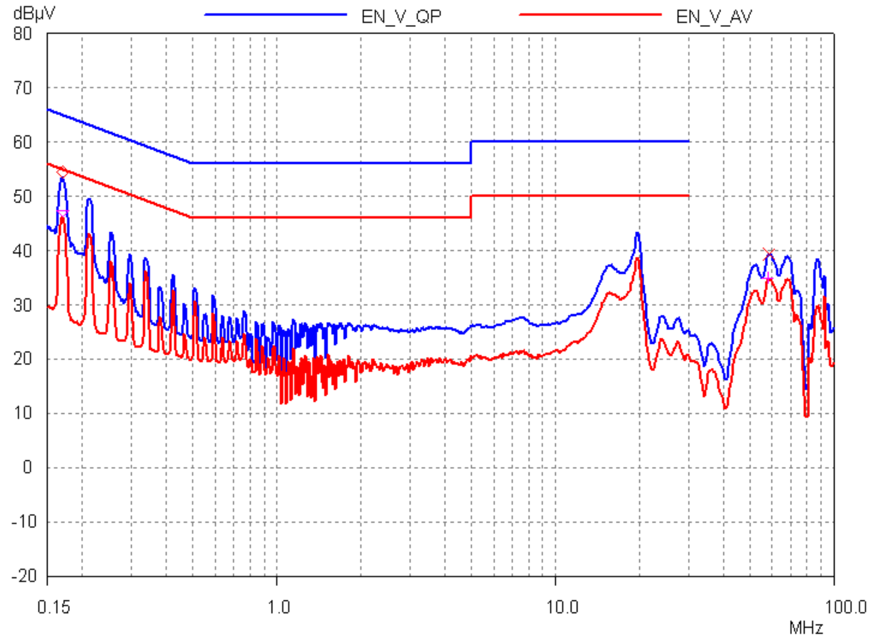

Figure 31 – Worst-case Conducted EMI: 115 VAC, Line Conductor, 35 W Continuous Load, Output Connected to PE.

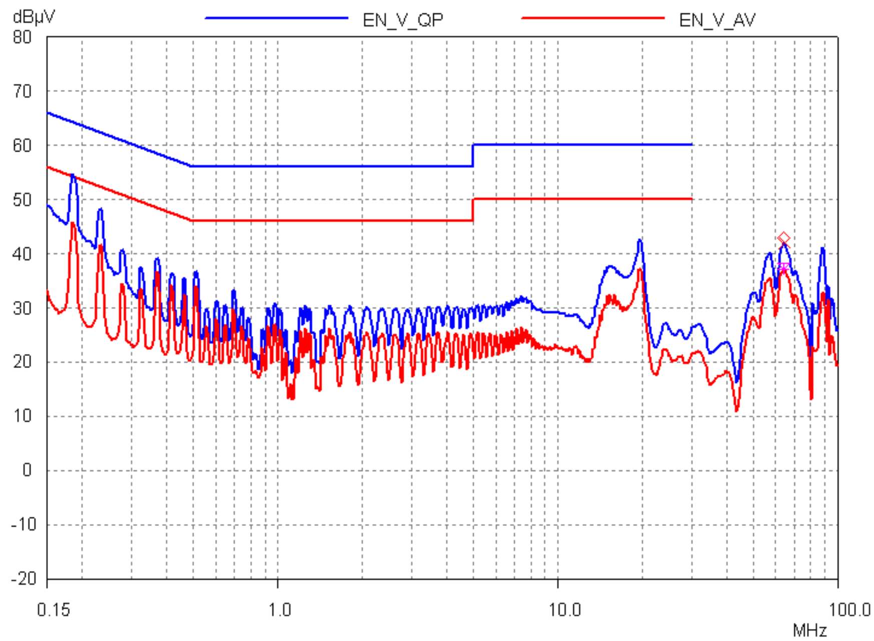

Figure 32 – Worst-case Conducted EMI at 230 VAC, Line Conductor, 35 W Continuous Load, Output Connected to PE.

15 Revision History

Date	Author	Rev.	Description & changes	Reviewed
21-Apr-09	TS	1.1	Initial Release	Apps & Mktg

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