DESIGN EXAMPLE REPORT

Title	***65 W Adapter Using TOP258EN***
Specification	90 – 265 VAC Input; 19 VDC, 3.42 A Output
Application	Notebook Adapter
Author	Applications Engineering Department
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Summary and Features

- Very compact, low parts-count design
  - Internal current limit reduction eliminates need for current limit on secondary-side
  - Primary side overvoltage protection (OVP) eliminates second optocoupler
- 700 V MOSFET reduces solution cost
  - Allows lower-cost Schottky output diode: 60 V, 20 A replaces 100 V, 40 A
  - 132 kHz operation reduces transformer size, reducing cost
  - Low MOSFET capacitance allows higher frequency operation without efficiency penalty
- Highly energy efficient
  - Very low no-load input power: <200 mW @ 265 VAC
  - High full-load efficiency: >86%
  - High average efficiency: >87%
- Excellent transient load response
- Hysteretic thermal protection
- Over-load protection with automatic recovery
- Latching fault protection

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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 a notebook adapter power supply employing the Power Integrations® TOPSwitch®-HX TOP258EN. This power supply operates over a universal input range and provides a 19 V, 65 W output. It has been designed and tested to operate in a sealed enclosure in an external ambient temperature environment of up to 40 °C.

The high voltage (700 V) rating of the MOSFET in the TOPSwitch-HX allows the transformer primary to secondary turns ratio to be increased in this design (relative to a design using a 600 V or 650 V MOSFET). This allows using a 60 V, 20 A Schottky output diode instead of a 100 V, 40 A diode; increasing efficiency and lowering cost.

The TOPSwitch-HX, by design, maintains virtually constant efficiency across a very wide load range without using special operating modes to meet specific load thresholds. This optimizes performance for existing and emerging energy-efficiency regulations. Maintaining constant efficiency ensures design optimization for future energy-efficiency regulation changes without the need for redesign.

The low MOSFET capacitance of TOPSwitch-HX allows a higher switching frequency without the efficiency penalty which occurs with standard discrete MOSFETs. The 132 kHz switching frequency (rather than the 70 kHz to 100 kHz frequency used for a discrete MOSFET) reduces the transformer size required, and so reduces cost.

This power supply offers the following protection features:

- OVP with latching shutdown
- Latching open-loop protection
- Auto-recovery type overload protection
- Auto-restart during brownout or line sag conditions
- Accurate thermal overload protection with auto-recovery, using a large hysteresis

This document provides complete design details including specifications, the schematic, bill of materials, and transformer design and construction information. This information includes performance results pertaining to regulation, efficiency, standby, transient load, power-limit data, and conducted EMI immunity.

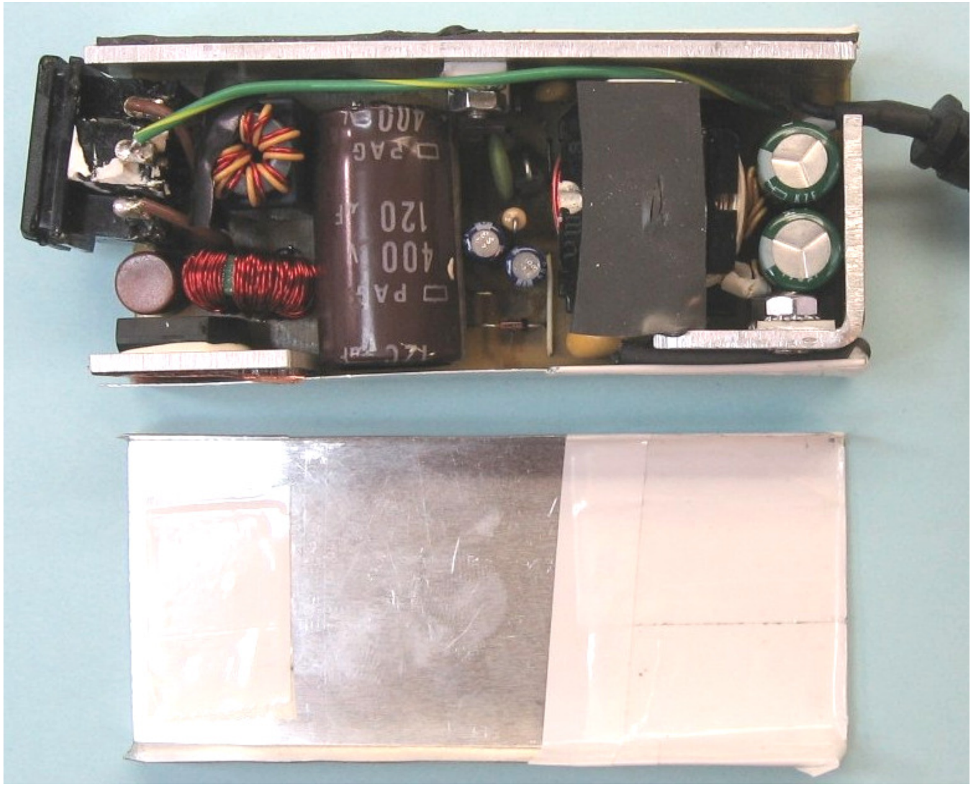

Figure 1 – Power Supply Photograph Showing Populated PCB and Shield / Heatspreader.
(9.4 cm x 4 cm x 2.2 cm)

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2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	3 Wire – with P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				0.3	W	
Output						
Output Voltage 1	V_{OUT1}	18.4	19	19.6	V	± 5%
Output Ripple Voltage 1	$V_{RIPPLE1}$			100	mV	20 MHz bandwidth
Output Current 1	I_{OUT1}		3.42		A	
Total Output Power						
Continuous Output Power	P_{OUT}		65		W	
Peak Output Power	P_{OUT_PEAK}				W	
Efficiency						
Full Load	η	87			%	Measured at P_{OUT} 25 °C
Required average efficiency at 25%, 50%, 75% and 100 % of P_{OUT}	η_{CEC}	85			%	California Energy Commission (CEC)
	$\eta_{ES2.0}$	87			%	ENERGYSTAR 2008
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Surge		1			kV	1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω
		2			kV	Common Mode: 12 Ω
Dimensions	l x w x h	9.4 x 4 x 2.2			cm	Populated PCB
		10.1 x 4.7 x 2.9				Case External
Ambient Temperature	T_{AMB}	0		50	°C	Free convection, sea level

3 Schematic

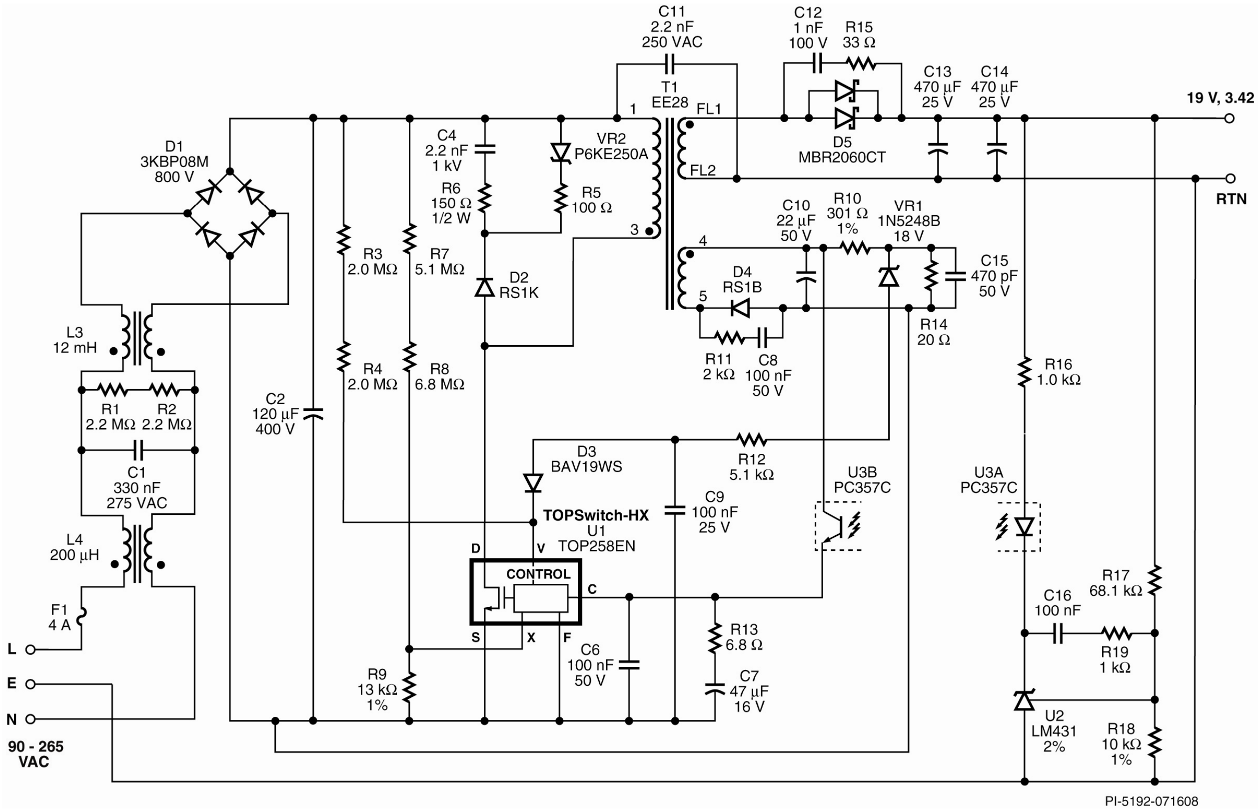

Figure 2 – Schematic.

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4 Circuit Description

4.1 General

This power supply employs a TOP258EN off-line switcher, (U1), in a flyback configuration. IC U1 has an integrated 700 V MOSFET and a multi-mode controller. It regulates the output by adjusting the MOSFET duty cycle, based on the current fed into its CONTROL (C) pin.

4.2 Energy Efficiency

The EcoSmart feature of U1 automatically provides constant efficiency over the entire load range. It uses a proprietary Multi-cycle-modulation (MCM) function to eliminate the need for special operating modes triggered at specific loads. This simplifies circuit design since it removes the need to design for aberrant or specific operating conditions or load thresholds.

4.3 Output Power Limiting with Line Voltage

Resistors R7, R8, and R9 reduce the external current limit of U1 as the line voltage increases. This allows the supply to limit the output power to <100 VA at high line while still delivering the rated output at low line, and to provide a constant output power level with changing line voltages. The combined value of line-sensing resistors R3 and R4 (4 MΩ) sets the under-voltage and overvoltage thresholds for U1. This value also sets the maximum duty cycle at specific voltages.

4.4 Output Overvoltage Protection

Open-loop faults cause the output voltage to exceed the specified maximum value. To prevent excessive output voltage levels in such cases, U1 utilizes an output overvoltage shutdown function. An increase in output voltage causes an increase in the bias winding on the primary side, sensed by VR1. A sufficient rise in the bias voltage causes VR1 to conduct and a current to be injected into the Voltage (V) pin of U1. When the current exceeds 112 μA, U1 enters the overvoltage shutdown mode. This shutdown is hysteretic and attempts are made to restart the power supply at regular intervals to check if the fault condition is removed. To change this mode to a latching shutdown, reduce the value of R12 enough to cause current into the V pin to exceed 336 μA during an open-loop condition.

4.5 Thermal Overload Protection

IC U1 has an integrated accurate hysteretic thermal overload protection function. When the junction temperature of U1 reaches +142 °C during a fault condition, the IC shuts down. It automatically recovers once the junction temperature has decreased by 75 °C.

4.6 AC Input and EMI Filtering

Common-mode inductors L3 and L4 provide filtering on the AC input. X-capacitor C1 provides differential filtering, and resistors R1 and R2 provide safety from shock if the AC is removed, by ensuring a path for C1 to discharge. Bridge rectifier D1 rectifies the AC input, and bulk capacitor C2 filters the DC.

Y-capacitor C11, connected between the primary and secondary side provides common-mode filtering.

4.7 TOP258EN and Primary

Capacitor C7 provides the auto-restart timing for U1. At startup this capacitor is charged through the DRAIN (D) pin. Once it is charged U1 begins to switch. Capacitor C7 stores enough energy to ensure the power supply starts up. After start-up the bias winding powers the controller via the CONTROL pin. Bypass capacitor C6 is placed as physically close as possible to U1. Resistor R13 provides compensation to the feedback loop.

The clamp network formed by VR2, C4, R5, R6, and D2 limits the drain voltage (preventing spikes at MOSFET turn off) and dissipates transformer leakage inductance energy. Capacitor C4 does not discharge below the value of VR2 during low frequency operating modes to improve light load efficiency and reduce no-load input power. Resistor R6 dampens high-frequency ringing.

4.8 Output Regulation

Schottky diode D5 rectifies the output. A snubber network (C12, R15) dampens ringing across the diodes and reduces high frequency conducted and radiated noise. Capacitors C13 and C14 provide output filtering. Resistors R17 and R18 provide a voltage divider and set the DC setpoint of the output. Capacitor C16 and R19 form the phase compensation for the feedback control loop. Resistor R16 limits the gain of the feedback system to ensure power supply stability throughout the range of operation.

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5 PCB Layout

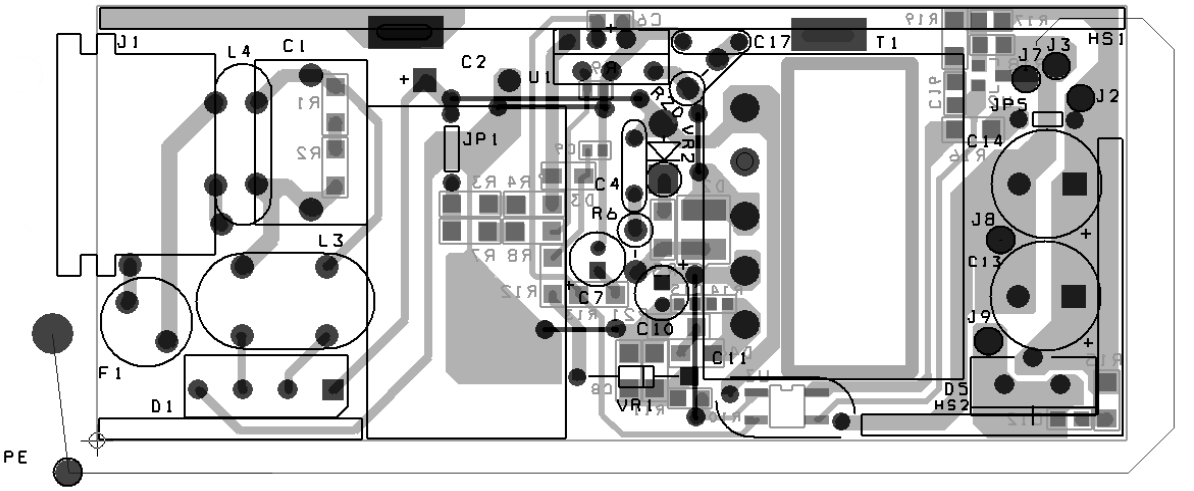

Figure 3 – Printed Circuit Layout.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C1	330 nF, 275 VAC, Film, X2	LE334-M	OKAYA
2	1	C2	120 µF, 400 V, Electrolytic, (18 x 30)	EPAG401ELL121MM30S	Nippon Chemi-Con
3	1	C4	2.2 nF, 1 kV, Disc Ceramic	NCD222K1KVY5FF	NIC Components Corp
4	2	C6 C16	100 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H104K	Panasonic
5	1	C7	47 µF, 16 V, Electrolytic, Low ESR, 500 mΩ, (5 x 11.5)	ELXZ160ELL470MEB5D	Nippon Chemi-Con
6	1	C8	100 nF, 50 V, Ceramic, X7R, 1206	ECJ-3VB1H104K	Panasonic
7	1	C9	100 nF 25 V, Ceramic, X7R, 0603	ECJ-1VB1E104K	Panasonic
8	1	C10	22 µF, 50 V, Electrolytic, Very Low ESR, 340 mΩ, (5 x 11)	EKZE500ELL220ME11D	Nippon Chemi-Con
9	1	C11	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
10	1	C12	1 nF, 100 V, Ceramic, X7R, 0805	ECJ-2VB2A102K	Panasonic
11	2	C13 C14	470 µF, 25 V, Electrolytic, Very Low ESR, 38 mΩ, (10 x 16)	EKZE250ELL471MJ16S	Nippon Chemi-Con
12	1	C15	470 pF 50 V, Ceramic, X7R, 0603	ECJ-1VC1H471J	Panasonic
13	1	D1	800 V, 3 A, Bridge Rectifier, Glass Passivated	3KBP08M-E4/51	Vishay
14	1	D2	800 V, 1 A, Fast Recovery, 250 ns, SMA	RS1K-13-F	Diodes, Inc
15	1	D3	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diode Inc.
16	1	D4	100 V, 1 A, Fast Recovery, 150 ns, SMA	RS1B-13-F	Diodes, Inc
17	1	D5	60 V, 20 A, Dual Schottky, TO-220AB	MBR2060CT	Vishay
18	1	F1	4 A, 250 V,Fast, TR5	3701400041	Wickman
19	1	HS1	Heatsink	Custom	Power Integrations
20	1	HS2	Heatsink	Custom	Power Integrations
21	1	J1	AC Input Receptacle, 2.5 A 250 V	PF-190	Rong Feng
22	6	J2 J3 J6 J7 J8 J9	PCB Terminal Hole, 22 AWG	N/A	N/A
23	2	JP1 JP5	Wire Jumper, Insulated, 22 AWG, 0.3 in	C2004-12-02	Gen Cable
24	1	L3	12 mH,xA, Ferite Toroid, 4 Pin, Output		
25	1	L4	200 µH,xA, Ferite Toroid, 4 Pin, Output		
26	1	NUT1	Nut, Hex, Kep 4-40, S ZN Cr3 plating RoHS		
27	1	POWR CLIP1	Heatsink Hardware, Edge Clip 21N (4.7 lbs) 10 mm L x 7 mm W x 0.5 mm H	CLP212SG	Aavid Thermalloy
28	2	R1 R2	2.2 MΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ225V	Panasonic
29	3	R3 R4 R11	2 MΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ205V	Panasonic
30	1	R5	100 Ω, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ101V	Panasonic
31	1	R6	150 Ω, 5%, 1/2 W, Carbon Film	CFR-50JB-150R	Yageo
32	1	R7	5.1 MΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ515V	Panasonic
33	1	R8	6.8 MΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ685V	Panasonic
34	1	R9	13 kΩ, 1%, 1/16 W, Metal Film, 0603	ERJ-3EKF1302V	Panasonic
35	1	R10	301 Ω, 1%, 1/8 W, Metal Film, 0805	ERJ-6ENF3013V	Panasonic
36	1	R12	5.1 kΩ 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ512V	Panasonic
37	1	R13	6.8 Ω, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ6R8V	Panasonic
38	1	R14	20 Ω, 5%, 1/10 W, Metal Film, 0603	ERJ-3GEYJ200V	Panasonic
39	1	R15	33 Ω, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ330V	Panasonic
40	1	R16	1.0 kΩ, 1%, 1/4 W, Metal Film, 1206	ERJ-8ENF1001V	Panasonic
41	1	R17	68.1 kΩ, 1%, 1/8 W, Metal Film, 0805	ERJ-6ENF6812V	Panasonic
42	1	R18	10 kΩ, 1%, 1/8 W, Metal Film, 0805	ERJ-6ENF1002V	Panasonic
43	1	R19	1 kΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ102V	Panasonic
44	1	SCREW1	SCREW MACHINE PHIL 4-40X5/16 SS	PMSSS 440 0031 PH	Building Fasteners
45	1	T1	Bobbin, EE28. Vertical, Extd creepage, 10 pins	YW-490-00B	Yih-Hwa Enterprises
46	1	U1	TOPSwitch-HX, TNY258EN, eSIP-7C	TOP258EN	Power Integrations
47	1	U2	2.495 V Shunt Regulator IC, 2%, -40 to 85C, SOT23	LM431AIM	National Semiconductor
48	1	U3	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N3TJ00F	Sharp
49	1	VR1	18 V, 5%, 500 mW, DO-35	1N5248B-T	Diode Inc.
50	1	VR2	250 V, 600 W Pk, 5%, TVS, DO204AC (DO-15)	P6KE250ARL	ST

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7 Transformer Specification

7.1 Electrical Diagram

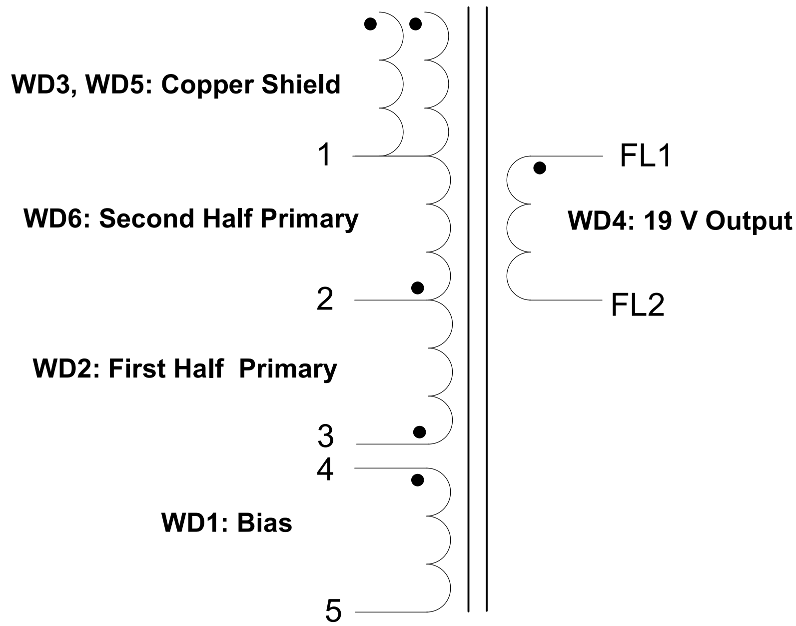

Figure 4 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Primary to Secondary	3000 VAC
Primary Inductance	Pins 1-3, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	452 μH, ±5%
Resonant Frequency	Pins 1-3, all other windings open	1 MHz (Min.)
Primary Leakage Inductance	Pins 1-3, with Pins 4-5 and secondary shorted, measured at 100 kHz, 0.4 V_{RMS}	5 μH (Max.)

7.3 Materials

Item	Description
[1]	Core: EE28 PC44 gapped to ALG of 478 nH/T^2
[2]	Bobbin: EE28. Vertical, extended creepage, 10 pins
[3]	Magnet Wire: #32 AWG, double coated
[4]	Magnet Wire: #25 AWG, double coated
[5]	Triple Insulated Wire: #24 AWG, Triple Insulated Wire
[6]	Tape, 3M Polyester Film, 2.0 mils thick, 9.6 mm wide
[7]	Copper Foil Tape 2 mils
[8]	Tape, 3M Polyester Film, 2.0 mils thick, 13 mm wide
[9]	Varnish

7.4 Transformer Build Diagram

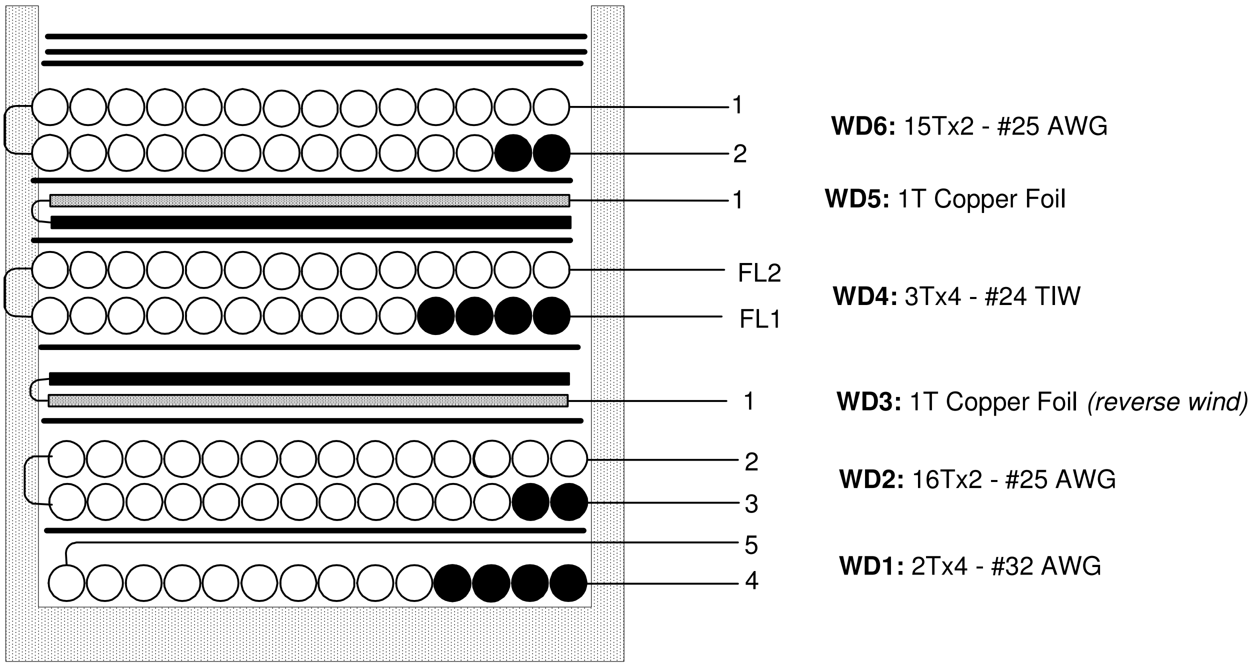

Figure 5 – Transformer Build Diagram.

FL – Flying leads. Mark the start of the secondary winding to denote electrical polarity.

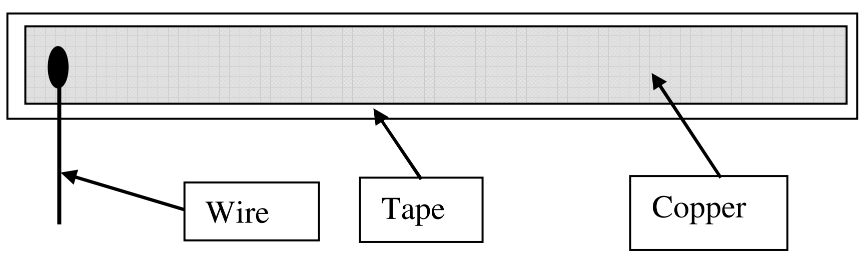

Figure 6 – WD3 and WD5 Copper Foil Preparation. Build using Items [3], [7], and [8].

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7.5 Transformer Construction

Bobbin Preparation	Primary side of the bobbin (item [2]) orients such that the pins are on the right hand side. Winding direction is clockwise.
Quadfilar Bias Winding	Starting at Pin 4, wind 2 quadfilar turns of item [3]. Spread turns evenly across bobbin. Finish at Pin 5.
Basic Insulation	Use one layer of item [6].
Primary	Start at Pin 3. Wind 16 bifilar turns of item [4] in 2 layers. Finish on Pin 2.
Basic Insulation	Use one layer of item [6].
Copper Shield	Use the prepared copper shield. Start on pin 1. Wind 1 turn in anticlockwise direction. Place tape of item [6] first to avoid shortage. Do not terminate this winding.
Basic Insulation	Use one layer of item [6] for basic insulation.
Quadfilar Secondary Winding	Wind 3 quadrifilar turns of item [5] (about 2 layers). Spread turns evenly across bobbin. Finish on temporary pins on secondary side. After one layer of tape to secure the winding in place, cut out the connection to the temporary pins for start and finish this winding. Leave secondary winding leads as flying. Mark the starting end of the winding for identification.
Basic Insulation	Use one layer of item [6] for basic insulation.
Copper Shield	Use the prepared copper shield. Wind 1 turn in clockwise direction. Place tape of item [6] first to avoid shortage. Finish on Pin 1.
Basic Insulation	Use one layer of item [6].
Primary	Start at Pin 2. Wind 15 bifilar turns of item [4] in 2 layers. Finish on Pin 1.
Final Assembly	Assemble and secure core halves so that the tape wrapped E core is at the bottom of the transformer. Varnish impregnate in item [9].

8 Transformer Spreadsheet

ACDC_TOPSwitchHX_021308; Rev.1.8; Copyright Power Integrations 2008	INPUT	INFO	OUTPUT	OUTPUT	UNIT	TOP_HX_021308: 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	19.00				Volts	Output Voltage (main)
PO_AVG	65.00				Watts	Average Output Power
PO_PEAK			65.00	65.00	Watts	Peak Output Power
n	0.83				%/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	120	uFarads	Input Filter Capacitor
ENTER TOPSWITCH-HX VARIABLES						
TOPSwitch-HX	**TOP258EN**				Universal / Peak	115 Doubled/230V
Chosen Device		*TOP258EN*	Power Out	Power Out	148 W / 148 W	195W
KI	0.48					External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN_EXT			1.920	1.920	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX_EXT			2.208	2.208	Amps	Use 1% resistor in setting external ILIMIT
Frequency (F)=132kHz, (H)=66kHz	**F**		F	F		Select 'H' for Half frequency - 66kHz, or 'F' for Full frequency - 132kHz
fS			132000	132000	Hertz	TOPSwitch-HX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			119000	119000	Hertz	TOPSwitch-HX Minimum Switching Frequency
fSmax			145000	145000	Hertz	TOPSwitch-HX Maximum Switching Frequency
High Line Operating Mode			FF	FF		Full Frequency, Jitter enabled
VOR	200.00				Volts	Reflected Output Voltage
VDS			10	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	0.60					Ripple to Peak Current Ratio (0.3 < KRP < 1.0 : 1.0< KDP<6.0)
PROTECTION FEATURES						
LINE SENSING						
VUV_STARTUP			101	101	Volts	Minimum DC Bus Voltage at which the power supply will start-up
VOV_SHUTDOWN			490	490	Volts	Typical DC Bus Voltage at which power supply will shut-down (Max)
RLS			4.4	4.4	M-ohms	Use two standard, 2.2 M-Ohm, 5% resistors in series for line sense functionality.
OUTPUT OVERVOLTAGE						

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VZ			27	27	Volts	Zener Diode rated voltage for Output Overvoltage shutdown protection
RZ			5.1	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	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			1.04	1.04		Margin to current limit at low line.
ILIMIT_EXT_VMIN			1.82	1.82	A	Peak primary Current at VMIN
ILIMIT_EXT_VMAX			1.75	1.75	A	Peak Primary Current at VMAX
RIL			12.72	12.72	k-ohms	Current limit/Power Limiting resistor.
RPL			N/A	N/A	M-ohms	Resistor not required. Use RIL resistor only
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES						
Core Type	EI28		EI28	EI28		Core Type
Core		*EI28*			*P/N:*	PC40EI28-Z
Bobbin		*EI28_BOBBIN*			*P/N:*	BE-28-1110CPL
AE			0.86	0.86	cm^2	Core Effective Cross Sectional Area
LE			4.82	4.82	cm	Core Effective Path Length
AL			4300	4300	nH/T^2	Ungapped Core Effective Inductance
BW			9.6	9.6	mm	Bobbin Physical Winding Width
M	0.00				mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2.00					Number of Primary Layers
NS	3		3	3		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS						
VMIN			84	84	Volts	Minimum DC Input Voltage
VMAX			375	375	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS						
DMAX			0.73	0.73		Maximum Duty Cycle (calculated at PO_PEAK)
IAVG			0.93	0.93	Amps	Average Primary Current (calculated at average output power)
IP		***Warning***	1.82	1.82	Amps	Peak Primary Current (calculated at Peak output power)
IR			1.09	1.09	Amps	Primary Ripple Current (calculated at average output power)
IRMS			1.12	1.12	Amps	Primary RMS Current (calculated at average output power)
TRANSFORMER PRIMARY DESIGN PARAMETERS						
LP			452	452	uHenries	Primary Inductance
LP Tolerance	5		5	5		Tolerance of Primary Inductance
NP			31	31		Primary Winding Number of Turns
NB			2	2		Bias Winding Number of Turns
ALG			478	478	nH/T^2	Gapped Core Effective Inductance
BM		***Warning***	3119	3119	Gauss	Operating flux density should be below 3000 Gauss, Increase turns

						OR increase core size
BP			3965	3965	Gauss	Peak Flux Density (BP<4200) at ILIMITMAX and LP_MAX. Note: Recommended values for adapters and external power supplies <=3600 Gauss
BAC			936	936	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1918	1918		Relative Permeability of Ungapped Core
LG			0.20	0.20	mm	Gap Length (Lg > 0.1 mm)
BWE			19.2	19.2	mm	Effective Bobbin Width
OD			0.62	0.62	mm	Maximum Primary Wire Diameter including insulation
INS			0.07	0.07	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.55	0.55	mm	Bare conductor diameter
AWG			24	24	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			406	406	Cmils	Bare conductor effective area in circular mils
CMA			362	362	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
Primary Current Density (J)			5.49	5.49	Amps/m m^2	Primary Winding Current density (3.8 < J < 9.75)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)						
Lumped parameters						
ISP			18.71	18.71	Amps	Peak Secondary Current
ISRMS			7.01	7.01	Amps	Secondary RMS Current
IO_PEAK			3.42	3.42	Amps	Secondary Peak Output Current
IO			3.42	3.42	Amps	Average Power Supply Output Current
IRIPPLE			6.12	6.12	Amps	Output Capacitor RMS Ripple Current
CMS			1402	1402	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			18	18	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			1.03	1.03	mm	Secondary Minimum Bare Conductor Diameter
ODS			3.20	3.20	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			1.09	1.09	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS						
VDRAIN		***Warning***	755	755	Volts	!!! REDUCE DRAIN VOLTAGE Vdrain<680, reduce VACMAX, reduce VOR
PIVS			56	56	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			44	44	Volts	Bias Rectifier Maximum Peak Inverse Voltage

Note – The very high reflected output voltage (VOR) levels in this design require special considerations, and so the following warnings can be ignored:

- Peak Primary current (IP) – The margin between the peak primary current during normal operation and the worst case minimum current limit is less than recommended. Check both the transient response and control-loop bandwidth to ensure this performance is satisfactory.
- Maximum flux density (BM) - Ideally this flux density should be kept below 3000 Gauss. We can ignore this warning since the AC flux is below 1000 and BP is below 4200 Gauss.

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- Max Drain Voltage (VDRAIN) – VDRAIN must not exceed the rated voltage of the MOSFET (700 V). The spreadsheet assumes a clamping voltage of 1.8 times VOR (360 V). This design has a lowered clamping voltage of 240 V, which ensures VDRAIN stays within specified limits. See maximum drain voltage waveforms.

9 Performance Data

All measurements were performed at room temperature.

9.1 Efficiency

The following efficiency data was taken at room temperature, using a 60 Hz AC input. The output voltage was measured at the end of a cable connected to the output. The cable has a DC resistance of approximately 0.1 Ώ. The unit was operated at full load for 15 minutes prior to taking the measurements.

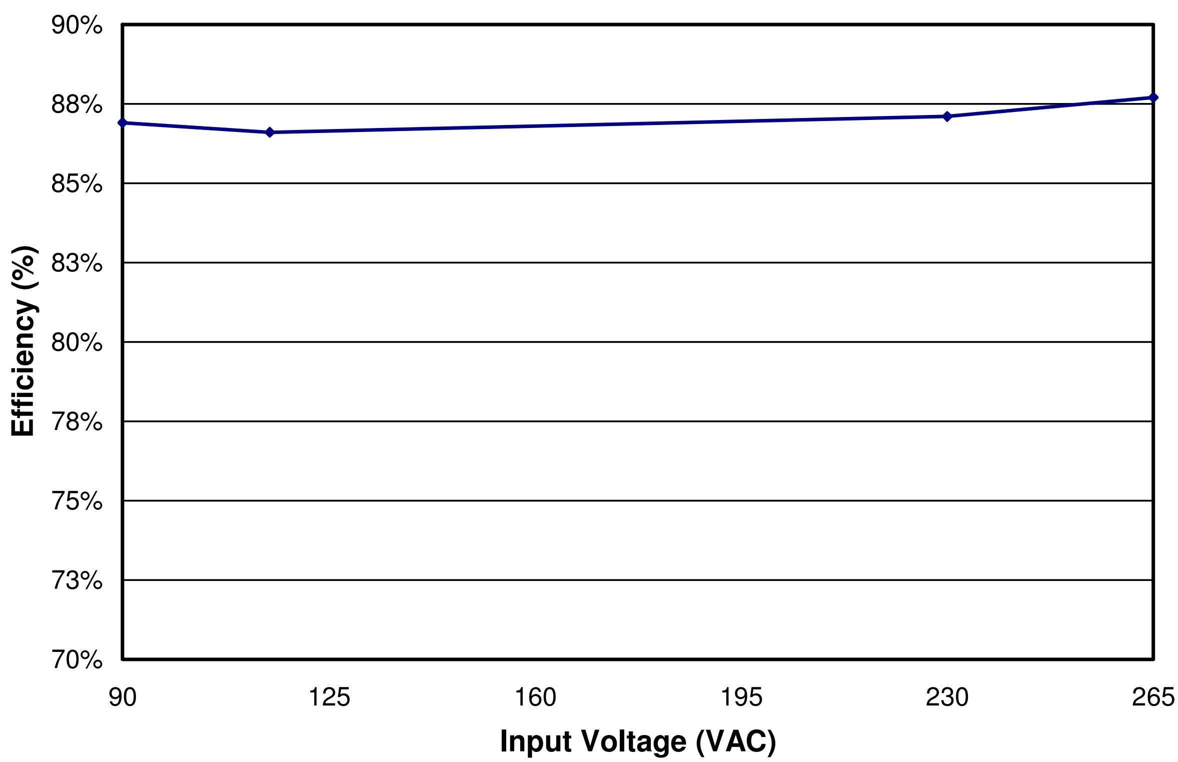

Figure 7 – Efficiency vs. Input Voltage, Room Temperature, 60 Hz.

9.1.1 Active Mode CEC Measurement Data

All single output adapters, including those provided with products, for sale in California after Jan 1st, 2007, must meet the California Energy Commission (CEC) requirement for minimum active-mode efficiency, and no-load input power. The minimum active mode efficiency is defined as the average efficiency measured at 25%, 50%, 75% and 100% of rated output power, with the limit based on the nameplate output power:

Nameplate Output (P_O)	Minimum Efficiency in Active Mode of Operation
< 1 W	$0.5 \times P_O$
≥ 1 W to ≤ 51 W	$0.09 \times \ln(P_O) + 0.5$ [ln = natural log]
> 51 W	0.85

For adapters that use a single input voltage only the measurement is made at the rated single nominal input voltage (115 VAC *or* 230 VAC). For universal input adapters the measurement is made at both nominal input voltages (115 VAC and 230 VAC).

To meet the standard, the measured average efficiency (or efficiencies for universal input supplies) must be greater than or equal to the efficiency specified by the CEC/Energy Star standard. The data below shows the results for this power supply design.

Percent of Full Load	Efficiency (%)	
	115 VAC	230 VAC
25	88.03	87.11
50	87.67	87.44
75	87.42	87.37
100	86.47	87.74
Average	87.4	87.42
ENERGY STAR 2.0	87	
CEC 2008 specified minimum average efficiency (%)	85	

For the latest up to date information please visit the PI Green Room:
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9.2 Output Diode Efficiency Comparison

The following table shows how using different output diodes with different ratings affects efficiency in this design. All three diodes used the same power supply unit and use the same TOP258EN device.

% of Full Load	MBR2060CT 60 V, 20 A Schottky Diode		MBR41H100CT1 100 V, 40 A Schottky Diode		B30H60G 60 V, 30 A Schottky Diode	
	Efficiency (%)		Efficiency (%)		Efficiency (%)	
	115 VAC	230 VAC	115 VAC	230 VAC	115 VAC	230 VAC
25	88.03	87.11	87.62	86.25	87.94	87.94
50	87.67	87.44	87.26	87.21	88.47	87.54
75	87.42	87.37	86.81	88.04	88.11	89.06
100	86.47	87.74	86.17	87.20	87	89.65
Average	87.4	87.42	86.96	87.18	87.88	88.05
Energy Star 2.0 Requirement	87	87	87	87	87	87
CEC 2008 Requirement	85	85	85	85	85	85
Margin* (ES 2.0)	0.89	0.9	0.46	0.68	1.38	1.55

* The test method specified for measuring efficiency for Energy Star 2.0 (ES 2.0 in the preceding table) rounds data to nearest percent. Using this method a measured efficiency of 86.5% would be rounded up to 87% and meets the Energy Star 2.0 87% requirement.

9.3 No-load Input Power

The unit was operated for 15 minutes prior to measurements being taken.

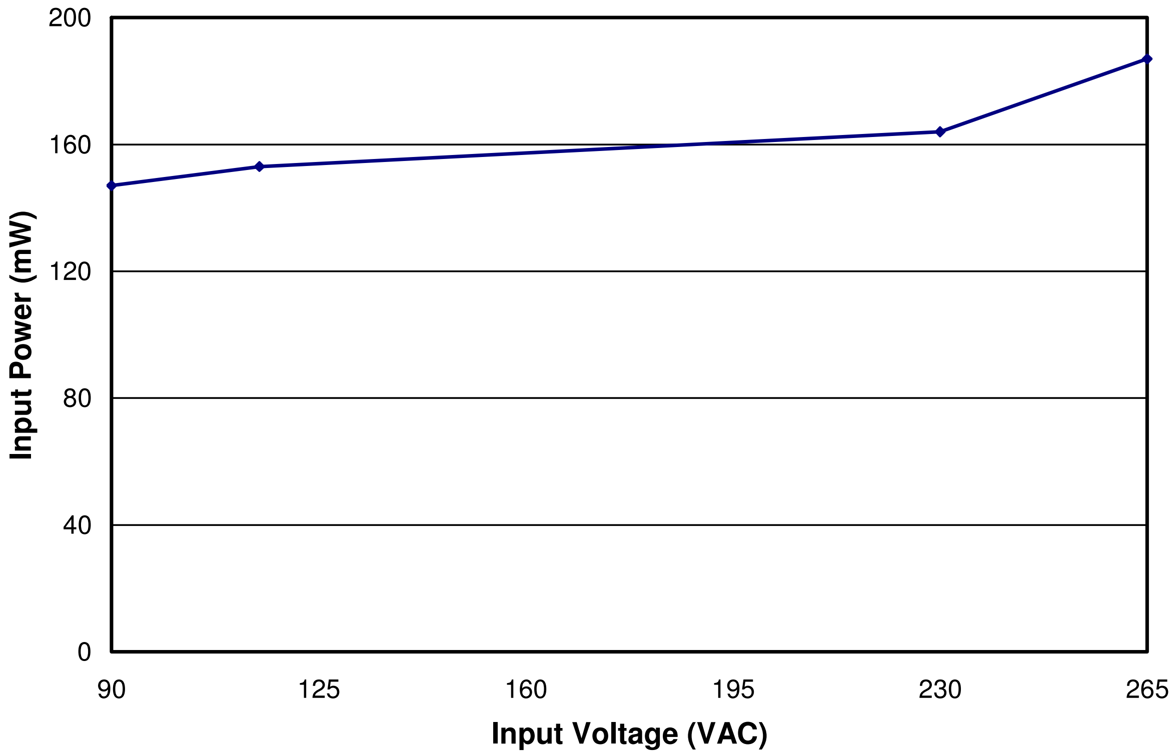

Figure 8 – Zero Load Input Power vs. Input Line Voltage, Room Temperature, 60 Hz.

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9.4 Available Standby Output Power

The chart below shows the available output power for a given level of line voltage with input power levels of 1 W, 2 W, and 3 W.

The voltage measurements were taken at the end of an output cable, which had a DC resistance of approximately 0.1 Ω. The unit was allowed to warm up prior to taking data.

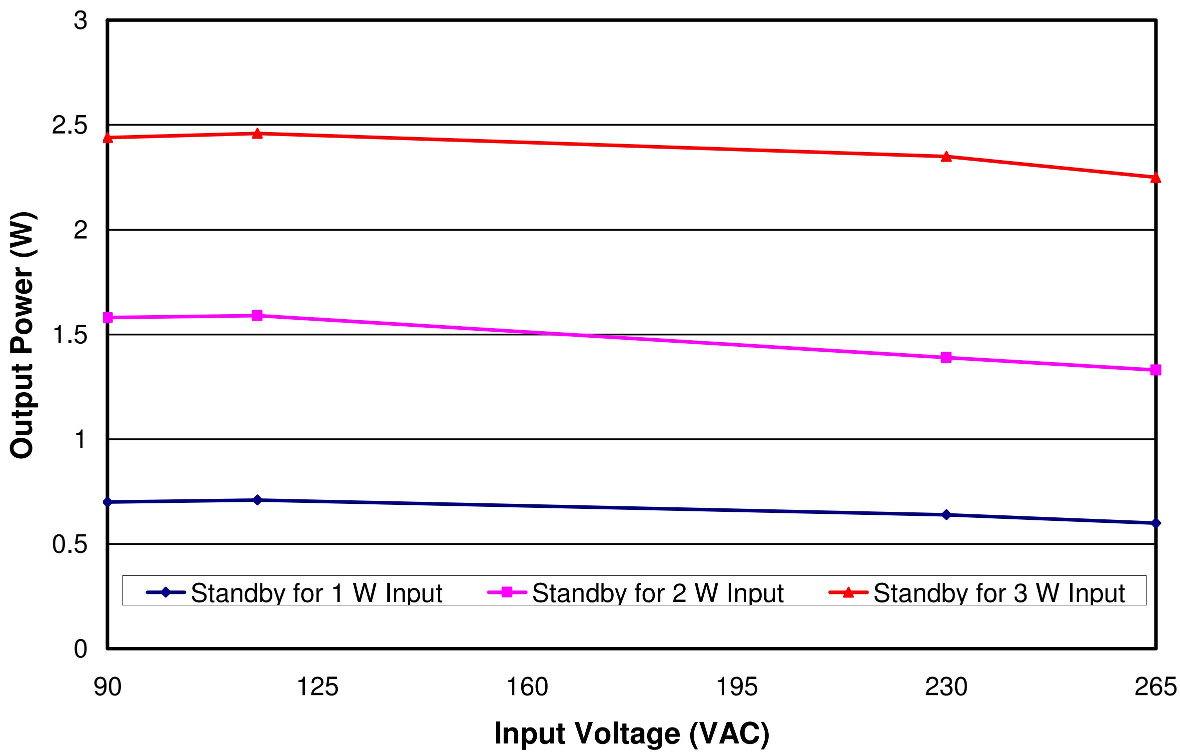

Figure 9 – Standby Power Availability vs. Input Voltage**.**

9.5 Regulation

The following data was taken at room temperature, using a 60 Hz AC input. The voltage measurements were taken at the end of an output cable with a DC resistance of approximately 0.1 Ώ.

9.5.1 Load

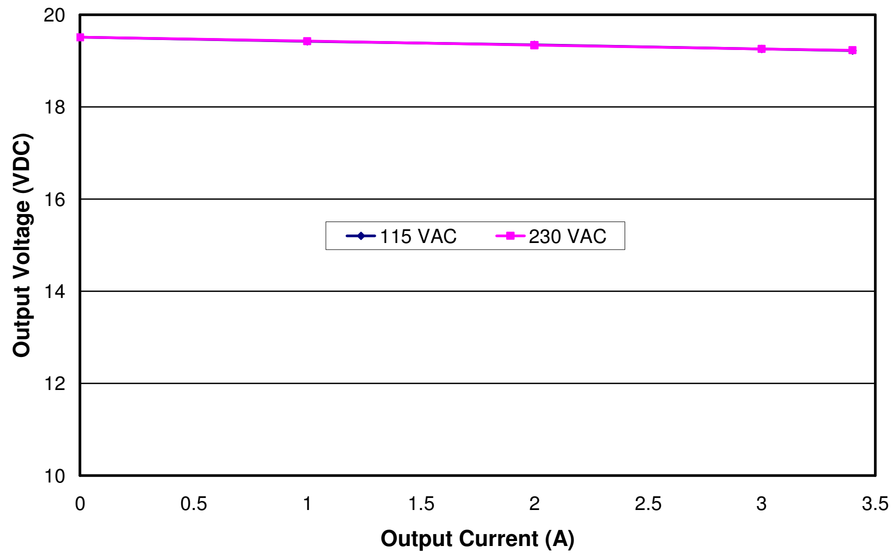

Figure 10 – Load Regulation, Room Temperature.

9.5.2 Line

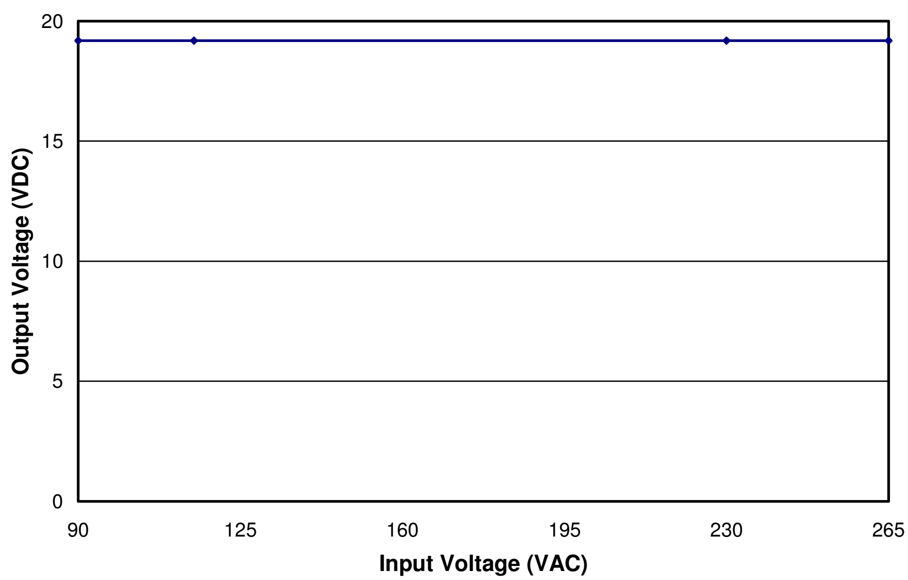

Figure 11 – Line Regulation, Room Temperature, Full Load.

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Thermal Performance

The power supply was placed inside a sealed plastic case to restrict airflow. The chamber temperature was controlled to maintain a constant temperature inside the box. The supply was operated at its rated output power (65 W). To measure the device (U1) temperature, a T-type thermocouple was attached on the heatsink, very close to the tab. The output diode (D5) temperature was measured by attaching a T-type thermocouple to its tab. The transformer (T1) core temperature was measured by attaching a T-type thermocouple firmly to the outer side of the windings.

Item	Temperature (°C)		
	90 VAC	**115 VAC**	**230 VAC**
Ambient	40	25	25
Transformer (T1)	121 (110*)	102	72
TOPSwitch (U1)	109	81	104
Rectifier (D5)	120	99	99
Bridge (D1)	94	84	-

*With heat spreading glue applied.

10 Waveforms

10.1 Drain Voltage and Current, Normal Operation

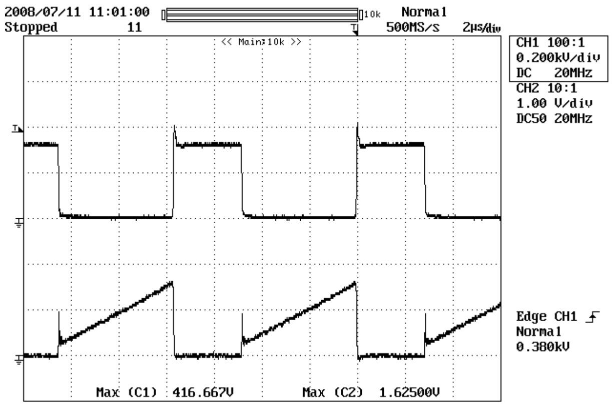

Figure 12 – 90 VAC, Full Load.
Upper: V_{DRAIN}, 200 V, 2 µs / div.
Lower: : I_{DRAIN}, 1.0 A / div.

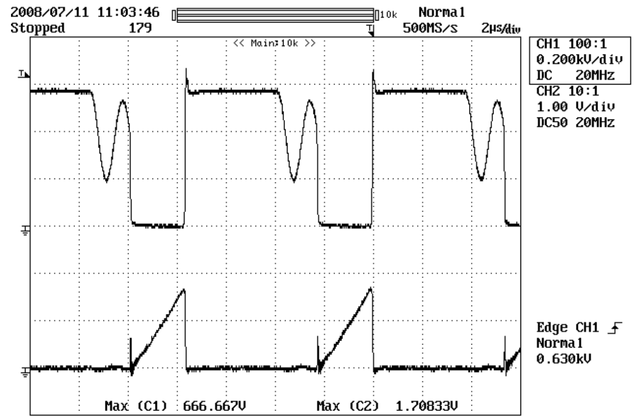

Figure 13 – 265 VAC, Full Load.
Upper: V_{DRAIN}, 200 V, 2 µs / div.
Lower: : I_{DRAIN}, 1.0 A / div.

10.2 Output Voltage Start-up Profile

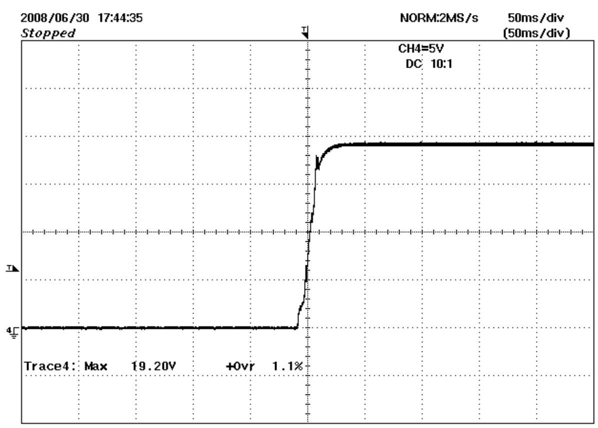

Figure 14 – Start-up Profile, 115 VAC, 3.42 A load.

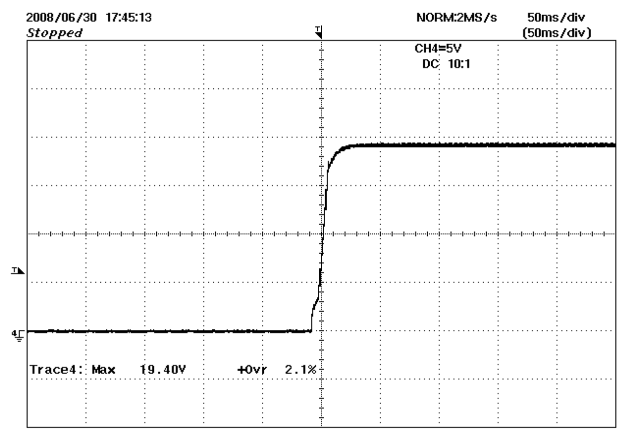

Figure 15 – Start-up Profile, 230 VAC, 3.42 A load.

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10.3 Drain Voltage and Current Start-up Profile

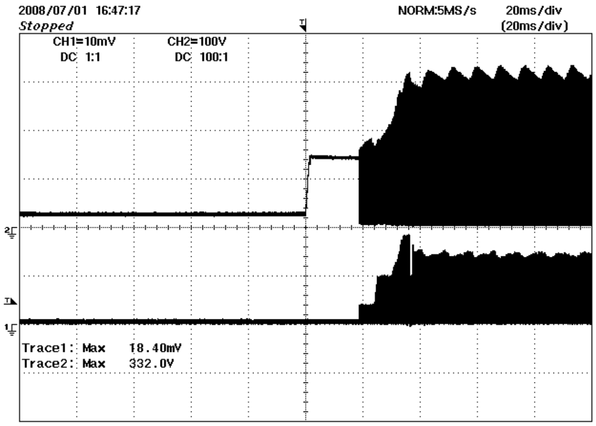

Figure 16 – 90 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 100 V & 20 ms / div.
Lower: I_{DRAIN}, 1.0 A / div.

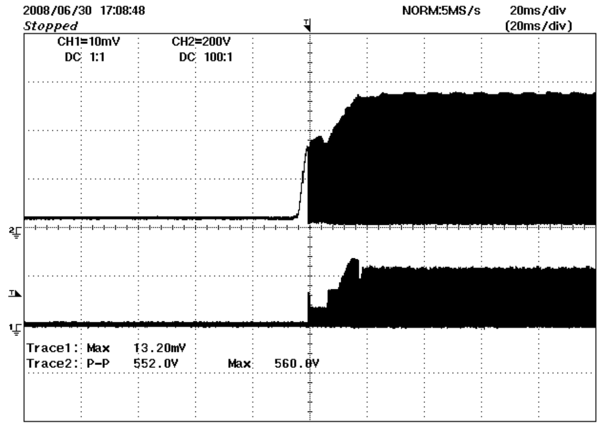

Figure 17 – 265 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 200 V & 20 ms / div.
Lower: I_{DRAIN}, 1.0 A / div.

10.4 Load Transient Response (50% to 100% Load Step)

In the figures shown below, the oscilloscope's signal averaging function was used to better enable viewing the load transient response. The load's current step was used to trigger the oscilloscope to capture the waveform. Since the output switching and line frequency occur essentially at random with respect to the load transient, contributions to the output ripple from these sources average out, leaving only the load step response.

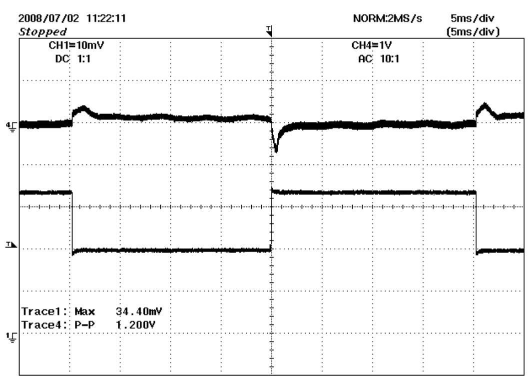

Figure 18 – Transient Response, 115 VAC, 50-100% Load Step.
Top: Output Voltage.
Bottom: Load Current, 1 A/div.

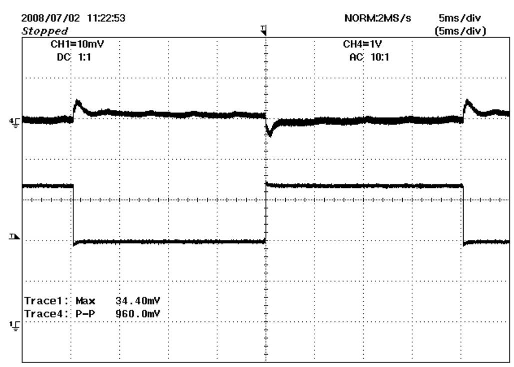

Figure 19 – Transient Response, 230 VAC, 50-100% Load Step.
Upper: Output Voltage.
Bottom Load Current, 1 A/div.

10.5 Output Ripple Measurements

10.5.1 Ripple Measurement Technique

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

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

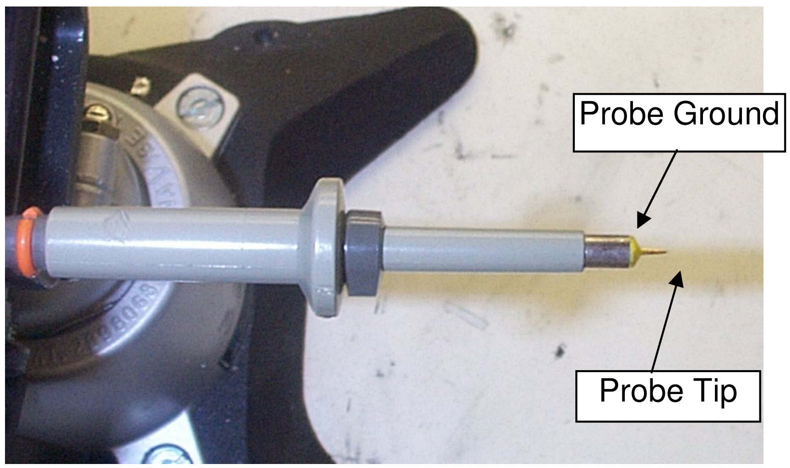

Figure 20 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

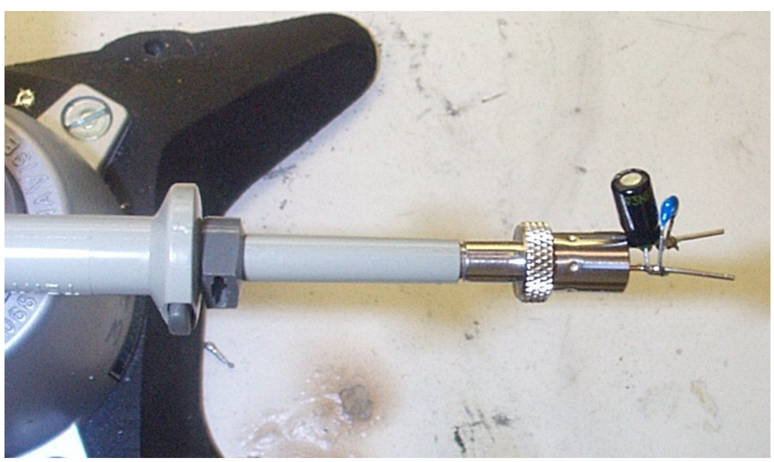

Figure 21 – Oscilloscope Probe with Probe Master (**www.probemaster.com**) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added)

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10.5.2 Measurement Results

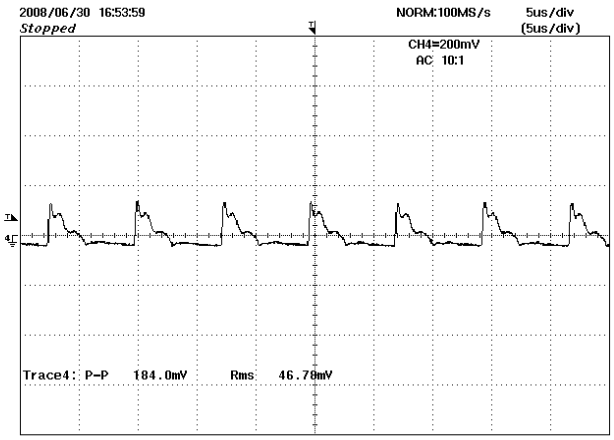

Figure 22 – Ripple, 115 VAC, Full Load.

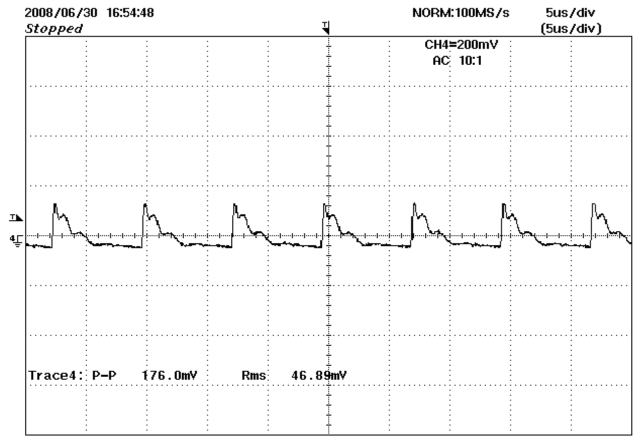

Figure 23 – 5 V Ripple, 230 VAC, Full Load.

11 Control Loop Measurements

The following control-loop measurements were taken at room temperature using a 60 Hz AC input and a 3.42 A load.

11.1 115 VAC Maximum Load

At 115 VAC the loop crossover frequency was measured as 2 kHz. The phase and gain margins were 45º and 9 dB, respectively.

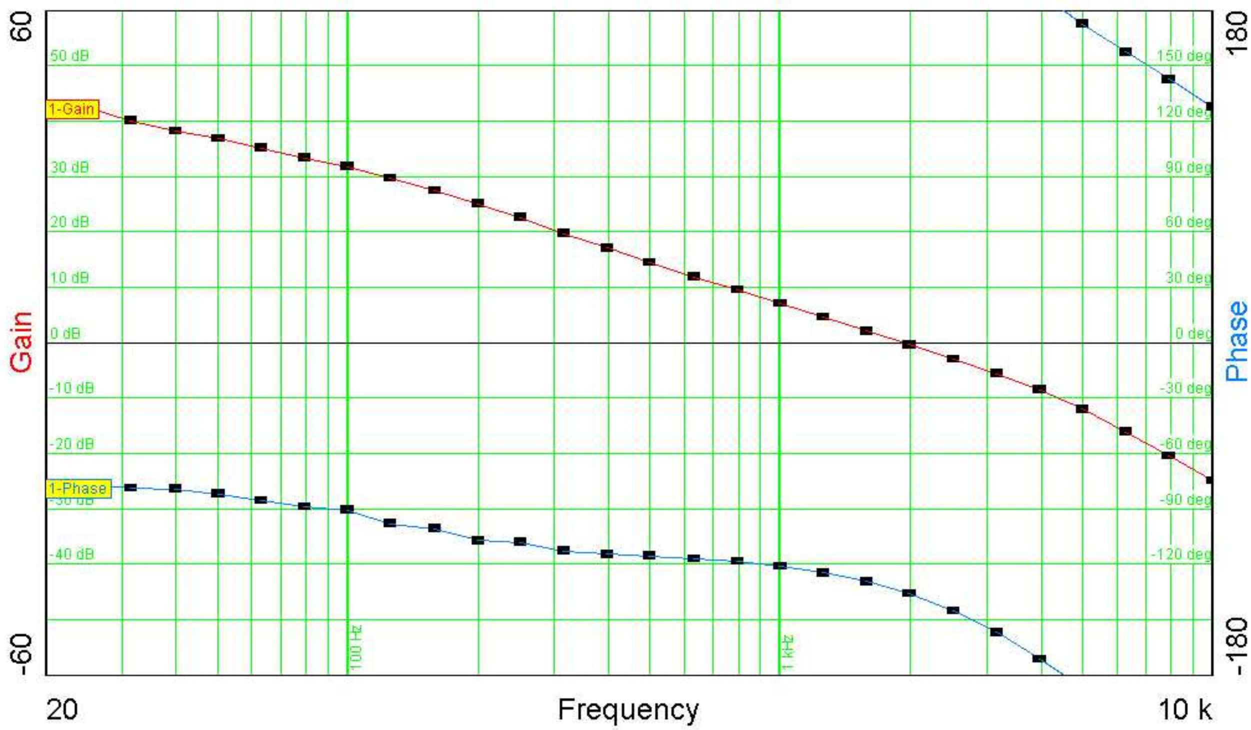

Figure 24 – Gain-Phase Plot, 115 VAC, Maximum Steady-state Load.
Vertical Scale: Gain = 10 dB/div, Phase = 30 °/div.
Crossover Frequency = 2.0 kHz Phase Margin = 45°.

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11.2 230 VAC Maximum Load

At 230 VAC the loop crossover frequency was measured as 500 Hz. The phase and gain margins were 60º and 30 dB, respectively.

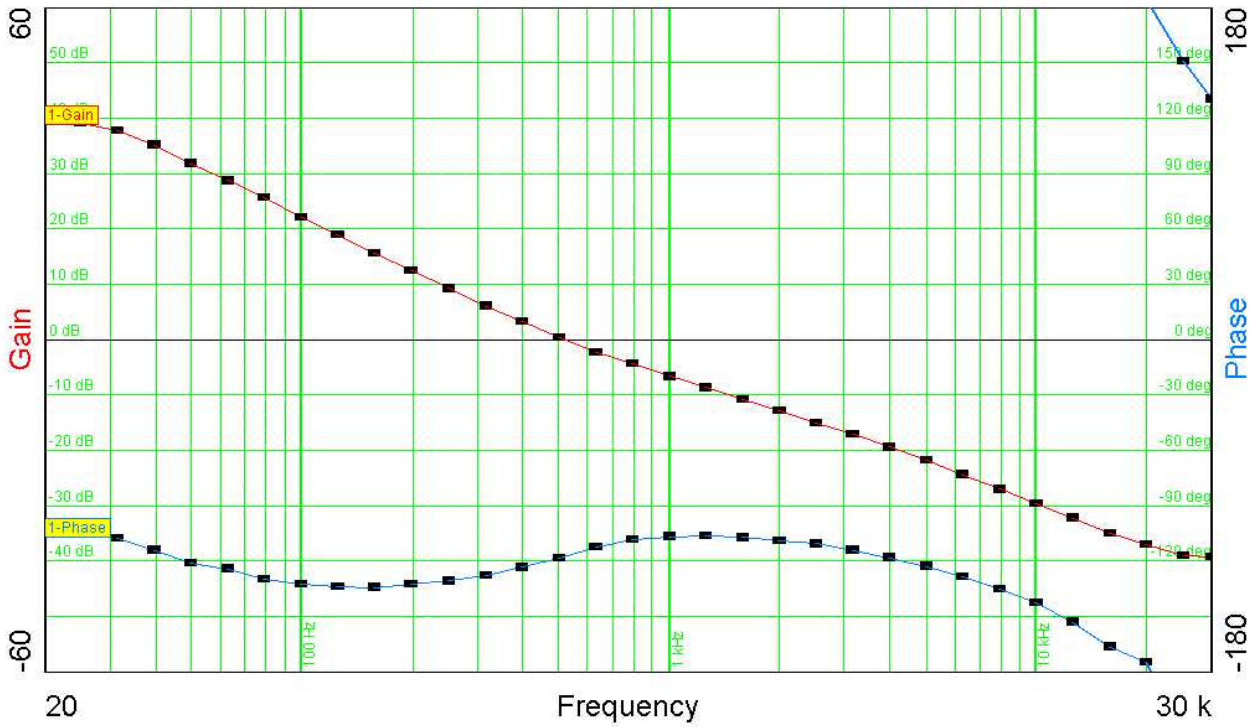

Figure 25 – Gain-Phase Plot, 230 VAC, Maximum Steady-state Load.
Vertical Scale: Gain = 10 dB/div, Phase = 30 °/div.
Crossover Frequency = 500 Hz, Phase Margin = 60°.

12 Conducted EMI

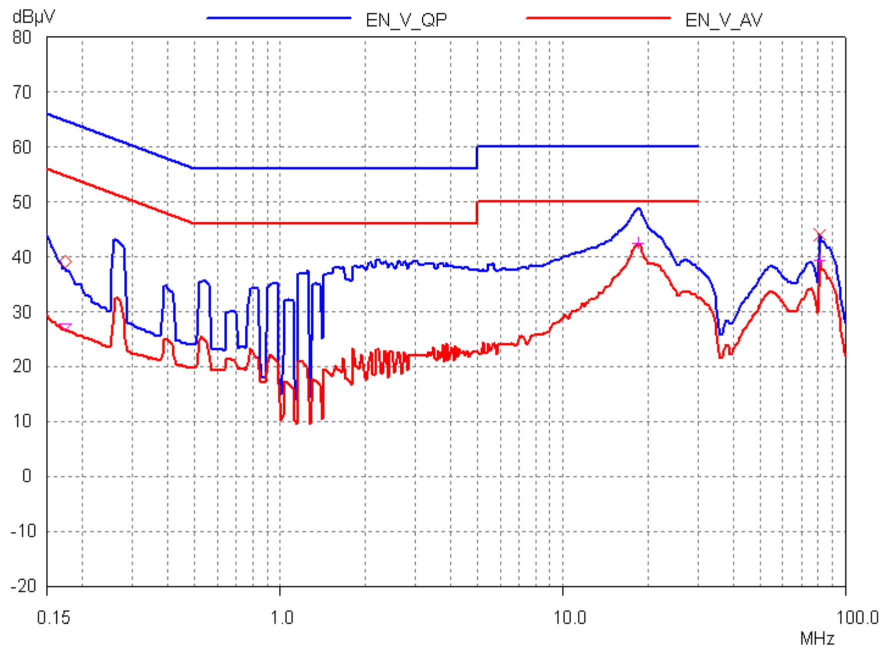

Figure 26 – Conducted EMI, Maximum Steady-state Load, 115 VAC, 60 Hz, EN55022 B Limits. Output was Grounded

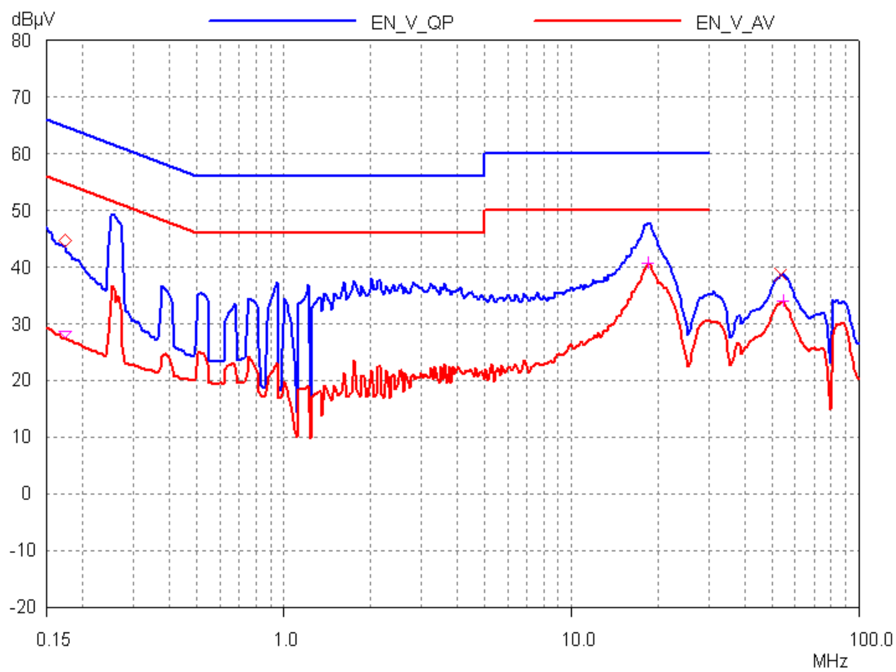

Figure 27 – Conducted EMI, Maximum Steady-state Load, 230 VAC, 60 Hz, EN55022 B Limits. Output was Grounded

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
17-Jul-08	JD	1.0	Initial Release	

Notes

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Notes

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