Design Example Report

Title	***5 W, 5 V Charger using TNY274P***
Specification	Input: 85 – 264 VAC Output: 5 V / 1 A
Application	Portable Audio / MP3 Player
Author	Power Integrations Applications Department
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Revision	1.1

Summary and Features

- CVCC adapter
- High Efficiency
- Meets CEC efficiency and no-load specs
- <100 mW No Load Consumption
- Low conducted EMI without Y cap
- CC mode has good temperature compensation

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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 document is an engineering report describing a design for a 5 V / 1 A adapter. The power supply utilizes a TNY274 as the switching controller.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, and performance data.

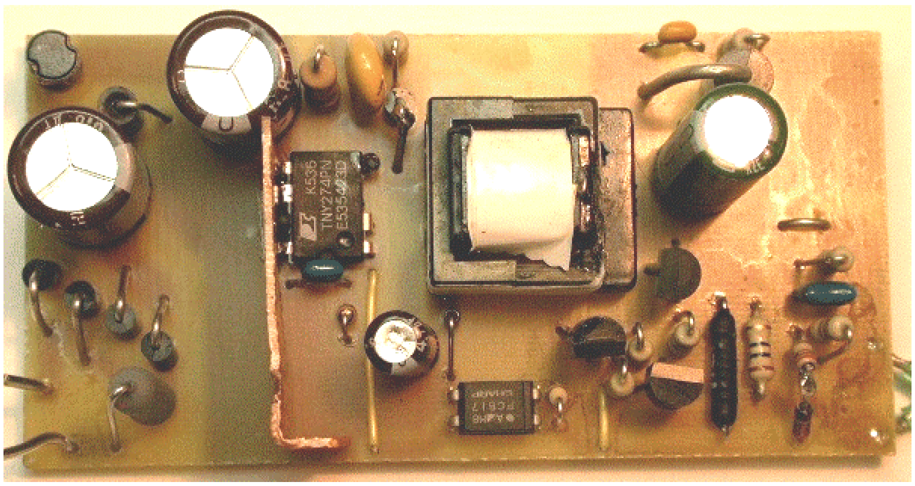

Figure 1 – Populated Circuit Board Photograph.

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2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				0.3	W	
Output						
Output Voltage (CV)	V_{OUT}	4.75	5	5.25	V	± 5%
Output Voltage (CC)	V_{OUT}		1		V	CC prior to auto-restart
Output Ripple Voltage	V_{RIPPLE}			100	mV	20 MHz bandwidth
Output Current	I_{OUT}	0		1	A	CV Operation Mode
Total Output Power						
Continuous Output Power	P_{OUT}			5	W	
Efficiency						
Full Load	η	68	70		%	Measured at P_{OUT} 25 °C
Required average efficiency at 25, 50, 75 and 100 % of P_{OUT}	η_{CEC}	63.5			%	Per California Energy Commission (CEC) / Energy Star requirements
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950, UL1950 Class II				
Surge		1.5			kV	1.2/50 μs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω Common Mode: 12 Ω
Ambient Temperature	T_{AMB}	0		50	°C	Free convection, sea level

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3 Schematic

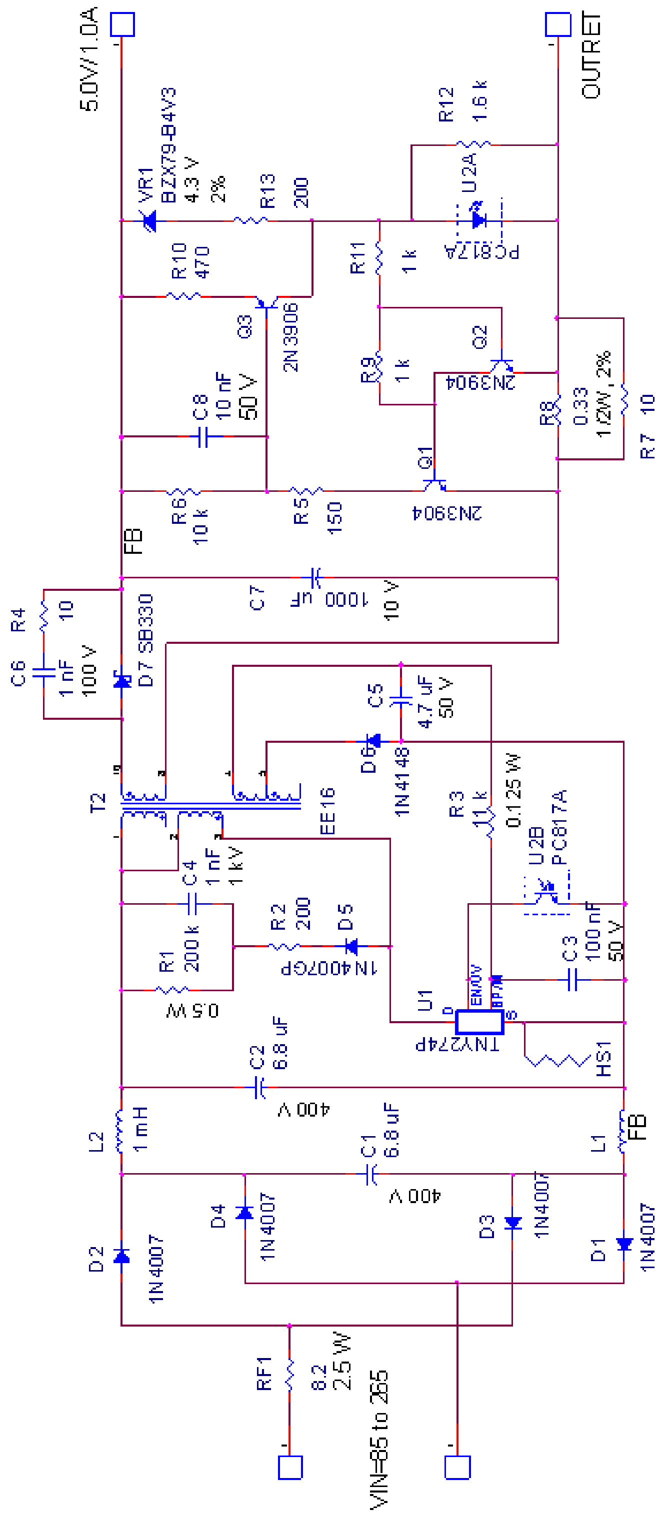

Figure 2 – Schematic.

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4 Circuit Description

4.1 Primary clamp snubber

D5 is a normal recovery, glass passivated 1N4007G for good EMI and higher efficiency. If the glass passivated version of the 1N4007 is not available then the FR107 is recommended. Standard plastic 1N4007 types are not recommended due to excessive drain ringing.

4.2 Bias supply

D6, C5 and R3 provide a small bias current to the TNY274 to reduce no-load consumption and reduce its temperature.

4.3 CVCC circuit

Transistors Q1-Q3, and associated resistors form the constant current regulation circuit. Resistor R8 and R7 form the current sense resistor. In CC mode the voltage drop on it is regulated to 0.35 V. This CC circuit has built in temperature compensation.

VR1 regulates the output in CV mode.

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5 PCB Layout

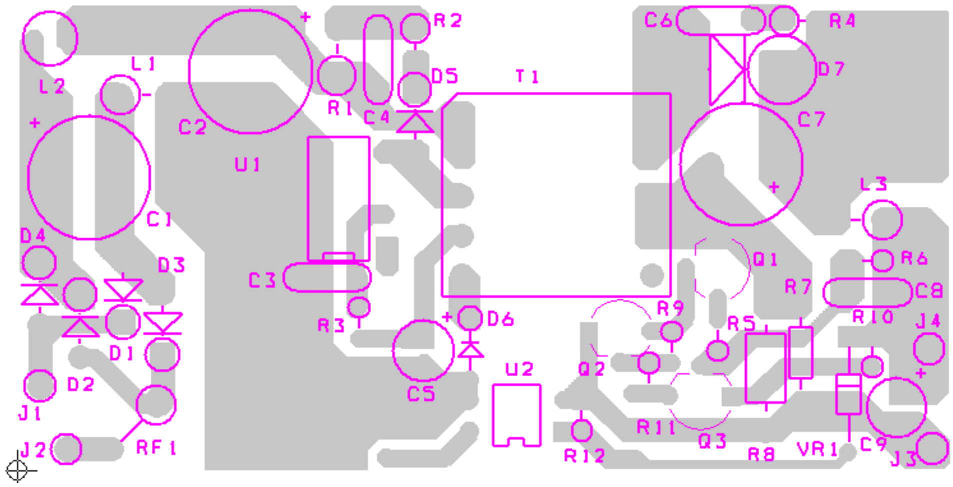

Figure 3 – Printed Circuit Layout.

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6 Bill Of Materials

Item	Qty	Part Reference	Value	Description
1	2	C1 C2	6.8 uF	6.8 uF, 400 V, Electrolytic, (10 x 16),
2	1	C3	100 nF	100 nF, 50 V, Ceramic, Z5U
3	1	C4	1 nF	1 nF, 1 kV, Disc Ceramic
4	1	C5	4.7 uF	4.7 uF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)
5	1	C6	1 nF	1 nF, 100 V, Ceramic, X7R
6	1	C7	1000 uF	1000 uF, 10 V, Electrolytic, Very Low ESR, 41 mOhm, (8 x 20)
7	1	C8	10 nF	10 nF, 50 V, Ceramic, Z5U
8	4	D1 D2 D3 D4	1N4007	1000 V, 1 A, Rectifier, DO-41
9	1	D5	1N4007GP	1000 V, 1 A, Rectifier, Glass Passivated, 2 us, DO-41
10	1	D6	1N4148	75 V, 300 mA, Fast Switching, DO-35
11	1	D7	SB330	30 V, 3 A, Schottky, DO-201AD
12	1	HS1	HS	HEATSINK Custom
13	1	L1	Ferrite Bead	3.5 mm x 7.6 mm, 75 Ohms at 25 MHz, 22 AWG hole, Ferrite Bead
14	1	L2	1 mH	1 mH, 0.15 A, Ferrite Core
15	2	Q1 Q2	2N3904	NPN, Small Signal BJT, 40 V, 0.2 A, TO-92
16	1	Q3	2N3906	PNP, Small Signal BJT, 40 V, 0.2 A, TO-92
17	1	R1	200 k	200 k, 5%, 1/2 W, Carbon Film
18	1	R2	200	200 R, 5%, 1/4 W, Carbon Film
19	1	R3	11 k	11 k, 5%, 1/8 W, Carbon Film
20	1	R4	10	10 R, 5%, 1/4 W, Carbon Film
21	1	R5	150	150 R, 5%, 1/8 W, Carbon Film
22	1	R6	10 k	10 k, 5%, 1/8 W, Carbon Film
23	1	R7	10	10 R, 5%, 1/8 W, Carbon Film
24	1	R8	0.33	0.33 R, 1%, 1/2 W
25	2	R9 R11	1 k	1 k, 5%, 1/8 W, Carbon Film
26	1	R10	470	470 R, 5%, 1/8 W, Carbon Film
27	1	R12	1.6 k	1.6 k, 5%, 1/8 W, Carbon Film
28	1	R13	200	200 R, 5%, 1/8 W, Carbon Film
29	1	RF1	8.2	8.2 R, 2.5 W, Fusible/Flame Proof Wire Wound
30	1	T1	EE16	Bobbin, EE16, Horizontal, 10 pins
31	1	U1	TNY274P	TinySwitch-III, TNY274P, DIP-8C
32	1	U2	PC817A	Opto coupler, 35 V, CTR 80-160%, 4-DIP
33	1	VR1	BZX79-B4V3	4.3 V, 500 mW, 2%, DO-35

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7 Transformer Specification

7.1 Electrical Diagram

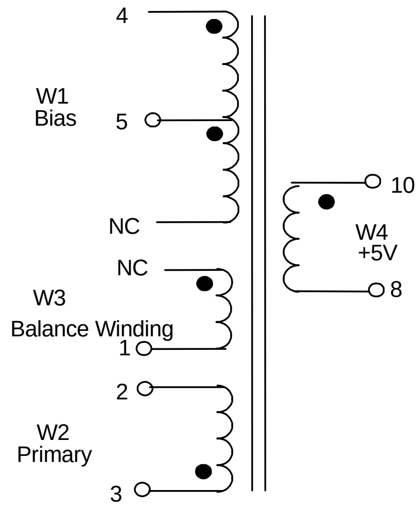

Figure 4 – Transformer Electrical Diagram.

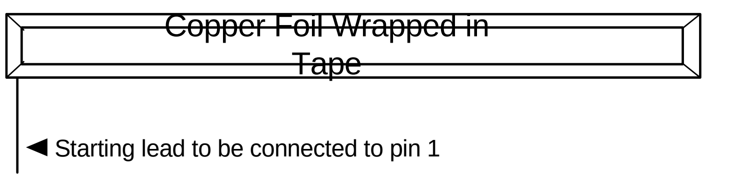

Figure 5 – Copper Foil preparation for winding 3.

7.2 Electrical Specifications

Electrical Strength	60 second, 60 Hz, from Pins 1-5 to Pins 6-10	3000 VAC
Primary Inductance	Pins 2-3, all other windings open, measured at 132 kHz.	2519µH, -0/+12%
Resonant Frequency	Pins 2-3, all other windings open	733 kHz (Min.)
Primary Leakage Inductance	Pins 2-3, with Pins 8-10 shorted, measured at 132 kHz.	65µH (Max.)

7.3 Materials

Item	Description
[1]	Core: EE16 Gapped for 174 nH/T^2
[2]	Bobbin: EE16 Horizontal 10 Pins
[3]	Magnet Wire: 34 AWG
[4]	Triple Insulated Wire: 26 AWG
[5]	Copper Foil 0.06 mm tick, 7.6mm wide
[6]	Tape, 8.6 mm Wide
[7]	Tape, 12 mm Wide
[8]	Varnish

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7.4 Transformer Build Diagram

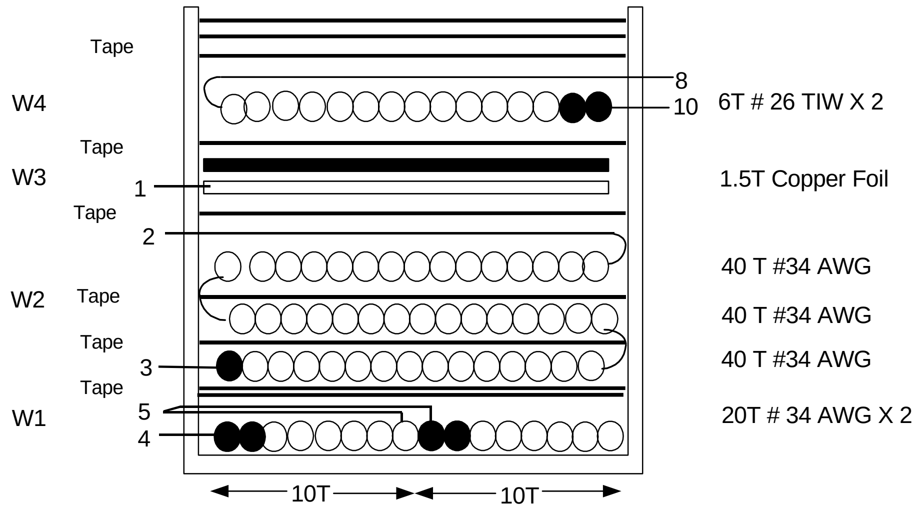

Figure 6 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	Place the bobbin [2] on the winding machine with the primary pin side oriented to the left hand side.
W1 Bias Winding + Core Cancellation	Start at Pin 4. Wind 10 bifilar turns of item [3] from left to right. Take the lead out of the winding area and terminate it at pin 5. Bring the lead back to the winding area and continue winding on the same layer. Wind 10 more turns. The whole layer must be uniformly and tightly wound. Cut the finishing lead just at the end of the winding.
Basic Insulation	Use two layers of item [6] for basic insulation.
W2 Primary	Start at Pin 3. Wind 40 turns of item [3] from left to right in 1 layer. Use one layers of item [6] for basic insulation. Continue winding on a second layer. Wind 40 turns from right to left. Use one layers of item [6] for basic insulation. Wind 40 more from left to right on a third layer. Terminate on pin 2. The three layers should be uniformly and tightly wound.
Basic Insulation	Use one layers of item [6] for basic insulation.
W3, Balance Winding	Prepare winding as shown in figure 5 using items [5] and [7]. *Very important. For this winding reverse the winding direction of the machine.* Start at pin 1, Wind 1.5 turns of copper foil. Finish lead is left unconnected.
Basic Insulation	Use one layer of item [6] for basic insulation.
W4 Secondary Winding	Start at Pins 10. Wind 6 bifilar turns of item [4] Spread turns evenly across bobbin. Finish on Pin 8.
Outer Wrap	Wrap windings with 3 layers of tape item [6].
Final Assembly	Assemble and secure core halves. Varnish impregnate using item [8].

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8 Transformer Spreadsheets

ACDC_TinySwitch-III_031006; Rev.1.11; Copyright Power Integrations 2006	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**ACDC_TinySwitch-III_031006_Rev1-11.xls; TinySwitch-III Continuous/Discontinuous Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					**Customer**
VACMIN	85			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	5.33			Volts	Output Voltage (at continuous power)
IO	1.00			Amps	Power Supply Output Current (corresponding to peak power)
Power			5.33	Watts	Continuous Output Power
n	0.68				Efficiency Estimate at output terminals. Under 0.7 if no better data available
Z	0.81				Z Factor. Ratio of secondary side losses to the total losses in the power supply. Use 0.5 if no better data available
tC	3.00			mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	13.60		13.6	uFarads	Input Capacitance

ENTER TinySwitch-III VARIABLES					
TinySwitch-III	**Auto**		**TNY274**		Recommended TinySwitch-III
Chosen Device		*TNY274*			
Chose Configuration	**STD**		Standard Current Limit		Enter "RED" for reduced current limit (sealed adapters), "STD" for standard current limit or "INC" for increased current limit (peak or higher power applications)
ILIMITMIN			0.233	Amps	Minimum Current Limit
ILIMITTYP			0.250	Amps	
ILIMITMAX			0.267	Amps	Maximum Current Limit
fSmin			124000	Hertz	Minimum Device Switching Frequency
I^2fmin			7.425	A^2kHz	I^2f (product of current limit squared and frequency is trimmed for tighter tolerance)
VOR	117.00		117	Volts	Reflected Output Voltage (VOR < 135 V Recommended)
VDS			10	Volts	TinySwitch-III on-state Drain to Source Voltage
VD	0.50		0.5	Volts	Output Winding Diode Forward Voltage Drop
KP			0.65		Ripple to Peak Current Ratio (KP < 6)
KP_TRANSIENT			0.40		Transient Ripple to Peak Current Ratio. Ensure KP_TRANSIENT > 0.25

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ENTER BIAS WINDING VARIABLES				
VB		22.00	Volts	Bias Winding Voltage
VDB		0.70	Volts	
NB		22.64		Bias Winding Number of Turns
VZOV		28.00	Volts	Over Voltage Protection zener diode voltage.

UVLO VARIABLES				
V_UV_TARGET		87.87	Volts	Target DC under-voltage threshold, above which the power supply with start
V_UV_ACTUAL		84.70	Volts	Typical DC start-up voltage based on standard value of RUV_ACTUAL
RUV_IDEAL		3.43	Mohms	Calculated value for UV Lockout resistor
RUV_ACTUAL		3.30	Mohms	Closest standard value of resistor to RUV_IDEAL

ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EE16**		**EE16**		Enter Transformer Core
Core		*EE16*		*P/N:*	PC40EE16-Z
Bobbin		*EE16_BOBBIN*		*P/N:*	EE16_BOBBIN
AE			0.192	cm^2	Core Effective Cross Sectional Area
LE			3.5	cm	Core Effective Path Length
AL			1140	nH/T^2	Ungapped Core Effective Inductance
BW			8.6	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3		Number of Primary Layers
NS	6		6		Number of Secondary Turns

DC INPUT VOLTAGE PARAMETERS				
VMIN		80	Volts	Minimum DC Input Voltage
VMAX		375	Volts	Maximum DC Input Voltage

CURRENT WAVEFORM SHAPE PARAMETERS			
DMAX	0.63		Duty Ratio at full load, minimum primary inductance and minimum input voltage
IAVG	0.11	Amps	Average Primary Current
IP	0.23	Amps	Minimum Peak Primary Current
IR	0.15	Amps	Primary Ripple Current
IRMS	0.15	Amps	Primary RMS Current

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TRANSFORMER PRIMARY DESIGN PARAMETERS				
LP		2519	uHenries	Typical Primary Inductance. +/- 12% to ensure a minimum primary inductance of 2249 uH
LP_TOLERANCE		12	%	Primary inductance tolerance
NP		120		Primary Winding Number of Turns
ALG		174	nH/T^2	Gapped Core Effective Inductance
BM		2909	Gauss	Maximum Operating Flux Density, BM<3000 is recommended
BAC		952	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur		1654		Relative Permeability of Ungapped Core
LG		0.12	mm	Gap Length (Lg > 0.1 mm)
BWE		25.8	mm	Effective Bobbin Width
OD		0.21	mm	Maximum Primary Wire Diameter including insulation
INS		0.04	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA		0.17	mm	Bare conductor diameter
AWG		34	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM		40	Cmils	Bare conductor effective area in circular mils
CMA		273	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)

TRANSFORMER SECONDARY DESIGN PARAMETERS				
Lumped parameters				
ISP		4.68	Amps	Peak Secondary Current
ISRMS		2.29	Amps	Secondary RMS Current
IRIPPLE		2.06	Amps	Output Capacitor RMS Ripple Current
CMS		458	Cmils	Secondary Bare Conductor minimum circular mils
AWGS		23	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)

VOLTAGE STRESS PARAMETERS				
VDRAIN		640	Volts	Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)
PIVS		24	Volts	Output Rectifier Maximum Peak Inverse Voltage

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9 Performance Data

All measurements performed at room temperature, 60 Hz input frequency. Efficiency measurements were done at the end of the cable on the load side.

9.1 Efficiency

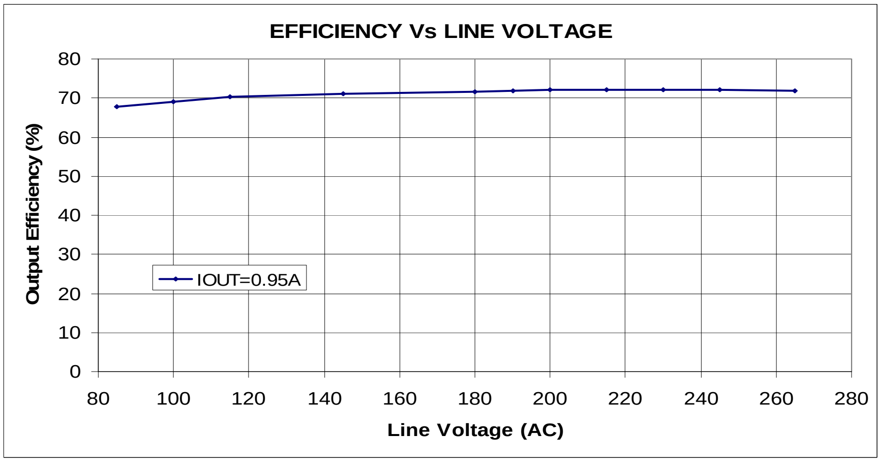

Figure 7 – Efficiency vs. Input Voltage, Room Temperature, 60 Hz.

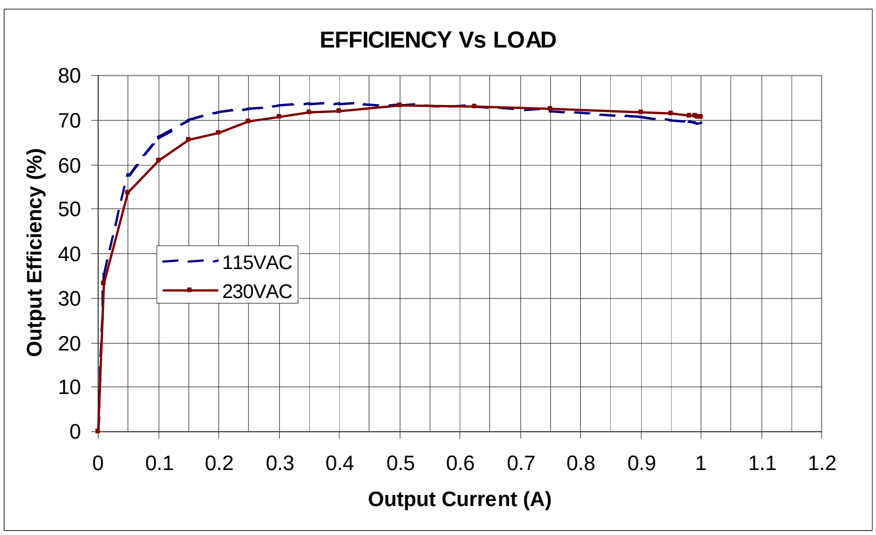

Figure 8 – Efficiency Vs Load.

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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. Minimum active mode efficiency is defined as the average efficiency of 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	$0.49 \times P_O$
≥ 1 W to ≤ 49 W	$0.09 \times \ln(P_O) + 0.49$ [ln = natural log]
> 49 W	0.84 W

For adapters that are single input voltage only then 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.

Percent of Full Load	Efficiency (%)	
	115 VAC	230 VAC
25	72.63	69.55
50	73.31	73.25
75	72.08	72.5
100	69.25	70.80
Average	71.82	71.52
CEC specified minimum average efficiency (%)	*63.48*	

More states within the USA and other countries are adopting this standard, for the latest up to date information please visit the PI Green Room:

http://www.powerint.com/greenroom/regulations.htm

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9.2 No-load Input Power

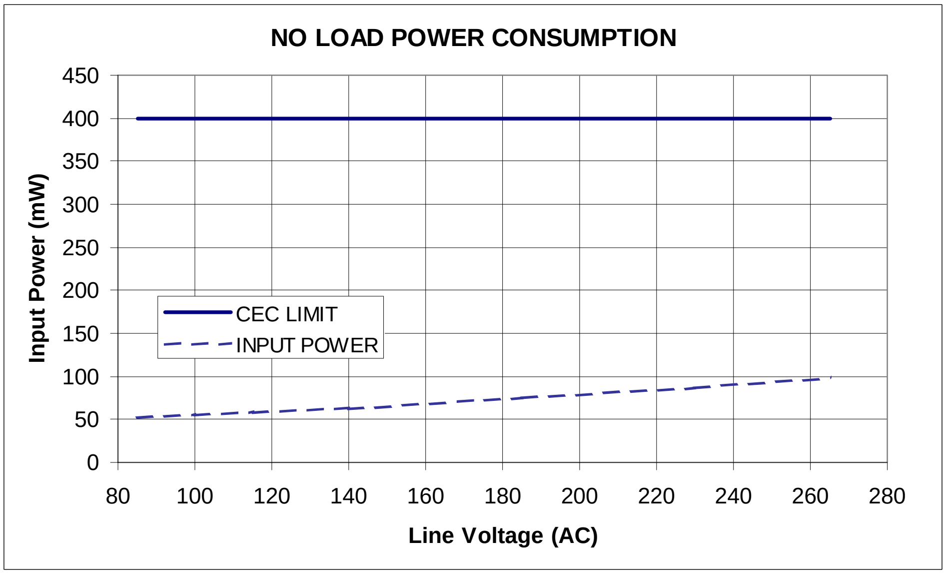

Figure 9 – Zero Load Input Power vs. Input Line Voltage, Room Temperature, 60 Hz.

Note: CEC limit is actually 500 mW, not 400 mW as shown in figure above.

9.3 Regulation

9.3.1 Output Characteristic.

Measurements were done at the end of the cable on the load side.

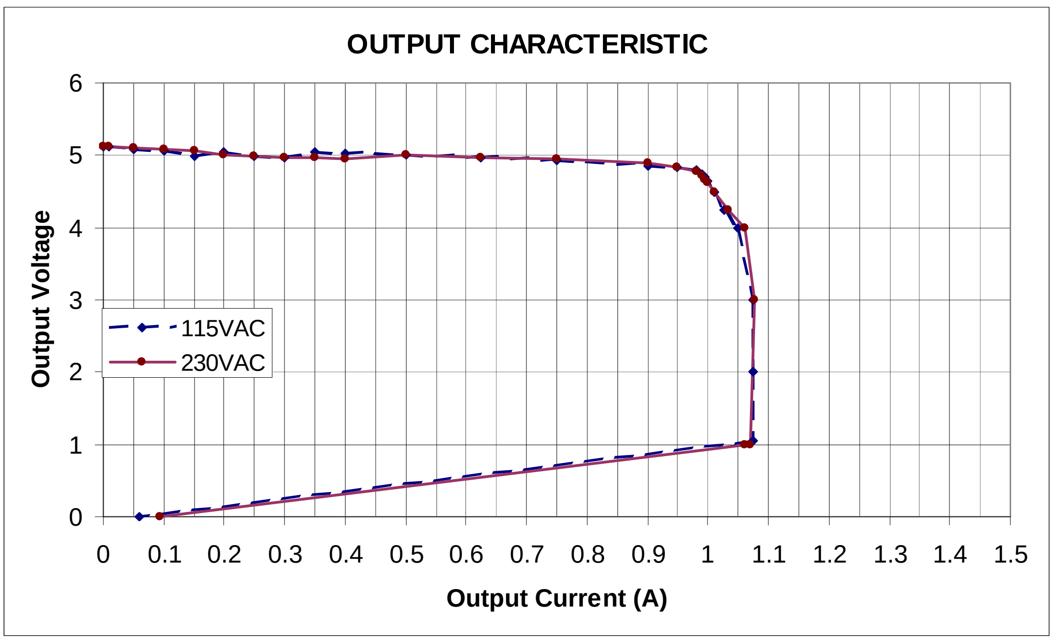

Figure 10 – Output Characteristic.

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10 Thermal Performance

When doing this test, the unit was put inside of a cardboard box. The box was put inside a thermal chamber. No free air was flowing around the unit.

Item	Temperature (°C)	
	85 VAC	265 VAC
Ambient	50	50
TinySwitch (U1)	93	83
Transformer (T1)	81	84
Output Rectifier (D7)	88	90
Output Capacitor (C7)	77	78

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11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

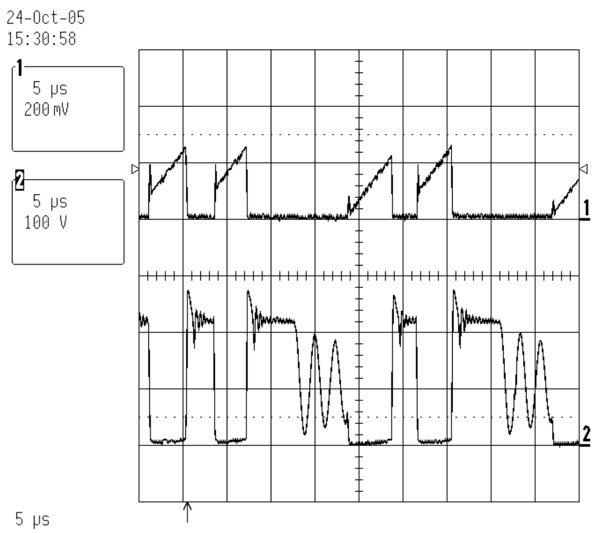

Figure 11 – 85 VAC, Full Load.
Upper: I_{DRAIN}, 0.2 A / div
Lower: V_{DRAIN}, 100 V, 2 µs / div

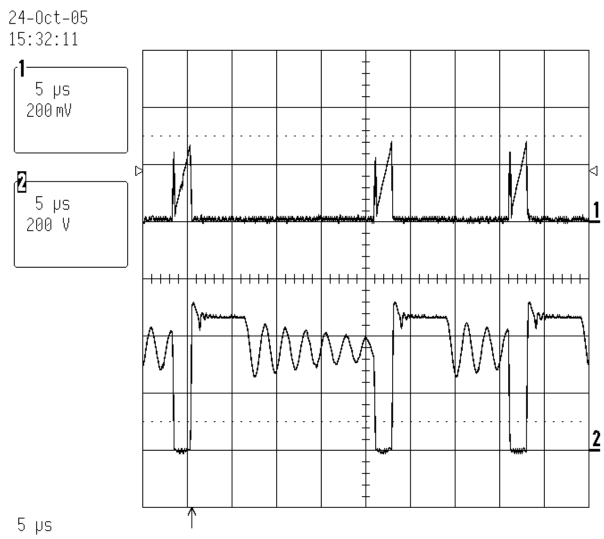

Figure 12 – 265 VAC, Full Load
Upper: I_{DRAIN}, 0.2 A / div
Lower: V_{DRAIN}, 200 V / 2 µs /div

11.2 Output Voltage Start-up Profile

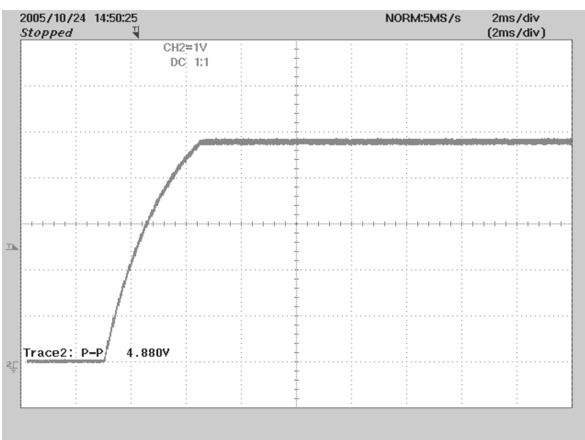

Figure 13 – Start-up Profile, 115VAC
1 V, 2 ms / div.

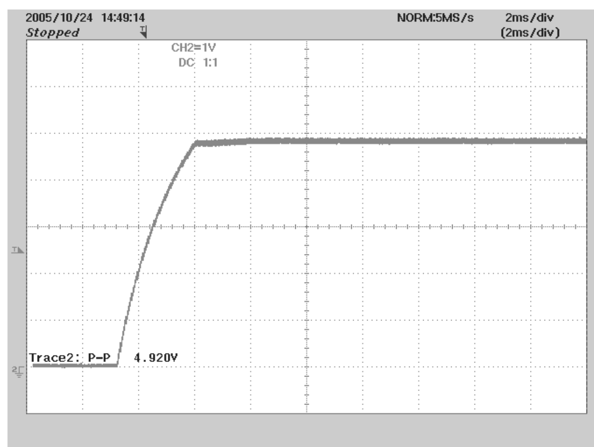

Figure 14 – Start-up Profile, 230 VAC
1 V, 2 ms / div.

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11.3 Drain Voltage and Current Start-up Profile

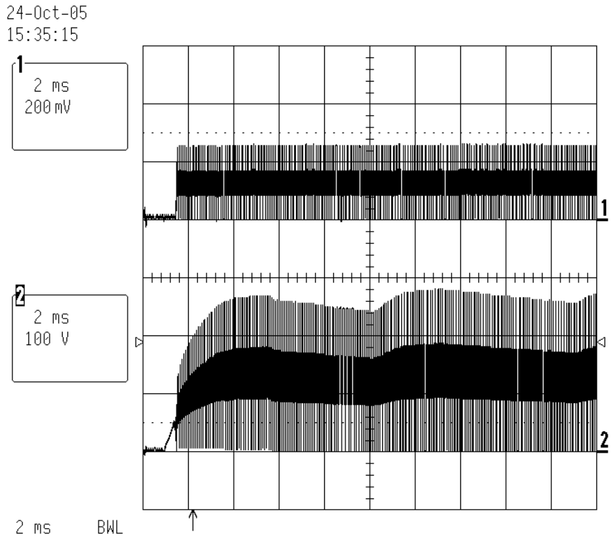

Figure 15 – 85 VAC Input and Maximum Load.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V & 2 ms / div.

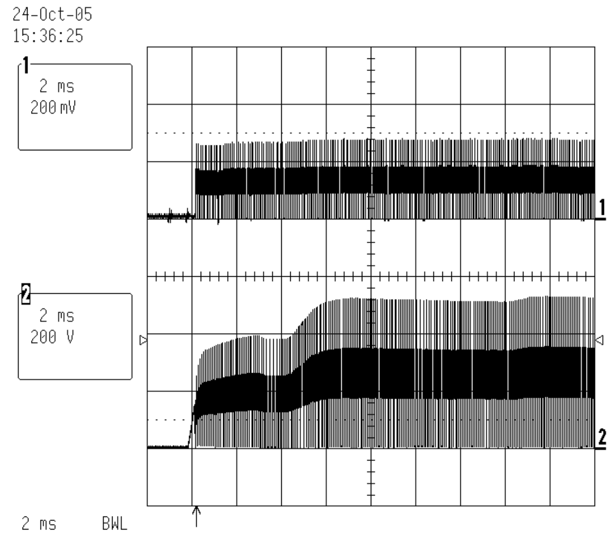

Figure 16 – 265 VAC Input and Maximum Load.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 200 V & 2 ms / div.

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11.4 Load Transient Response (75% to 100% Load Step)

In the figures shown below, signal averaging was used to better enable viewing the load transient response. The oscilloscope was triggered using the load current step as a trigger source. 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 will average out, leaving the contribution only from the load step response.

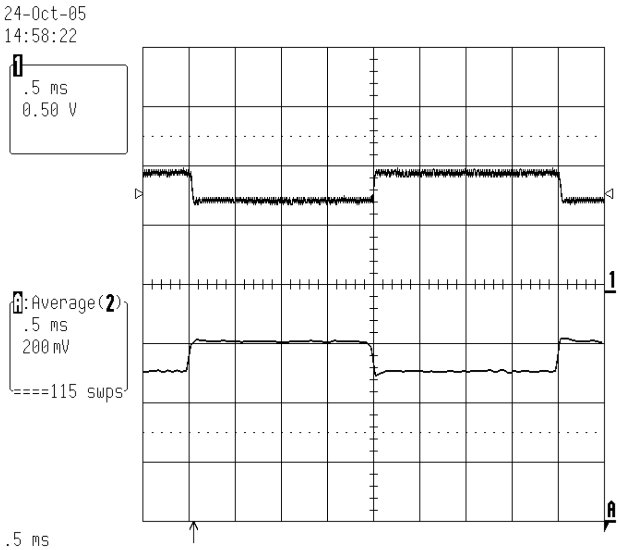

Figure 17 – Transient Response, 115 VAC, 75-100-75% Load Step.
Top: Load Current, 0.5 A/div.
Bottom: Output Voltage
200 mV, 0.5 ms / div.

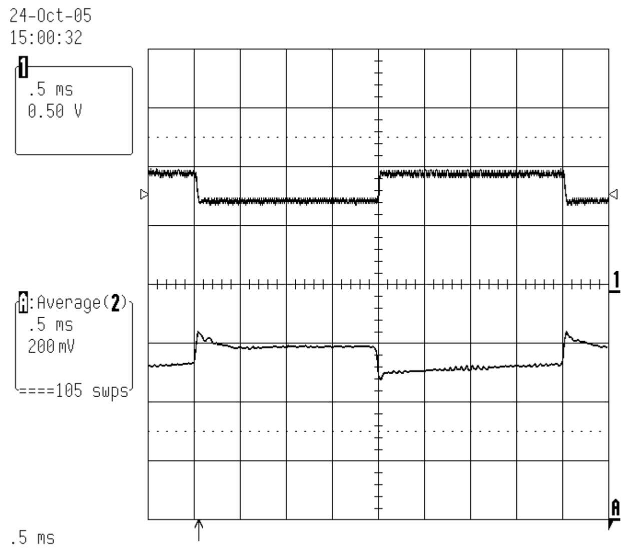

Figure 18 – Transient Response, 230 VAC, 75-100-75% Load Step
Upper: Load Current, 0.5 A/ div.
Bottom: Output Voltage
200 mV, 0.5 ms / div.

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11.5 Output Ripple Measurements

11.5.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pickup. Details of the probe modification are provided in Figures 19 and 20.

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 μF/50 V ceramic type and one (1) 1.0 μF/50 V aluminum electrolytic. ***The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).***

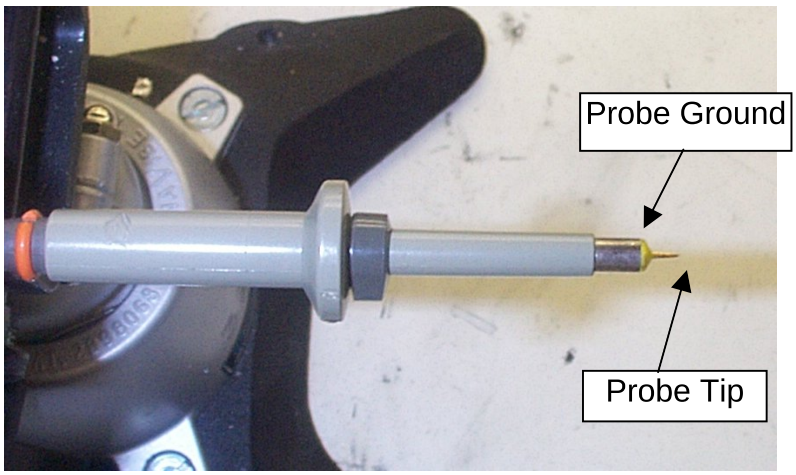

Figure 19 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

Figure 20 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

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11.5.2 Measurement Results

Ripple measurements were done at the end of the cable on the load side.

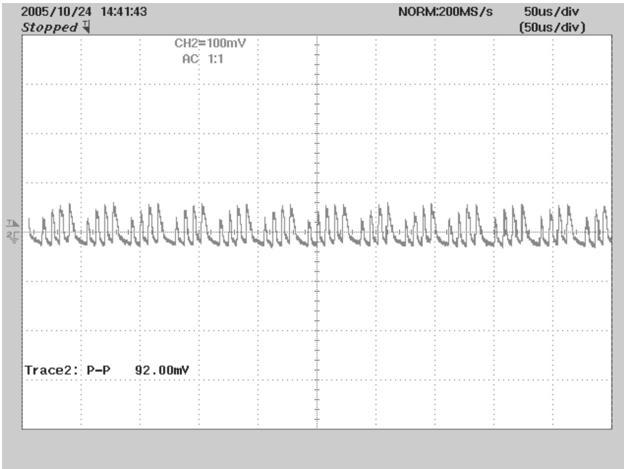

Figure 21 – Ripple, 85 VAC, Full Load.
50 uS, 100 mV / div

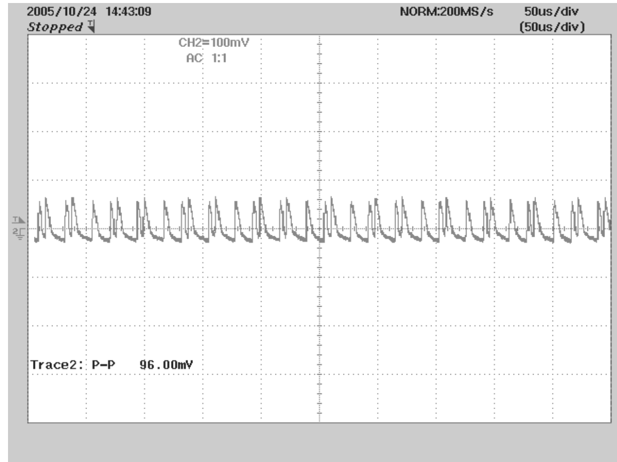

Figure 22 – 5 V Ripple, 115 VAC, Full Load.
50 uS, 100 mV / div

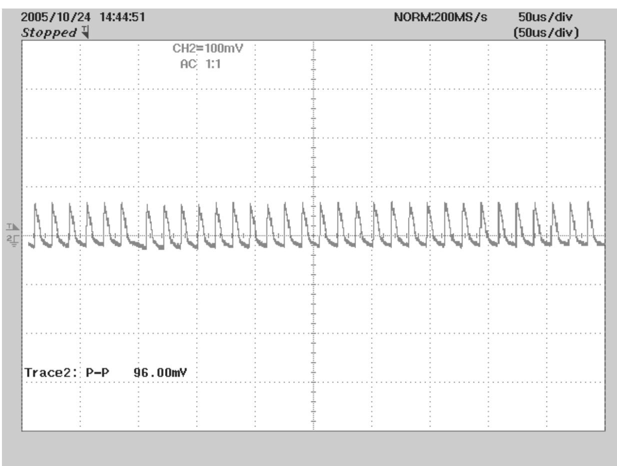

Figure 23 – Ripple, 230 VAC, Full Load.
50 uS, 100 mV / div

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12 Conducted EMI

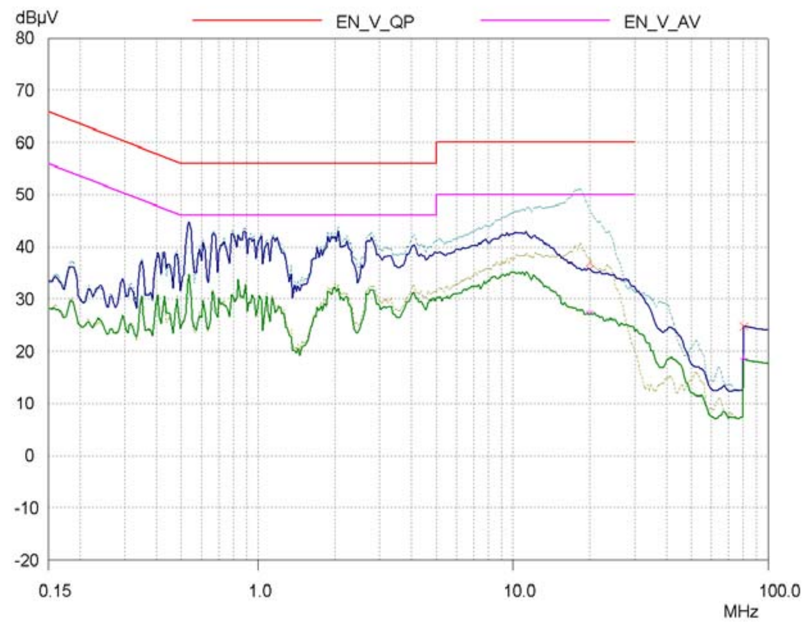

Figure 24 – Conducted EMI, Maximum Steady State Load, 115 VAC, 60 Hz, and EN55022 B Limits. Bolt Traces With OUTRETURN connected to ARTHAND, Light traces With OUTRETURN connected to GND

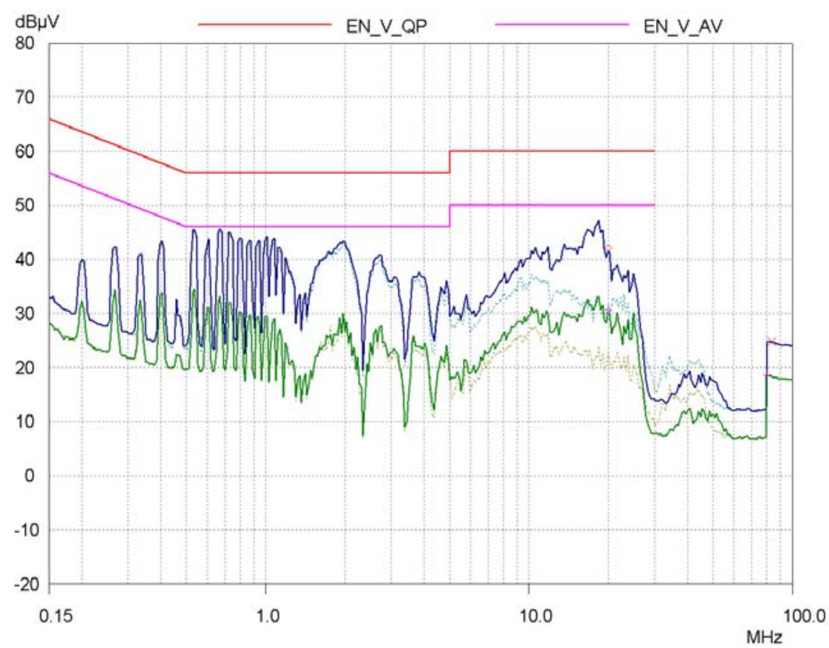

Figure 25 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55022 B Limits. Bolt traces with OUTRETURN CONNECTED TO GND. Light Traces with OUTRET Connected to ARTHAND

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
November 20, 2005	VC	1.0	Initial release	JC / VC
July 19, 2006	PV	1.1	Edits and corrections	KM

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