Design Example Report

Title	***3W Power Supply using LNK501P***
Specification	Input: 90 – 265 VAC Output: 12V / 250mA
Application	Industrial
Author	Power Integrations Applications Department
Document Number	DER-57
Date	April 20, 2005
Revision	1.0

Summary and Features

This document is an engineering prototype report for a universal input, power factor corrected power supply unit providing 12V at 250mA.

- Very low cost, low component count isolated power supply
- Extremely simple circuit configuration designed for high volume low cost manufacture
- High input power factor
- Small EE16 transformer allows compact size
- No Optocoupler or sense resistors required
- Efficiency greater than 65%

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Table Of Contents

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.

Design Reports contain a power supply design specification, schematic, bill of materials, and transformer documentation. Performance data and typical operation characteristics are included. Typically only a single prototype has been built.

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1 Introduction

This document is an engineering prototype report for a universal input, power factor corrected power supply unit providing 12V at 250mA.

This power supply uses *LinkSwitch* – an integrated IC combining a 700 V high voltage MOSFET, PWM controller, start-up, thermal shut down and fault protection circuitry. This power supply is designed to provide a cost effective replacement for linear transformer based Auxiliary power supplies while providing the additional benefits of universal input range and high-energy efficiency.

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

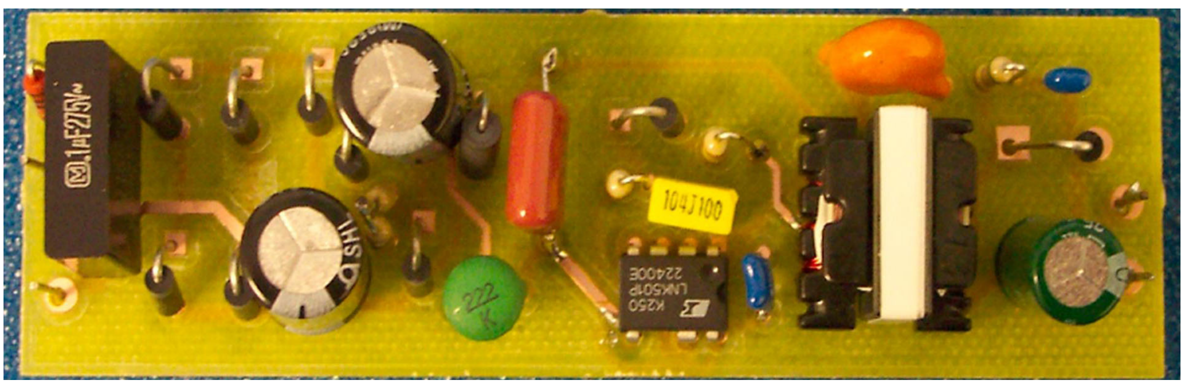

Figure 1 – Prototype Circuit Board Picture

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2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no Protective Ground
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (265 VAC)				0.3	W	
Output						
Output Voltage	V_{OUT}	8	12	15	V	
Output Ripple Voltage	$V_{RIPPLE\ R}$			500	mV	
Output Current	I_{OUT}	50		250	mA	
Input Power Factor	**%**	65				0.25A Load / 120VAC / 220VAC
Continuous Output Power	P_{OUT}		3		W	
Efficiency	η		70		%	Measured at output peak power point, 25 °C
Environmental						
Ambient Temperature	T_{AMB}	0		60	°C	
Conducted EMI	Meets CISPR22B / EN55022B & FCC B with artificial hand connected to output return					
Safety	Designed to meet IEC950, UL1950 Class II					

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3 Schematic

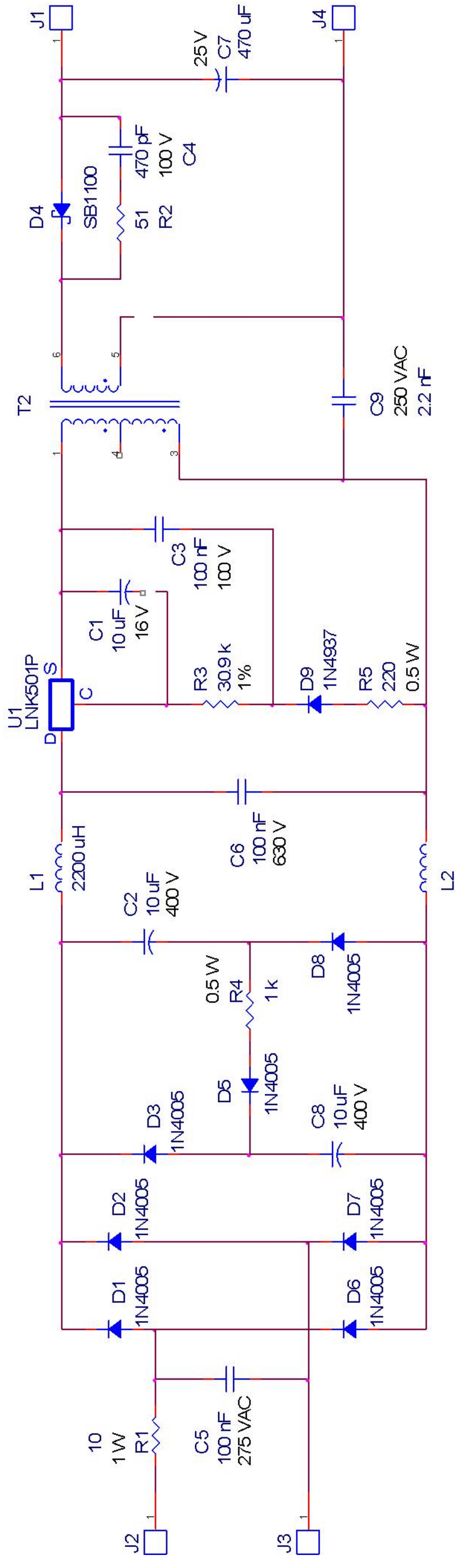

Figure 2 – Schematic

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4 Circuit Description

The schematic shown in Figure 2 provides two isolated outputs from a universal input voltage range of 90 VAC to 265 VAC.

4.1 Input Stage

The incoming AC is rectified and filtered by D1, D2, D3, D5, D6, D7, D8, R4, C2, and C8 with a high power factor. Resistor R1 is a flameproof fusible type to protect against fault conditions and is a requirement to meet safety agency fault testing. Please consult with a safety engineer or local safety agency.

L1 and L2 provide differential mode filtering of switching frequency noise generated by the LNK500 power stage. C6 provides local energy storage for the Flyback stage. C5 is a safety X1 capacitor that helps filter switching noise of the bridge rectifier and maintains compliance to the conducted EMI requirements of EN55022 Class B in conjunction with safety Y1 capacitor C9.

4.2 LinkSwitch Operation

When power is applied to the supply, high voltage DC appears at the DRAIN pin of *LinkSwitch* (U1). The CONTROL pin capacitor C1 is then charged through a switched high voltage current source connected internally between the DRAIN and CONTROL pins. When the CONTROL pin voltage reaches approximately 5.7 V relative to the SOURCE pin, the internal current source is turned off. The internal control circuitry is activated and the high voltage internal MOSFET starts to switch, using the energy in C1 to power the IC.

As the current ramps in the primary of Flyback transformer T1, energy is stored. This energy is delivered to the output when the MOSFET turns off each cycle.

The secondary of the transformer is rectified and filtered by D4 and C7 to provide the DC output to the load.

Control of the output characteristic is entirely sensed from the primary-side by monitoring the primary-side V_{OR} (reflected output voltage). While the output diode is conducting, the voltage across the transformer primary is equal to the output voltage plus diode drop multiplied by the turn’s ratio of the transformer. Since the *LinkSwitch* is connected on the high side of the transformer, the V_{OR} can be sensed directly.

Diode D9 and capacitor C3 form the primary clamp network. The voltage held across C3 is essentially the V_{OR} with a small error due to the parasitic leakage inductance.

The *LinkSwitch* has three operating modes determined by the current flowing into the CONTROL pin.

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During start-up, as the output voltage, and therefore the reflected voltage and voltage across C3 increases, the feedback current increases from 0 to approximately 2mA through R3 into the CONTROL pin. The internal current limit is increased during this period until reaching 100%, providing an approximately constant output current.

Once the output voltage reaches the regulated value, the output voltage is regulated through control of the duty cycle. As the current into the CONTROL pin exceeds approximately 2mA, the duty cycle begins to reduce, reaching 30% at a CONTROL pin current of 2.3mA.

If the duty cycle reaches a 3% threshold, the switching frequency is reduced, which reduces energy consumption under light or no load conditions.

As the output load increases beyond the peak power point (defined by $\frac{1}{2} \cdot L \cdot I^2 \cdot f$) and the output voltage and V_{OR} falls, the reduced CONTROL pin current will lower the internal current providing an approximately constant current output characteristic. If the output load is further increased and the output voltage falls further to below a CONTROL pin current of 1mA, the CONTROL pin capacitor C1 will discharge and the supply will enter auto-restart.

4.3 Transformer

The transformer is designed to always be discontinuous; all the energy is transferred to the load during the MOSFET off time. The energy stored in the transformer during discontinuous mode operation is $\frac{1}{2} \cdot L \cdot I^2 \cdot f$ where L is the primary inductance, I^2 is the peak primary current squared and f is the switching frequency.

Since the value of *LinkSwitch* current limit and frequency directly determines the peak power, the parameter of current squared times frequency is defined in the datasheet. This parameter, together with the output power, is used to specify the transformer primary inductance.

As *LinkSwitch* is powered by the energy stored in the leakage inductance of the transformer, only a low cost two winding transformer is required. Leakage inductance should be kept low, ideally at less than 2% of the primary inductance. High leakage inductance will cause the output current limit characteristic to walk out as the output voltage decreases and increases the no-load consumption of the supply.

4.4 Clamp and Feedback Components

Diode D9 should either be a fast (t_{rr} <250 ns) or ultra-fast type to prevent the voltage across *LinkSwitch* from reversing and ringing below ground. A fast diode is preferred, being lower cost.

Capacitor C3 is typically fixed at 0.1 µF and should be rated above the V_{OR} and be stable with both temperature and applied voltage. Low-cost, Metalized plastic film capacitors are ideal; high value, low-cost ceramic capacitors are not recommended. Dielectrics

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used for these capacitors such as Z5U and Y5U are not stable and can cause output instability as their value changes with voltage and temperature. Stable dielectrics such as COG/NPO are acceptable but are costly when compared to a Metalized plastic film capacitor.

R3 was selected to program the peak power point to be 250mA when a transformer with a nominal L_P value was used. The expression used to size R3 is from Power Integrations Application note, AN-35. C1 sets the auto-restart period and also the time the output has to reach regulation before entering auto-restart from start-up.

4.5 Output Stage

Diode D4 should be rated for 80% of applied reverse voltage and thermally for average current multiplied by forward voltage at maximum ambient. Here a 1 A, 100 V Schottky diode was used to reduce the losses and improve efficiency. R2 and C4 from a snubber network to reduce ringing on D4. Capacitor C7 should be rated for output voltage and ripple current.

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5 PCB Layout

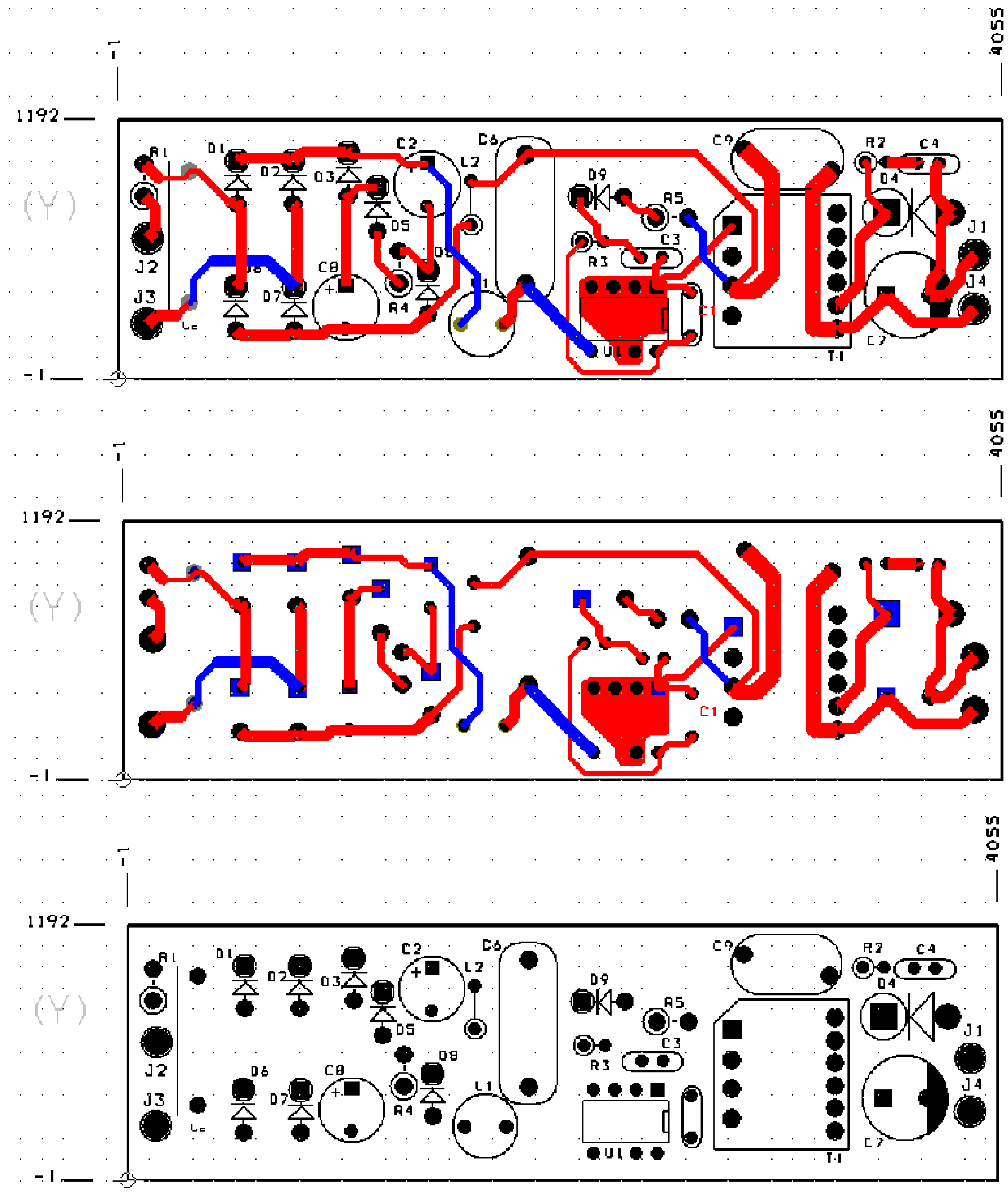

Figure 3 – Printed Circuit Layout

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6 Bill Of Materials

Item	Quantity	Reference	Part Description
1	2	C2, C8	Capacitor, 10 µF, 400 V
2	1	C1	Capacitor, 10 µF, 16 V, General Purpose
3	1	C3	Capacitor, 0.1 µF, 5%, 100 V, Metallized Film – Capacitor, Panasonic, part # ECQ-V1104JM
4	1	C4	Capacitor, Ceramic, 470 pF, 100 V
5	1	C5	Capacitor, X-cap, 0.1 µF
6	1	C6	Capacitor, Film, 100 nF, 630V
7	1	C7	Capacitor, 470 µF, 25 V, Low ESR Panasonic FC Series
8	1	C9	Capacitor, Y-cap, 2200 pF
9	7	D1, D2, D3, D5, D6, D7, D8	Diode, 1N4005, 1 A, 600 V
10	1	D9	Diode, 1N4937, 1 A, 600 V, Fast Rectifier
11	1	D4	Diode, SB1100, 1 A, 100 V, Schottky
12	1	L1	Inductor, 2.2 mH
13	1	L2	Ferrite Bead
14	1	R1	10 Ω, 1 W, Fusible
15	1	R2	51 Ω, 5%, 1/4 W
16	1	R5	220 Ω, 5%, 1/2 W
17	1	R4	1 kΩ, 5%, 1/2 W
18	1	R3	30.9 kΩ, 1%, 1/4 W
19	1	T1	Custom EE16
20	1	U1	LNK501P – Power Integrations, Inc

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7 Transformer Specification

A	B	D	F	G	I
LinkSwitch 030304; Rev.1.6; Copyright Power Integrations 2004	INPUT	INFO	OUTPUT	UNIT	LinkSwitch 030304: LinkSwitch Flyback Supply Design Spreadsheet
ENTER APPLICATION VARIABLES					**Customer**
VACMIN	90			Volts	Minimum AC Input Voltage
VACMAX	135			Volts	Maximum AC Input Voltage
fL	60			Hertz	AC Mains Frequency
VO	10			Volts	Output Voltage
IO	0.25			Amps	Continuous Output current
tC	3			msec	Bridge Rectifier Conduction Time Estimate
CIN	9.4			uFarads	Input Filter Capacitor
TARGETED / ESTIMATED LOSSES					
P_NO_LOAD_GOAL			300	mW	Target No Load losses for Power supply
PCORE			123.9	mW	Estimated Core Losses at peak Flux Density (BP)
RSEC			0.2	Ohms	Estimated Resistance of transformer secondary winding.
P_NO_LOAD_LOSS			265	mW	Power losses at no load (includes feedback and switching losses). No Load losses target achieved
DC INPUT VOLTAGE PARAMETERS					
VMIN			111.7	Volts	Minimum DC Input Voltage
VMAX			190.92	Volts	Maximum DC Input Voltage
ENTER OUTPUT CABLE PARAMETERS					
RCABLE			0.3	Ohms	Resistance of total length of cable from power supply terminals to load and back.
VCABLE			0.075	Volts	Drop along cable connecting power supply to load
ENTER LINKSWITCH & OUTPUT DIODE VARIABLES					
LINKSwitch	**LNK500**			*Universal*	*115 Doubled/230*
			Power	*3.5*	*5.5*
I^2 f			2710	A^2 Hz	I^2 f (typical) co-efficient for LinkSwitch
VOR	60		60.00	Volts	Reflected Output Voltage (40<VOR<60 recommended)
VLEAK			6.00	Volts	Error in Feedback voltage as a result of leakage inductance in primary circuit.
VD			1.1	Volts	Output Winding Diode Forward Voltage Drop (0.5~0.7V for schottky and 0.7~1.0V for PN diode)
VR			100	Volts	Rated Peak Rep Reverse Voltage of secondary diode
ID	3			Amps	Rated Average Forward current for secondary diode
DISCONTINUOUS MODE CHECK					
KDP			1.85		Ensure KDP > 1.15 for discontinuous mode operation.
TON			5.55	us	Linkswitch conduction time
TDON			9.85	us	Secondary Diode conduction time
VOLTAGE STRESS ON LINKSWITCH AND OUTPUT DIODE					
VDRAIN			336.92	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			45.56	Volts	Output Rectifier Maximum Reverse Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.23		Maximum Operating Duty Cycle
IAVG			0.030	Amps	Average Primary Current
IRMS			0.071	Amps	Primary RMS Current
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EE16**				
Core		*PC40EE16-Z*			
Bobbin		*BE-16-116CP*			
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
VE			795	mm^3	Effective Core Volume
BW			8.5	mm	Bobbin Physical Winding Width
KCORE			437	kW/m^3	Core losses per unit volume
T(n)	0.961		0.9610		Estimated transformer efficiency. T(n)=(PSCU+PCORE/2)/POEFF. Re-iterate with n = 0.961
M			0	mm	Safety Margin Width
NS	22				Number of Secondary Turns
TRANSFORMER PRIMARY DESIGN PARAMETERS					
dLP			1.030		Constant to account for reduction of inductance at higher flux densities. (0.999<dLP<1.05)
LP			2326.4	uHenries	Primary Inductance
L	3		**3**		Number of Primary Layers

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A	B	D	F	G	I
NP			**118**		Primary Winding Number of Turns
ALG			167	nH/T^2	Gapped Core Effective Inductance
BP			**2872**	Gauss	Peak Flux Density (BP<3500)
LG			0.12	mm	Core Gap Length for primary inductance
OD			0.22	mm	Maximum Primary Wire Diameter including insulation to give specified number of layers.
DIA			0.17	mm	Bare conductor diameter
AWG			34	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CMA		*Commen*	**569**	Cmils/Amp	increasing NS
TRANSFORMER SECONDARY DESIGN PARAMETERS					
ISP			1.36	Amps	Peak Secondary Current
ISRMS			0.51	Amps	Secondary RMS Current
IRIPPLE			0.44	Amps	Output Capacitor RMS Ripple Current
AWGS			33	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.18	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.39	mm	Secondary Maximum Insulated Wire Outside Diameter
INSS			0.10	mm	Maximum Secondary Insulation Wall Thickness
VSEC			0.05	Volts	Voltage Drop across secondary winding
FEEDBACK CIRCUIT COMPONENTS					
RFB			26.20	k-Ohms	Feedback resistor
PRFB			138.6	mW	Losses in the Feedback resistor
ESTIMATED LOSSES IN POWER SUPPLY AND EFFICIENCY					
PCABLE			18.75	mW	Power loss in Output Cable
PSCU			51	mW	Transformer Secondary Copper Losses
PDIODE			275	mW	Output Diode conduction loss
PBIAS			151.8	mW	Power Loss in Feedback circuit
PCONDUCTION			210.7	mW	Conduction Losses in LinkSwitch calculated at 100C
PCORE			123.9	mW	Core Losses at peak Flux Density
EFFICIENCY ESTIMATE			75.0	%	Estimated Power Supply Efficiency
ADDITIONAL OUTPUT					
VX	0			Volts	Auxiliary Output Voltage
VDX	0			Volts	Auxiliary Diode Forward Voltage Drop
NX			0.00		Auxiliary Number of Turns
PIVX			0.00	Volts	Auxiliary Rectifier Maximum Peak Inverse Voltage

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7.1 Transformer Winding

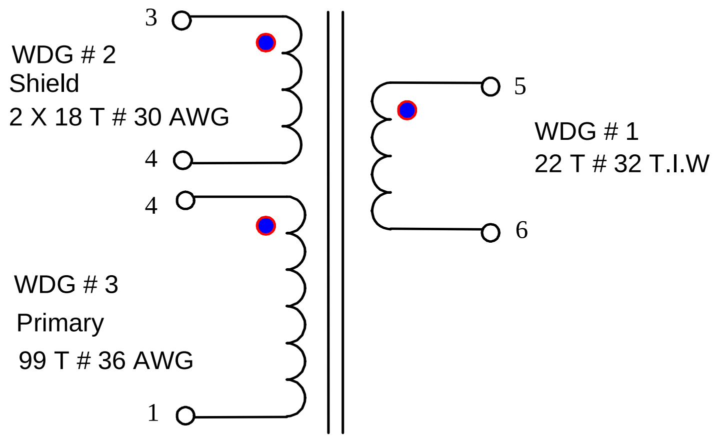

Figure 4 – Transformer Winding Diagram

7.2 Electrical Specifications

Electrical Strength	60Hz 1 minute, from Pins 1-4 to Pins 5-8	3 kV for 1 minute
Primary Inductance	All windings open	2.3mH –0%, +20%
Resonant Frequency	All windings open	300 kHz min.
Leakage Inductance	L_{13} with pins 5-6 shorted	50µH max.

7.3 Materials

Item	Description
[1]	Core: EE16, Gapped for AL = Nominal - 200 nH/T^2
[2]	Bobbin: Vertical 10 pins
[3]	Magnet Wire: # 30 AWG
[4]	Magnet Wire: # 36 AWG
[5]	Magnet Wire: # 32 AWG Triple-Insulated
[6]	Tape: 3M 1298 Polyester Film (white)
[7]	Varnish

Design Notes:

Power Integrations Device	
Frequency of Operation	42 kHz
Mode	Discontinuous
Primary Current	0.075 Arms
Reflected Voltage (Secondary to Primary)	60 V
Maximum DC Input Voltage	200 V
Minimum DC Input Voltage	111 V

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7.4 Transformer Build Diagram

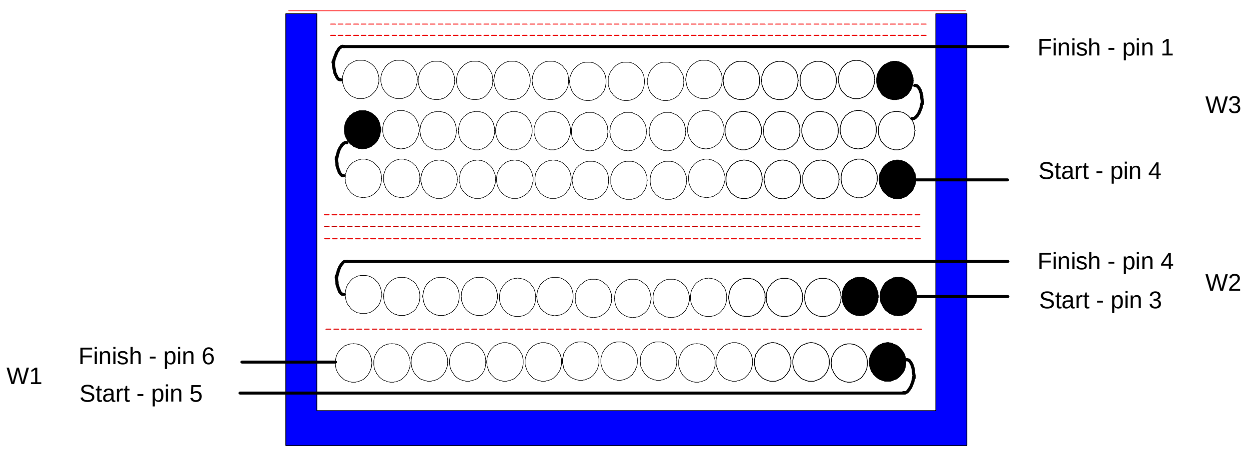

Figure 5 – Transformer Build Diagram

7.5 Transformer Construction

All windings should be wound in the forward direction.

Bobbin orientation	Place the bobbin on the winding machine with pins 1-4 on the right side and pins 5-8 on the left side.
W1 (Secondary Winding)	Wind 22 turns from right to left with # 32 triple-insulated magnet wire starting from pin 5 and finishing to pin 6.
Insulation	One layer of tape for insulation.
W2 (Primary)	Wind 18 turns from right to left with 2 x # 30 bifilar magnet wires starting from pin 3 and finishing to pin 4.
Insulation	Three layer of tape for insulation.
W3 (Primary)	Wind 99 turns from right to left with # 36 magnet wire starting from pin 3 and finishing to pin 1.
Outer Insulation	3 layers of tape for insulation.
Core Assembly	Assemble and secure core halves.
Final Assembly	Vanish transformer – Do not impregnate.

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8 Performance Data

All measurements were performed at room temperature, 60 Hz input frequency unless otherwise specified.

8.1 Line and Load Regulation

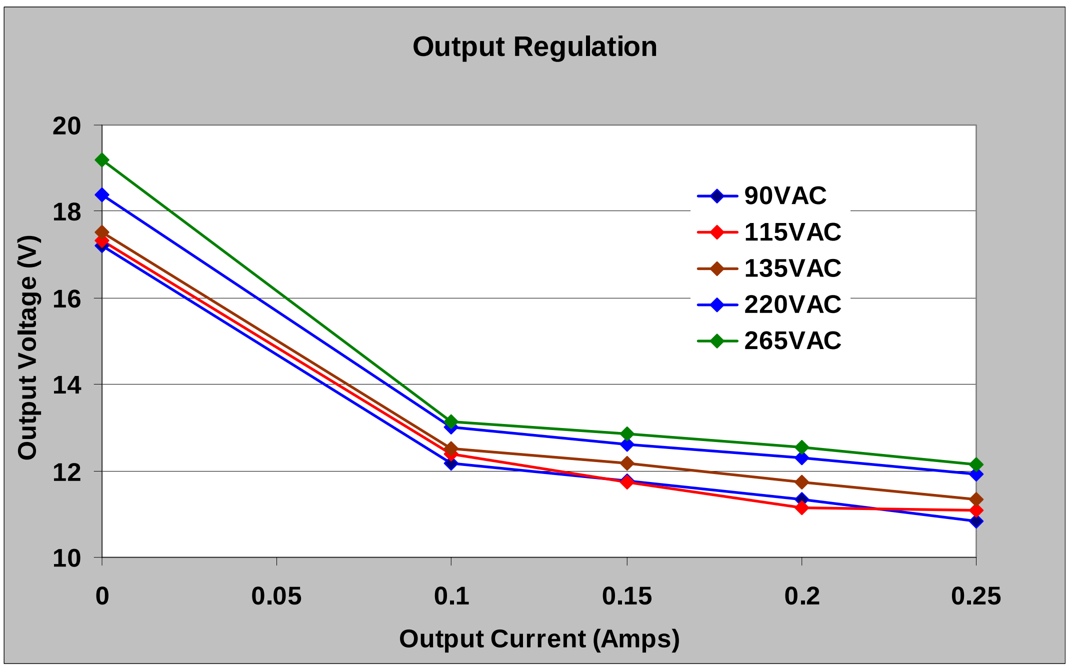

Figure 6 – Output Load Regulation at Selected Input Voltages

Note: a small preload can be used to reduce the peak voltage under no load conditions if so desired.

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8.2 Input Current

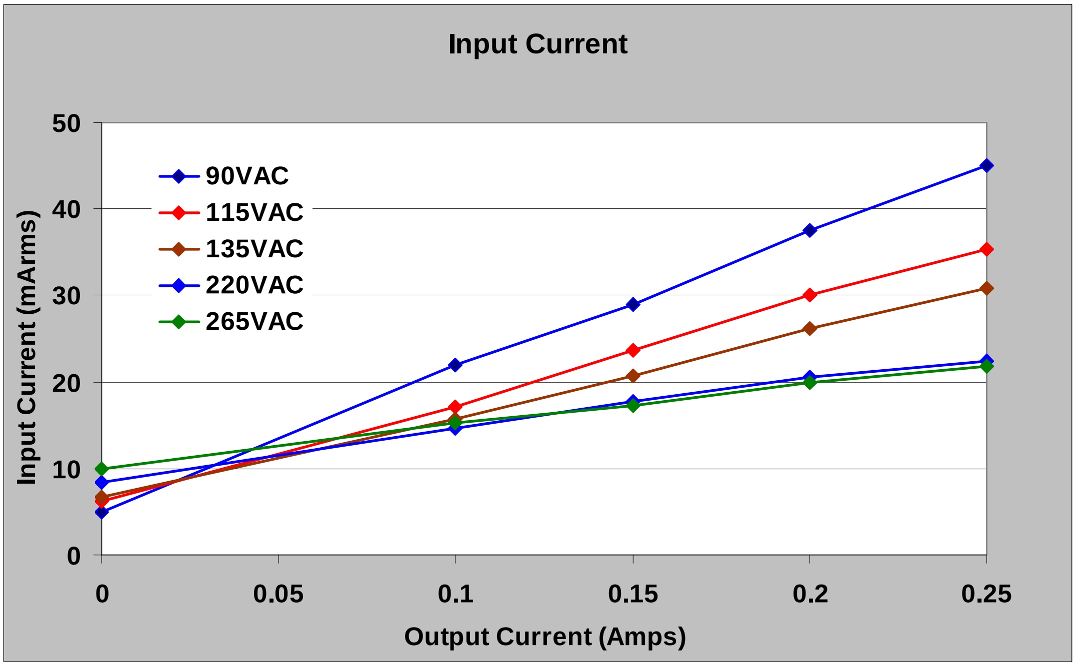

Figure 7 – Input Current

8.3 Efficiency

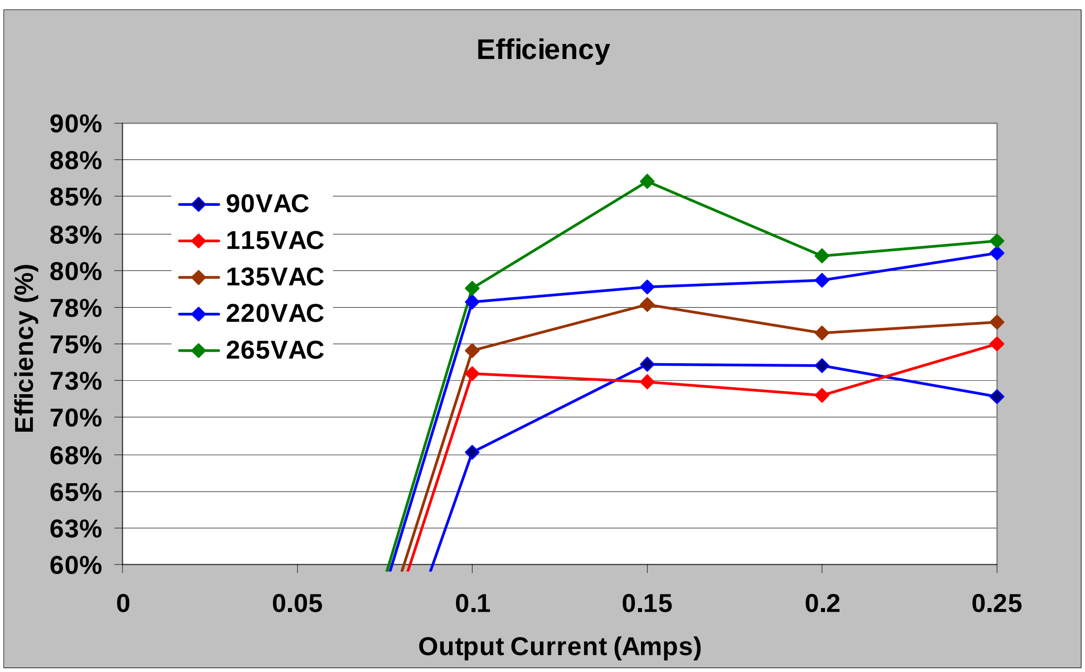

Figure 8 – Efficiency

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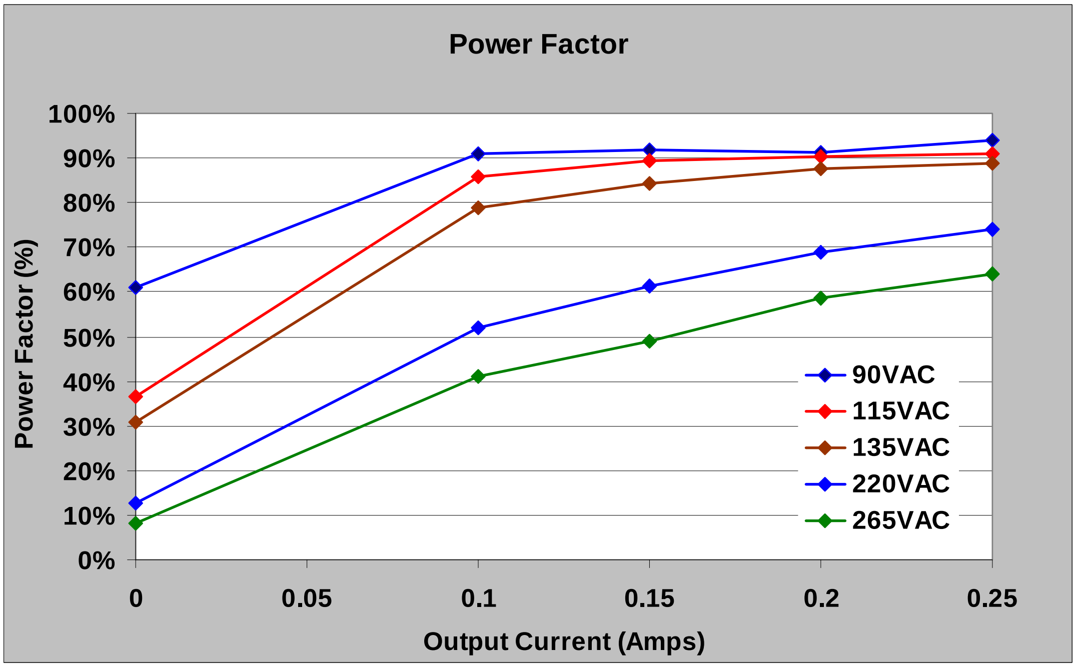
8.4 Power Factor



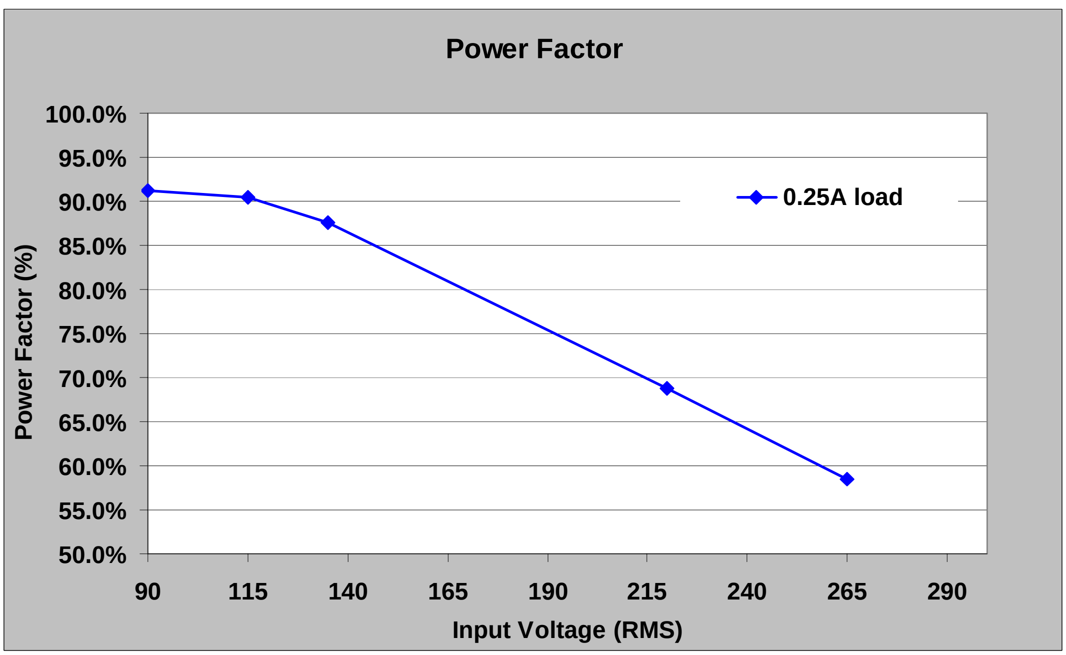


Figure 9 – Power Factor

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8.5 Standby Power

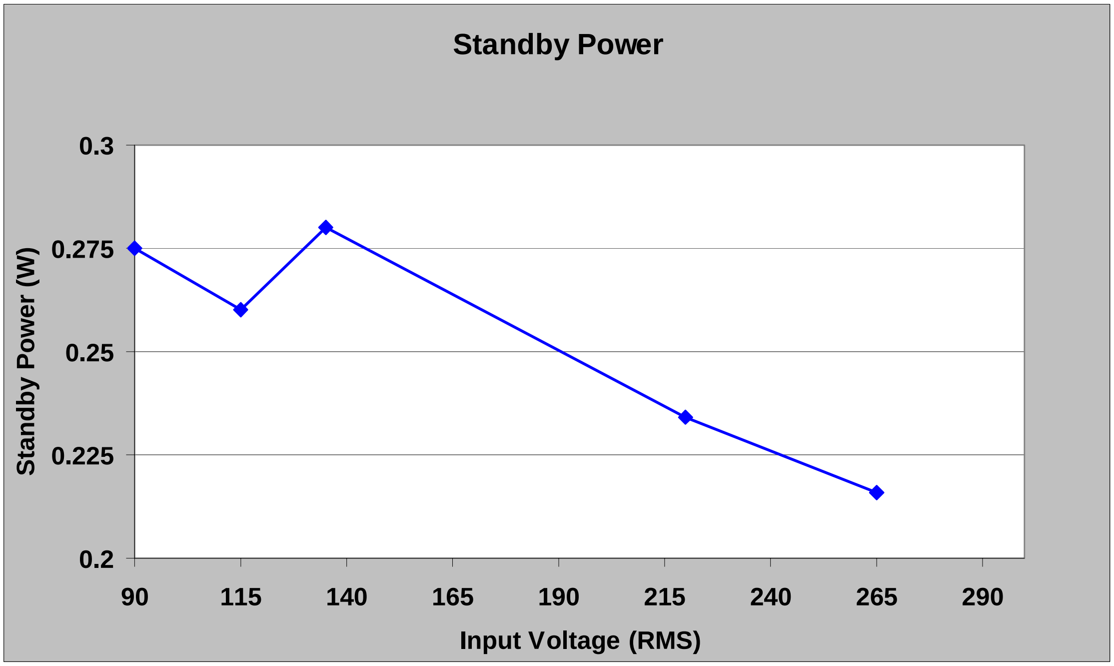

Figure 10 – Standby Power

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9 Waveforms

9.1 Output Voltage Start-up Profile

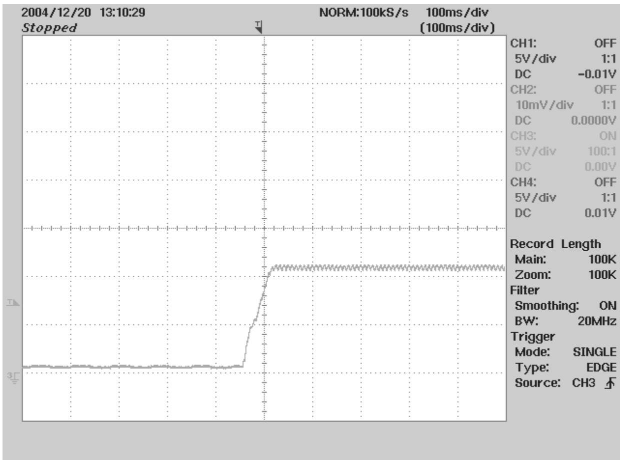

Figure 11 - Start-up Profile, 90VAC, 0.2A Load
5 V, 100 ms / div.

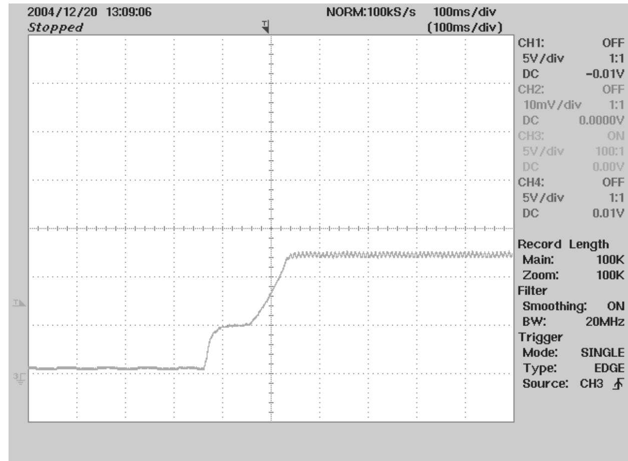

Figure 12 - Start-up Profile, 265 VAC, 0.2A Load
5 V, 100 ms / div.

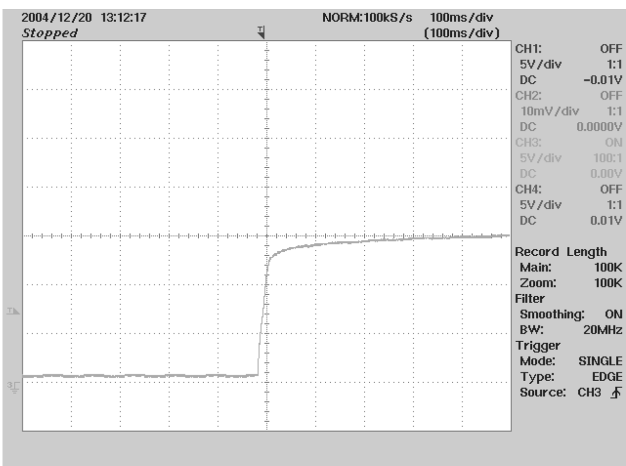

Figure 13 - Start-up Profile, 90VAC, No Load
5 V, 100 ms / div.

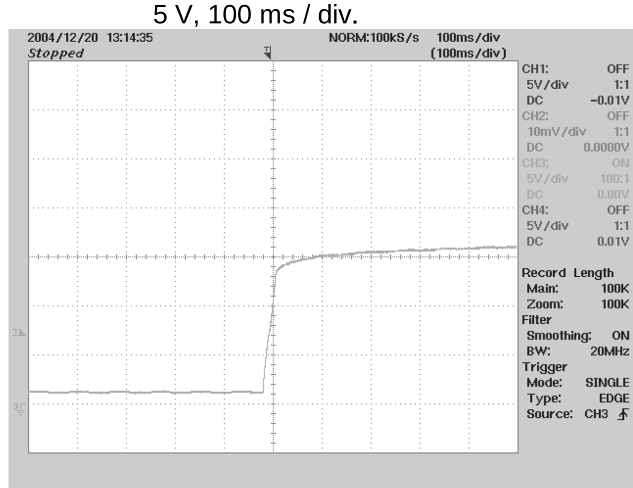

Figure 14 - Start-up Profile, 265 VAC, No Load
5 V, 100 ms / div.

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9.2 Input Current Profile

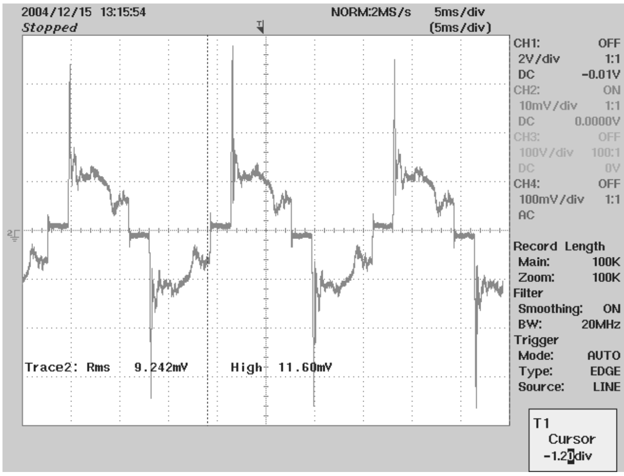

Figure 15 – Input Current Profile, 90VAC, 0.25A Load
50 mA/DIV, 5 ms / div.

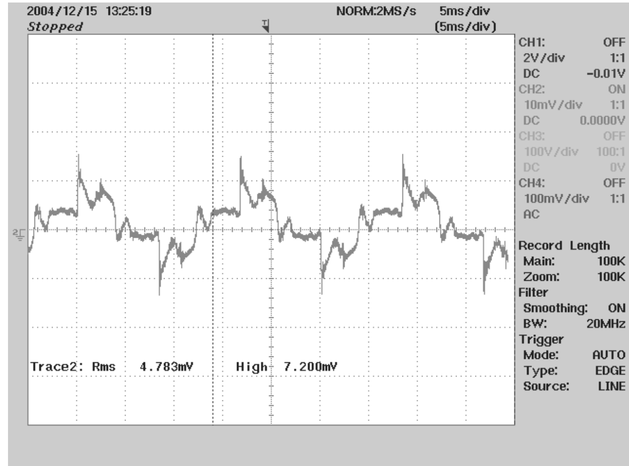

Figure 16 - Input Current Profile, 265VAC, 0.25A Load
50 mA/DIV, 5 ms / div.

9.3 Bulk Capacitor Voltage Profile

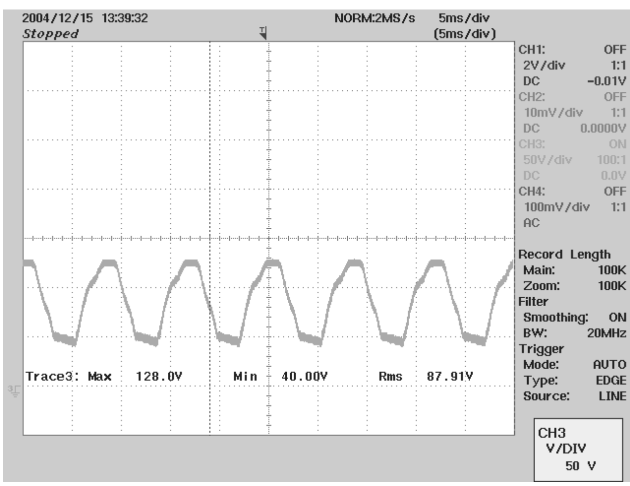

Figure 17 – Bulk Cap Voltage, 90VAC, 0.25A Load
50 V/DIV, 5 ms / div.

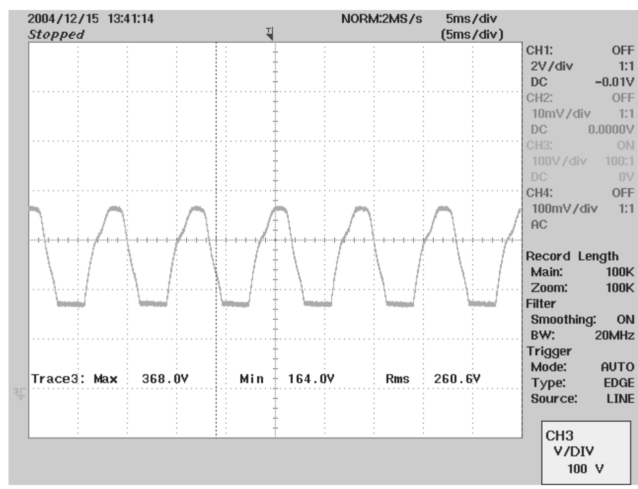

Figure 18 - Bulk Cap Voltage, 265VAC, 0.25A Load
100 V/DIV, 5 ms / div.

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10 Output Ripple Measurements

10.1.1 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 Figure 19 and Figure 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).***

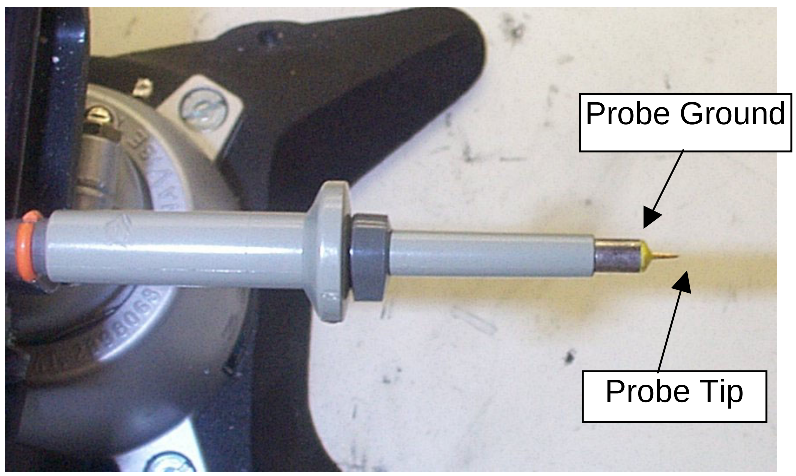

Figure 19 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

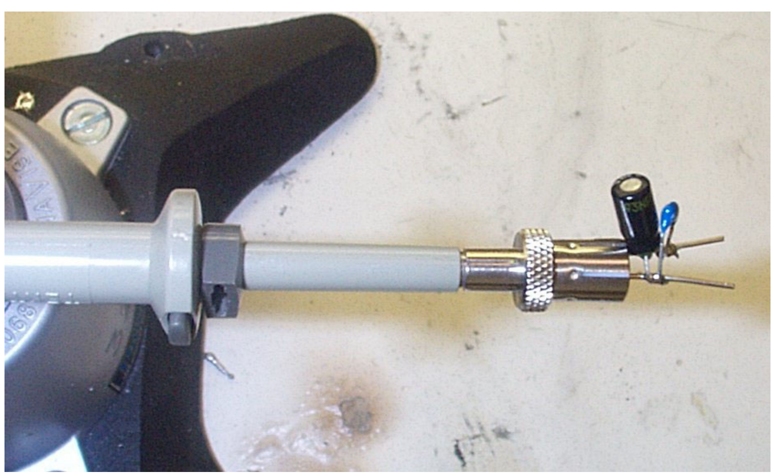

Figure 20 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

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10.1.2 Measurement Results

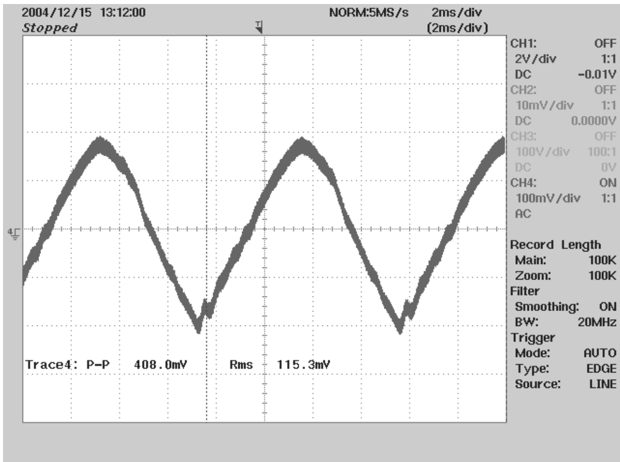

Figure 21 – Ripple Profile, 90VAC, 0.25A Load
100 mV/DIV, 2 ms / div.

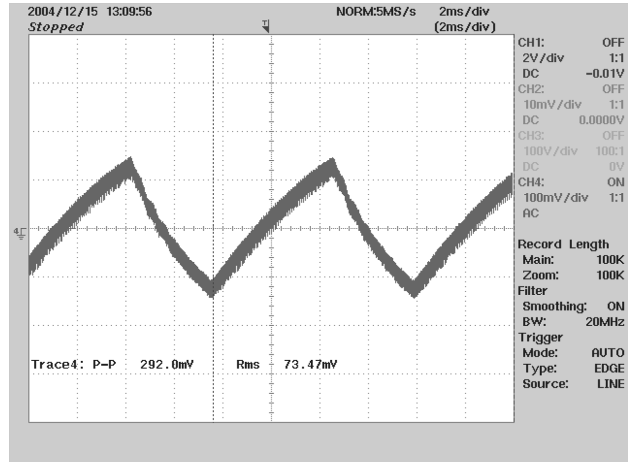

Figure 22 – Ripple Profile, 265VAC, 0.25A Load
100 mV/DIV, 2 ms / div.

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11 Conducted EMI

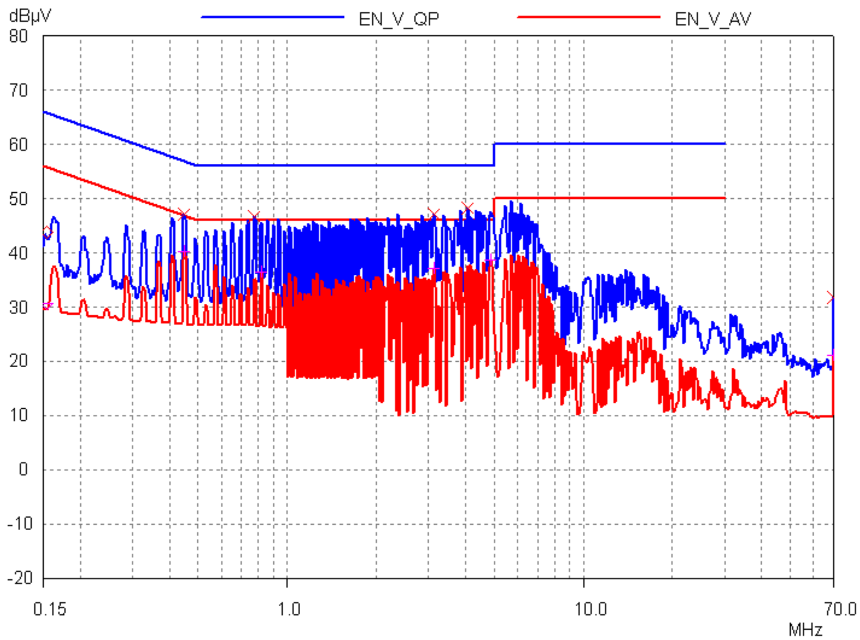

Figure 23 – Conducted EMI, V_{IN} = 120 VAC, 60 Hz Line, 250mA Load

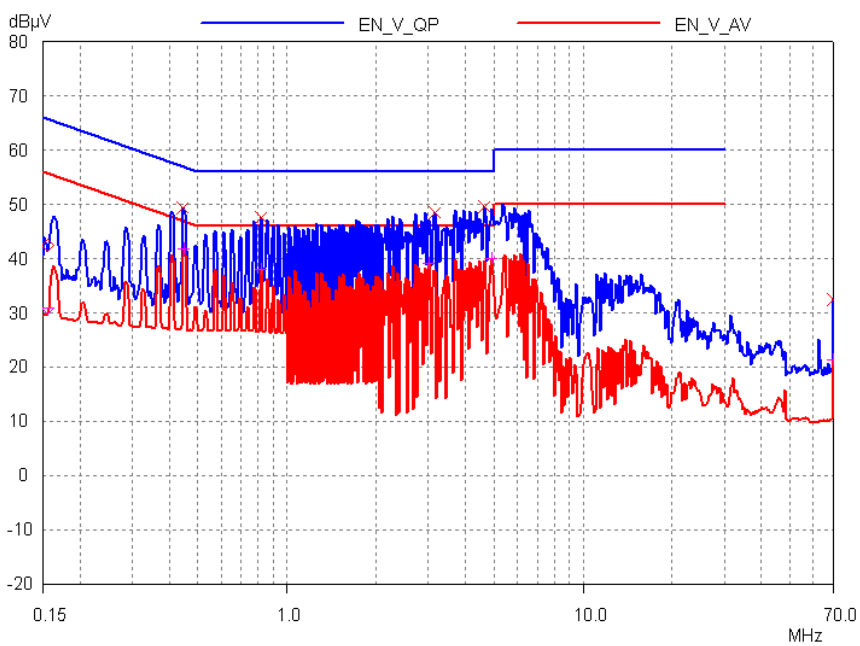

Figure 24 – Conducted EMI, V_{IN} = 120 VAC, 60 Hz Neutral, 250mA Load

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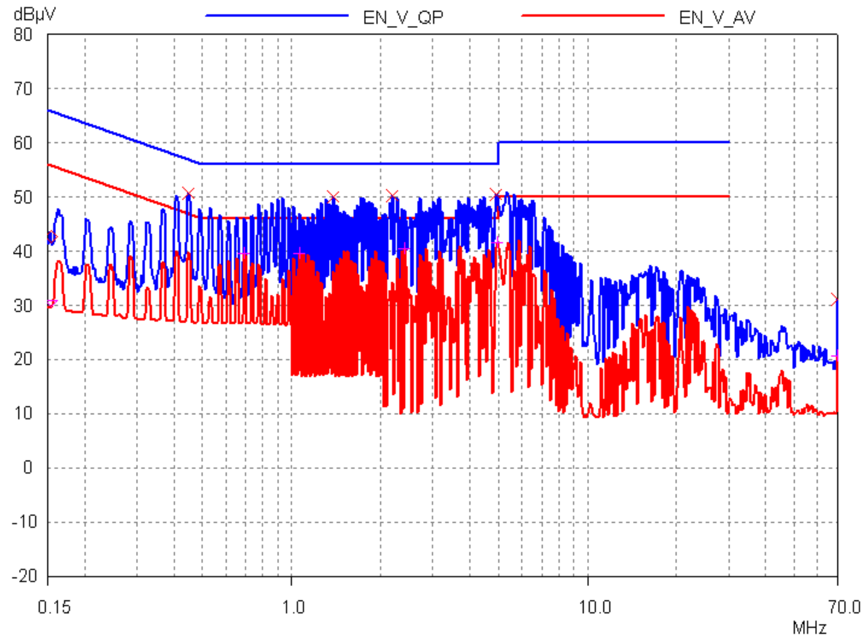

Figure 25 – Conducted EMI, V_{IN} = 230 VAC, 60 Hz Line, 250mA Load

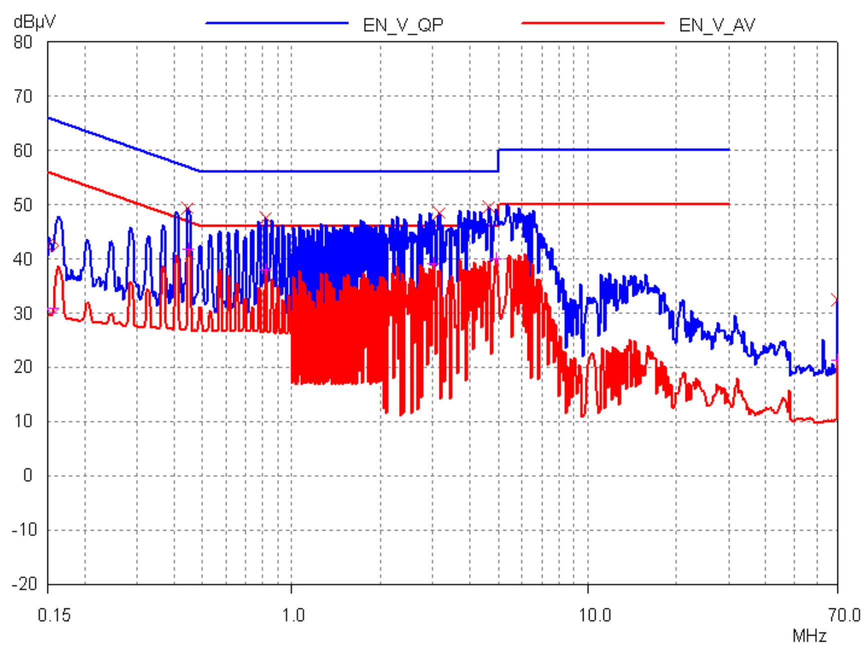

Figure 26 – Conducted EMI, V_{IN} = 230 VAC, 60 Hz Line, 250mA Load

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12 Revision History

Date	Author	Revision	Description & changes	Reviewed
April 20, 2005	RSP/EC	1.0	Initial release	KM / AM

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