Design Example Report

Title	***3.9W Power Supply using TNY263P***
Specification	Input: 85 – 275V_{AC} Output: 12V/175mA, 9V/110mA, 5V/160mA
Application	Refrigerator
Author	Power Integrations Applications Department
Document Number	DER-52
Date	April 20, 2005
Revision	1.0

Summary and Features

This document is an engineering prototype report describing a Refrigerator power supply utilizing a *TinySwitch-II* TNY263.

- No Y-Cap
- No X-Cap
- No Common-Mode Choke
- Low Component Count
- Good Cross Regulation
- No Load Input Power <400mW

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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.

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 describing a Refrigerator power supply utilizing a *TinySwitch-II* TNY263. This power supply is intended as a general purpose evaluation platform for *TinySwitch-II*.

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

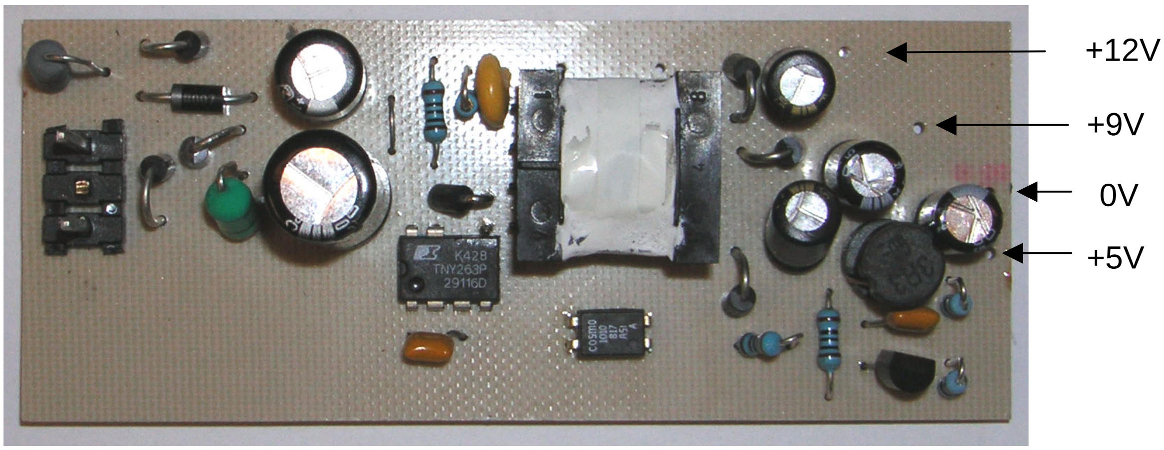

Figure 1 – Populated Circuit Board Photograph.

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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}		50		Hz	
No-load Input Power (230 VAC)					W	
Output						
Output Voltage 1	V_{OUT1}		5		V	± 5%
Output Ripple Voltage 1	$V_{RIPPLE1}$		5		mV	20 MHz Bandwidth
Output Current 1	I_{OUT1}		160		mA	
Output Voltage 1	V_{OUT1}		9		V	± 7%
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	20 MHz Bandwidth
Output Current 1	I_{OUT1}		110		mA	
Output Voltage 1	V_{OUT1}		12		V	± 10%
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	20 MHz Bandwidth
Output Current 1	I_{OUT1}		175		mA	
Total Output Power						
Continuous Output Power	P_{OUT}			3.9	W	
Peak Output Power	P_{OUT_PEAK}			3.9	W	
Efficiency estimated	η	72		77	%	
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950, UL1950 Class II				
Surge		4			kV	1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω Common Mode: 12 Ω
Surge		3			kV	100 kHz ring wave, 500 A short circuit current, differential and common mode
Ambient Temperature	T_{AMB}	0		50	^{o}C	Adapter Enclosure

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3 Schematic

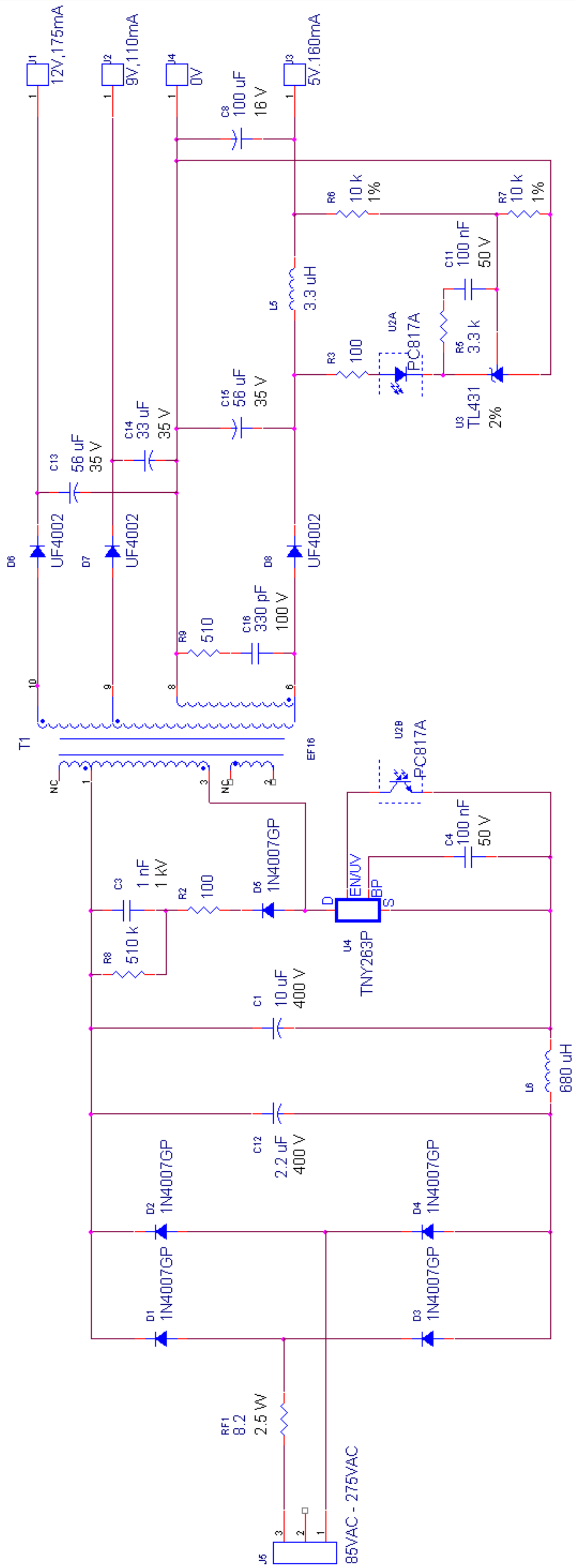

Figure 2 – Schematic.

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4 Circuit Description

The schematic in Figure 2 shows an off-line flyback converter using the TNY263P. The circuit is designed to operate from 85 VAC to 265 VAC input and provides multiple outputs (i.e. +5V, +9V, +12V).

4.1 TinySwitch-II Primary

AC input power is rectified by a full bridge diodes, consisting of D1 through D4. The rectified DC is then filtered by the bulk storage capacitors C12 and C1. Inductor L6, C1 and C12 form a pi (π) filter, which attenuates conducted differential-mode EMI noise.

The rectified DC rail is applied to one end of the transformer primary, the other end being connected to the drain pin of the integrated MOSFET of U4.

To keep the peak DRAIN voltage acceptably below the BV_{DSS} (700V) of U4, diode D5, C3, R8, and R2 form a primary clamp. This network clamps the voltage spike seen on the DRAIN due to primary and secondary reflected leakage inductance.

Capacitor C4 stores energy through the internal high voltage device and provides bias supply for U4.

4.2 Output Rectification

The secondary has three isolated windings. Each output is rectified and filtered to provide +5V, +9V & +12V DC outputs. The +5V output has a post filter to reduce the high frequency output voltage ripple.

4.3 Output Feedback

The regulation is realized with a TL431 shunt regulator to keep the 5V output tolerance within the specification.

For a relaxed 5V tolerance the TL431 regulation circuit could be replaced with a Zener diode regulation.

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5 PCB Layout

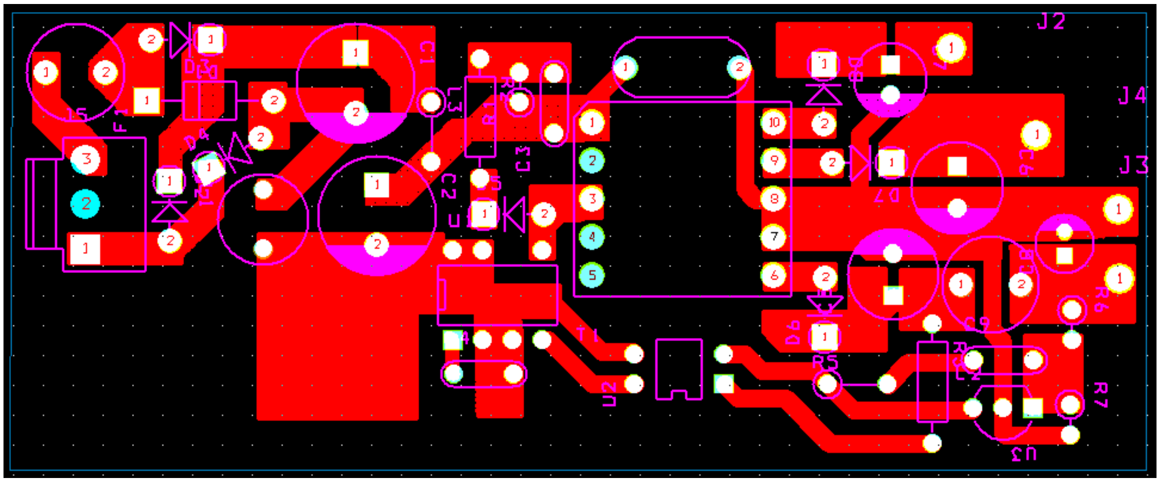

Figure 3 – Printed Circuit Layout.

Notes:
Parts which are not used in the prototype:
L3, C10 (Y-Cap)
Parts which are different to the layout:
C1, L1, F1
Parts which are not included in the layout:
R9, C16

A fully updated layout file is available upon request.

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6 Bill Of Materials

Item	Qty	Value	Description	Part Reference	Mfg
1	1	10 uF	10uF,400V, Electrolytic, Gen. Purpose	C1	United Chemi-Con
2	1	1 nF	1 nF, 1 kV, Disc Ceramic	C3	NIC Components Corp
3	2	100 nF	100 nF, 50 V, Ceramic, X7R	C4 C11	Panasonic
4	1	100 uF	100 uF, 16 V, Electrolytic, Gen. Purpose, (5 x 11)	C8	United Chemi-Con
5	1	2.2 uF	2.2 uF, 400 V, Electrolytic, (8 x 11.5)	C12	United Chemi-Con
6	2	56 uF	56 uF, 35 V, Electrolytic, Low ESR, 250 mOhm, (6.3 x 11.5)	C13 C15	United Chemi-Con
7	1	33 uF	33 uF, 35 V, Electrolytic, Low ESR, 50 mOhm, (5 x 11.5)	C14	United Chemi-Con
8	1	330 pF	330 pF, 100 V, Ceramic, COG	C16	Panasonic
9	5	1N4007GP	1000 V, 1 A, Rectifier, Glass Passivated, 2 us, DO-41	D1 D2 D3 D4 D5	Vishay
10	3	UF4002	100 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	D6 D7 D8	Vishay
11	1	3.3 uH	3.3 uH, 0.285 A, Iron Core	L5	API Delevan
12	1	680 uH	680 uH, 0.113 A,	L6	Wuerth Elektronik
13	2	100	100 R, 5%, 1/4 W, Carbon Film	R2 R3	Yageo
14	1	3.3 k	3.3 k, 5%, 1/4 W, Carbon Film	R5	Yageo
15	2	10 k	10 k, 1%, 1/4 W, Metal Film	R6 R7	Yageo
16	1	510 k	510 k, 5%, 1/4 W, Carbon Film	R8	Yageo
17	1	510	510 R, 5%, 1/4 W, Carbon Film	R9	Yageo
18	1	8.2	8.2 R, 2.5 W, Fusible/Flame Proof Wire Wound	RF1	Vitrohm
19	1	EF16	Bobbin, EF16, Horizontal, 10 pins	T1	Ngai Cheong Electronics
20	1	PC817A	Opto coupler, 35 V, CTR 80-160%, 4-DIP	U2	Isocom, Sharp
21	1	TL431	2.495 V Shunt Regulator IC, 2%, 0 to 70C, TO-92	U3	Texas Instruments
22	1	TNY263P	TinySwitch-II, TNY263P, DIP-8B	U4	Power Integrations

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7 Transformer Specification

7.1 Electrical Diagram

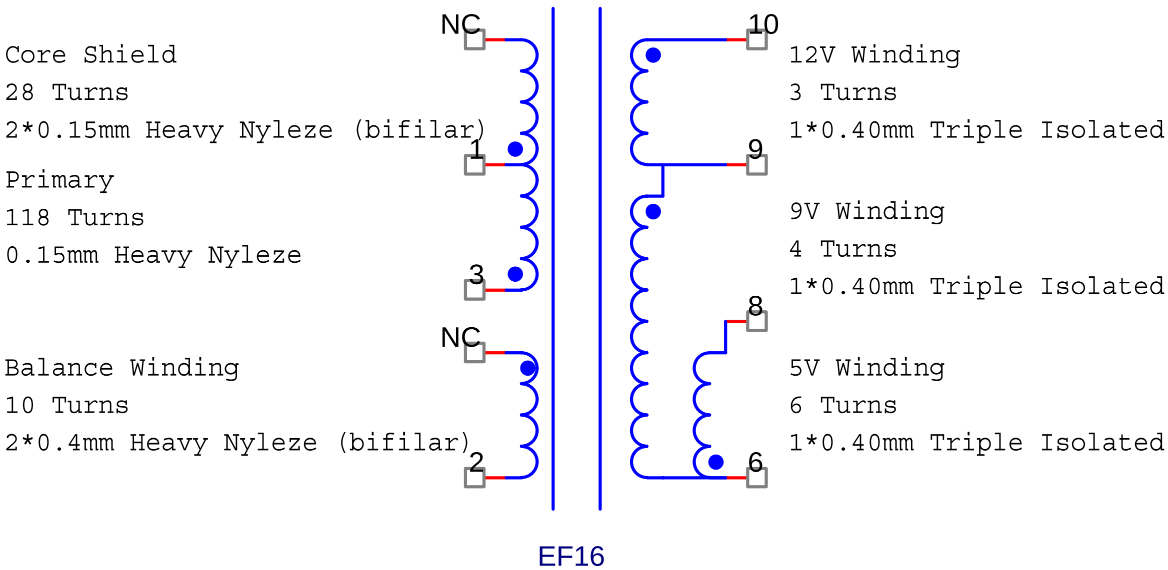

Figure 4 –Transformer Electrical Diagram

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Pins 1-3 to Pins 8-10	3000 VAC
Primary Inductance	Pins 1-3, all other windings open, measured at 100 kHz, 0.4 VRMS	1990 µH, -0/+20%
Resonant Frequency	Pins 1-3, all other windings open	950 kHz (Min.)
Primary Leakage Inductance	Pins 1-3, with Pins 8-10 shorted, measured at 100 kHz, 0.4 VRMS	50 µH (Max.)

7.3 Materials

Item	Description
[1]	Core: PC40EF16-Z, TDK or equivalent Gapped for AL of 143 nH/T^2
[2]	Bobbin: EF16 Horizontal 10 pin
[3]	Magnet Wire: 0.15mm
[4]	Magnet Wire: 0.4mm
[5]	Triple Insulated Wire: 0.4mm
[6]	Tape: 3M 1298 Polyester Film, 2.0 mils thick, 9.8 mm wide
[7]	Varnish

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7.4 Transformer Build Diagram

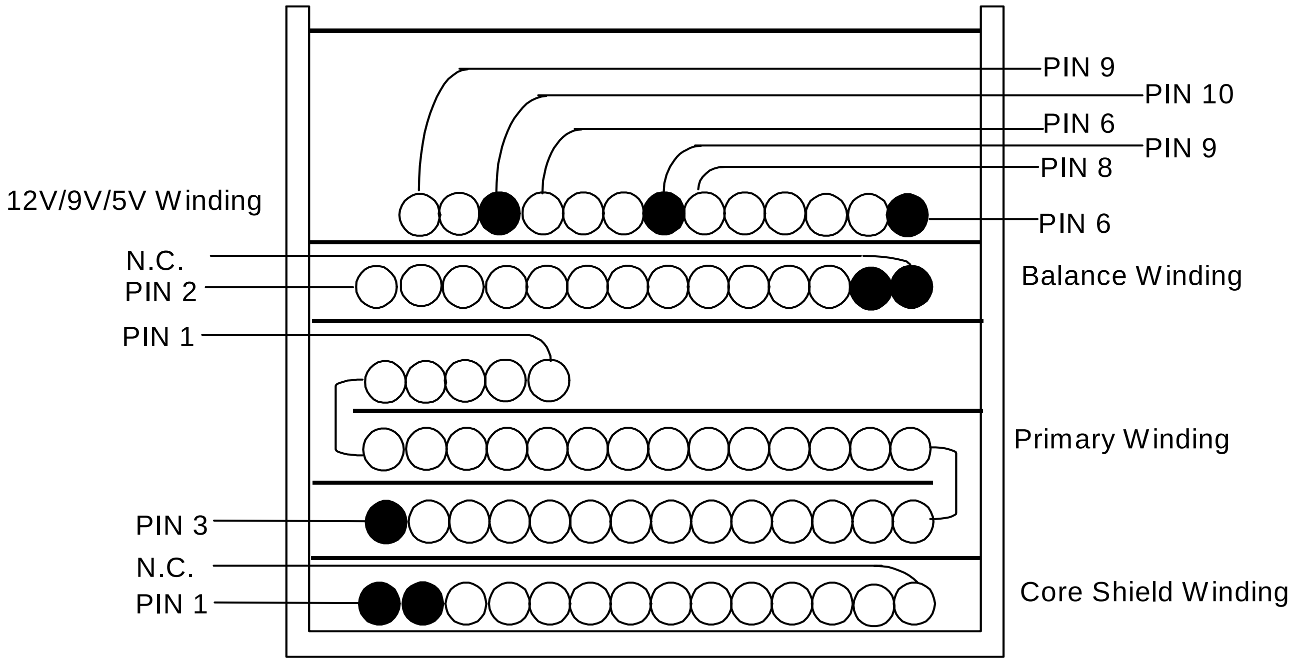

Figure 5 – Transformer Build Diagram.

7.5 Transformer Construction

Core Shield	Start at PIN1. Wind 28 bifilar turns of item [3] from left to right covering a single full layer. Leave the end of winding inside.
Tape	1 layer of item [6] for mechanical fixing.
Primary	Start at Pin 3. Wind 118 turns of item [3] in approximately 2 1/2 layers from left to right. The first layer should have about 53 turns, the second 53 turns too and the third 10 turns. Bring finish lead back to start. Finish on Pin 1.
Basic Insulation	1 layer of item [6] for basic insulation.
Balance Winding	Starting temporary at Pin 6, wind 10 bifilar turns of item [4] from right to the left. Spread turns evenly across bobbin. Finish at Pin 2. Remove the wire from Pin 6 and leave the end of winding inside.
Insulation	Use 1 layers of item [6] for basic insulation
12V, 9V and 5V Windings	Start at Pin 6. Wind 6 turns of item [5] from right to left. Terminate on Pin 8. In the same layer start at Pin 9. Wind 4 turns of item [5] and terminate on Pin 6. For the 12V Winding start at Pin 10 and wind 3 turns of item [5]. Terminate Winding on Pin 9.
Outer Wrap	Wrap windings with 2 layers of tape item [6].
Final Assembly	Assemble and secure core halves so that the tape wrapped E core is at the bottom of the transformer. Varnish impregnate (item [9]).

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8 Transformer Spreadsheets

	INPUT	INFO	OUTPUT	UNIT		
ENTER APPLICATION VARIABLES						
VACMIN	85			Volts	Minimum AC Input Voltage	
VACMAX	275			Volts	Maximum AC Input Voltage	
fL	50			Hertz	AC Mains Frequency	
VO	5			Volts	Output Voltage	
PO	3.89			Watts	Output Power	
n	0.75				Efficiency Estimate	
Z	0.5		0.50		Loss Allocation Factor	
tC			3.00	mSeconds	Bridge Rectifier Conduction Time Estimate	
CIN	12.2			uFarads	Input Filter Capacitor	
ENTER TinySwitch-II VARIABLES						
TinySwitch-II	**tny263**			Universal	115 Doubled/230V	
Chosen Device		TNY263	Power Out	4.7W	7.5W	
ILIMITMIN			0.20	Amps	TinySwitch-II Minimum Current Limit	
ILIMITMAX			0.23	Amps	TinySwitch-II Maximum Current Limit	
fS			132000.00	Hertz	TinySwitch-II Switching Frequency	
fSmin			120000.00	Hertz	TinySwitch-II Minimum Switching Frequency (inc. jitter)	
fSmax			144000.00	Hertz	TinySwitch-II Maximum Switching Frequency (inc. jitter)	
VOR	118			Volts	Reflected Output Voltage	
VDS			10.00	Volts	TinySwitch-II on-state Drain to Source Voltage	
VD	1			Volts	Output Winding Diode Forward Voltage Drop	
KP			1.05		Ripple to Peak Current Ratio (0.6<KRP<1.0 : 1.0<KDP<6.0)	
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES						
Core Type	**ef16**					
Core		EF16		P/N:	PC40EF16-Z	
Bobbin		EF16_BOBBIN		P/N:		0
AE			0.20	cm^2	Core Effective Cross Sectional Area	
LE			3.76	cm	Core Effective Path Length	
AL			1100.00	nH/T^2	Ungapped Core Effective Inductance	
BW			10.00	mm	Bobbin Physical Winding Width	
M	0			mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)	
L	2				Number of Primary Layers	
NS	6				Number of Secondary Turns	
DC INPUT VOLTAGE PARAMETERS						
VMIN			92.19	Volts	Minimum DC Input Voltage	
VMAX			388.91	Volts	Maximum DC Input Voltage	
CURRENT WAVEFORM SHAPE PARAMETERS						
DMAX			0.59		Maximum Duty Cycle	
IAVG			0.06	Amps	Average Primary Current	
IP			0.20	Amps	Minimum Peak Primary Current	
IR			0.20	Amps	Primary Ripple Current	
IRMS			0.09	Amps	Primary RMS Current	
TRANSFORMER PRIMARY DESIGN PARAMETERS						
LP			1989.19	uHenries	Primary Inductance	
NP			118.00		Primary Winding Number of Turns	
ALG			142.86	nH/T^2	Gapped Core Effective Inductance	
BM			1887.04	Gauss	Maximum Flux Density, (BP<3100)	
BAC			943.52	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)	
ur			1637.47		Relative Permeability of Ungapped Core	
LG			0.15	mm	Gap Length (Lg > 0.1 mm)	
BWE			20.00	mm	Effective Bobbin Width	
OD			0.17	mm	Maximum Primary Wire Diameter including insulation	
INS			0.04	mm	Estimated Total Insulation Thickness (= 2 * film thickness)	
DIA			0.13	mm	Bare conductor diameter	
AWG			36.00	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)	
CM			25.40	Cmils	Bare conductor effective area in circular mils	
CMA			296.98	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)	
TRANSFORMER SECONDARY DESIGN PARAMETERS						
Lumped parameters						
ISP			3.84	Amps	Peak Secondary Current	
ISRMS			1.40	Amps	Secondary RMS Current	
IO			0.78	Amps	Power Supply Output Current	
IRIPPLE			1.17	Amps	Output Capacitor RMS Ripple Current	
CMS			280.74	Cmils	Secondary Bare Conductor minimum circular mils	
AWGS			25.00	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)	
DIAS			0.46	mm	Secondary Minimum Bare Conductor Diameter	
ODS			1.67	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire	
INSS			0.60	mm	Maximum Secondary Insulation Wall Thickness	
VOLTAGE STRESS PARAMETERS						

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VDRAIN		656.71	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS		24.78	Volts	Output Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)				
1st output				
VO1	5	5.00	Volts	Output Voltage (if unused, defaults to single output design)
IO1	0.16	0.16	Amps	Output DC Current
PO1		0.80	Watts	Output Power
VD1		1.00	Volts	Output Diode Forward Voltage Drop
NS1		6.00		Output Winding Number of Turns
ISRMS1		0.29	Amps	Output Winding RMS Current
IRIPPLE1		0.24	Amps	Output Capacitor RMS Ripple Current
PIVS1		24.78	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1		57.74	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1		32.00	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1		0.20	mm	Minimum Bare Conductor Diameter
ODS1		1.67	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output				
VO2	9		Volts	Output Voltage
IO2	0.11		Amps	Output DC Current
PO2		0.99	Watts	Output Power
VD2	1		Volts	Output Diode Forward Voltage Drop
NS2		10.00		Output Winding Number of Turns
ISRMS2		0.20	Amps	Output Winding RMS Current
IRIPPLE2		0.17	Amps	Output Capacitor RMS Ripple Current
PIVS2		41.96	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS2		39.69	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS2		34.00	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS2		0.16	mm	Minimum Bare Conductor Diameter
ODS2		1.00	mm	Maximum Outside Diameter for Triple Insulated Wire
3rd output				
VO3	12		Volts	Output Voltage
IO3	0.175		Amps	Output DC Current
PO3		2.10	Watts	Output Power
VD3	1		Volts	Output Diode Forward Voltage Drop
NS3		13.00		Output Winding Number of Turns
ISRMS3		0.32	Amps	Output Winding RMS Current
IRIPPLE3		0.26	Amps	Output Capacitor RMS Ripple Current
PIVS3		54.85	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS3		63.15	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS3		32.00	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS3		0.20	mm	Minimum Bare Conductor Diameter
ODS3		0.77	mm	Maximum Outside Diameter for Triple Insulated Wire
Total power		3.89	Watts	Total Output Power

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9 Performance Data

All measurements performed at room temperature, 50 Hz input frequency.

9.1 Efficiency

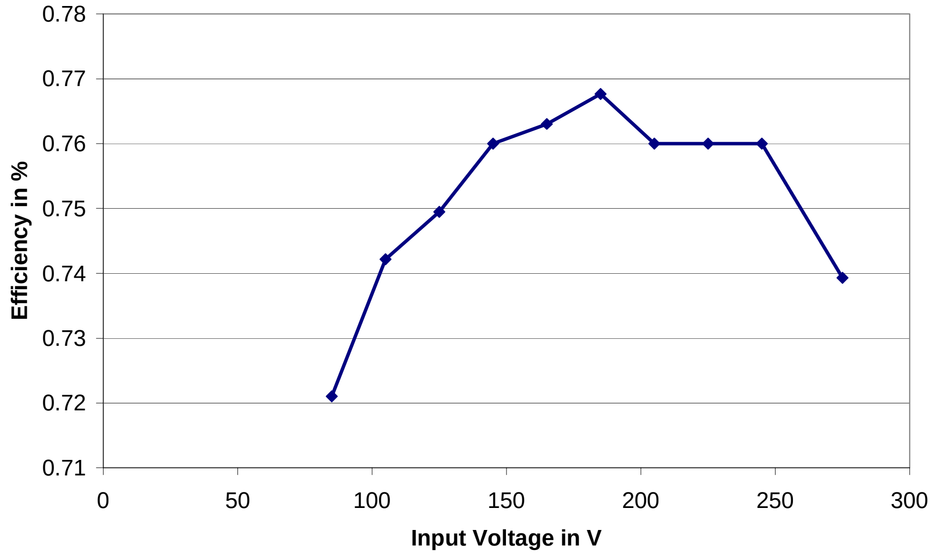

Figure 6- Efficiency vs. Input Voltage, Room Temperature, 50 Hz.

9.2 No-load Input Power

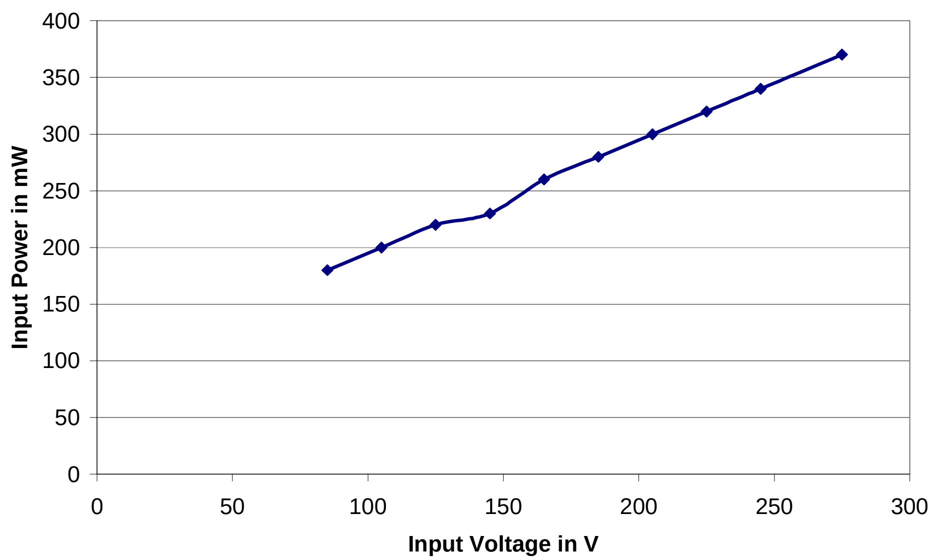

Figure 7- Zero Load Input Power vs. Input Line Voltage, Room Temperature, 50 Hz.

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9.3 Regulation

9.3.1 Load

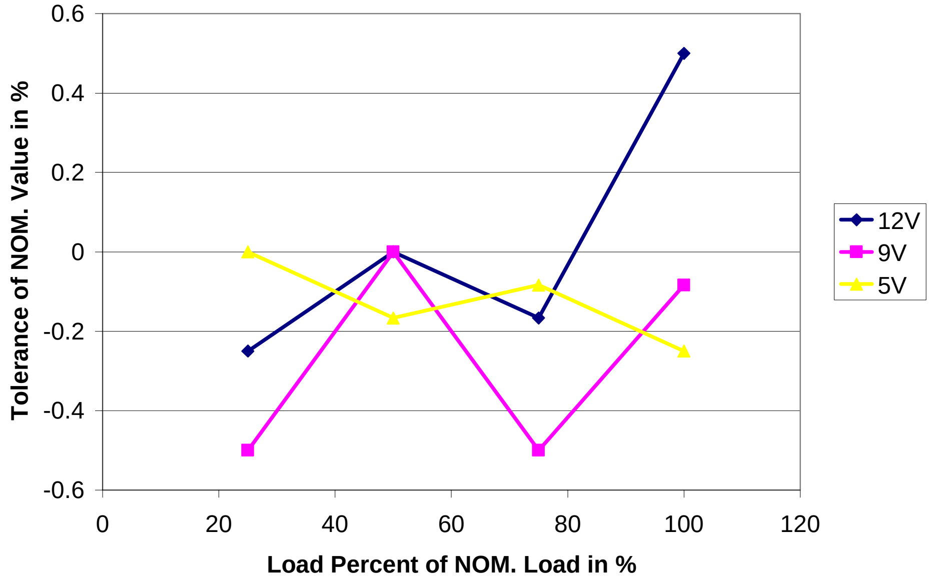

Figure 8 –Load Regulation, Room Temperature.

9.3.2 Line

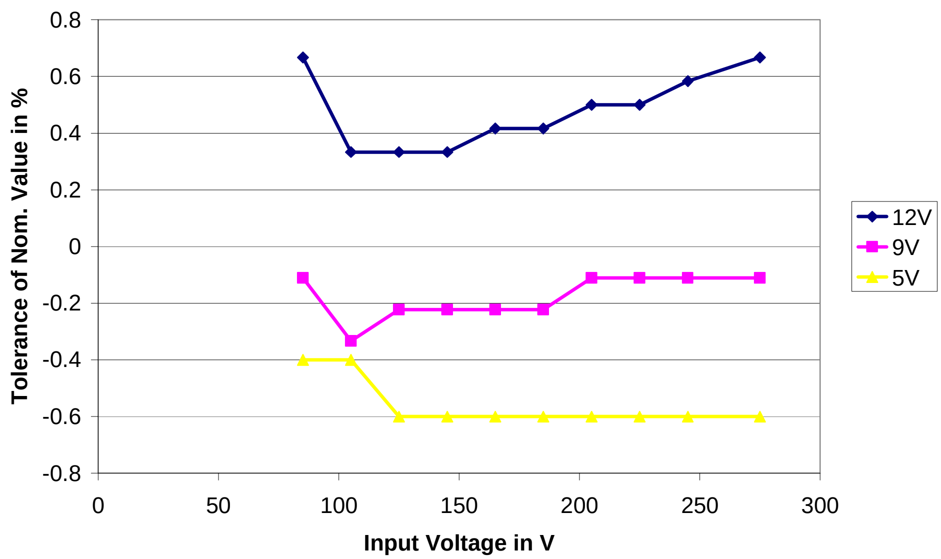

Figure 9 – Line Regulation, Room Temperature, Full Load.

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9.3.3 Cross Regulation

	12V Rail (A)	9V Rail (A)	5V Rail (A)
Min Load (X)	0.035	0.022	0.036
Max Load (M)	0.175	0.11	0.16
Load Combinations			
12V - 9V -5V	Voltage (V)	Voltage (V)	Voltage (V)
XXX	12.16	9.08	4.99
XXM	13.1	9.6	4.85
XMX	12.15	8.67	5
MXX	11.44	8.88	5
XMM	12.9	9.03	4.93
MMX	11.48	8.67	5
MMM	12.06	8.99	4.97
Min (V)	11.44	8.67	4.85
Max (V)	13.1	9.6	5
% Below	**-4.67**	**-3.67**	**-3.00**
% Above	**9.17**	**6.67**	**0.00**

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10 Thermal Performance

Temperature (°C)			
Item	**85 VAC**	**115 VAC**	**230 VAC**
Ambient	25	25	25
Inductor (L6)	41.5	36	37
Transformer (T1)	48.5	46.5	46
Clamp Resistor (R8)	44	44.5	45
Snubber Resistor (R9)	38	37	36.5
***TNY263P* (U4)**	45.5	42	44.5
Rectifier 12V (D8)	47	45.5	47.5

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11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

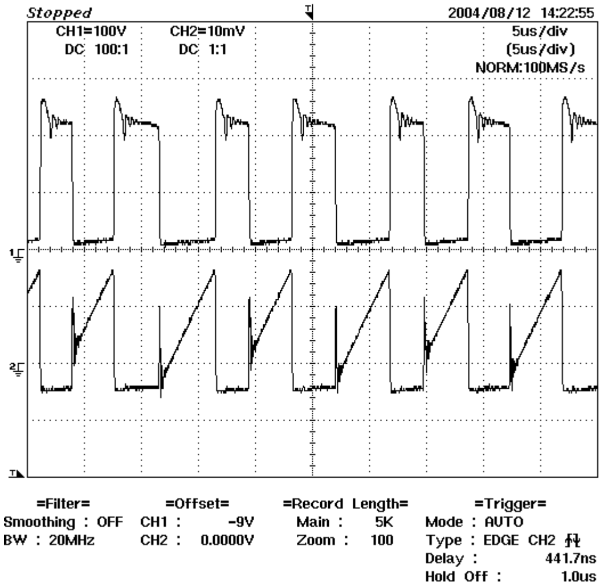

Figure 10 - 85 VAC, Full Load.
Lower: I_{DRAIN}, 100 mA / div
Upper: V_{DRAIN}, 100 V, 5 µs / div

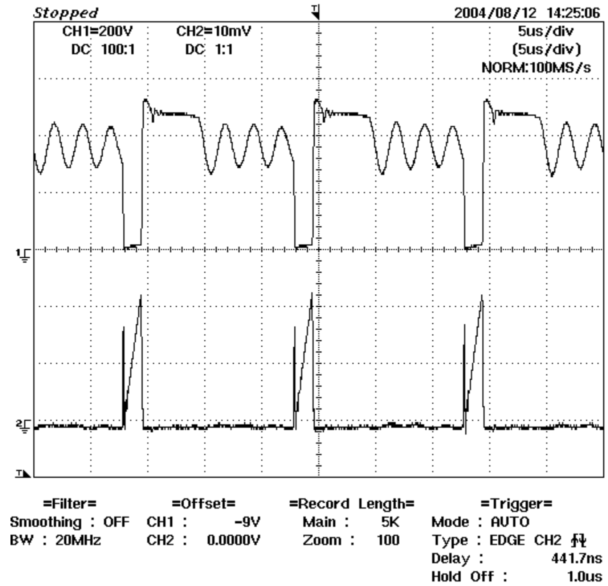

Figure 11 - 275 VAC, Full Load
Lower: I_{DRAIN}, 100 mA / div
Upper: V_{DRAIN}, 200 V / div

11.2 Output Voltage Start-up Profile

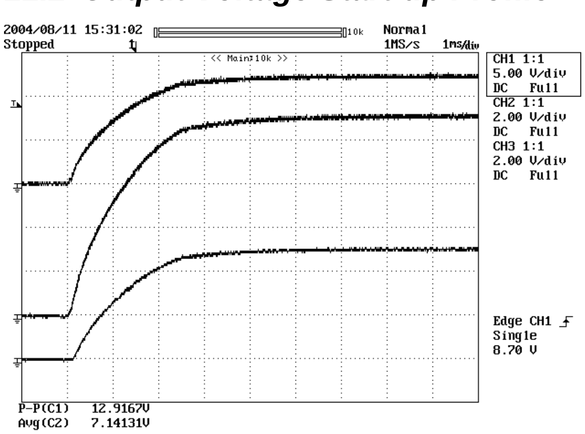

Figure 12 - Start-up Profile, 85VAC

CH1: 12V (5V, 1 ms / div.)
CH2: 9V (2V, 1 ms / div.)
CH3: 5V (2V, 1 ms / div.)

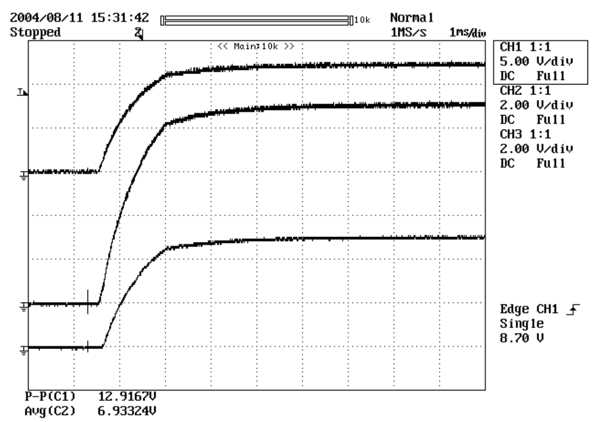

Figure 13 - Start-up Profile, 275VAC

CH1: 12V (5V, 1 ms / div.)
CH2: 9V (2V, 1 ms / div.)
CH3: 5V (2V, 1 ms / div.)

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11.3 Drain Voltage and Current Start-up Profile

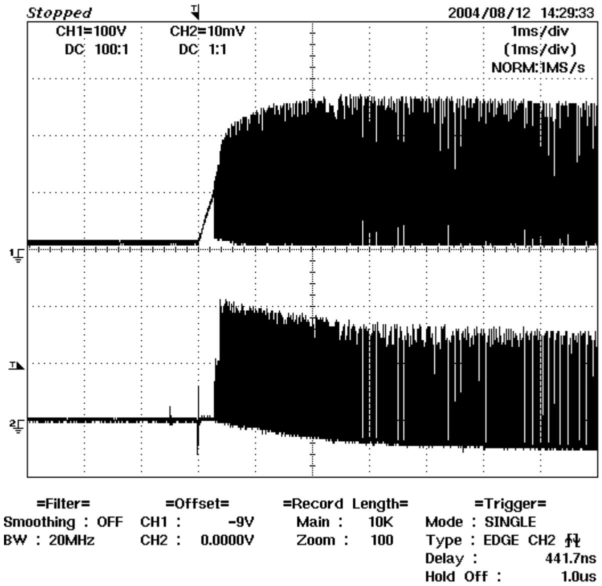

Figure 14 - 85 VAC Input and Maximum Load.
Lower: I_{DRAIN}, 100 mA / div.
Upper: V_{DRAIN}, 100 V & 1 ms / div.

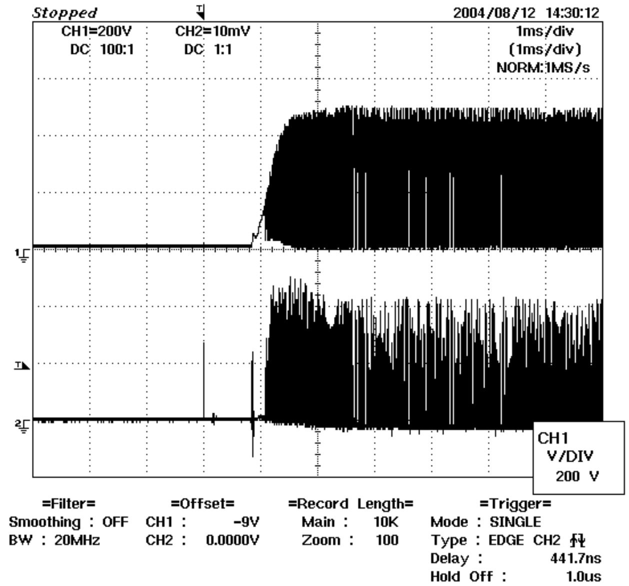

Figure 15 - 265 VAC Input and Maximum Load.
Lower: I_{DRAIN}, 100 mA / div.
Upper: V_{DRAIN}, 200 V & 1 ms / div.

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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.

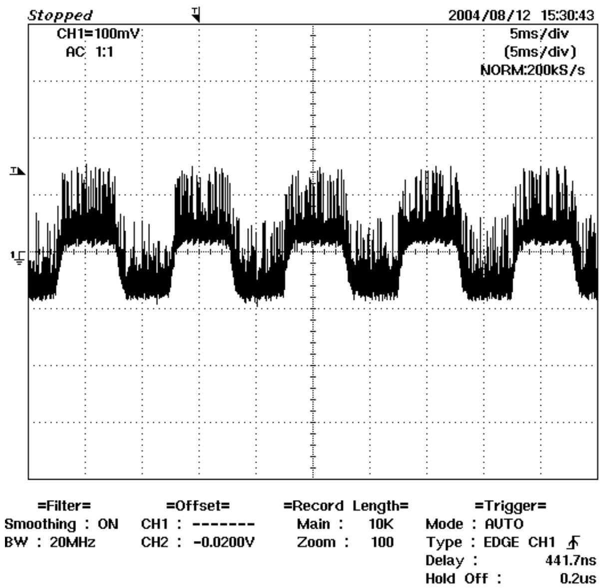

Figure 16 – Transient Response, 230 VAC, 75-100-75% Load Step.
12V Output Voltage
100 mV, 5 ms / div.

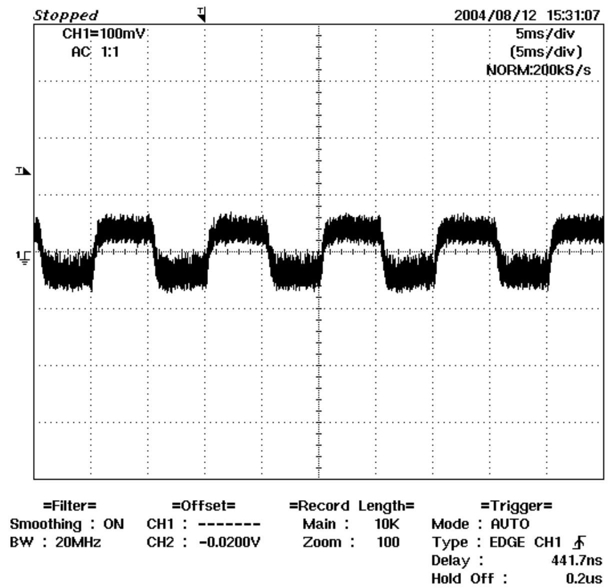

Figure 17 – Transient Response, 230 VAC, 75-100-75% Load Step
9V Output Voltage
100 mV, 5 ms / div.

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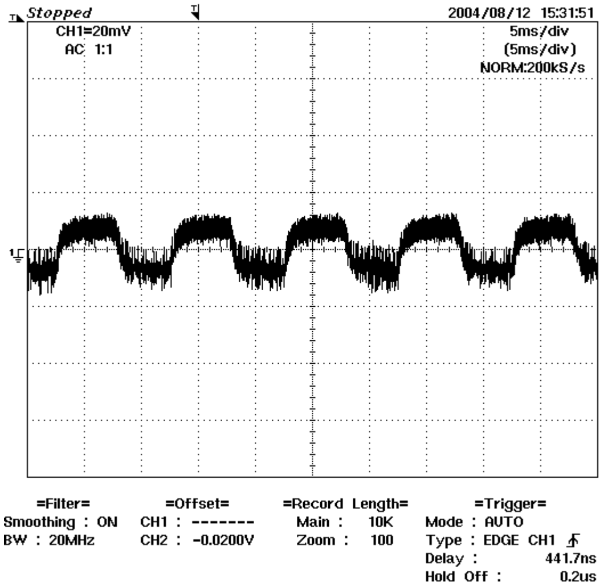

Figure 18 – Transient Response, 230 VAC, 75-100-75% Load Step.
5V Output Voltage
20 mV, 5 ms / div.

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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 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).***

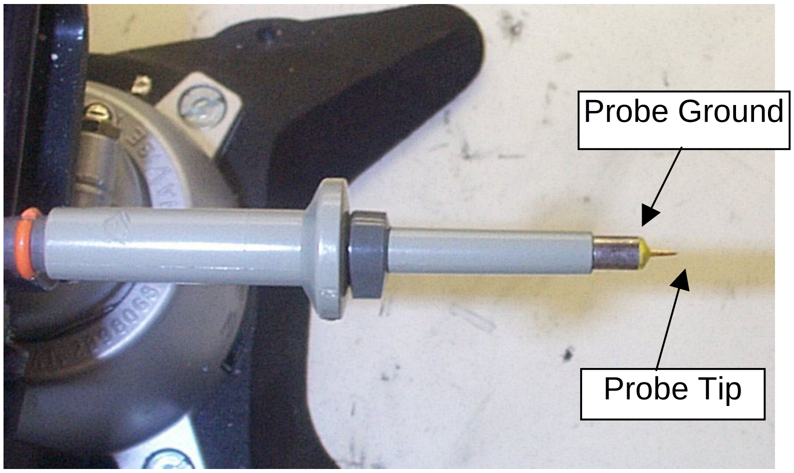

Figure 19 - Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

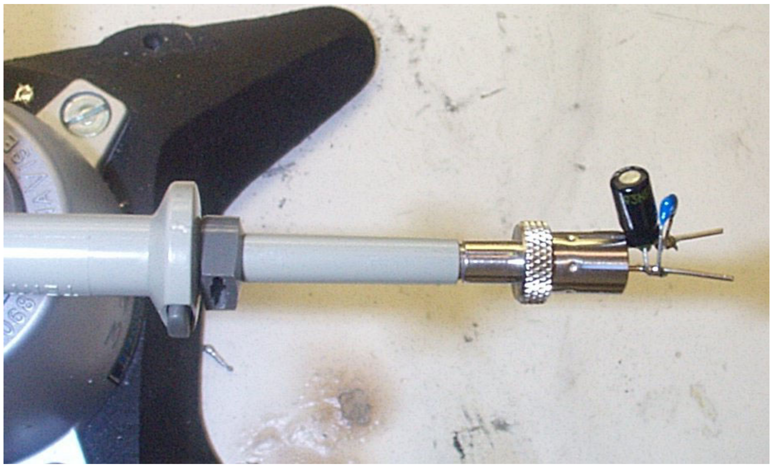

Figure 20 - Oscilloscope Probe with Probe Master 5125BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

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11.5.2 Measurement Results

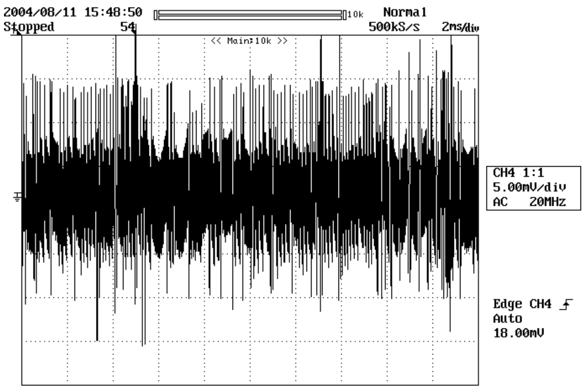

Figure 21 – 5V Ripple, 115 VAC, Full Load.
2 ms, 5 mV / div

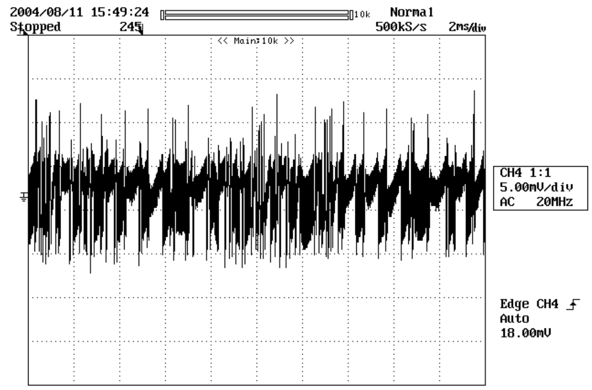

Figure 22 - 5 V Ripple, 230 VAC, Full Load.
2 ms, 5 mV / div

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12 Conducted EMI

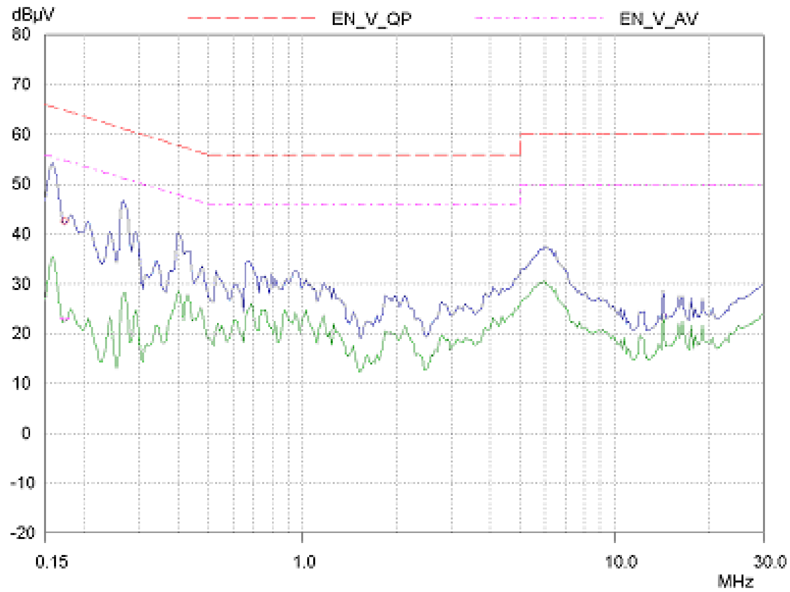

Figure 23 - Conducted EMI, Maximum Steady State Load, 115 VAC, 50 Hz, Secondary Ground floating, and EN55022 B Limits.

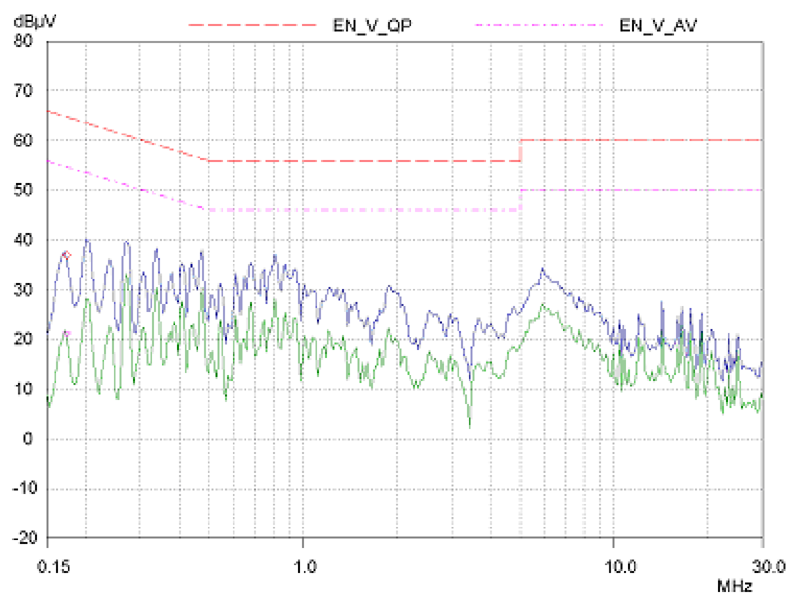

Figure 24 - Conducted EMI, Maximum Steady State Load, 230 VAC, 50 Hz, Secondary Ground floating, and EN55022 B Limits.

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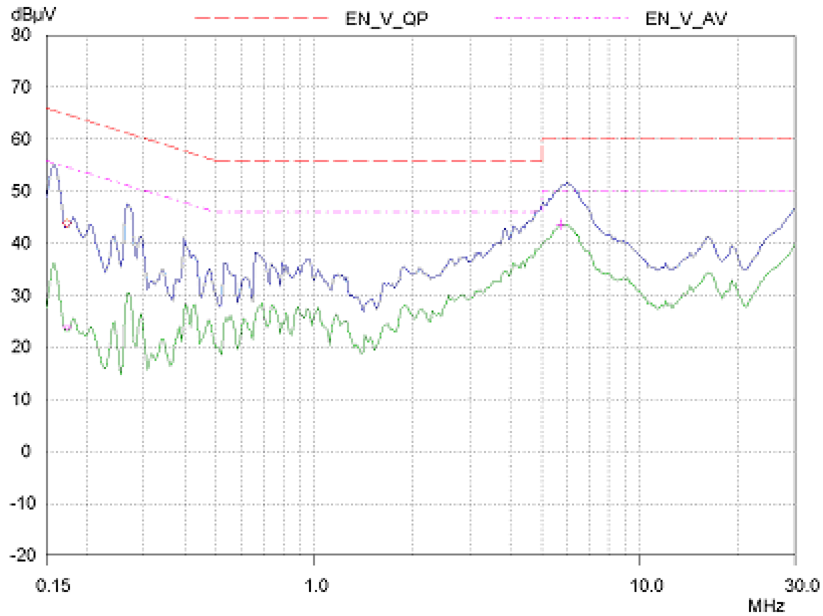

Figure 25 - Conducted EMI, Maximum Steady State Load, 115 VAC, 50 Hz, Secondary Ground connected to Earth, and EN55022 B Limits.

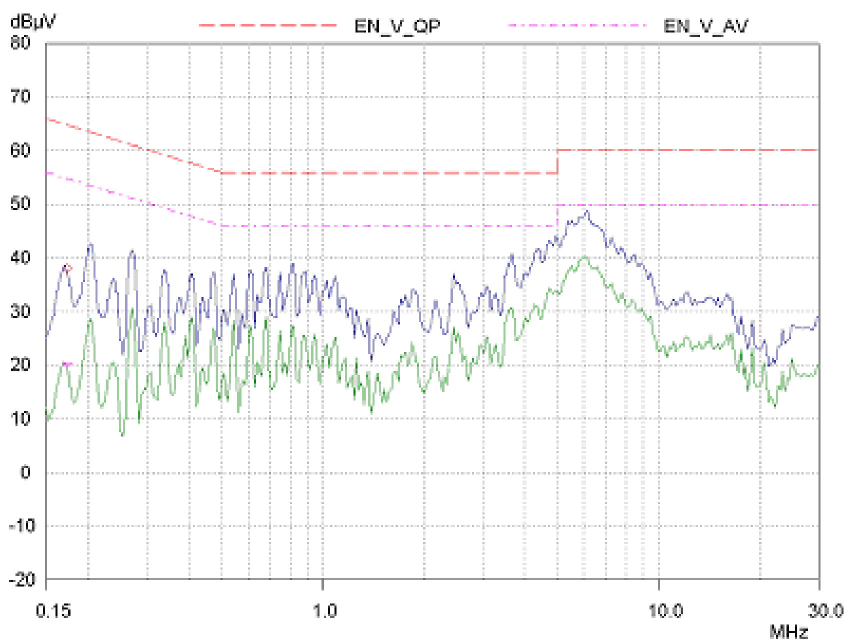

Figure 26 - Conducted EMI, Maximum Steady State Load, 230 VAC, 50 Hz, Secondary Ground connected to Earth, and EN55022 B Limits.

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
April 20, 2005	HM	1.0	Initial release	VC / AM

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PATENT INFORMATION

The products and applications illustrated herein (including circuits external to the products and transformer construction) may be covered by one or more U.S. and foreign patents or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at *www.powerint.com*.

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