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## Design Example Report

<b>Title</b>	<b><i>24 W Primary-side Regulated Flyback Power Supply using TOP245Y</i></b>
<b>Specification</b>	Input: 90 – 265 VAC Output: 8V / 3A
<b>Application</b>	LED Lighting
<b>Author</b>	Power Integrations Applications Department
<b>Document Number</b>	DER-100
<b>Date</b>	December 7, 2005
<b>Revision</b>	2.0

### Summary

This report details the design of a primary-side regulated isolated Flyback converter.

- Provides 8 V @ 3 A
- Typical Efficiency 80 %.
- Primary-side regulation
- Low parts count

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](http://www.powerint.com).

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### Important Notes:

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 isolated source to provide power 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.



## 1 Introduction

This document is an engineering report giving performance characteristics of a 24 W Flyback converter – 8 V @ 3 A. This design uses *TOPSwitch-GX* – an integrated IC comprising a high voltage *MOSFET*, and *PWM* controller.

This document contains power supply specification, schematic, bill-of-materials, transformer documentation, printed circuit layout, and performance data. A photo of the power supply prototype is shown in Figure 1.



Figure 1 – Power Supply Prototype – Top View

## 2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
<b>Input</b> Voltage	$V_{IN}$	90		265	Vac	
<b>Outputs</b> Output Voltage	$V_{OUT}$		8		V	20 MHz Bandwidth Continuous
Output Ripple Voltage	$V_{RIPPLE}$			200	mV	
Output Current	$I_{OUT}$			3	A	
Continuous Output Power	$P_{OUT}$		24		W	
<b>Conducted EMI Margin</b>		10			dB	EN550022 B, FCC B
<b>Efficiency</b>	$\eta$		80		%	At full load
Ambient Temperature	$T_{AMB}$	0		50	°C	Free convection, Sea level

Table 1 – Power Supply Specification



### 3 Schematic

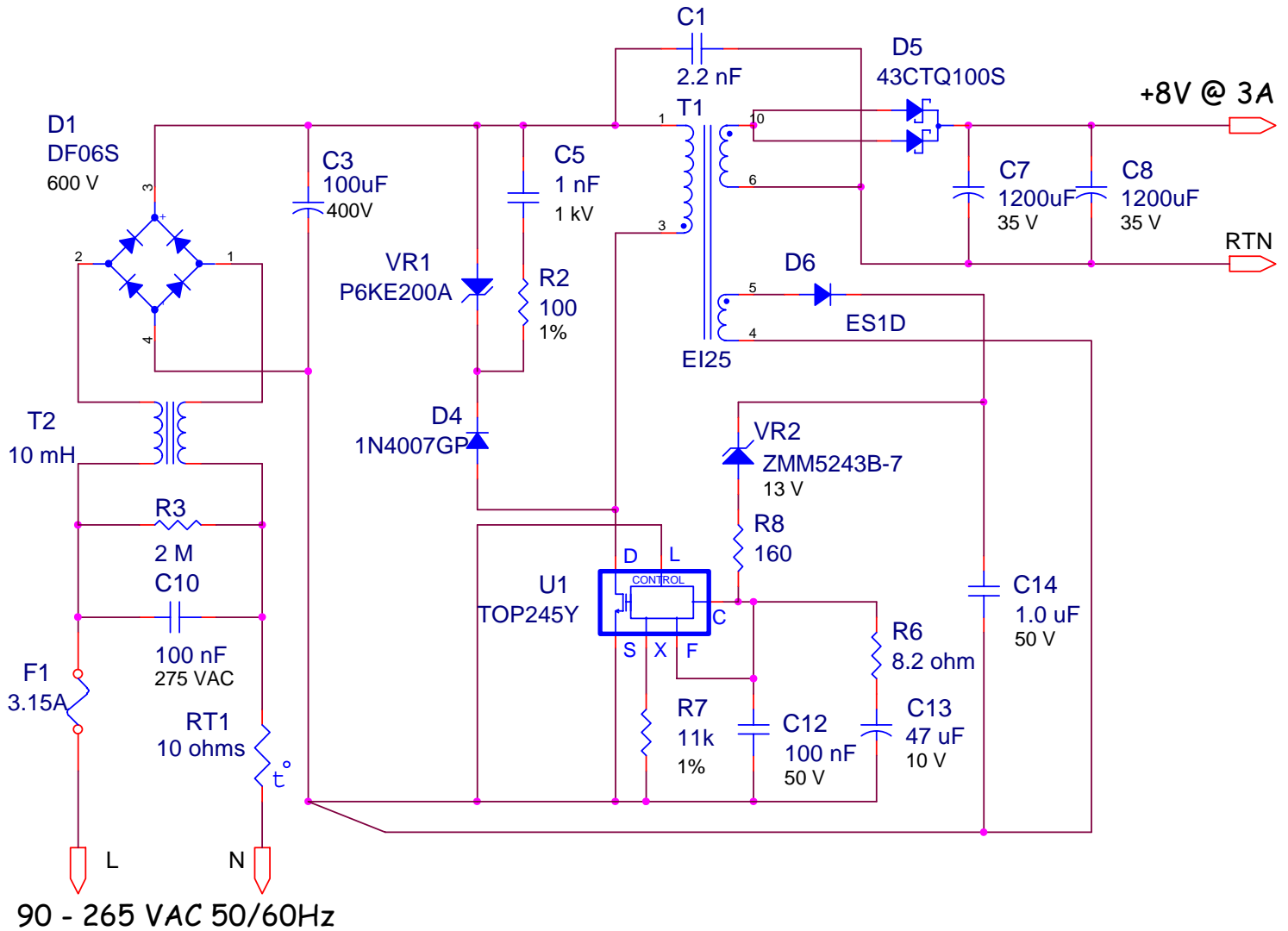


Figure 2 – 24 W, Power Supply Schematic



## 4 Bill Of Materials

Item	QTY	Part Reference	Description	Mfg	Mfg Part Number
1	1	C1	2.2nF, Ceramic, Y1	Vishay	440LD22
2	1	C3	100uF, 400 V, Electrolytic, High Ripple	Panasonic	
3	1	C5	1nF, 1 kV, Disc Ceramic	NIC Components Corp	NCD102K1KVY5F
4	2	C7 C8	100uF, 35 V, Electrolytic, Low ESR	Panasonic	
5	1	C10	100nF, 275 VAC, Film, X2	Panasonic	ECQ-U2A104ML
6	1	C12	100nF, 50 V, Ceramic, X7R, 0805	Panasonic	ECU-V1H221KBN
7	1	C13	47uF, 10 V, Electrolytic, Gen. Purpose, (5 x 11)	United Chemi-Con	KME10VB22RM5X11LL
8	1	C14	1.0uF, 50 V, Ceramic, Z5U	Panasonic	ECU-S1H105MEB
9	1	D1	600 V, 1 A, Bridge Rectifier, SMD, DFS	Vishay	
10	1	D4	1000 V, 1 A, Rectifier, DO-41	Vishay	1N4007GP
11	1	D5	100 V, 43 A, Dual Schottky, (D2-PAK)	International Rectifier	43CTQ100S
12	1	D6	100 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC	Vishay	ES1D
13	1	F1	3.15 A, 250V, Slow, TR5	Wickman	3,721,500,041
14	1	R2	100 R, 1%, 1/4 W, Metal Film	Yageo	MFR-25FBB-102R
15	1	R3	2 M, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ205V
16	1	R6	8.2 R, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ8R2V
17	1	R7	15 k, 1%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6ENF1502V
18	1	R8	160 R, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8ENF1620V
19	1	RT1	NTC Thermistor, 5 Ohms, 2.8 A	Thermometrics	CL160
20	1	T1	Bobbin, EI25, Horizontal, 10 pins	Epcos	
21	1	T2	10 mH, 1A, Common Mode Choke	Tokin	SC-01-E100G
22	1	U1	TOPSwitch-GX, TOP245Y, TO-263-7C	Power Integrations	TOP245Y
23	1	VR1	200 V, 5 W, 5%, DO204AC (DO-15)	Vishay	P6KE200A
24	1	VR2	13 V, 5%, 500 mW, DO-213AA (MELF)	Diodes Inc	ZMM5243B-7

**Table 2 – Bill of Materials**

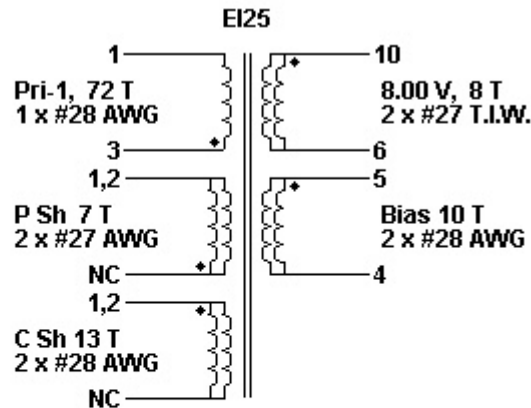


## 5 Transformer Specification

### Transformer Construction



### Electrical Diagram



**KEY**

- Pri-1 = Primary Winding (Section 1)
- Pri-2 = Primary Winding (Section 2)
- C Sh = Cancellation Shield Winding
- P Sh = Primary Shield
- S Sh = Secondary Shield
- T.I.W = Triple Insulated Wire

### Winding Order

Secondary Winding
Primary Balanced Shield Winding
Bias Winding
Primary Winding (Section 1)
Cancellation Shield Winding

### Core Information

Core Type	<b>EI25</b>
Core Material	<b>NC-2H or Equivalent</b>
Estimated Gap length, mm	<b>0.362</b>
Gapped Effective Inductance, nH/t <sup>2</sup>	<b>133</b>
Primary Inductance, uH	<b>686</b>

### Bobbin Information (Manual Input)

Bobbin Reference	<b>Generic, 5 pri. + 5 sec.</b>
Bobbin Orientation	<b>Vertical</b>



Number of Primary pins	<b>5</b>
Number of Secondary pins	<b>5</b>
Margin on Bottom, mm	<b>0.0</b>
Margin on Top, mm	<b>0.0</b>

**Primary Winding (Manual Input)**

<i>Parameter</i>	<i>Section 1</i>
Number of Turns	<b>72</b>
Wire Size, AWG	<b>28</b>
Filar	<b>1</b>
Layers	<b>2.69</b>
Start Pin(s)	<b>3</b>
Termination Pin(s)	<b>1</b>

**BIAS Winding**

<i>Parameter</i>	<i>Value</i>
Number of Turns	<b>10</b>
Wire Size, AWG	<b>28</b>
Filar	<b>2</b>
Layers	<b>0.75</b>
Start Pin(s)	<b>5</b>
Termination Pin(s)	<b>4</b>

**Shield Information**

<i>Parameter</i>	<i>Primary</i>	<i>Cancellation</i>
Number of Turns	<b>7</b>	<b>13</b>
Wire Size, AWG	<b>27</b>	<b>28</b>
Filar	<b>2</b>	<b>2</b>
Layers	<b>0.58</b>	<b>0.97</b>
Start Pin(s)	<b>NC</b>	<b>1,2</b>
Termination Pin(s)	<b>1,2</b>	<b>NC</b>

**Secondary Winding (Manual Input)**

<i>Parameter</i>	<i>Output 1 (main)</i>
Spec Voltage, V	<b>8.00</b>
Spec Current, A	<b>3.00</b>
Actual Voltage, V	<b>8.00</b>
Number of Turns	<b>8</b>
Wire Size, AWG	<b>27</b>
Filar	<b>2</b>
Layers	<b>0.90</b>
Start Pin(s)	<b>10</b>
Termination Pin(s)	<b>6</b>

**Winding Instruction****Cancellation Shield Winding**

Start on pin(s) 1,2 and wind 13 turns (x 2 filar) of item [6]. in exactly 1 layer. Leave this end of





the bobbin.

Add 1 layer of tape, item [3], to secure the winding in place.

#### **Primary Winding**

Start on pin(s) 3 and wind 72 turns of item [6] in 3.00 layer(s) from left to right. Add 1 layer of tape, item [4], in between each primary winding layer. At the end of 1st layer, continue to wind the next layer from right to left. At the end of 2nd layer, continue to wind the next layer from left to right. On the final layer, spread the winding evenly across entire bobbin. Finish winding on pin(s) 1.

Add 1 layer of tape, item [3], for insulation.

#### **Bias Winding**

Start on pin(s) 5 and wind 10.0 turns (x 2 filar) of item [6]. Spread the winding evenly across entire bobbin. Finish on pin(s) 4.

Add 1 layer of tape, item [3], for insulation.

#### **Primary Balanced Shield Winding**

Start on any (temp) pin on the secondary side and wind 7 turns (x 2 filar) of item [8]. Spread the winding evenly across entire bobbin. Finish this winding on pin(s) 1,2.

Cut out wire connected to temp pin on secondary side. Leave this end of primary shield winding not connected. Bend the end 90 deg and cut the wire in the middle of the bobbin.

Add 3 layers of tape, item [3], for insulation.

#### **Secondary Winding**

Start on pin(s) 10 and wind 8 turns (x 2 filar) of item [7]. Spread the winding evenly across entire bobbin. Finish on pin(s) 6.

Add 2 layers of tape, item [3], for insulation.

#### **Core Assembly**

Assemble and secure core halves. Item [1].

#### **Varnish**

Dip varnish uniformly in item [5]. Do not vacuum impregnate.

### **Comments**

**1. For non-margin wound transformers use triple insulated wire for all secondary windings.**

### **Materials**

<i>Item</i>	<i>Description</i>
[1]	<b>Core: EI25, NC-2H or Equivalent, gapped for ALG of 133 nH/t<sup>2</sup></b>
[2]	<b>Bobbin: Generic, 5 pri. + 5 sec.</b>
[3]	<b>Barrier Tape: Polyester film 9.80 mm wide</b>
[4]	<b>Separation Tape: Polyester film 9.8 mm wide</b>
[5]	<b>Varnish</b>
[6]	<b>Magnet Wire: 28 AWG, Solderable Double Coated</b>
[7]	<b>Triple Insulated Wire: 27 AWG</b>
[8]	<b>Magnet Wire: 27 AWG, Solderable Double Coated</b>

### **Electrical Test Specifications**



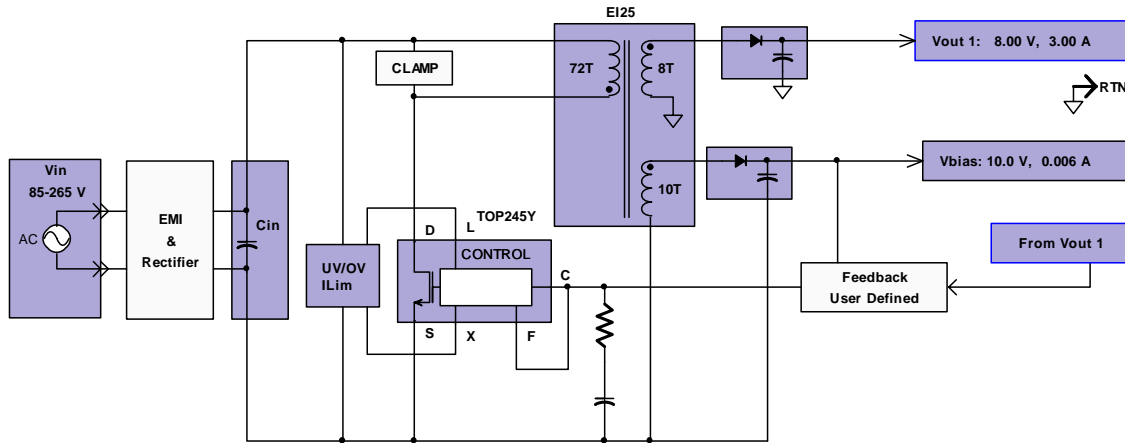
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<b><i>Parameter</i></b>	<b><i>Condition</i></b>	<b><i>Spec</i></b>
Electrical Strength, VAC	<b>60 Hz 1 minute, from pins 1 - 5 to pins 6 - 10.</b>	<b>3000</b>
Nominal Primary Inductance, uH	<b>Measured at 1 V pk-pk, typical switching frequency, between pin 1 to pin 3, with all other Windings open.</b>	<b>754 +/- 10%</b>
Primary Leakage, uH	<b>Measured between Pin 1 to Pin 3, with all other Windings shorted.</b>	<b>22.63 Goal</b>



## 6 Transformer Design Spread Sheet

Design Passed



## Design Results

### Power Supply Input

Var	Value	Output 1. (main)	Units	Description
VACMIN	<b>85</b>		Volts	Min Input AC Voltage.
VACMAX	<b>265</b>		Volts	Max Input AC Voltage
FL	<b>50</b>		Hertz	Line Frequency
TC	<b>2.44</b>		mSeconds	Diode Conduction Time
Z	<b>0.57</b>			Loss Allocation Factor
N	<b>77.0</b>		%	Efficiency Estimate

### Power Supply Outputs

Var	Value	Output 1. (main)	Units	Description
VOx		<b>8.00</b>	Volts	Output Voltage
IOx		<b>3.00</b>	Amps	Output Current
VB	<b>10.0</b>		Volts	Bias Voltage
IB	<b>0.006</b>		Amps	Bias Current



**Device Variables**

<b>Var</b>	<b>Value</b>	<b>Output 1. (main)</b>	<b>Units</b>	<b>Description</b>
Device	<b>TOP245Y</b>			PI Device Name
PO	<b>24.1</b>		Watts	Total Output Power
VDRAIN	<b>559</b>		Volts	Maximum Drain Voltage
VDS	<b>4.83</b>		Volts	Drain to Source Voltage
FS	<b>66000</b>		Hertz	Switching Frequency
KRPKDP	<b>0.78</b>			Continuous/Discontinuous Operating Ratio
KI	<b>0.75</b>			KI Factor
ILIMITEXT	<b>1.26</b>		Amps	Device Current Limit External Minimum
ILIMITMIN	<b>1.67</b>		Amps	Current Limit Minimum
ILIMITMAX	<b>1.93</b>		Amps	Current Limit Maximum
IP	<b>1.14</b>		Amps	Peak Primary Current
IRMS	<b>0.50</b>		Amps	Primary RMS Current
DMAX	<b>0.45</b>			Maximum Duty Cycle

**Power Supply Components Selection**

<b>Var</b>	<b>Value</b>	<b>Output 1. (main)</b>	<b>Units</b>	<b>Description</b>
VBRIDGE	<b>600</b>		Volts	Diode Bridge Voltage Rating
IAVG	<b>0.32</b>		Amps	Average Diode Bridge Current
CIN	<b>100.0</b>		uFarads	Input Capacitance
VMIN	<b>98.6</b>		Volts	Minimum DC Input Voltage
VMAX	<b>374.8</b>		Volts	Maximum DC Input Voltage
VCLO	<b>130</b>		Volts	Clamp Zener Voltage
PZ	<b>1.3</b>		Watts	Primary Zener Clamp Loss
VDB	<b>0.70</b>		Volts	Bias Diode Forward Voltage Drop
PIVB	<b>61</b>		Volts	Bias Rectifier Max Peak Inverse Voltage

**Power Supply Output Parameters**

<b>Var</b>	<b>Value</b>	<b>Output 1. (main)</b>	<b>Units</b>	<b>Description</b>
VDx		<b>0.70</b>	Volts	Output Winding Diode Forward Voltage Drop
PIVSx		<b>50</b>	Volts	Output Rectifier



				Maximum Peak Inverse Voltage
ISP <sub>x</sub>		<b>10.01</b>	Amps	Peak Secondary Current
ISRMS <sub>x</sub>		<b>4.81</b>	Amps	Secondary RMS Current
IRIPPLE <sub>x</sub>		<b>3.76</b>	Amps	Output Capacitor RMS Ripple Current

### Transformer Construction Parameters

<b>Var</b>	<b>Value</b>	<b>Output 1. (main)</b>	<b>Units</b>	<b>Description</b>
Core/Bobbin	<b>EI25</b>			Core Type
Core Manuf.	<b>Generic</b>			Core Manufacturer
Bobbin Manuf	<b>Generic</b>			Bobbin Manufacturer
LP	<b>686</b>		uHenries	Primary Inductance
NP	<b>71.7</b>			Primary Number of Turns
NB	<b>9.8</b>			Bias Winding Number of Turns
AWG	<b>28</b>		AWG	Primary Wire Gauge
CMA	<b>322</b>		Cmils/A	Primary Winding Current Capacity
VOR	<b>78.00</b>		Volts	Reflected Output Voltage
BW	<b>9.80</b>		mm	Bobbin Winding Width
M	<b>0.0</b>		mm	Safety Margin Width
L	<b>3.00</b>			Primary Number of Layers
AE	<b>41.00</b>		mm <sup>2</sup>	Core Cross Sectional Area
ALG	<b>133</b>		nH/T <sup>2</sup>	Gapped Core Effective
BM	<b>2668</b>		Gauss	Maximum Flux Density
BP	<b>3369</b>		Gauss	Peak Flux density
BAC	<b>1041</b>		Gauss	AC Flux Density for Core Loss
LG	<b>0.362</b>		mm	Estimated Gap Length
LI	<b>10.3</b>		uHenries	Primary Leakage Inductance
LSEC	<b>20</b>		nHenries	Secondary Trace Inductance

LSEC	<b>20</b>		nHenries	Secondary Trace Inductance
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**Secondary Parameters**

<i>Var</i>	<i>Value</i>	<i>Output 1. (main)</i>	<i>Units</i>	<i>Description</i>
NSx		<b>8.0</b>		Secondary Number of Turns
Rounded Down NSx				Rounded to Integer Secondary Number of Turns
Rounded Down Vox			Volts	Auxiliary Output Voltage for Rounded down to Integer Secondary Number of Turns
Rounded Up NSx				Rounded to Next Integer Secondary Number of Turns
Rounded Up Vox			Volts	Auxiliary Output Voltage for Rounded up to Next Integer Secondary Number of Turns
AWGSx Range		<b>17 - 21</b>	AWG	



## 7 Performance Data

### 7.1 Line and Load Regulation

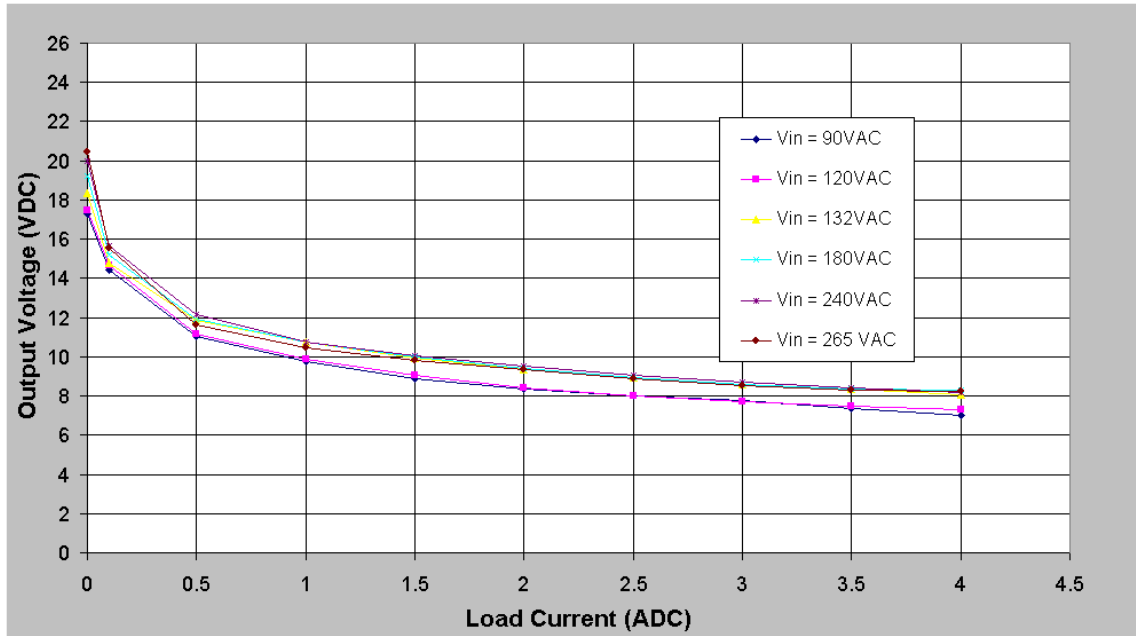


Figure 3 – Output Line/Load Regulation

### 7.2 Efficiency

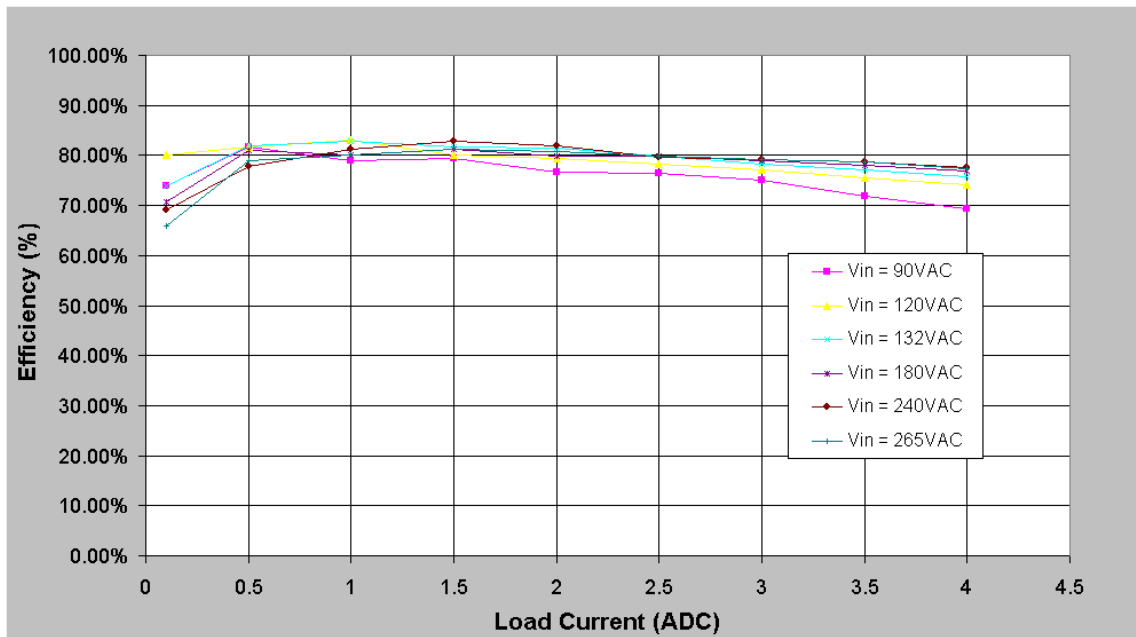
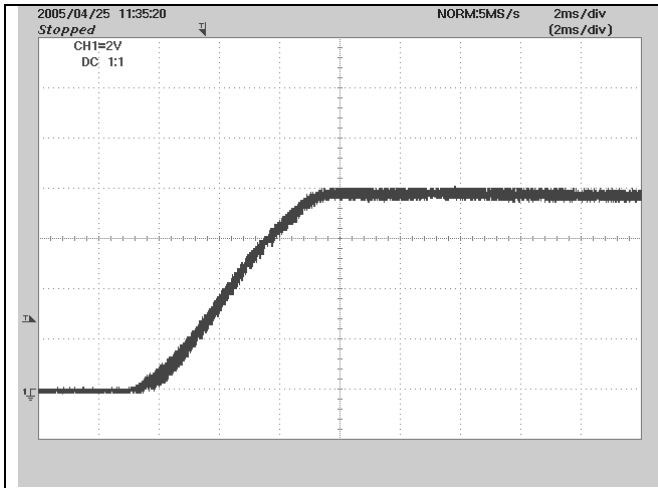


Figure 4 – Efficiency

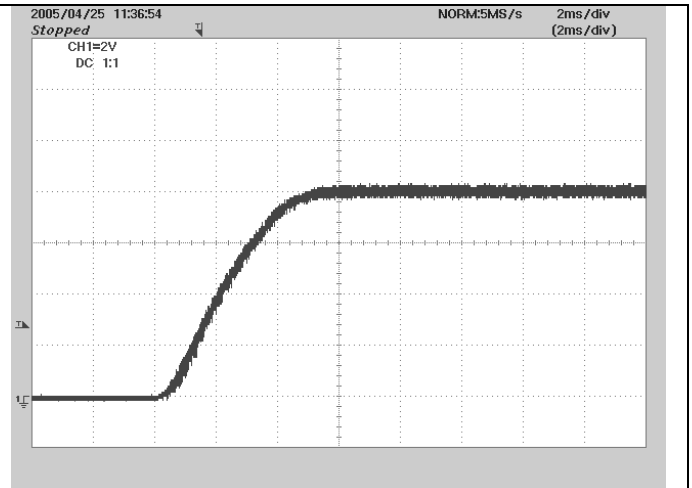


## 8 Waveforms

### 8.1 Output Voltage Startup

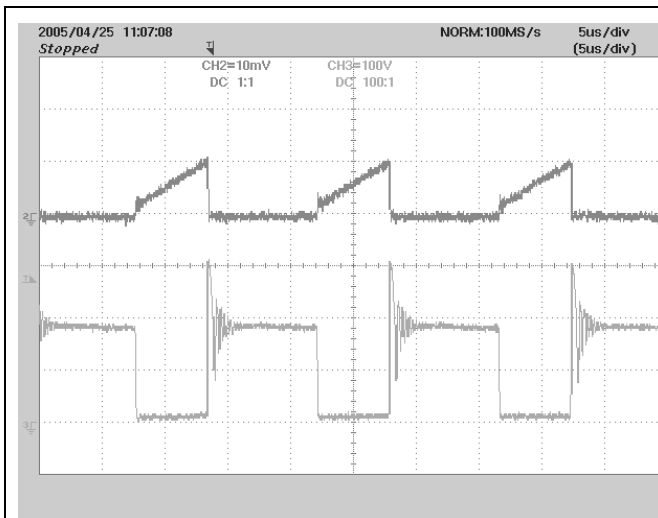


**Figure 5** – Vin = 90 VAC, LOAD = 3 A  
V: 2V/div; T: 2msec/div

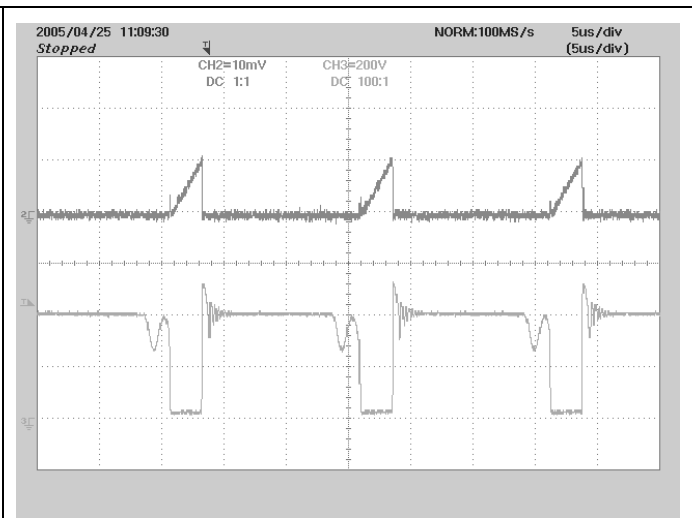


**Figure 6** – Vin = 265 VAC, LOAD = 3 A  
V: 2V/div; T: 2msec/div

### 8.2 Drain Voltage / Current



**Figure 7** – Vin = 90 VAC, LOAD = 3 A  
Top: Drain Current (1A/div)  
Bottom: Drain Voltage (100V/div); T: 5µsec/div



**Figure 8** – Vin = 265 VAC, LOAD = 3 A  
Top: Drain Current (1A/div)  
Bottom: Drain Voltage (200V/div); T: 5µsec/div



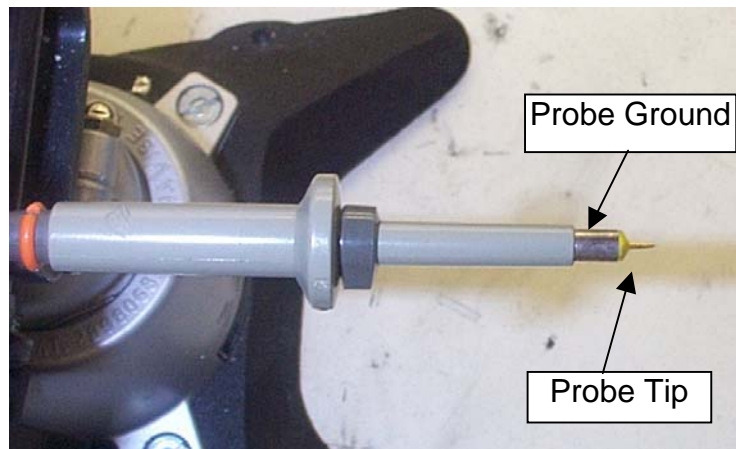


### 8.3 Output Ripple Measurements

#### 8.3.1 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 9 and Figure 10.

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



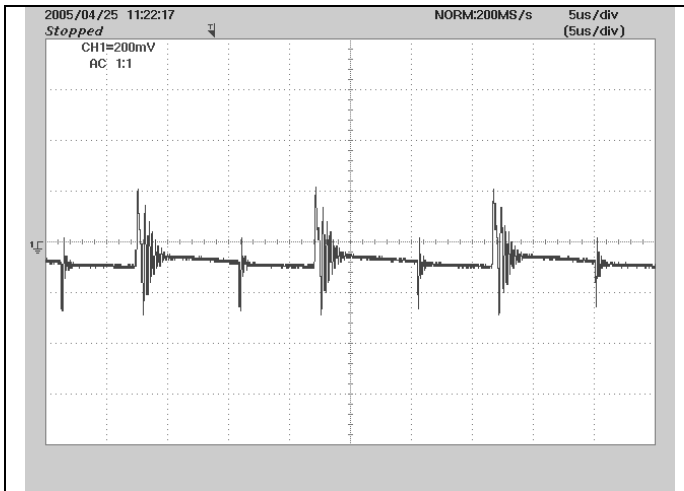
**Figure 9** – Oscilloscope Probe Prepared for Ripple Measurement  
(End Cap and Ground Lead Removed)



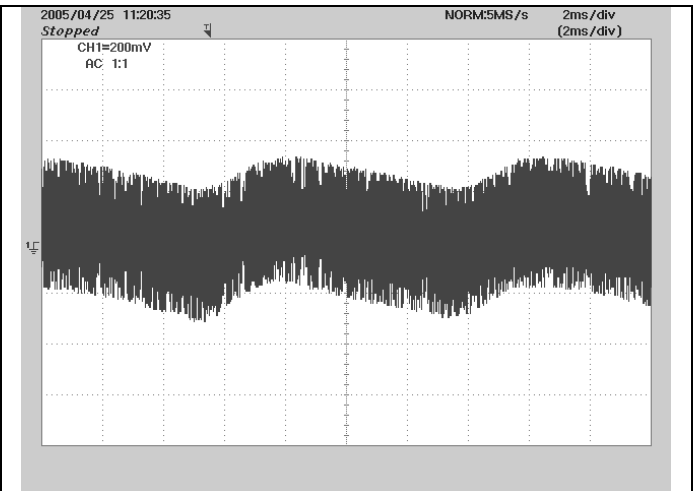
**Figure 10** – Oscilloscope Probe with Probe Master 5125BA BNC Adapter

(Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added).

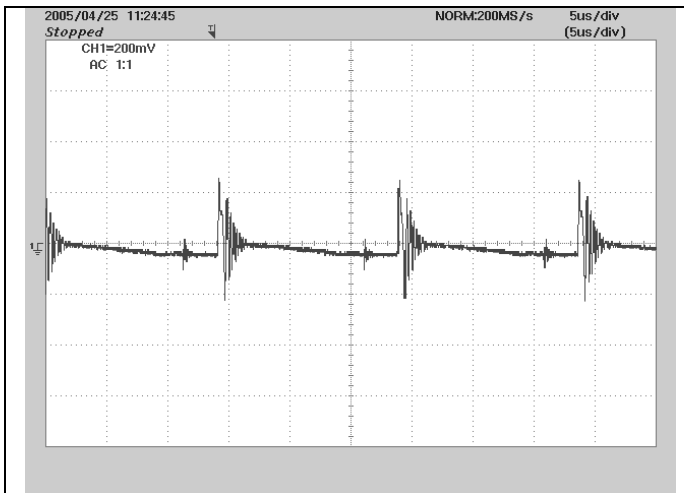
### 8.3.2 Output Voltage Ripple



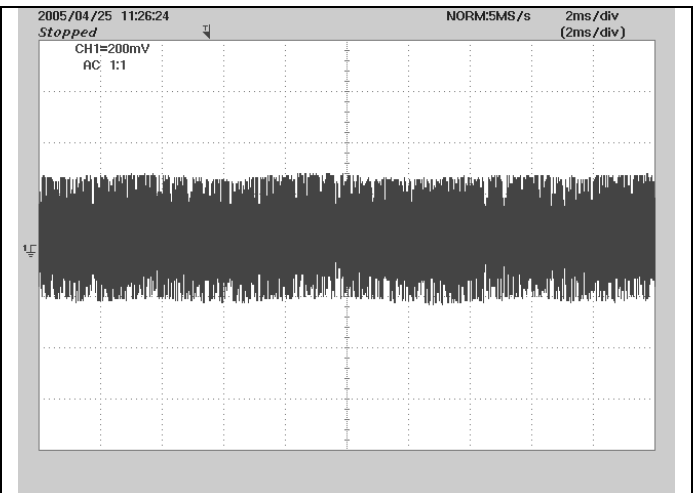
**Figure 11** – Output Ripple, 3 A Load, 90 VAC  
V: 200mV/div; T: 5 $\mu$ sec/div



**Figure 12** – Output Ripple, 3 A Load, 90 VAC  
V: 200mV/div; T: 2msec/div



**Figure 13** – Output Ripple, 3 A Load, 265 VAC  
V: 200mV/div; T: 5 $\mu$ sec/div



**Figure 14** – Output Ripple, 3 A Load, 265 VAC  
V: 200mV/div; T: 2msec/div



### 9 EMI Tests

A conducted EMI scan of the prototype was taken to determine the effectiveness of the input filter and transformer ESHIELD® construction. The following plots show the peak spectra of the converter against quasi-peak (QP) and average (AVG) limits of EN55022 Class B. Both scans were taken at 120 VAC / 60Hz input with maximum load applied to the outputs. Since the peak scans are below the average limits, it is expected that the QP and Average scans would have greater than 10db of margin below the limits.

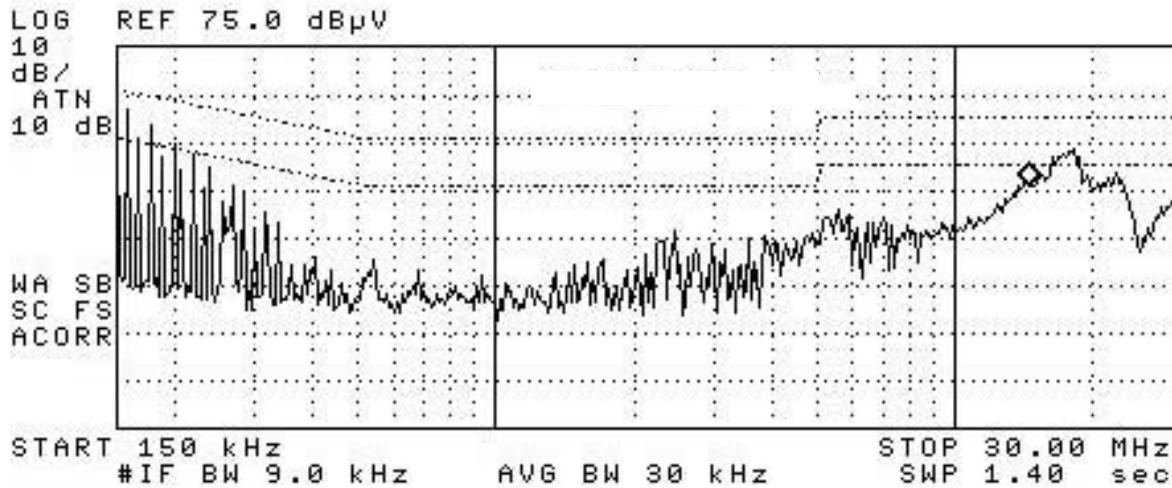


Figure 15 – EMI Test Results, 3 A Load, 120 VAC (Line)

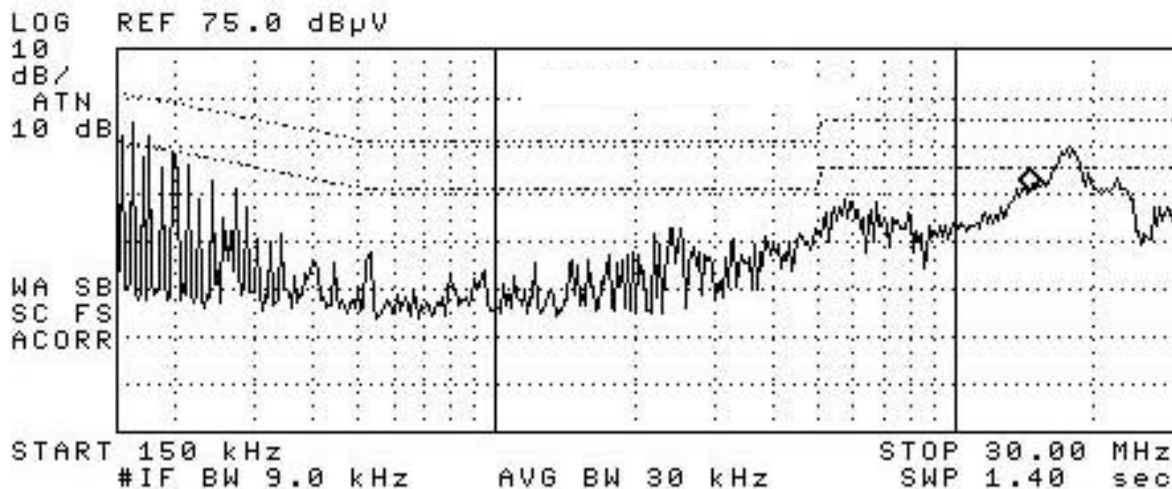


Figure 16 – EMI Test Results, 3 A Load, 120 VAC (Neutral)



## 10 Revision History

<b>Date</b>	<b>Author</b>	<b>Revision</b>	<b>Description &amp; changes</b>	<b>Reviewed</b>
September 12, 2005	RSP	1.0	Initial Release	AM / VC
December 7, 2005	RSP	2.0	Edit schematic to see cut-off area	VC



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