Design Example Report

Title	***60W Power Supply using TOP247Y***
Specification	Input: 90-265 VAC Output: 20V/3A
Application	LCD Monitor
Author	Power Integrations Applications Department
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Revision	1.0

Summary and Features

This design uses a TOP247Y and EER28L core transformer to create an LCD monitor supply that features the following:

- Standby performance: delivers 585 mW at 1W input @ 240Vac
- Uses crowbar secondary circuit for low-cost over-voltage protection, which forces the unit into auto-restart
- No Load input power < 300 mW
- Meets EN550022 B for conducted EMI
- Min Efficiency 85% (90 Vac and full load)

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Important Note:
Although the prototype hardware is designed to satisfy safety isolation requirements, this 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.

The layout shown in this report has been engineered to follow Power Integrations' design guidelines to minimize EMI and susceptibility. Changing the layout may worsen EMI and other aspects of performance.

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 report of a 60 W Flyback power supply with 90-265 Vac input and 20V 3A output. The power supply uses TOPSwitch-GX TOP247Y, which comprises of 700 V MOSFET and PWM controller in a single IC.

The document contains the power supply specification, schematic, PCB Layout, bill of materials and performance data.

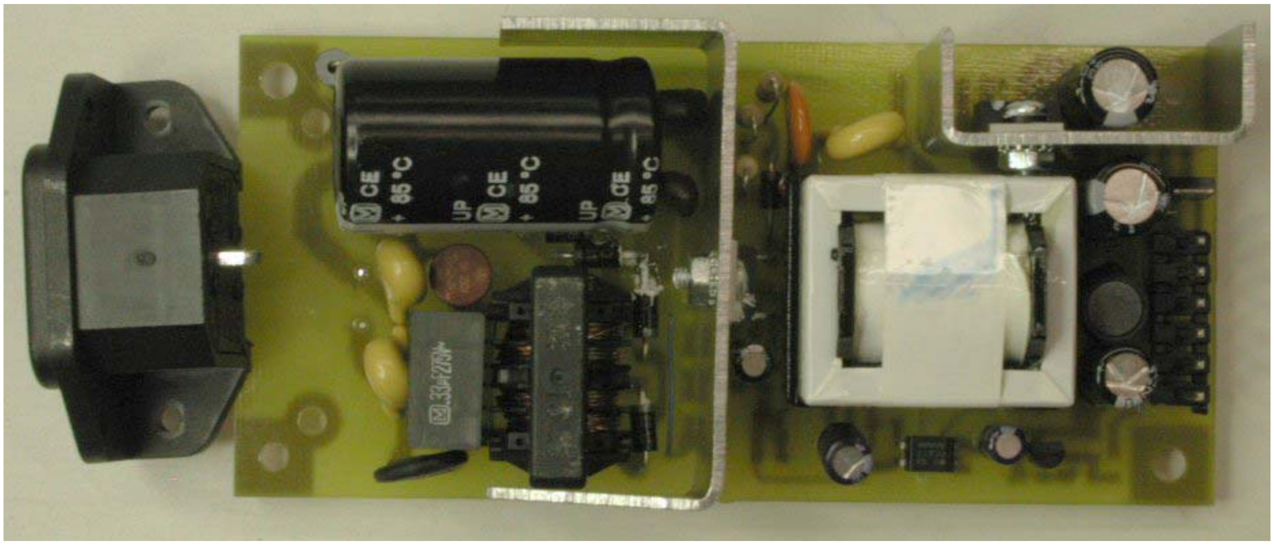

Figure 1 – LCD Monitor Prototype Power Supply – Top View

Figure 2 – LCD Monitor Prototype Power Supply – Bottom View

Note: The prototype layout requires some additional components mounted on the underside.

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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 P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
No-load Input Power	P_{NoLoad}			0.3	W	
Output						
Output Voltage 1	V_{OUT}	19	20	21	V	
Output Ripple Voltage 1	V_{RIPPLE}			200	mV	20 MHz Bandwidth
Output Current 1	I_{OUT}	0		3	A	
Total Output Power						
Continuous Output Power	P_{OUT}		60		W	
Dynamic Load recovery time				1	mS	@ 50 % - 100 % step load
Hold-up time		10			mS	
Over-voltage protection		110		135	%	of nominal output voltage
Efficiency	η	85	87.5		%	
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950, UL1950 Class II				
Surge				2	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	^{o}C	Free convection, sea level

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3 Schematic

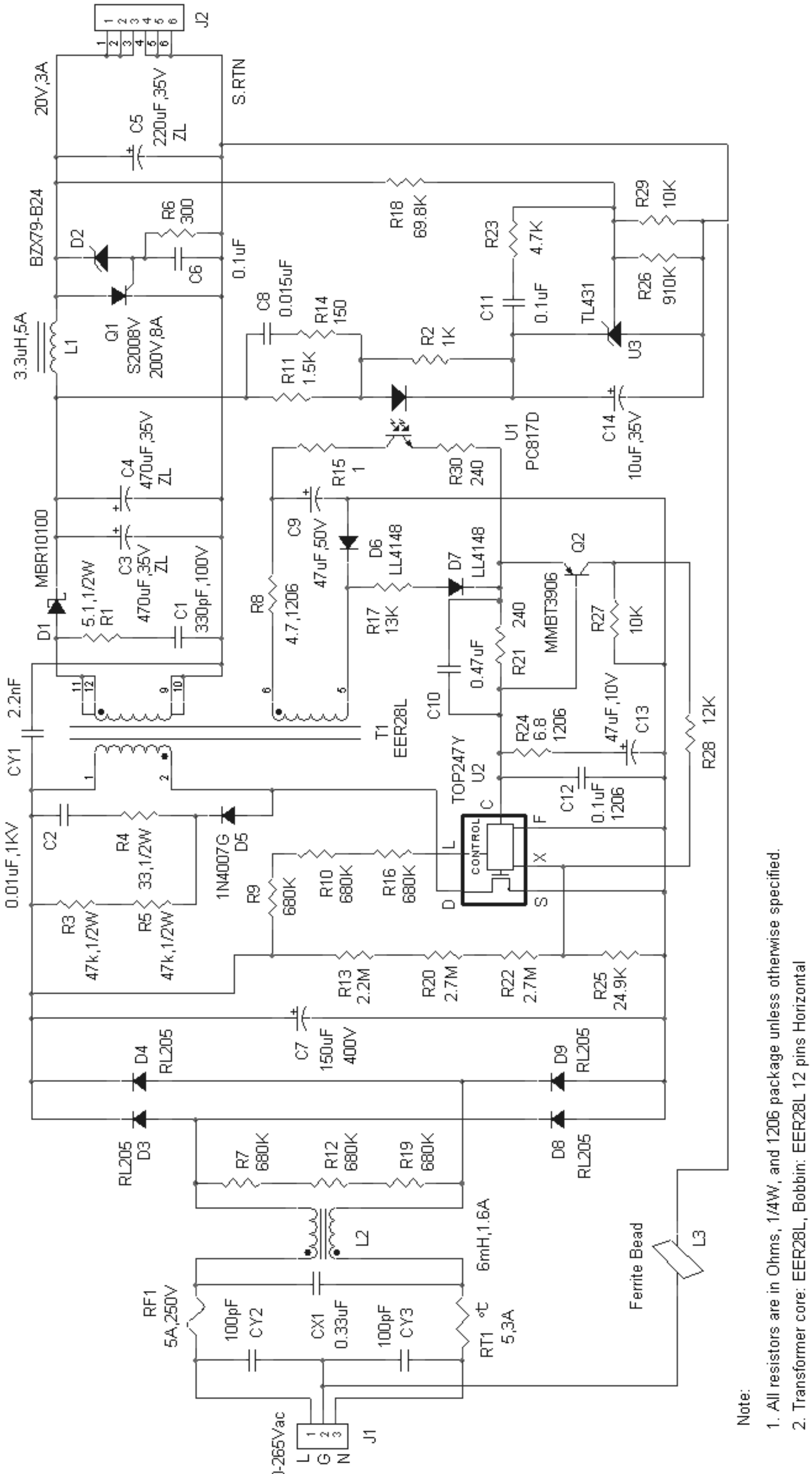

Figure 3 – LCD Monitor Power Supply Schematic – 90-265 Vac, 20V, 3A

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4 Principle of Operation

The schematic in Figure 1 shows an off-line Flyback converter using the TOP247Y. The circuit is designed for 90 VAC to 265 VAC input, with one output: 20V, 3A.

4.1 Input EMI Filtering

Capacitor CX1 and the L2 leakage inductance help to filter differential mode conducted EMI. Inductor L2 and CY2-CY3 filter common mode conducted EMI.

4.2 TOPSwitch Primary

The AC line voltage is rectified and filtered to generate a high voltage DC bus via D3, D4, D8, D9 and C7. Diode D5, C2, R3, R4, and R5 clamp leakage spikes generated when the MOSFET in U2 switches off. D5 is a glass-passivated normal recovery rectifier. The slow, <u>controlled</u> recovery time of D5 allows energy stored in C2 to be recycled back to the output, significantly increasing efficiency. <u>A normal (non-passivated) 1N4007 should not be substituted for the glass-passivated device</u>. Resistors R9, R10, and R16 set the turn-on voltage of the supply to approximately 76 VAC. C12 bypasses the U2 control pin. C13 has three functions. It provides the energy required by U2 during startup, sets the auto-restart frequency during fault conditions, and also acts to roll off the gain of U2 as a function of frequency. R24 adds a zero to the control loop to stabilize the power supply control loop. D6, R8 and C9 provide rectified and filtered bias power for U1 and U2. Components Q2, D7, C10, R13, R17, R20, R21, R22, R25, R27, and R28 provide a signal to the U2's "X-pin" to program it for frequency reduction at light load. This reduces the supply input power consumption under light load. Resistors R13, R20, and R22 reduce the U2 maximum current limit as a function of line voltage, making the maximum overload power more independent of line voltage.

4.3 Output Rectification

The T1output is rectified and filtered by D1, C3 and C4 for the 20V output. Components C1 and R1 provide snubbing for D1. Components L1, and C5 provide additional high frequency output filtering. Ferrite bead L3 provides some high frequency isolation between the secondary return and primary safety ground to improve EMI.

4.4 Output Feedback

Resistors R18, R26, and R27 are used to set the output voltage. Shunt regulator U1 drives Opto-coupler U1 through resistor R11 to provide feedback information to the U2 control pin. The opto-coupler output also provides power to U2 during normal operating conditions. Capacitor C14 provides a path to the opto-coupler during supply start-up to reduce output voltage overshoot. Capacitor C11 and R23 provide frequency compensation for error amplifier U3. Capacitor C13 rolls off the gain of U2 at relatively low frequency. Resistor R24 provides a zero to cancel the phase shift of C13. Resistor R11 sets the gain of the direct signal path from the supply output through U1 and U3. Components C11 and R23 reduce the high frequency gain of U3. C8 and R14 increase the high frequency gain.

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4.5 Protection

Components Q1, D2, C6, and R6 provide over voltage protection of the output voltage. When output voltage exceeds 23.5V nominal, D2 breaks down and 1.5V appears at the gate of Q1, and turns ON the Q1, which in turn shorts the output, thus forcing the power supply into auto-restart mode. Components R6 and C6 help prevent false triggering of Q2.

5 PCB Layout

Notes:

1. PCB layout shown is a prototype layout and does not have provision for the following components, they are soldered on the bottom side of the PCB.
   1.1. C1, R1 (snubber across secondary winding).
   1.2. R27 (pull-down resistor of Q2).
   1.3. R2 (resistor across opto-coupler diode to bleed C14 – soft start capacitor, when power supply is OFF).
2. A green wire is soldered between secondary return and earth ground on the primary side, on the bottom side of the PCB. Running a PCB trace will not meet safety creepage of 6.54mm from primary traces. If this wire is run on the top side of the PCB, then heat sink requires a hole to run the wire. Another option is to have one mounting hole on secondary side connected to secondary return, and another mounting hole on the primary side connected to the ferrite bead L3 whose other end is connected to the earth ground, this option will eliminate the wire.

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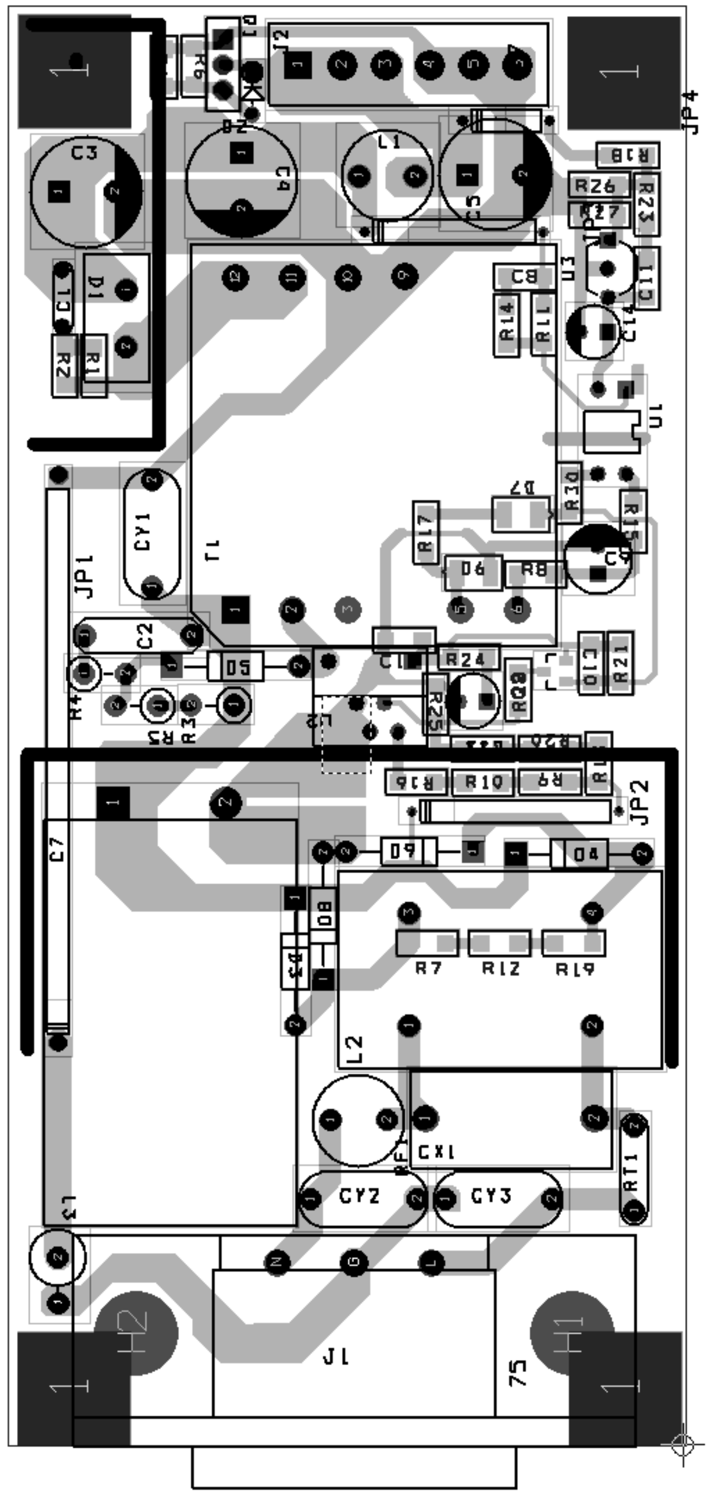

Figure 4 – Printed Circuit Board

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6 Bill Of Materials

Item	Qty	Reference	Description	P/N	Manu.
1	1	CX1	0.33 µF, 250 Vac, safety Film capacitor	Generic	Generic
2	1	CY1	2.2 nF, 4KV, safety ceramic capacitor	Generic	Generic
3	2	CY2, CY3	100 pF, 2.5KV, safety ceramic capacitor	Generic	Generic
4	1	C1	330 pF, 100V, X7R ceramic capacitor	Generic	Generic
5	1	C2	0.01 µF, 1KV, Z5U ceramic capacitor	Generic	Generic
6	2	C3, C4	470 µF, 35V, AL Electrolytic cap	35ZL470 10x20	Rubycon
7	1	C5	220 µF, 35V, AL Electrolytic cap	35ZL220 10x12.5	Rubycon
8	3	C6, C11, C12	0.1 µF, 50V, X7R ceramic cap	Generic	Generic
9	1	C7	150 µF, 400V, AL Electrolytic cap	Generic	Generic
10	1	C8	0.015 µF, 50V, X7R ceramic cap	Generic	Generic
11	1	C9	47 µF, 50V, AL Electrolytic cap	Generic	Generic
12	1	C10	0.47 µF, 25V, X7R ceramic cap	Generic	Generic
13	1	C13	47 µF, 10V, AL Electrolytic cap	Generic	Generic
14	1	C14	10 µF, 35V, AL Electrolytic cap	Generic	Generic
15	1	D1	MBR10100, Schottky diode, 100V, 10A	Generic	Generic
16	1	D2	Zener diode, 24V, 0.5W, ± 2 %	BZX79-B24	Philips
17	4	D3, D4, D8, D9	Diode, 600V, 2A, General purpose	RL205	Rectron
18	1	D5	Glass passivated diode, 1000V, 1A, $t_{rr} = 2\ \mu S$ (typical)	1N4007GP	Generic
19	2	D6, D7	Switching diode, 75V, 500 mA	LL4148	Generic
20	1	J1	AC Connector, 3-wire, 250 Vac	Generic	Generic
21	1	J2	Output Connector, 6-pin	Generic	Generic
22	1	L1	3.3uH, 5A, Ferrite drum core Inductor	Generic	Generic
23	1	L2	6mH, 1.6A, Common mode choke	ELF18N016A	Panasonic
24	1	L3	Ferrite Bead	2673021801	Fair-Rite
25	1	Q1	SCR, 200V, 8A	S2008V	Teccor
26	1	Q2	MMBT3906, PNP Transistor	Generic	Generic
27	1	RF1	5A, 250V, Fuse	Generic	Generic
28	1	RT1	5 Ω, 3A, Thermistor	Generic	Generic
29	1	R1	5.1 Ω, 1/2W, resistor	Generic	Generic
30	1	R2	1 KΩ, 5%, 1206	Generic	Generic

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Item	Qty	Reference	Description	P/N	Manu.
31	2	R3, R5	47 K Ω, 1/2W, 5%, Resistor	Generic	Generic
32	1	R4	33 Ω, 1/2W, 5%, Resistor	Generic	Generic
33	1	R6	300 Ω, 1/4W, 5%, Resistor	Generic	Generic
34	6	R7, R9, R10, R12, R16, R19	680 KΩ, 5%, 1206, resistor	Generic	Generic
35	1	R8	4.7 Ω, 5%, 1206, resistor	Generic	Generic
36	1	R11	1.5 KΩ, 5%, 1206, resistor	Generic	Generic
37	1	R13	2.2 MΩ, 1%, 1206, resistor	Generic	Generic
38	1	R14	150 Ω, 5%, 1206, resistor	Generic	Generic
39	1	R15	1 Ω, 5%, 1206, resistor	Generic	Generic
40	1	R17	13 KΩ, 5%, 1206, resistor	Generic	Generic
41	1	R18	69.8 KΩ, 1%, 1206, resistor	Generic	Generic
42	2	R22, R20	2.7 MΩ, 1%, 1206, resistor	Generic	Generic
43	2	R21, R30	240 Ω, 5%, 1206, resistor	Generic	Generic
44	1	R23	4.7 KΩ, 5%, 1206, resistor	Generic	Generic
45	1	R24	6.8 Ω, 5%, 1206, resistor	Generic	Generic
46	1	R25	24.9 KΩ, 1%, 1206, resistor	Generic	Generic
47	1	R26	910 KΩ, 1%, 1206, resistor	Generic	Generic
48	2	R27, R29	10 KΩ, 1%, 1206, resistor	Generic	Generic
49	1	R28	12 KΩ, 5%, 1206, resistor	Generic	Generic
50	1	T1	Core: EER28L, Bobbin: 12 pin Horizontal	Custom	Custom
51	1	U1	Opto-coupler, CTR = 150-300 %	PC817D	Sharp
52	1	U2	TOPSwitch-GX	TOP247Y	Power Integrations
53	1	U3	Reference voltage regulator, 1%	TL431	Generic

Table 1 – Bill of Materials

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7 Transformer

7.1 Transformer Winding

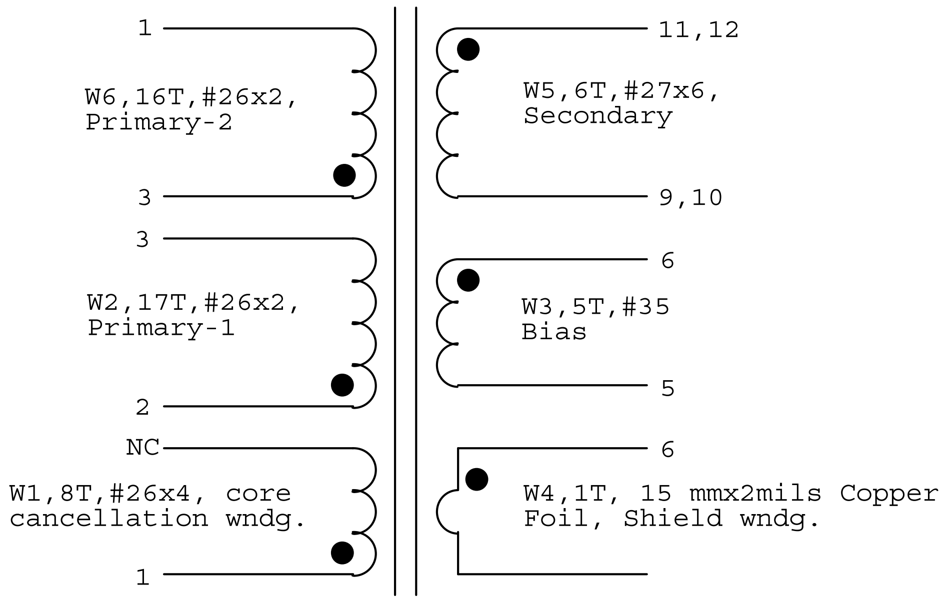

Figure 5 – Transformer Winding

Note:

1. NC: Not connected.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Pins 1-6 to Pins 7-12.	3000 Vac
Primary Inductance	Pins 1-2, all other windings open, measured at 132 kHz	390 µH – 411 µH – 432 µH
Resonant Frequency	Pins 1-2, all other windings open	300 kHz (Min.)
Primary Leakage Inductance	Pins 1-2, with Pins 5-12 shorted, measured at 132 kHz.	4.3 µH (Max.)

Table 2 – Transformer Electrical Specifications

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7.3 Transformer Construction

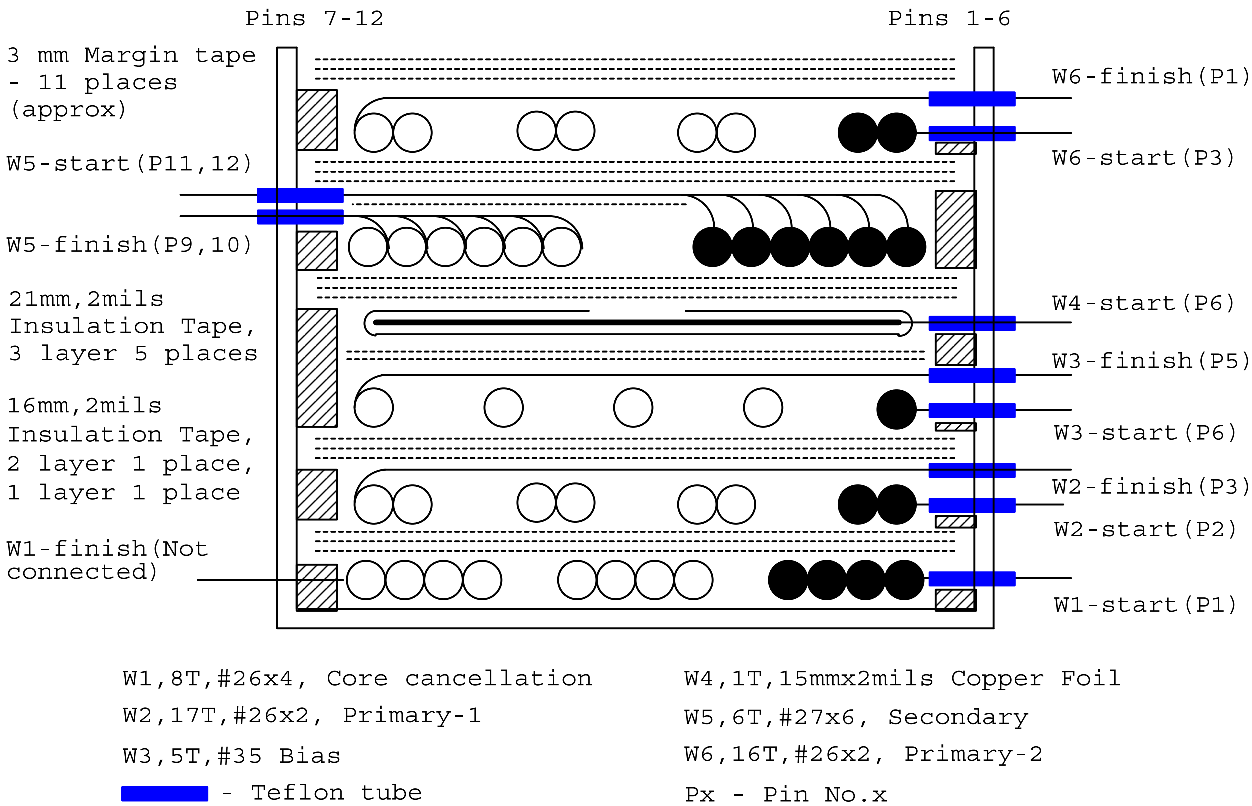

Figure 6 – Transformer Construction

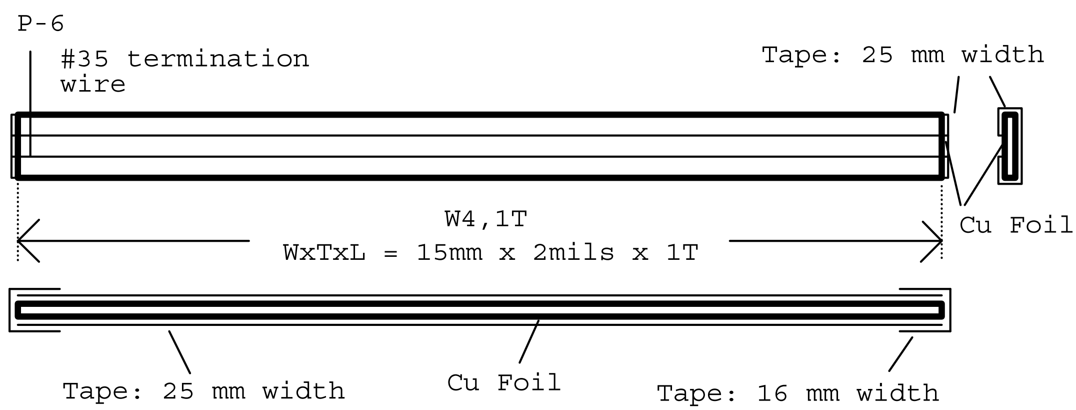

Figure 7 – W4 copper foil construction

Note: WxTxL: Width x Thickness x Length

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7.4 Transformer Materials

Item	Description
[1]	Core: EER28L Generic, gapped for A_L = 358 nH/T^2 - 377 nH/T^2 - 397 nH/T^2
[2]	Bobbin: Horizontal 12-pin, generic, bobbin width = 21.8 mm
[3]	Magnet wire: # 26 AWG
[4]	Magnet wire: # 27 AWG
[5]	Magnet wire: # 35 AWG
[6]	Copper Foil: 15 mm x 2 mils
[7]	Tape: 3M 1298 Polyester Film (white) 25 mm x 2 mils (to wrap around copper foil)
[8]	Tape: 3M 1298 Polyester Film (white) 21 mm x 2 mils
[9]	Tape: 3M 1298 Polyester Film (white) 16 mm x 2 mils
[10]	Tape: 3M 1298 Polyester Film (white) 8 mm x 2 mils (to wrap the core together)
[11]	Margin Tape: 3M 1298 Polyester Film (white) 3 mm x 5 mils
[12]	Teflon tube
[13]	Varnish

Table 3 – Transformer Bill of Materials

7.5 Design Notes

Power Integrations Device	TOP247Y
Frequency of Operation	132 KHz
Mode	Continuous/ discontinuous
Peak Current	1.89 A
Reflected Voltage (Secondary to Primary)	115 V
Maximum AC Input Voltage	265 Vac
Minimum AC Input Voltage	90 Vac

Table 4 – Power Supply Design Parameters

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7.6 Transformer Winding Instruction

All windings should be wound in the forward direction.

Bobbin orientation	Place the bobbin on the winding machine with pins 1-6 on the right side and pins 7-12 on the left side.
Margin Tape	Apply 3 mm margin tape on both sides of the bobbin appropriately, whenever necessary. Use Figure 6 as reference.
Teflon Tube	Use Teflon tube for all windings termination to meet safety creepage between primary and secondary.
W1 (Core Cancellation Winding)	Wind 8 turns from right to left with # 26 x 4 (quadfilar) magnet wire starting from pin 1, cut the wire after 8 turns and leave the finishing end unconnected. Use 8 mm tape to secure the wires end in place.
Basic Insulation	3 layers of 21 mm tape for insulation.
W2 (Primary Winding-1)	Wind 17T from right to left with # 26 x 2 (bifilar) magnet wire starting from pin 2 and finishing at 3.
Basic Insulation	3 layers of 21 mm tape for insulation.
W3 (Bias winding)	Wind 5 turns from right to left with # 35 magnet wire starting from pin 6 and finishing at pin 5. Spread the 5T evenly across the width of the bobbin.
Basic Insulation	2 layers of 16 mm tape for insulation.
W4 (Shield winding)	Prepare the Copper foil as shown in Figure 7. Wind 1T with copper foil starting from pin 6 and leave the finishing end unconnected. 8 mm tape can be used to secure the copper foil in place while winding.
Basic Insulation	3 layers of 21 mm tape for insulation.
W5 (Secondary winding)	Wind 6 turns from right to left with # 27 x 6 (hexa-filar) magnet wire starting temporarily from pins 1-2 and finishing at pins 9-10 – one layer of 16 mm tape – bring the starting end from pins 1-2 to pins 11-12 and terminate them.
Basic Insulation	3 layers of 21 mm tape for insulation.
W6 (Primary Winding-2)	Wind 16T from right to left with # 26 x 2 (bifilar) magnet wire starting from pin 3 and finishing at 1.
Outer Insulation	3 layers of 21 mm tape for insulation.
Core Assembly	Assemble and secure core halves.
Final Assembly	Impregnate transformer uniformly with varnish.

Note:

1. Teflon tube is not used in the prototype transformer.

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8 Transformer Design Spreadsheet

ACDC_TOPGX_Rev1.2_052901 Copyright Power Integrations Inc. 2001	INPUT	INFO	OUTPUT	UNIT	TOP_GX_052901.xls: TOPSwitch-GX Continuous/Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	85			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	20			Volts	Output Voltage
PO	60			Watts	Output Power
n	0.82				Efficiency Estimate
Z	0.5				Loss Allocation Factor
VB	15			Volts	Bias Voltage
tC	3			mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	150			uFarads	Input Filter Capacitor
ENTER TOPSWITCH-GX VARIABLES					
TOP-GX	**top246**			*Universal*	*115 Doubled/230V*
Chosen Device		*TOP246*	*Power Out*	*90W*	*150W*
KI	0.83				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN			*2.017*	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX			*2.465*	Amps	Use 1% resistor in setting external ILIMIT
Frequency - (F)=132kHz, (H)=66kHz	**f**				Full (F) frequency option - 132kHz
fS	132000		*1.32E+05*	Hertz	TOPSwitch-GX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			*1.24E+05*	Hertz	TOPSwitch-GX Minimum Switching Frequency
fSmax			*1.40E+05*	Hertz	TOPSwitch-GX Maximum Switching Frequency
VOR	115			Volts	Reflected Output Voltage
VDS	5			Volts	TOPSwitch on-state Drain to Source Voltage
VD	1			Volts	Output Winding Diode Forward Voltage Drop
VDB	1			Volts	Bias Winding Diode Forward Voltage Drop
KP	**0.48**				Ripple to Peak Current Ratio (0.4 < KRP < 1.0 : 1.0< KDP<6.0)
Core Type	**EER28L**				
Core		*EER28L*		*P/N:*	PC40EER28L-Z
Bobbin		*EER28L_BOBBIN*		*P/N:*	BEER-28L-1112CPH
AE		0.847	0.847	cm^2	Core Effective Cross Sectional Area
LE		7.83	7.83	cm	Core Effective Path Length
AL		2800	2800	nH/T^2	Ungapped Core Effective Inductance
BW		21.8	21.8	mm	Bobbin Physical Winding Width
M	3.15			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			87	Volts	Minimum DC Input Voltage

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VMAX			375	Volts	Maximum DC Input Voltage
DMAX			0.58		Maximum Duty Cycle
IAVG			0.84	Amps	Average Primary Current
IP			1.89	Amps	Peak Primary Current
IR			0.91	Amps	Primary Ripple Current
IRMS			1.12	Amps	Primary RMS Current

LP			411	uHenries	Primary Inductance
NP			33		Primary Winding Number of Turns
NB			5		Bias Winding Number of Turns
ALG			381	nH/T^2	Gapped Core Effective Inductance
BM			**2795**	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			**3642**	Gauss	Peak Flux Density (BP<4200)
BAC			671	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			2060		Relative Permeability of Ungapped Core
LG			**0.24**	mm	Gap Length (Lg > 0.1 mm)
BWE			31	mm	Effective Bobbin Width
OD			0.94	mm	Maximum Primary Wire Diameter including insulation
INS			0.08	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.86	mm	Bare conductor diameter
AWG			20	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			1024	Cmils	Bare conductor effective area in circular mils
CMA			**918**	Cmils/Amp	!!!!!!!!! DECREASE CMA> (decrease L(primary layers),increase NS,smaller Core)

Lumped parameters

ISP			10.36	Amps	Peak Secondary Current
ISRMS			5.17	Amps	Secondary RMS Current
IO			3.00	Amps	Power Supply Output Current
IRIPPLE			4.21	Amps	Output Capacitor RMS Ripple Current
CMS			1034	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			19	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.91	mm	Secondary Minimum Bare Conductor Diameter
ODS			2.58	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			0.83	mm	Maximum Secondary Insulation Wall Thickness

VOLTAGE STRESS PARAMETERS

VDRAIN			636	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVS			88	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			67	Volts	Bias Rectifier Maximum Peak Inverse Voltage

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9 Performance Data

All measurements are performed at room temperature, and 60 Hz input line frequency.

9.1 Line and Load regulation

Load regulation: 19.96V for 0A – 0.5A, 19.95V for 0.51A – current limit.
Line regulation: No change.

9.2 Efficiency

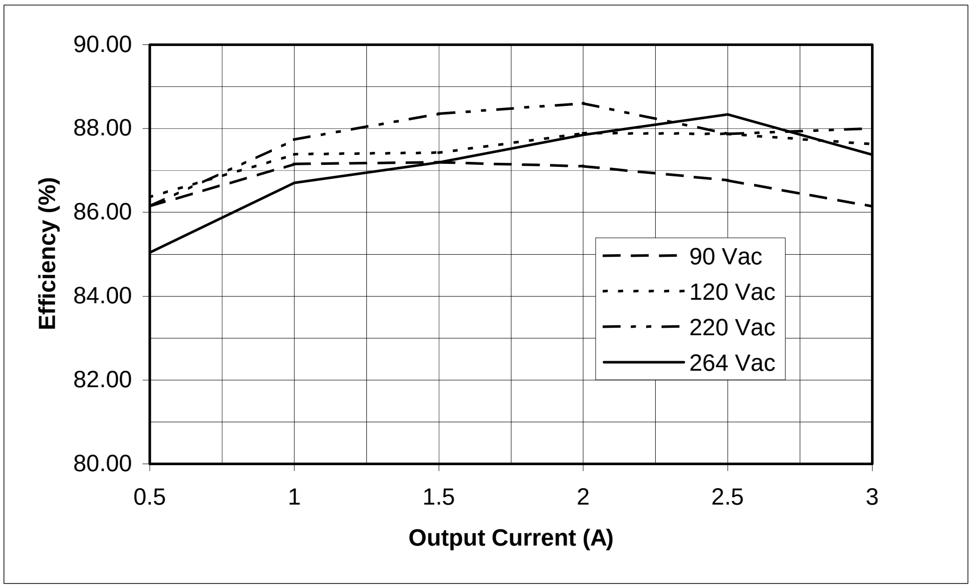

Figure 8 – Efficiency versus Output current

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9.3 No-load Input Power

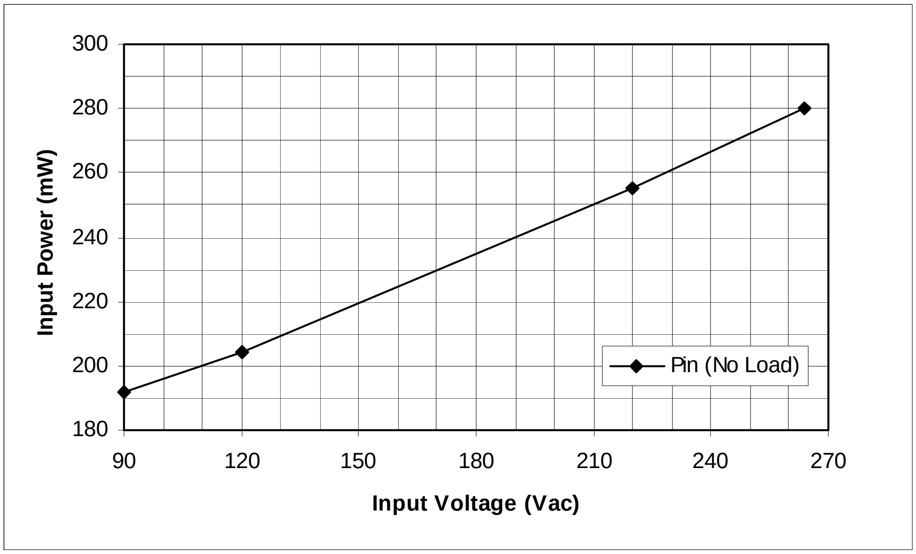

Figure 9 – No Load Input Power versus Input Voltage

9.4 Output Power for 1 W Input Power

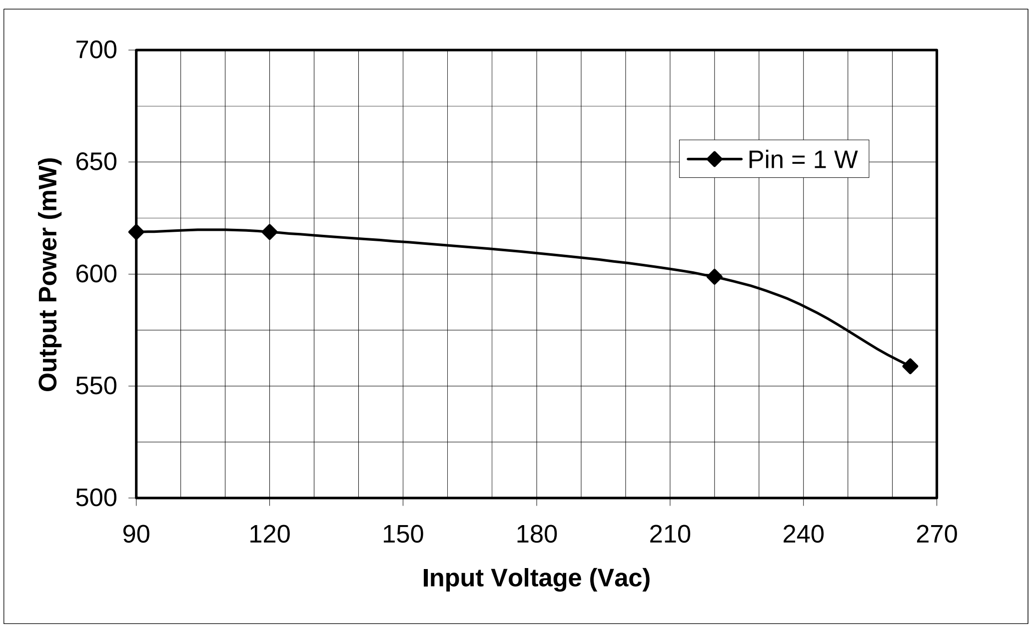

Figure 10 – Output power versus Input voltage for 1 W Input power

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10 Output Ripple Measurements

10.1 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 11 and Figure 12.

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).*

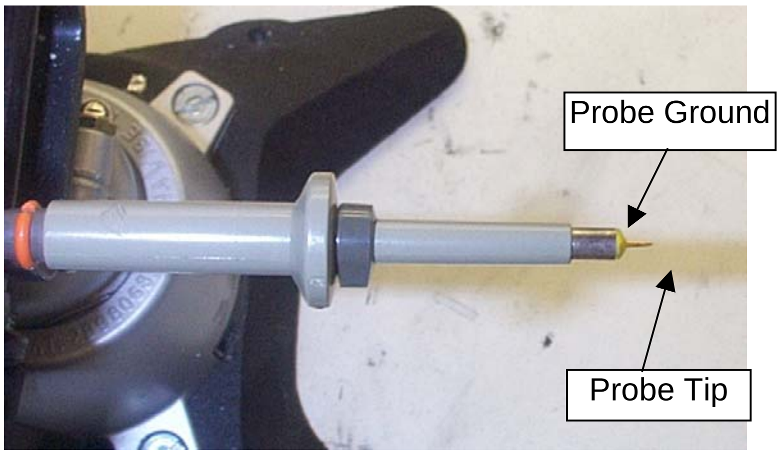

Figure 11 – Oscilloscope Probe Prepared for Ripple Measurement
(End Cap and Ground Lead Removed)

Figure 12 – 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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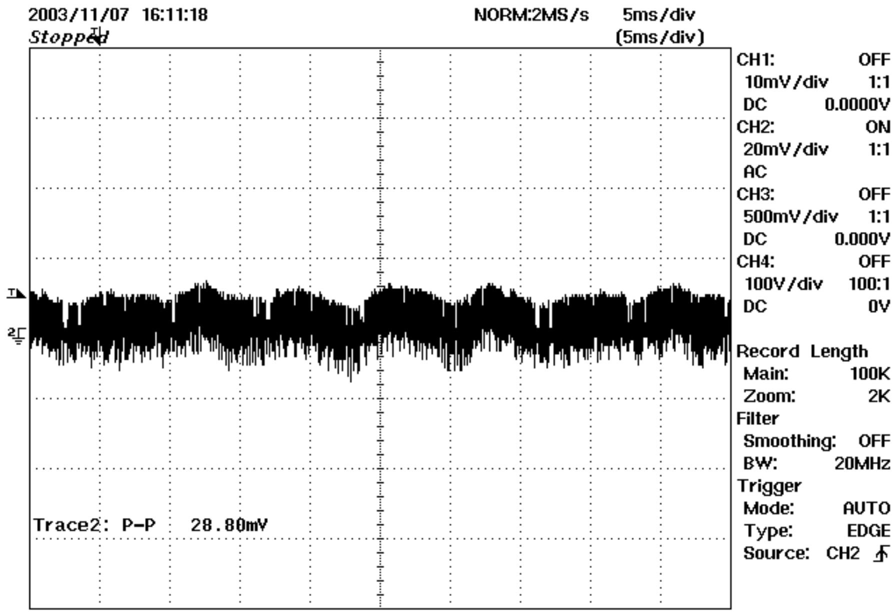

Figure 13 – Output Voltage Ripple (worst case) 90 Vac, 20V, 3A load

11 Over-voltage Protection

This is the output voltage when the opto-coupler is shorted out, simulating an OVP condition. Vpeak = 23.6V.

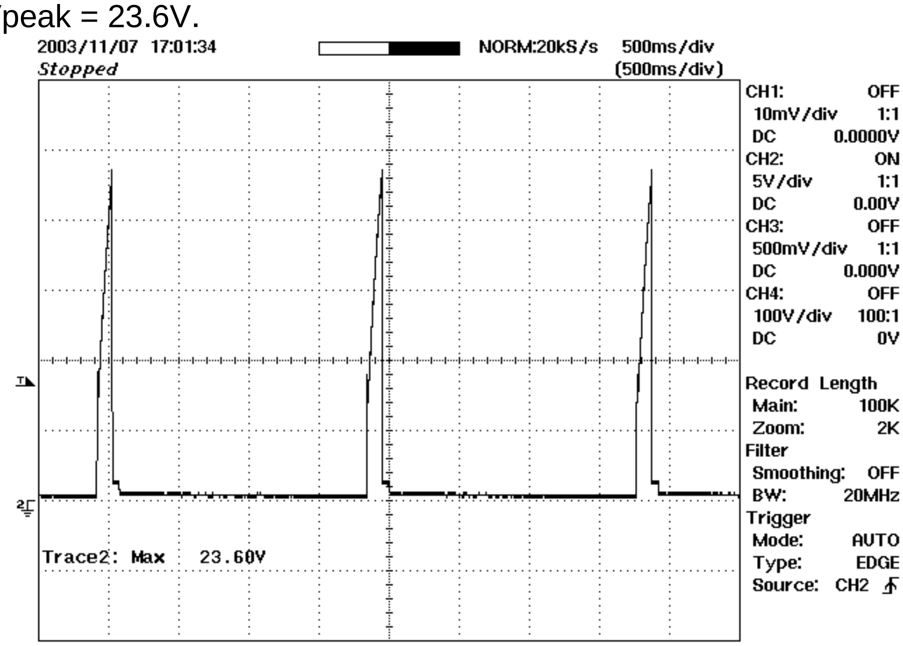

Figure 14 – Output voltage with over-voltage protection

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12 Dynamic Load Transient

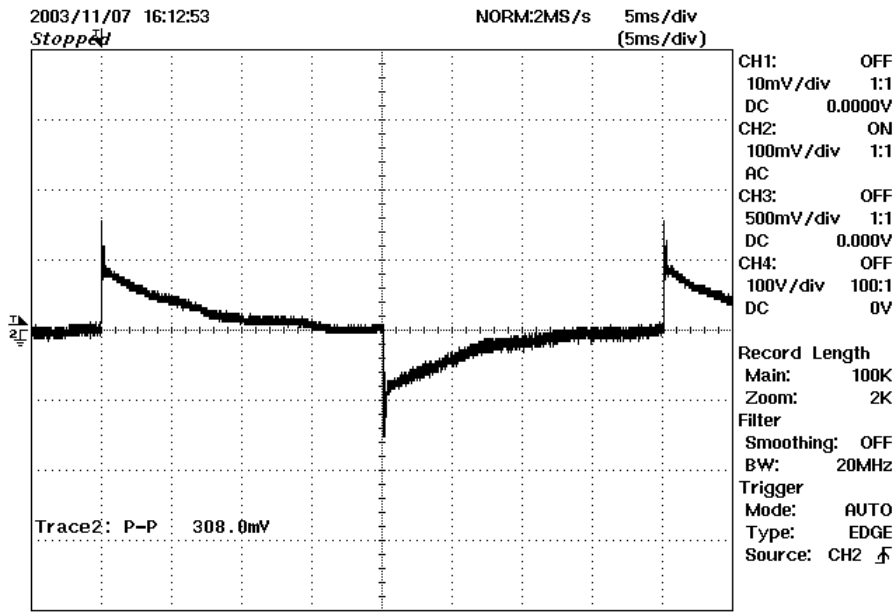

Figure 15 – Dynamic Load Transient – Step Load 1.5A ↔ 3A, 90 Vac

It can be seen that ΔV_O = 308 mV only, which is well within the regulation band. Therefore, recovery time is irrelevant.

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13 Conducted EMI

The conducted EMI tests are done at 220 Vac, 3A resistive load and for Neutral (worst case).

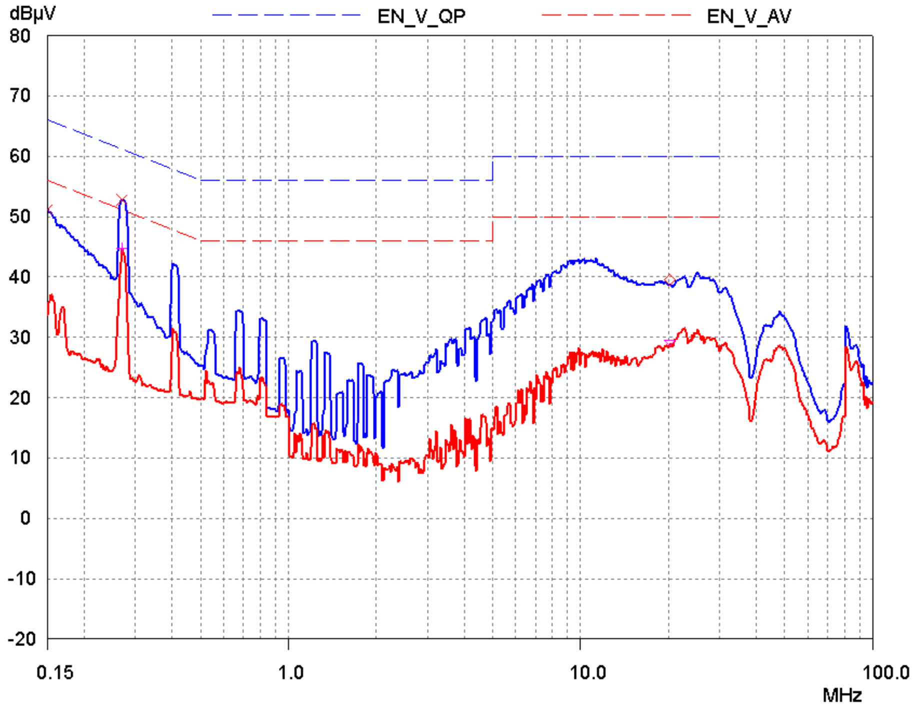

Figure 16 – Conducted EMI – EN55022 Class B, with 3-wire input, Neutral (worst case)

14 Revision History

Date	Author	Revision	Description & changes	Reviewed
March 30, 2004	MJ	1.0	First Release	VC / AM

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