



Design Example Report

Title	<i>15 W, Multiple Output, Isolated Power Supply using TOP244P</i>
Specification	Input: 85-265 VAC Output: 5V/0.1A, 12V/0.2A, 24V/0.5A
Application	Refrigerator
Author	Power Integrations Applications Department
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Revision	1.0

Summary and Features

- Low cost (low component count with single sided printed circuit board)
- Meets EN/UL 1000-4-5 CLASS 4 (4 kV), using line overvoltage protection feature
- Designed to IEC60950 safety standard requirements
- Compact Design (L = 113 mm, W = 39 mm, H = 25 mm)
- High efficiency ($\geq 73\%$ at 85 VAC)
- Line undervoltage shutdown prevents turn-off output glitches
- Line overvoltage shutdown provides extended line swell protection
- Hysteretic thermal shutdown provides automatic supply recovery after fault removal

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.

Table Of Contents

1	Introduction.....	3
2	Power Supply Specification	4
3	Schematic.....	5
4	Circuit Description	6
5	PCB Layout	9
6	Bill Of Materials	10
7	Transformer Specification.....	11
	7.1 Electrical Specifications	11
	7.2 Materials	11
	7.3 Transformer Build Diagram.....	12
	7.4 Transformer Construction	12
	7.5 Design Notes	13
8	Transformer Spreadsheets.....	15
9	Performance Data	16
	9.1 Efficiency.....	16
	9.2 Regulation.....	17
	9.2.1 Load.....	17
	9.2.2 Line.....	17
	9.2.3 Cross-Regulation Table	18
10	Waveform Scope Plot.....	19
11	Revision History.....	20

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 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.



1 Introduction

This document is an engineering report describing a low cost, isolated converter for a appliance application.

Included is the power supply specification, schematic, Bill of materials, transformer documentation, printed circuit layout, and performance data.

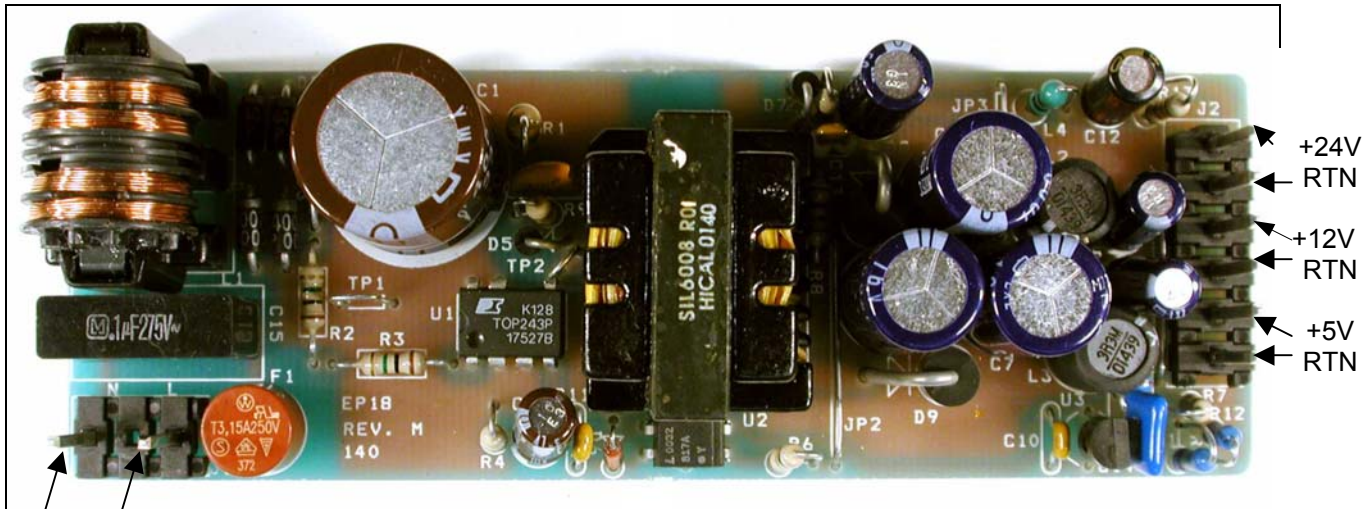


Figure 1 –Populated Circuit Board (L x W x H: 113 mm x 39 mm x 25mm).

Input AC

Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input Voltage	V_{IN}	85		265	VAC	50/60 Hz
Output Output Voltage 1	V_{OUT1}	4.75	5	5.25	V	±5% Total Peak to Peak, 20 MHz BW
Output Ripple Voltage 1	$V_{RIPPLE1}$			75	mV	
Output Current 1	I_{OUT1}	0.05		0.1	A	
Output Voltage 2	V_{OUT2}	11.04	12	12.96	VDC	±8% Total Peak to Peak, 20 MHz BW
Output Ripple Voltage 2	$V_{RIPPLE2}$			75	mV	
Output Current 2	I_{OUT2}	0.05		0.2	A	
Output Voltage 3	V_{OUT3}	21.1	24	26.9	VDC	±12% Total Peak to Peak, 20 MHz BW
Output Ripple Voltage 3	$V_{RIPPLE3}$			150	mV	
Output Current 3	I_{OUT3}	0.05		0.5	A	
Total Output Power Continuous Output Power	P_{OUT}		15		W	Full Load
Efficiency	η	73			%	Full Load, 25 °C, $V_{IN(MIN)}$
Ambient Temperature	T_{AMB_EXT}	0	25	50	°C	External Ambient Range



3 Schematic

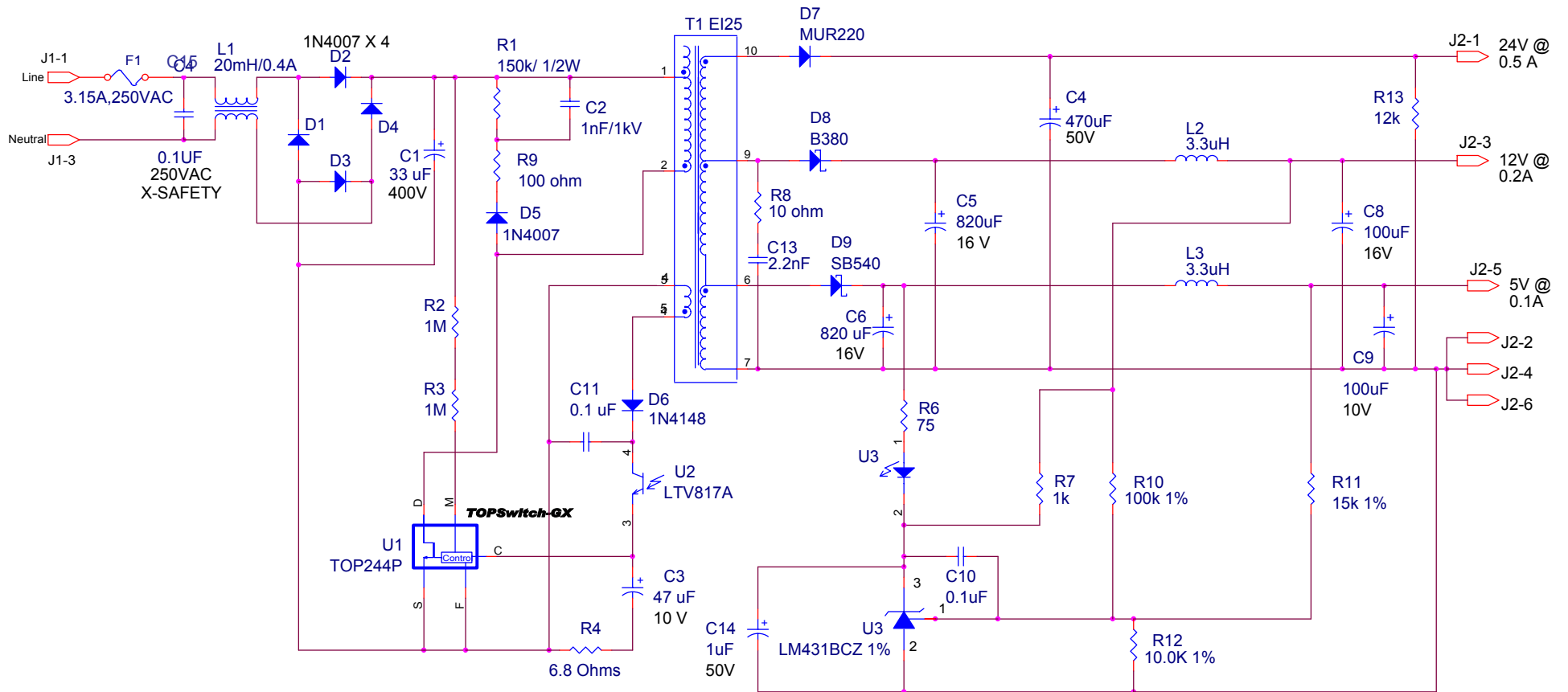


Figure 2 – Circuit Schematic.



4 Circuit Description

This circuit is a low-cost multi-output Flyback switching power supply designed for appliance applications using the TOP244P integrated circuit.

The circuit schematic details a 15 W, 3 output (5 VDC, 12 VDC and 24 VDC) power supply that operates from an 85 VAC to 265 VAC input. The high efficiency (>73%) allows the power supply to operate within specifications at elevated ambient temperature.

The AC input is rectified and filtered by D1 to D4 and C1 to create a high voltage DC bus that is connected to transformer T1. The other side of T1 is driven by the high-voltage MOSFET of TOP244P¹ (U1). Fuse F1 protects against primary-side components failures, while U1 protects against secondary components failures, and overloaded/shorted outputs.

The combined value of the line sensing resistors R2 and R3, connected to the MULTI-FUNCTION (M) pin of U1, sets the undervoltage and overvoltage thresholds and provides a line feed forward function.

On increasing line voltage, the power supply is inhibited until the undervoltage (UV) threshold is reached (~100 VDC). On reducing line voltage, the UV function turns off the power supply when the line input voltage is below the UV threshold and the output goes out of regulation. This allows the power supply to continue operating at input voltages significantly below the UV threshold until output regulation is lost, but eliminates output glitches by preventing restart until the input voltage goes back above the UV threshold.

The overvoltage function turns off the power supply if the input voltage exceeds approximately 450 V. In the off state, the power supply can withstand severe line transients or extended line swell conditions without damage. The supply resumes operation when the input voltage falls below the overvoltage threshold.

The line feed forward function independently modulates the duty cycle of U1 to reject the AC line frequency ripple component of the input voltage, reducing the line frequency ripple at the output of the supply. The output ripple specifications can be met without increased control loop gain since line feed forward operates independent of the main control loop. This simplifies the design of the power supply control loop.

A low cost RCD (R1, C2, R9 and D5) snubber circuit limits the turn-off voltage spike (caused by the leakage inductance) to a safe level on the DRAIN pin of U1. Resistor R9 is required in series with the slow recovery diode (D5) to reduce the diode reverse recovery spike and damp the subsequent oscillations which might allow the drain to ring below source at low line.

¹ The "P" and "G" packages allow either line sensing or external current limit programming through the M pin. "Y" and "R" packages allow both functions via the L and X pins. Reducing the current limit in this design would allow a smaller transformer to be used, if desired.



The bias winding is rectified and filtered by D6 and C11 to power U1. Capacitor C3 is used to decouple the CONTROL pin, determine the auto-restart frequency and together with R4, forms part of the control loop compensation.

The secondary winding is rectified and filtered by D7, R5, C4 (24 V) D8, C5 (12 V) and D9, C7, C8 (5 V), with additional switching frequency ripple and high frequency spike noise filtering provided by L2, C8 (12 V) and L3, C9 (5 V) to give the DC outputs.

The choice of Schottky diodes for the 5 V and 12 V outputs was driven by both voltage regulation and efficiency considerations.

The snubber (C13 and R8) reduces the 10 MHz to 30 MHz conducted EMI due secondary leakage inductance. The current through the pre-load resistor R13 adds to the spec minimum load to keep the 24 V output in regulation. The 3.3 V and 5 V output voltages are determined by the voltage set at the adjust pin of U3 (shunt regulator) by the voltage divider formed by R10, R11 and R12. The current through R12 sets the output voltages, while the current contribution of R10 and R11 sets the regulation band for 12 V and 5 V outputs, respectively. Other output voltages are possible by adjusting the transformer turns ratios, choosing the output diodes forward voltage drops and voltage divider settings. Optocoupler U2 applies the feedback signal from U3 to the CONTROL pin of U1. Resistor R6 is used to set the overall gain of the supply control loop, while R7 provides bias current for U3. Capacitor C10 provides frequency compensation for U3 stabilizing the power supply control loop. Capacitor C14 is used to close the feedback loop (bypassing U3) through optocoupler U2 during start-up, before U3 takes over the control loop. The ability to close the feedback loop in conjunction with the built-in soft-start feature of *TOPSwitch-GX* completely controls the start-up drain current profile, preventing transformer saturation and output overshoot.

The 5 V and 12 V secondary layout switching loops are minimized and, along with closely coupled transformer secondary windings, achieve low secondary leakage inductance and in turn, good cross-regulation. Optimizing the number of primary turns minimizes leakage. This also reduces the number of primary layers and improves primary to secondary coupling.

The power supply meets IEC60950/UL1950 safety requirements. Primary-to-secondary isolation is assured by using parts/materials (opto/transformer insulation) with the correct level of isolation and creepage distances (opto slot/transformer bobbin).

The power supply passed IEC/UL 1000-4-5, Class 4 line surge test (Class 3 only is required). All three outputs had monitor LEDs that showed no output disruption during the 90 high voltage surge pulses of Class 3. During Class 4 testing the outputs were disrupted for one second (LEDs blinked indicating the operation of the overvoltage shutdown feature) when applying the 2 kV, 2 Ω differential pulse and the 4 kV, 2 Ω differential pulses (L1/GND, L2/GND) and were unaffected during the 4 kV, 12 Ω common-mode pulses (L1, L2/GND).



The switching frequency jitter of TOP244 (U1) allows the unit to meet worldwide conducted EMI standards using a low cost, common-mode inductor (L1) in combination with a small value capacitor (C15). Careful transformer construction and PCB layout eliminate the need for a Y-rated capacitor between primary and secondary. Removal of the Y cap is necessary in voice applications to eliminate line frequency audio hum (“ground loops”). The common-mode inductance of L1 and the transformer construction attenuate common-mode conducted emission currents caused by the switching waveform on the DRAIN of U1, charging and discharging various stray capacitances. The differential inductance of L1 together with C15 attenuate differential-mode emission currents caused by the fundamental and harmonics of the primary current waveform.



5 PCB Layout

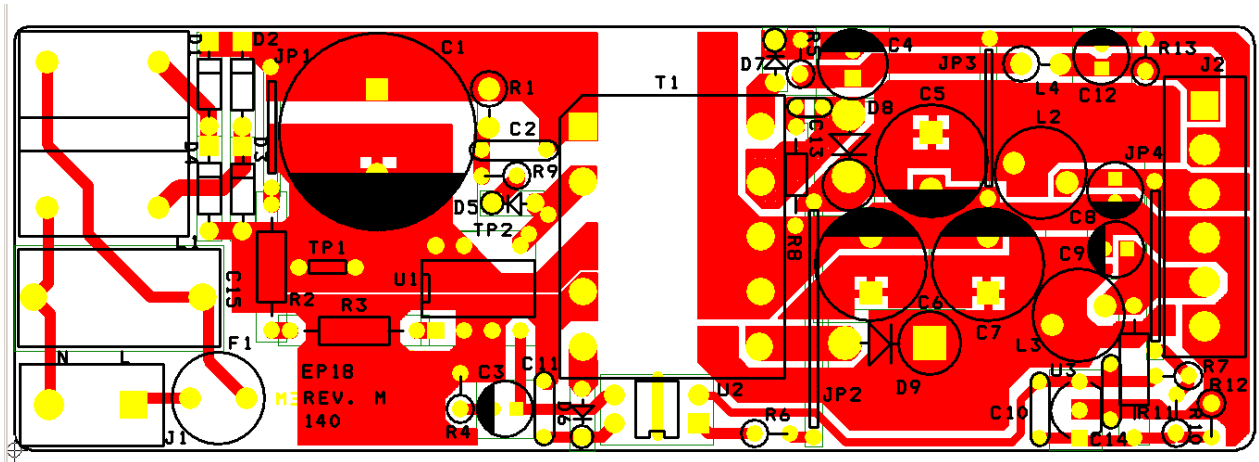


Figure 3 – Printed Circuit Layout. Actual Size Board (L = 113 mm, W = 39 mm, H = 25 mm).

Layout shown in Figure 3 is for an unmodified EP18 demo board; the secondary circuit has been modified for this prototype.

For the drain-to-source voltage waveforms, connect the high voltage probe tip to TP2 and the probe ground to test point TP1.

For switching current waveforms, add a wire loop in the provided holes and cut open the copper trace. Use a Tektronix A6302 current probe and AM503 current probe amplifier (with TM501 power module) or equivalent.

6 Bill Of Materials

Bill Of Materials

Item	Qty.	Ref.	Description	Part number	Manufacturer
1	1	C1	33 μ F, 400 V, 105 °C	KMX400VB33	UCC
2	1	C2	1 nF, 1 kV, 6.5 mm, LS = 6.4mm		Philips Centra
3	1	C3	47 μ F, 10 V	KME10VB47RMX11LL	UCC
4	1	C4	470 μ F, 50 V		
5	2	C5-C6	820 μ F 16 V / 1000 μ F, 16 V	EEU-FC1C821 / LXZ216VB102M10X20LL	Panasonic UCC
6	1	C8	100 μ F, 16 V		
7	1	C9	100 μ F, 10 V		
8	2	C10,11	0.1 μ F, 50 V	K104M15Z5UF5TH5	BC
9	1	C13	2200 pF, 100 V, multilayer cer.	C315C222K1R5CA	Kemet
10	1	C14	1 μ F, 50 V, ceramic		Any
11	1	C15	0.1 μ F 250 VAC, X1	F1772-410-2000	Vishay
12	5	D1-D5	1 A, 1000 V	1N4007	General Semi.
13	1	D6	0.15 A, 75 V, 4 ns	1N4148	General Semi.
14	1	D7	2 A, 200 V, 50 ns	MUR220	On Semi.
15	1	D8	3 A, 80 V, Schottky	B380	General Semi.
16	1	D9	5 A, 40 V, Schottky	SB540	General Semi.
17	1	F1	250 VAC, 3.15 A	19372K	Wickman
18	1	J1	HEADER 3	26-48-1031	Molex
19	1	J2	HEADER 6	26-48-1061	Molex
20	1	L1	20 mH, 0.4 A	SS11V-05230	Tokin
21	2	L2, L3	3.3 μ H, 2.66 A	822MY-3R3M	Toko
22	1	R1	150 k Ω , 1/2 W		Any
23	2	R2, R3	1 M Ω , 1/4 W		Any
24	1	R4	6.8 Ω , 1/4 W		Any
25	1	R8	10 Ω , 1/4 W		Any
26	1	R6	75 Ω , 1/4 W		Any
27	1	R7	1 k Ω , 1/4 W		Any
28	1	R9	100 Ω , 1/4 W		Any
29	1	R10	100 k Ω \pm 1%, 1/4 W		Any
30	1	R11	15 k Ω \pm 1%, 1/4 W		Any
31	1	R12	10.0 k Ω \pm 1%, 1/4 W		Any
32	1	R13	12 k Ω , 1/4 W		Any
33	1	T1	EI25 XFMR (custom)	SIL6008 Rev D	HiCal
34	1	U1	TOPSwitch-GX	TOP244P	Power Integrations
35	1	U2	Optocoupler	LTV817A	Liteon
36	1	U3	Shunt Regulator, 2.5 V 1%	LM431BCZ	National Semiconductor



7 Transformer Specification

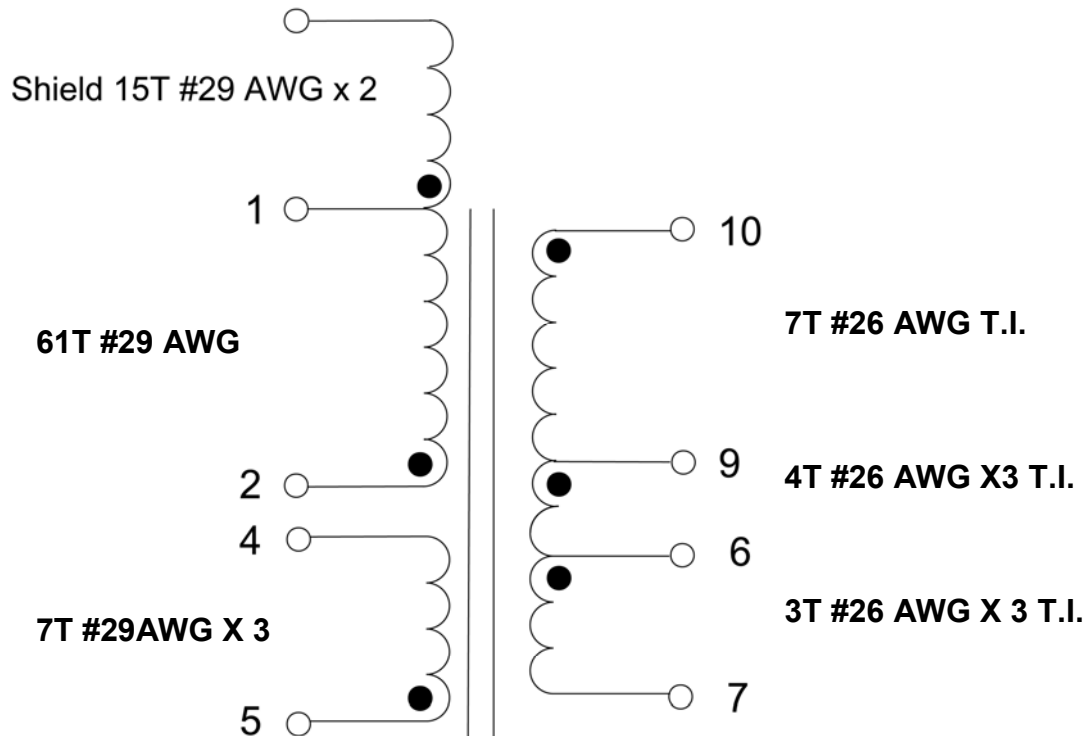


Figure 4 - Transformer Electrical Diagram.

7.1 Electrical Specifications

Electrical Strength	1 minute, 60 Hz, from Pins 1-5 to Pins 6-10	3000 VAC
Primary Inductance	Pins 1-2, all windings open, 130 kHz measurement frequency	397 μ H +/-10%
Resonant Frequency	Pins 1-2, all windings open	0.5 MHz minimum
Primary Leakage Inductance	Pins 1-2, Pins 6-10 shorted, 130 kHz measurement frequency	8 μ H maximum

7.2 Materials

Item	Description
[1]	Core: EI25, Nippon Ceramic FEI-25, NC-2H material or equivalent, gapped for AL of 105 nH/T ² . Note: Core longer than standard EI25.
[2]	Bobbin: YW-360-02B by YIH-HWA Enterprise, 10 PIN, with secondary-side pedestal. Pin 3 removed.
[3]	Magnet Wire: #29 AWG Heavy Nyleze
[4]	Triple Insulated Wire (TIW): #26 AWG
[5]	Tape: 3M 1298 Polyester Film (white) 10.58 mm wide by 2.2 mm thick
[6]	Varnish

7.3 Transformer Build Diagram

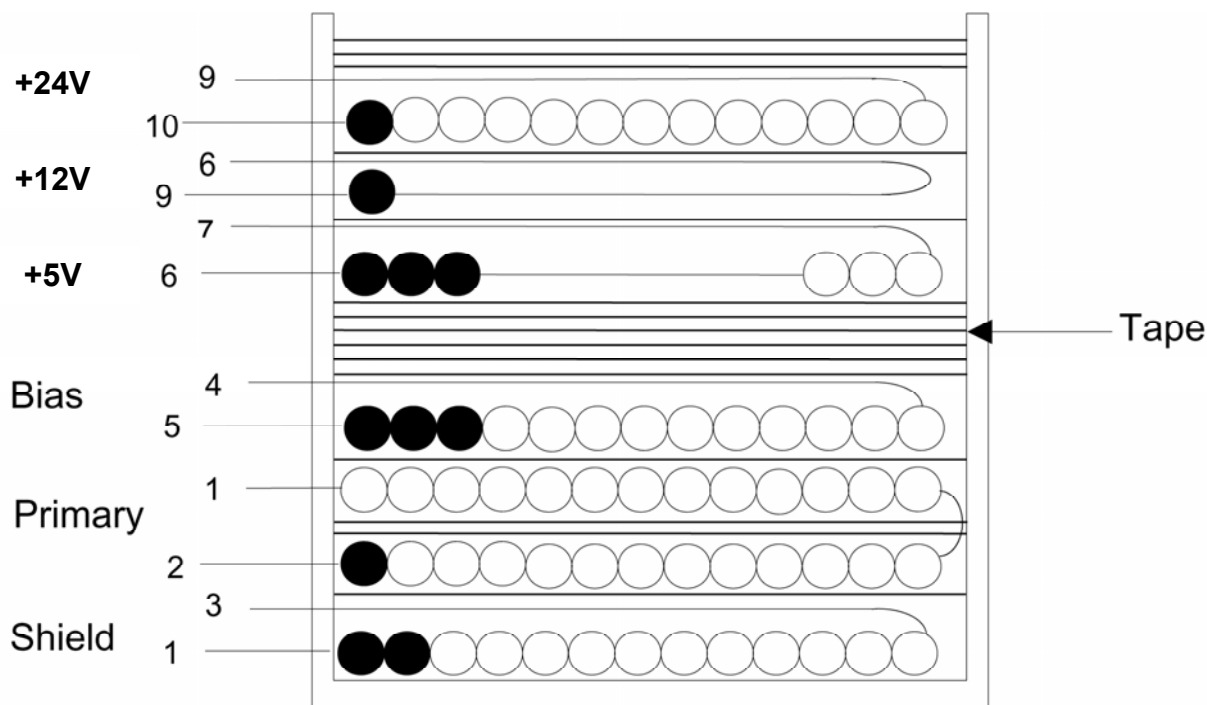


Figure 5 – Transformer Build Diagram.

7.4 Transformer Construction

Shield	Start at Pin 1. Wind 15 turns of item [3], bifilar parallel, from left to right, over entire length of the bobbin. Finish on Pin 3.
Tape Insulation	1 Layer of tape [5] for insulation
Double Primary Layer	Start at Pin 2. Wind 30 turns of item [3] from left to right over entire length of the bobbin. Apply 2 layers of tape, item [5], for spacing . Wind remaining 31 turns in the next layer from right to left, over entire length of the bobbin. Finish on Pin 1.
Tape Insulation	1 Layer of tape [5] for insulation.
Bias Winding	Start at Pin 5. Wind 9 turns parallel trifilar of item [3] from left to right, uniformly over entire width of bobbin . Finish on Pin 4.
Tape Insulation	6 Layers of tape [5] for spacing .
5 V Winding	Start at Pin 6. Wind 3 turns parallel trifilar of item [4] from left to right, uniformly over entire width of bobbin . Finish on Pin 7. Secure turns with 1 layer of tape.
12 V Winding	Start at Pin 9. Wind 4 turn of item [4] from left to right over entire width of bobbin . Finish on Pin 6. Secure turns with 1 layer of tape.
24 V Winding	Start at Pin 10. Wind 7 of item [4] from left to right uniformly, over entire width of bobbin. Finish on Pin 9.
Tape Insulation	3 Layers of tape [5] for insulation.
Final Assembly	Assemble core with the "I" side on top . Secure core. Dip varnish the transformer [6].



7.5 Design Notes

Power Integrations Device	TOP244P
Frequency of Operation	132 kHz
Mode	Continuous/Discontinuous
Peak Primary Current	0.79 A
Reflected Voltage	113 V
Maximum DC Input	375 V
Minimum DC Input	80 V



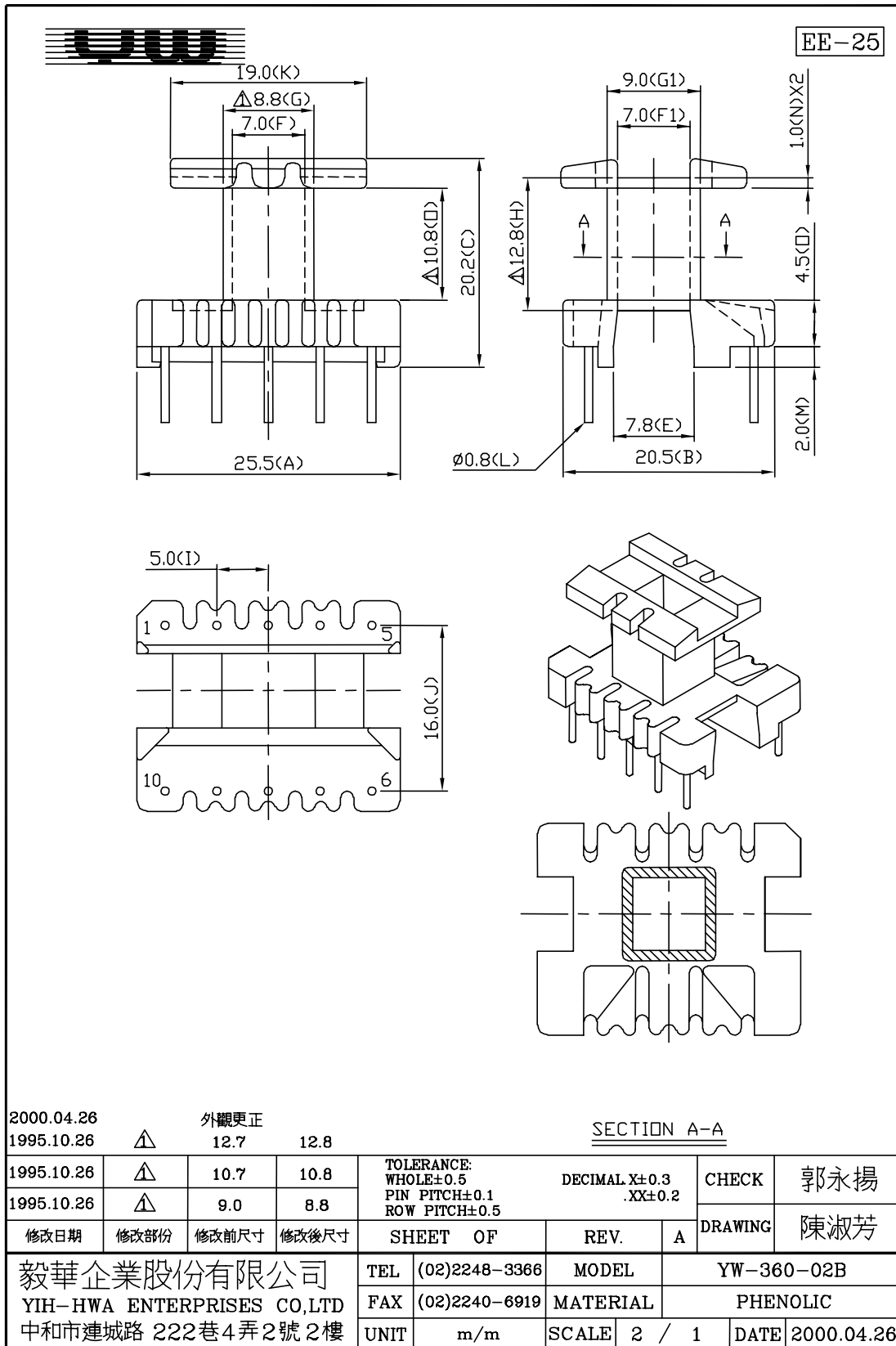


Figure 6 - E125 Bobbin Drawing.



8 Transformer Spreadsheets

Power Supply Input						
VACMIN	Volts	85			Min Input AC Voltage	
VACMAX	Volts	265			Max Input AC Voltage	
FL	Hertz	50			AC Main Frequency	
TC	mSeconds	2.69			Bridge Rectifier Conduction Time Estimate	
Z		0.49			Loss Allocation Factor	
N	%	83.0			Efficiency Estimate	
Power Supply Outputs						
VOx	Volts		5.00	12.00	24.00	Output Voltage
IOx	Amps		0.100	0.200	0.500	Output Current
VB	Volts	15.00				Bias Voltage
IB	Amps	0.006				Bias Current
Device Variables						
Device		TOP243Y/F				Device Name
PO	Watts	14.99				Total Output Power
VDRAIN	Volts	631				Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
VDS	Volts	6.6				Device On-State Drain to Source Voltage
FS	Hertz	132000				Device Switching Frequency
KRPKDP		1.17				Ripple to Peak Current Ratio
KI		1.00				External Current Limit Ratio
ILIMITEXT	Amps	0.84				Device Current Limit External Minimum
ILIMITMIN	Amps	0.84				Device Current Limit Minimum
ILIMITMAX	Amps	0.96				Device Current Limit Maximum
IP	Amps	0.79				Peak Primary Current
IRMS	Amps	0.34				Primary RMS Current
DMAX		0.57				Maximum Duty Cycle
Power Supply Components Selection						
CIN	uFarads	33.0				Input Filter Capacitor
VMIN	Volts	80				Minimum DC Input Voltage
VMAX	Volts	375				Maximum DC Input Voltage
VCL0	Volts	170				Clamp Zener Voltage
PZ	Watts	2.5				Estimated Primary Zener Clamp Loss
VDB	Volts	0.7				Bias Winding Diode Forward Voltage Drop
PIVB	Volts	67				Bias Rectifier Maximum Peak Inverse Voltage
Power Supply Output Parameters						
VDx	Volts		0.5	0.7	1.0	Output Winding Diode Forward Voltage Drop
PIVSx	Volts		23	54	107	Output Rectifier Maximum Peak Inverse Voltage
ISPx	Amps		0.50	1.00	2.49	Peak Secondary Current
ISRMSx	Amps		0.18	0.35	0.88	Secondary RMS Current
IRIPPLEx	Amps		0.14	0.29	0.72	Output Capacitor RMS Ripple Current
Transformer Construction Parameters						
Core/Bobbin		EI25				Core and Bobbin Type
Core Manuf.		Generic				Core Manufacturing
Bobbin Manuf		Generic				Bobbin Manufacturing
LP	uHenries	397				Primary Inductance
NP		61				Primary Winding Number of Turns
NB		8.56				Bias Winding Number of Turns
OD Actual	mm	0.25				Primary Actual Wire Diameter
Primary Current Density	A/mm ²	7				Primary Winding Current Density
VOR	Volts	112.48				Reflected Output Voltage
BW	mm	9.80				Bobbin Physical Winding Width
M	mm	0.0				Safety Margin Width
L		2.0				Number of Primary Layers
AE	cm ²	0.41				Core Effective Cross Section Area
ALG	nH/T ²	105				Gapped Core Effective Inductance
BM	mTesla	125				Maximum Operating Flux Density
BP	mTesla	152				Peak Flux Density
BAC	mTesla	63				AC Flux Density for Core Curves
LG	mm	0.46				Gap Length
LL	uHenries	7.9				Estimated Transformer Primary Leakage Inductance
LSEC	nHenries	30				Estimated Secondary Trace Inductance
Secondary Parameters						
NSx			3.00	6.93	13.64	Secondary Number of Turns
Rounded Down NSx				6	13	Rounded to Integer Secondary Number of Turns
Rounded Down Vox	Volts			10.30	22.83	Auxiliary Output Voltage for Rounded to Integer NSx
Rounded Up NSx				7	14	Rounded to Next Integer Secondary Number of Turns
Rounded Up Vox	Volts			12.13	24.67	Auxiliary Output Voltage for Rounded to Next Integer NSx



9 Performance Data

All measurements performed at room temperature.

9.1 Efficiency

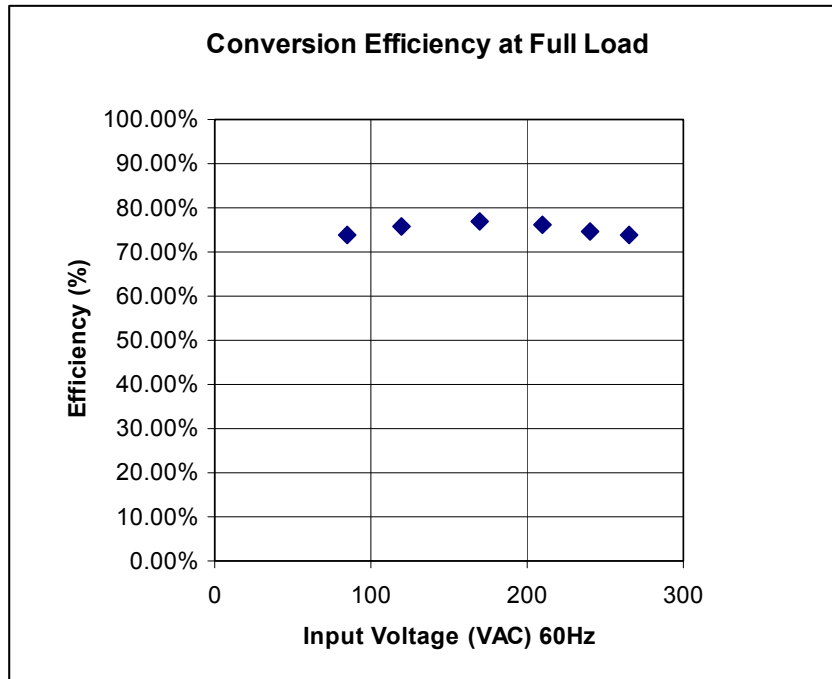


Figure 7 - Efficiency vs. Input Voltage at Full Load.



9.2 Regulation

9.2.1 Load

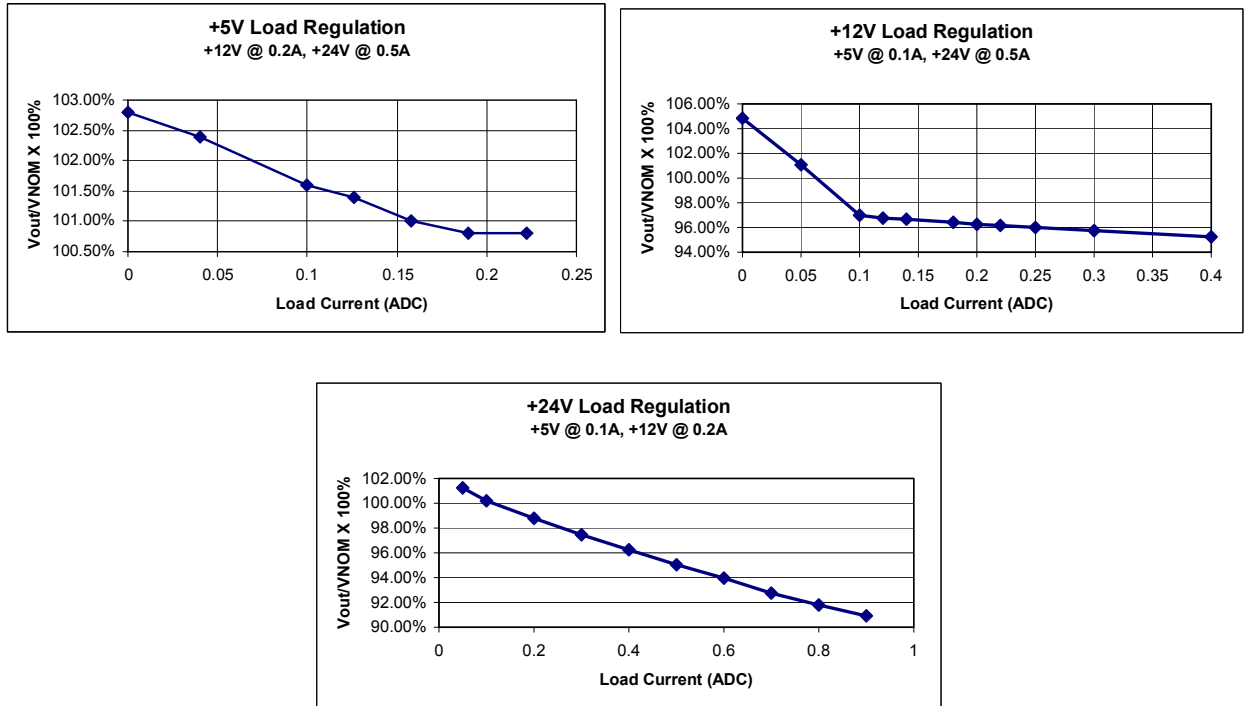


Figure 8 - Load Regulation at 85 VAC.

9.2.2 Line

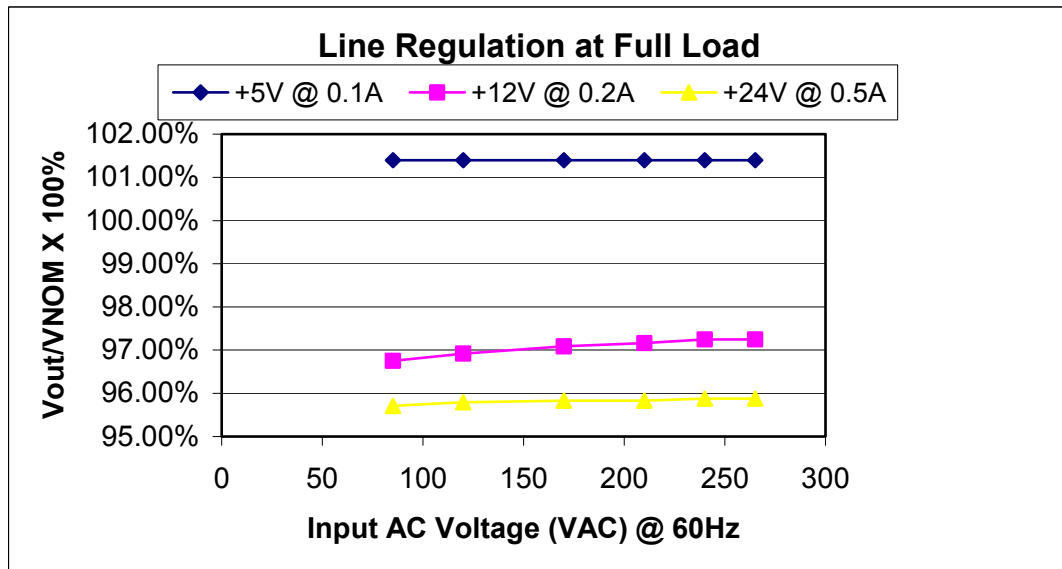


Figure 9 - Line Regulation at Full Load.



9.2.3 Cross-Regulation Table

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0	0	0
85VAC	5.05	11.78	23.69
120VAC	5.05	11.78	23.68
265VAC	5.05	11.77	23.68

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.1A	0.05A	0.05A
85VAC	5.01	12.12	24.33
120VAC	5.01	12.13	24.33
265VAC	5.00	12.16	24.40

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.05A	0.05A	0.5A
85VAC	5.07	11.63	22.01
120VAC	5.07	11.65	22.01
265VAC	5.06	11.71	22.02

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.1A	0.05A	0.5A
85VAC	5.05	11.83	22.60
120VAC	5.05	11.85	22.61
265VAC	5.04	11.90	22.60

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.05A	0.2A	0.05A
85VAC	5.04	11.90	24.17
120VAC	5.04	11.91	24.17
265VAC	5.04	11.92	24.23

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.1A	0.2A	0.05A
85VAC	5.02	12.00	25.07
120VAC	5.03	11.99	24.40
265VAC	5.03	11.98	24.40

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.05A	0.2A	0.5A
85VAC	5.09	11.46	22.65
120VAC	5.09	11.48	22.67
265VAC	5.09	11.54	22.72

Output Winding	+5VDC	+12VDC	+24VDC
Load Current			
Input Voltage	0.1A	0.2A	0.5A
85VAC	5.06	11.69	23.10
120VAC	5.06	11.69	23.09
265VAC	5.05	11.74	23.12

Universal Input Tolerance		
	min tol	max tol
+5VDC	0.00%	1.80%
+12VDC	-4.50%	1.33%
+24VDC	-8.29%	4.46%



10 Waveform Scope Plot

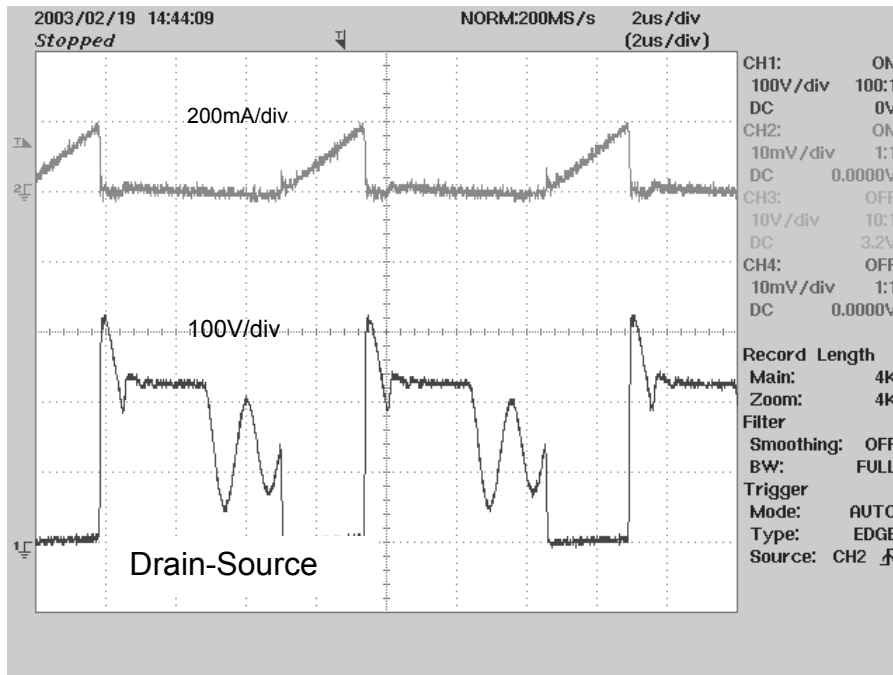


Figure 10 - Drain Current and Drain-to-source Voltage at Full Load ($V_{IN} = 120$ VAC, 60 Hz).



11 Revision History

Date	Author	Revision	Description & changes	Reviewed
March 30, 2004	RSP	1.0	Initial release	VC / AM



Notes



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