



Design Example Report

Title	<i>32W (47W peak) Multiple Output supply using TOP245P</i>
Specification	Input: 195 - 265 VAC Output: 3.3V/3A, 5V/2A (2.5A Peak), 12V/0.5A (1.5A Peak), 20V/0.3A
Application	Set Top Box
Author	Power Integrations Applications Department
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Summary and Features

This report describes a design for a multiple output power supply, such as required for a Set Top Box, featuring the following:

- Very high full power efficiency (> 83% at full power)
- 32W Continuous power rating
- <0.5W no-load consumption
- Efficiency >75% at 10% output power
- Small DIL08 package for TOP245P requiring no external heatsink
- 50W peak power capability allows for high peak output power demands (e.g. for hard disk spin-up)
- Low EMI (Meets EN55022 with output ground connected to Earth)

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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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 engineering report describes a multiple output evaluation board designed using TOP245P. The specification chosen is targeted towards new Set Top Box systems that incorporate a hard disk. These systems require a peak power capability when the hard disk is first spun-up.

Peak power operation requires magnetics and diodes specified to handle the currents at the specified peak power point. If peak power operation is not required, designing the supply for maximum continuous power will save additional cost.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, and measured performance data from the prototype unit shown in Figure 1.

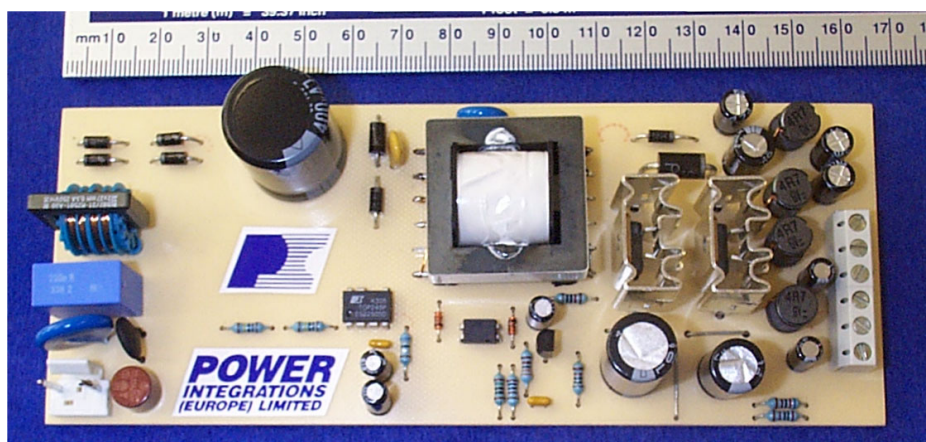


Figure 1 – Populated Circuit Board (Scale in cm)



2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	195		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage 1	V_{OUT1}		3.3		V	$\pm 5\%$
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	20 MHz Bandwidth
Output Current 1	I_{OUT1}	1		3	A	
Output Voltage 2	V_{OUT2}		5		V	$\pm 5\%$
Output Ripple Voltage 2	$V_{RIPPLE2}$				mV	20 MHz Bandwidth
Output Current 2	I_{OUT2}	1		2	A	2.5A Peak for 10s
Output Voltage 3	V_{OUT3}		12		V	$\pm 7\%$
Output Ripple Voltage 3	$V_{RIPPLE3}$				mV	20 MHz Bandwidth
Output Current 3	I_{OUT3}	0.35		0.5	A	1.5A Peak for 10s
Output Voltage 4	V_{OUT4}		20		V	$\pm 7\%$
Output Ripple Voltage 4	$V_{RIPPLE4}$				mV	20 MHz Bandwidth
Output Current 4	I_{OUT4}	0.1	0.3	0.3	A	
Total Output Power						
Continuous Output Power	P_{OUT}			31.9	W	
Peak Output Power	P_{OUT_PEAK}			46.4	W	
Efficiency	η	75			%	Measured at P_{OUT} (32 W), 25 °C
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950, UL1950 Class II				
Surge		4			kV	1.2/50 μ s surge, IEC 1000-4-5, 12 Ω series impedance, differential and common mode
Surge		3			kV	100 kHz ring wave, 500 A short circuit current, differential and common mode
Ambient Temperature	T_{AMB}	0		50	°C	Free convection, sea level

Table 1 - Power Supply Specification





4 Circuit Description

This power supply uses the latest generation TOPSwitch in a DIL08 package to minimize heatsink requirements. It is designed for 32W continuous operation in a 50°C ambient with magnetics designed to allow short peak power levels of up to 50W.

4.1 Input EMI Filtering

Due to the frequency jittering function of TOPSwitch, the input EMI filtering is minimal, consisting of a 15mH common-mode choke and 220nF x-capacitor. Protection is provided by a 1A, 250V antisurge fuse. Inrush limiting is provided by a thermistor. Surge protection is provided by a VDR on the input. If only 4kV surge is required, this part can be removed since the TOP245P incorporates over-voltage shutdown giving additional protection.

4.2 TOPSwitch Primary

On the primary side of the supply, the TOPSwitch integrates a number of functions:-

- Frequency jitter which reduces the QP and AV EMI levels by up to 10dB
- Soft-Start which prevents transformer saturation during start-up. This increases long term reliability
- Line UV and OV detection to give additional differential surge withstand capability
- Regulation to zero load without pre-load due to very low minimum duty cycle capability
- Line feed forward which improves 100Hz ripple rejection
- Hysteretic thermal and short circuit protection to increase long term reliability

A 47uF input capacitor has been used to provide the high peak power capability. If peak power operation is not required, this can be reduced to 33uF, 400V which will save further cost.

4.3 Output Rectification

A fully AC stacked design has been used to give good cross-regulation. A snubber is placed across D7 to reduce high frequency common-mode EMI emissions. Post filters are used on all outputs to meet noise and ripple requirements.

4.4 Output Feedback

Full PWM feedback has been implemented using a TL431 reference and opto-coupler. Feedback is split over the 3V3 and 5V rails, each giving equal influence to the feedback network. D10, R10 and C11 provide a soft-finish function, ensuring a monotonic rise in the output voltages with zero overshoot.



5 PCB Layout

The evaluation board was implemented using a single copper layer. Figure 3 shows the component placement and underside copper routing.

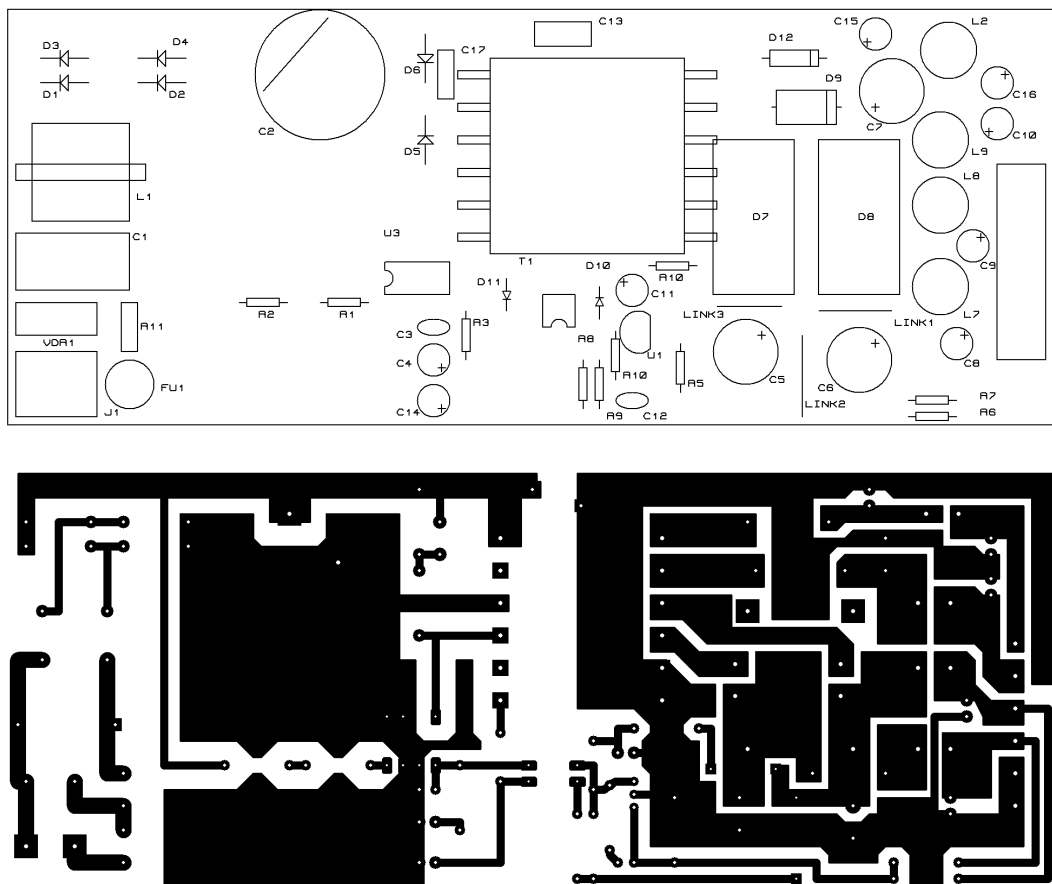


Figure 3 – Printed Circuit Layout (Scale not 1:1)



6 Bill Of Materials

Reference	Quantity	Value
R1,R2	2	1M
R3	1	6R8
R4	1	3k3
R5	1	10k, 1%
R6	1	22k, 1%
R7	1	6k8, 1%
R8	1	150R
R9	1	1k
R10	1	10k
R11	1	20R, 2W NTC
R12	1	3R3
C1	1	220nF, X2 CAP
C2	1	47uF, 400V
C3,C12	2	100nF
C4	1	47uF, 10V
C5	1	1000uF, 35V
C6	1	470uF, 35V
C7	1	100uF, 35V
C8,C9	2	100uF, 10V
C10	1	47uF, 16V
C11	1	22uF, 10V
C13	1	2.2nF, Y1_CLASS
C14	1	1uF, 50V
C15	1	39uF, 35V
C16	1	47uF, 35V
C17	1	1nF, 1kV
C18	1	4.7nF
U1	1	TL431
U2	1	PC817
U3	1	TOP245P
D1,D2,D3,D4	4	1N4007
D5	1	1N4937
D6	1	P4KE200
D7,D8	2	MBR1035
D9	1	SR506
D10	1	BAS19
D11	1	IN4148
D12	1	UF4002
FU1	1	1A, 250V
T1	1	EF30 Custom Transformer
L2	1	4.7uH, 1A
L7,L8,L9	3	4.7uH, 3.2A
VDR1	1	300V

Total of 52 components



7 Transformer Specification

7.1 Electrical Diagram

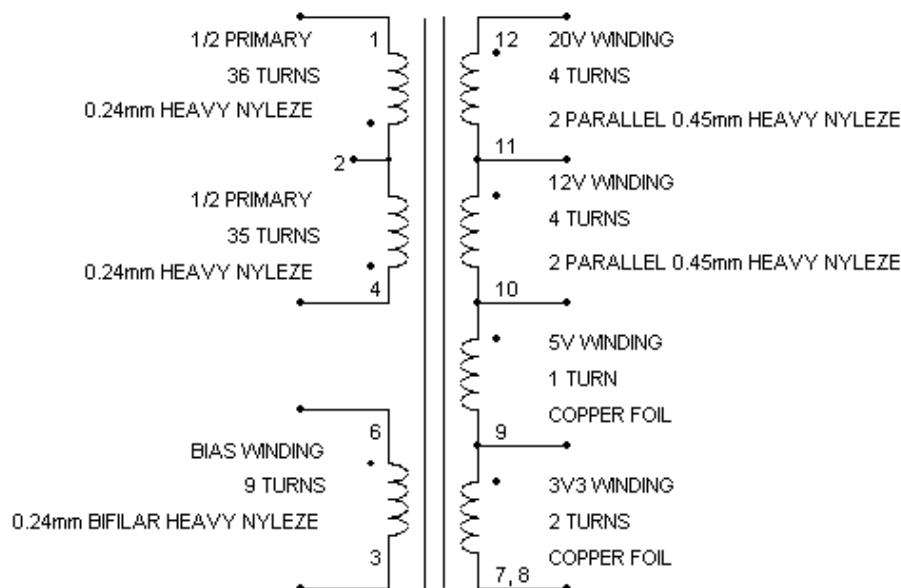


Figure 4 –Transformer Electrical Diagram

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Pins 1-4 to Pins 7-12	3000 VAC
Primary Inductance	Pins 1-4, all other windings open, measured at 100 kHz, 0.4 VRMS	1180 μ H, -0/+20%
Resonant Frequency	Pins 1-4, all other windings open	600 kHz (Min.)
Primary Leakage Inductance	Pins 1-4, with Pins 7-8 shorted, measured at 100 kHz, 0.4 VRMS	50 μ H (Max.)

7.3 Materials

Item	Description
[1]	Core: EF30 CORE, 3C85, Gapped for 234nH/T^2 (Approximately 0.28mm)
[2]	Bobbin: EF30, 10 pin
[3]	Magnet Wire: 0.24mm Diameter Heavy Nyleze
[4]	Copper Foil: See section below
[5]	Tape: 16mm wide insulation tape
[6]	Tape: 3mm margin tape
[7]	Magnet Wire: 0.45mm Diameter Heavy Nyleze
[8]	Varnish



7.4 Transformer Build Diagram

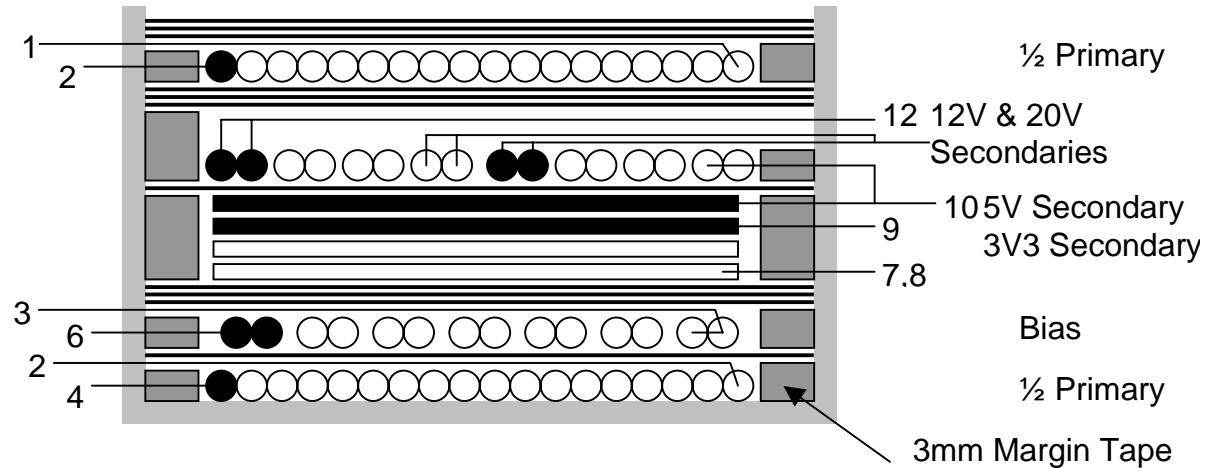
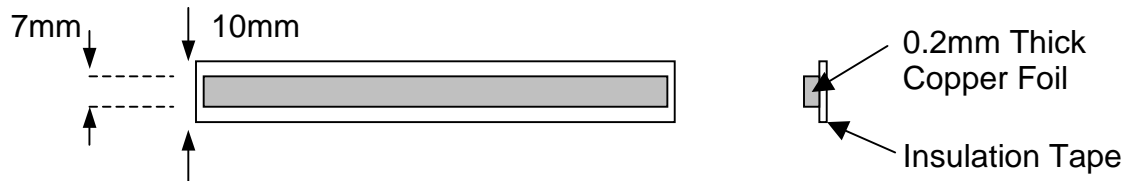


Figure 5 – Transformer Build Diagram



7.5 Transformer Construction

Bobbin Preparation	Place 3mm of Margin tape on each side of the EF30 Bobbin
1/2 Primary	Start at Pin 4. Wind 36 turns of item [3] in approximately 1 layer. Bring finish lead back to start. Finish on Pin 2.
Basic Insulation	Use two layers of item [5] for basic insulation.
Bifilar Bias Winding	Starting at Pin 6, wind 9 bifilar turns of item [3]. Spread turns evenly across bobbin. Finish at Pin 3.
Insulation	Use three layers of item [5] for safety insulation.
3V3 and 5V Windings	Start at Pins 7 and 8. Wind 2 turns of copper foil [4]. Bring termination wire out onto pin 9. Continue with one further copper foil turn and finish with termination on pin 10.
12V and 20V Windings	Start at Pin 10. Wind 4 turns of 4 parallel strands of item [7] using half the bobbin width. Terminate on pin 11. Continue with 4 further turns of 4 parallel strands of item [7] using the remaining half bobbin width. Finish on pin 12.
1/2 Primary	Start at Pin 2. Wind 35 turns of item [3] in approximately 1 layer. Bring finish lead back to start. Finish on Pin 1.
Outer Wrap	Wrap windings with 3 layers of tape item [5].
Final Assembly	Assemble and secure core halves. Varnish impregnate (item [8]).

8 Transformer Spreadsheets

This design was produced using PLEExpert assuming a TOP245P device with a current limit capability of 1.1A and an $R_{ds(on)}$ of 4 Ω . The data below reflects the full continuous load, which gives approximately 0.7A peak primary current. The transformer has been designed to operate with safe flux levels with primary currents of up to 1.2A allowing for the peak power capability.

Power Supply Input

VACMIN	Volts	195					Min Input AC Voltage
VACMAX	Volts	265					Max Input AC Voltage
FL	Hertz	50					AC Main Frequency
TC	mSeconds	1.81					Bridge Rectifier Conduction Time Estimate
Z		0.68					Loss Allocation Factor
N	%	74.0					Efficiency Estimate

Power Supply Outputs

VOx	Volts		3.30	5.00	12.00	20.00	Output Voltage
IOx	Amps		3.000	2.000	0.500	0.300	Output Current
VB	Volts	15.00					Bias Voltage
IB	Amps	0.006					Bias Current

Device Variables

Device		TOP245P					Device Name
PO	Watts	31.99					Total Output Power
VDRAIN	Volts	678					Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
FS	Hertz	132000					Device Switching Frequency
KRPKDP		0.70					Ripple to Peak Current Ratio
KI		1.00					External Current Limit Ratio
IP	Amps	0.75					Peak Primary Current
IRMS	Amps	0.31					Primary RMS Current
DMAX		0.36					Maximum Duty Cycle

Power Supply Components Selection

CIN	uFarads	47.0					Input Filter Capacitor
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VMIN	Volts	247					Minimum DC Input Voltage
VMAX	Volts	375					Maximum DC Input Voltage
VCLO	Volts	200					Clamp Zener Voltage
PZ	Watts	2.0					
VDB	Volts	0.7					Bias Winding Diode Forward Voltage Drop
PIVB	Volts	59					Bias Rectifier Maximum Peak Inverse Voltage

Power Supply Output Parameters

VDx	Volts		0.5	0.5	0.7	0.7	Output Winding Diode Forward Voltage Drop
PIVSx	Volts		14	20	47	77	Output Rectifier Maximum Peak Inverse Voltage
ISPx	Amps		7.74	5.16	1.29	0.77	Peak Secondary Current
ISRMSx	Amps		4.22	2.81	0.70	0.42	Secondary RMS Current
IRIPPLEx	Amps		2.96	1.97	0.49	0.30	Output Capacitor RMS Ripple Current

Transformer Construction Parameters

Core/Bobbin		E30/15/7 Margin					Core and Bobbin Type
Core Manuf.		Generic					Core Manufacturing
Bobbin Manuf		Generic					Bobbin Manufacturing
LP	uHenries	1181					Primary Inductance
NP		71					Primary Winding Number of Turns
NB		8.26					Bias Winding Number of Turns
OD Actual	mm	0.25					Primary Actual Wire Diameter
Primary Current Density	A/mm^2	6					Primary Winding Current Density
VOR	Volts	135.00					Reflected Output Voltage
BW	mm	17.30					Bobbin Physical Winding Width
M	mm	3.0					Safety Margin Width
L		2.0					Number of Primary Layers



AE	cm ²	0.60					Core Effective Cross Section Area
ALG	nH/T ²	234					Gapped Core Effective Inductance
BM	mTesla	207					Maximum Operating Flux Density
BP	mTesla	267					Peak Flux Density
BAC	mTesla	73					AC Flux Density for Core Curves
LG	mm	0.28					Gap Length
LL	uHenries	17.7					Estimated Transformer Primary Leakage Inductance
LSEC	nHenries	20					Estimated Secondary Trace Inductance

Secondary Parameters

NSx			2.00	2.89	6.68	10.89	Secondary Number of Turns
Rounded Down NSx				2	6	10	Rounded to Integer Secondary Number of Turns
Rounded Down Vox	Volts			3.27	10.62	18.17	Auxiliary Output Voltage for Rounded to Integer NSx
Rounded Up NSx				3	7	11	Rounded to Next Integer Secondary Number of Turns
Rounded Up Vox	Volts			5.16	12.51	20.05	Auxiliary Output Voltage for Rounded to Next Integer NSx
ODS Actual Range	mm		0.64 - 1.03	0.51 - 0.81	0.25 - 0.40	0.20 - 0.32	Secondary Actual Wire Diameter Range Comment: Wire diameter is greater than recommended maximum (0.40 mm) and may overheat. Tip: Consider a parallel winding technique (bifilar, trifilar), increase size of transformer (larger BW), reduce margin (M).



9 Performance Data

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

9.1 Efficiency

Full power efficiency was measured as a function of line voltage and Figure 6 gives the resulting profile.

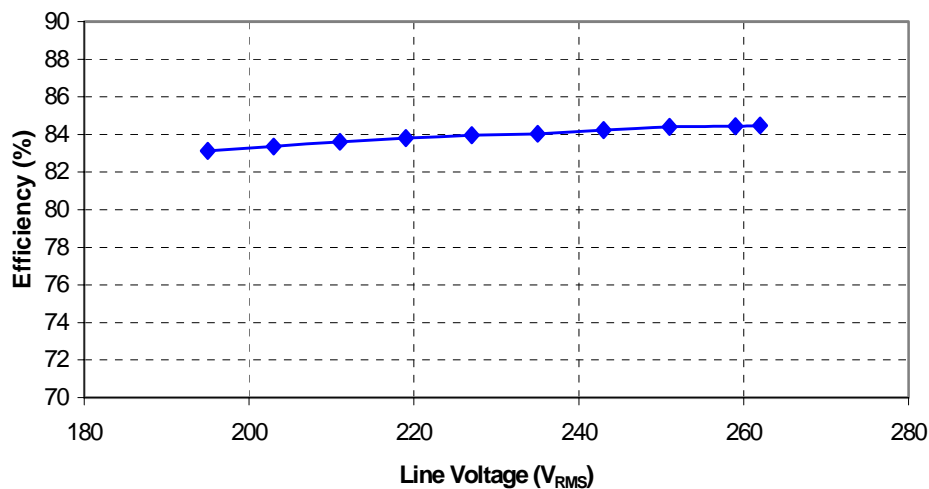


Figure 6- Full Continuous Power Conversion Efficiency

Efficiency as a function of output power was measured at 230V input, each rail load increased from zero to 100% load simultaneously in 10% load steps. Figure 7 shows the resulting efficiency profile.

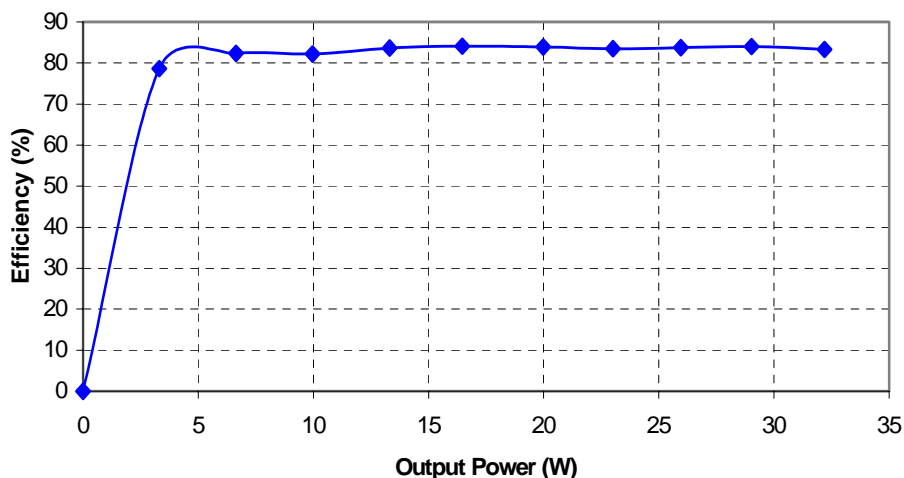


Figure 7 - Efficiency Variation with Load



9.2 No-load Input Power

Under zero output load conditions, the input power was measured at 400mW at 265V_{AC} input.

9.3 Peak Power

The prototype was loaded to the specified peak power levels in Table 1 and the temperature of the TOP245P monitored. The 46W peak power level can easily be supplied in 25°C ambient conditions. Under peak power levels, the TOP245P temperature was measured at 86°C. Thus, a peak power of 46W in 50°C ambient is achievable and only thermal shutdown will limit the time the peak power can be delivered for. With the high operating efficiency of this design, peak power levels of above 50W can be achieved for a few seconds.

9.4 Regulation

9.4.1 Load

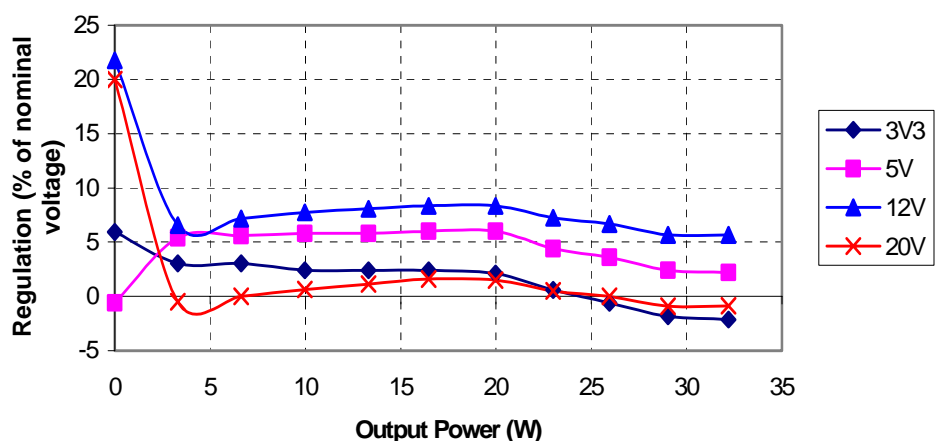


Figure 8 – Load Regulation, Room Temperature, 230V_{AC} Input



9.4.2 Line

Line regulation was measured at full continuous output power. The regulation, expressed as a percentage on nominal rail voltage, and as a function of line voltage is shown in Figure 9 below.

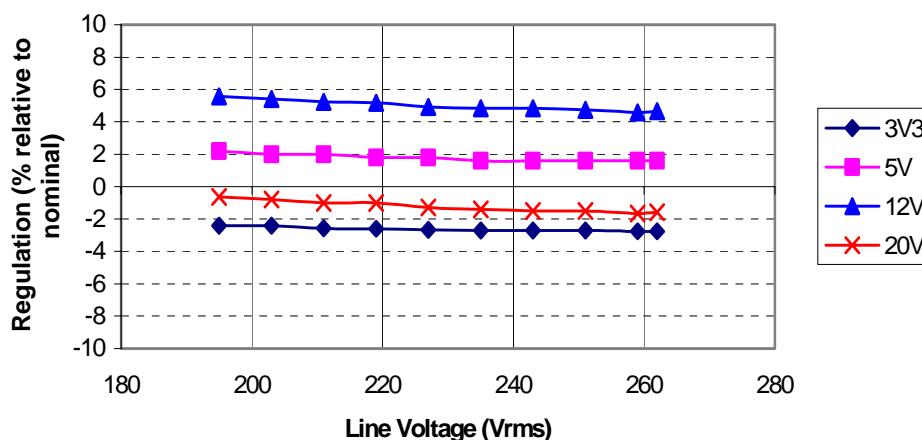


Figure 9 – Line Regulation, Room Temperature, Full Load.

9.5 Cross Regulation

Figure 10 gives the cross regulation results at 230V input.

3V3 - 5V - 12V - 20V	3V3	5V	12V	20V
XXXX	3.38	5.28	12.70	19.95
XXXM	3.39	5.28	12.67	19.63
XXMX	3.38	5.28	12.63	19.92
XXMM	3.39	5.00	12.62	19.64
XMXX	3.40	5.19	12.94	20.53
XXMM	3.39	5.18	12.79	19.86
XMMX	3.39	5.19	12.77	20.30
XMMM	3.33	5.10	12.55	19.58
MXXX	3.33	5.25	13.19	20.85
MXXM	3.28	5.20	12.87	20.00
MXMX	3.30	5.17	12.92	20.57
MXMM	3.27	5.10	12.72	19.80
MMXX	3.25	5.15	13.00	20.76
MMXM	3.24	5.12	12.80	19.93
MMMX	3.24	5.14	12.83	20.79
MMMM	3.22	5.12	12.69	19.84
Min (V)	3.22	5.00	12.55	19.58
Max (V)	3.40	5.28	13.19	20.85
% Below	-2.42	0.00	4.58	-2.10
% Above	3.03	5.60	9.92	4.25
Min Load (X)	1	1	0.35	0.1
Max Load (M)	3	2	0.5	0.3

Figure 10 - Cross Regulation



10 Thermal Performance

At full continuous output power, the temperature of key components was monitored using thermocouples. In a 25°C ambient, Figure 11 gives the resulting temperature profiles.

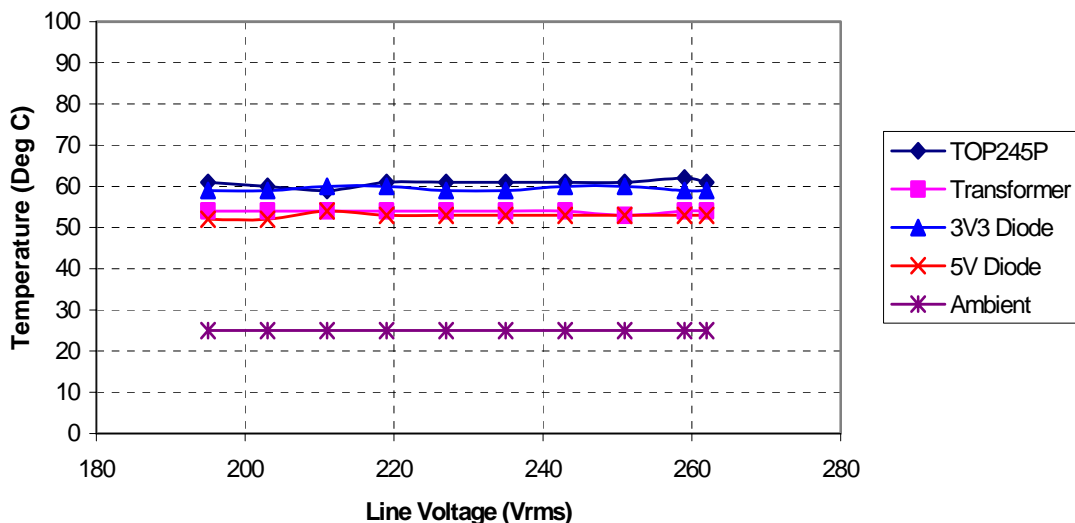


Figure 11 - Key Component Temperature Rise variation with Line Voltage

All key components are operating well within specified temperature ranges and this design would support operation in ambient levels up to 50°C.

11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

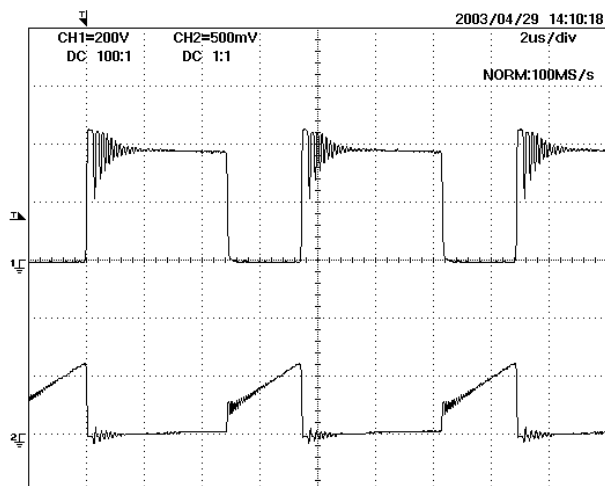


Figure 12 - 195 V_{AC}, Full Continuous Load

Lower: I_{DRAIN} , 0.5 A / div Upper: V_{DRAIN} , 200 V, 2 μ s / div

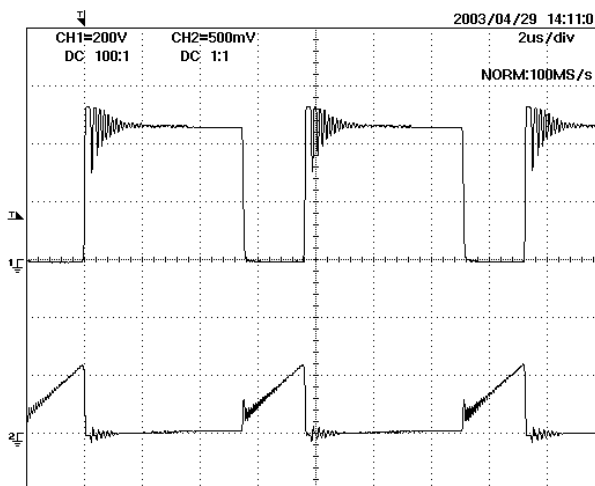


Figure 13 - 265 V_{AC}, Full Continuous Load

Lower: I_{DRAIN} , 0.5 A / div Upper: V_{DRAIN} , 200 V / div



11.2 Output Voltage Start-up Profile (Full Power)

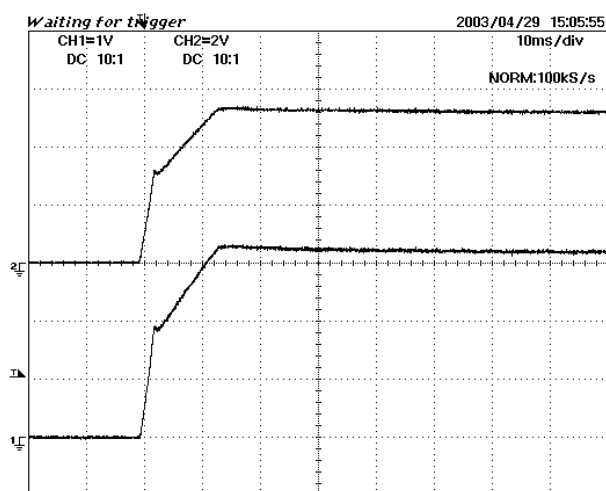


Figure 14 -Start-up Profile, 230V_{AC}

Lower: 3V3, 1 V / div

Upper: 5V, 2 V / div

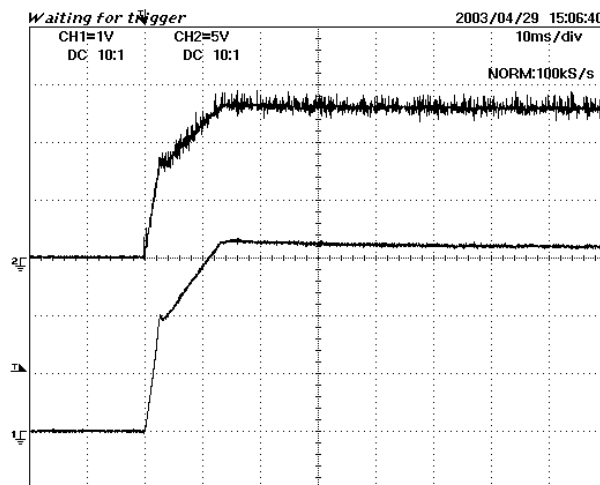


Figure 15 - Start-up Profile, 230V_{AC}

Lower: 3V3, 1 V / div

Upper: 12V, 5 V / div

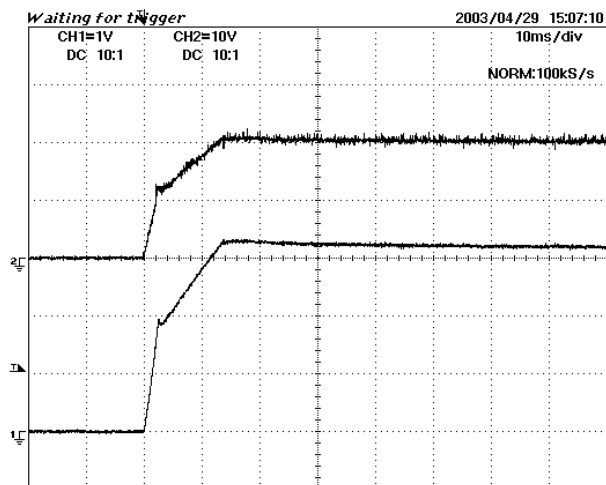


Figure 16 - Start-up Profile, 230V_{AC}

Lower: 3V3, 1 V / div

Upper: 20V, 10 V / div

11.3 Drain Voltage and Current Start-up Profile

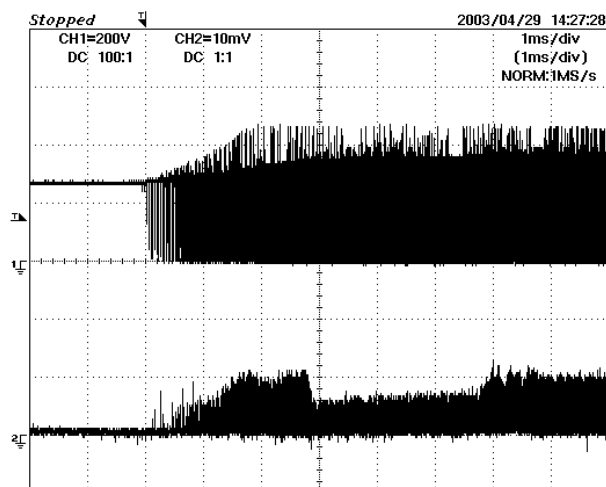


Figure 17 - 195 V_{AC} Input and Maximum Load.

Lower: I_{DRAIN} , 0.5 A / div.

Upper: V_{DRAIN} , 200 V & 1 ms / div.

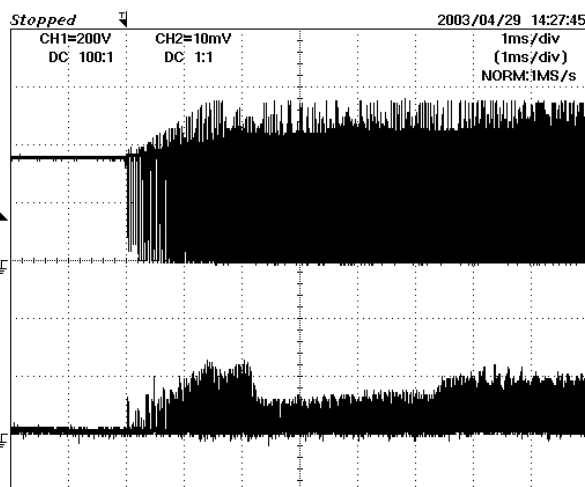


Figure 18 - 265 V_{AC} Input and Maximum Load.

Lower: I_{DRAIN} , 0.5 A / div.

Upper: V_{DRAIN} , 200 V & 1 ms / div.

11.4 Load Transient Response

Figure 19 shows the load transient response of the 3V3 rail when subjected to a load change for 3A to 4A.

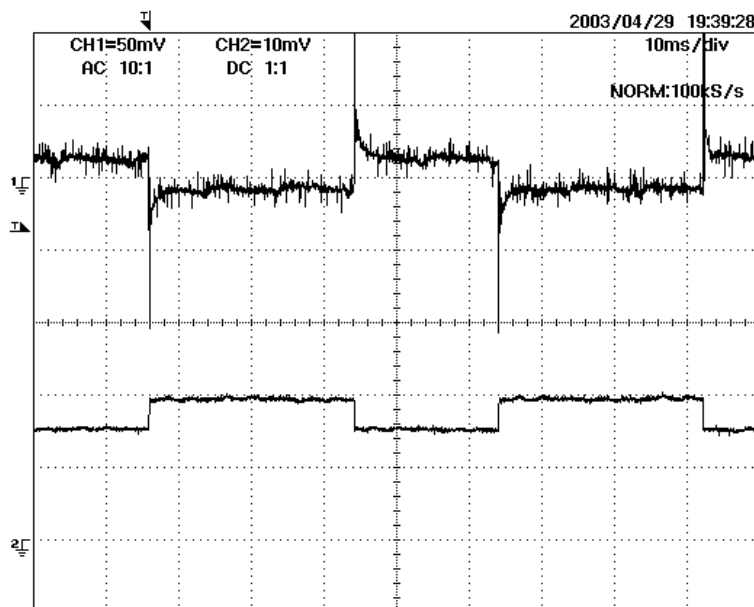


Figure 19 – Transient Response, 230 V_{AC}, 3A to 4A Step load change on 3V3. Full Load.

Lower – Current at 2A / div, Upper – AC coupled 3V3 voltage at 50mV / div



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 20 and Figure 21.

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).***

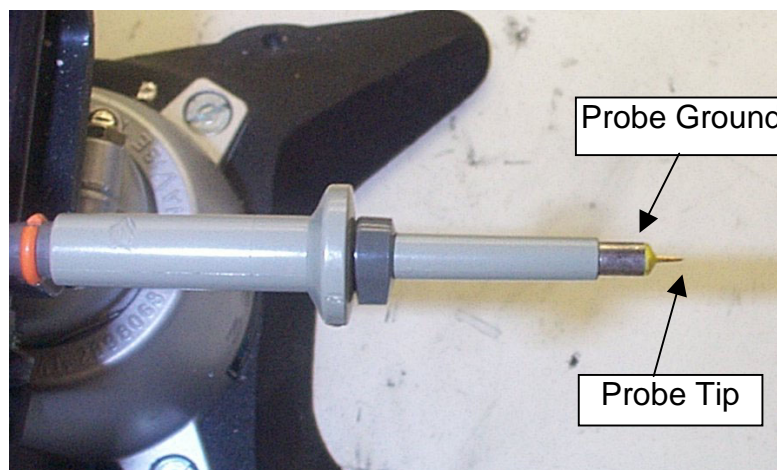


Figure 20 - Oscilloscope Probe Prepared for Ripple Measurement.
(End Cap and Ground Lead Removed)

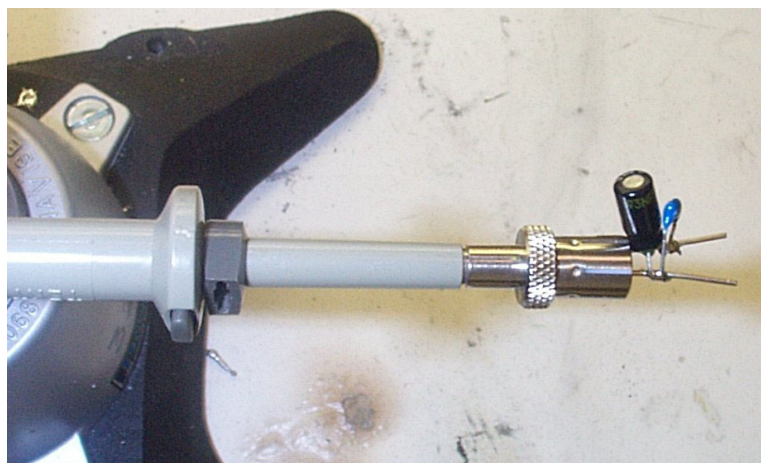
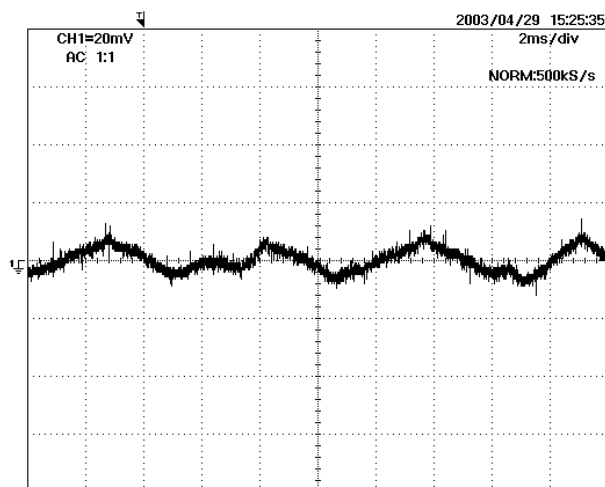
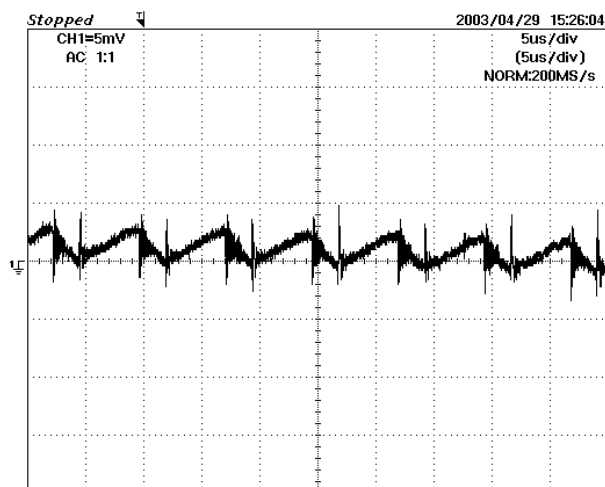


Figure 21 - Oscilloscope Probe with Probe Master 5125BA BNC Adapter.
(Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

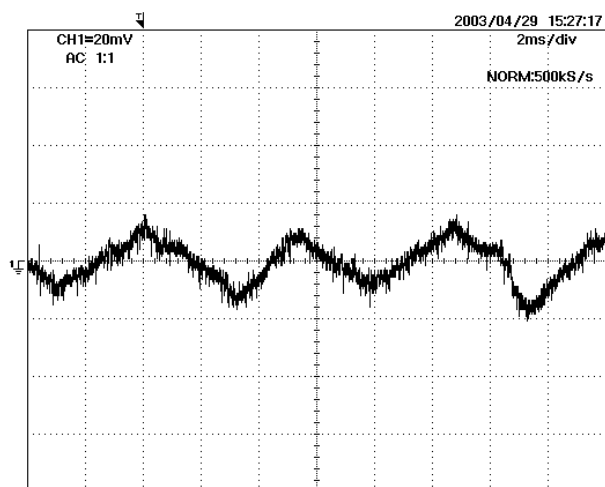
11.5.2 Measurement Results

**Figure 22** – 3V3 Ripple, 230 V_{AC}, Full Load.

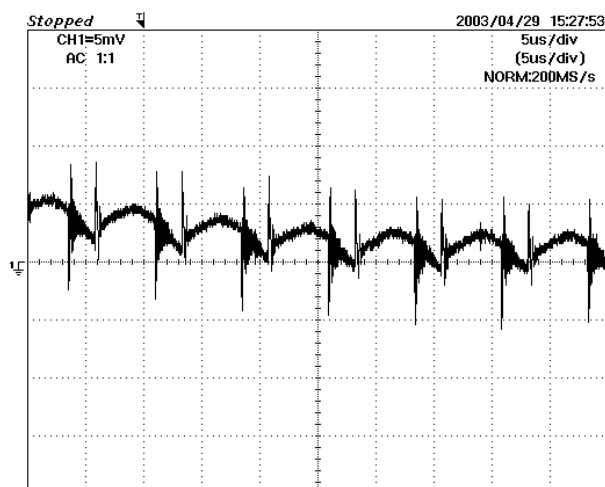
2 ms / div, 20 mV / div

**Figure 23** – 3V3 Switching Noise, 230 V_{AC}, Full Load.

5us / div, 5 mV / div

**Figure 24** – 5V Ripple, 230 V_{AC}, Full Load.

2 ms / div, 20 mV / div

**Figure 25** – 5V Switching Noise, 230 V_{AC}, Full Load.

5 us / div, 5 mV / div



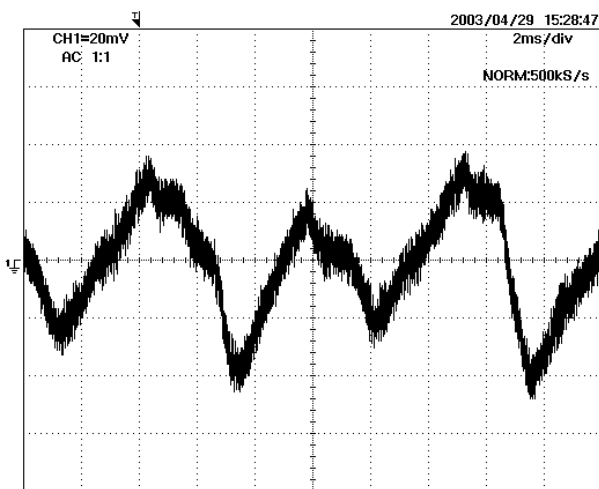


Figure 26 – 12V Ripple, 230 V_{AC}, Full Load.

2 ms / div, 20 mV / div

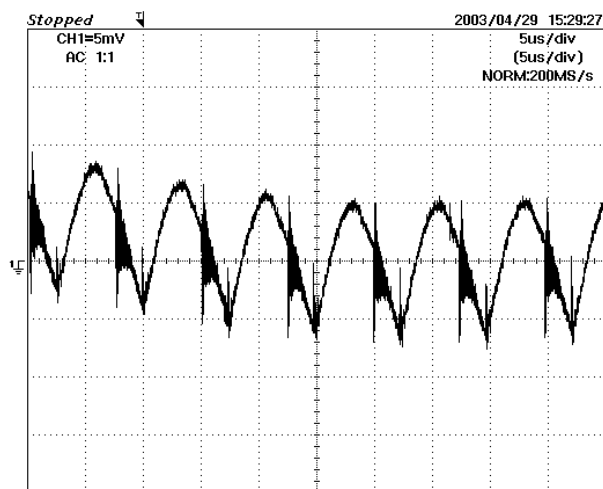


Figure 27 – 12V Switching Noise, 230 V_{AC}, Full Load.

5us / div, 5 mV / div

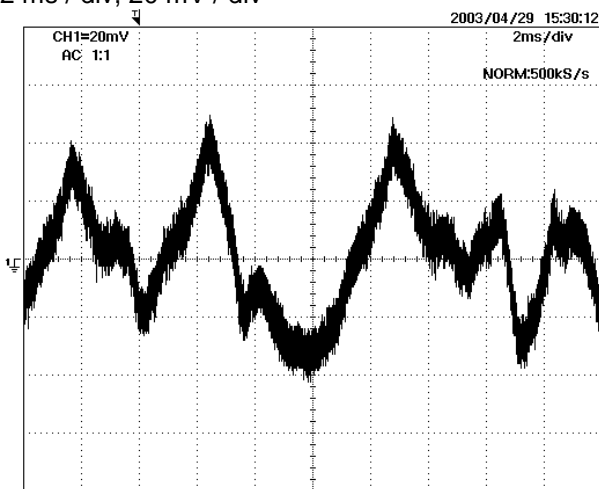


Figure 28 – 20V Rail Ripple, 230 V_{AC}, Full Load.

2 ms / div, 20 mV / div

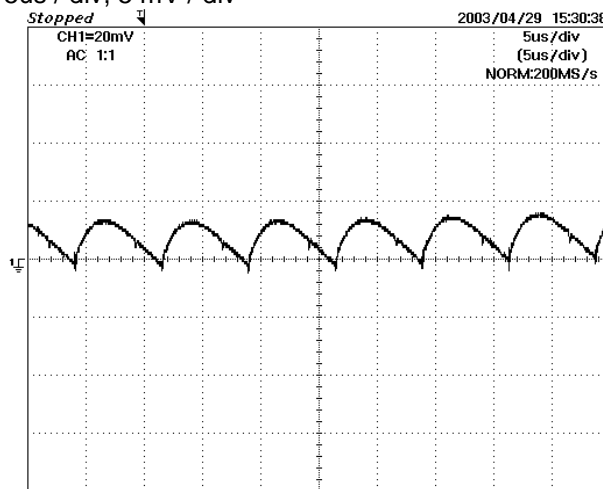


Figure 29 – 20V Rail Switching Noise, 230 V_{AC}, Full Load.

5us / div, 20 mV / div

12 Conducted EMI

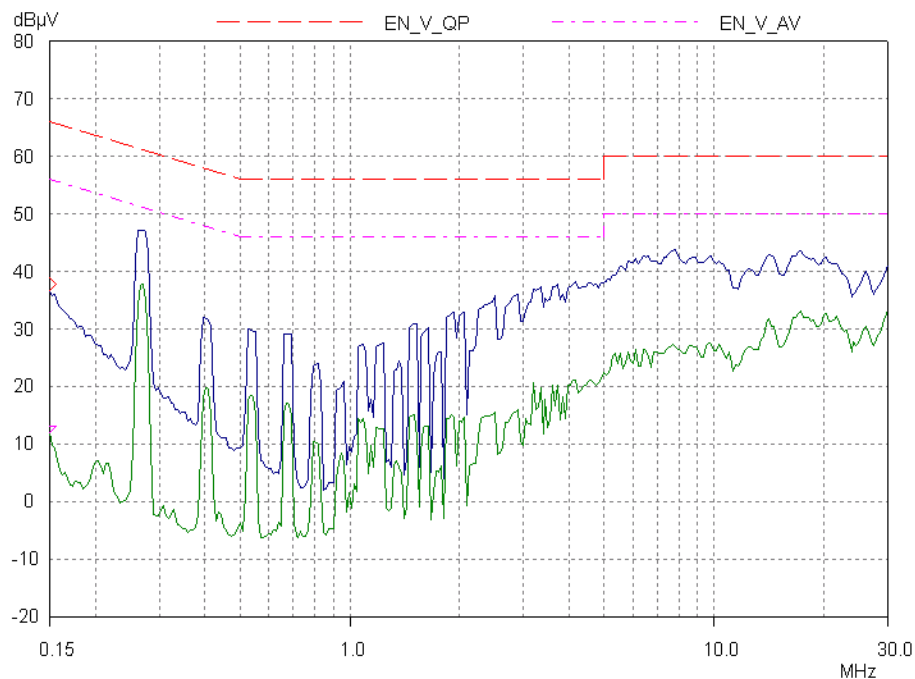


Figure 30 - Conducted EMI, Full Continuous Power, 230 V_{AC}, and EN55022 B Limits.

Output ground connected to protective earth. Worst case live/neutral measurement.

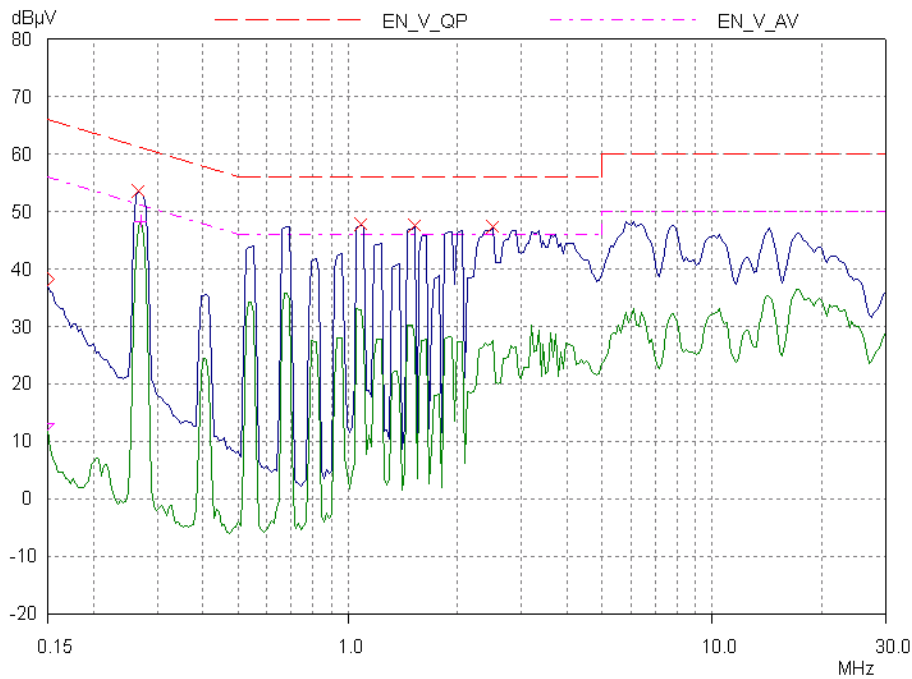


Figure 31 - Conducted EMI, Full Continuous Power, 230 V_{AC}, and EN55022 B Limits.

Output ground floating. Worst case live/neutral measurement.



13 Revision History

Date	Author	Revision	Description & changes	Reviewed
March 30, 2004	IM	1.0	First Draft Released	VC / AM

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