Design Example Report

Title	***19.3 W Wide Range Flyback Power Supply using TOP243Y***
Specification	Input: 207 – 400 VAC Outputs: +14 V / 1.2 A; +5 V / 0.5 A
Application	Oven Control
Author	Power Integrations Applications Department
Document Number	DER-105
Date	October 26, 2005
Revision	1.0

Summary and Features

- StackFET® Flyback Topology delivers full load over extremely wide input AC voltage range
- Very good Cross Regulation without using Linear Regulators
- 132 kHz Switching Frequency with jitter to reduce conducted EMI
- Auto-restart function for automatic and self-resetting open-loop, overload and short-circuit protection
- Built-in Hysteretic thermal shutdown at 135C
- EcoSmart for extremely low standby power consumption <500 mW at 265 VAC

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Table Of Contents

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.

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1 Introduction

This document is an engineering report describing a wide-range non-isolated StackFET® Flyback converter using *TOPSwitch-GX* TOP243Y.

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

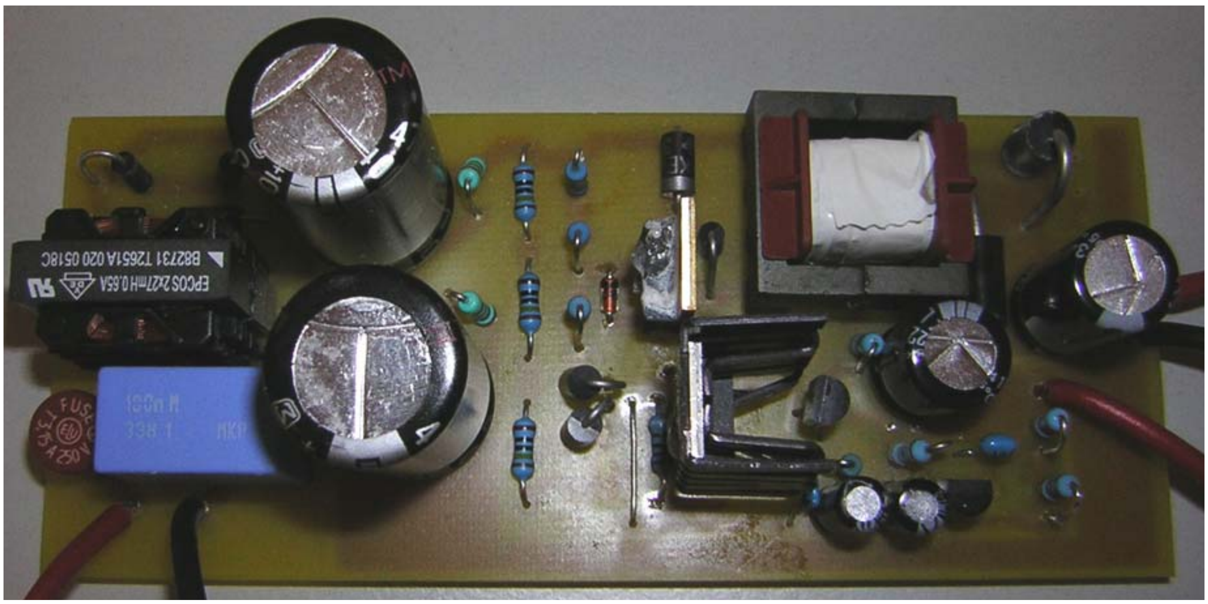

Figure 1 – Populated Circuit Board Photograph

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2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	207		400	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				0.3	W	
Output						
Output Voltage 1	V_{OUT1}	12.6	14	15.4	V	± 10%
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	20 MHz bandwidth
Output Current 1	I_{OUT1}		1.2		A	
Output Voltage 2	V_{OUT1}	4.75	5	5.25	V	± 5%
Output Ripple Voltage 2	$V_{RIPPLE1}$				mV	20 MHz bandwidth
Output Current 2	I_{OUT1}		0.5		A	
Total Output Power						
Continuous Output Power	P_{OUT}			19.3	W	
Peak Output Power	P_{OUT_PEAK}			19.3	W	
Efficiency	η	79			%	Measured at P_{OUT} (19.3 W), 25 ^{o}C
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		85	^{o}C	Free convection, sea level

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3 Schematic

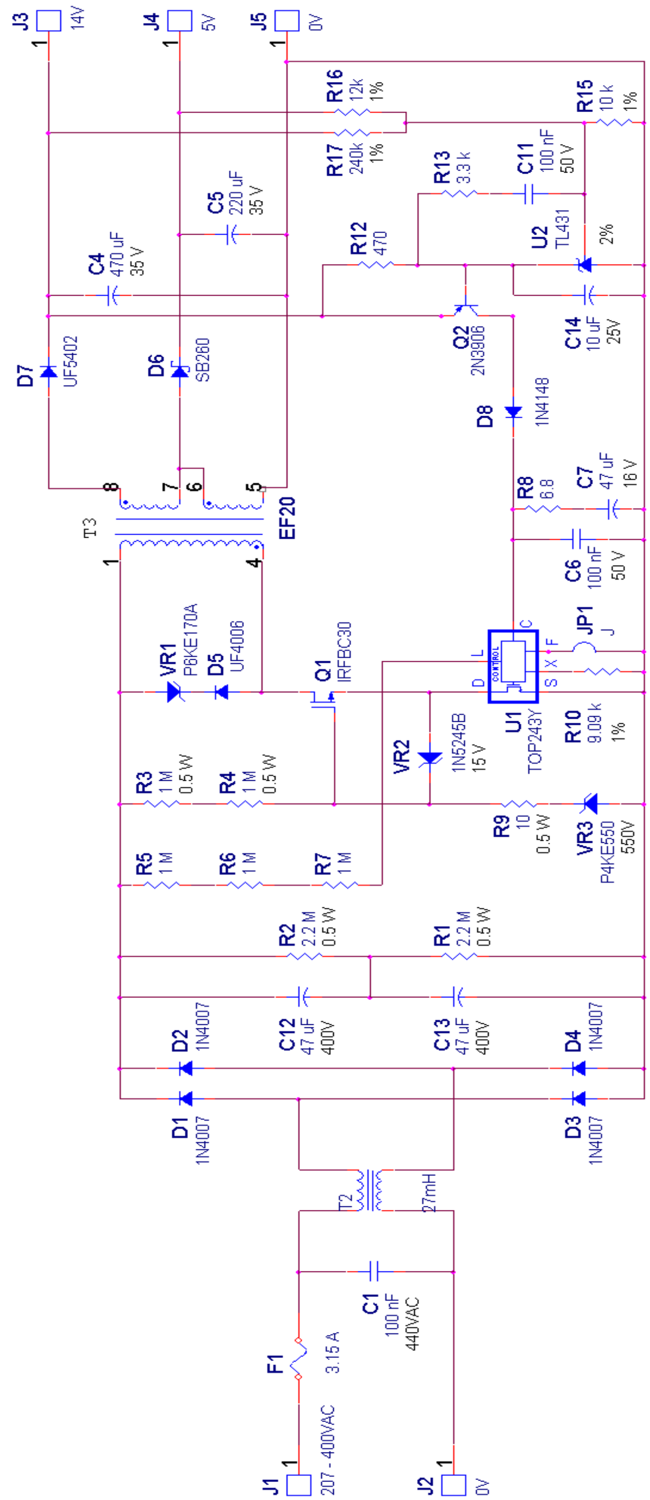

Figure 2 – Schematic

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4 Circuit Description

4.1 Input EMI Filtering

AC input power is rectified and filtered by D1-D4 to produce a DC voltage across the series stacked high voltage electrolytic capacitors C12 and C13. R1 and R2 help maintain voltage equalization across the series connected capacitors.

4.2 TOPSwitch Primary

The rectified high voltage DC is applied to the transformer T3 primary winding. The other end of the primary winding is connected to a high voltage MOSFET (Q1) that is cascade connected to the Drain of TOPSwitch-GX (U1). This configuration is called StackFet.

VR3 clamps the maximum Drain-Source voltage across TOPSwitch to less than 600 V. VR2 ensures that the maximum Gate-Source voltage of Q1 does not exceed 15 V. R3 and R4 provide bias to enhance the gate of Q1 when its Source is switched low by the Drain of U1.

VR1 and D5 clamp the leakage inductance spike to limit the effective voltage across Q1 and U1 to about 740 V pk at 400 VAC input.

There is no Bias winding necessary, because of the non-isolated topology the Bias voltage is taken from the 14V output from the secondary side.

4.3 Output Rectification

D6 and D7 along with capacitors C4 and C5 are used to rectify and filter the two output secondary windings of T3.

4.4 Output Feedback

A voltage divider consisting of resistors R17, R16 and R15 monitors the voltage on the 14 V and 5 V outputs. The resistor values are weighted so that the voltage feedback loop is controlled mostly be the 5 V output, with some contribution from the 14 V output. Sharing the voltage regulation control between the two outputs in this manner improves the cross regulation for the 14 V output at the expense of a slight change in the regulation of the 5 V output.
The voltage from R17, R16 and R15 is applied to the reference pin of the shunt regulator of U3. These resistor values and the reference voltage of U2 are used to set the output voltages of the supply. The Optocoupler usually used for isolation in the feedback circuit is replaced by a simple PNP Transistor Q2, which provides the feedback current to TOPSwitch. Note: If gain needs to be reduced, insert a ~220Ω resistor in series with Q2's emitter.

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5 PCB Layout

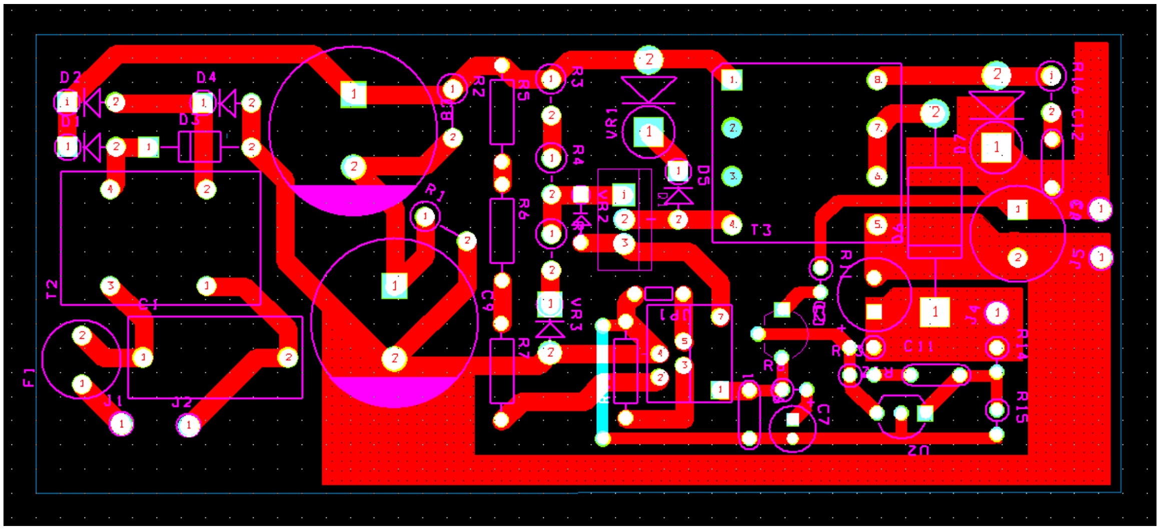

Figure 3 – Printed Circuit Layout

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6 Bill Of Materials

Item	Qty	Value	Description	Part Reference	Mfg	Mfg Part Number
1	1	100 nF	100 nF, 440VAC, Film, X2	C1	Vishay	2222 338 10104
2	1	470 uF	470 uF, 35 V, Electrolytic, Low ESR, 52 mOhm, (10 x 20)	C4	United Chemi-Con	LXZ35VB471MJ20LL
3	1	220 uF	220 uF, 35 V, Electrolytic, Low ESR, 90 mOhm, (8 x 15)	C5	United Chemi-Con	LXZ35VB221MH15LL
4	2	100 nF	100 nF, 50 V, Ceramic, X7R	C6 C11	Panasonic	ECU-S1H104KBB
5	1	47 uF	47 uF, 16 V, Electrolytic, Gen. Purpose, (5 x 11)	C7	United Chemi-Con	KME16VB47RM5X11LL
6	2	47 uF	47 uF, 400 V, Electrolytic, High Ripple, 105C	C12 C13	Panasonic	
7	1	10uF	10uF, 25V, Electrolytic, Gen. Purpose	C14	Panasonic	
8	4	1N4007	1000 V, 1 A, Rectifier, DO-41	D1 D2 D3 D4	Vishay	1N4007
9	1	UF4006	600 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	D5	Vishay	UF4006
10	1	SB260	60 V, 2 A, Schottky, DO-204AC	D6	Vishay	SB260
11	1	UF5402	200 V, 3 A, Ultrafast Recovery, 50 ns, DO-201AD	D7	Vishay	UF5402
12	1	1N4148	75 V, 300 mA, Fast Switching, DO-35	D8	Vishay	1N4148
13	1	3.15 A	3.15 A, 250V,Fast, TR5	F1	Wickman	3,701,315,041
14	1	J	Wire Jumper, Non insulated, 22 AWG, 0.3 in	JP1	Alpha	298
15	1	IRFBC30	600 V, 3.6 A, 2.2 Ohms, N-Channel, TO-220AB	Q1	International Rectifier	IRFBC30
16	1	2N3906	PNP, Small Signal BJT, 40 V, 0.2 A, TO-92	Q2	Fairchild	2N3906
17	2	2.2 M	2.2 M, 5%, 1/2 W, Carbon Film	R1 R2	Yageo	CFR-50JB-2M2
18	2	1 M	1 M, 5%, 1/2 W, Carbon Film	R3 R4	Yageo	CFR-50JB-1M0
19	3	1 M	1 M, 5%, 1/4 W, Carbon Film	R5 R6 R7	Yageo	CFR-25JB-1M0
20	1	6.8	6.8 R, 5%, 1/4 W, Carbon Film	R8	Yageo	CFR-25JB-6R8
21	1	10	10 R, 5%, 1/2 W, Carbon Film	R9	Yageo	CFR-50JB-10R
22	1	9.09 k	9.09 k, 1%, 1/4 W, Metal Film	R10	Yageo	MFR-25FBF-9K09
23	1	470	470 R, 5%, 1/4 W, Carbon Film	R12	Yageo	CFR-25JB-470R
24	1	3.3 k	3.3 k, 5%, 1/4 W, Carbon Film	R13	Yageo	CFR-25JB-3K3
25	1	10 k	10 k, 1%, 1/4 W, Metal Film	R15	Yageo	MFR-25FBF-10K0
26	1	12k	12 k, 1%, 1/4 W, Metal Film	R16	Yageo	MFR-25FBF-12K
27	1	240k	240 k, 1%, 1/4 W, Metal Film	R17	Yageo	MFR-25FBF-240K
28	1	27mH	Common Mode Choke, 27mH, 0.65A	T2	Epcos	B82731T2651A020
29	1	EF20	Bobbin EF20, 8-Pin, Horizontal	T3	Custom	
30	1	TOP243Y	TOPSwitch-GX, TOP243Y, TO220-7C	U1	Power Integrations	TOP243Y
31	1	TL431	2.495 V Shunt Regulator IC, 2%, 0 to 70C, TO-92	U2	Texas Instruments	TL431CLP
32	1	P6KE170A	170 V, 5 W, 5%, TVS, DO204AC (DO-15)	VR1	Vishay	P6KE170A
33	1	1N5245B	15 V, 5%, 500 mW, DO-35	VR2	Microsemi	1N5245B
34	1	P4KE550	200 V, 5 W, 5%, DO204AC (DO-15)	VR3	Vishay	P4KE550A
35	1	Heatsink		HS1		

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7 Transformer Specification

7.1 Electrical Diagram

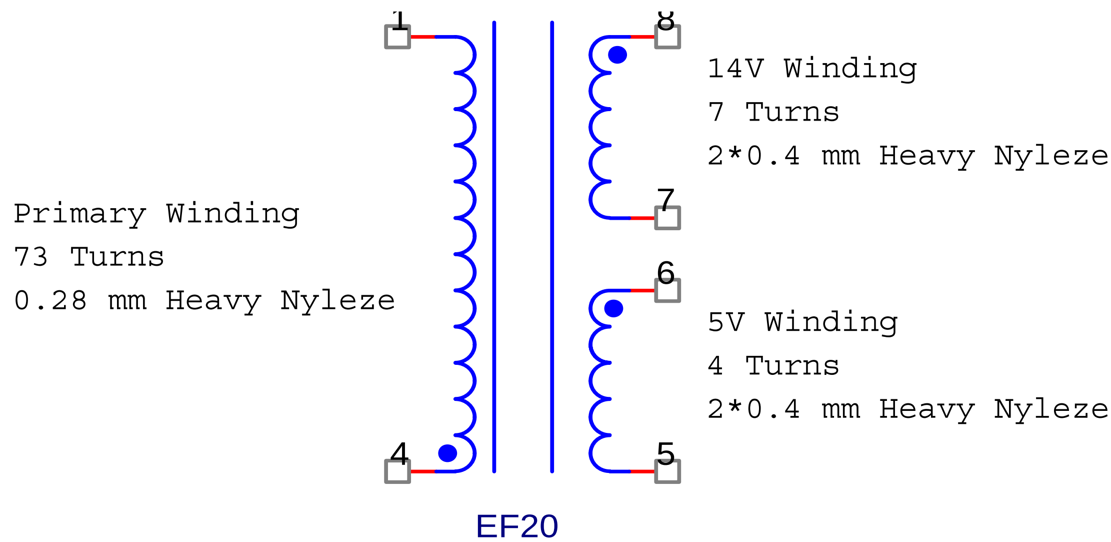

Figure 4 – Transformer Electrical Diagram

7.2 Electrical Specifications

Electrical Strength	1 second, 50 Hz, from Pins 1-4 to Pins 8-5 (Pins 7/6 shorted)	3000 VAC
Primary Inductance	Pins 1-4, all other windings open, measured at 100 kHz, 0.4 VRMS	1 mH, -0/+20%
Primary Leakage Inductance	Pins 1-4, with Pins 8-5 shorted, measured at 100 kHz, 0.4 VRMS	50 µH (Max.)

7.3 Materials

Item	Description
[1]	Core: EF20, Epcos gapped for AL = 196 nH/T^2
[2]	Bobbin: EF20 Horizontal, 8 Pins
[3]	Magnet Wire: 0.28mm
[4]	Magnet Wire: 0.4mm
[5]	Tape: 3M 1298 Polyester Film 12mm
[6]	Varnish

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7.4 Transformer Build Diagram

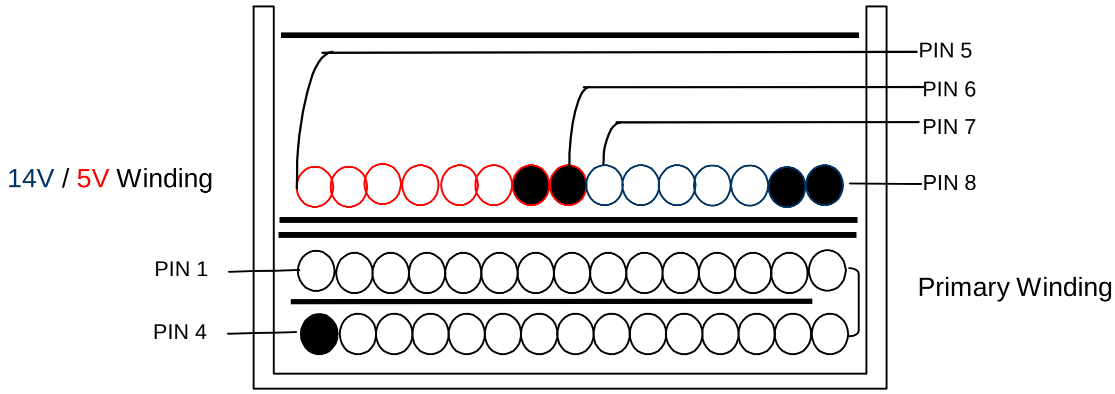

Figure 5 – Transformer Build Diagram

7.5 Transformer Construction

Primary	Start at Pin 4. Wind 37 turns of item [3] in approximately 1 layer. Use one layer of item [5] for basic insulation. Wind remaining 36 primary turns, finish on Pin1.
Basic Insulation	Use two layers of item [5] for basic insulation.
Secondary Windings	Start at Pin 8. Wind 7 bifilar turns of item [4]. Finish on Pin 7. Start at Pin 6. Wind 4 bifilar turns of item [4] in the same layer. Finish on Pin 5. Spread turns evenly across bobbin.
Outer Wrap	Wrap windings with 3 layers of tape [item [5].
Final Assembly	Assemble and secure core halves so that the tape wrapped E core is at the bottom of the transformer. Varnish impregnate (item [6]).

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8 Transformer Spreadsheets

	INPUT	INFO	OUTPUT	UNIT	
ENTER APPLICATION VARIABLES					
VACMIN	207			Volts	
VACMAX	400			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	5			Volts	Output Voltage (main)
PO	19.3			Watts	Output Power
n	0.7				Efficiency Estimate
Z	0.5				Loss Allocation Factor
VB	12			Volts	Bias Voltage
tC	3			mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	23.5			uFarads	Input Filter Capacitor
ENTER TOPSWITCH-GX VARIABLES					
TOP-GX	**top243**			*Universal*	*115 Doubled/230V*
Chosen Device		*TOP243*	*Power Out*	*30W*	*45W*
KI	0.85				External Ilimit reduction factor (KI=1.0 for default ILIMIT, KI <1.0 for lower ILIMIT)
ILIMITMIN			*0.689*	Amps	Use 1% resistor in setting external ILIMIT
ILIMITMAX			*0.842*	Amps	Use 1% resistor in setting external ILIMIT
Frequency (F)=132kHz, (H)=66kHz	**F**				Full (F) frequency option - 132kHz
fS			*132000*	Hertz	TOPSwitch-GX Switching Frequency: Choose between 132 kHz and 66 kHz
fSmin			*124000*	Hertz	TOPSwitch-GX Minimum Switching Frequency
fSmax			*140000*	Hertz	TOPSwitch-GX Maximum Switching Frequency
VOR	100			Volts	Reflected Output Voltage
VDS	10			Volts	TOPSwitch on-state Drain to Source Voltage
VD	0.5			Volts	Output Winding Diode Forward Voltage Drop
VDB	0.7			Volts	Bias Winding Diode Forward Voltage Drop
KP	0.8				Ripple to Peak Current Ratio (0.4 < KRP < 1.0 : 1.0< KDP<6.0)
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EF20**				
Core		*EF20*		*P/N:*	PC40EF20-Z
Bobbin		*EF20_BOBBIN*		*P/N:*	*
AE			0.335	cm^2	Core Effective Cross Sectional Area
LE			4.49	cm	Core Effective Path Length
AL			1570	nH/T^2	Ungapped Core Effective Inductance
BW			12.2	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	4				Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			263	Volts	Minimum DC Input Voltage
VMAX			566	Volts	Maximum DC Input Voltage
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.28		Maximum Duty Cycle
IAVG			0.10	Amps	Average Primary Current
IP			0.62	Amps	Peak Primary Current
IR			0.49	Amps	Primary Ripple Current
IRMS			0.21	Amps	Primary RMS Current

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TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1035	uHenries	Primary Inductance
NP			73		Primary Winding Number of Turns
NB			9		Bias Winding Number of Turns
ALG			196	nH/T^2	Gapped Core Effective Inductance
BM			2621	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			3576	Gauss	Peak Flux Density (BP<4200)
BAC			1048	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1675		Relative Permeability of Ungapped Core
LG			0.19	mm	Gap Length (Lg > 0.1 mm)
BWE			24.4	mm	Effective Bobbin Width
OD			0.34	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.28	mm	Bare conductor diameter
AWG			30	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			102	Cmils	Bare conductor effective area in circular mils
CMA			482	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			11.21	Amps	Peak Secondary Current
ISRMS			6.10	Amps	Secondary RMS Current
IO			3.86	Amps	Power Supply Output Current
IRIPPLE			4.73	Amps	Output Capacitor RMS Ripple Current
CMS			1221	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			3.05	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			1.07	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN		***Warning***	796	Volts	!!! REDUCE DRAIN VOLTAGE Vdrain<680, reduce VACMAX, reduce VOR
PIVS			36	Volts	Output Rectifier Maximum Peak Inverse Voltage
PIVB			84	Volts	Bias Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1	5		5	Volts	Output Voltage
IO1	0.5		0.5	Amps	Output DC Current
PO1			2.50	Watts	Output Power
VD1	0.6		0.6	Volts	Output Diode Forward Voltage Drop
NS1			4.07		Output Winding Number of Turns
ISRMS1			0.791	Amps	Output Winding RMS Current
IRIPPLE1			0.61	Amps	Output Capacitor RMS Ripple Current
PIVS1			37	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1			158	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			28	AWG	Wire Gauge (Rounded up to next larger standard AWG value)

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DIAS1			0.32	mm	Minimum Bare Conductor Diameter
ODS1			3.00	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output					
VO2	14			Volts	Output Voltage
IO2	1.2			Amps	Output DC Current
PO2			16.80	Watts	Output Power
VD2	1			Volts	Output Diode Forward Voltage Drop
NS2			10.91		Output Winding Number of Turns
ISRMS2			1.897	Amps	Output Winding RMS Current
IRIPPLE2			1.47	Amps	Output Capacitor RMS Ripple Current
PIVS2			99	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS2			379	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS2			24	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS2			0.51	mm	Minimum Bare Conductor Diameter
ODS2			1.12	mm	Maximum Outside Diameter for Triple Insulated Wire

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9 Performance Data

9.1 Efficiency

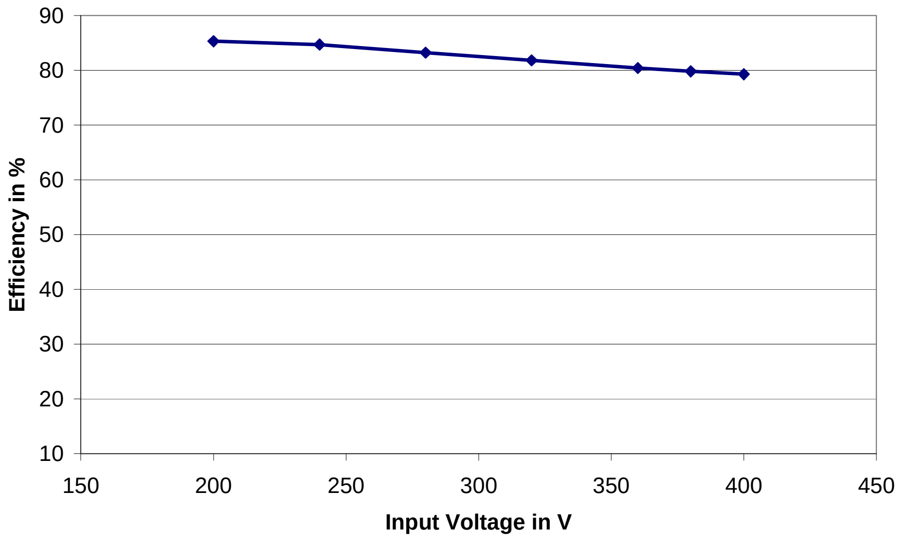

Figure 6 – Efficiency vs. Input Voltage, Room Temperature, 50 Hz.

9.2 No-load Input Power

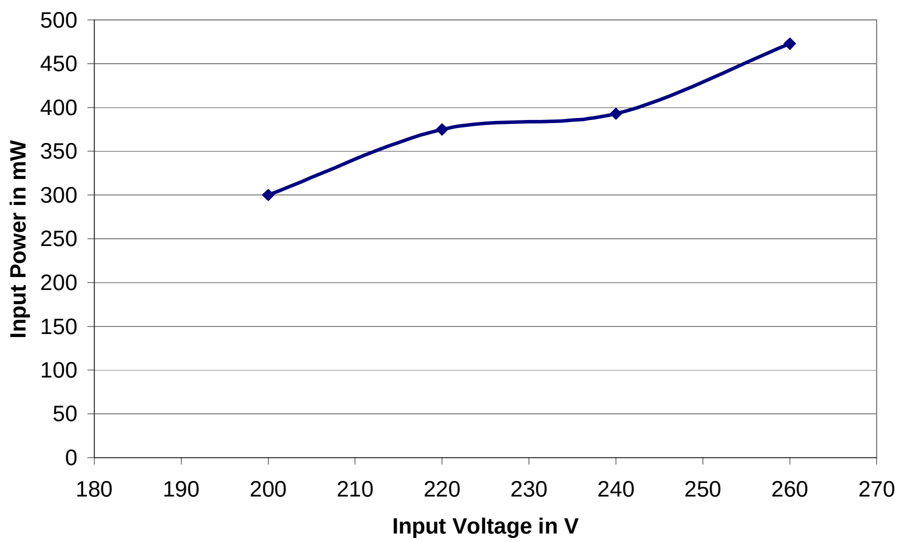

Figure 7 – Zero Load Input Power vs. Input Line Voltage, Room Temperature, 50 Hz.

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9.3 Regulation

9.3.1 Load

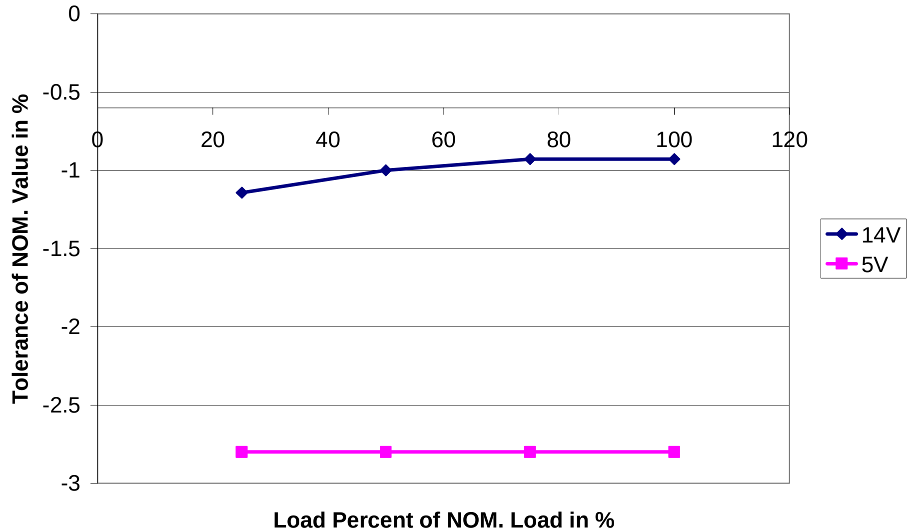

Figure 8 – Load Regulation, Room Temperature

9.3.2 Line

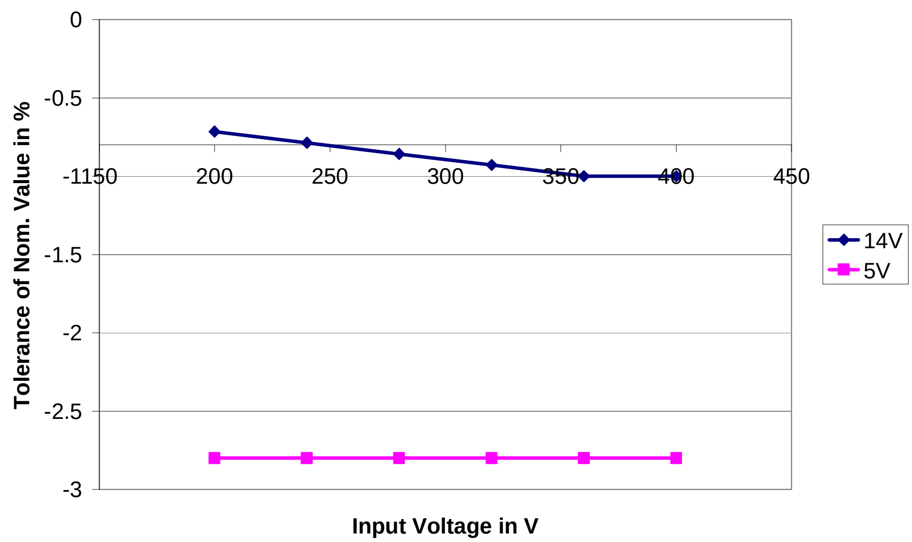

Figure 9 – Line Regulation, Room Temperature, Full Load

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10 Thermal Performance

Temperature (°C)			
Item	**200 VAC**	**300 VAC**	**400 VAC**
Ambient	29	29	29
MOSFET (Q1)	46	44.8	50.8
***TOPSwitch* (U1)**	60.5	52.6	52.6
Transformer (T3)	61.8	63	63.6
Rectifier (D7)	79.9	73.6	72.4

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11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

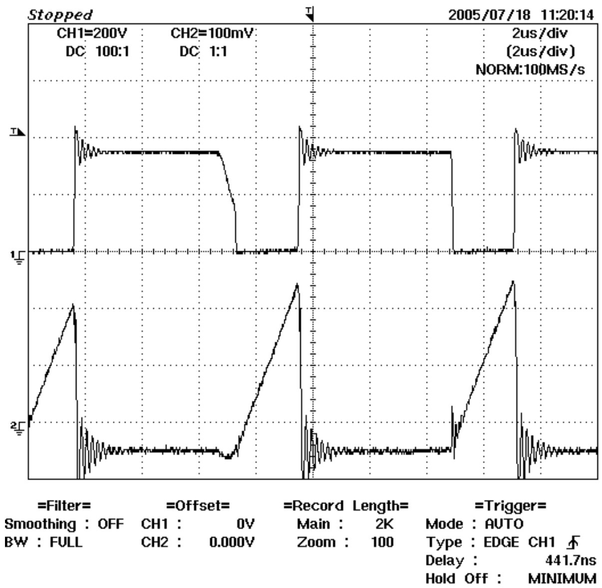

Figure 10 – 200 VAC, Full Load
Upper: I_{DRAIN}, 0.2 A / div
Lower: V_{DRAIN}, 200 V, 2 µs / div

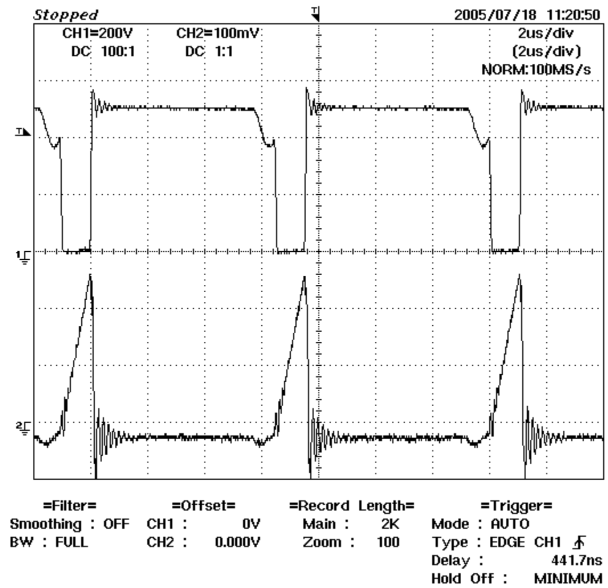

Figure 11 – 400 VAC, Full Load
Upper: I_{DRAIN}, 0.2 A / div
Lower: V_{DRAIN}, 200 V / div

11.2 Output Voltage Start-up Profile

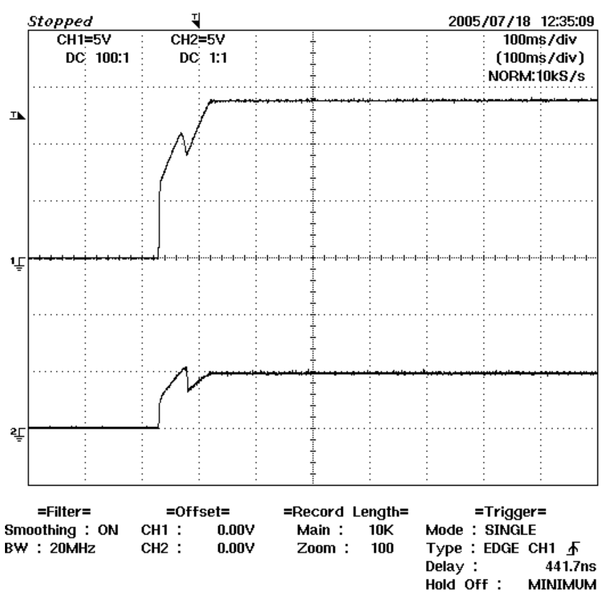

Figure 12 – Start-up Profile, 200 VAC
100 ms / div. Upper: 12 V, Lower: 5 V

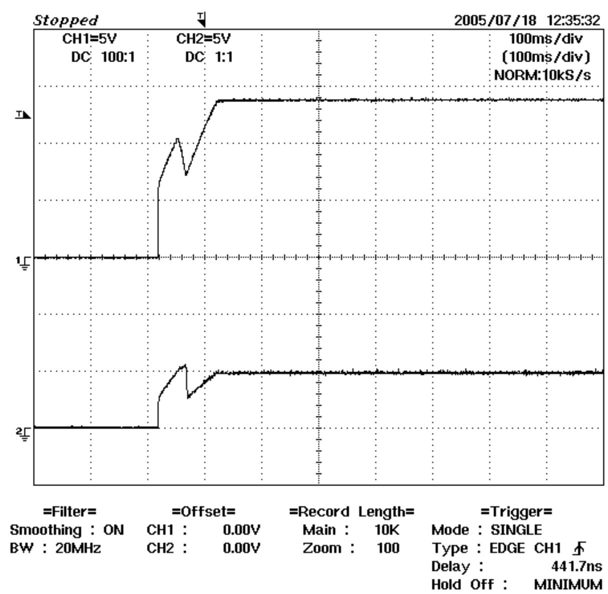

Figure 13 – Start-up Profile, 400 VAC
100 ms / div. Upper: 12 V, Lower: 5 V

11.3 Drain Voltage and Current Start-up Profile

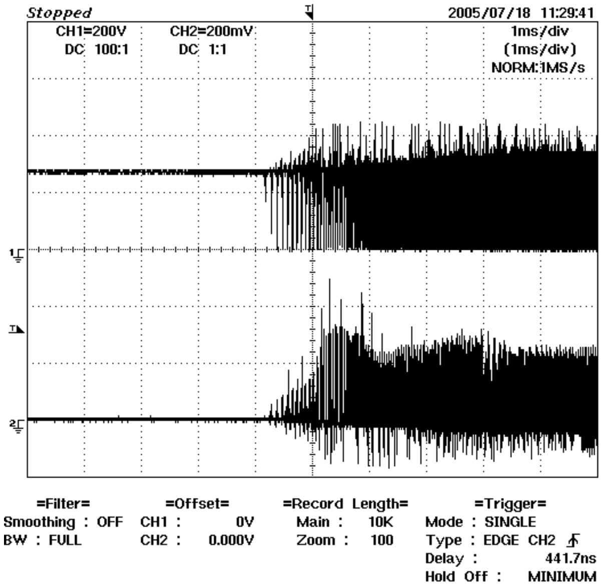

Figure 14 – 200 VAC Input and Maximum Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V & 1 ms / div.

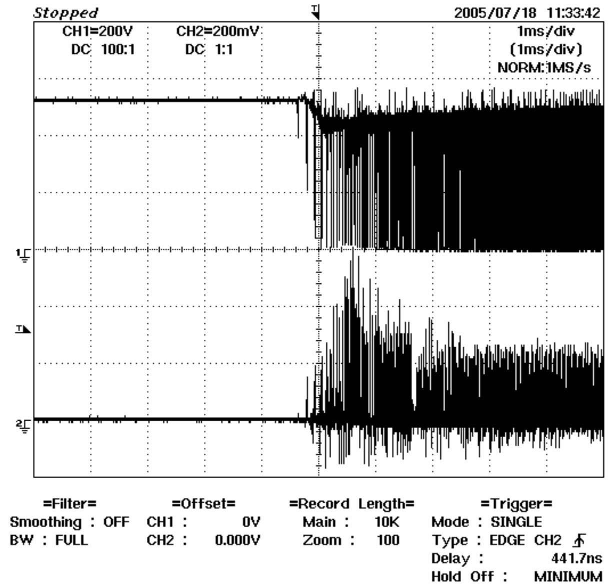

Figure 15 – 400 VAC Input and Maximum Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 200 V & 1 ms / div.

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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.

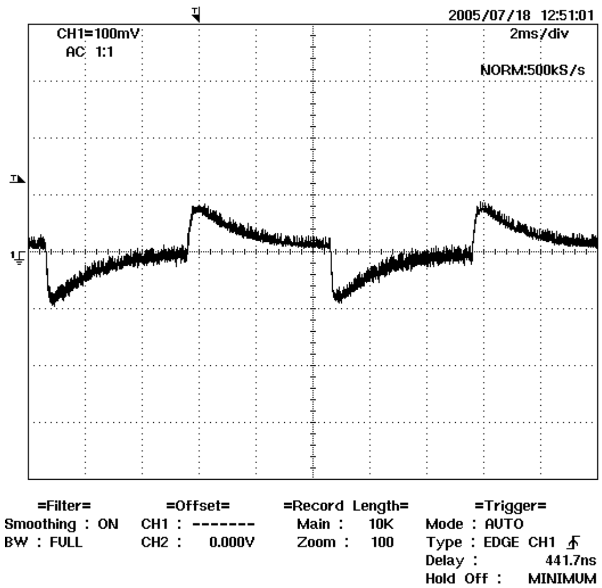

Figure 16 – Transient Response, 200 VAC, 75-100-75% Load Step
5 V Output Voltage
100 mV, 5 ms/ div.

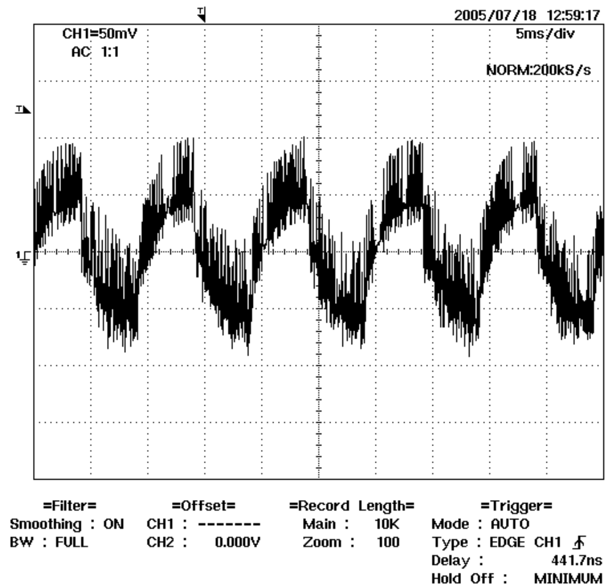

Figure 17 – Transient Response, 200 VAC, 75-100-75% Load Step
14 V Output Voltage
100 mV, 5ms / div.

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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 18 and Figure 19.

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).***

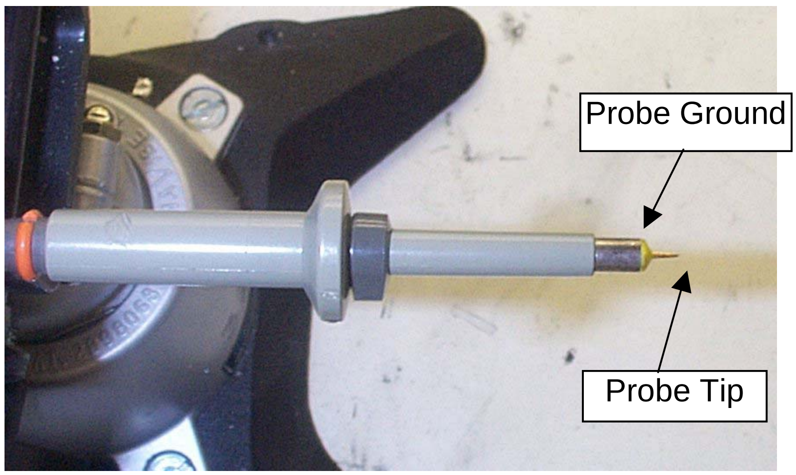

Figure 18 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

Figure 19 – 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

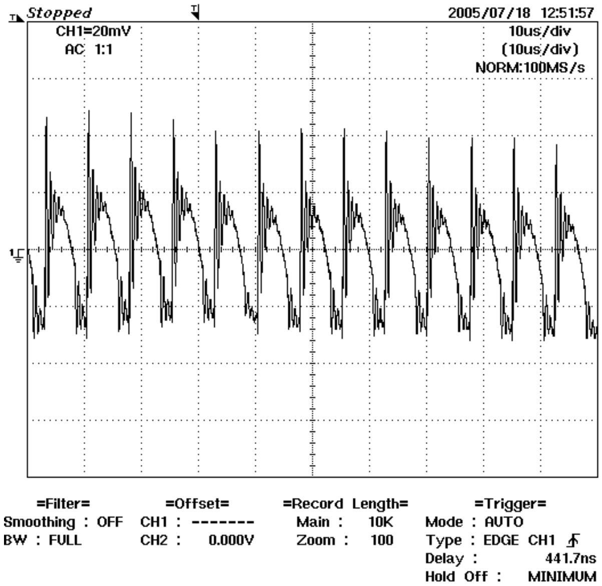

Figure 20 – 5 V Ripple, 200 VAC, Full Load
10 us, 20 mV / div

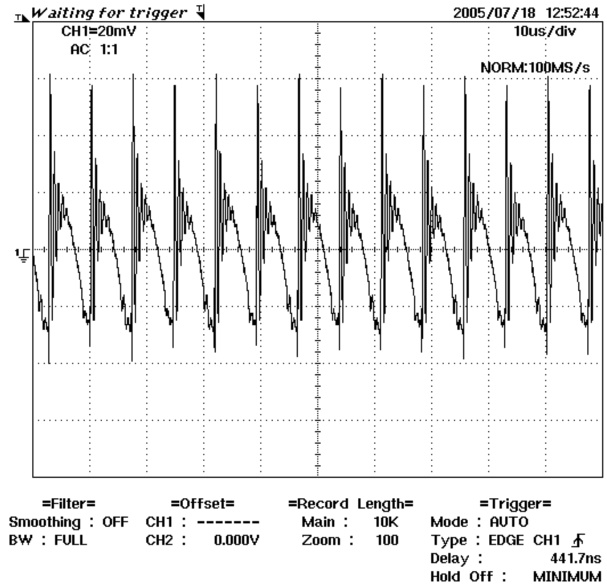

Figure 21 – 5 V Ripple, 400 VAC, Full Load
10 us, 20 mV / div

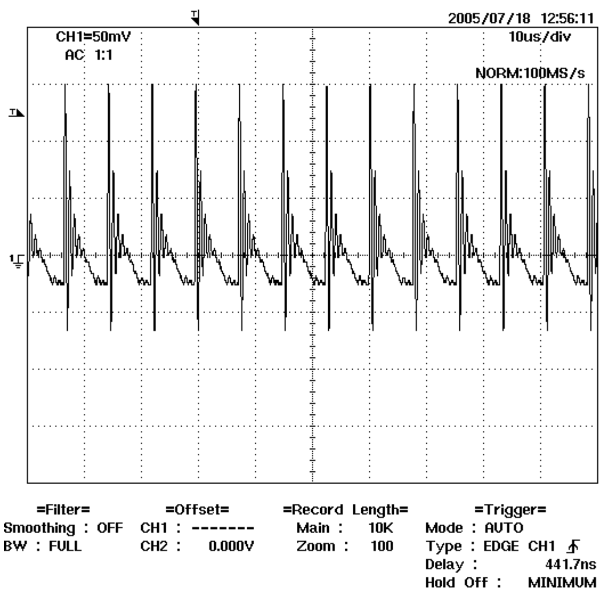

Figure 22 – 14 V Ripple, 200 VAC, Full Load
2 ms, 50 mV /div

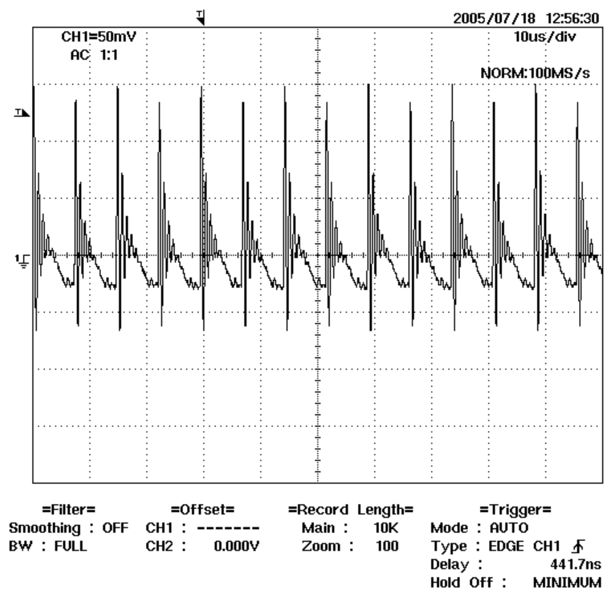

Figure 23 – 14 V Ripple, 400 VAC, Full Load
2 ms, 50 mV /div

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12 Conducted EMI

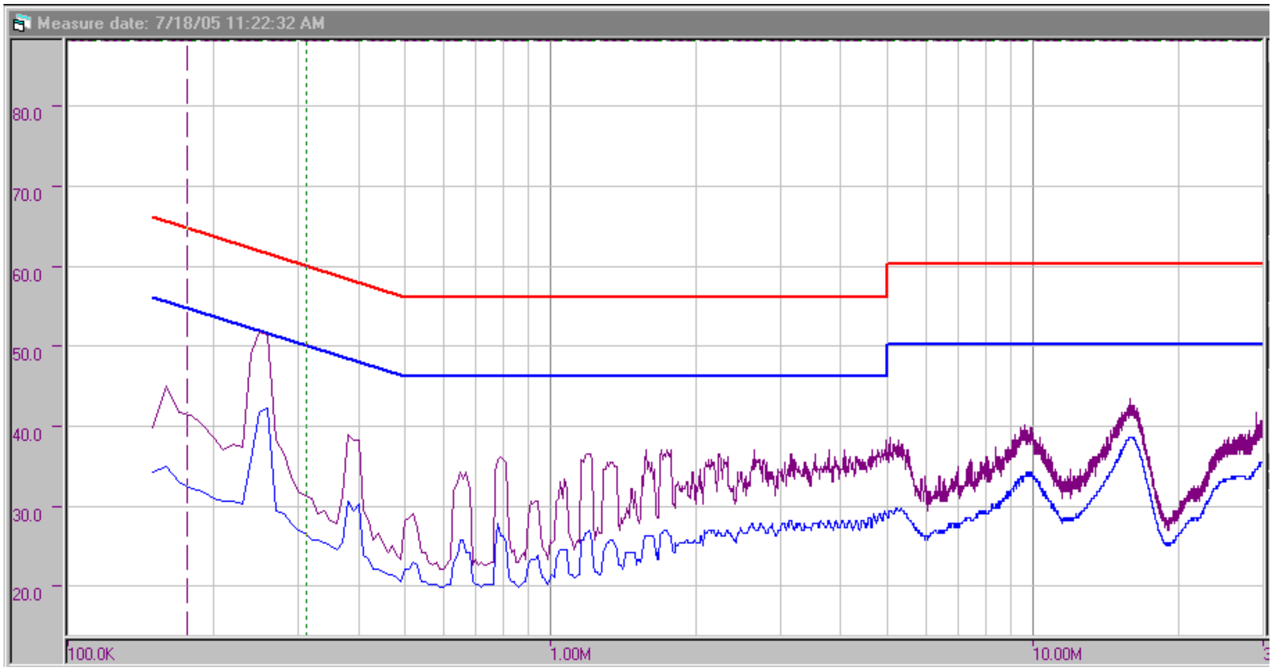

Figure 24 – Conducted EMI, Maximum Steady State Load, 200 VAC, 50 Hz, and EN55022 B Limits

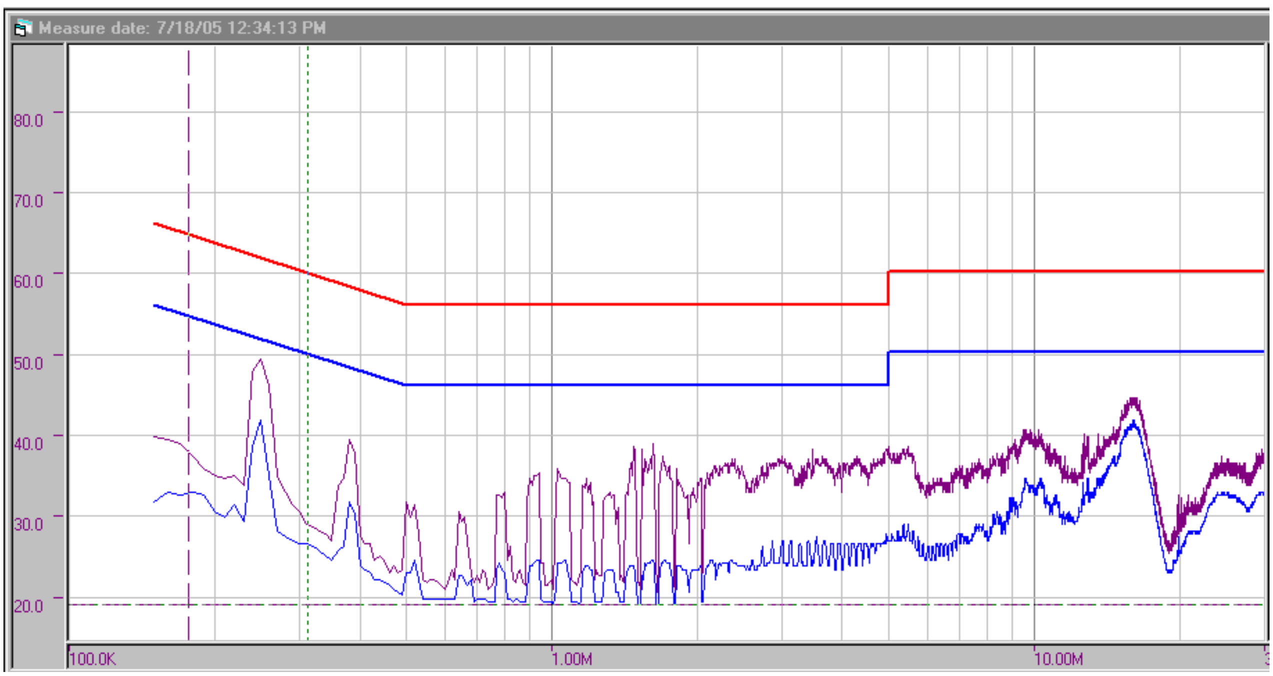

Figure 25 – Conducted EMI, Maximum Steady State Load, 300 VAC, 50 Hz, and EN55022 B Limits

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
10-26-05	HM	1.0	Initial Release	KM/JC/VC

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