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## Design Example Report

<b>Title</b>	<b><i>19.3 W Wide Range Flyback Power Supply Using TOPSwitch™-GX TOP243Y</i></b>
<b>Specification</b>	207 VAC – 400 VAC Input; 14 V / 1.2 A and 5 V / 0.5 A Outputs
<b>Application</b>	Oven Control
<b>Author</b>	Applications Engineering Department
<b>Document Number</b>	DER-105
<b>Date</b>	July 23, 2012
<b>Revision</b>	1.1

### 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 135 °C
- EcoSmart™ for extremely low standby power consumption <500 mW at 265 VAC

The products and applications illustrated herein (including circuits external to the products and transformer construction) may be covered by one or more U.S. and foreign patents or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at [www.powerint.com](http://www.powerint.com).

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### Important Notes:

Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolated source to provide power to the prototype board.

Design Reports contain a power supply design specification, schematic, bill of materials, and transformer documentation. Performance data and typical operation characteristics are included. Typically only a single prototype has been built.



## 1 Introduction

This document is an engineering report 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.

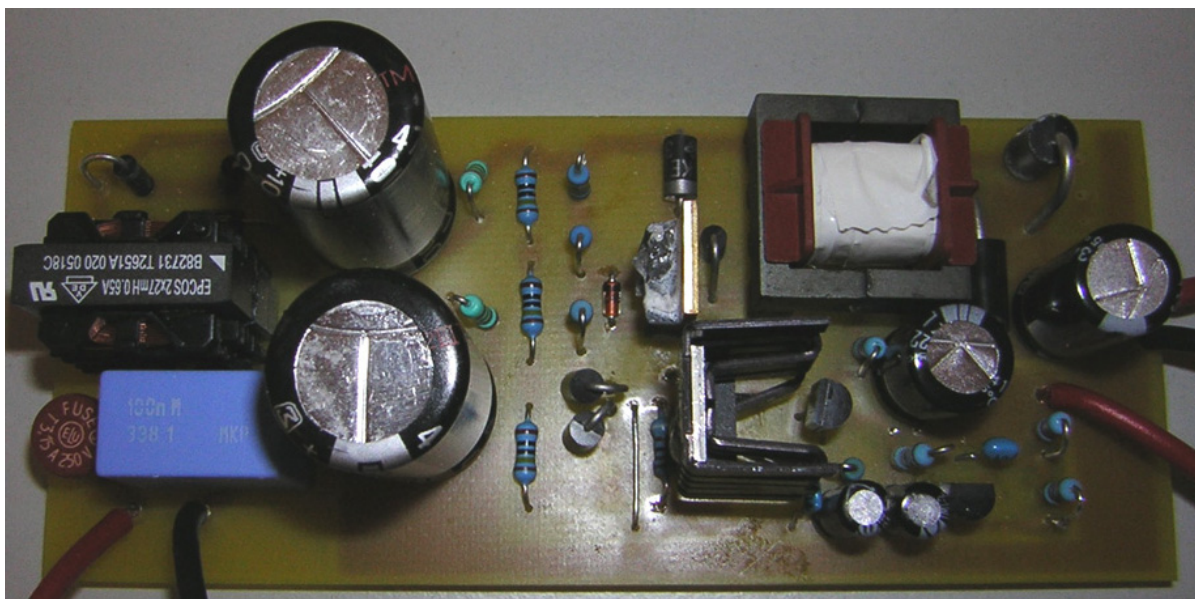


Figure 1 – Populated Circuit Board Photograph.



## 2 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
<b>Input</b>						
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	
<b>Output</b>						
Output Voltage 1	$V_{OUT1}$	12.6	14	15.4	V	±10% 20 MHz bandwidth
Output Ripple Voltage 1	$V_{RIPPLE1}$				mV	
Output Current 1	$I_{OUT1}$		1.2		A	±5% 20 MHz bandwidth
Output Voltage 2	$V_{OUT2}$	4.75	5	5.25	V	
Output Ripple Voltage 2	$V_{RIPPLE2}$				mV	
Output Current 2	$I_{OUT2}$		0.5		A	
<b>Total Output Power</b>						
Continuous Output Power	$P_{OUT}$			19.3	W	
Peak Output Power	$P_{OUT\_PEAK}$			19.3	W	
<b>Efficiency</b>	$\eta$	79			%	Measured at $P_{OUT}$ (19.3 W), 25 °C
<b>Environmental</b>						
Conducted EMI		Meets CISPR22B / EN55022B				1.2/50 $\mu$ s surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 $\Omega$ Common Mode: 12 $\Omega$
Safety		Designed to meet IEC950, UL1950 Class II				
Surge		4			kV	
Surge		3			kV	100 kHz ring wave, 500 A short circuit current, differential and common mode
Ambient Temperature	$T_{AMB}$	0		85	°C	Free convection, sea level



### 3 Schematic

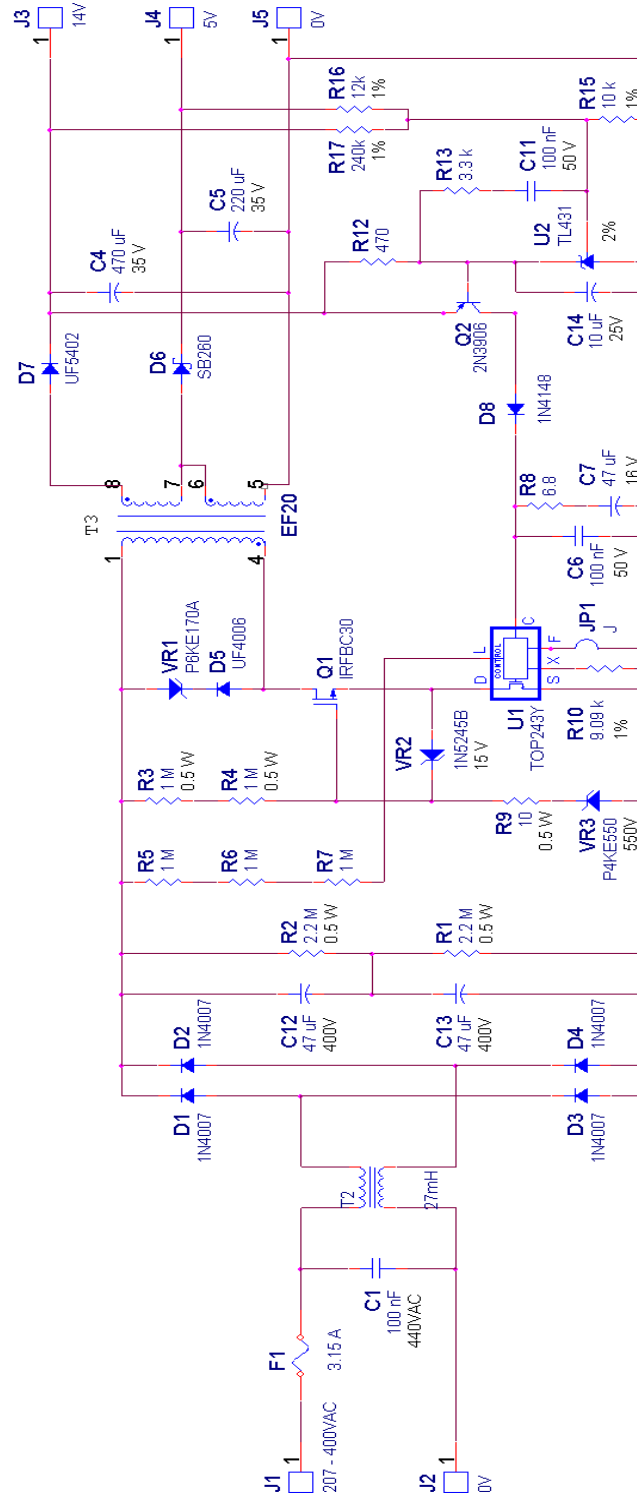


Figure 2 – Schematic.



## 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.

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

Zener diode VR1 and D5 clamp the leakage inductance spike to limit the effective voltage across Q1 and U1 to about 740 V peak at 400 VAC input. It is recommended that the maximum voltage ( $V_{DS}$ ) across U1 is maintained to below 80% of the  $BV_{DSS}$  rating of the device.

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

### 4.3 Output Rectification

Diode 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 by 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-GX. Note: If gain needs to be reduced, insert a  $\sim 220 \Omega$  resistor in series with Q2's emitter.



## 5 PCB Layout

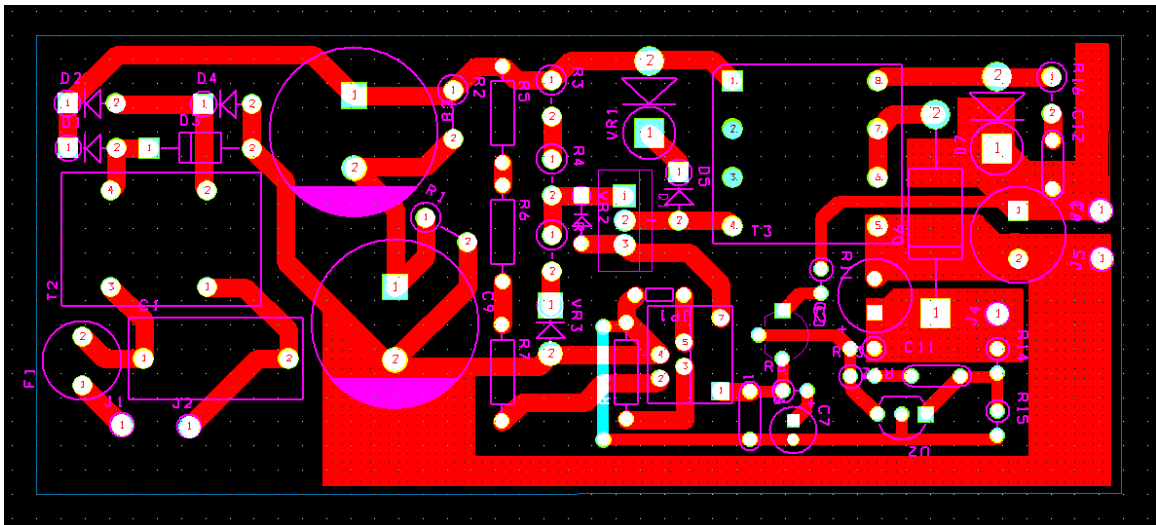


Figure 3 – Printed Circuit Layout.



## 6 Bill of Materials

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





## 7 Transformer Specification

### 7.1 Electrical Diagram

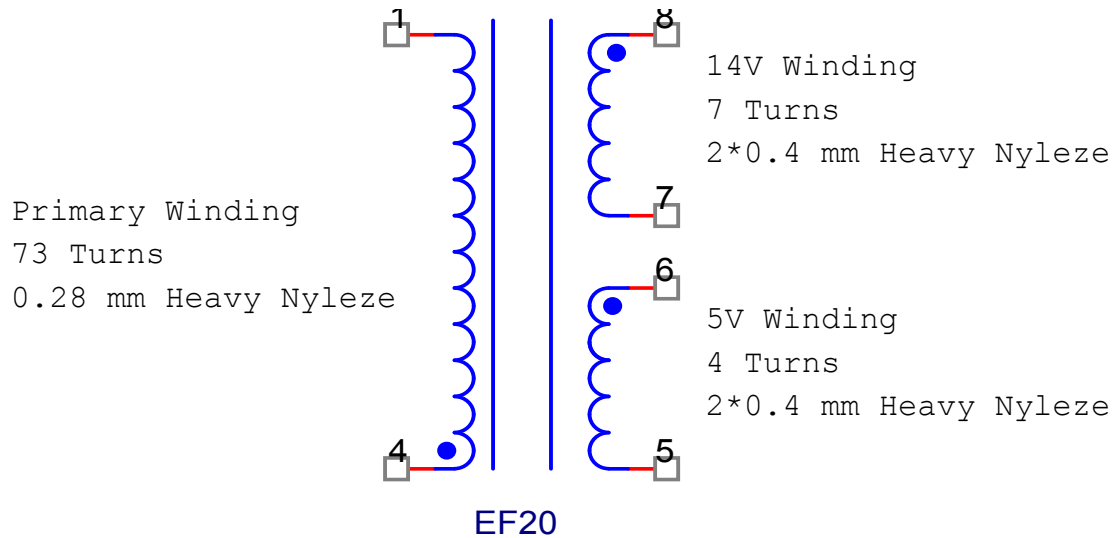


Figure 4 – Transformer Electrical Diagram

### 7.2 Electrical Specifications

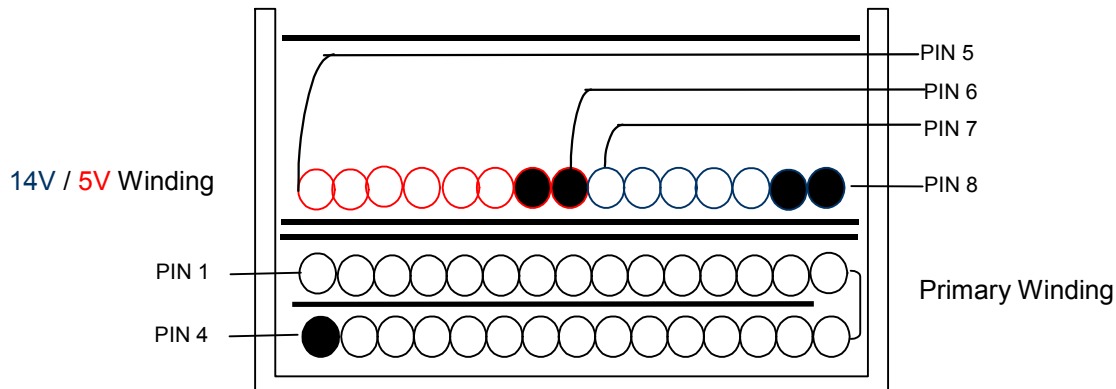
<b>Electrical Strength</b>	1 second, 50 Hz, from pins 1-4 to pins 8-5 (pins 7/6 shorted).	3000 VAC
<b>Primary Inductance</b>	Pins 1-4, all other windings open, measured at 100 kHz, 0.4 V <sub>RMS</sub> .	1 mH, -0/+20%
<b>Primary Leakage Inductance</b>	Pins 1-4, with Pins 8-5 shorted, measured at 100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

### 7.3 Materials

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



**7.4 Transformer Build Diagram**



**Figure 5 – Transformer Build Diagram.**

**7.5 Transformer Construction**

<b>Primary</b>	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 pin 1.
<b>Basic Insulation</b>	Use two layers of item [5] for basic insulation.
<b>Secondary Windings</b>	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.
<b>Outer Wrap</b>	Wrap windings with 3 layers of tape [item [5]].
<b>Final Assembly</b>	Assemble and secure core halves so that the tape wrapped E core is at the bottom of the transformer. Varnish impregnate (item [6]).



## 8 Transformer Design Spreadsheet

	INPUT	INFO	OUTPUT	UNIT	
<b>ENTER APPLICATION VARIABLES</b>					
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
$\eta$	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
<b>ENTER TOPSWITCH-GX VARIABLES</b>					
<b>TOP-GX</b>	<b>top243</b>			<i>Universal</i>	<i>115 Doubled/230V</i>
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	<b>F</b>				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)
<b>ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES</b>					
<b>Core Type</b>	<b>EF20</b>				
Core		EF20		P/N:	PC40EF20-Z
Bobbin		EF20_BOBB IN		P/N:	*
AE			0.335	cm <sup>2</sup>	Core Effective Cross Sectional Area
LE			4.49	cm	Core Effective Path Length
AL			1570	nH/T <sup>2</sup>	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
<b>DC INPUT VOLTAGE PARAMETERS</b>					
VMIN			263	Volts	Minimum DC Input Voltage
VMAX			566	Volts	Maximum DC Input Voltage
<b>CURRENT WAVEFORM SHAPE PARAMETERS</b>					
DMAX			0.28		Maximum Duty Cycle
I <sub>AVG</sub>			0.10	Amps	Average Primary Current
I <sub>P</sub>			0.62	Amps	Peak Primary Current
I <sub>R</sub>			0.49	Amps	Primary Ripple Current
I <sub>RMS</sub>			0.21	Amps	Primary RMS Current



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		<b>Warning</b>	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)
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



## 9 Performance Data

### 9.1 Efficiency

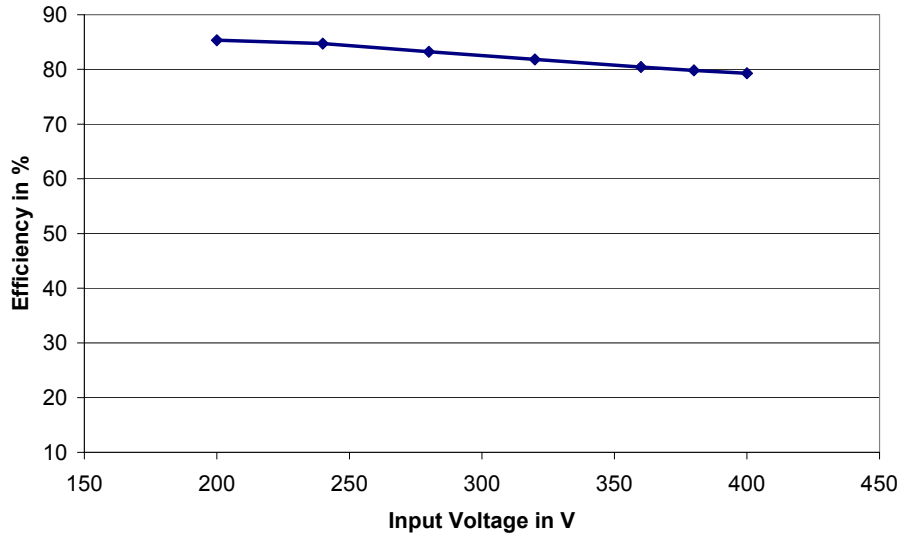


Figure 6 – Efficiency vs. Input Voltage, Room Temperature, 50 Hz.

### 9.2 No-load Input Power

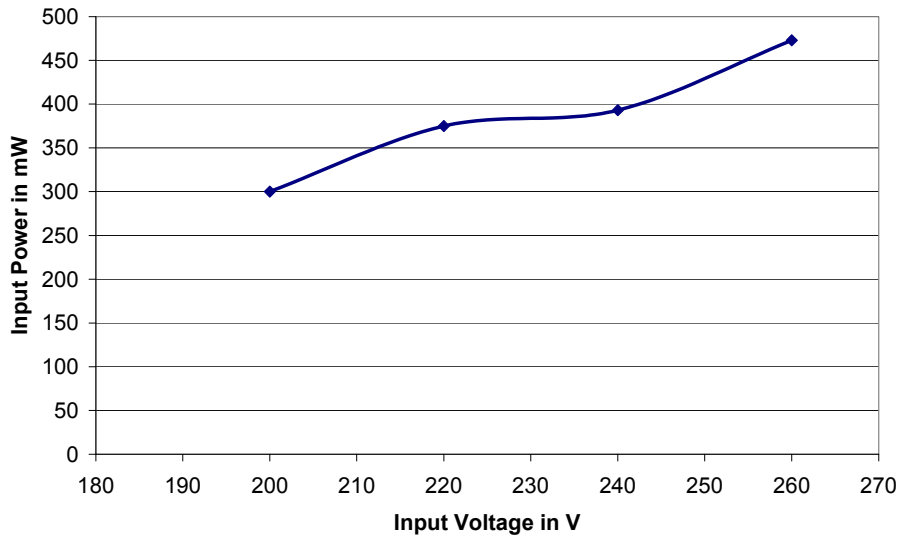


Figure 7 – Zero Load Input Power vs. Input Line Voltage, Room Temperature, 50 Hz.



### 9.3 Regulation

#### 9.3.1 Load

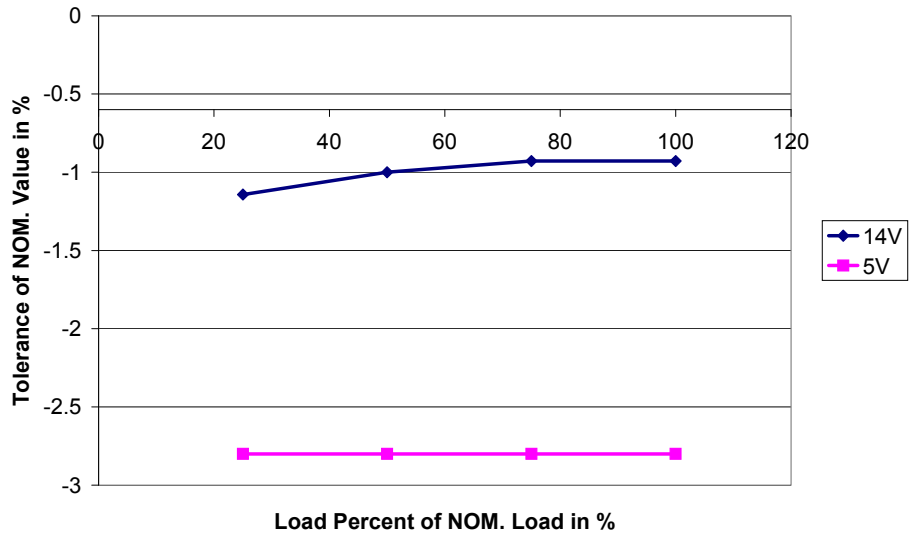


Figure 8 – Load Regulation, Room Temperature.

#### 9.3.2 Line

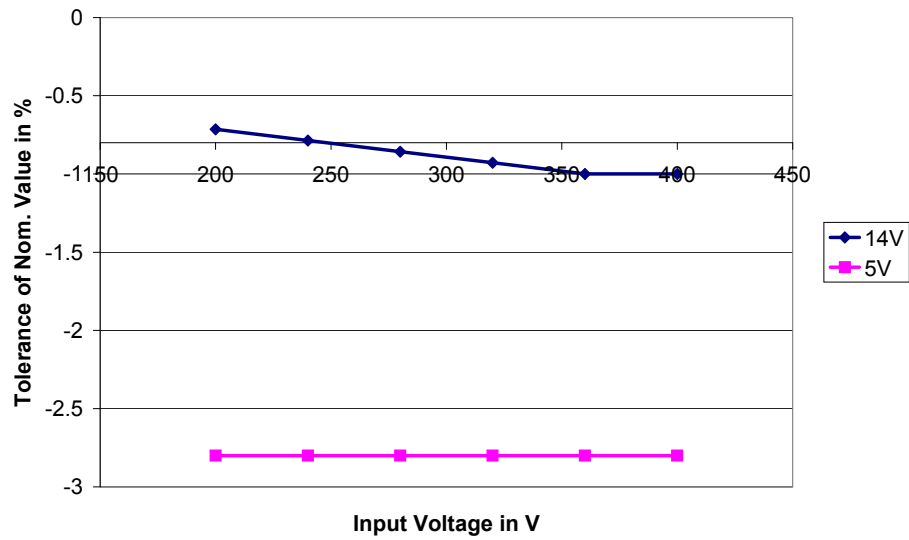


Figure 9 – Line Regulation, Room Temperature, Full Load.



## 10 Thermal Performance

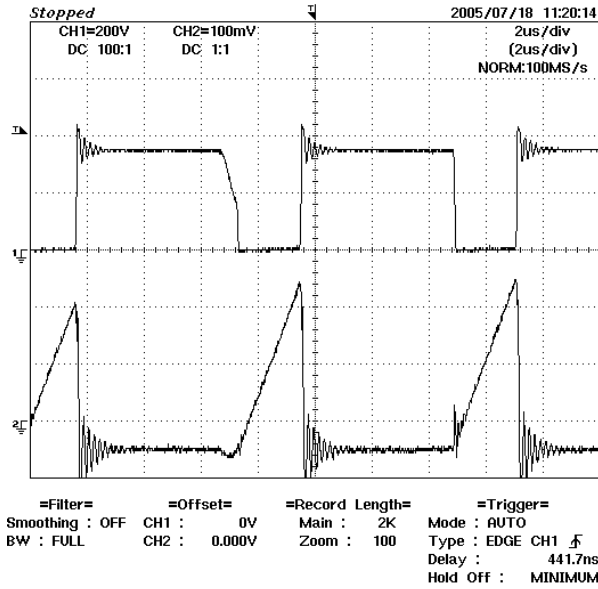
Temperature (°C)			
Item	200 VAC	300 VAC	400 VAC
Ambient	29	29	29
MOSFET (Q1)	46	44.8	50.8
TOPSwitch-GX (U1)	60.5	52.6	52.6
Transformer (T3)	61.8	63	63.6
Rectifier (D7)	79.9	73.6	72.4



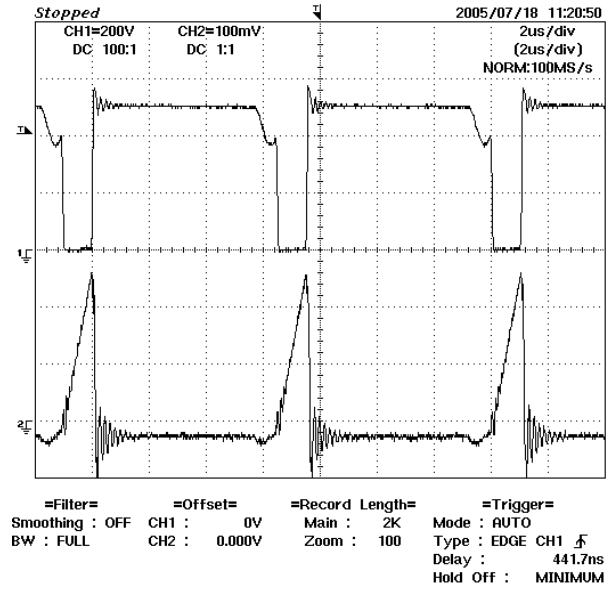


## 11 Waveforms

### 11.1 Drain Voltage and Current, Normal Operation

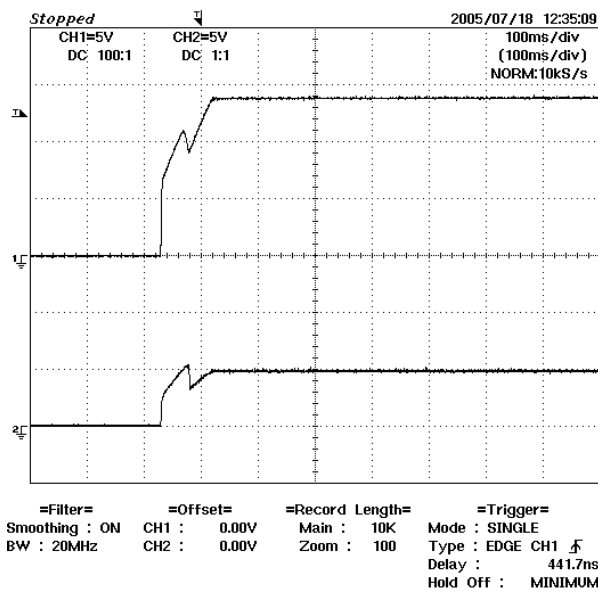


**Figure 10 – 200 VAC, Full Load.**  
 Upper:  $I_{DRAIN}$ , 0.2 A / div.  
 Lower:  $V_{DRAIN}$ , 200 V, 2  $\mu$ s / div.

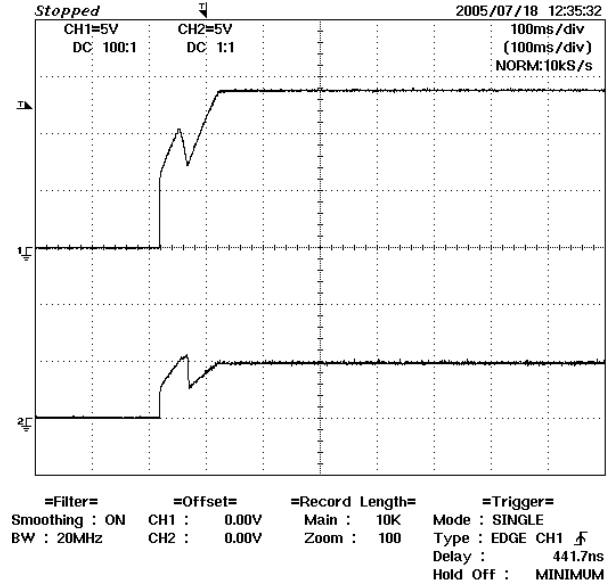


**Figure 11 – 400 VAC, Full Load.**  
 Upper:  $I_{DRAIN}$ , 0.2 A / div.  
 Lower:  $V_{DRAIN}$ , 200 V / div.

### 11.2 Output Voltage Start-up Profile



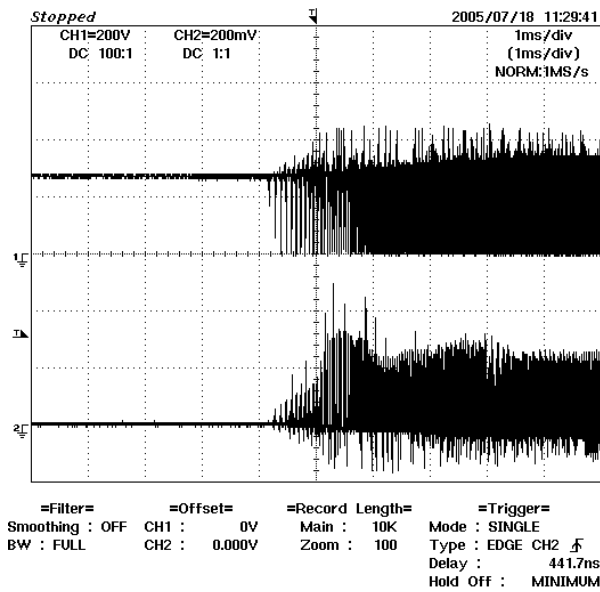
**Figure 12 – Start-up Profile, 200 VAC.**  
 100 ms / div.  
 Upper: 12 V.  
 Lower: 5 V.



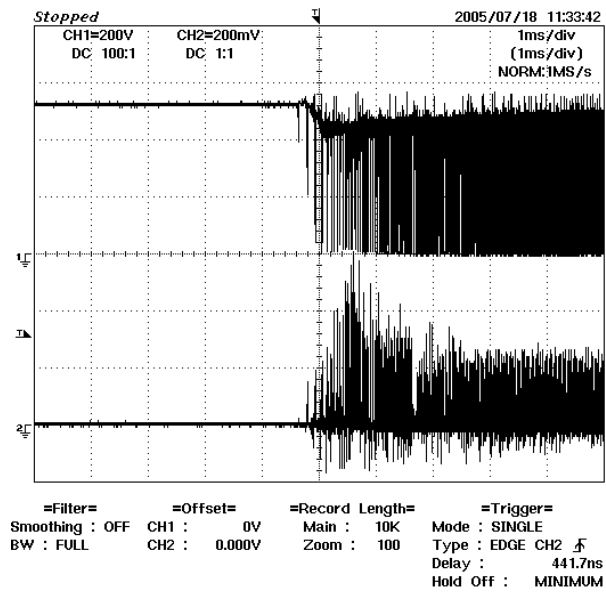
**Figure 13 – Start-up Profile, 400 VAC.**  
 100 ms / div.  
 Upper: 12 V.  
 Lower: 5 V.



### 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.



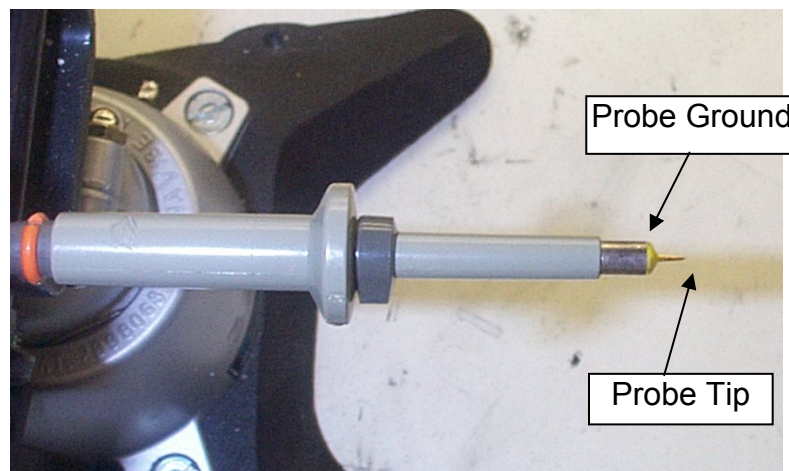


## 11.5 Output Ripple Measurements

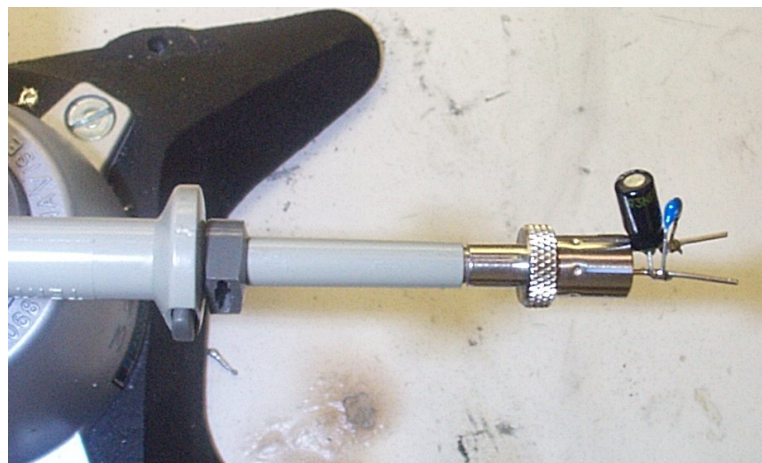
### 11.5.1 Ripple Measurement Technique

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick-up. Details of the probe modification are provided in in the figures below.

The 5125BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1  $\mu\text{F}$  / 50 V ceramic type and one (1) 1.0  $\mu\text{F}$  / 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)

11.5.2 Measurement Results

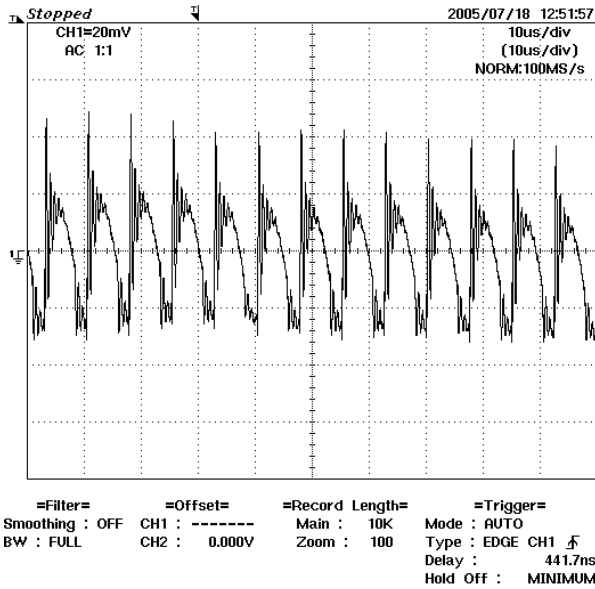


Figure 20 – 5 V Ripple, 200 VAC, Full Load.  
 10 µs, 20 mV / div.

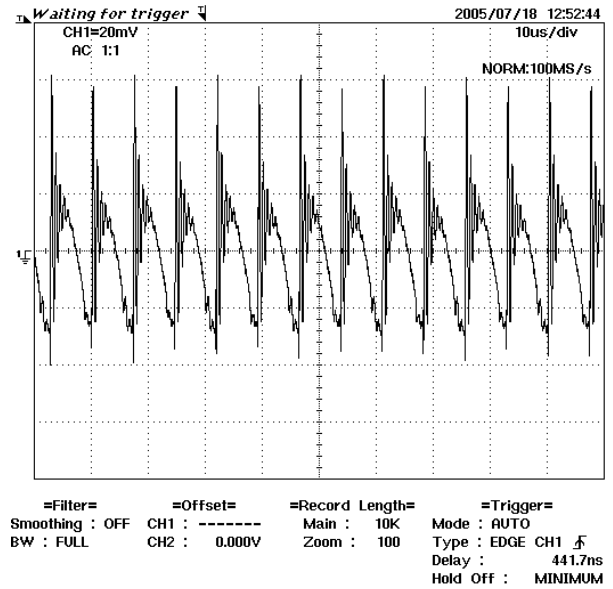


Figure 21 – 5 V Ripple, 400 VAC, Full Load.  
 10 µs, 20 mV / div.

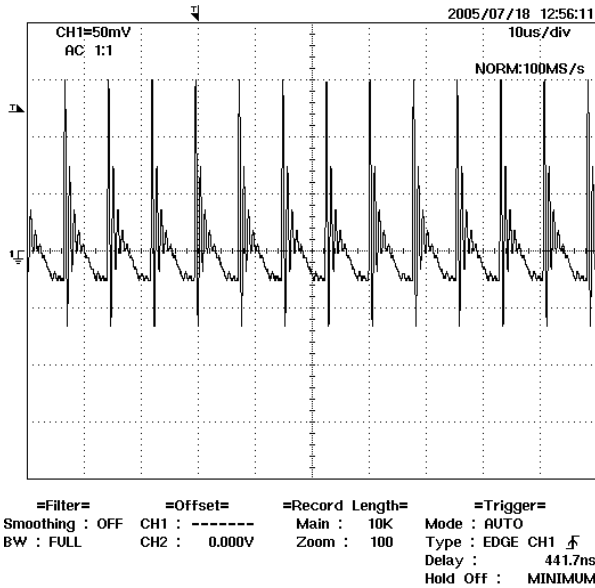


Figure 22 – 14 V Ripple, 200 VAC, Full Load.  
 2 ms, 50 mV /div.

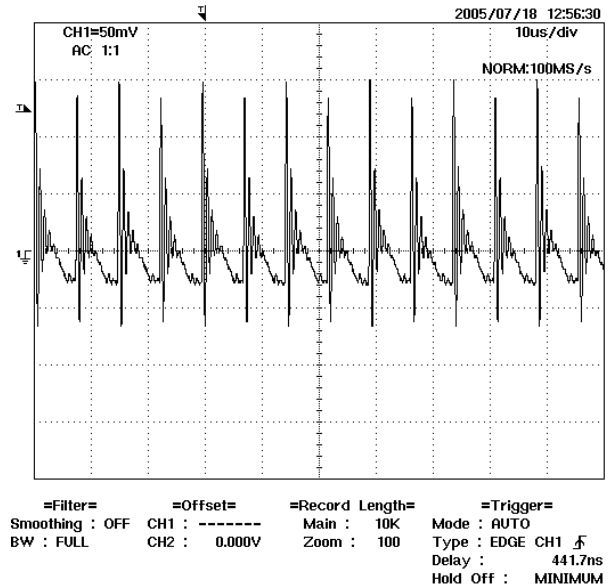


Figure 23 – 14 V Ripple, 400 VAC, Full Load.  
 2 ms, 50 mV /div.

## 12 Conducted EMI

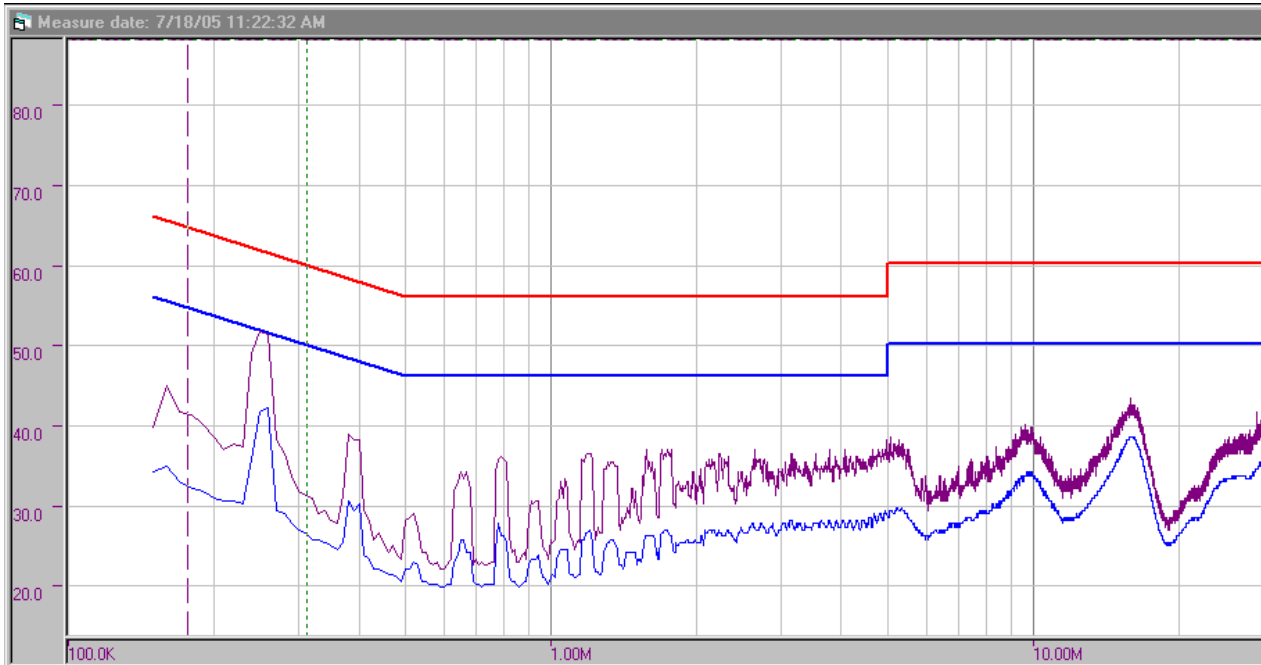


Figure 24 – Conducted EMI, Maximum Steady-State Load, 200 VAC, 50 Hz, and EN55022 B Limits.

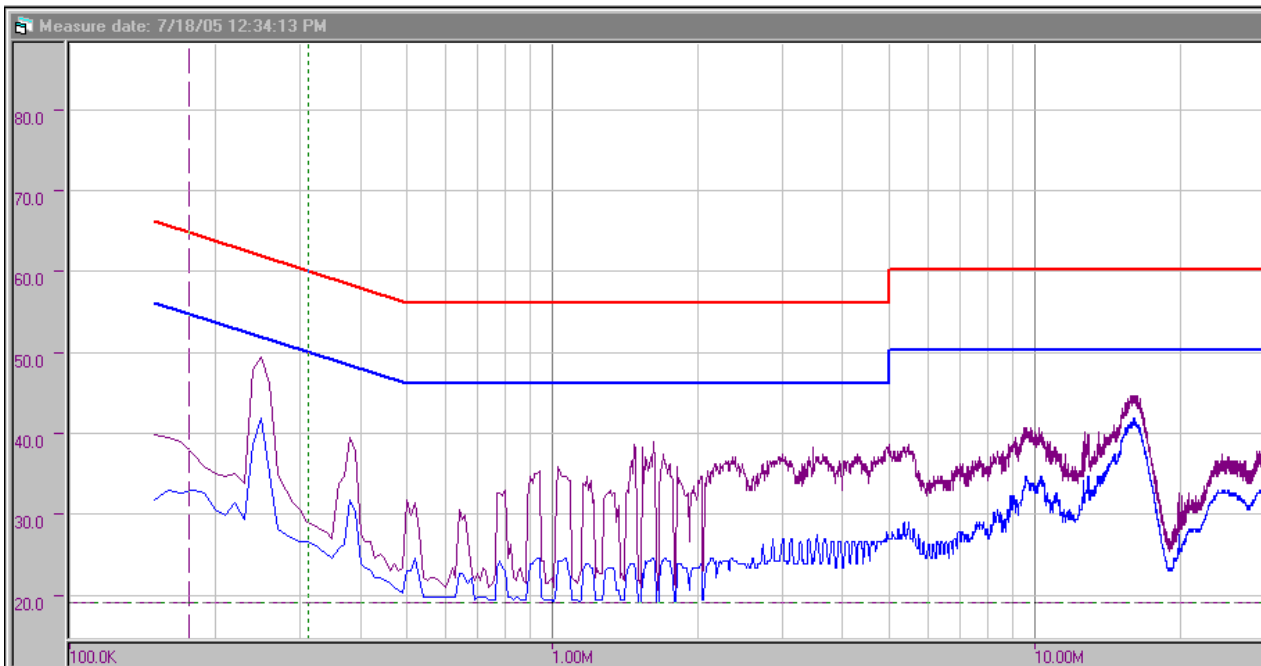


Figure 25 – Conducted EMI, Maximum Steady-State Load, 300 VAC, 50 Hz, and EN55022 B Limits.



### 13 Revision History

Date	Author	Revision	Description & changes	Reviewed
26-Oct-05	HM	1.0	Initial Release	KM/JC/VC
23-Jul-12	KM	1.1	Trademark and text updates	



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