8 Transformer Design Spreadsheet

ACDC_LNK-CV_100608; Rev.0.8; Copyright Power Integrations 2008	INPUT	INFO	OUTPUT	UNIT	ACDC_LNK-CV_100608_Rev0-8.xls; LinkSwitch-CV Continuous/Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	85			Volts	Minimum AC Input Voltage
VACMAX	265			Volts	Maximum AC Input Voltage
fL	50			Hertz	AC Mains Frequency
VO	5			Volts	Output Voltage
PO	3,75			Watts	Output Power
n	0,72				Efficiency Estimate
Z			0,5		Loss Allocation Factor
tC			3	mSeconds	Bridge Rectifier Conduction Time Estimate
CIN	14,7			uFarads	Input Filter Capacitor
ENTER LinkSwitch-CV VARIABLES					
LinkSwitch-CV	LNK623P		LNK623P		Chosen LinkSwitch-CV device
ILIMITMIN			0,186	Amps	LinkSwitch-CV Minimum Current Limit
ILIMITMAX			0,214	Amps	LinkSwitch-CV Maximum Current Limit
fS			100000	Hertz	LinkSwitch-CV Switching Frequency
I2FMIN			3600	A^2Hz	LinkSwitch-CV Min I2F (power Co-efficienct)
I2FMAX			4680	A^2Hz	LinkSwitch-CV Max I2F (power Co-efficienct)
VOR	85		85	Volts	Reflected Output Voltage
VDS			10	Volts	LinkSwitch-CV on-state Drain to Source Voltage
VD			0,5	Volts	Output Winding Diode Forward Voltage Drop
DCON			5,599807	us	Output Diode conduction time
KP_TRANSIENT			0,966787		Worst case ripple to peak current ratio. Maintain KP_TRANSIENT below 0.25
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	EF16		EF16		
Core		EF16		P/N:	PC40EF16-Z
Bobbin		EF16 BOBBIN		P/N:	
AE			0,201	cm^2	Core Effective Cross Sectional Area
LE			3,76	cm	Core Effective Path Length
AL			1100	nH/T^2	Ungapped Core Effective Inductance
BW			10	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3		Number of Primary Layers
NS	8		8		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			97,415	Volts	Minimum DC Input Voltage
VMAX			374,7666	Volts	Maximum DC Input Voltage

FEEDBACK VARIABLES					
NFB			7		Feedback winding number of turns
VFLY			4,8125		Voltage on the Feedback winding when LinkSwitch-CV turns off
RUPPER			11,03082	k-ohms	Upper resistor of feedback network
RLOWER			7,844136	k-ohms	Lower resistor of feedback network
Bias Winding Parameters					
Add Bias winding	NO		NO		Enter 'Yes' if you want to add a Bias winding
VB			N/A		Bias Winding Voltage
NB			N/A		Number of Bias winding turns. Bias winding is assumed to be AC stacked on top of the Feedback winding
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0,492997		Maximum Duty Cycle
IAVG			0,053465	Amps	Average Primary Current
IP			0,186	Amps	Minimum Peak Primary Current
IR			0,1551	Amps	Primary Ripple Current
IRMS			0,082381	Amps	Primary RMS Current
TRANSFORMER **PRIMARY DESIGN PARAMETERS**					
LPMIN			2559,052	uHenries	Minimum Primary Inductance
LP_TOL			10		
NP			123,6364		Primary Winding Number of Turns
ALG			167,412	nH/T^2	Gapped Core Effective Inductance
BM			2265,476	Gauss	Maximum Flux Density, (BM<2500) Calculated at typical current limit and typical primary inductance
BP			2644,428	Gauss	Peak Flux Density, (BP<3000) Calculated at maximum current limit and maximum primary inductance
BAC			820,9717	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1637,471		Relative Permeability of Ungapped Core
LG			0,127914	mm	Gap Length (Lg > 0.1 mm)
BWE			30	mm	Effective Bobbin Width
OD			0,242647	mm	Maximum Primary Wire Diameter including insulation
INS			0,046868	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0,19578	mm	Bare conductor diameter
AWG			33	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			50,79683	Cmils	Bare conductor effective area in circular mils
CMA		Info	616,6093	Cmils/Amp	CAN DECREASE CMA < 500 (decrease L(primary layers),increase NS,smaller Core)
TRANSFORMER SECONDARY DESIGN PARAMETERS					

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Lumped parameters					
ISP			2,874545	Amps	Peak Secondary Current
ISRMS			1,291119	Amps	Secondary RMS Current
IO			0,75	Amps	Power Supply Output Current
IRIPPLE			1,050947	Amps	Output Capacitor RMS Ripple Current
CMS			258,2238	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			25	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0,456749	mm	Secondary Minimum Bare Conductor Diameter
ODS			1,25	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
INSS			0,396625	mm	Maximum Secondary Insulation Wall Thickness
VOLTAGE STRESS PARAMETERS					
VDRAIN			573,2666	Volts	Maximum Drain Voltage Estimate (Includes Effect of Leakage Inductance)
PIVB			N/A	Volts	Bias Diode Maximum Peak Inverse Voltage
PIVS			29,2496	Volts	Output Rectifier Maximum Peak Inverse Voltage
TRANSFORMER SECONDARY DESIGN PARAMETERS (MULTIPLE OUTPUTS)					
1st output					
VO1	5		5	Volts	Output Voltage (if unused, defaults to single output design)
IO1	0,15		0,15	Amps	Output DC Current
PO1			0,75	Watts	Output Power
VD1			0,5	Volts	Output Diode Forward Voltage Drop
NS1			8		Output Winding Number of Turns
ISRMS1			0,258224	Amps	Output Winding RMS Current
IRIPPLE1			0,210189	Amps	Output Capacitor RMS Ripple Current
PIVS1			29,2496	Volts	Output Rectifier Maximum Peak Inverse Voltage
CMS1			51,64477	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS1			32	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS1			0,203459	mm	Minimum Bare Conductor Diameter
ODS1			1,25	mm	Maximum Outside Diameter for Triple Insulated Wire
2nd output					
VO2	12			Volts	Output Voltage
IO2	0,25			Amps	Output DC Current
PO2			3	Watts	Output Power
VD2			0,7	Volts	Output Diode Forward Voltage Drop
NS2			18,47273		Output Winding Number of Turns
ISRMS2			0,430373	Amps	Output Winding RMS Current
IRIPPLE2			0,350316	Amps	Output Capacitor RMS Ripple Current
PIVS2			67,99454	Volts	Output Rectifier Maximum Peak Inverse Voltage

CMS2			86,07462	Cmils	Output Winding Bare Conductor minimum circular mils
AWGS2			30	AWG	Wire Gauge (Rounded up to next larger standard AWG value)
DIAS2			0,256342	mm	Minimum Bare Conductor Diameter
ODS2			0,541339	mm	Maximum Outside Diameter for Triple Insulated Wire
Total power			3,75	Watts	Total Output Power

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9 Performance Data

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

9.1 Efficiency

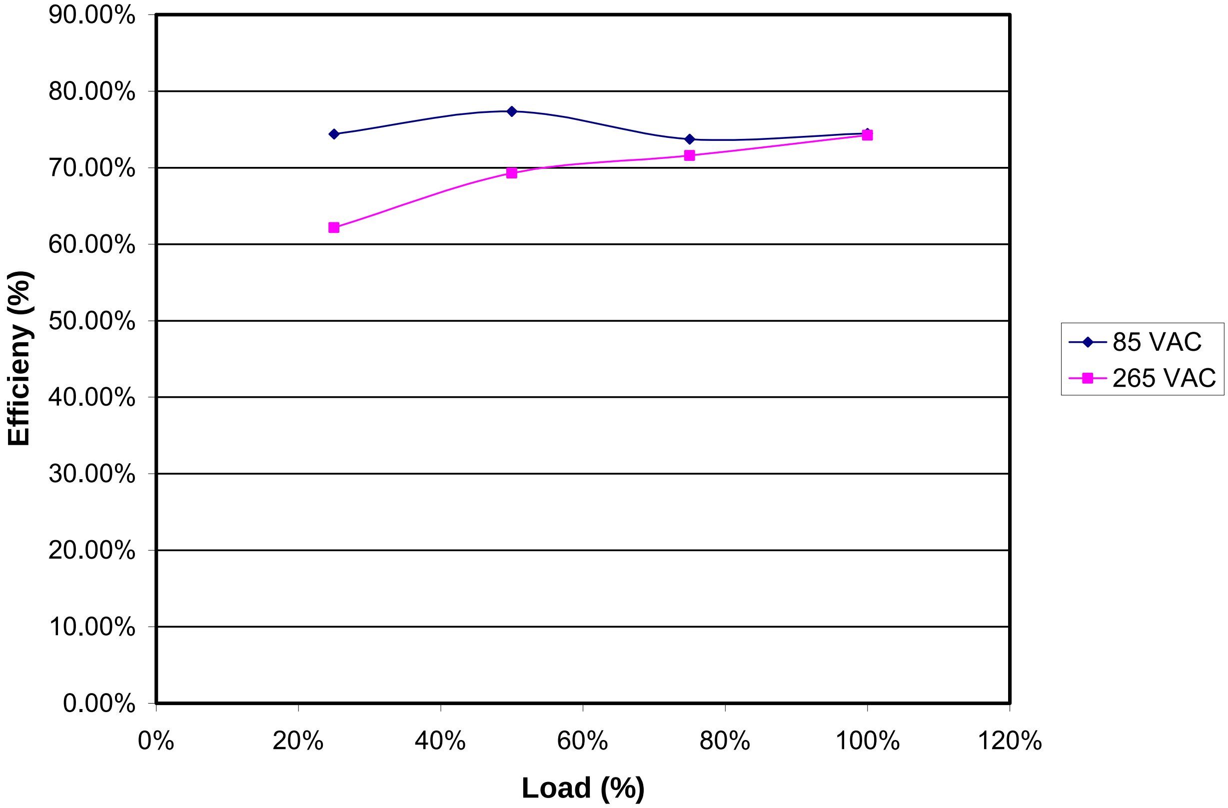

Figure 5 – Efficiency vs. Load, Room Temperature, 50 Hz.

9.1 Active Mode Efficiency

% of Full Load	% Efficiency at 115 VAC	% Efficiency at 230 VAC
25	72.4	62.2
50	77.1	69.3
75	74.9	71.6
100	75.8	74.3
Average Efficiency	**75.1%**	**69.3%**
CEC Requirement	**61.9%**	
NOTE: for this application (multiple output) this standard is not applicable, however the values can be used as reference		

9.2 Energy Efficiency Requirements

The external power supply requirements below all require meeting active mode efficiency and no-load input power limits. Minimum active mode efficiency is defined as the average efficiency of 25, 50, 75 and 100% of output current (based on the nameplate output current rating).

For adapters that are single input voltage only then the measurement is made at the rated single nominal input voltage (115 VAC or 230 VAC), for universal input adapters the measurement is made at both nominal input voltages (115 VAC and 230 VAC).

To meet the standard the measured average efficiency (or efficiencies for universal input supplies) must be greater than or equal to the efficiency specified by the standard.

The test method can be found here:

http://www.energystar.gov/ia/partners/prod_development/downloads/power_supplies/EPSupplyEffic_TestMethod_0804.pdf

For the latest up to date information please visit the PI Green Room:

http://www.powerint.com/greenroom/regulations.htm

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9.2.1 USA Energy Independence and Security Act 2007

This legislation mandates all single output single output adapters, including those provided with products, manufactured on or after July 1st, 2008 must meet minimum active mode efficiency and no load input power limits.

Active Mode Efficiency Standard Models

Nameplate Output (P_O)	Minimum Efficiency in Active Mode of Operation
< 1 W	$0.5 \times P_O$
≥ 1 W to ≤ 51 W	$0.09 \times \ln(P_O) + 0.5$
> 51 W	0.85

ln = natural logarithm

No-load Energy Consumption

Nameplate Output (P_O)	Maximum Power for No-load AC-DC EPS
All	≤ 0.5 W

This requirement supersedes the legislation from individual US States (for example CEC in California).

9.2.2 ENERGY STAR EPS Version 2.0

This specification takes effect on November 1st, 2008.

Active Mode Efficiency Standard Models

Nameplate Output (P_O)	Minimum Efficiency in Active Mode of Operation
≤ 1 W	$0.48 \times P_O + 0.14$
> 1 W to ≤ 49 W	$0.0626 \times \ln(P_O) + 0.622$
> 49 W	0.87

ln = natural logarithm

Active Mode Efficiency Low Voltage Models (V_O<6 V and $I_O \geq$ 550 mA)

Nameplate Output (P_O)	Minimum Efficiency in Active Mode of Operation
≤ 1 W	$0.497 \times P_O + 0.067$
> 1 W to ≤ 49 W	$0.075 \times \ln(P_O) + 0.561$
> 49 W	0.86

ln = natural logarithm

No-load Energy Consumption (both models)

Nameplate Output (P_O)	Maximum Power for No-load AC-DC EPS
0 to < 50 W	≤ 0.3 W
≥ 50 W to ≤ 250 W	≤ 0.5 W

9.2 No-load Input Power

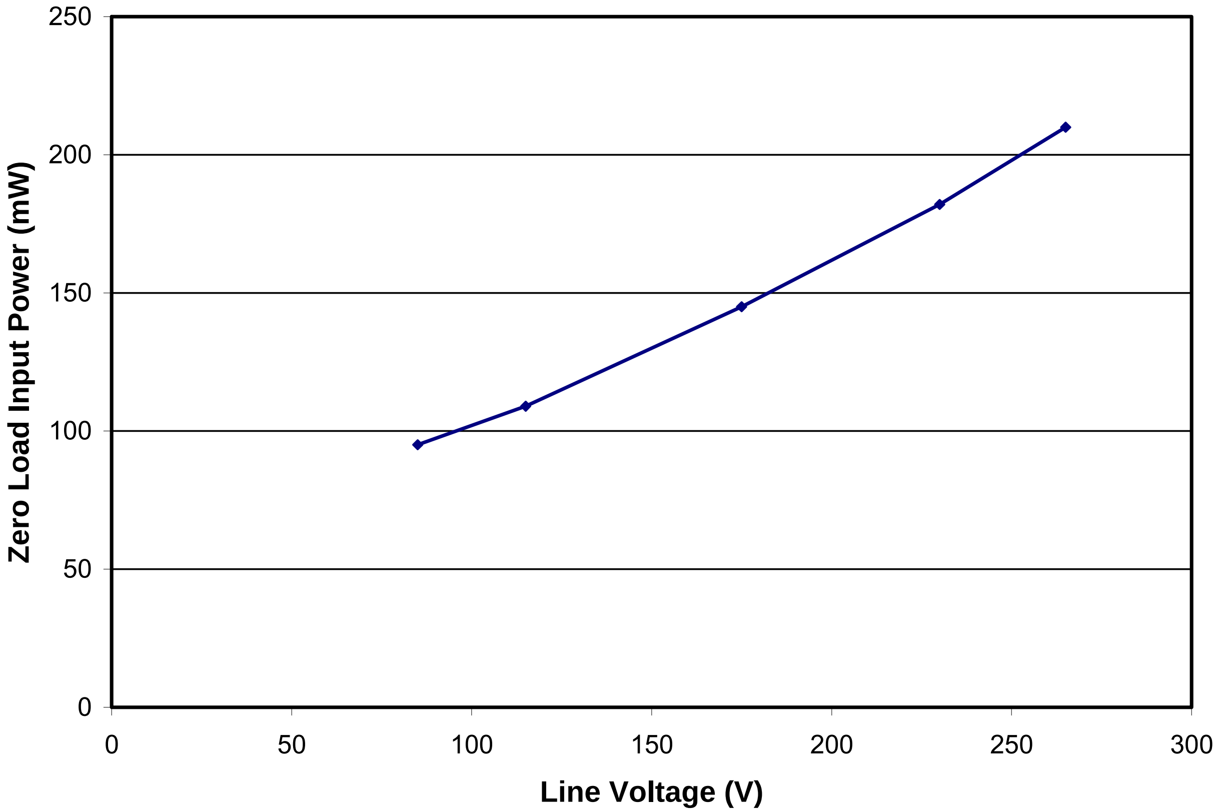

Figure 6 – Zero Load Input Power vs. Input Line Voltage, Room Temperature, 50 Hz.

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9.3 *Regulation*

Line Voltage	Rail (V)	Load (A)	Actual Voltage (V)	Line Voltage	Rail (V)	Load (A)	Actual Voltage (V)
85 VAC	5	0.15	5.137	230 VAC	5	0.15	5.115
	12	0.25	11.76		12	0.25	11.71
	5	0.1	5.18		5	0.1	5.15
	12	0.25	11.75		12	0.25	11.68
	5	0.05	4.93		5	0.05	4.85
	12	0.005	11.99		12	0.005	11.9
	5	0.1	5.14		5	0.1	5.11
	12	0.15	11.78		12	0.15	11.71
	5	0.15	4.94		5	0.15	4.87
	12	0.02	11.96		12	0.02	11.88
	5	0.15	5.12		5	0.15	5.08
	12	0.1	11.77		12	0.1	11.7
	5	0.15	5.07		5	0.15	5.04
	12	0.2	11.8		12	0.2	11.76
115 VAC	5	0.15	5.14	265 VAC	5	0.15	5.107
	12	0.25	11.77		12	0.25	11.7
	5	0.1	5.18		5	0.1	5.14
	12	0.25	11.76		12	0.25	11.67
	5	0.05	4.91		5	0.05	4.84
	12	0.005	11.97		12	0.005	11.9
	5	0.1	5.14		5	0.1	5.1
	12	0.15	11.78		12	0.15	11.7
	5	0.15	4.92		5	0.15	4.86
	12	0.02	11.94		12	0.02	11.87
	5	0.15	5.12		5	0.15	5.08
	12	0.1	11.78		12	0.1	11.69
	5	0.15	5.07		5	0.15	5.02
	12	0.2	11.8		12	0.2	11.73

Worst case deviation:
5 V Rail: +3.6% / -2.8%
12 V Rail: -0.1% / -2.8%

10 Thermal Performance

Item	Temperature in °C	
	85 VAC	265 VAC
Ambient	23	23
LNK623PG (U1)	50.5	55.8

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11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

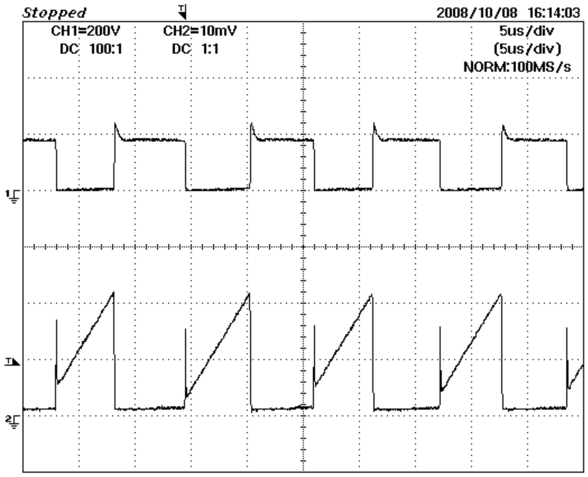

Figure 7 – 85 VAC, Full Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.1 A, 5 μs / div.

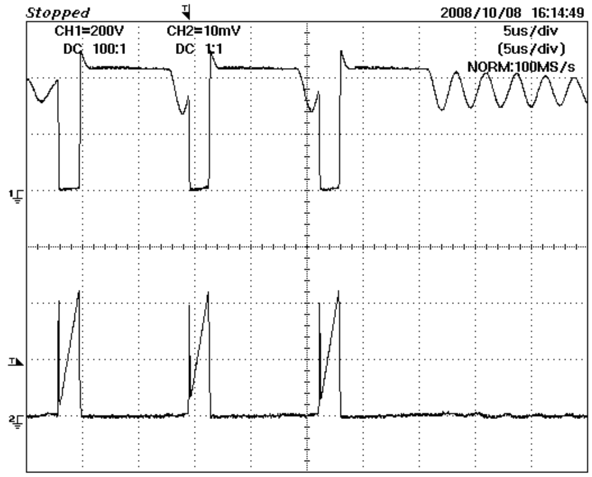

Figure 8 – 265 VAC, Full Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.1 A, 5 μs / div.

11.2 Output Voltage Start-up Profile

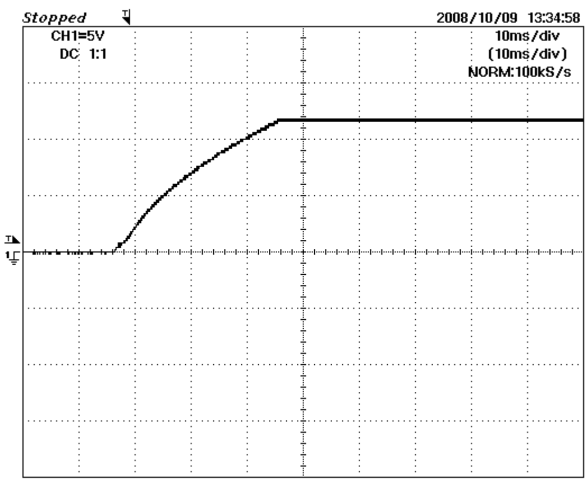

Figure 9 – Start-up Profile, 85 VAC
12 V, 5 V / div, 10 ms / div.

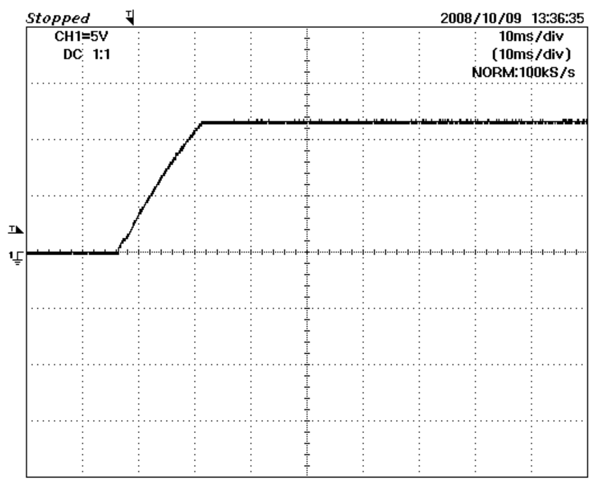

Figure 10 – Start-up Profile, 265 VAC
12 V, 5 V / div, 10 ms / div.

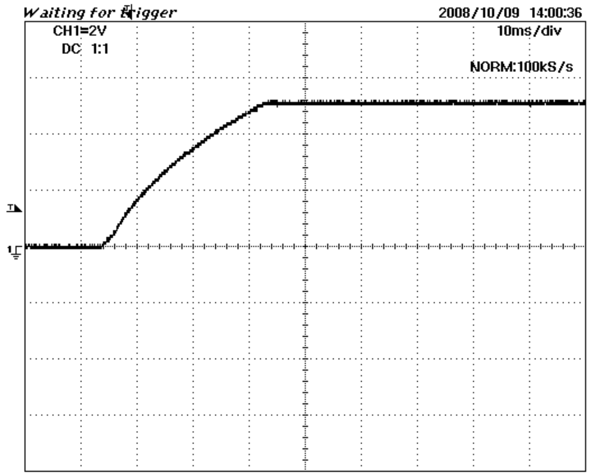

Figure 11 – Start-up Profile, 85 VAC
5 V, 2 V / div, 10 ms / div.

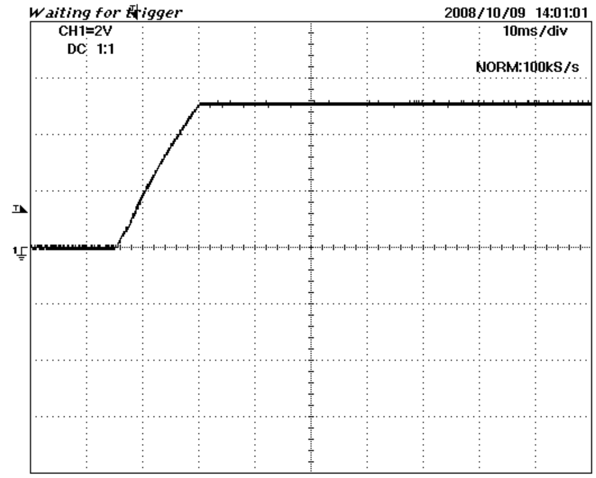

Figure 12 – Start-up Profile, 265 VAC
5 V, 2 V / div, 10 ms / div.

11.3 Drain Voltage and Current Start-up Profile

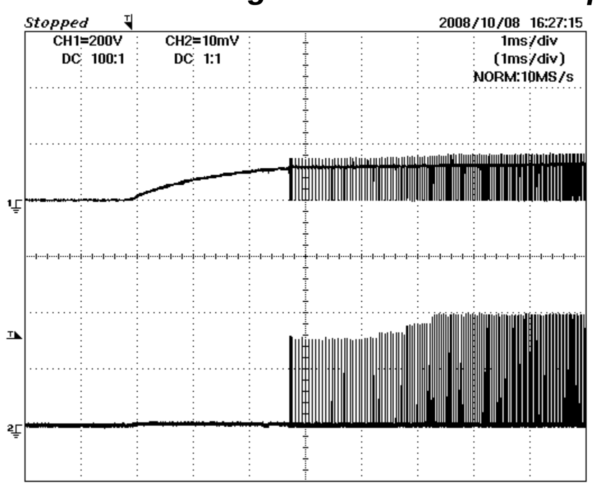

Figure 13 – 85 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.1 A, 1 ms / div.

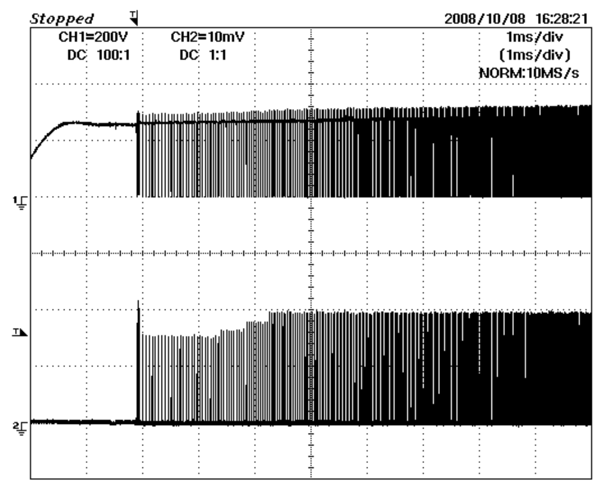

Figure 14 – 265 VAC Input and Maximum Load.
Upper: V_{DRAIN}, 200 V / div.
Lower: I_{DRAIN}, 0.1 A, 1 ms / div.

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11.4 Load Transient Response

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.

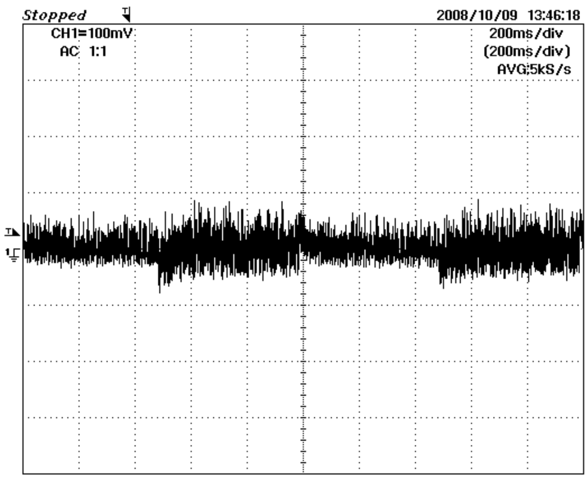

Figure 15 – Transient Response, 115 VAC, 50-100-50% 12 V Load Step.
12 V Output Voltage.
100 ms / div.

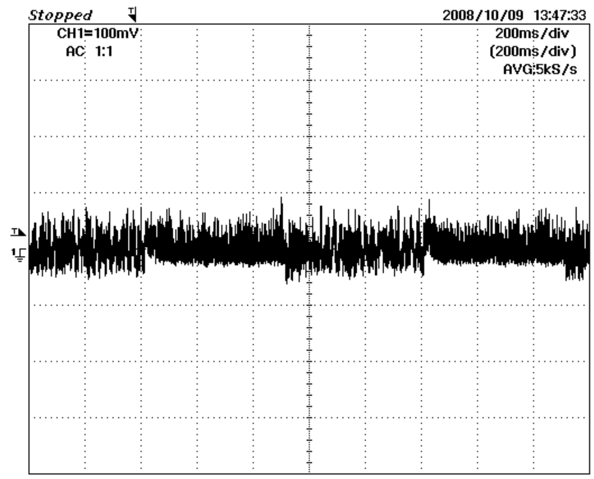

Figure 16 – Transient Response, 230 VAC, 50-100-50% 12 V Load Step.
12 V Output Voltage.
100 ms / div.

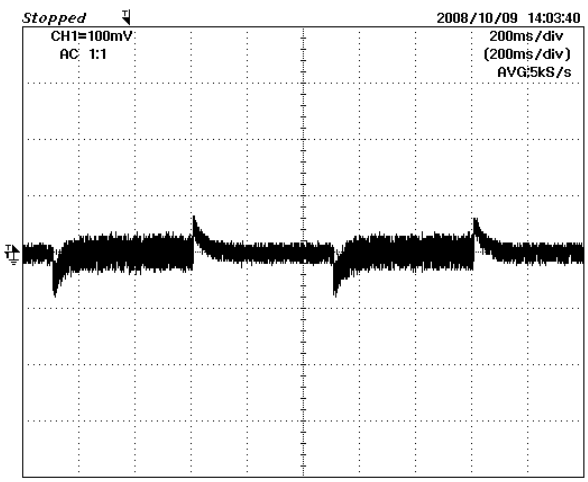

Figure 17 – Transient Response, 115 VAC, 50-100-50% 12 V Load Step.
5 V Output Voltage.
100 ms / div.

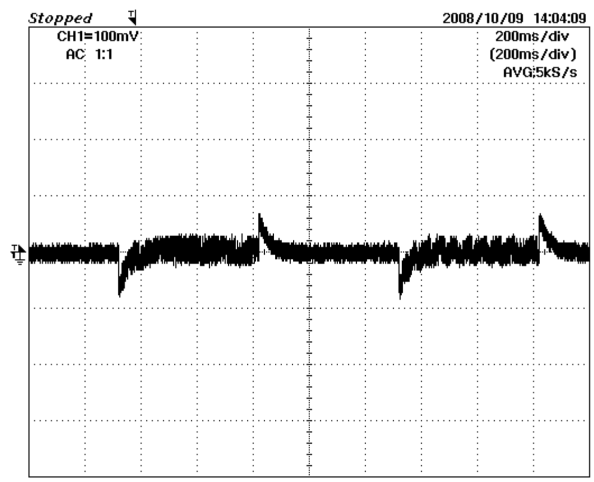

Figure 18 – Transient Response, 230 VAC, 50-100-50% 12 V Load Step.
5 V Output Voltage.
100 ms / div.

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 pickup. Details of the probe modification are provided in Figure 19 and Figure 20.

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).***

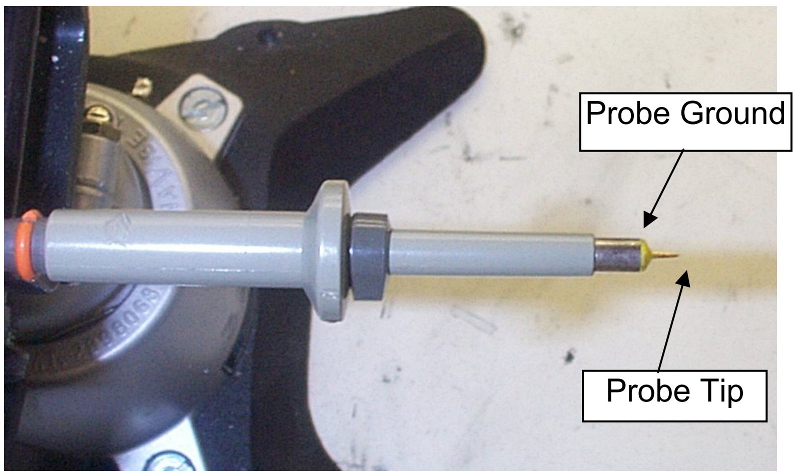

Figure 19 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

Figure 20 – 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

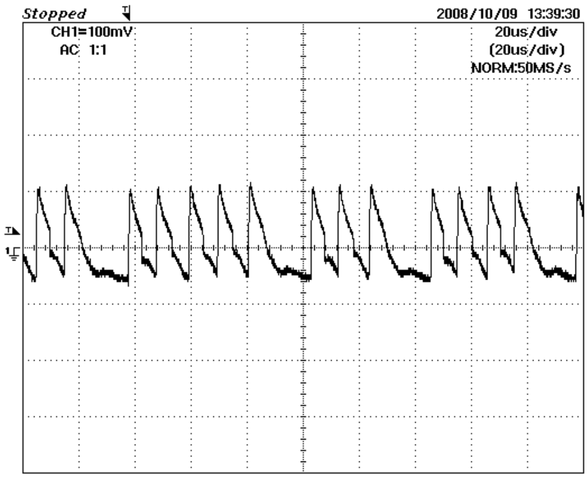

Figure 21 – 12 V Output Ripple, 85 VAC, Full Load. 20 µs, 100 mV / div.

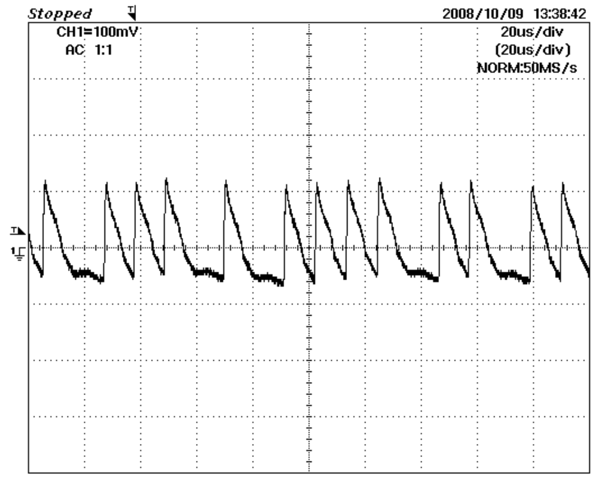

Figure 22 – 12 V Output Ripple, 265 VAC, Full Load. 20 µs, 100 mV / div.

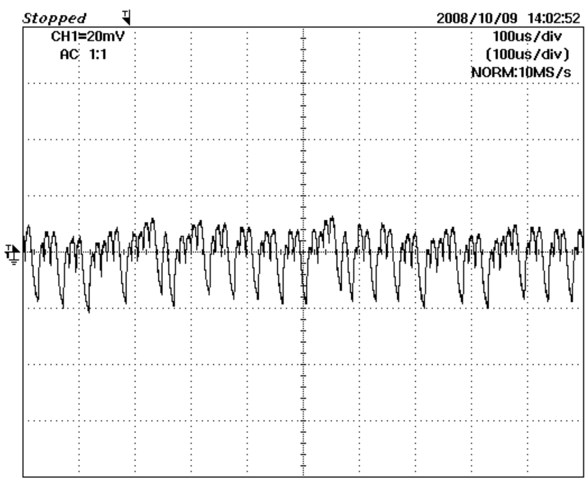

Figure 23 – 5 V Output Ripple, 85 VAC, Full Load. 100 µs, 20 mV / div.

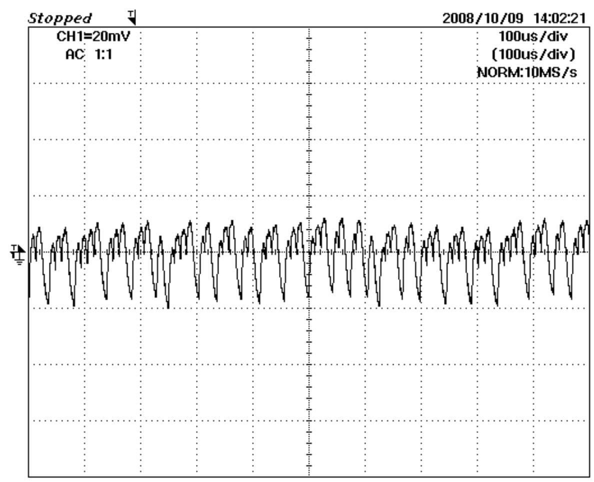

Figure 24 – 5 V Output Ripple, 265 VAC, Full Load. 100 µs, 20 mV / div.

12 Conducted EMI

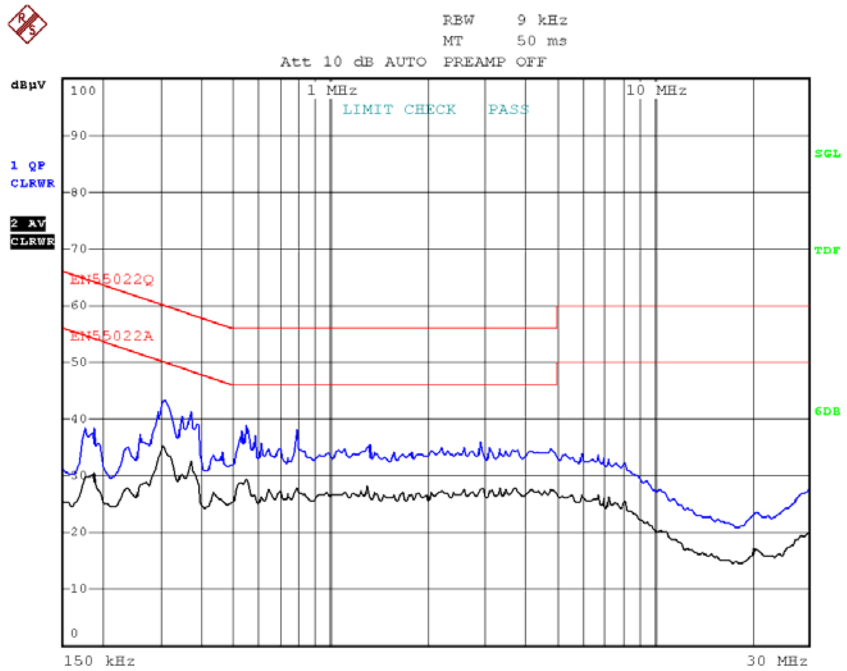

Figure 25 – Conducted EMI, Maximum Steady State Load, 115 VAC, 50 Hz, and EN55022 B Limits, L-Line, Secondary Ground connected to Artificial Hand.

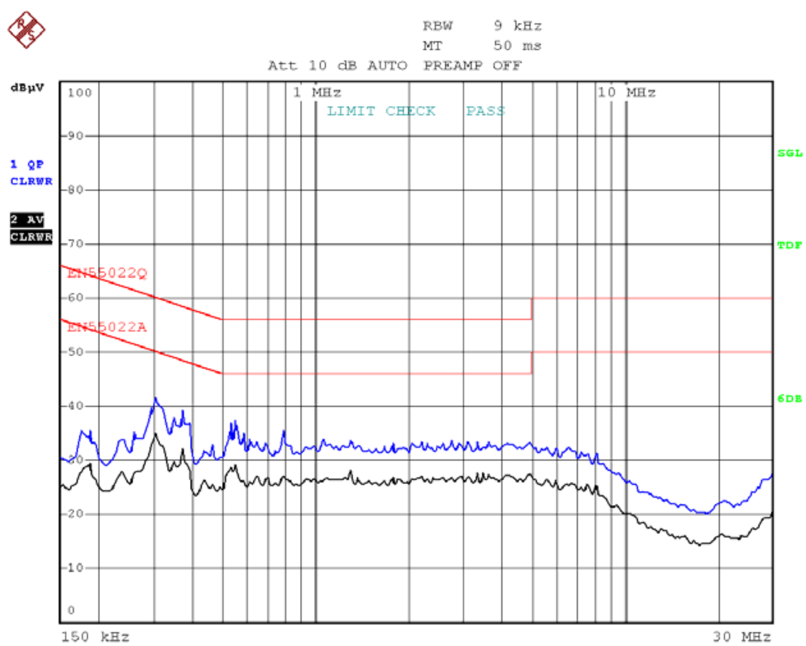

Figure 26 – Conducted EMI, Maximum Steady State Load, 115 VAC, 50 Hz, and EN55022 B Limits, N-Line, Secondary Ground connected to Artificial Hand.

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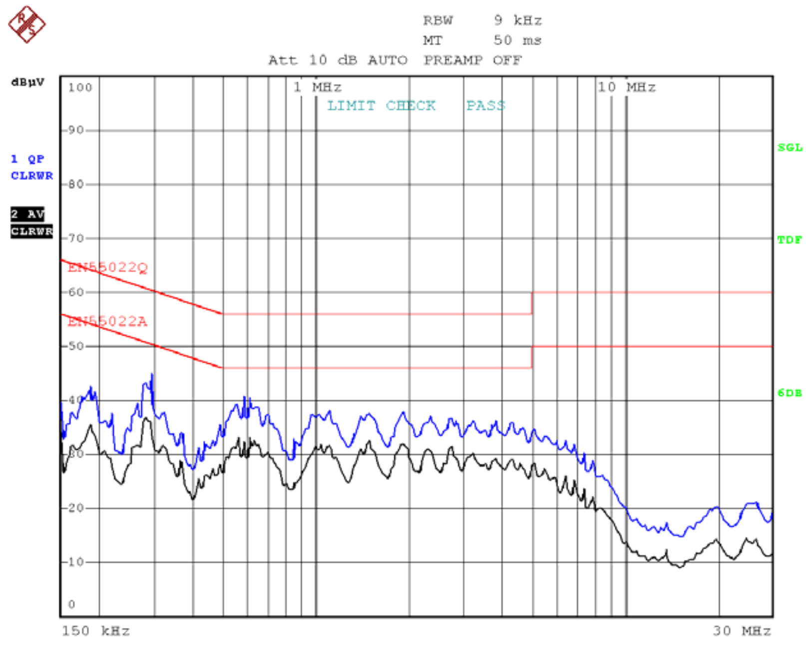

Figure 27 – Conducted EMI, Maximum Steady State Load, 230 VAC, 50 Hz, and EN55022 B Limits, L-Line, Secondary Ground connected to Artificial Hand.

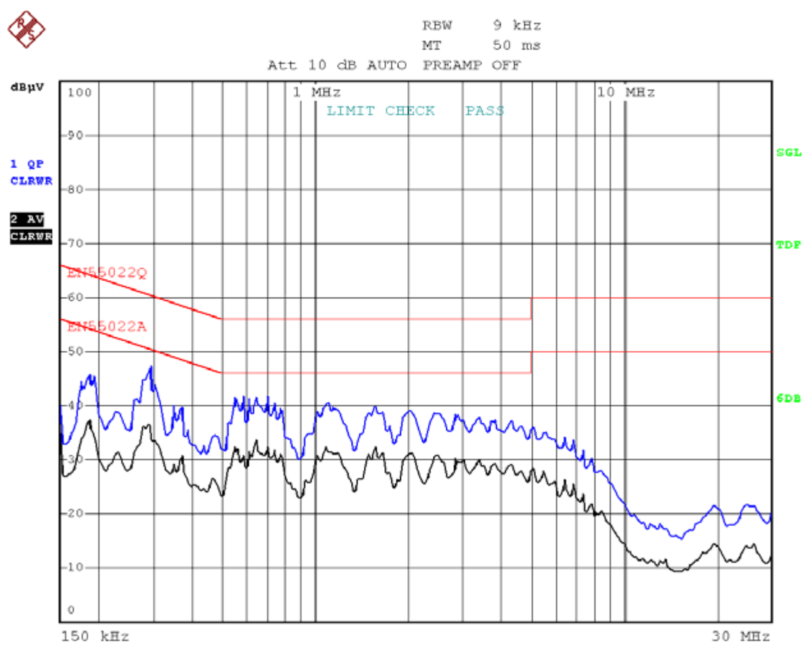

Figure 28 – Conducted EMI, Maximum Steady State Load, 230 VAC, 50 Hz, and EN55022 B Limits, N-Line, Secondary Ground connected to Artificial Hand.

13 Revision History

Date	Author	Revision	Description & changes	Reviewed
01-May-09	RP	1.0	Initial Release	Mktg & Apps

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