DESIGN EXAMPLE REPORT

Title	***5.32 W LED Driver Using LNK606PG***
Specification	85 - 265 VAC Input; 7.6 V, 700 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-184
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Revision	1.0

Summary and Features

- Accurate primary side constant current, constant voltage (CC/CV) controller eliminates optocoupler and all secondary side CV/CC control circuitry
  - No current-sense resistors for maximized efficiency
  - Low part-count solution for lower cost
- Auto-restart protection feature reduces power delivered to the output by 95% under output short circuit or open loop conditions
- Hysteretic thermal shutdown protects power supply from damage
- CEC and ENERGY STAR 2.0 regulations:
  - On/Off control provides constant efficiency to very light loads
    - No-load consumption <250 mW at 265 VAC
    - Ultra-low leakage current: <5 µA at 265 VAC input (no Y capacitor required)
  - Meets EN55015 and CISPR-22 Class B EMI
  - Green package: halogen free and RoHS compliant

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Important Note:
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.

1 Introduction

This engineering report describes the design for a 7.6 V, 700 mA constant voltage/constant current (CV/CC) universal-input power supply for LED driver applications. This power supply utilizes the LNK606PG, a member of the LinkSwitch-II device family.

This document contains the power supply specifications, schematic, bill of materials, transformer specifications, and typical performance characteristics for this power supply design.

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2 Prototype Photo

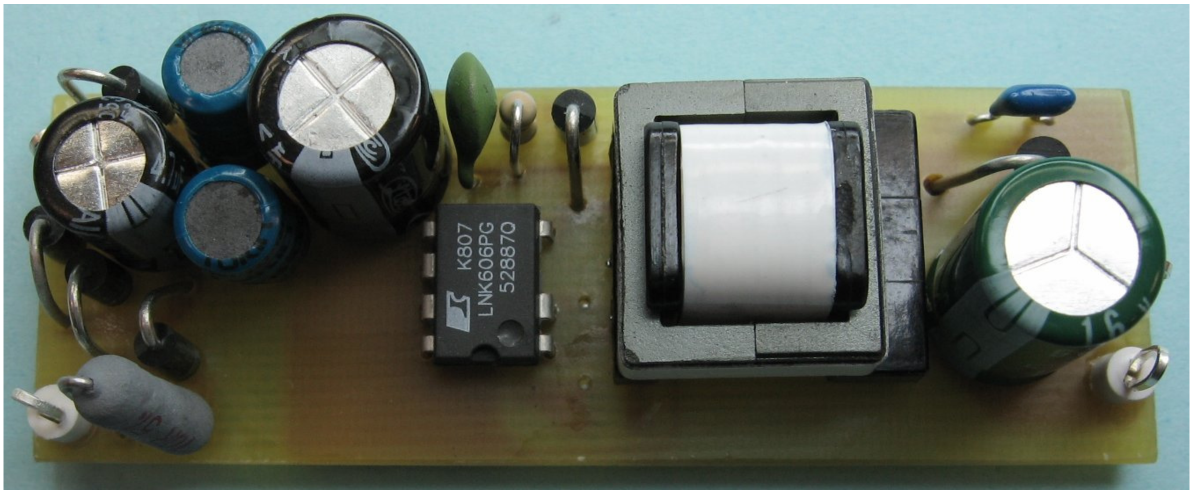

Figure 1 – Prototype Top View.

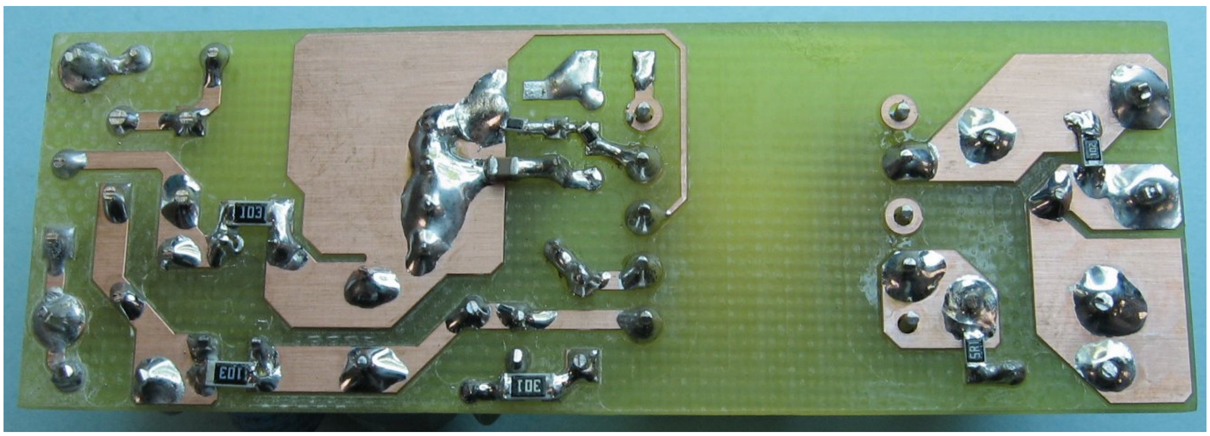

Figure 2 – Prototype Bottom View.

3 Power Supply Specification

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	85		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
No-load Input Power (230 VAC)				300	mW	
Output						
Output Voltage 1	V_{OUT1}		7.6		V	Measured at the output capacitor
Output Ripple Voltage 1	$V_{RIPPLE1}$		200		mV	20 MHz bandwidth
Output Current 1	I_{OUT1}	630	700	770	mA	+/- 10%
Total Output Power						
Continuous Output Power	P_{OUT}		5.32		W	
Efficiency						
Full Load	η	72.66			%	Energy Star II P_{OUT}, 25 °C (115 & 230VAC)
Required average efficiency at 25, 50, 75 and 100 % of P_{OUT}	η_{CEC}	64			%	Per California Energy Commission (CEC Tier 2) / Energy Star requirements
Environmental						
Conducted EMI		Meets CISPR22B / EN55152B				
Safety		Designed to meet IEC950, UL1950 Class II				
Surge		2			kV	1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω Common Mode: 12 Ω
Ambient Temperature	T_{AMB}	-5		50	°C	Free convection, sea level

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4 Schematic

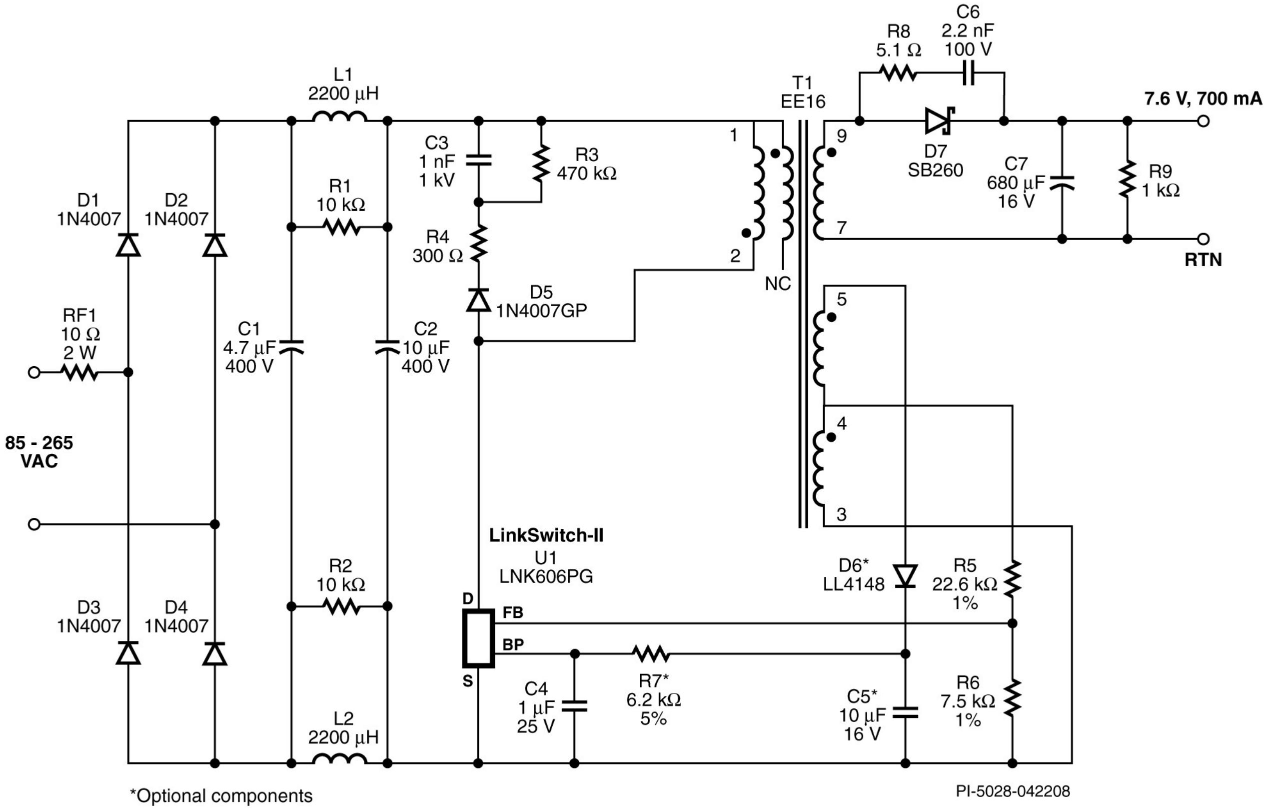

Figure 3 – Circuit Schematic.

Note: D6, C5, and R7 are optional for the bias supply circuitry. Using a bias supply reduces no-load consumption.

5 Circuit Description

This circuit uses the LNK606PG in a primary-side regulated flyback power-supply configuration.

The LNK606PG device (U1) incorporates a power switching device, oscillator, CC/CV control engine, and startup and protection functions all as part of one IC. The integrated 700 V MOSFET allows sufficient voltage margin for universal input AC applications. The power supply delivers full output current during the maximum forward voltage drop of the LED.

The LNK606PG's IC package provides extended creepage distance between high and low voltage pins (both at the package and the PCB), which is required in high humidity conditions to prevent arcing and to further improve reliability. The EE16 transformer bobbin provides extended creepage to meet safety spacing requirements.

5.1 LNK606PG Operation

The LNK606PG monolithically integrates a 700 V power MOSFET switch and On/Off control function (for transformer core and CV/CC). The constant voltage (CV) regulation uses a unique ON/OFF control scheme which provides tight regulation over a wide temperature range. Adjusting the switching frequency to regulate the output current ensures a linear constant current (CC) characteristic, even when the voltage drops. This makes the LNK606PG ideal for driving LEDs, which require a constant current level for proper operation. In addition, this integrated voltage and current regulator compensates for tolerances in transformer inductance and internal device parameters as well as in input voltage variations.

The LNK606PG also provides a sophisticated range of protection features such as auto-restart and integrated hysteretic thermal shutdown. Auto-restart is triggered by fault conditions which include an open feedback loop or shorted output. Accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

5.2 Input Filter

Diodes D1 through D4 rectify the AC input and bulk storage capacitors C1 and C2 filter the resulting DC. C1 and C2, with inductors L1 and L2, also attenuate conducted differential-mode EMI noise. R1 and R2 dampen any resulting resonant ringing between capacitors and inductors. This configuration, along with Power Integrations' transformer E-Shield™ technology, ensures this design meets EMI standard EN55015 class B with 10 dB of margin, using no Y capacitor. RF1 is a fusible resistor which limits inrush current at startup, and fuses if any component fails from excess input current.

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5.3 LNK606PG Primary

The LNK606PG is completely self-powered from the BP (BYPASS) pin and decoupling capacitor C4. (C4 provides high frequency decoupling as well as energy storage.) U1 uses the energy stored in C4 when the internal MOSFET is on. (When the MOSFET is off, the internal 6 V regulator draws current from the voltage on the DRAIN pin.)

The rectified and filtered input voltage is applied to one side of the primary winding of T1. The other side of the transformer's primary winding is driven by U1's integrated MOSFET. An RCD-R clamp consisting of D5, R3, R4, and C3 limits any drain voltage spikes caused by leakage inductance.

U1 automatically compensates for tolerance in primary magnetizing inductance through a feedback mechanism at the FB pin. The output power is directly proportional to the set primary inductance. Changes to the output power, sensed at FB, cause adjustments to be made in the switching frequency, compensating for the inductance fluctuations.

5.4 Output Rectification and Filtering

Diode D7 rectifies the transformer's secondary output and C7 filters it. (A Schottky barrier-type diode was chosen for higher efficiency.) C7's low ESR reduces output voltage ripple, eliminating the need for an LC post filter. R8 and C6 form a snubber network for removing high-frequency conducted as well as radiated EMI. Pre-load resistor R9 acts as a bleeder to C7 when there is no load attached.

5.5 Output Regulation

The LNK606PG regulates output using On/Off control for CV regulation, and frequency control for constant current (CC) regulation. The 1% tolerance of feedback resistors R5 and R6 assists in centering both the nominal output voltage and the CC regulation threshold tightly. Diode D6 and capacitor C5 rectify and filter the bias voltage. The CV feature provides output over-voltage protection (OVP) in case any LEDs have open-circuit failures. The bias winding is optional.

Traversing from no load to full load, the controller within the LinkSwitch-II first operates in the CV region. Upon detecting the maximum power point, the controller goes into CC mode.

In the CV region, the output voltage is regulated by using on-off control. Output voltage is maintained by skipping switching cycles. Regulation is maintained by adjusting the ratio of enabled and disabled cycles. This also optimizes the efficiency of the converter over the entire load range. At light loads the current limit is reduced to decrease the transformer flux density, which reduces audible noise and switching losses. As the load current increases, the current limit is increased and fewer and fewer cycles are skipped.

At the maximum power point, no switching cycles are skipped and the controller within the LinkSwitch-II transitions into CC mode. A further increase in the demand for load current causes the output voltage to drop. This drop in output voltage is reflected on the FB pin voltage. In response to the reduction of voltage at the FB pin, the switching frequency is linearly reduced to achieve constant output current.

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6 PCB Layout

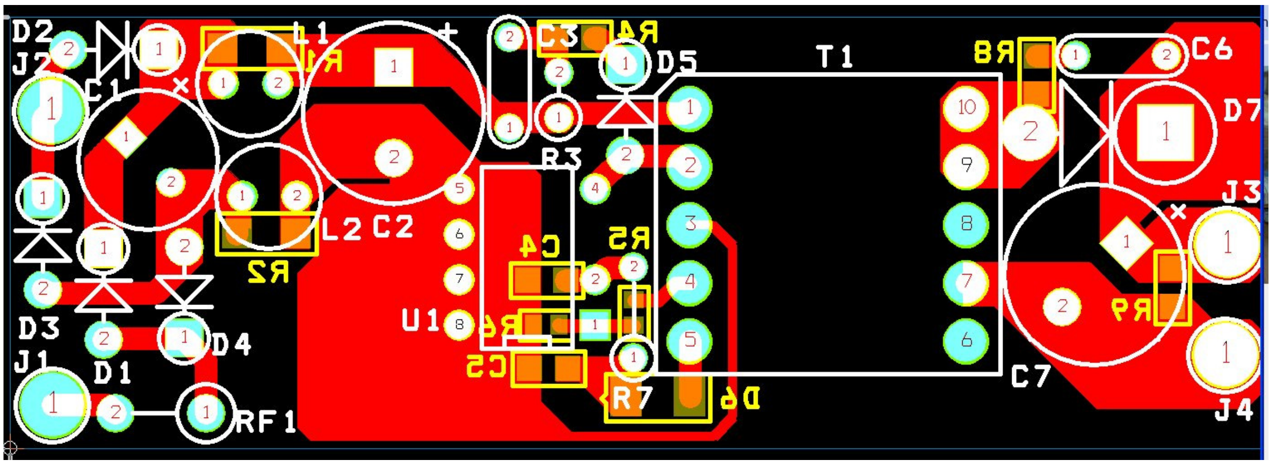

Figure 4 – PCB Layout.

Note: D6, C5, R7 are optional for bias supply. Using a bias supply reduces the no-load power consumption.

7 Bill of Materials

Item	Qty	Part Ref.	Description	Mfg Part Number	Mfg
1	1	C1	4.7 µF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G4R7MK0811MLL3	Taicon Corporation
2	1	C2	10 µF, 400 V, Electrolytic, Low ESR, 79 mA, (10 x 12.5)	TYD2GM100G13O	Ltec
3	1	C3	1 nF, 1 kV, Disc Ceramic	ECK-D3A102KBP	Panasonic - ECG
4	1	C4	1 µF, 25 V, Ceramic, X7R, 0805	ECJ-2FB1E105K	Panasonic
5	1	C5	10 µF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
6	1	C6	2.2 nF, 100 V, Ceramic, COG	B37986G1222J000	Epcos
7	1	C7	680 µF, 16 V, Electrolytic, Very Low ESR, 38 mΩ, (10 x 16)	EKZE160ELL681MJ16S	Nippon Chemi-Con
8	4	D1 D2 D3 D4	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
9	1	D5	1000 V, 1 A, Rectifier, Glass Passivated, 2 us, DO-41	1N4007GP	Vishay
10	1	D6	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diode Inc.
11	1	D7	60 V, 2 A, Schottky, DO-204AC	SB260	Vishay
12	2	L1 L2	2200 µH, 0.21 A	SBC4-222-211	Tokin
13	2	R1 R2	10 kΩ, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ103V	Panasonic
14	1	R3	470 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-470K	Yageo
15	1	R4	300 Ω, 5%, 1/4 W, Metal Film, 1206	ERJ-8GEYJ301V	Panasonic
16	1	R5	22.6 kΩ, 1%, 1/16 W, Metal Film, 0603	ERJ-3EKF2262V	Panasonic
17	1	R6	7.5 kΩ, 1%, 1/16 W, Metal Film, 0603	ERJ-3EKF7501V	Panasonic
18	1	R7	6.2 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-6K2	Yageo
19	1	R8	5.1 Ω, 5%, 1/8 W, Metal Film, 0805	ERJ-6GEYJ5R1V	Panasonic
20	1	R9	1 kΩ, 5%, 1/8 W, Metal Film, 0805	ERJ-6GEYJ102V	Panasonic
21	1	RF1	10 Ω, 2 W, Fusible/Flame Proof Wire Wound	CRF253-4 10R	Vitrohm
22	1	T1	Bobbin, EE16, Horizontal, 10 pins	PM-9820	Ho Jinn Plastic
23	1	U1	LinkSwitch-II, LNK606PG, CV/CC, DIP-8C	LNK606PG	Power Integrations

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8 Transformer Specification

8.1 Electrical Diagram

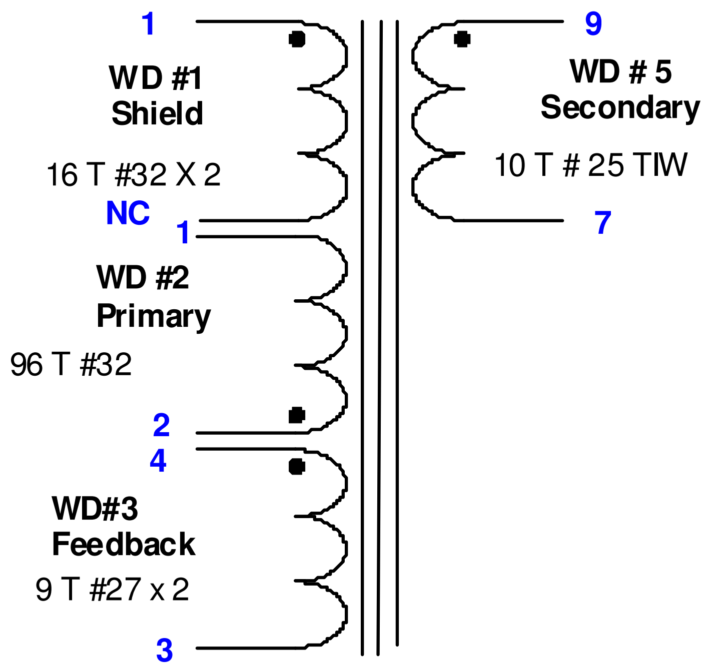

Figure 5 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Primary to Secondary	3000 VAC
Primary Inductance	Pins 1-2, all other windings open, measured at 66 kHz, 0.4 VRMS	1.13 mH, ±10%
Resonant Frequency	Pins 1-2, all other windings open	700 kHz (Min.)
Primary Leakage Inductance	Pins 1-2, with Pins 10 and 9 shorted, measured at 66 kHz, 0.4 VRMS	80 µH (Max.)

8.3 Materials

Item	Description
[1]	Core: PC44, gapped for A_L of 110 nH/t^2
[2]	Bobbin: Horizontal 10 pin, EE16
[3]	Magnet Wire: #32 AWG
[4]	Magnet Wire: #32 AWG
[5]	Magnet Wire: #27 AWG
[6]	Triple Insulated Wire: #25 AWG
[7]	Tape, 3M 1298 Polyester Film, 2.0 Mils thick, 8.4 mm wide
[8]	Varnish

8.4 Transformer Build Diagram

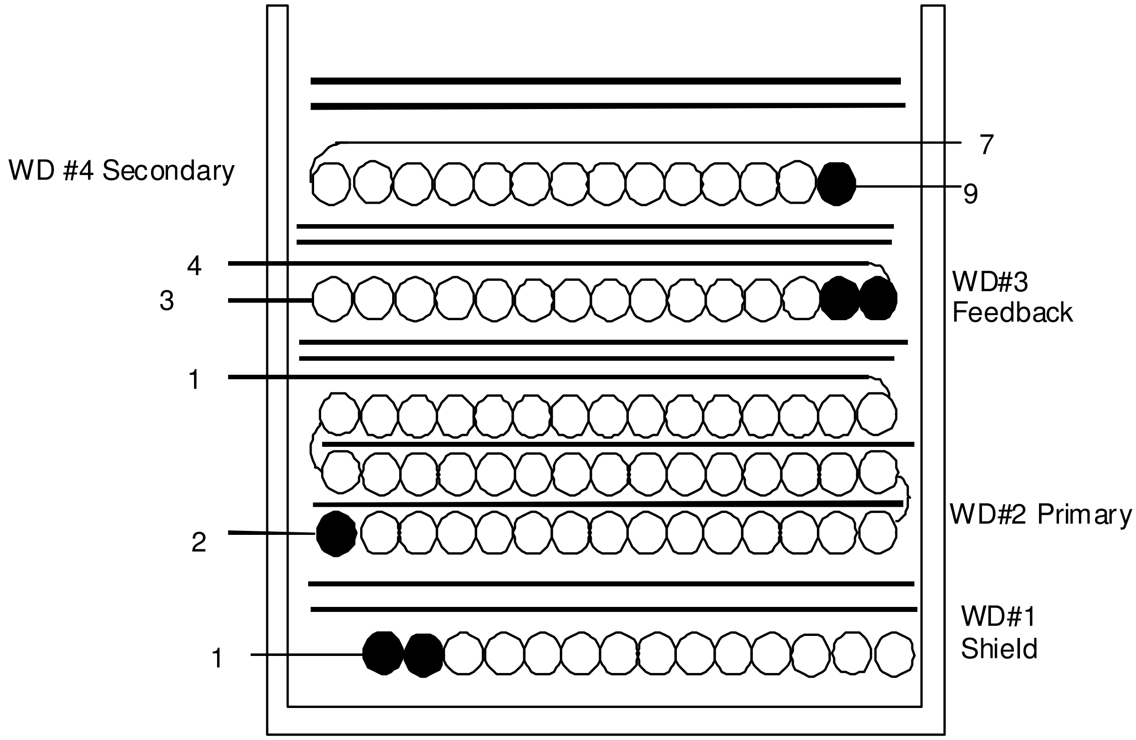

Figure 6 – Transformer Build Diagram.

8.5 Transformer Construction

WD1 Shield Winding	Primary pin side of the bobbin oriented to left hand side. Start at pin 1. Wind 16 bifilar turns of item [3] from left to right. Wind with tight tension across bobbin evenly. Cut at the end.
Insulation	2 Layers of tape [7] for insulation.
WD #2 Primary Winding	Start at Pin 2. Wind 32 turns of item [4] from left to right. Apply one layer of tape [7]. Then wind another 32 turns on the next layer from right to left. Apply one layer of tape [7]. Wind the last 32 turns from left to right. Terminate on pin 1. Wind with tight tension and spread turns across bobbin evenly.
Insulation	2 layers of tape [7] for basic insulation.
WD #3 Feedback Winding	Starting at pin 8 temporarily, wind 9 bifilar turns of item [5]. Wind from right to left with tight tension spreading turns across entire bobbin width. Finish on pin 3. Flip the starting lead to pin 4.
Insulation	2 layers of tape [7] for basic insulation.
WD #4 Secondary Winding	Start at pin 9 wind 10 turns of item [6] from right to left. Spread turns evenly across bobbin. Finish on pin 7.
Core Assembly	Assemble and secure core halves.
Varnish	Dip varnish assembly with item [8].

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9 Design Spreadsheet

ACDC_LinkSwitch-II_030308; Rev.0.23; Copyright Power Integrations 2008	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-II_030308_Rev0-23.xls; LinkSwitch-II Discontinuous Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	85			V	Minimum AC Input Voltage
VACMAX	265			V	Maximum AC Input Voltage
fL	50			Hz	AC Mains Frequency
VO	7.6			V	Output Voltage (at continuous power)
IO	0.7			A	Power Supply Output Current (corresponding to peak power)
Power			5.32	W	Continuous Output Power
n	0.74		0.74		Efficiency Estimate at output terminals. Under 0.7 if no better data available
Z			0.50		Z Factor. Ratio of secondary side losses to the total losses in the power supply. Use 0.5 if no better data available
tC			3.00	ms	Bridge Rectifier Conduction Time Estimate
Add Bias Winding	YES		YES		Choose Yes to add a Bias winding to power the LinkSwitch-II.
CIN	14.7			uF	Input Capacitance
ENTER LinkSwitch-II VARIABLES					
Chosen Device	LNK606		LNK606		Chosen LinkSwitch-II device
Package			PN		Select package (PN, GN or DN)
ILIMITMIN			0.38	A	Minimum Current Limit
ILIMITTYP			0.41	A	Typical Current Limit
ILIMITMAX			0.44	A	Maximum Current Limit
FS			66.00	kHz	Typical Device Switching Frequency at maximum power
VOR			77.76	V	Reflected Output Voltage (VOR < 135 V Recommended)
VDS			10.00	V	LinkSwitch-II on-state Drain to Source Voltage
VD			0.50	V	Output Winding Diode Forward Voltage Drop
KP			2.15		Ensure KDP > 1.3 for discontinuous mode operation
FEEDBACK WINDING PARAMETERS					
NFB			9.00		Feedback winding turns
VFLY			7.29	V	Flyback Voltage
VFOR			8.17	V	Forward voltage
BIAS WINDING PARAMETERS					
VB			10.00	V	Bias Winding Voltage. Bias winding is assumed to be AC-STACKED on top of Feedback winding
NB			4.00		Bias Winding number of turns
DESIGN PARAMETERS					
DCON	5		5.00	us	Output diode conduction time
TON			4.44	us	LinkSwitch-II On-time (calculated at minimum inductance)
RUPPER			18.14	k-ohm	Upper resistor in Feedback resistor divider
RLOWER			5.95	k-ohm	Lower resistor in resistor divider
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					

Core Type					
Core	EE16				Enter Transformer Core
Bobbin					EE16_BOBBIN
AE			19.20	mm^2	Core Effective Cross Sectional Area
LE			35.00	mm^2	Core Effective Path Length
AL			1140.00	nH/turn^2	Ungapped Core Effective Inductance
BW			8.60	mm	Bobbin Physical Winding Width
M			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	3		3.00		Number of Primary Layers
NS			10.00		Number of Secondary Turns. To adjust Secondary number of turns change DCON

DC INPUT VOLTAGE PARAMETERS					
VMIN			87.20	V	Minimum DC bus voltage
VMAX			374.77	V	Maximum DC bus voltage

CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.29		Maximum duty cycle measured at VMIN
IAVG			0.09	A	Input Average current
IP			0.38	A	Peak primary current
IR			0.38	A	primary ripple current
IRMS			0.14	A	Primary RMS current

TRANSFORMER PRIMARY DESIGN PARAMETERS					
LPMIN			1014.75	uH	Minimum Primary inductance
LPTYP			1127.50	uH	Typical Primary inductance
LP_TOLERANCE			10.00		Tolerance in primary inductance
NP			96.00		Primary number of turns. To adjust Primary number of turns change BM_TARGET
ALG			110.11	nH/turn^2	Gapped Core Effective Inductance
BM_TARGET			2500.00	Gauss	Target Flux Density
BM		*Info*	2508.01	Gauss	Maximum Operating Flux Density (calculated at nominal inductance), BM < 2500 is recommended
BP			2951.93	Gauss	Peak Operating Flux Density (calculated at maximum inducatnce and max current limit), BP < 3000 is recommended
BAC			1254.00	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			165.37		Relative Permeability of Ungapped Core
LG			0.20	mm	Gap Length (LG > 0.1 mm)
BWE			25.80	mm	Effective Bobbin Width
OD			0.27	mm	Maximum Primary Wire Diameter including insulation
INS			0.05		Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.22	mm	Bare conductor diameter
AWG			32.00		Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			64.00		Bare conductor effective area in circular mils
CMA			466.91		Primary Winding Current Capacity (200 < CMA < 500)

TRANSFORMER SECONDARY DESIGN PARAMETERS					
Lumped parameters					
ISP			3.66	A	Peak Secondary Current
ISRMS			1.39	A	Secondary RMS Current

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IRIPPLE	1.20	A	Output Capacitor RMS Ripple Current
CMS	278.69		Secondary Bare Conductor minimum circular mils
AWGS	25.00		Secondary Wire Gauge (Rounded up to next larger standard AWG value)

VOLTAGE STRESS PARAMETERS			
VDRAIN	558.06	V	Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)
PIVS	46.64	V	Output Rectifier Maximum Peak Inverse Voltage

FINE TUNING				
RUPPER_ACTUAL	22.6		k-ohm	Actual Value of upper resistor (RUPPER) used on PCB
RLOWER_ACTUAL	7.5		k-ohm	Actual Value of lower resistor (RLOWER) used on PCB
Actual (Measued) Output Voltage (VDC)			V	Measured Output voltage from first prototype
Actual (Measured) Output Current (ADC)			Amps	Measured Output current from first prototype
RUPPER_FINE		22.60	k-ohm	New value of Upper resistor (RUPPER) in Feedback resistor divider. Nearest standard value is 22.6 k-ohms
RLOWER_FINE		7.50	k-ohm	New value of Lower resistor (RLOWER) in Feedback resistor divider. Nearest standard value is 7.5 k-ohms

10 Performance Data

All measurements performed at room temperature, 60 Hz input frequency.

10.1 Active-Mode CEC Measurement Data

All single output adapters, including those provided with products, for sale in California after July 1, 2006, must meet the California Energy Commission (CEC) requirement for minimum active-mode efficiency and no-load input power. Minimum active-mode efficiency is defined as the average efficiency at 25%, 50%, 75%, and 100% of rated output power, with the limit based on the nameplate output power:

Nameplate Output (P_O)	Minimum Efficiency in Active Mode of Operation
< 1 W	$0.49 \times P_O$
≥ 1 W to ≤ 49 W	$0.09 \times \ln(P_O) + 0.5$ [ln = natural log]
> 49 W	0.85 W

For single-input voltage adapters the measurement is made at the rated single nominal input voltage (either 115 VAC or 230 VAC). For universal input adapters the measurement is made at both nominal input voltages (115 VAC and 230 VAC).

The measured average efficiency (or efficiencies for universal input supplies) must be greater than or equal to the efficiency specified by the CEC/Energy Star standard.

Percent of Full Load	Efficiency (%)	
	115 VAC	230 VAC
25	73.2	68.2
50	76.4	73.3
75	76.8	74.8
100	77	75.6
Average	**75.85**	**73**
CEC specified minimum average efficiency (%)	**65**	

More states within the USA and other countries are adopting this standard. For the latest up-to-date information please visit the PI Green Room:

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

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10.2 Efficiency with LED Load – Full Load

This data was taken using 4 LEDs, W5SG-GYHY-5K8L.

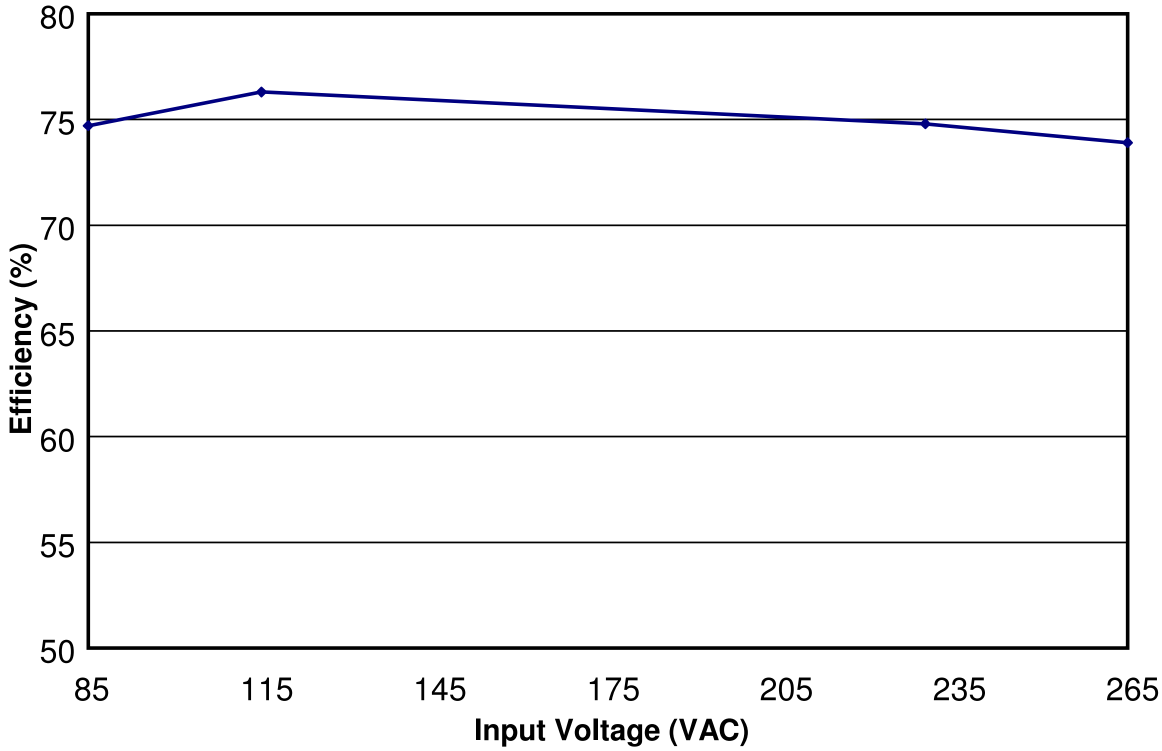

Figure 7 – Full-load Efficiency**.**

10.3 No-load Input Power

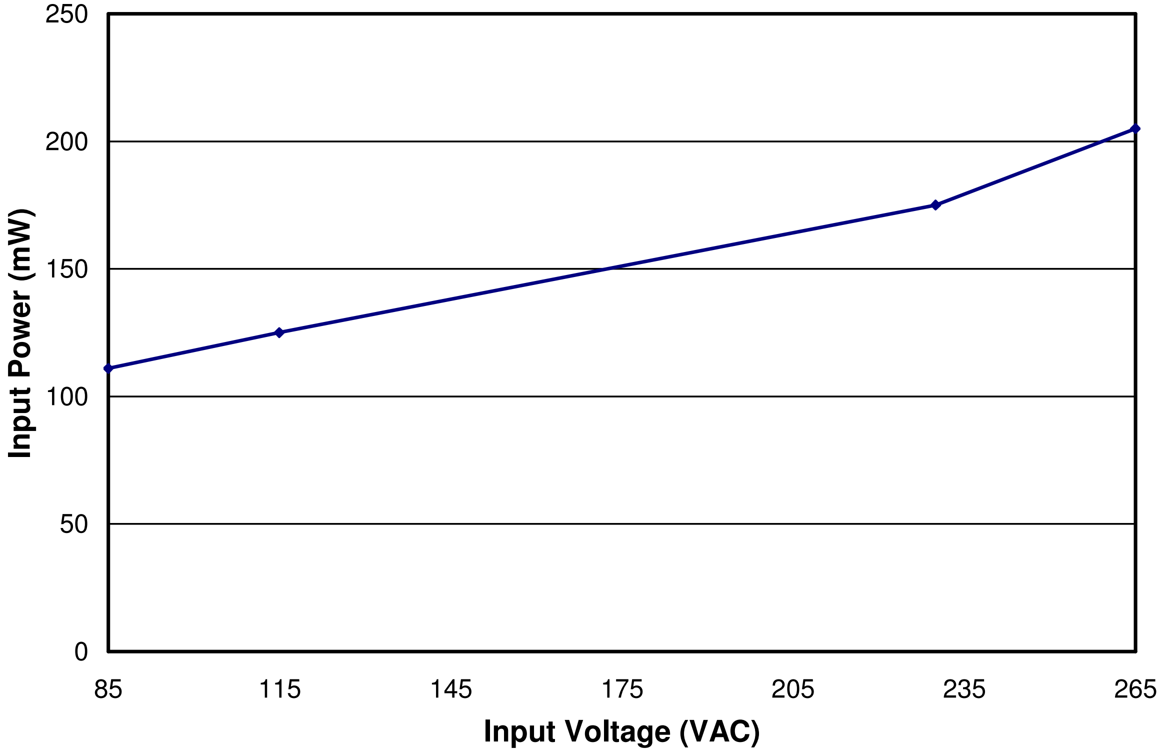

Figure 8 – No-load Power Consumption.

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10.4 Output Characteristic

The output voltage was measured at the board. The data was taken at room temperature.

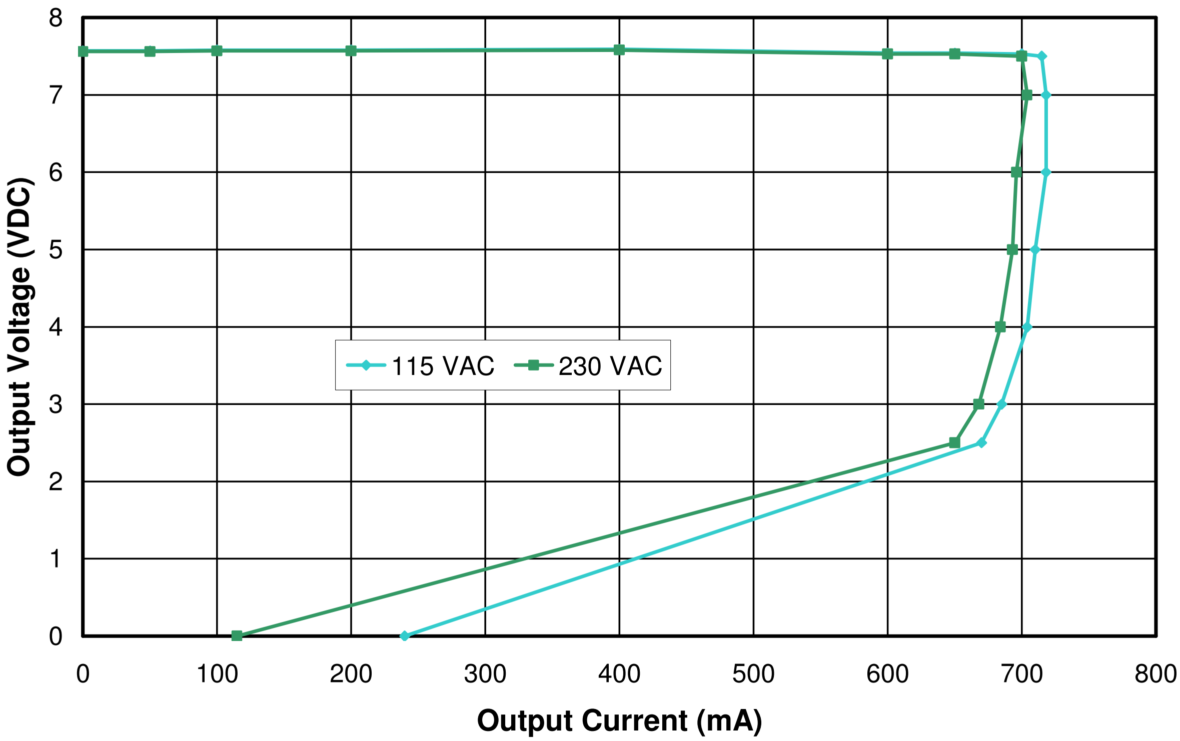

Figure 9 – Output Characteristic.

10.5 Thermal Performance

Thermal performance was measured by putting the whole unit inside a plastic enclosure. The enclosure was also put inside a box protected from air flow. A thermal probe, for ambient temperature measurement, was placed about 1 inch away from the enclosure, suspended in air.

Results:

Input Voltage	85 VAC	265 VAC
Ambient	51.4 °C	52 °C
LNK606PG	75 °C	81 °C
Transformer	67.9 °C	71.8 °C
Output Diode	86.6 °C	89.9 °C

10.6 Output Ripple Measurements

10.6.1 Ripple Measurement Technique

For DC output ripple measurements, use a modified oscilloscope test probe to reduce spurious signals. Details of the probe modification are provided in figures below.
.

Tie two capacitors in parallel across the probe tip of the 4987BA probe adapter. Use a 0.1 μF / 50 V ceramic type and 1.0 μF / 50 V aluminum electrolytic. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs. (Refer to Figure 10 and Figure 11.)

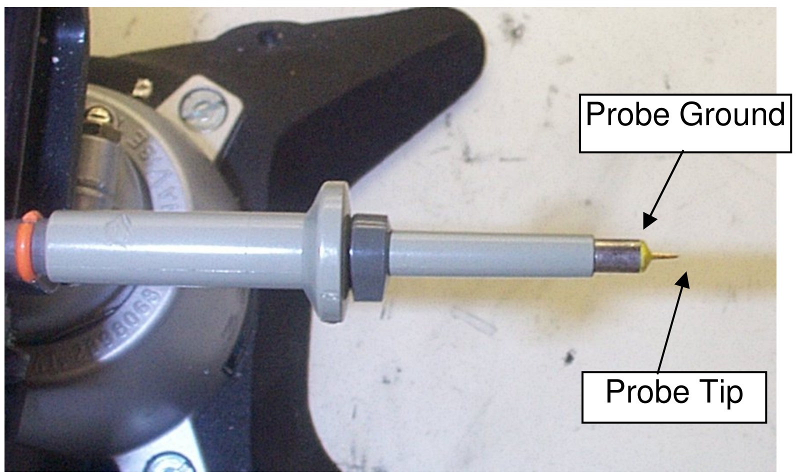

Figure 10 – Oscilloscope Probe Prepared for Ripple Measurement. (End cap and ground lead removed)

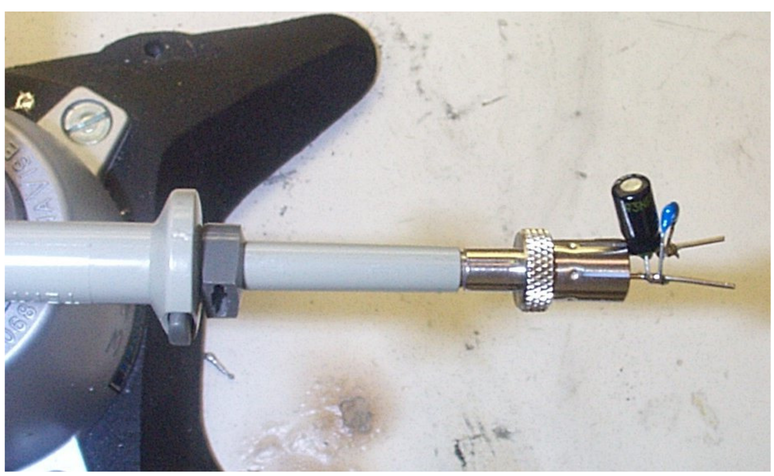

Figure 11 – Oscilloscope Probe with Probe Master 5125BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel, decoupling capacitors added)

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10.6.2 Measurement Results

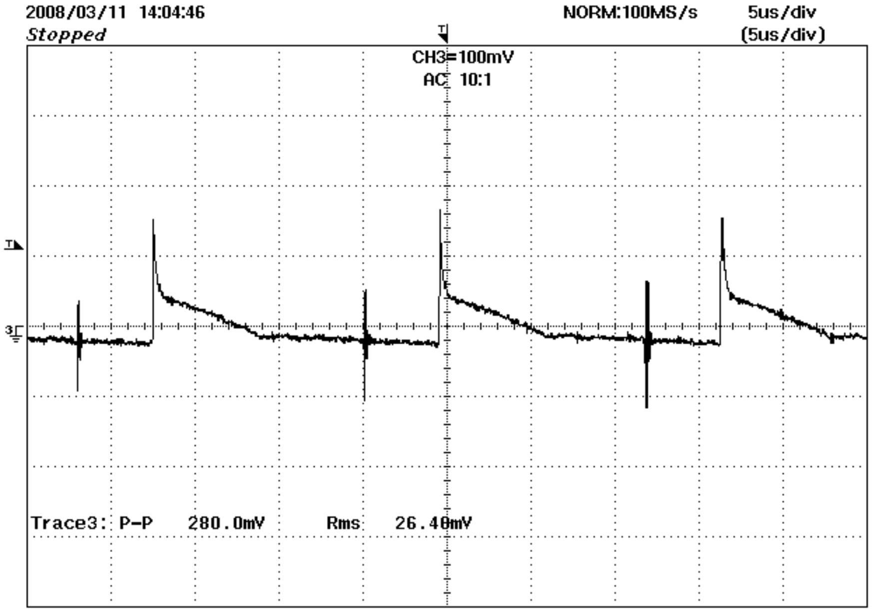

Figure 12 – Output Ripple and Noise at 85 VAC Input. 5 µs/div, 100 mV/div.

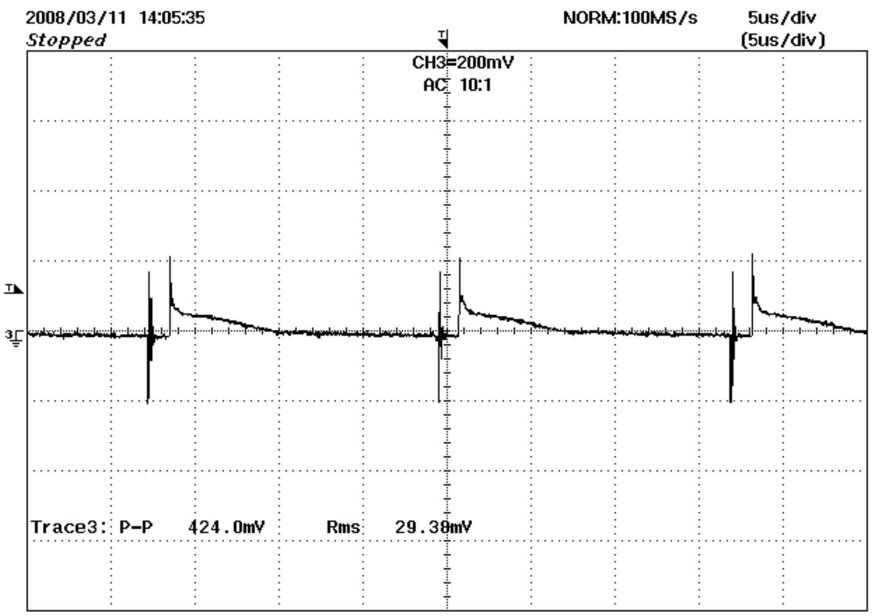

Figure 13 – Output Ripple and Noise at 265 VAC Input. 5 µs/div, 200 mV/div.

11 Waveforms

11.1 Output Startup Profile

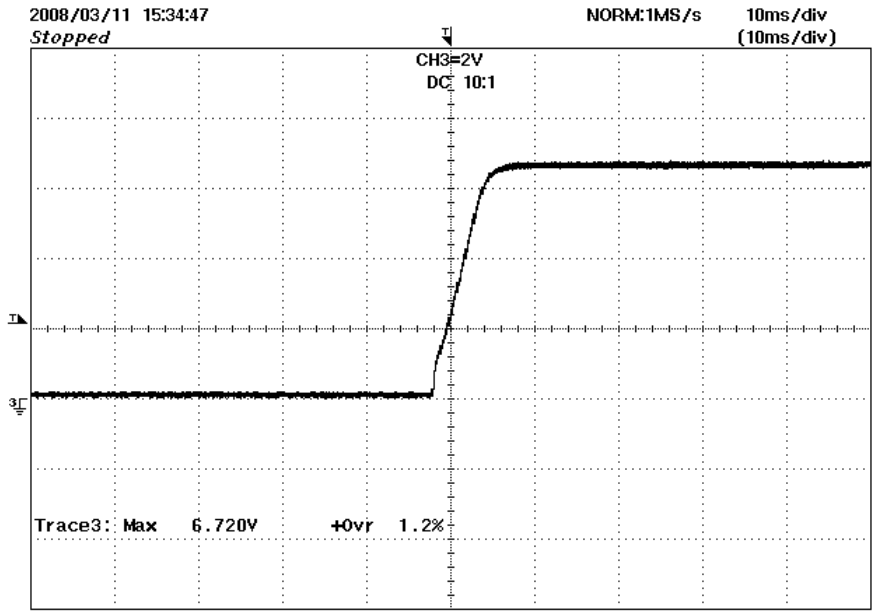

Figure 14 – Output Start-up at 115 VAC, Full Load. 10 ms/div, 2 V/div.

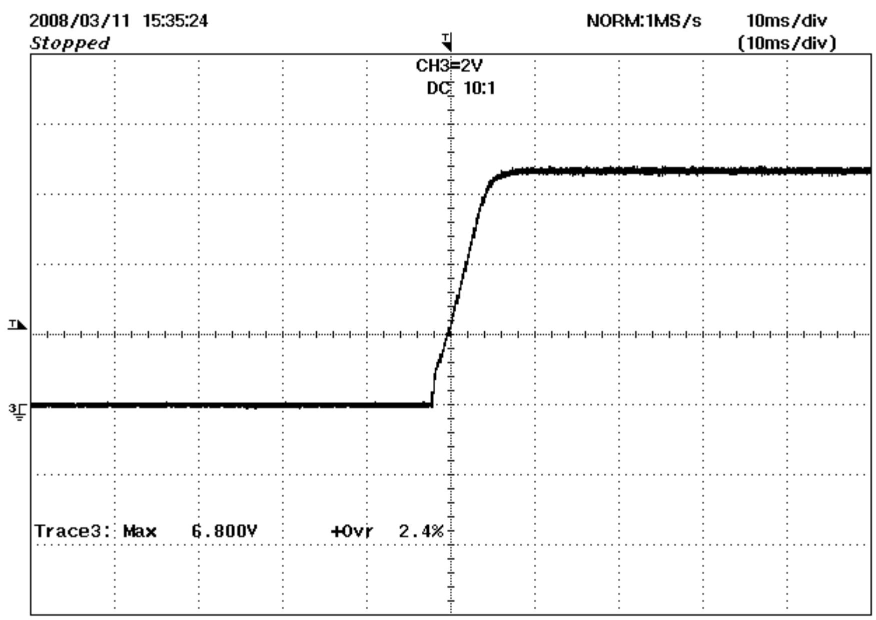

Figure 15 – Output Start-up at 230 VAC, Full Load. 10 ms/div, 2 V/div.

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11.2 Drain Voltage

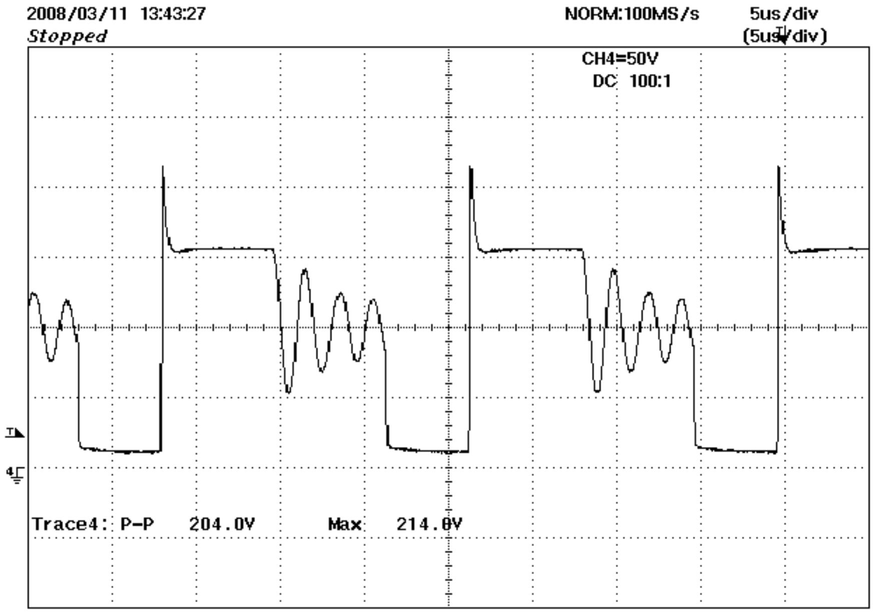

Figure 16 – Drain Voltage at 85 VAC Input. 5 µs/div, 50 V/div.

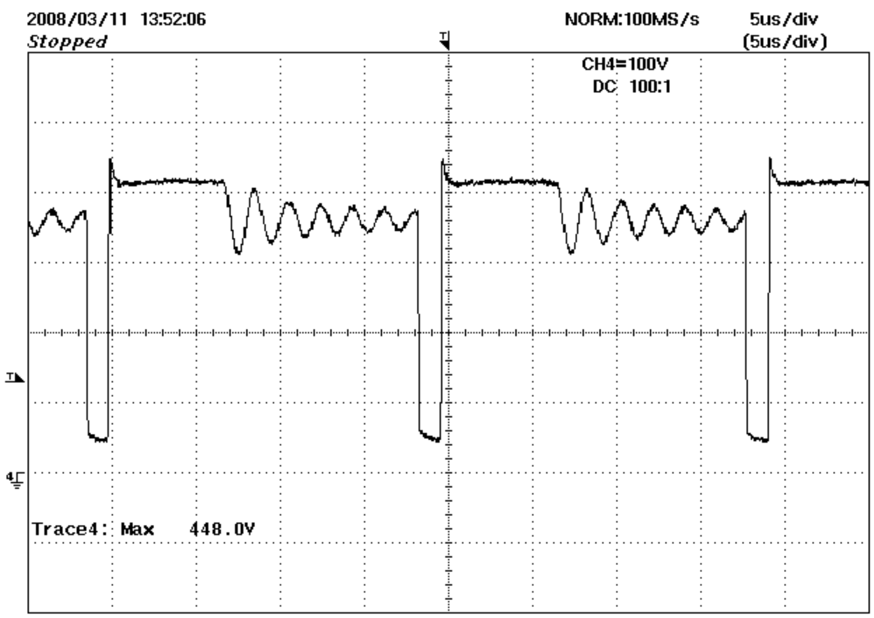

Figure 17 – Drain Voltage at 265 VAC Input. 5 µs/div, 100 V/div.

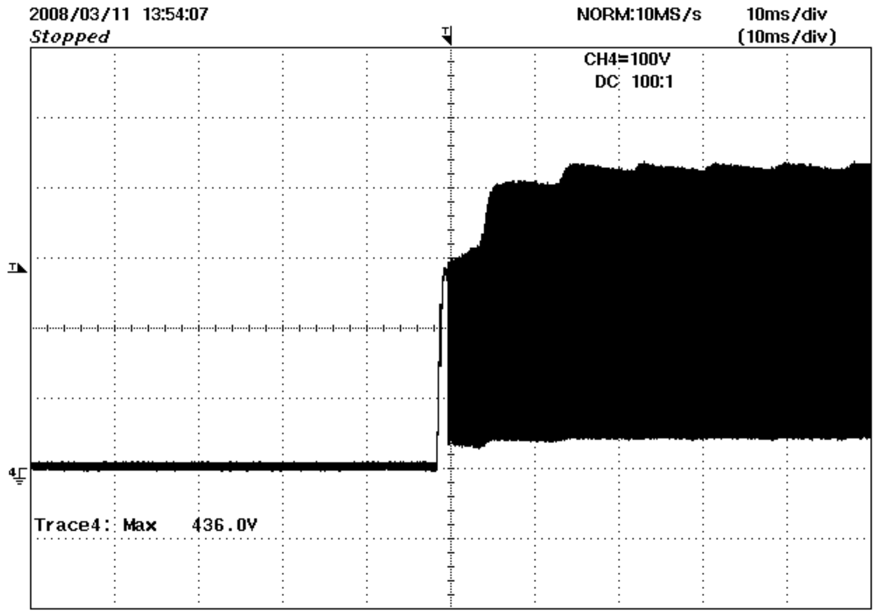

Figure 18 – Drain Voltage During Start-up at 265 VAC. 10 ms/div, 100 V/div.

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12 Conducted EMI

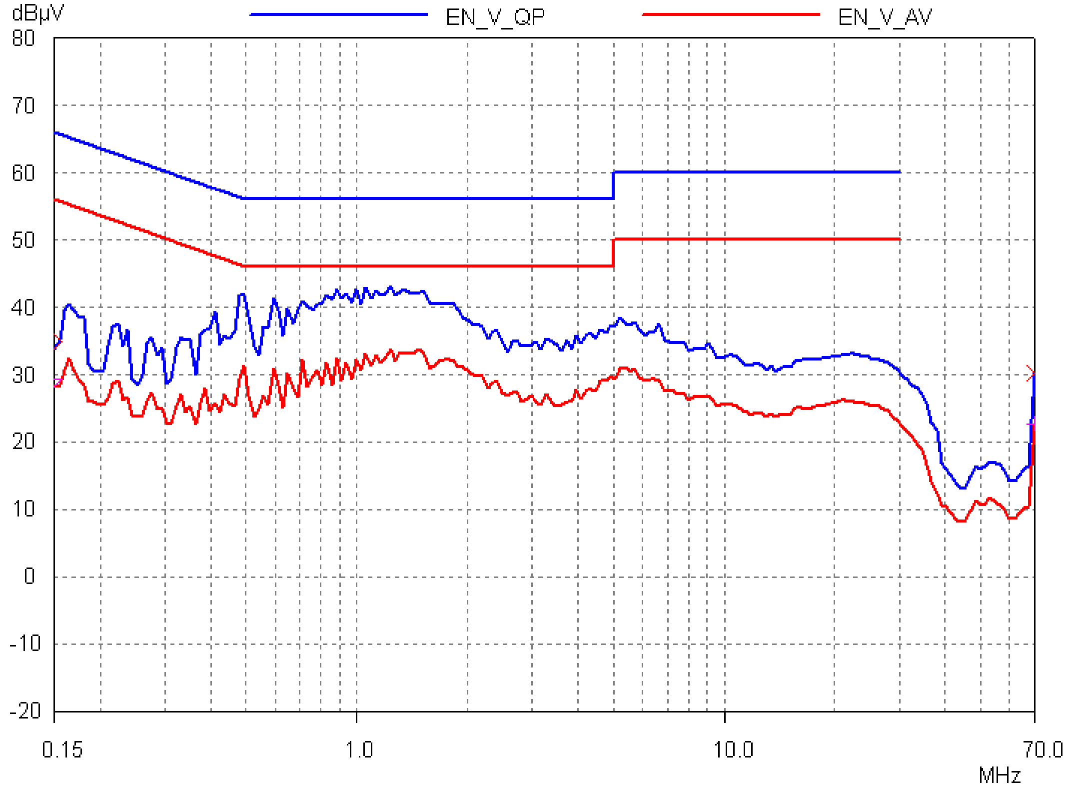

Figure 19 – Conducted EMI at 115 VAC. Output RTN Connected to Protective Earth (PE). EN55015B Limits Also Shown.

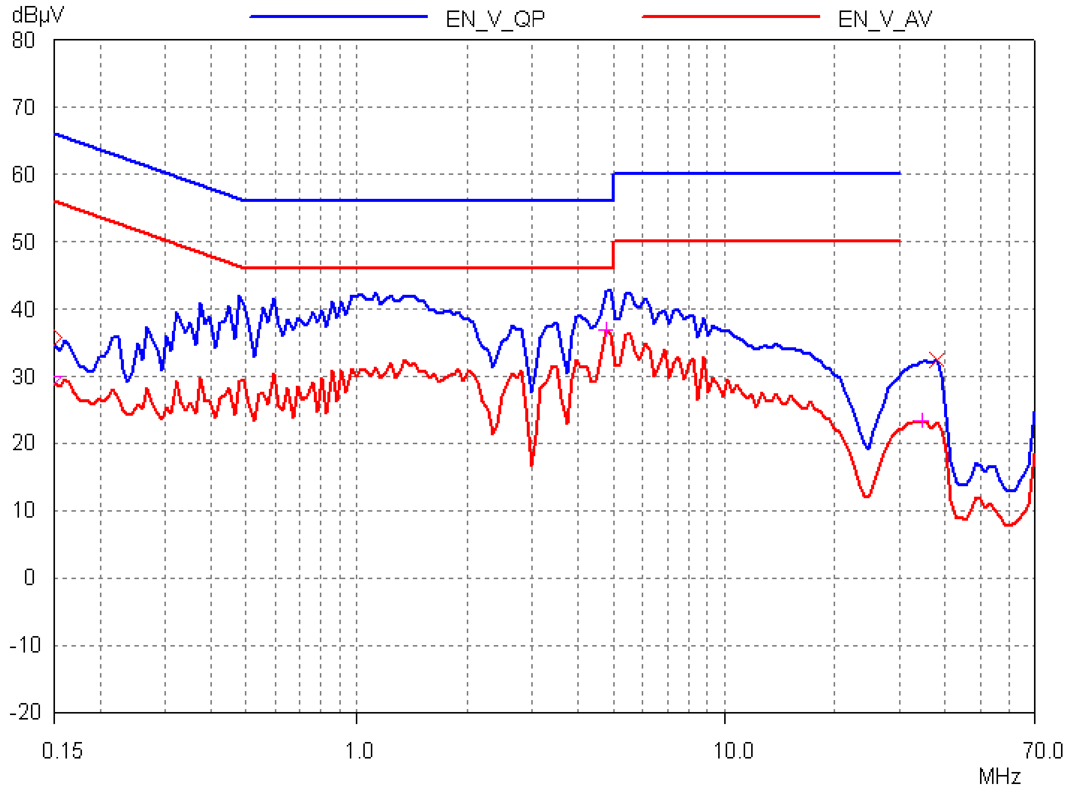

Figure 20 – Conducted EMI at 230 VAC. Output RTN Connected to PE. EN55015B Limits Also Shown.

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
15-May-08	YG	1.0	Initial Release	SGK

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