DESIGN EXAMPLE REPORT

Title	***4.2 W LED Driver Using LNK605DG***
Specification	85 – 265 VAC Input; 12 V, 350 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-185
Date	May 15, 2008
Revision	1.0

Summary and Features

- Accurate primary-side constant voltage/constant current (CV/CC) controller eliminates secondary side control and optocoupler
  - ±5% output voltage and ±10% output current accuracy including line, load, temperature and component tolerance
  - No current-sense resistors for maximized efficiency
  - Low part-count solution for lower cost
- Over-temperature protection – tight tolerance (±5%) with hysteretic recovery for safe PCB temperatures under all conditions
- Auto-restart output short circuit and open-loop protection
- EcoSmart® – Easily meets all existing and proposed international energy efficiency standards – China (CECP) / CEC / EPA / European Commission
  - ON/OFF control provides constant efficiency to very light loads
    - No-load consumption <200 mW at 265 VAC
    - Ultra-low leakage current: <5 µA at 265 VAC input (no Y capacitor required)
  - Easy compliance to EN55015 and CISPR-22 Class B EMI
  - Green package: halogen free and RoHS compliant

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Table of Contents

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 universal input, 12 V, 350 mA CV/CC power supply for LED driver applications. This power supply utilizes the LNK605DG device from the Power Integrations LinkSwitch-II family.

This document contains the power supply and transformer specifications, schematics, bill of materials, and typical performance characteristics pertaining to this power supply.

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2 Prototype Photo

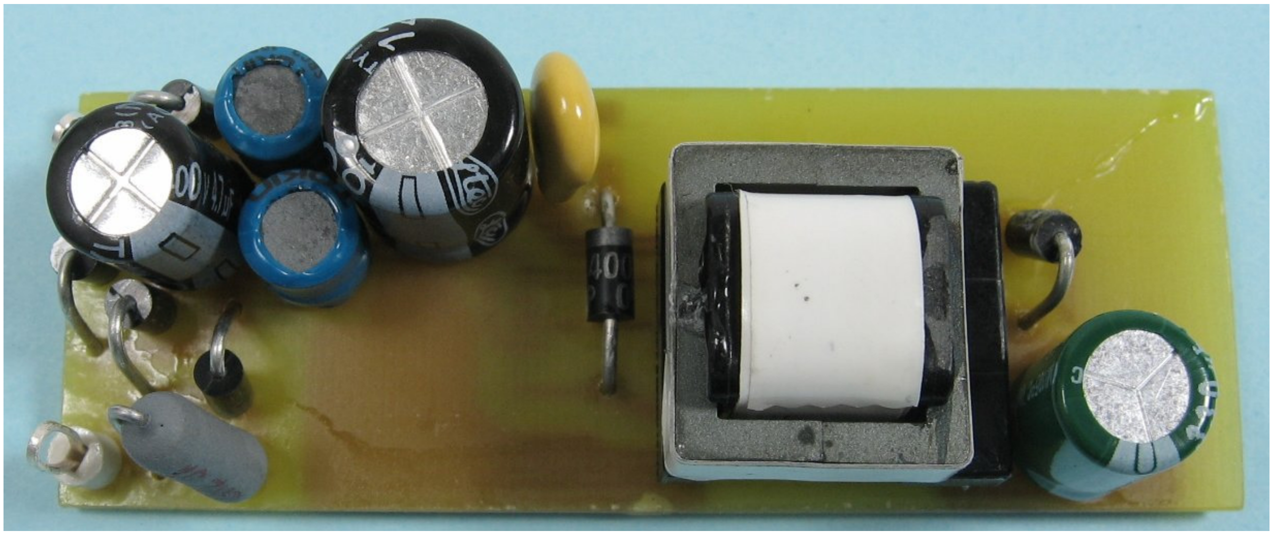

Figure 1 – Prototype Top View.

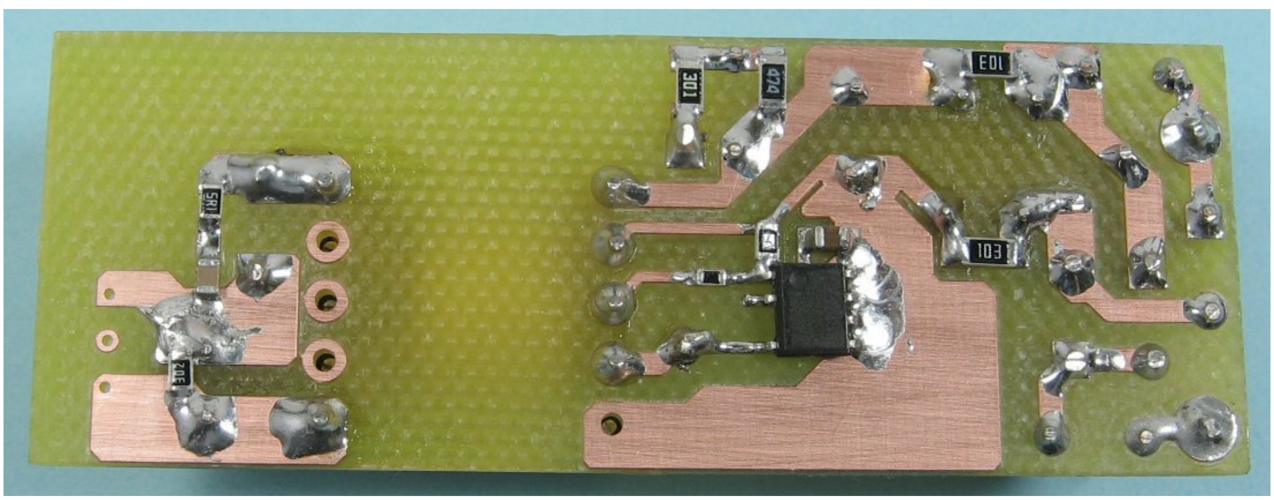

Figure 2 – Prototype Bottom View.

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				200	mW	265 VAC
Output						
Output Voltage 1	V_{OUT1}	11.4	12	12.6	V	Measured at the output capacitor
Output Ripple Voltage 1	$V_{RIPPLE1}$		300		mV	20 MHz bandwidth
Output Current 1	I_{OUT1}	315	350	385	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		4.2		W	
Efficiency						
Full Load	η	75			%	
Environmental						
Conducted EMI		Meets CISPR22B / EN55015B				
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

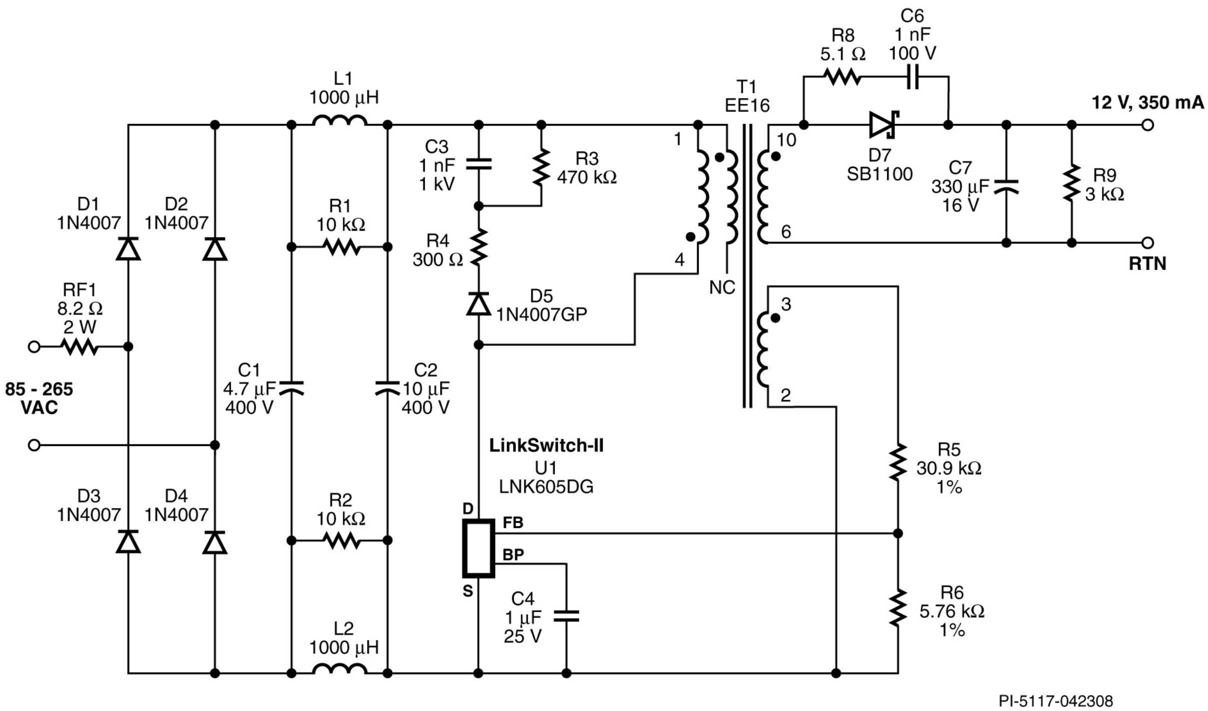

Figure 3 – Circuit Schematic.

5 Circuit Description

This circuit utilizes the LNK605DG in a primary-side regulated flyback power-supply configuration.

The LNK605DG device (U1) incorporates a power switching device, an oscillator, a CV/CC control engine, and startup and protection functions all as part of one IC. It has an integrated 700 V MOSFET that 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 LNK605DG'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 LNK605DG Operation

The LNK605DG monolithically integrates a 700 V power MOSFET switch with an ON/OFF control function (for transformer core and CV/CC functions). The constant voltage (CV) regulation uses the unique ON/OFF control scheme which provides tight regulation over a wide temperature range. Beyond the maximum power point, the switching frequency is reduced to provide constant-current operation. This makes the LNK605DG ideal for driving LEDs, which require a constant current level for consistent light output. In addition, this integrated voltage and current regulator compensates for not only transformer inductance tolerances and internal device parameters, but input voltage variations as well.

The LNK605DG also provides a sophisticated range of protection features such as auto-restart and over-temperature protection. Auto-restart is triggered by fault conditions such as an open feedback loop or a shorted output. Over-temperature protection employs accurate hysteretic thermal shutdown to ensure safe average PCB temperatures under all conditions.

5.2 Input Filter

Diodes D1, D2, D3, and D4 rectify the AC input power. The rectified DC is filtered by the bulk storage capacitors C1 and C2. Inductors L1 and L2, with capacitors C1 and C2, form pi (π) filters which attenuate conducted differential-mode EMI noise. This configuration, along with Power Integrations' transformer E-shield™ technology, allows this design to meet EMI standard EN55015 class B with 10 dB of margin, and without using a Y capacitor. Resistors R1 and R2 damp out excessive ringing and improve EMI immunity. Fusible, flameproof resistor RF1 provides differential EMI filtering, limits inrush current when AC is first applied ,and act as a fuse.

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5.3 LNK605DG Primary

The LNK605DG device (U1) incorporates a power switching device, an oscillator, a CC/CV control engine, and startup and protection functions all in one IC. The 700 V MOSFET allows for sufficient voltage margin in universal input AC applications. The device is completely self-powered from the bypass (BP) pin and decoupling capacitor C4.

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 the integrated MOSFET in U1. An RCD-R clamp consisting of D5, R3, R4, and C3 limits any drain-voltage spikes caused by leakage inductance.

5.4 Output Rectification

The transformer's secondary is rectified by D7, a Schottky-barrier diode (chosen for higher efficiency), and filtered by C7. In this application C7 has a low ESR, by design, which enables the circuit to meet the required output voltage ripple requirement without using an LC-post filter.

5.5 Output Regulation

The LNK605DG regulates output using ON/OFF control for CV regulation, and frequency control for constant current (CC) regulation. Feedback resistors R5 and R6 have 1% tolerance values to accurately center both the nominal output voltage and the current in CC operation. The CV feature provides output over-voltage protection (OVP) in case any LEDs fail open-circuit.

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.

While the LNK605DG operates in the CV region, it regulates the output voltage by ON/OFF control. It maintains the output voltage level by adjusting the ratio of enabled cycles to disabled cycles. This also optimizes the efficiency of the converter over the entire load range.

When the LNK605DG enters a state where no switching cycles are skipped (concurrent with the maximum power point) 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 this voltage reduction at the FB pin, the switching frequency is reduced to achieve constant output current.

6 PCB Layout

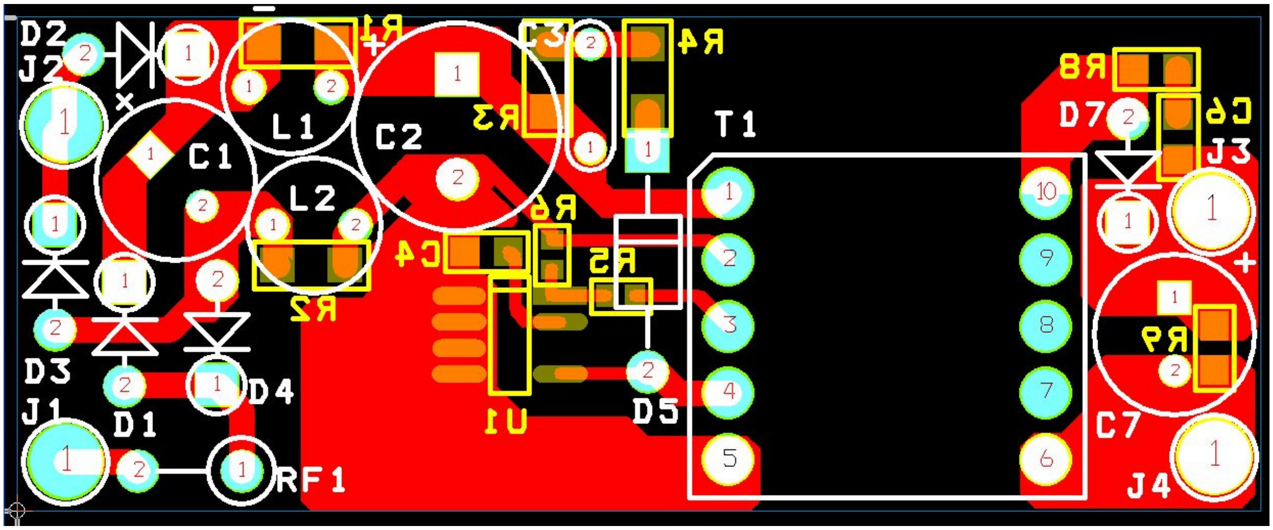

Figure 4 – PCB Layout (61mm x 24mm).

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7 Bill of Materials

Item	Qty	Ref Des	Description	Mfg	Mfg Part Number
1	1	C1	4.7 µF, 400 V, Electrolytic, (8 x 11.5)	Taicon Corporation	TAQ2G4R7MK0811MLL3
2	1	C2	10 µF, 400 V, Electrolytic, Low ESR, 79 mA, (10 x 12.5)	Ltec	TYD2GM100G13O
3	1	C3	1 nF, 1 kV, Disc Ceramic	Panasonic - ECG	ECK-D3A102KBP
4	1	C4	1 µF, 25 V, Ceramic, X7R, 0805	Panasonic	ECJ-2FB1E105K
6	1	C6	1 nF, 100 V, Ceramic, X7R, 0805	Panasonic	ECJ-2VB2A102K
7	1	C7	330 µF, 16 V, Electrolytic, Very Low ESR, 53 mΩ, (8 x 15)	Nippon Chemi-Con	EKZE160ELL331MH15D
8	4	D1 D2 D3 D4	1000 V, 1 A, Rectifier, DO-41	Vishay	1N4007-E3/54
9	1	D5	1000 V, 1 A, Rectifier, Glass Passivated, 2 us, DO-41	Vishay	1N4007GP
11	1	D7	100 V, 1 A, Schottky, DO-41	Fairchild	SB1100
12	4	J1 J2 J3 J4	Test Point, WHT,THRU-HOLE MOUNT	Keystone	5012
13	2	L1 L2	1000 uH, 0.18 A, 7 x 10.5 mm	Tokin	SBC2-102-181
14	2	R1 R2	10 kΩ, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ103V
15	1	R3	470 kΩ, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ474V
16	1	R4	300 Ω, 5%, 1/4 W, Metal Film, 1206	Panasonic	ERJ-8GEYJ301V
17	1	R5	30.9 kΩ, 1%, 1/16 W, Metal Film, 0603	Panasonic	ERJ-3EKF3092V
18	1	R6	5.76 kΩ, 1%, 1/16 W, Metal Film, 0603	Panasonic	ERJ-3EKF5761V
20	1	R8	5.1 Ω, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ5R1V
21	1	R9	3 kΩ, 5%, 1/8 W, Metal Film, 0805	Panasonic	ERJ-6GEYJ302V
22	1	RF1	8.2 Ω, 2 W, Fusible/Flame Proof Wire Wound	Vitrohm	CRF253-4 5T 8R2
23	1	T1	Bobbin, EE16, Horizontal, 10 pins	Ho Jinn Plastic	PM-9820
24	1	U1	LinkSwitch-II, LNK605DG, CV/CC, DIP-8C	Power Integrations	LNK605DG

8 Transformer Specification

8.1 Electrical Diagram

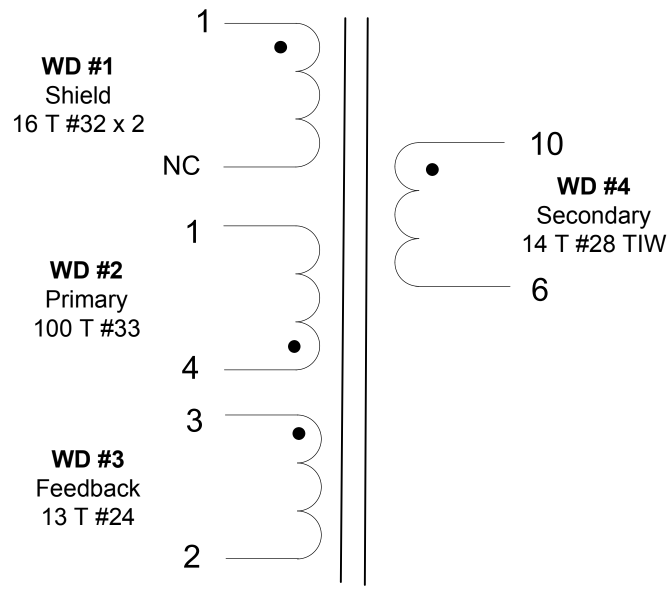

Figure 5 –Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from Primary to Secondary	3000 VAC
Primary Inductance	Pins 1-4, all other windings open, measured at 66 kHz, 0.4 VRMS	1.545 mH, ±10%
Resonant Frequency	Pins 1-4, all other windings open	500 kHz (Min.)
Primary Leakage Inductance	Pins 1-4, with Pins 6 and 10 shorted, measured at 66 kHz, 0.4 VRMS	70 μH (Max.)

8.3 Materials

Item	Description
[1]	Core: PC44, gapped for A_L of 139 nH/t^2
[2]	Bobbin: Horizontal 10 pin, EE16
[3]	Magnet Wire: #32 AWG
[4]	Magnet Wire: #33 AWG
[5]	Magnet Wire: #24 AWG
[6]	Triple Insulated Wire: #28 AWG
[7]	Tape, 3M 1298 Polyester Film, 2.0 Mils thick, 8.4 mm wide
[8]	Varnish

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8.4 Transformer Build Diagram

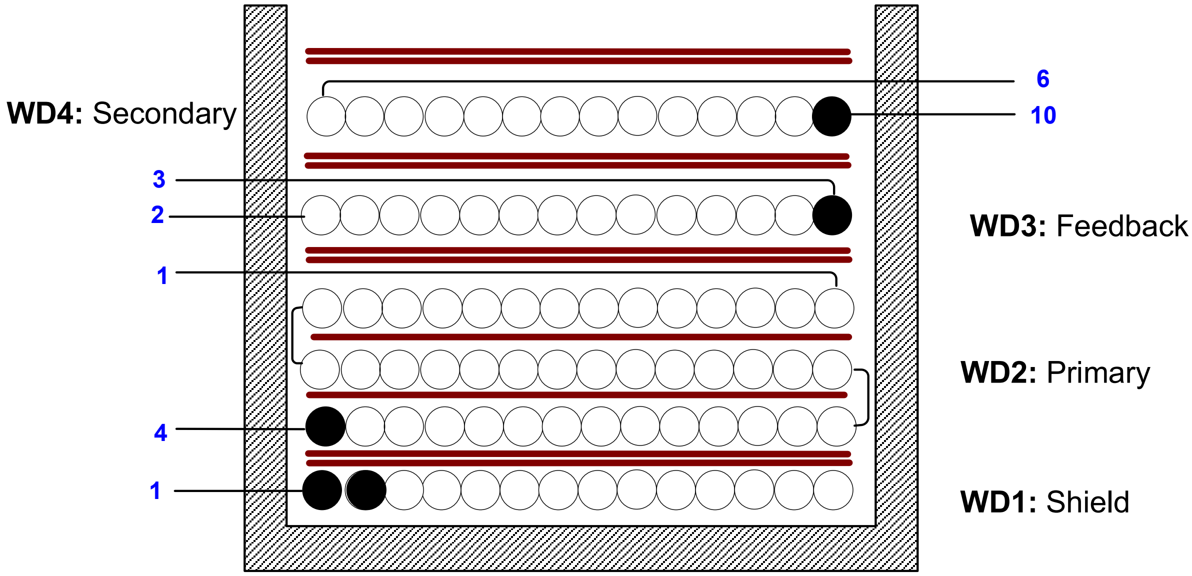

Figure 6 – Transformer Build Diagram.

8.5 Transformer Construction

WD #1 Shield	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 4. Wind 34 turns of item [4] from left to right. Apply one layer of tape [7]. Then wind another 33 turns on the next layer from right to left. Apply one layer of tape [7]. Wind the last 33 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 13 turns of item [5]. Wind from right to left with tight tension spreading turns across entire bobbin width. Finish on pin 2. Flip the starting lead to pin 3.
Insulation	2 layers of tape [7] for basic insulation.
WD #4 Secondary Winding	Start at pin 10 wind 14 turns of item [6] from right to left. Spread turns evenly across bobbin. Finish on pin 6.
Core Assembly	Assemble and secure core halves.
Varnish	Dip varnish assembly with item [8].

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	12			V	Output Voltage (at continuous power)
IO	0.35			A	Power Supply Output Current (corresponding to peak power)
Power			4.20	W	Continuous Output Power
n	0.75		0.75		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	no		N/A		Choose Yes to add a Bias winding to power the LinkSwitch-II.
CIN	9.4			uF	Input Capacitance

ENTER LinkSwitch-II VARIABLES					
Chosen Device	LNK605		LNK605		Chosen LinkSwitch-II device
Package			DN		Select package (PN, GN or DN)
ILIMITMIN			0.29	A	Minimum Current Limit
ILIMITTYP			0.31	A	Typical Current Limit
ILIMITMAX			0.33	A	Maximum Current Limit
FS			66.00	kHz	Typical Device Switching Frequency at maximum power
VOR			89.29	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			2.23		Ensure KDP > 1.3 for discontinuous mode operation

FEEDBACK WINDING PARAMETERS					
NFB			13.00		Feedback winding turns
VFLY			11.61	V	Flyback Voltage
VFOR			10.16	V	Forward voltage

BIAS WINDING PARAMETERS					
VB			N/A	V	Output Voltage is greater than 10 V. The feedback winding itself can be used to provide external bias to the LinkSwitch. Additional Bias winding is not required.
NB			N/A		Bias Winding number of turns

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DESIGN PARAMETERS				
DCON	4.5	4.50	us	Output diode conduction time
TON		5.13	us	LinkSwitch-II On-time (calculated at minimum inductance)
RUPPER		26.06	k-ohm	Upper resistor in Feedback resistor divider
RLOWER		4.97	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	2	2.00		Number of Primary Layers
NS		14.00		Number of Secondary Turns. To adjust Secondary number of turns change DCON

DC INPUT VOLTAGE PARAMETERS				
VMIN		78.16	V	Minimum DC bus voltage
VMAX		374.77	V	Maximum DC bus voltage

CURRENT WAVEFORM SHAPE PARAMETERS				
DMAX		0.34		Maximum duty cycle measured at VMIN
IAVG		0.08	A	Input Average current
IP		0.29	A	Peak primary current
IR		0.29	A	primary ripple current
IRMS		0.11	A	Primary RMS current

TRANSFORMER PRIMARY DESIGN PARAMETERS				
LPMIN		1390.60	uH	Minimum Primary inductance
LPTYP		1545.11	uH	Typical Primary inductance
LP_TOLERANCE		10.00		Tolerance in primary inductance
NP		100.00		Primary number of turns. To adjust Primary number of turns change BM_TARGET
ALG		139.06	nH/turn^2	Gapped Core Effective Inductance
BM_TARGET		2500.00	Gauss	Target Flux Density
BM		2494.71	Gauss	Maximum Operating Flux Density (calculated at nominal inductance), BM < 2500 is recommended
BP		2936.27	Gauss	Peak Operating Flux Density (calculated at maximum inductance and max current limit), BP < 3000 is recommended
BAC		1247.35	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur		165.37		Relative Permeability of Ungapped Core
LG		0.15	mm	Gap Length (LG > 0.1 mm)
BWE		17.20	mm	Effective Bobbin Width
OD		0.17	mm	Maximum Primary Wire Diameter including insulation

INS	0.04		Estimated Total Insulation Thickness (= 2 * film thickness)
DIA	0.13	mm	Bare conductor diameter
AWG	36.00		Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM	25.40		Bare conductor effective area in circular mils
CMA	227.94		Primary Winding Current Capacity (200 < CMA < 500)

TRANSFORMER SECONDARY DESIGN PARAMETERS			
Lumped parameters			
ISP	2.06	A	Peak Secondary Current
ISRMS	0.74	A	Secondary RMS Current
IRIPPLE	0.66	A	Output Capacitor RMS Ripple Current
CMS	148.93		Secondary Bare Conductor minimum circular mils
AWGS	28.00		Secondary Wire Gauge (Rounded up to next larger standard AWG value)

VOLTAGE STRESS PARAMETERS			
VDRAIN	582.27	V	Maximum Drain Voltage Estimate (Assumes 20% zener clamp tolerance and an additional 10% temperature tolerance)
PIVS	64.47	V	Output Rectifier Maximum Peak Inverse Voltage

FINE TUNING				
RUPPER_ACTUAL	30.9	30.90	k-ohm	Actual Value of upper resistor (RUPPER) used on PCB
RLOWER_ACTUAL	5.76	5.76	k-ohm	Actual Value of lower resistor (RLOWER) used on PCB
Actual (Measured) Output Voltage (VDC)		12.00	V	Measured Output voltage from first prototype
Actual (Measured) Output Current (ADC)		0.35	Amps	Measured Output current from first prototype
RUPPER_FINE		30.90	k-ohm	New value of Upper resistor (RUPPER) in Feedback resistor divider. Nearest standard value is 30.9 k-ohms
RLOWER_FINE		5.76	k-ohm	New value of Lower resistor (RLOWER) in Feedback resistor divider. Nearest standard value is 5.62 k-ohms

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10 Performance Data

All measurements were taken at room temperature, 60 Hz input frequency.

10.1 Efficiency with LED Load – Full Load

This data was taken using three 350 mA, 3.5 V LEDs connected in a series string.

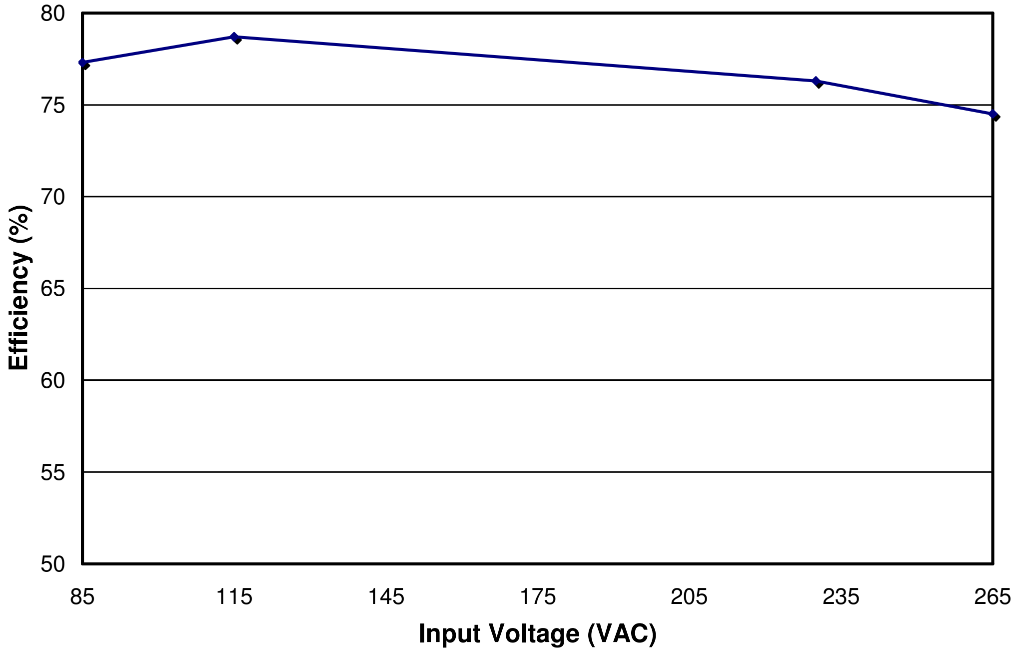

Figure 7 – Full-load Efficiency vs Input Voltage.

10.2 No-load Input Power

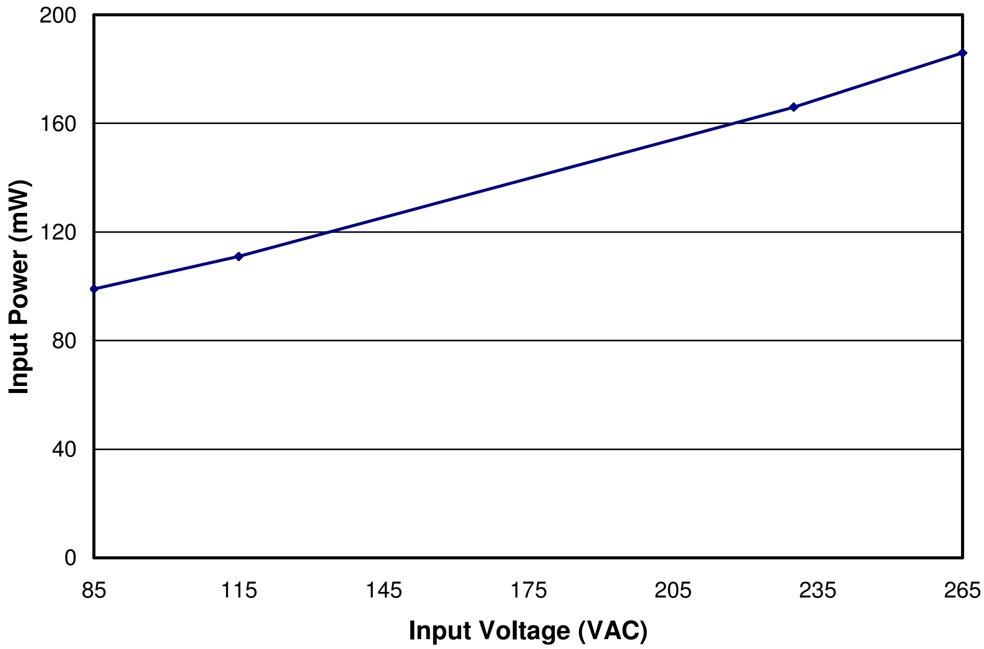

Figure 8 – No load Power Consumption.

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10.3 Output Characteristic

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

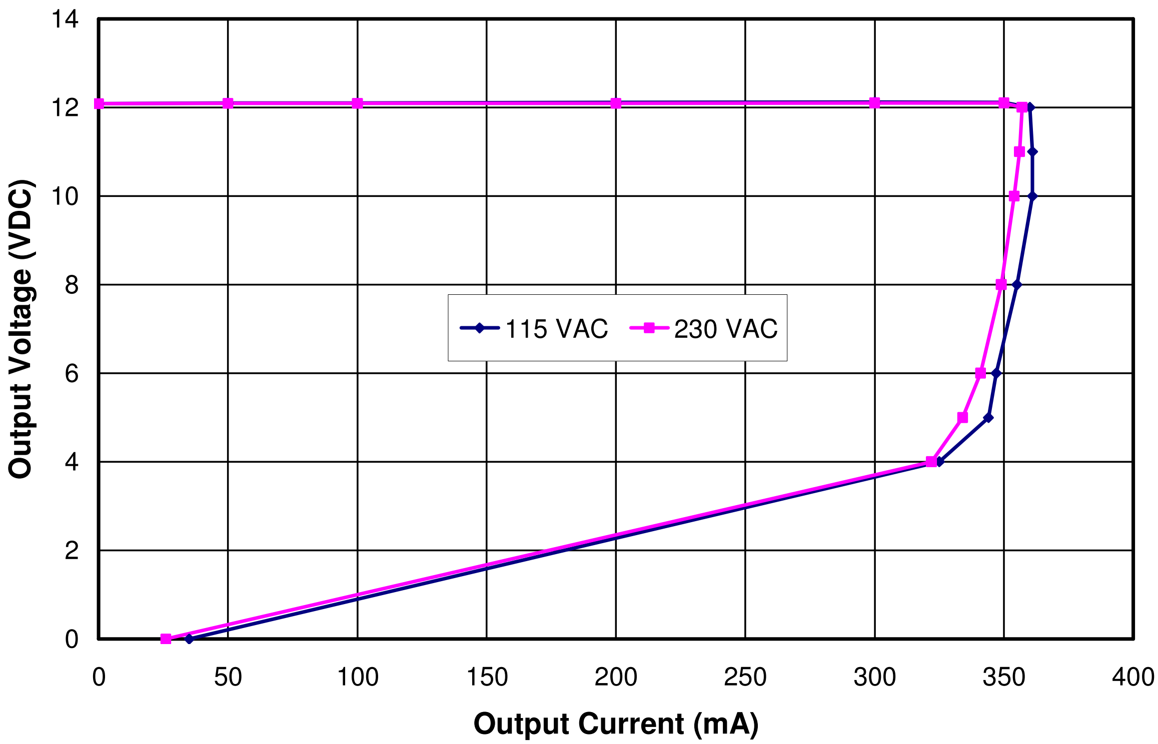

Figure 9 – Output Voltage Characteristic.

10.4 Thermal Performance

Thermal performance was measured by putting the power supply inside a plastic enclosure. The enclosure was placed inside a box, protected from air flow. An ambient thermal probe was placed about one inch away from the enclosure. A thermocouple was soldered to U1 at its source (for measuring its source temperature) and a thermocouple was soldered to output diode D5. The thermocouple monitoring the transformer core temperature was taped in place.

Results:

Input Voltage	85 VAC	265 VAC
Ambient	50.4 °C	50.5 °C
U1	76.9 °C	83.9 °C
T1	67.3 °C	69.7 °C
D7	74.9 °C	74.7 °C

10.5 Output Ripple Measurements

10.5.1 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 capacitor and a 1.0 µF/50 V aluminum-electrolytic capacitor. The aluminum-electrolytic capacitor is polarized, so always maintain proper polarity across DC outputs.

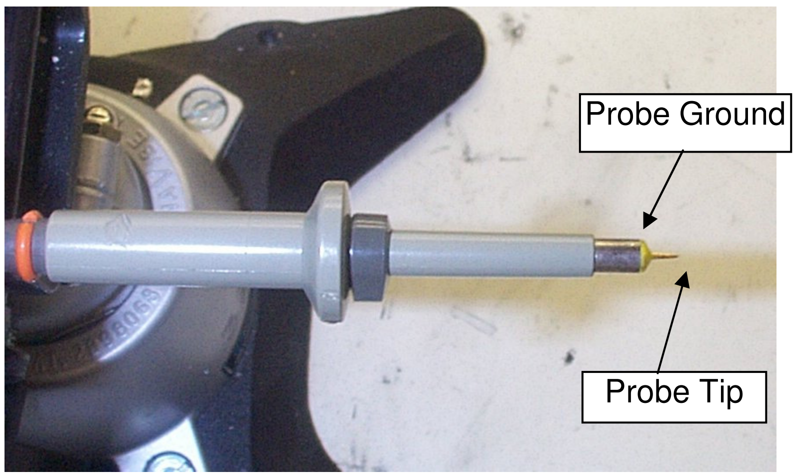

Figure 10 – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed)

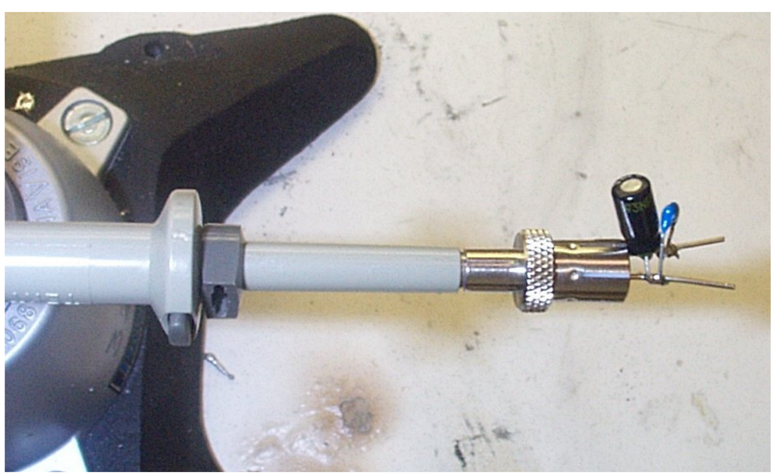

Figure 11 – Oscilloscope Probe with Probe Master 4987BA BNC Adapter. (Modified with wires for probe ground for ripple measurement, and two parallel decoupling capacitors added)

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10.5.2 Measurement Results

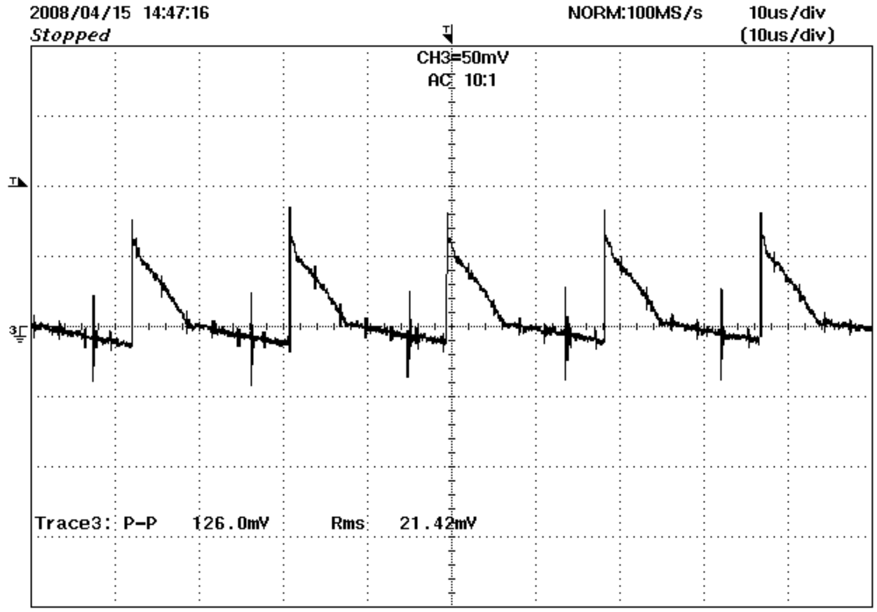

Figure 12 – Output Ripple and Noise at 85 VAC Input and LED Load.

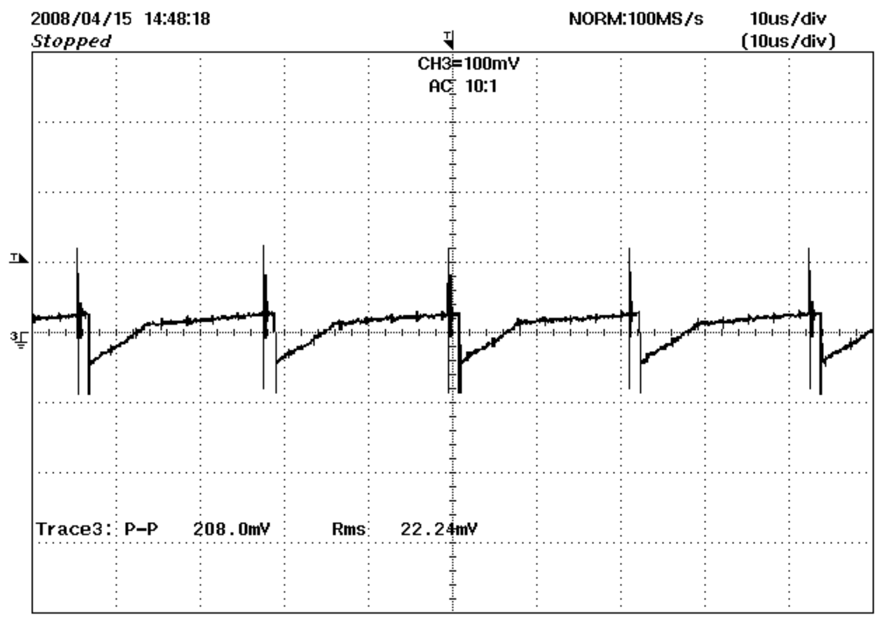

Figure 13 – Output Ripple and Noise at 265 VAC Input and LED Load.

11 Output Current Ripple

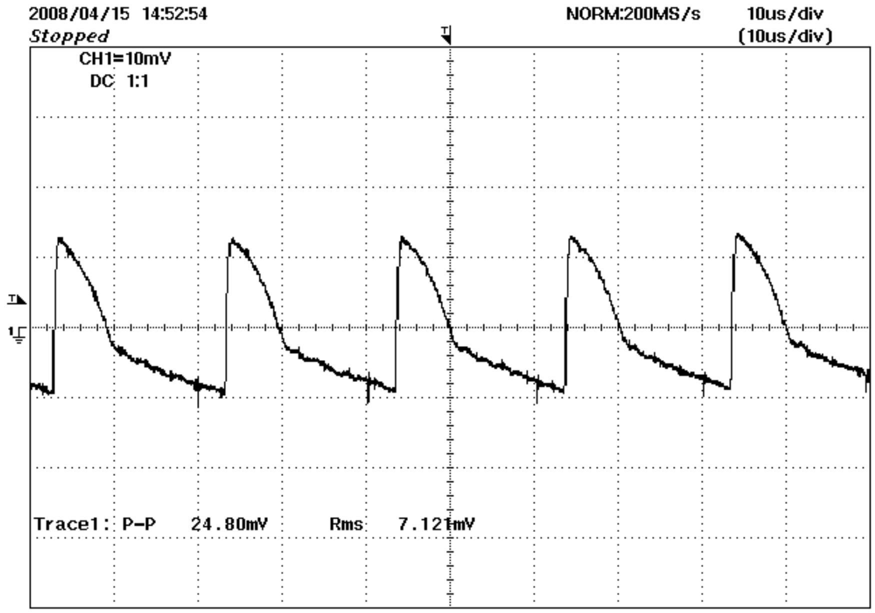

Figure 14 – Output Current Ripple at 115 VAC Input and LED Load. Current: 10 mA/div, 10 µs/div.

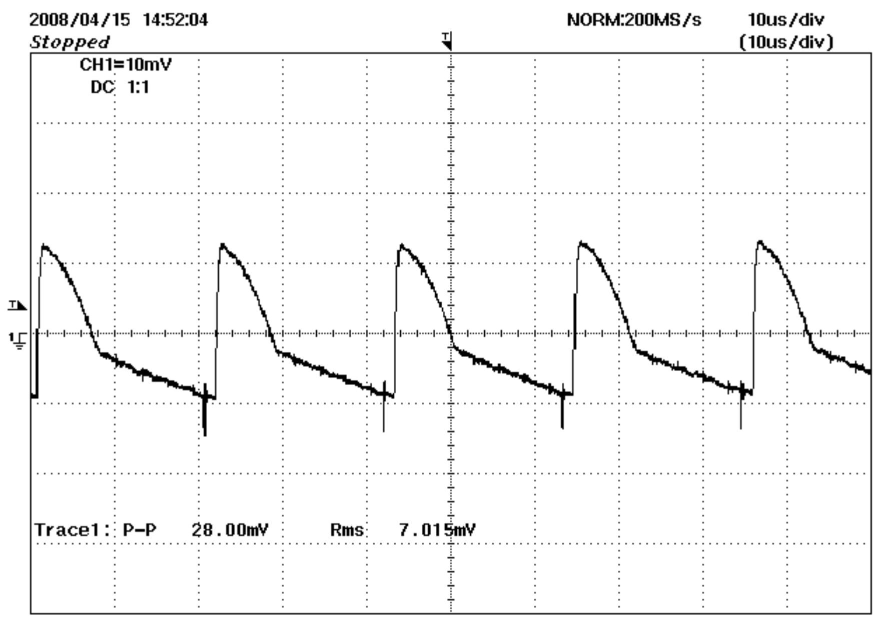

Figure 15 – Output Current Ripple at 230 VAC and LED Load. Current: 10 mA/div, 10 µs/div.

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12 Waveforms

12.1 Output Voltage Startup Profile

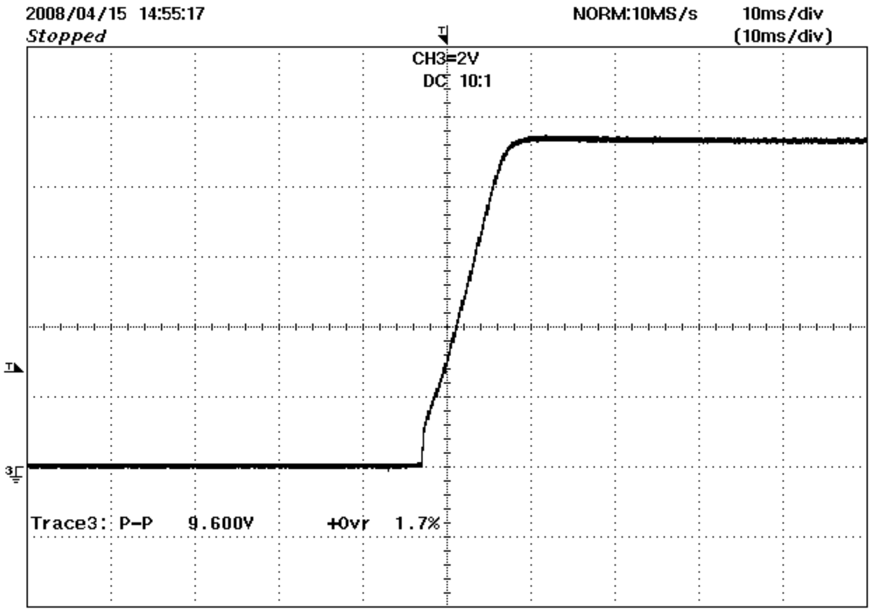

Figure 16 – Output Voltage at Startup (115 VAC), Full Load. 2 V/div and 10 ms/div.

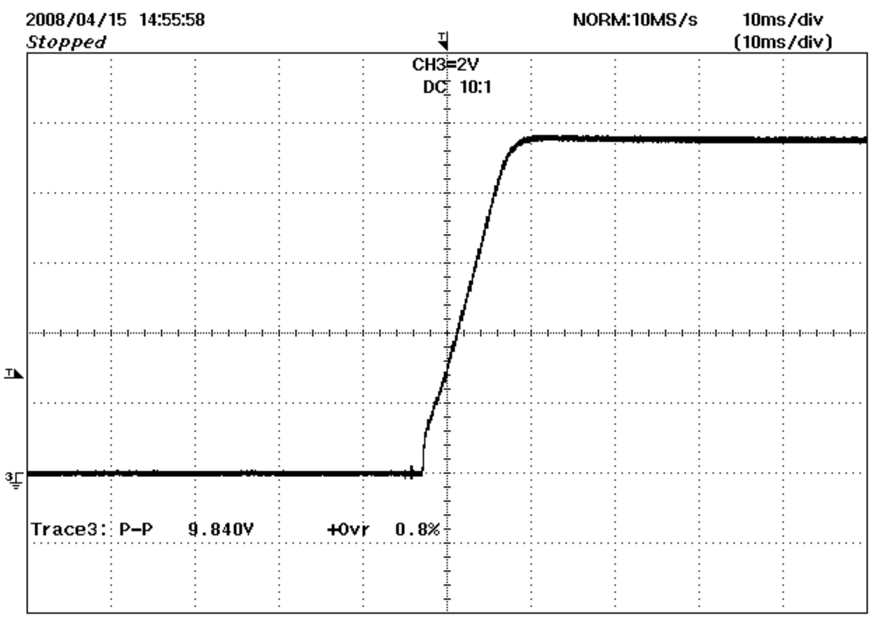

Figure 17 – Output Voltage at Startup (230 VAC), Full Load. 2 V/div and 10 ms/div.

12.2 Output Current Startup Profile

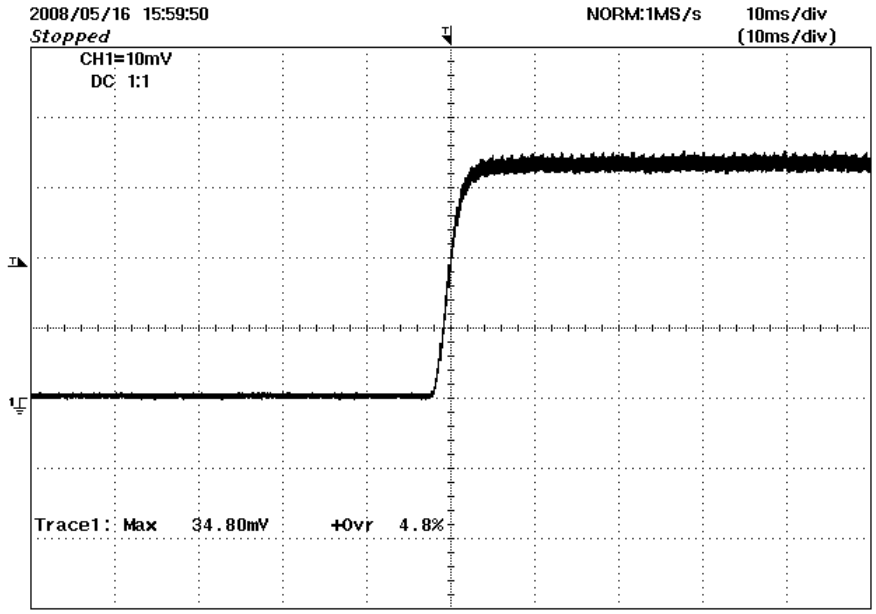

Figure 18 – LED Current at Startup (115 VAC), Full Load. 100 mA/div and 10 ms/div.

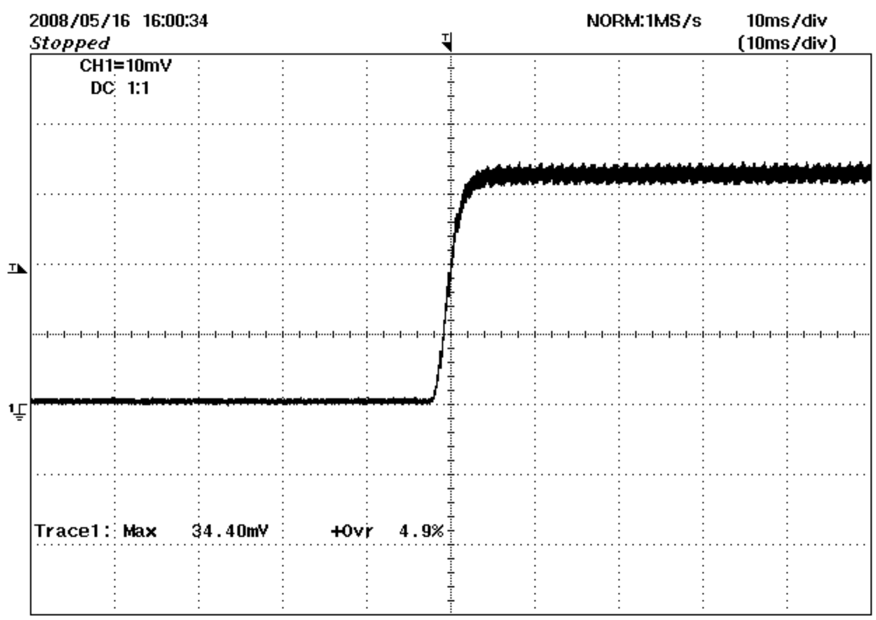

Figure 19 – LED Current at Startup (115 VAC), Full Load. 100 mA/div and 10 ms/div.

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12.3 Drain Voltage

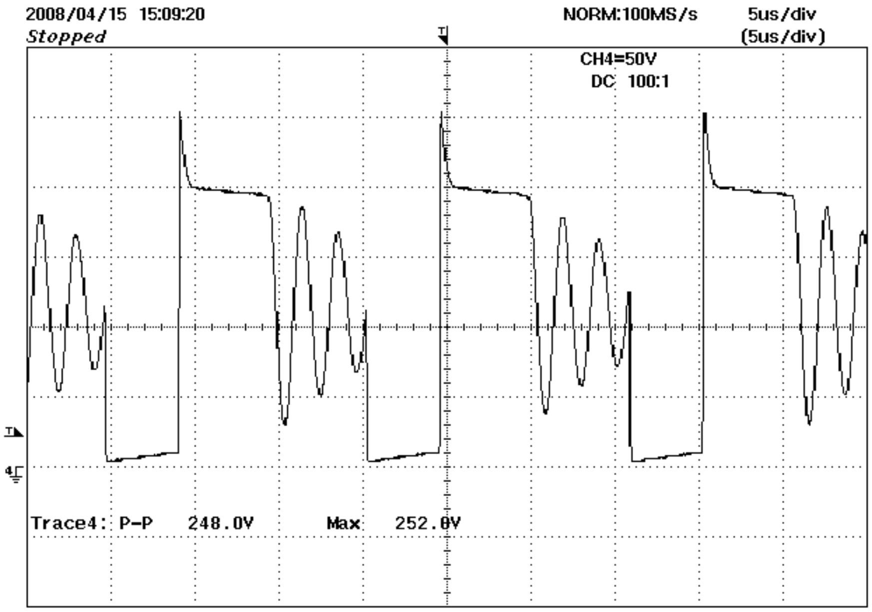

Figure 20 – Drain Voltage at 85 VAC Input. 50 V/div and 5 µs/div.

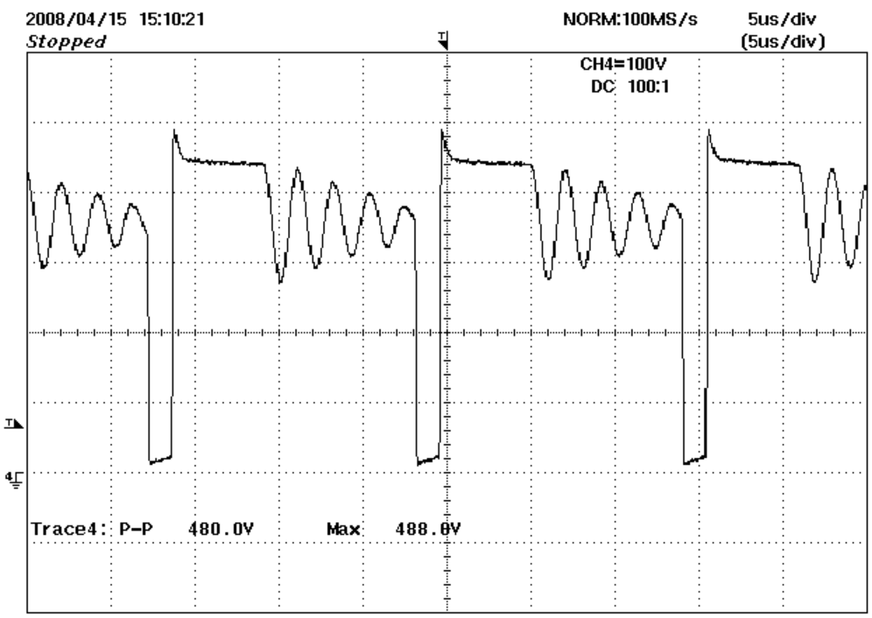

Figure 21 – Drain Voltage at 265 VAC Input. 100 V/div and 5 µs/div.

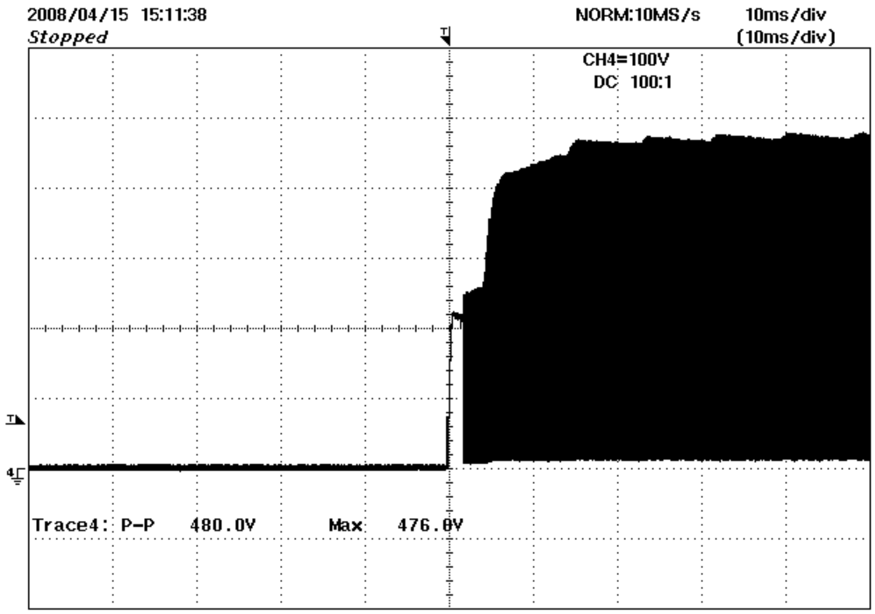

Figure 22 – Drain Voltage During Startup at 265 VAC. 100 V/div and 10 ms/div.

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13 Conducted EMI

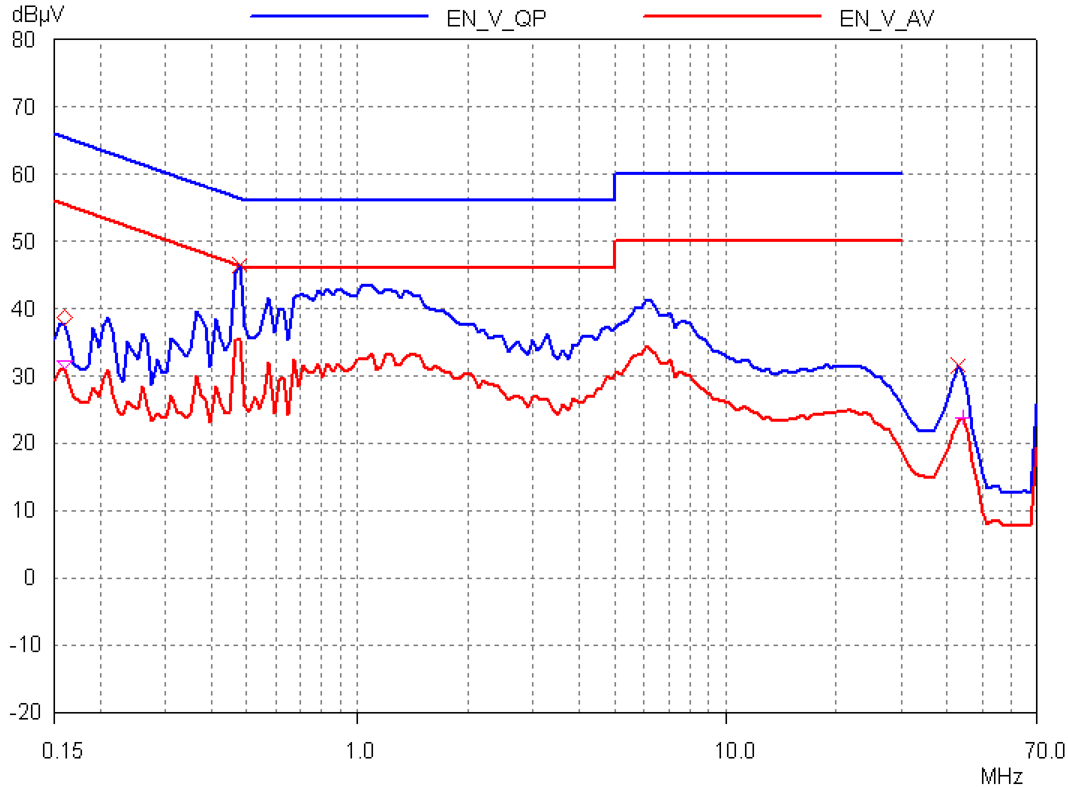

Figure 23 – Conducted EMI at 115 VAC, Output RTN Connected to PE.
EN55015B Limits.

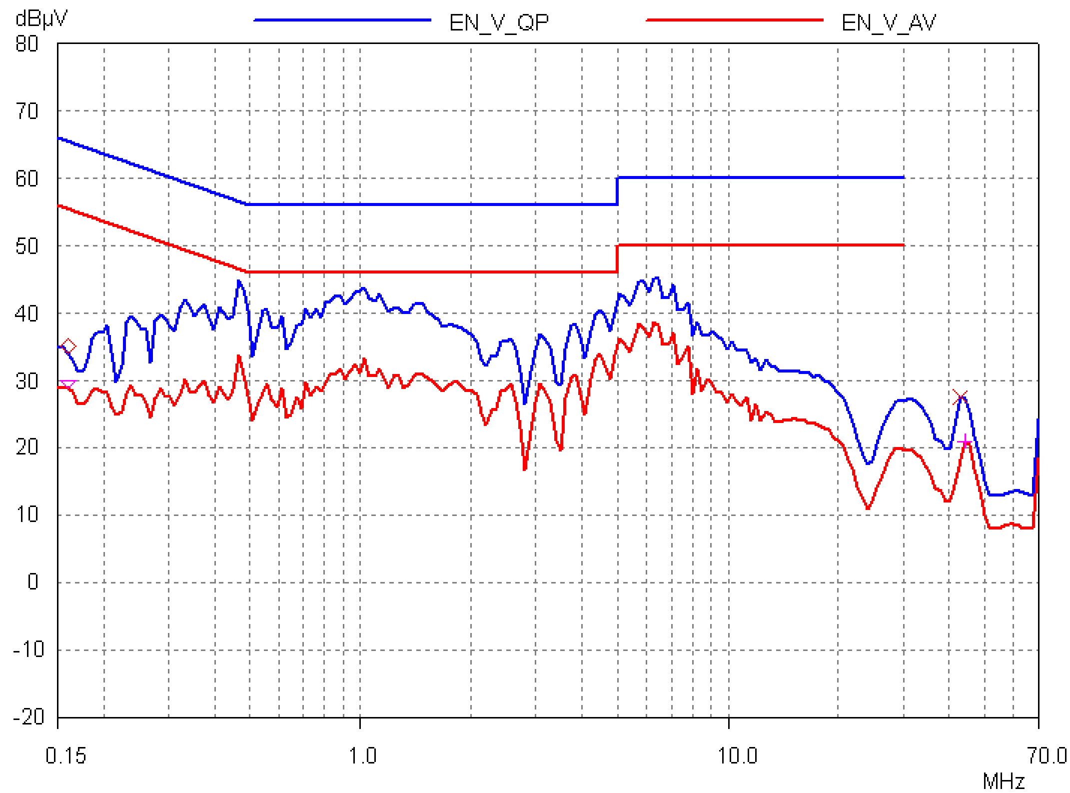

Figure 24 – Conducted EMI at 230 VAC with Output RTN Connected to PE. EN55015B Limits.

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14 Revision History

Date	Author	Revision	Description & changes	Reviewed
15-May-08	SGK	1.0	Initial release	JD

Notes

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