Design Example Report

Title	***10 W Power Factor Corrected TRIAC Dimmable Non-Isolated Buck A19 Lamp Replacement LED Driver Using LinkSwitch™-PL LNK460KG***
Specification	90 VAC – 132 VAC Input; 30 V - 36 V, 280 mA Output
Application	LED Driver for A19 Lamp Replacement
Author	Applications Engineering Department
Document Number	DER-328
Date	November 7, 2012
Revision	1.0

Summary and Features

- Single-stage power factor corrected and accurate constant current (CC) output
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >85 % at 120 VAC input
- Fast start-up time (<150 ms) – no perceptible delay
- Integrated protection and reliability features
  - No-load protection / hard short-circuit protected
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during line brown-out or brown-in
- PF >0.95 at 120 VAC
- %ATHD <20% at 120 VAC
- Meets IEC 2.5 kV ring wave, 500 V differential line surge and EN55015 conducted EMI

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5245 Hellyer Avenue, San Jose, CA 95138 USA.
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Important Note:
Although this board is designed to satisfy safety requirements for non-isolated LED drivers, 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.

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1 Introduction

This document is an engineering report describing a non-isolated LED driver (power supply) utilizing a LNK460KG from the LinkSwitch-PL family of devices.

The DER-328 provides a single 10 W dimmable constant current output.

The key design goals were high efficiency and small size. This allowed the driver to fit into A19 sized lamps and be as close to a production design as possible.

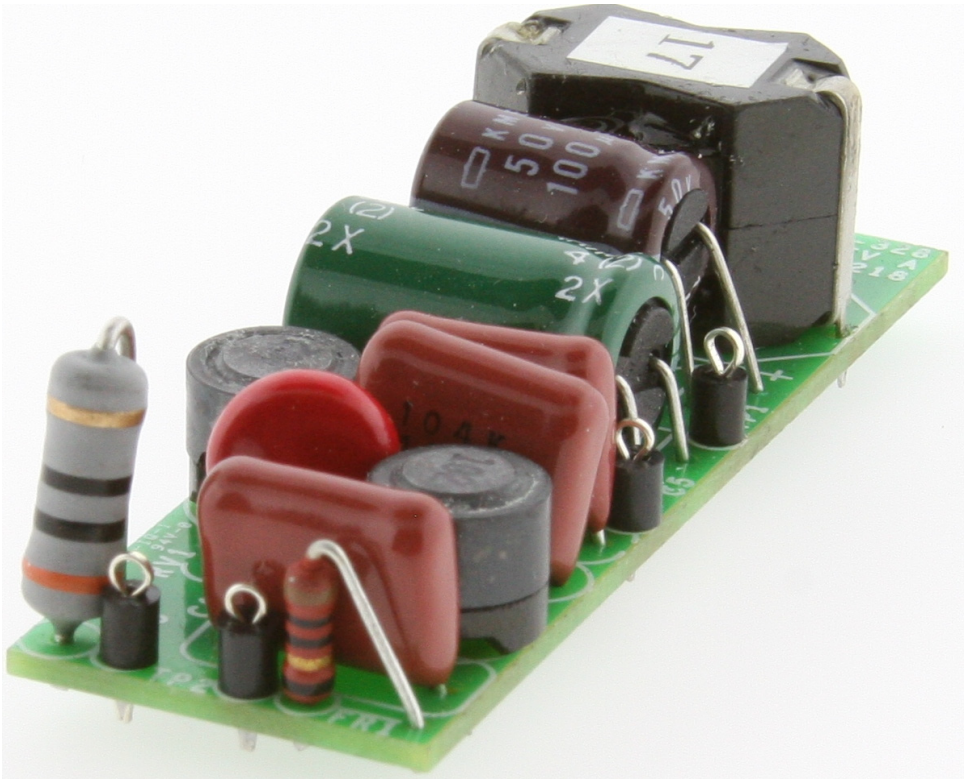

Figure 1 – PCB Assembly (54.5 mm x 16 mm).

The board was optimized to operate with U.S. leading-edge TRIAC dimmers over an AC input voltage range of 90 VAC to 132 VAC, 60 Hz. LinkSwitch-PL IC based designs provide a high power factor (>0.95).

The form factor of the board was chosen to meet the requirements for standard A19 LED replacement lamps. The output is non-isolated and requires the mechanical design of the enclosure to isolate the output of the supply and the LED load from the user.

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

2 Power Supply Specifications

The table below represents the minimum acceptable performance for the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	120	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	57	60	63	Hz	
Output						
Output Voltage	V_{OUT}	30	33	36	V	
Output Current	I_{OUT}		280		mA	At 115 VAC +7% / - 5%
Total Output Power						
Continuous Output Power	P_{OUT}			10	W	
Efficiency						
Nominal	η		85		%	Measured at P_{OUT} 25 °C at 115 VAC
Environmental						
Conducted EMI		Meets CISPR22B / EN55015				
Ring Wave (100 kHz) (7 strikes) Differential Mode (L1-L2)			2.5		kV	2 Ω Short-Circuit Series Impedance
Power Factor		0.95				At 115 VAC
ATHD				15	%	At 115 VAC
Harmonic Currents		EN 61000-3-2 Class D				Class D Limits (For P_{IN} < 25 W Limit)

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2.1 Schematic

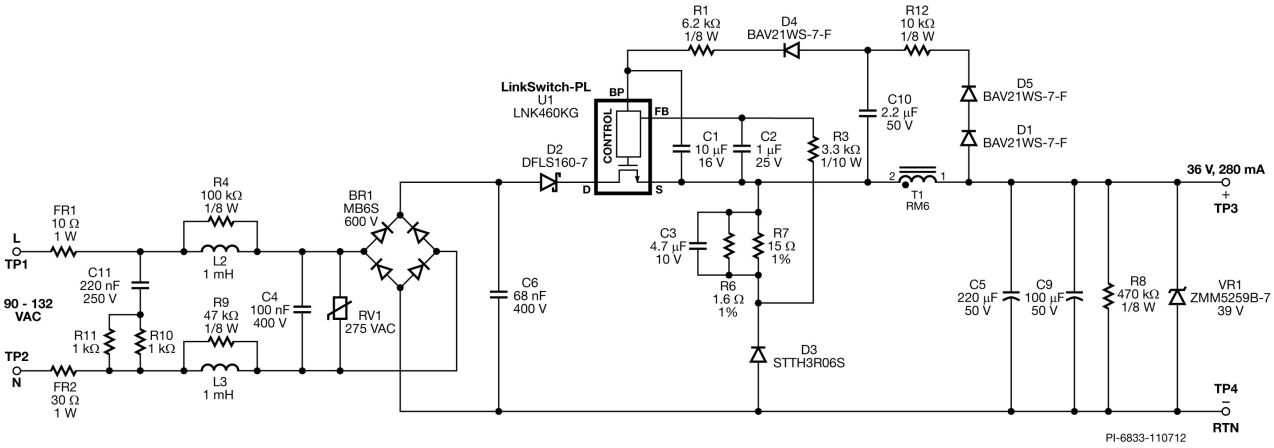

Figure 2 – Schematic for 36 V / 280 mA Replacement Lamp.

3 Circuit Description

The LinkSwitch-PL (U1) family are highly integrated power ICs designed for use in LED driver applications. The LinkSwitch-PL provides high power factor output current regulation in a combined single stage. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET is incorporated into the IC.

3.1 Input Stage

Fuse FR1 provides protection against component failure. The maximum input voltage is clamped by RV1 during differential line surges.

The AC input is full wave rectified by BR1 with C6 providing decoupling for the switching current through U1.

Capacitor C4, C11 and differential chokes L1 and L3 form the EMI filter. Filter capacitance is limited to maintain high power factor. The input multiple L filter network plus the frequency jittering feature of LinkSwitch-PL allows compliance with Class B emission limits. Resistors R4 and R9 damp the resonance of the EMI filter if needed, preventing peaks in the EMI spectrum when measured in a system (driver plus enclosure).

3.2 Buck Topology Using LinkSwitch-PL Devices

The buck power train is composed of U1 (power switch + control), D3 (freewheeling diode), C5 and C9 (output capacitors), and T1 (inductor). Diode D2 blocks potential current to flow back when voltage across U1 rings below ground during the switch off time. The bypass capacitor C1 provides supply for U1, initially charged via the internal supply of the IC during start-up. C1 is essential for higher efficiency and for deep dimming operation. It is kept charged via rectifier D1, D5 and smoothing capacitor C10. Diode D4 is used to prevent loading of C10 during start-up and R1 limits the current into BYPASS (BP) pin.

3.3 Output Current Feedback

The output current is indirectly sensed via resistors R6/R7 and the signal that appears across the sense resistor is actually the inductor current during the switch off time, this is filtered through a low pass filter (R3 and C2) to get an average FEEDBACK (FB) pin voltage of 290 mV in steady-state operation. Bypass capacitor C3 is used to reduce dissipation across R6/R7 thereby increasing efficiency.

3.4 Disconnected Load Protection

The driver is protected during no-load operation via VR1. Zener diode VR1 will fail short once the output voltage exceeds the VR1 avalanche threshold. This will make U1 enter auto-restart mode and prevents excessive power draw from the input. This protects the circuit in the event that the load is disconnected.

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3.5 Overload and Short-Circuit Protection

LinkSwitch-PL U1 provides protection against overload and short-circuit via its integrated current limit protection. During a short, primary current will build-up until it reaches current limit which will force the IC into auto-restart mode.

3.6 Passive RRCD Bleeder and Damper

Resistors R10, R11 and C11 form a bleeder network which ensures the initial input current is high enough to meet the TRIAC latching and holding current requirement, especially in deep dimming (small TRIAC conduction angle). Total network resistance of FR1 and FR2 provides damping action that prevents input current from ringing negative every time the TRIAC turns on.

3.7 Line Surge Protection

MOV RV1 clamps the input voltage below the IC power MOSFET drain maximum rating during surge event.

4 PCB Layout and Outline

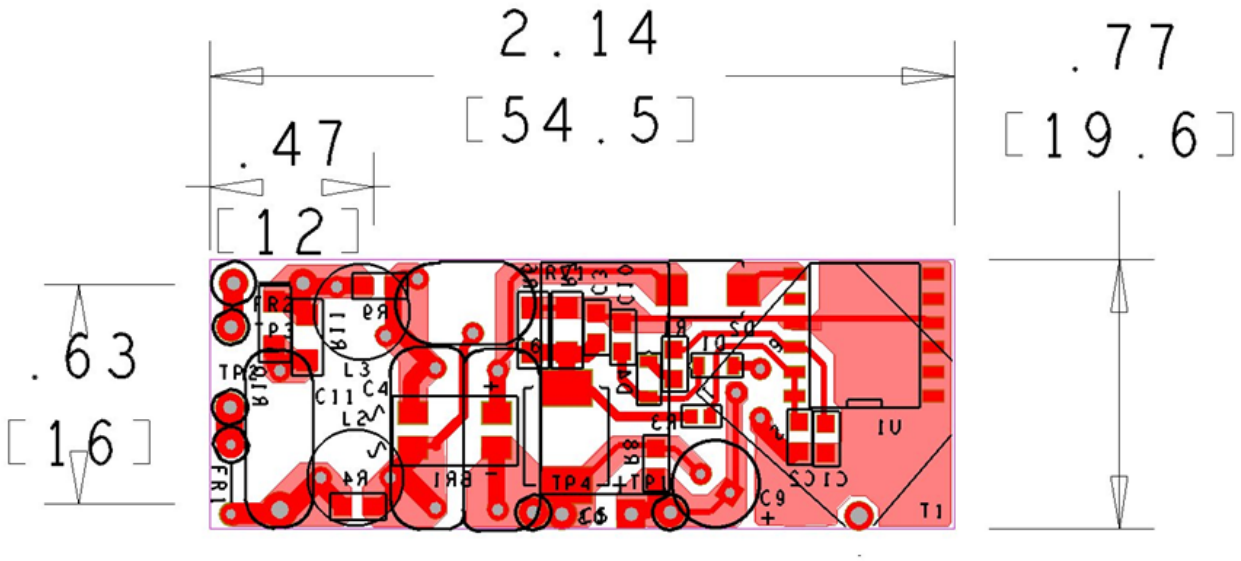

Figure 3 – Top and Bottom Printed Circuit Layout.

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5 Populated PCB

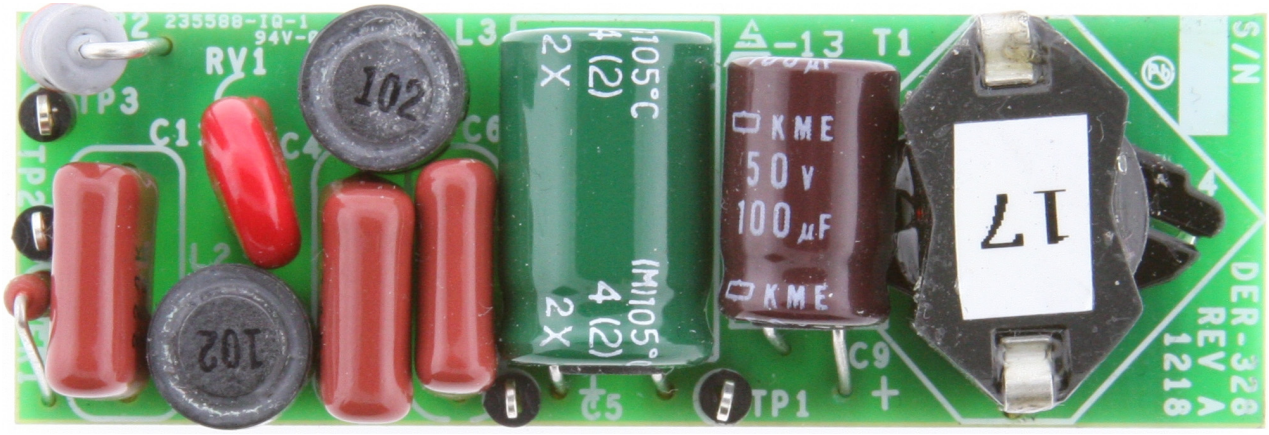

Figure 4 – Populated Circuit Board (Top Side).

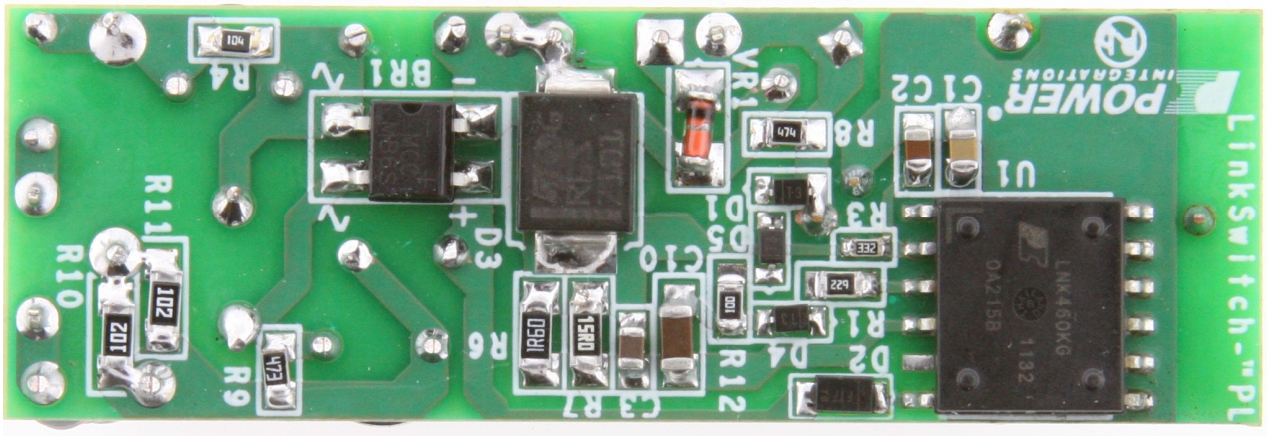

Figure 5 – Populated Circuit Board (Bottom Side).

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C1	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
3	1	C2	1 μF, 25 V, Ceramic, X5R, 0805	C2012X5R1E105K	TDK
4	1	C3	4.7 μF, 10 V, Ceramic, X7R, 0805	C0805C475K8PACTU	Kemet
5	1	C4	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
6	1	C5	220 μF, 50 V, Electrolytic, Very Low ESR, 42 mΩ, (10 x 16)	EKZE500ELL221MJ16S	Nippon Chemi-Con
7	1	C6	68 nF, 400 V, Film	ECQ-E4683KF	Panasonic
8	1	C9	100 μF, 50 V, Electrolytic, Gen. Purpose, (8 x 11.5)	KME50VB101M6X11LL	Nippon Chemi-Con
9	1	C10	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
10	1	C11	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
11	1	D1	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
12	1	D2	60 V, 1 A, DIODE SCHOTTKY, PWRDI 123	DFLS160-7	Diodes, Inc.
13	1	D3	600 V, 3 A, SMC, DO-214AB	STTH3R06S	ST Micro
14	1	D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
15	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
16	1	FR1	10 Ω, 5%, 1 W, Metal Film, Fusible	NFR0100001009JR500	Vishay
17	1	FR2	30 Ω, 5%, 1 W, Metal Oxide	RSF100JB-30R	Yageo
18	1	L2	1 mH, 0.23 A, Ferrite Core	CTSCH875DF-102K	CT Parts
19	1	L3	1 mH, 0.23 A, Ferrite Core	CTSCH875DF-102K	CT Parts
20	1	R1	6.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ622V	Panasonic
21	1	R3	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
22	1	R4	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
23	1	R6	1.6 Ω, 1%, 1/4 W, Thick Film, 1206	RC1206FR-071R6L	Yago
24	1	R7	15 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF15R0V	Panasonic
25	1	R8	470 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ474V	Panasonic
26	1	R9	47 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ473V	Panasonic
27	1	R10	1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ102V	Panasonic
28	1	R11	1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ102V	Panasonic
29	1	R12	10 R, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
30	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
31	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
32	1	TP1	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
33	1	TP2	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
34	1	TP3	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
35	1	TP4	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
36	1	U1	LinkSwitch-PL, eSOP-12B	LNK460KG	Power Integrations
37	1	VR1	39 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5259B-7	Diodes, Inc.

Total electrical components: 33 parts

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7 Inductor Specification

7.1 Electrical Diagram

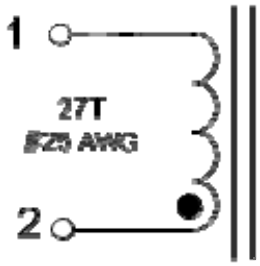

Figure 6 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 6-7, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	150 µH ±5%

7.3 Materials

Item	Description
[1]	Core: RM-6; TDK-PC95 or equivalent.
[2]	Bobbin: RM-6; 3/3 pin horizontal.
[3]	Magnet Wire: #25 AWG.
[4]	Tape, Polyester film, 3M 1350F-1 or equivalent, 9 mm wide.
[5]	Loctite Super Glue Control Gel.

7.4 Inductor Build Diagram

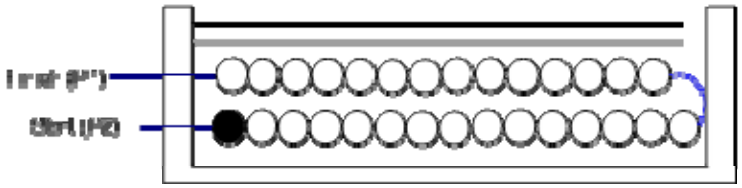

Figure 7 – Transformer Build Diagram.

7.5 Inductor Construction

Bobbin Preparation	For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left. Winding direction clockwise.
WDG 1	Start at pin 2. Wind 27 turns of item [3] and terminate at pin 1.
Insulation	Add 1 layer of tape of item [4].
Final Assembly	Grind the core to get the specified inductance. Apply tape to secure both cores. Cut pins 3, 4 and 5. Apply adhesive item [5] to core and bobbin to prevent core movement.

8 Inductor Design Spreadsheet

ACDC_LinkSwitch-PL-Buck_121611; Rev.1.0; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-PL Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	90		90.00	V	Minimum AC Input Voltage
VACTYP	115		115.00	V	Typical AC Input Voltage
VACMAX	132		132.00	V	Maximum AC Input Voltage
FL	60		60.00	Hz	AC Mains Frequency
VOMIN	30.00		30.00		Minimum Output Voltage of LED string
VO	33.00		33.00	V	Output Voltage of LED string
VOMAX	36.00		36.00		Maximum Output Voltage of LED string
IO	0.27		0.27	A	Output Current riving LED strings
PO			8.91	W	Continuous Output Power
n	0.87		0.87		Efficiency Estimate at output terminals. Under 0.7 if no better data available
Dimming Application	Yes				Enter Yes if design uses TRIAC dimming, otherwise select No
ENTER LinkSwitch-PL VARIABLES					
Chosen Device	**LNK460**		LNK460		Chosen LinkSwitch-II device
ILIMITMIN			1.64	A	Minimum Current Limit
ILIMITTYP			1.86	A	Typical Current Limit
ILIMITMAX			2.08	A	Maximum Current Limit
TON			2.15	us	Expected on-time of MOSFET at low line and PO
FSW			122.81	kHz	Expected switching frequency at low line and PO
Duty Cycle			26.44	%	Expected operating duty cycle at low line and PO
IRMS			0.26	A	Worst case primary RMS current at VO
IPK			1.68	A	Worst case peak primary current at VO
KDP		Warning	0.99		LinkSwitch-PL must operate in discontinuous mode (KP > 1) for good power factor. Consider reducing the primary inductance, changing the number of turns or increasing the device size
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type					
Core Type	**RM6S/I**		RM6S/I		Enter Transformer Core
Core Part Number					If custom core is used - Enter part number here
Bobbin part number			CSV-RM6S-4P-G		Bobbin Part number (if available)
AE			37.00	mm^2	Core Effective Cross Sectional Area
LE			29.20	mm^2	Core Effective Path Length
AL			2150.00	nH/turn^2	Ungapped Core Effective Inductance
BW			6.30	mm	Bobbin Physical Winding Width
INDUCTOR DESIGN PARAMETERS					
LPMIN			142.50	uH	Minimum Inductance (Includes inductance of input and output winding)
LPTYP	150.00		150.00	uH	Typical inductance (Includes inductance of input and output winding)
LP_TOLERANCE	5.00		5.00	%	Tolerance of the inductance
TURNS_TOTAL	27		27.00	Turns	Total number of turns (Includes input and output winding turns).
ALG			205.76	nH/turn^2	Gapped Core Effective Inductance
BM			2647.04	Gauss	Calculated Worst Case Maximum Flux

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					Density (BM < 3000 G)
BP			3284.01	Gauss	Calculated Worst Case Peak Flux Density (BP < 3400 G)
BAC			1323.52	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			135.02		Relative Permeability of Ungapped Core
LG			0.20	mm	Gap Length (Lg > 0.1 mm)
AWG			32.00		Main Winding Wire Gauge (Rounded to next smaller standard AWG value)
L			1.03		Number of Layers Main section)
CMA			244.25	Cmils	Current Density capacity 200 < CMA < 500
Bias Section					
Use Bias?	Auto		Yes		Is a Bias winding used?
TURNS_BIAS			4.00	Turns	
VBIAS			12.00	V	
PIVBS			27.66	V	
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			26.44	%	Duty cycle measured at minimum input voltage
IAVG			0.10	A	Input average current measured at the minimum input voltage
IP			1.68	A	Peak Primary current at maximum input voltage
ID_PK			0.00	A	Peak output winding current at the maximum input voltage
ISW_RMS			0.26	A	Switch RMS current measured at the minimum input voltage
ID_RMS			0.58	A	RMS current of freewheeling diode at maximum input voltage
IL_RMS			0.26	A	RMS current of the primary section of the inductor measured at the minimum input voltage
IL_TAP_RMS			0.63	A	RMS current of the output winding section of the inductor at the maximum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
RFEEDBACK			1.67	ohm	This is a first approximation for the sense resistor and will likely require fine tuning in the bench. Value calculated with typical inductance, and minimum input voltage.
CBP			10.00	uF	Minimum Bypass pin capacitor required
VOLTAGE STRESS PARAMETERS					
VDRAIN			222.68	V	Estimated worst case drain voltage at maximum input voltage and output voltage
PIVS			222.68	V	Output Rectifier Maximum Peak Inverse Voltage

Note: KDP is close to 1 to achieved optimum efficiency. No device failure if the system will operate in continuous mode and this will only occur below the operating input voltage. Compliance for THD and power factor will meet within the operating input voltage range.

9 Performance Data

All measurements performed at 25 ºC room temperature, 60 Hz input frequency unless otherwise specified.

9.1 Active Mode Efficiency

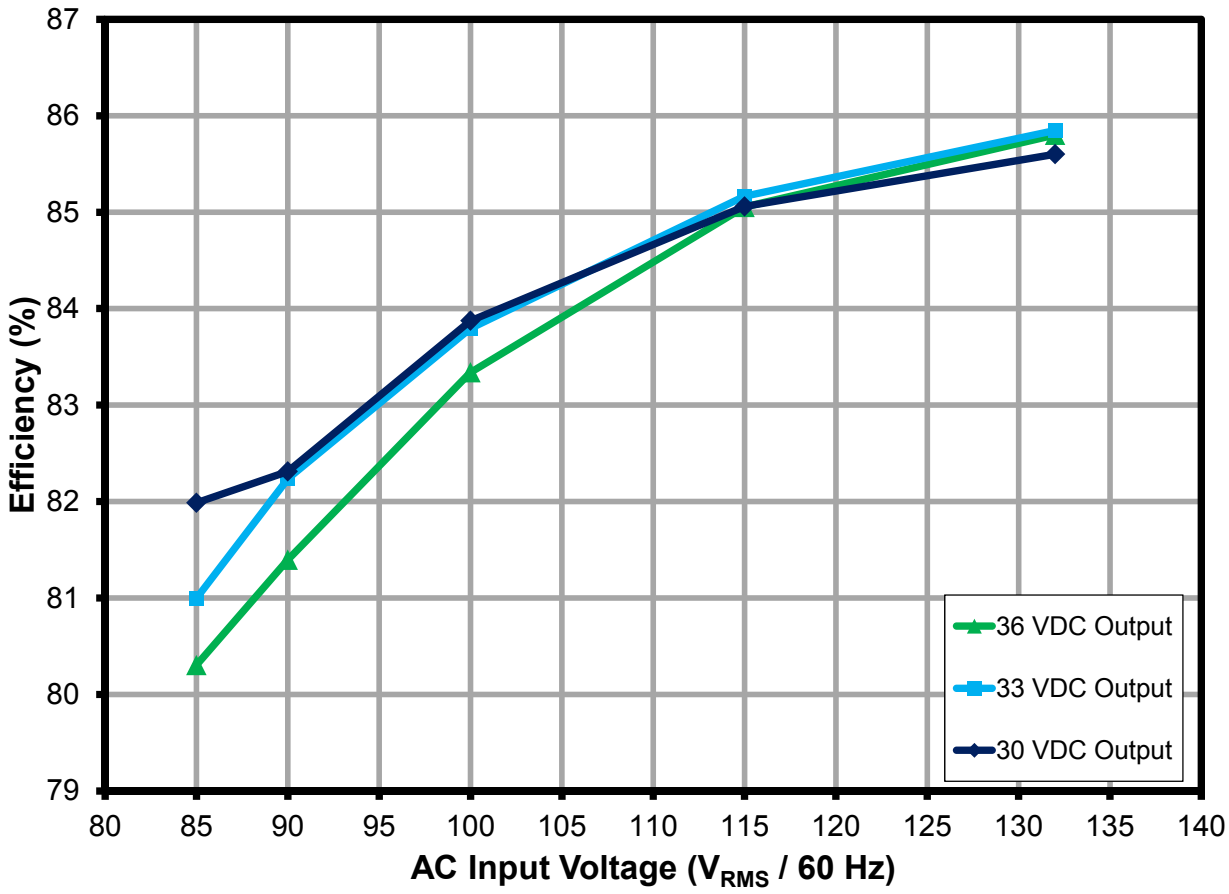

Figure 8 – Efficiency with Respect to AC Input Voltage at 280 mA.

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9.2 Line Regulation

The LinkSwitch-PL device regulates the output by controlling the power MOSFET on-time and switching frequency to maintain the average FEEDBACK pin at its 0.29 V threshold. Slight changes in output current may be observed when input or output conditions are changed or after AC cycling due to the device selecting a different operating state (selection of on-time and frequency).

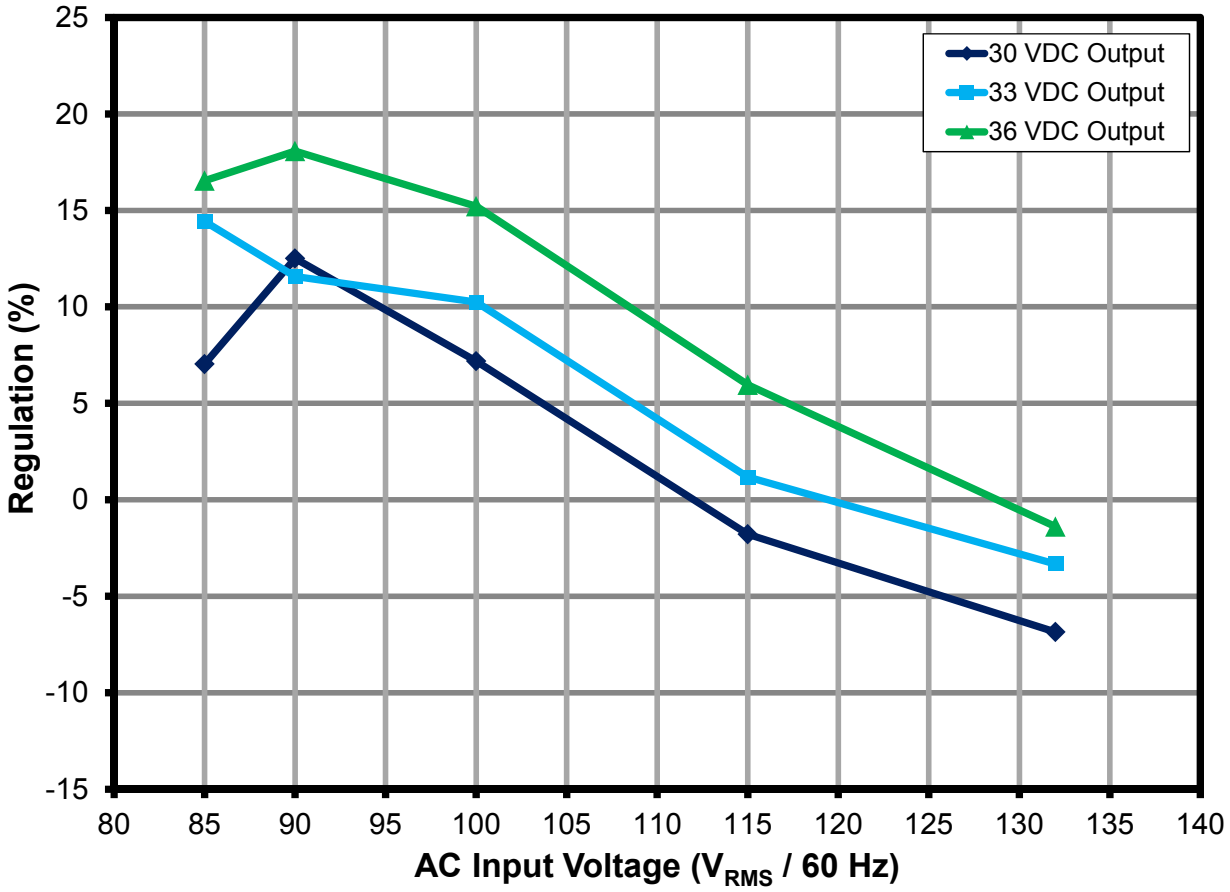

Figure 9 – Line Regulation, Room Temperature.

9.3 Power Factor

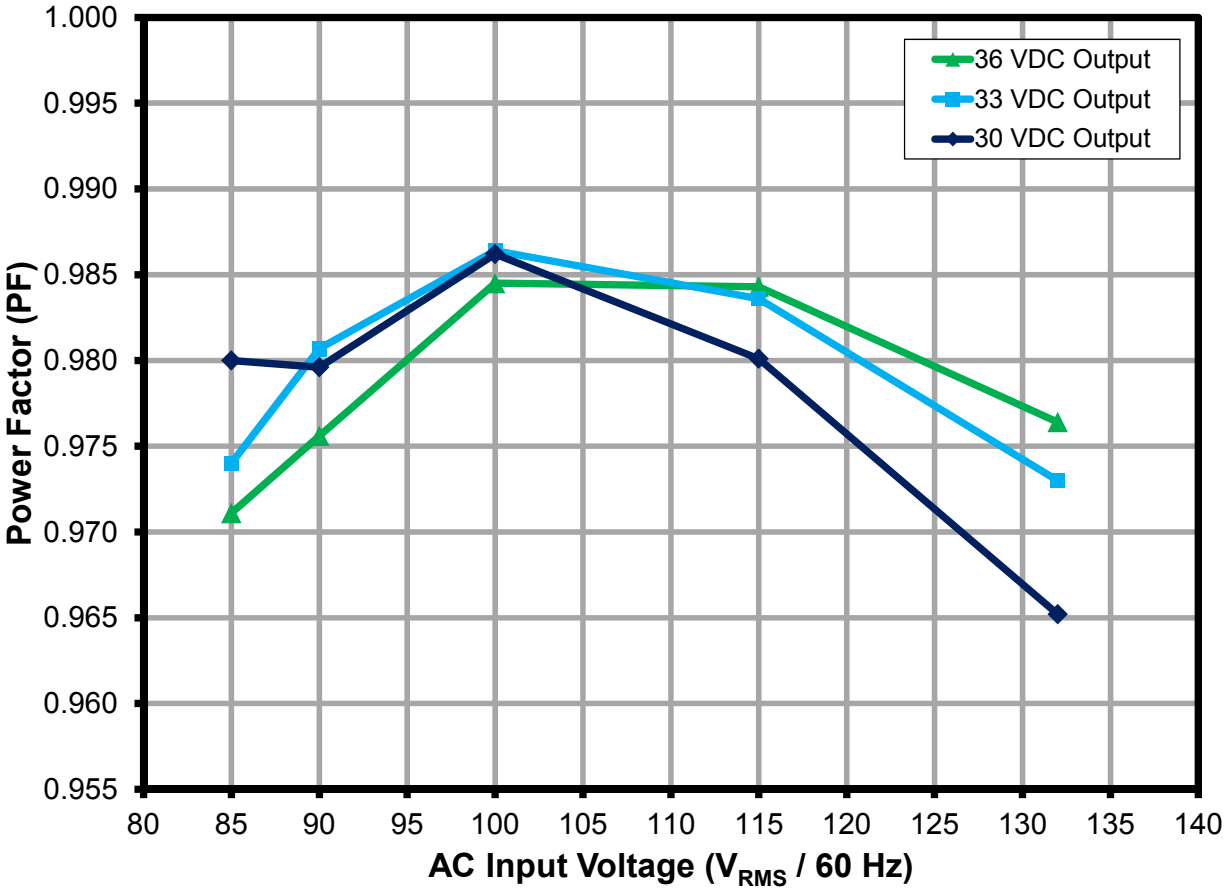

Figure 10 – High Power Factor within the Operating Range for 33 V LED.

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9.4 %THD

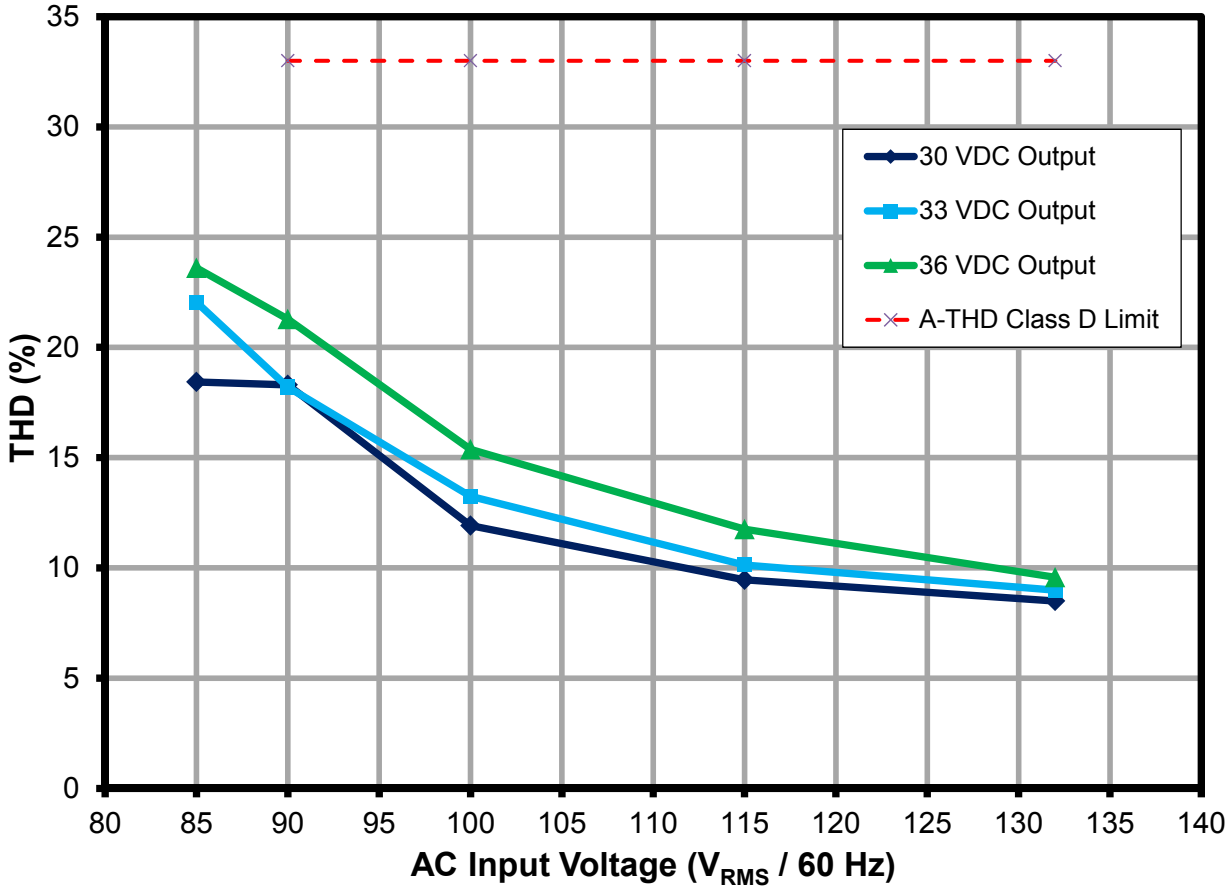

Figure 11 – Very Low %ATHD at 115 VAC.

9.5 Harmonic Content

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment[1]. Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

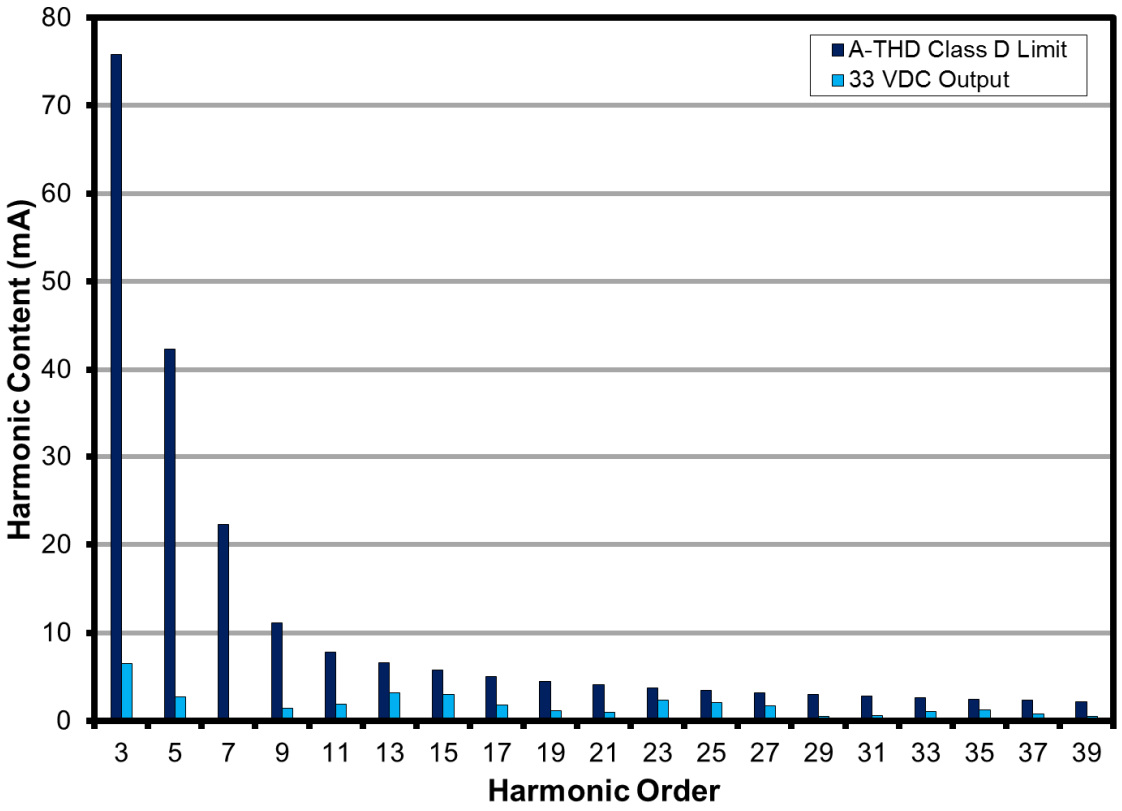

Figure 12 – Meets EN61000-3-2D Harmonics Contents Standards for <25 W Rating 115 V VAC Input.

[1] IEC6000-3-2 Section 7.3, table 2, column 2.

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9.6 Dimming Characteristic

The dimming characteristic was measured with a programmable AC supply to emulate an ideal TRIAC dimming characteristic. The reference design meets the dimming requirements as set by National Electrical Manufacturers Association (NEMA) (SSL 1-2010 Electronic Drivers for LED Devices, Arrays or Systems and SSL 6-2010 Solid Light Lighting for Incandescent Replacement-Dimming).

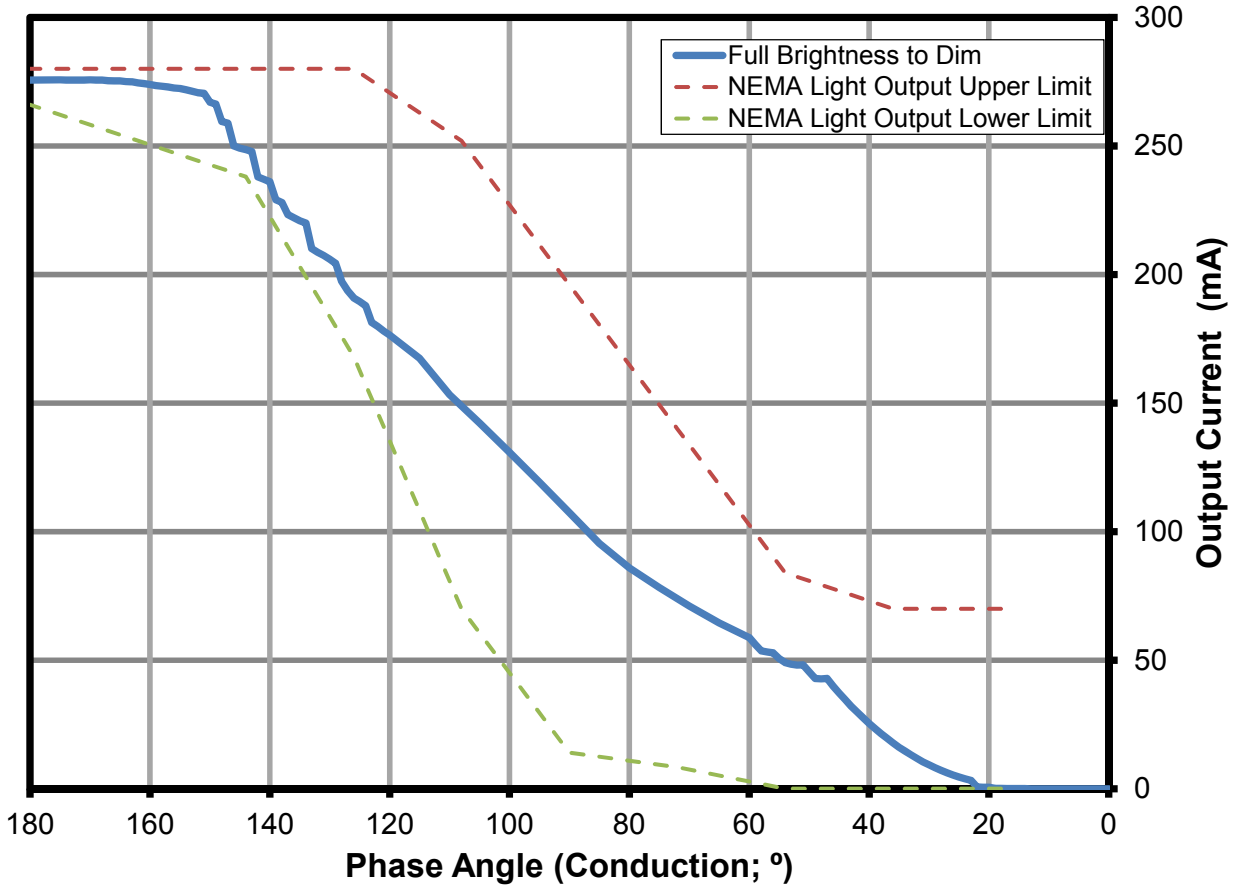

Figure 13 – Dimming Curve Characteristic from Full Dimming to Full Brightness.

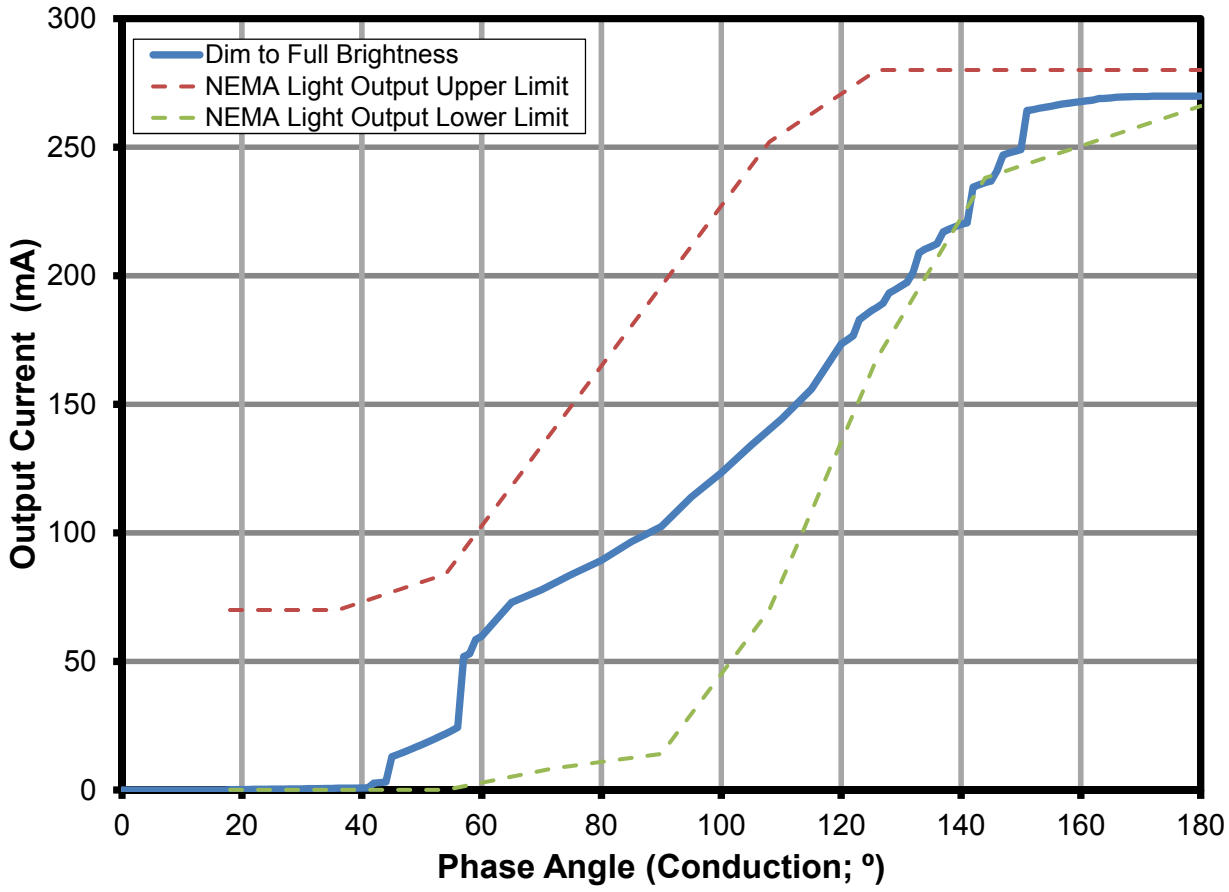

Figure 14 – Dimming Characteristic from Full Brightness to Full Dimming.

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9.7 Unit to Dimmer Compatibility

These are the list of U.S. dimmers whose operation was verified with this reference design. Users are not limited on the following list. Dimmers should be tested at their recommended operating AC line frequency to avoid flicker.

List of Dimmers	Type	Remarks	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
LUTRON LG 600PH-LA	L	Lutron 600-Watt Slide Dimmer LG-600PH-LA	600W	LG-600PH-WH	3.20	237	74
LUTRON S603P	L	Lutron Skylark Incandescent 600W 3-Way Preset Dimmer with On/Off	600W	S-603P-WH	0.74	246	332
LUTRON SLV600P	T	Lutron SLV-600P-WH 600-Watt Skylark Magnetic Low-Voltage Single-Pole Dimmer	600W	SLV600P-WH	3.40	246	72
LUTRON S600	L	Slide-to-Off Single Pole Skylark Dimmer Switch (RFI suppression)	600W	S-600-WH	0.73	282	386
LUTRON S-600PH-WH	L	Lutron Skylark 5-Amp White Gloss Dimmer	600W	S-600PH-WH	0.76	246	324
LUTRON DVCL153P	L	Cfl&led Dimmer, Paddle/slide, 120V, 600W	600W	DVWCL-153-PLH-WH	17.50	245	14
LUTRON DV603P	L	600W Diva Dimmer, 3-Way - Ivory	600W	DV-603P-WH	3.40	233	69
LUTRON DV600P	L	Lutron Diva DV-600P-WH Incand 600 Watt Single Pole Light Dimmer in White	600W	DV-600P-WH	3.50	233	67
LUTRON TG600PH-IV	L	Ivry Toggle Dimmer 1p Preset	600W	TG-600PH-WH	3.20	249	78
LUTRON AY600P	T	Lutron Ariadni AY-600P-WH Incand Preset 600 Watt Single Pole Light Dimmer in White	600W	AY-600P-WH	3.45	237	69
LUTRON GL600P-WH	L	Glyder Incandescent Single Pole 600 Watts Preset Dimmer, White	600W	GL-600P-WH	2.00	245	123
LEVITON 6633PLI	L	SureSlide 600W Incandescent Dimmer	600W	R62-06633-1LW	0.45	287	638
LEVITON 6631-LI	L	SureSlide 600W Incandescent Slide Dimmer, Single-Pol	600W	R62-06631-1LW	0.77	267	347
LEVITON IPI06	L	IllumaTech Incandescent Preset Slide Dimmer	600W	R60-IPI06-1LM	59.00	290	5
LEVITON 6161-I	Electronic	I 500 W, 120 VAC, Decora Brand Style 4 Level Dimmer	500W	R52-06161-00W	16.70	262	16
LEVITON RP106	L	IllumaTech Rotary Controls 120V AC 60Hz	600W	R52-RPI06-1LW	5.00	280	56
LEVITON 6681	L	A Push On and Push Off Dimmer	600W	R60-06681-0IW	0.70	270	386
LEVITON TGM10-1LW	T	1000VA, 120 Volt AC 60hz, Single-Pole & 3-Way, ToggleTouch Preset Digital Magnetic Low-Voltage ToggleTouch Dimmer, LED Locator Light - White	1KVA	TGM10-1LW	12.00	212	18
LEVITON 6684	L	Leviton 600-Watt 3-Way Lighted White/Ivory Push Dimmer	600W	R60-06684-1IW	0.25	234	936
LEVITON 6683			600W	6683	0.60	280	467
LEVITON 6613	L	SURESLIDE" MAGNETIC LOW VOLTAGE DIMMER *600VA, 120V AC, 60Hz	450W	R02-06613-PLW	4.10	278	68
COOPER SLC03				SLC03P-W-K-L	20.90	266	13
LUTRON GL600-WH	L	Lutron 15-Amp White Slide Dimmer	600W	GL-600-WH	0.70	281	401
LUTRON DVPDC-203P-WH	L	Diva, Screw Base Compact Fluorescent Dimming with Philips® DIMMABLE Energy Saver CFL, Single Pole/3-Way, 200W, White	200W	DVPDC-203P-WH	96.30	282	3
LUTRON LX600PL	L	Lyneo Lx Single Pole Dimmer 600W	500W	LX-600PL-wh	39.00	277	7
LUTRON D600P	L	Single Pole - Incandescent - Push On/Off - 600 Watt - White	600W	D-600P-WH	0.50	231	462
LUTRON CTCL-153PDH			600W		17.00	245	14
LUTRON S-600P			600W	S-600P	1.90	243	128

LUTRON TGLV-600P				TGLV-600P	3.60	265	74
LUTRON TGLV-600PR			450W	TGLV-600PR	3.60	246	68
LUTRON TT-300NLH-WH	L	Lutron Diva Satin 5-Amp Desert Stone Preset Dimmer	300W	TT-300NLH-WH	0.40	282	705
LUTRON TT-300H-WH	L	Lutron Credenza 300-Watt White Lamp Dimmer	300W	TT-300H-WH	0.22	282	1282
LUTRON NLV-1000-WH	L	Nova, Slide-To-Off Dimmers, Magnetic Low Voltage, Neon/Cold Cathode, Single Pole, 1000VA, White	800W	NLV-1000-WH	7.80	231	30
Lutron		MAELV -600			28.00	253	9
Lutron		S-600P			0.73	248	340
Lutron		S-600P			0.70	282	403
Cooper		S106P			0.40	248	620
Lutron		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, 3-Way, 1000W, White	1000	S-103P-WH	41.50	267	6
Lutron		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, Single Pole, 1000W, White	1000	S-10P-WH	17.30	223	13
Lutron		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, Single Pole, 600W, White	600	S-600PNLH-WH	1.90	250	132
Lutron		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, 3-Way, 600W, White	600	S-603PNL-WH	2.00	256	128
Lutron		Skylark, Dimmers with On/Off Switch, Magnetic Low Voltage, 3-Way, 600VA, White	600	SLV-603P-WH	3.60	244	68
Lutron		Skylark, Slide-To-Off Dimmers, Incandescent/Halogen, Eco-Dim, Single Pole/3-Way, 600W, Clamshell Packing, White	600	S-603PGH-WH	0.70	155	221
Lutron		Ariadni, Dimmers, Magnetic Low Voltage, Single Pole, 600VA, White	600	AYLV-600P-WH	3.36	248	74
Lutron		Ariadni, Dimmers, Magnetic Low Voltage, 3-Way, 600VA, White	600	AYLV-603P-WH	3.35	236	70
Lutron		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, 3-Way, 1000W, White	1000	AY-103PNL-WH	21.50	246	11
Lutron		Ariadni, Dimmers, Incandescent/Halogen, 3-Way, 1000W, White	1000	AY-103P-WH	32.60	260	8
Lutron		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, Single Pole, 1000W, White	1000	AY-10PNL-WH	31.40	284	9
Lutron		Ariadni, Dimmers, Incandescent/Halogen, Single Pole, 1000W, White	1000	AY-10P-WH	19.00	249	13
Lutron		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, 3-Way, 600W, White	600	AY-603PNL-WH	3.50	205	59
Lutron		Ariadni, Dimmers, Incandescent/Halogen, Eco-dim, Single Pole/3-Way, 600W, White	600	AY-603PG-WH	3.60	134	37
Lutron		Ariadni, Dimmers, Incandescent/Halogen, 3-Way, 600W, White	600	AY-603P-WH	3.40	232	68
Lutron		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, Single Pole, 600W, White	600	AY-600PNL-WH	3.60	244	68
Lutron		Diva, Dimmers with Locator Light, Electronic Low Voltage, Single Pole, 300W, White	300	DVELV-300P-WH	15.90	279	18
Lutron		Diva, Dimmers with Locator Light, Magnetic Low Voltage, Single Pole, 1000VA, White	1000	DVLV-10P-WH	4.80	220	46
Lutron		Diva, Dimmers with Locator Light, Magnetic Low Voltage, 3-Way, 1000VA, White	1000	DVLV-103P-WH	4.50	232	52
Lutron		Diva, Dimmers with Locator Light, Magnetic Low Voltage, 3-Way, 600VA, White	600	DVLV-603P-WH	4.50	233	52
Lutron		Skylark, Slide-To-Off Dimmers, Incandescent/Halogen, Single Pole, 1000W, White	1000	S-1000-WH	0.77	279	362
Lutron		Skylark, Dimmers with On/Off Switch, Electronic Low Voltage, Single Pole, 300W, White	300	SELV-300P-WH	20.00	267	13
Lutron		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, Single Pole, 600W, White	600	S-600P-WH	0.77	248	322
Lutron		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, 3-Way,1000W, White	1000	S-103PNL-WH	53.00	265	5
Lutron		Spacer System, Dimmer with IR Receiver, Electronic Low Voltage, Single Location, 600W, White		SPSELV-600-WH	28.50	252	9
Lutron		Glyder, Slide-To-Off Dimmers, Magnetic Low Voltage, Single Pole, 600W, White	600	GLV-600-WH	3.40	278	82

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10 Thermal Performance

10.1 Thermal Scans

The scan was conducted at ambient temperature of 25 ºC in an open frame configuration.

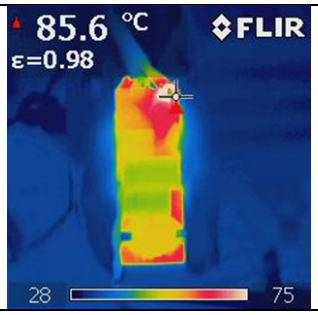
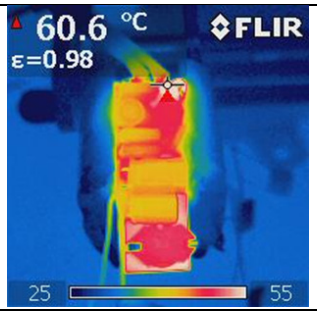
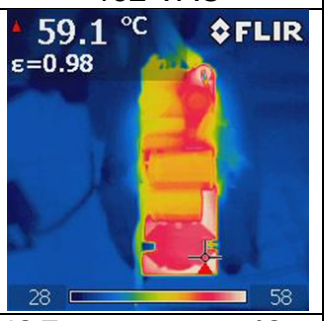
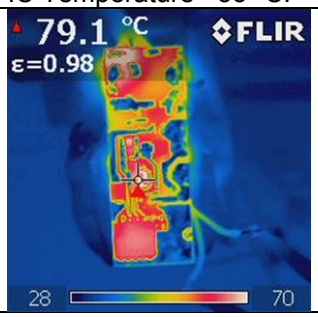
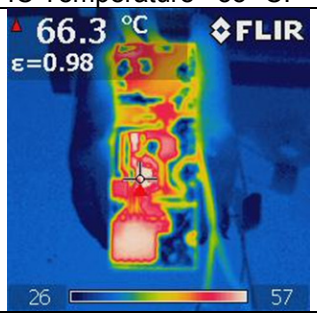
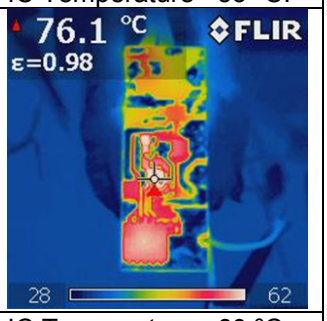
PCB SIDE	90 VAC	115 VAC	132 VAC
TOP			
	IC Temperature <55 ºC.	IC Temperature <55 ºC.	IC Temperature <55 ºC.
BOTTOM			
	IC Temperature <60 ºC.	IC Temperature <60 ºC.	IC Temperature <60 ºC.

Figure 15 – IR Thermal Scans Open Frame with 280 mA Load at 36 VDC.

11 Waveforms

11.1 Drain Voltage and Current, Normal Operation

No saturation in the inductor was seen. The unit is designed to work in discontinuous mode and the operating input voltage range.

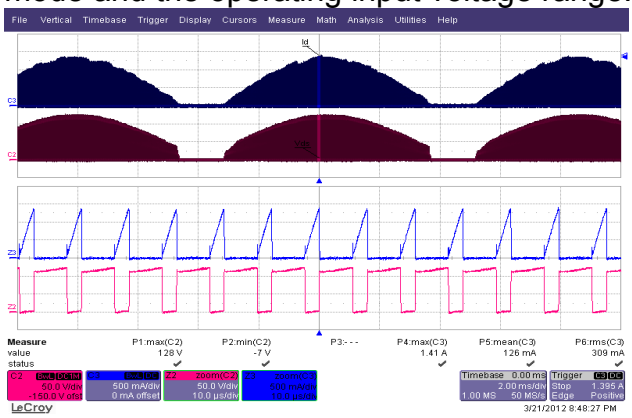


Figure 16 – 90 VAC / 60 Hz, 33 V LED String.
Ch2: V_{DRAIN}, 50 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 10 µs / div.

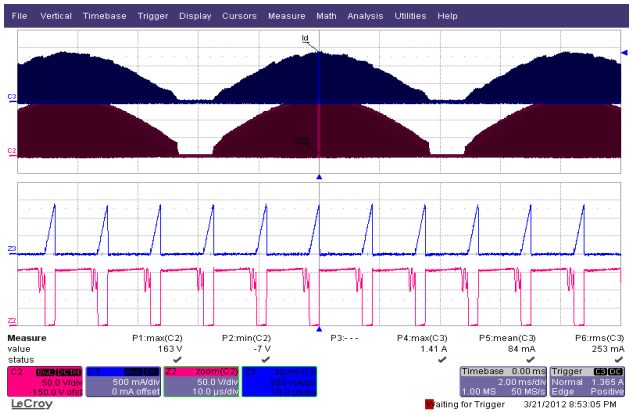


Figure 17 – 132 VAC / 60 Hz, 33 V LED String.
Ch2: V_{DRAIN}, 50 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 10 µs / div.

11.2 Drain Voltage and Current Start-up Profile

The LinkSwitch-PL family has a built in soft start thereby reducing the stress.

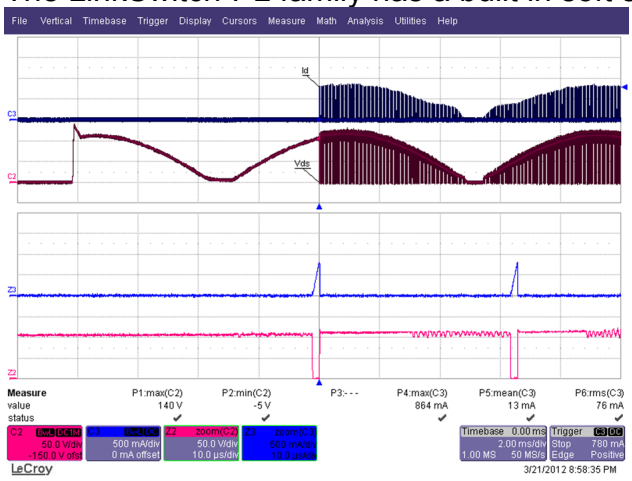


Figure 18 – 90 VAC / 50 Hz, 33 V LED String.
Ch2: V_{DS}, 50 V / div.
Ch3: I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

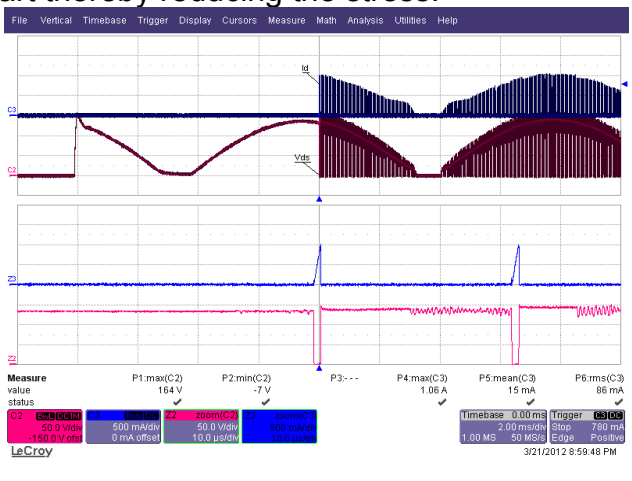


Figure 19 – 132 VAC / 50 Hz, 33 V LED String.
Ch2: V_{DS}, 50 V / div.
Ch3: I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

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11.3 Output Voltage Start-up Profile

Start-up time <100 ms; the lamp will emit light within 100 ms in non-dimming operation.

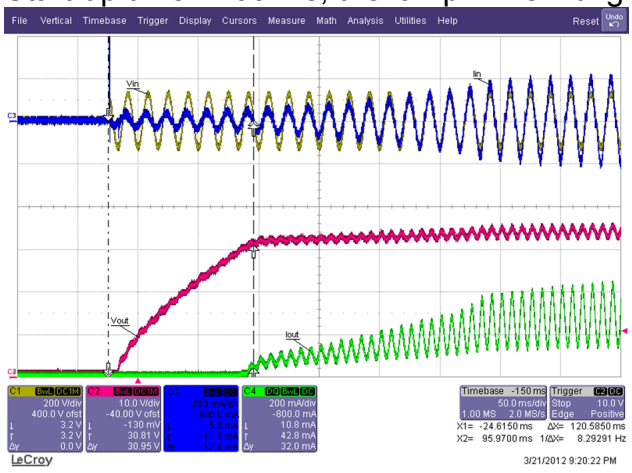

Figure 20 – 90 VAC / 60 Hz, 33 V LED.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 50 ms / div.

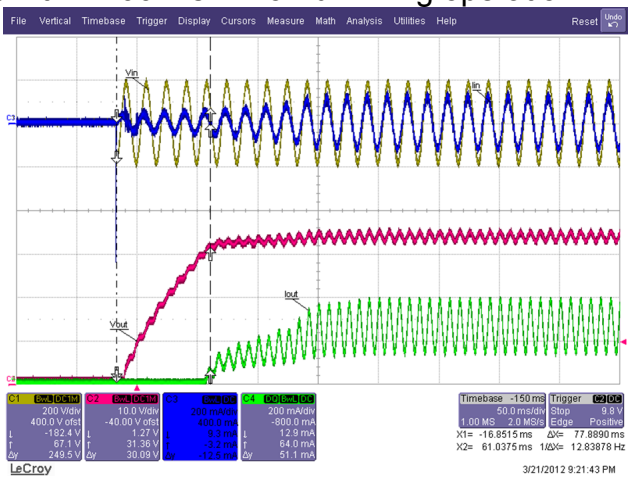

Figure 21 – 132 VAC / 60 Hz, 9 V LED.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 50 ms / div.

11.4 Input and Output Voltage and Current Profiles

Output current ripple is inversely proportional to the impedance of the LED. It is therefore necessary to verify the actual current ripple on the LED load to be used in the lamp. Increase output capacitance to reduce current ripple if neccessary.

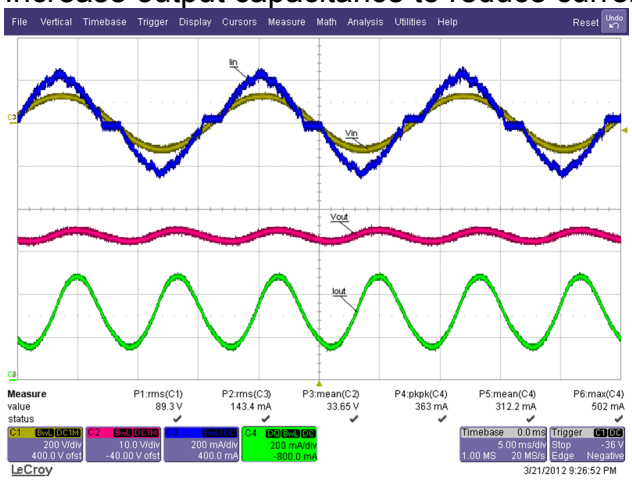

Figure 22 – 90 VAC / 50 Hz, 33 V LED String.
C_{OUT} = 270 µF
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 5 ms / div.

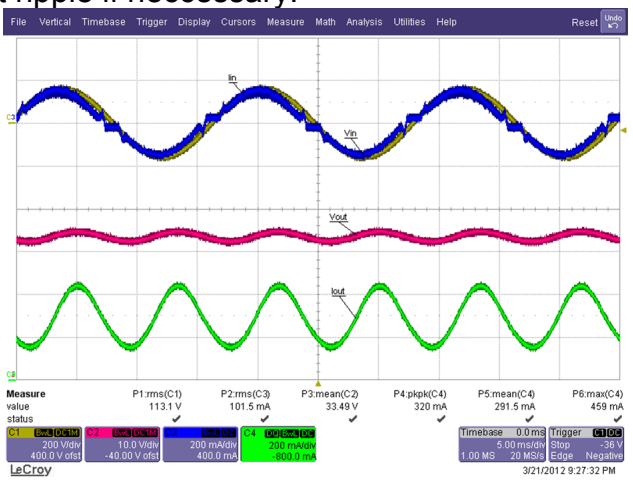

Figure 23 – 132 VAC / 50 Hz, 33 V LED String.
C_{OUT} = 270 µF
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 5 ms / div.

11.5 Drain Voltage and Current Profile: Running Operation Output Short

No saturation in the inductor during short-circuit, inductor current is limited by the I_{LIM}.

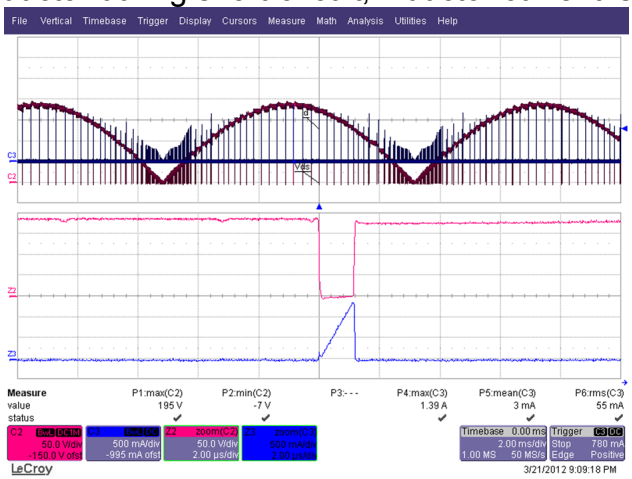

Figure 24 – 132 VAC / 50 Hz, Normal Operation then Output Short.
Ch2: V_{DRAIN}, 50 V / div.
Ch3: I_{DRAIN}, 0.5 A / div., 2 ms / div.
Z3: I_{DRAIN}, 0.5 A / div., 100 µs / div.

11.6 Drain Voltage and Current Profile: Start-up with Output Shorted

No saturation in the inductor during start up short-circuit due to the built-in soft-start.

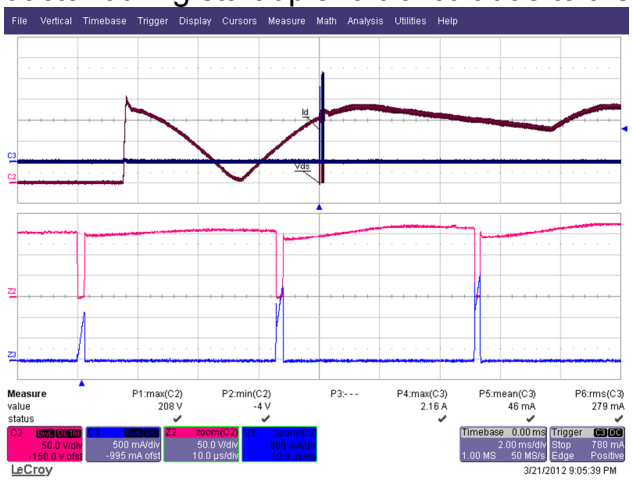

Figure 25 – 132 VAC / 50 Hz, Output Shorted.
Ch2: V_{DRAIN}, 50 V / div.
Ch3: I_{DRAIN}, 0.5 A / div., 2 ms / div.
Z3: I_{DRAIN}, 0.5 A / div., 100 µs / div.

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11.7 Disconnected Load Operation

The driver is protected during no-load operation via VR1. Zener diode VR1 will fail short-circuit once the output voltage exceeds VR1 avalanche threshold (after the load has been disconnected), leaving U1 to enter auto-restart mode.

11.8 Dimming Sample Waveforms

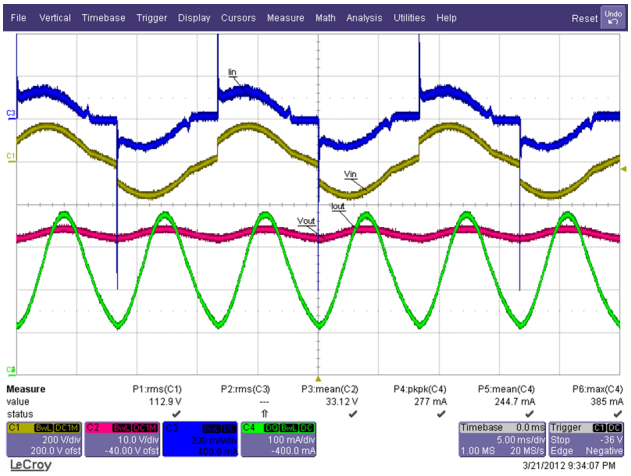

Figure 26 – 230 VAC / 50 Hz, Lutron Skylark S-600 Dimmer at Full TRIAC Conduction.
Load: 33 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

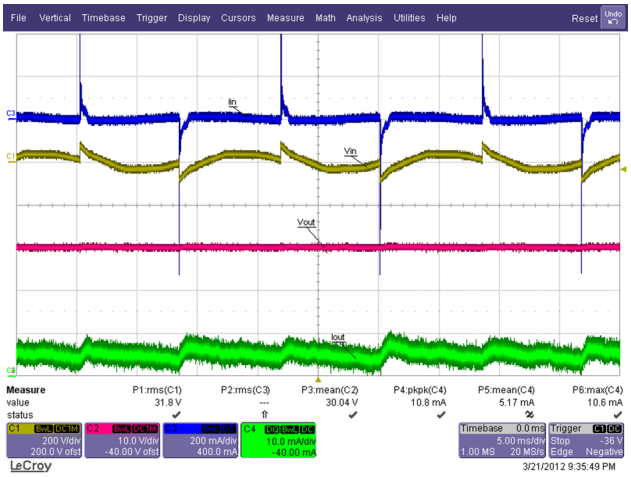

Figure 27 – 230 VAC / 50 Hz, Lutron Skylark S-600 Dimmer at Minimum TRIAC Conduction.
Load: 33 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

11.9 Line Surge Waveform

11.9.1 Ring Surge

Peak Drain voltage measured was 390 V well below the 725 V power MOSFET rating.

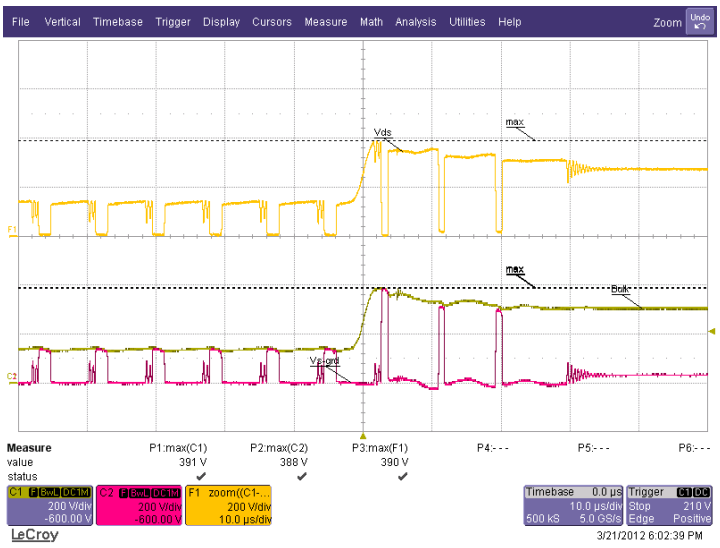

Figure 28 – 132 VAC / 60 Hz, 33 V Load,
V_{DS} = 390 $V_{PK;}$
(+) 2.5 kV Differential Ring Surge at 0º.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 200 V / div.
Time Scale: 10 µs / div.

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12 Conducted EMI

12.1 Equipment

Receiver:

Rohde & Schwartz
ESPI - Test Receiver (9 kHz – 3 GHz)
Model No: ESPI3

LISN:

Rohde & Schwartz
Two-Line-V-Network
Model No: ENV216

12.2 EMI Test Set-up

LED driver was placed inside a conical metal housing (for self-ballasted lamps; CISPR15 Edition 7.2) but since lamp housing is not available during the UUT was tested then it was evaluated as shown in the figure below.

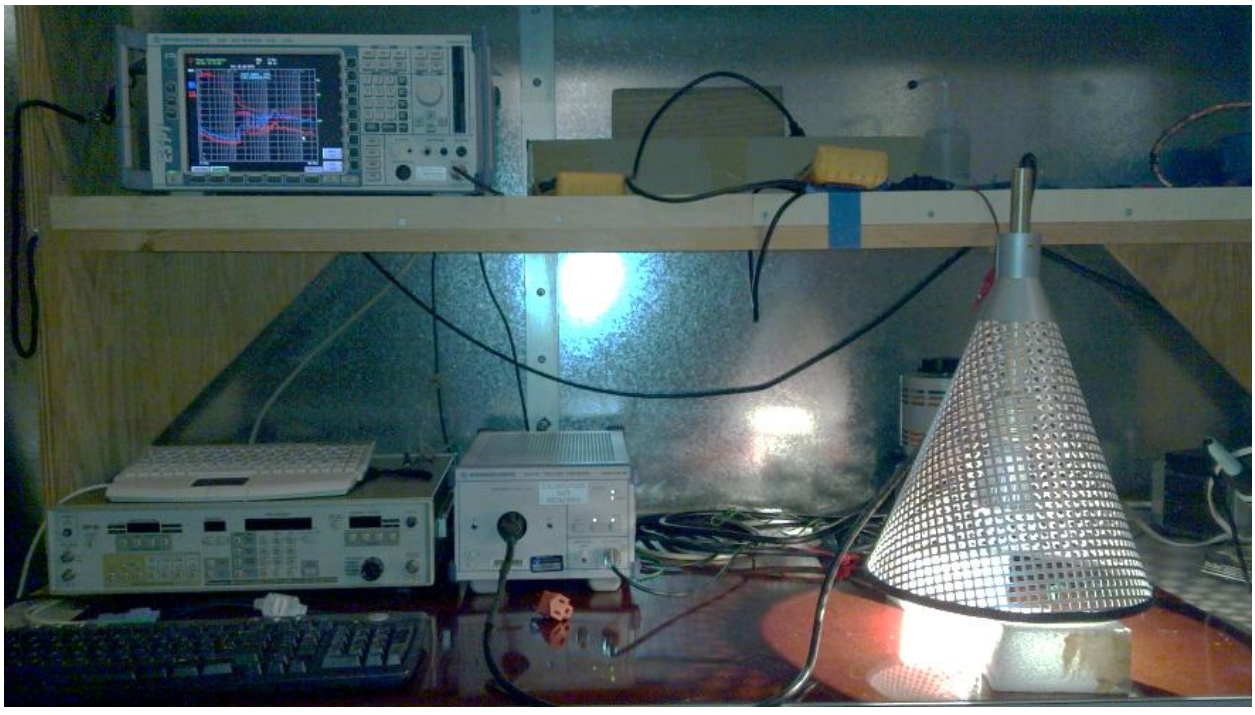

Figure 29 – Conducted Emissions Measurement Set-up.

12.3 EMI Test Result

Graphs plotted are Peak and Average measurement.

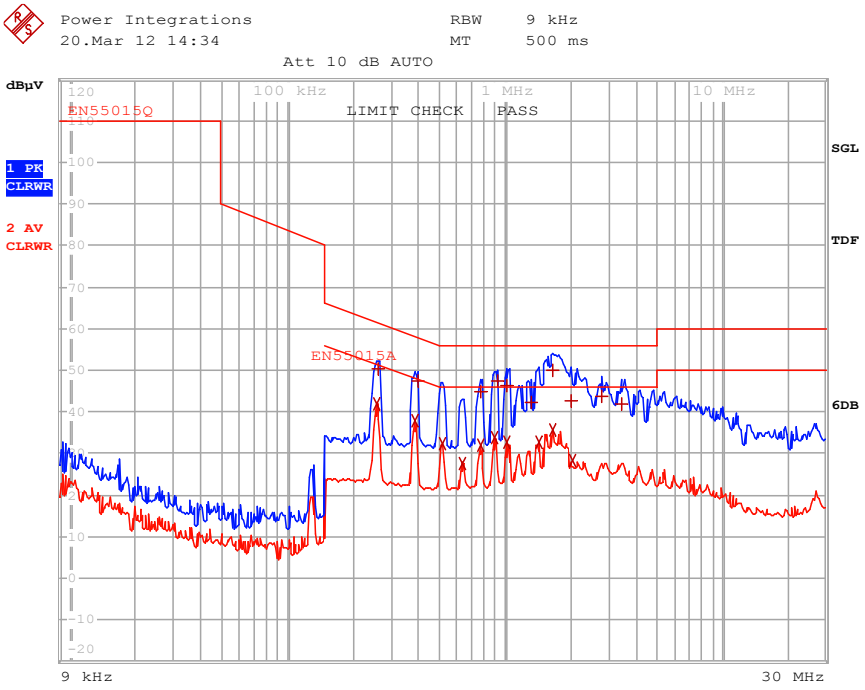

Figure 30 – Conducted EMI, 33 V output / 280 mA Steady-State Load, 1115 VAC, 60 Hz, and EN55015 Limits.

TRACE		FREQUENCY	LEVEL dBµV		DELTA LI
2	Average	256.711570318 kHz	42.08	L1 gnd	-9.44
1	Quasi Peak	261.871472881 kHz	50.20	L1 gnd	-11.16
2	Average	386.030632509 kHz	37.85	L1 gnd	-10.29
1	Quasi Peak	393.789848222 kHz	47.49	L1 gnd	-10.48
2	Average	515.159375557 kHz	32.34	L1 gnd	-13.65
2	Average	634.878262431 kHz	27.72	L1 gnd	-18.27
1	Quasi Peak	774.672132397 kHz	44.72	L1 gnd	-11.27
2	Average	774.672132397 kHz	31.95	L1 gnd	-14.04
2	Average	899.370296303 kHz	33.87	L1 gnd	-12.12
1	Quasi Peak	926.622115652 kHz	47.38	L1 gnd	-8.61
1	Quasi Peak	1.02356729084 MHz	46.38	L1 gnd	-9.61
2	Average	1.02356729084 MHz	32.60	L1 gnd	-13.39
1	Quasi Peak	1.32578199726 MHz	42.36	L1 gnd	-13.63
2	Average	1.42141774845 MHz	32.81	L1 gnd	-13.18
2	Average	1.65022187856 MHz	35.82	L1 gnd	-10.17
1	Quasi Peak	1.66672409735 MHz	50.10	L1 gnd	-5.89
1	Quasi Peak	2.03372014292 MHz	42.78	L1 gnd	-13.21
2	Average	2.05405734435 MHz	28.15	L1 gnd	-17.84
1	Quasi Peak	2.79624455326 MHz	43.68	L1 gnd	-12.31
1	Quasi Peak	3.41194975314 MHz	41.76	L1 gnd	-14.23

Figure 31 – Conducted EMI, 33 V / 280 mA Steady-State Load Steady-State Load, 115 VAC, 60 Hz, and EN55015 Limits; Line and Neutral Scan Design Margin Measurement.

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13 Revision History

Date	Author	Revision	Description and Changes	Reviewed
07-Nov-12	ME	1.0	Initial Release	Apps & Mktg

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Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@powerint.com

GERMANY
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@powerint.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@powerint.com

TAIWAN
5F, No. 318, Nei Hu Rd., Sec. 1
Nei Hu District
Taipei 114, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail: taiwansales@powerint.com

CHINA (SHANGHAI)
Rm 1601/1610, Tower 1
Kerry Everbright City
No. 218 Tianmu Road West
Shanghai, P.R.C. 200070
Phone: +86-021-6354-6323
Fax: +86-021-6354-6325
e-mail: chinasales@powerint.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@powerint.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D, 159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728
Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@powerint.com

EUROPE HQ
1st Floor, St. James's House
East Street, Farnham
Surrey GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
e-mail: eurosales@powerint.com

CHINA (SHENZHEN)
3rd Floor, Block A, Zhongtou International Business Center, No. 1061, Xiang Mei Road, FuTian District, ShenZhen, China, 518040
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
e-mail: chinasales@powerint.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI) Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@powerint.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@powerint.com

APPLICATIONS HOTLINE
World Wide +1-408-414-9660

APPLICATIONS FAX
World Wide +1-408-414-9760