Design Example Report

Title	***10 W, 88% Efficiency Low Line TRIAC Dimmable for BR30 Power Factor Corrected Non-Isolated Buck LED Driver Using LYTSwitch™-7 LYT7503D***
Specification	90 VAC – 132 VAC Input; 60 V, 170 mA Output
Application	BR-30 Dimmable LED Bulb
Author	Applications Engineering Department
Document Number	DER-586
Date	February 13, 2017
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant LED current (CC) regulation, ±5%
- High efficiency, > 88% at 120 VAC
- Low cost and low component count for compact PCB solution
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers
  - Fast start-up time (<500 ms) – no perceptible delay
  - Minimum dead-band or visible pop-on effect.
- Integrated protection features
  - Open load and output short-circuit protection
  - Thermal fold-back protection
  - No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 1 kV differential surge and EN55015 conducted EMI

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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 a low component count, TRIAC dimmable, non-isolated buck LED driver, designed to drive a nominal LED voltage string of 60 V at 170 mA from an input voltage range of 90 VAC to 132 VAC. This LED driver utilizes the LYT7503D from the LYTSwitch-7 family of devices.

The LYTSwitch-7 device is an SO-8 package LED driver controller IC designed for non-isolated buck topology applications. The LYTSwitch-7 ICs provide high efficiency, high power factor, accurate LED current regulation, and inherent dimming capability. LYTSwitch-7 ICs incorporate a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode control engine for accurate current regulation, high power factor and proprietary power MOSFET utilization for high efficiency. The controller also integrates protection features such as input and output overvoltage protection, thermal fold-back, over temperature shutdown, output short-circuit and overcurrent protection.

DER-586 is a single stage 10 W TRIAC dimmable LED driver with constant current output. The key design goals were design simplicity, high efficiency, low component count, accurate constant current regulation, compact PCB and acceptable dimming compatibility. The design is intended for BR-30 dimmable LED bulb applications.

This document contains the power supply specification, schematic diagram, bill of materials, printed circuit layout, and performance data.

Figure 1 – Populated Circuit Board.

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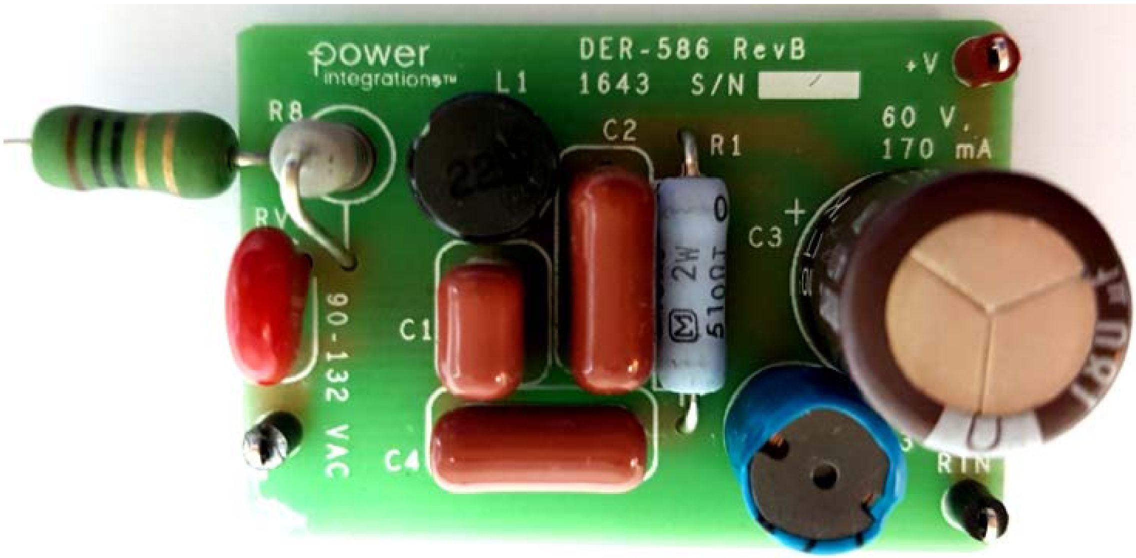

Figure 2 – Populated Circuit Board, Top View.

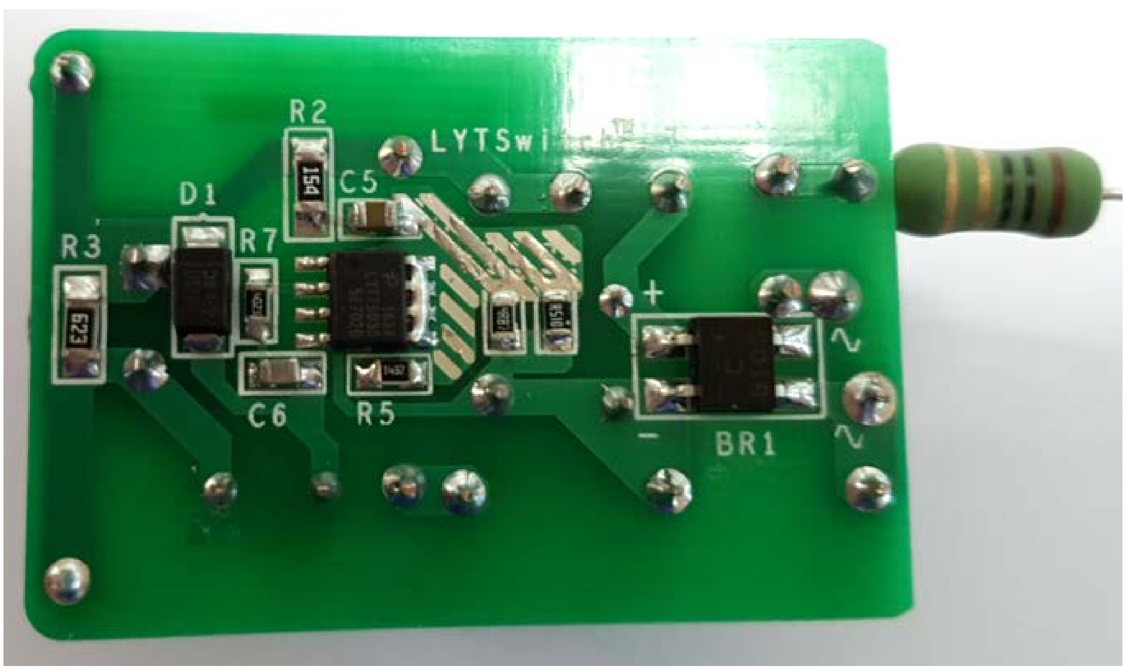

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}		60		V	
Output Current	I_{OUT}		170		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		10		W	
Efficiency						
Full Load	η		88		%	Measured at 120 VAC, 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 120 VAC, 50 Hz.
Ambient Temperature	T_{AMB}		40		^{o}C	Free convection, Sea Level.

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3 Schematic

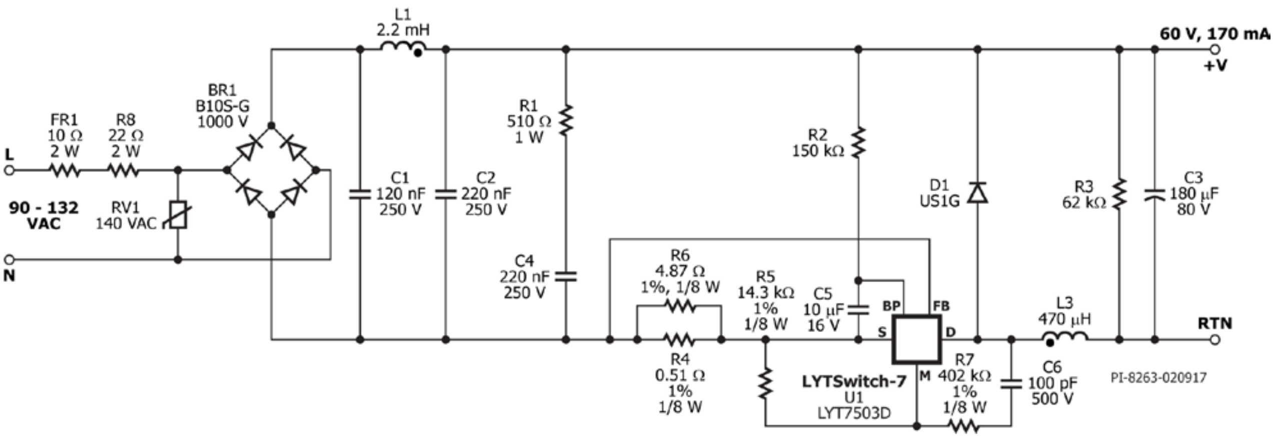

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-7 (U1-LYT7503D) combines a high-voltage power MOSFET switch with a variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. LYT7503D is configured to drive a 60 V LED string, TRIAC dimmable, non-isolated buck LED driver with 170 mA constant current output. The LYT7503D device was selected from the graph selection guidance located in the data sheet. The graph is a function of output power and output voltage requirement.

4.1 Input Stage

The fusible resistor FR1 provides safety protection against component failures that would lead to very high input current. Varistor RV1 provides clamping during differential line surge events to limit the maximum voltage spike across the primary. The maximum clamping voltage of RV1 must be lower than the Drain-to-Source breakdown voltage of the internal power MOSFET of LYT7503D (725 V) to ensure sufficient input overvoltage protection during line surge occurrence.

The AC input is full-wave rectified by BR1 to provide the pulsating DC input to the pi filter consisting of C1, C2 and L1. The values of C1, C2 and L1 were chosen to provide the best balance between high power factor, EMI performance, and dimming compatibility.

4.2 EMI Filter

The inductor L1 and capacitors, C1 and C2, form an EMI pi filter which works to filter differential mode noise. The LYTSwitch-7 ICs' variable frequency / on-time states and critical conduction mode control engine limits RFI emission to significant level which enables design to use simple EMI pi filter even for high power bulb and tube applications.

4.3 LYTSwitch-7 Control Circuit

The topology used for this LED driver is a low-side buck converter. During the on-time of the LYT7503D internal power MOSFET, current ramps through the buck inductor winding, charging the output capacitor, and provides current to the output load. The energy stored in the magnetic field of the inductor winding during on-time of the power MOSFET is then delivered to the load during off-time via output diode D1. The output capacitor C3 provides filtering to minimize LED ripple current while resistor R3 serves as a pre-load.

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1, which provides power to the IC during the switch on-time. The IC internal regulator draws power from high-voltage DRAIN (D) pin and charges the bypass capacitor C5 during the power switch off time. The typical BP pin voltage is 5.22 V. To keep the IC operating normally especially during the dead zone, where $V_{IN} < V_{OUT}$, the value of capacitor should be large enough to keep the BP voltage above the $V_{BP(RESET)}$ value of 4.5 V. Additional bias resistor R2 was employed to maintain the BP pin voltage for very fast AC on/off power cycling event and during low conduction angle operation. Recommended minimum value for the BP capacitor is 10 μF.

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Resistor R2 can be calculated as follows, where: I_{BP_EXT} can be between 150 µA – 500 µA.

$R2 = V_{OUT} - V_{BP} / I_{BP\_EXT}$

Constant output current regulation is achieved through the FEEDBACK (FB) pin directly sensing the drain current during the power MOSFET on-time using external current sense resistors (R_{FB}) R4 and R6, and comparing the voltage drop to a fixed internal reference voltage (V_{FB_REF}) of absolute value 280 mV typical. R_{FB} can be calculated as follows:

$R_{FB} = V_{FB\_REF} / k \times I_{OUT}$

Where: k is the ratio between I_{PK} and I_{OUT}; k = 4 for LYT750x.

Trimming R_{FB} may be necessary to center I_{OUT} at the nominal input voltage.

The MULTIFUNCTION (M) pin monitors the line for any line overvoltage event. When the internal power MOSFET is in on-state, the M pin is shorted internally to SOURCE (S) pin in order to detect the rectified input line voltage derived from the voltage across the inductor, i.e. (V_{IN}-V_{OUT}) and current flowing out of the M pin is defined by resistor R7, thus line overvoltage detection is calculated as;

$V_{LINE\_OVP} = I_{IOV} \times R7 + V_{OUT}$; where R7 is assumed to be 402 kΩ ±1%.

Once the measured current exceeds the input overvoltage threshold (I_{IOV}) of 1 mA typical, the IC will inhibit switching instantaneously and initiate auto-restart to protect the internal power MOSFET of the IC.

The M pin also monitors the output for any overvoltage and undervoltage event. When the internal power MOSFET is in off-state, the output voltage is monitored through a coupling capacitor (C6) and divider resistors R7 and R5. When an output open-load condition occurs, the voltage at the M pin will rise abruptly and when it exceeds the threshold of 2.4 V, the IC will inhibit switching instantaneously and initiate auto-restart to limit the output voltage from further rising. The overvoltage cut-off is typically 120% of the output voltage, which is equivalent to 2 V at the M pin ($V_{OUT\_OVP} = V_{OUT} \times 2.4$ V / 2 V). Resistor R7 is set to a fixed value of 402 kΩ ±1% and R5 will determine the output overvoltage limit. Any short-circuit at the output will be detected once the M pin voltage falls below the undervoltage threshold (V_{OUV}) of 0.95 V typical, then the IC will inhibit switching instantaneously and initiate auto-restart to limit the average input power to less than 1 W, preventing any components from overheating.

Resistor R5 can be calculated as follows:

$R5 = 2\ V \times R7 / (V_{OUT} - 2\ V)$; this is applicable only to low-side configuration buck.

Another function of the M pin is for zero current detection (ZCD). This is to ensure operation in critical conduction mode. The inductor demagnetization is sensed when the voltage across the inductor begins to collapse towards zero as flywheel diode (D1) conduction expires.

4.4 TRIAC Phase Dimming Control

The control mechanism of the LYTSwitch-7 LYT7503D provides inherent dimming capability which makes it suitable to use a simple RC damper (R1 and C4) to avoid the TRIAC current to fall below its holding current and turn off.

The relatively large impedance presented to the line by the LED allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. Resistors FR1 and R8 may be trimmed to damp this input current ringing and help reduce / minimize flickering or shimmering.

The voltage across C5 may be monitored for any dipping below the IC (LYT7503D) reset threshold of 4.5 V, that may cause flickering or shimmering on or near the minimum conduction angle. The value of capacitor C5 may be increased to smoothen out the voltage at BP pin of the IC. Consequently, the resistance of the pull-up resistor R2 may be made smaller to increase the charging current available to the BP pin capacitor C5. However, decreasing the resistance value of the pull-up resistor may degrade efficiency – a trade-off, therefore, should be considered.

For high leakage TRIACs, undesired restarting of the unit, characterized by a very quick burst of output currents at long intervals, may occur when the dimmer knob is positioned just below the minimum conduction angle where the unit should turn off. To address this, the pre-load resistor R3 is chosen to be very large to avoid charging of the BP pin capacitor through the internal connection to the Drain via the pre-load resistor.

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5 PCB Layout

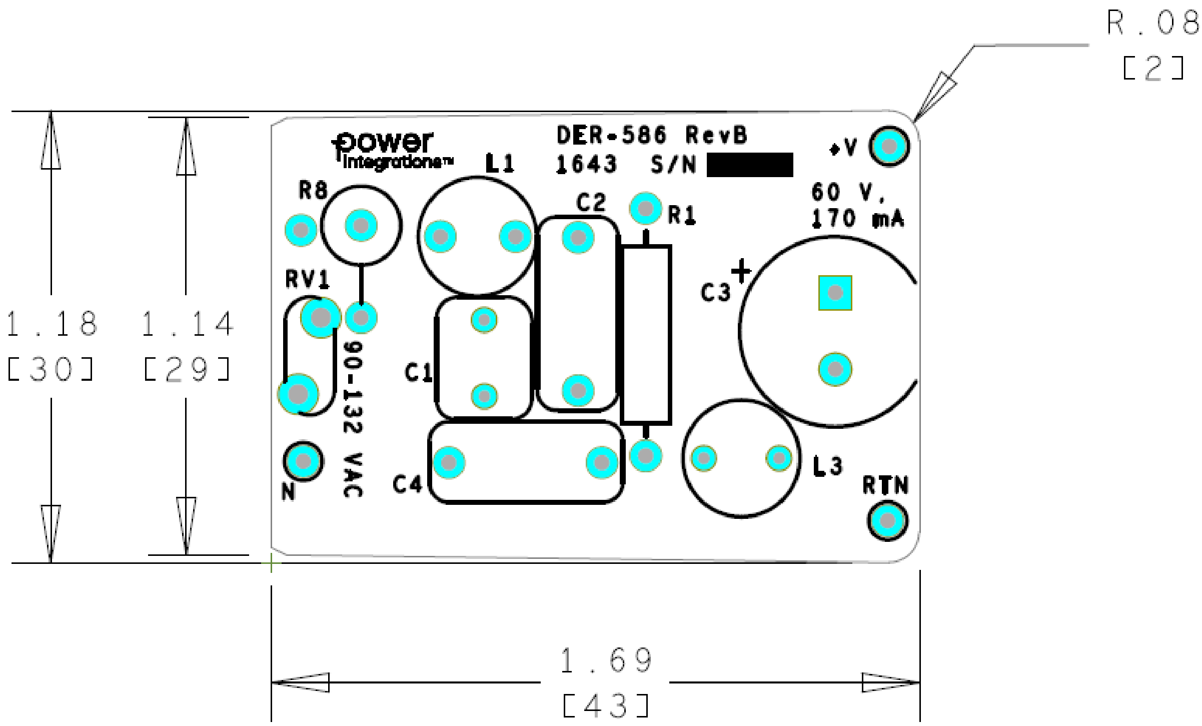

Figure 5 – Top Side.

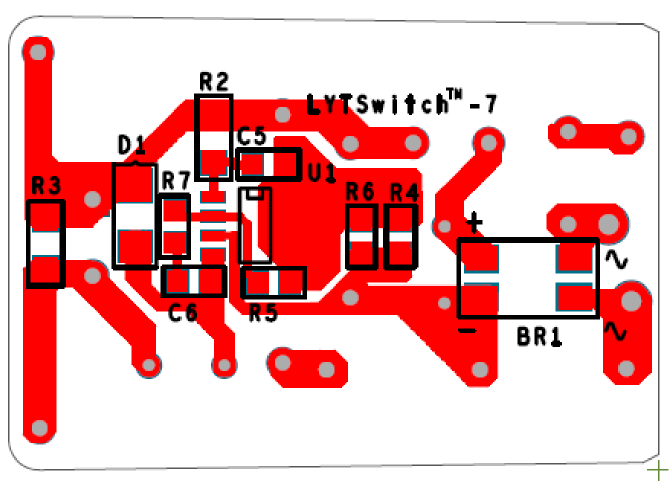

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	120 nF, 250 V, Radial, Film	ECQ-E2124JB	Panasonic
3	1	C2	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
4	1	C3	180 μF, 80 V, Electrolytic, 90 mΩ, (12.5 x 17.5)	EKZN800ELL181MK16S	Nippon Chemi-Con
5	1	C4	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
6	1	C5	10 μF, ±10%, 16 V, X7R, Ceramic, 0805	CL21B106KOQNNNE	Samsung
7	1	C6	100 pF, 500 V, Ceramic, NPO, 0805	501R15N101KV4T	Johanson Dielectrics
8	1	D1	Diode Ultrafast, GPP, 400 V, 1 A SMA	US1G-13-F	Diodes, Inc.
9	1	FR1	RES, 10 Ω, 5%, 2 W, Wire Wound, Fusible	FW20A10R0JA	Bourns
10	1	L1	2.2 mH, 0.18 A, Radial, 10%	RL875-222K-RC	Bourns
11	1	L3	470 μH, 0.49 A	SBC3-471-491	Tokin
12	1	R1	RES, 510 Ω, 5%, 1 W, Metal Oxide Film	ERG-1SJ511	Panasonic
13	1	R2	RES, 150 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ154V	Panasonic
14	1	R3	RES, 62 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ623V	Panasonic
15	1	R4	RES, SMD, 0.51 Ω, 1%, 1/8W 0805	RL0805FR-070R51L	Yageo
16	1	R5	RES, 14.3 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1432V	Panasonic
17	1	R6	RES, 4.87 Ω, 1%, 1/8 W, Thick Film, 0805	RC0805FR-074R87L	Yageo
18	1	R7	RES, 402 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4023V	Panasonic
19	1	R8	RES, 22 Ω, 5%, 2 W, Metal Oxide	RSF200JB-22R	Yageo
20	1	RV1	140 VAC, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
21	1	U1	LYTSwitch-7, Dimmable, SO-8	LYT7503D	Power Integrations

Miscellaneous

1	1	N	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
2	1	V+	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
3	1	RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone

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7 Inductor Design Spreadsheet

ACDC_LYTSwitch7_Buck_080516; Rev.1.1; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-7 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Low Line		AC line voltage range
VACMIN	90		90	V	Minimum AC line voltage
VACTYP	115		115	V	Typical AC line voltage
VACMAX	132		132	V	Maximum AC line voltage
FL	60		60	Hz	AC mains frequency
VO	60	Info1	60	V	!!Info1. VO is higher than recommended output voltage. Verify CC regulation.
IO	170		170	mA	Average output current specification
EFFICIENCY			0.90		Efficiency estimate
PO			10.20	W	Continuous output power
VD	0.70		0.70	V	Output diode forward voltage drop
ENTER LYTSWITCH-7 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	V	This Spreadsheet supports 725V device only
DEVICE	Auto		LYT7503D		Actual LYTSwitch-7 device
ILIMITMIN			1.06	A	Minimum Current Limit
ILIMITTYP			1.15	A	Typical Current Limit
ILIMITMAX			1.24	A	Maximum Current Limit
TON			2.94	us	On-time during the fixed on-time region at VACTYP
FSW			135	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			3.43		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	Off the shelf		Off the shelf		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			0.00	mm^2	Core effective cross cectional area
LE			0.00	mm	Core effective path length
AL			0.00	nH/turn^2	Core ungapped effective inductance
AW			0.00	mm^2	Window Area of the bobbin
BW			0.00	mm	Bobbin physical winding width
LAYERS	3.0		3.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN			250	uH	Absolute minimum design inductance
LP_TYP			459	uH	Typical Inductance
LP_TOLERANCE			10	%	Tolerance of the design inductance
LP_MAX			667	uH	Absolue maximum design inductance
TURNS			NA	Turns	Number of inductor turns
ALG			NA	nH/turn^2	Inductance per turns squared
BMAX			NA	Gauss	!!! Warning. Maximum flux density is too high. Increase NP or use bigger core size
BAC			NA	Gauss	AC flux density in the fixed peak current region
LG			NA	mm	Core air gap
BWE			NA	mm	Effective bobbin width
OD			NA	mm	Outer diameter of the wire with insulation
INS			NA	mm	Wire insulation
DIA			NA	mm	Outer diameter of the wire without insulation
AWG			NA		AWG of the bare wire.
CM			NA	Cmils	Bare wire circular mils
CMA			NA	Cmils/A	Bare wire circular mils per ampere

CURRENT DENSITY			NA	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR			NA		Area of the bobbin occupied by wire
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.12	A	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.61	A	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.15	A	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.17	A	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.22	A	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.458	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.453	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Components					
RUPPER			402.00	kOhms	Upper resistor on the M-pin divider network (E96 / 1%)
RLOWER	14.30	Info	14.30	kOhms	!!Info. The Rlower value provided is higher than calculated. For low-side buck, this could falsely trigger OVP at high input voltage and wide LED tolerance.Please verify on the bench.
VO_OVP			69.2	V	VO overvoltage threshold
Line_OVP			462	V	Line overvoltage threshold
CC			100	pF	Coupling Capacitor for Low Side Buck Configuration
RPRELOAD			60	kOhms	Minimum Output Preload Resistor
CBP			10	uF	BP Capacitor
RBP			174	kOhms	Recommended Pull-up Resistor from DC bus to BP pin
Dimming Components					
RDAMPER			33	ohms	Damper Resistor
RBLEED			510	ohms	Bleeder Resistor
CBLEED			220	nF	Bleeder Capacitor
VOLTAGE STRESS PARAMETERS					
VDRAIN			187	V	Estimated worst case drain voltage
PIVD			187	V	Output Rectifier Maximum Peak Inverse Voltage

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8 Performance Data

All measurements were performed at room temperature using LED load string. 1 minute soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

8.1 Efficiency

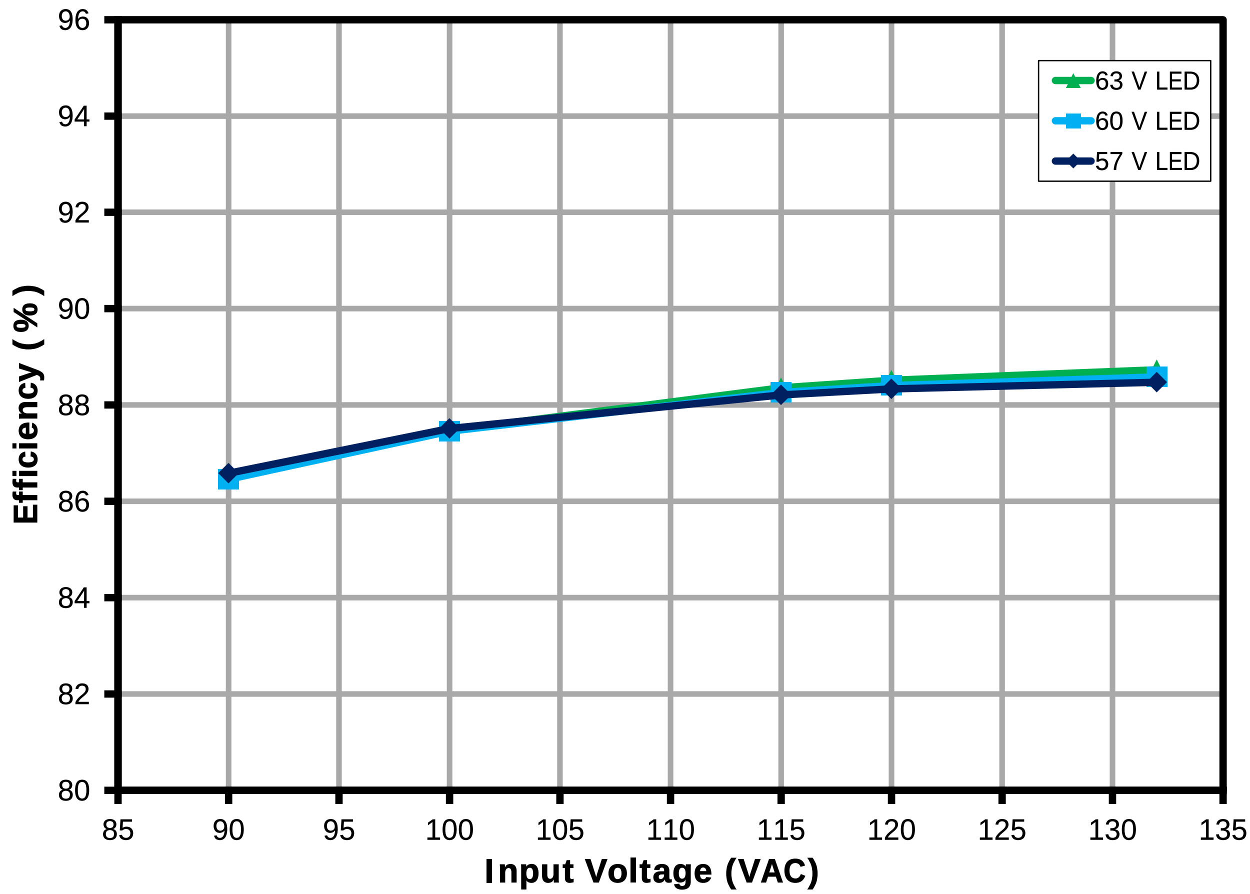

Figure 7 – Efficiency vs. Input Line Voltage.

8.2 Line Regulation

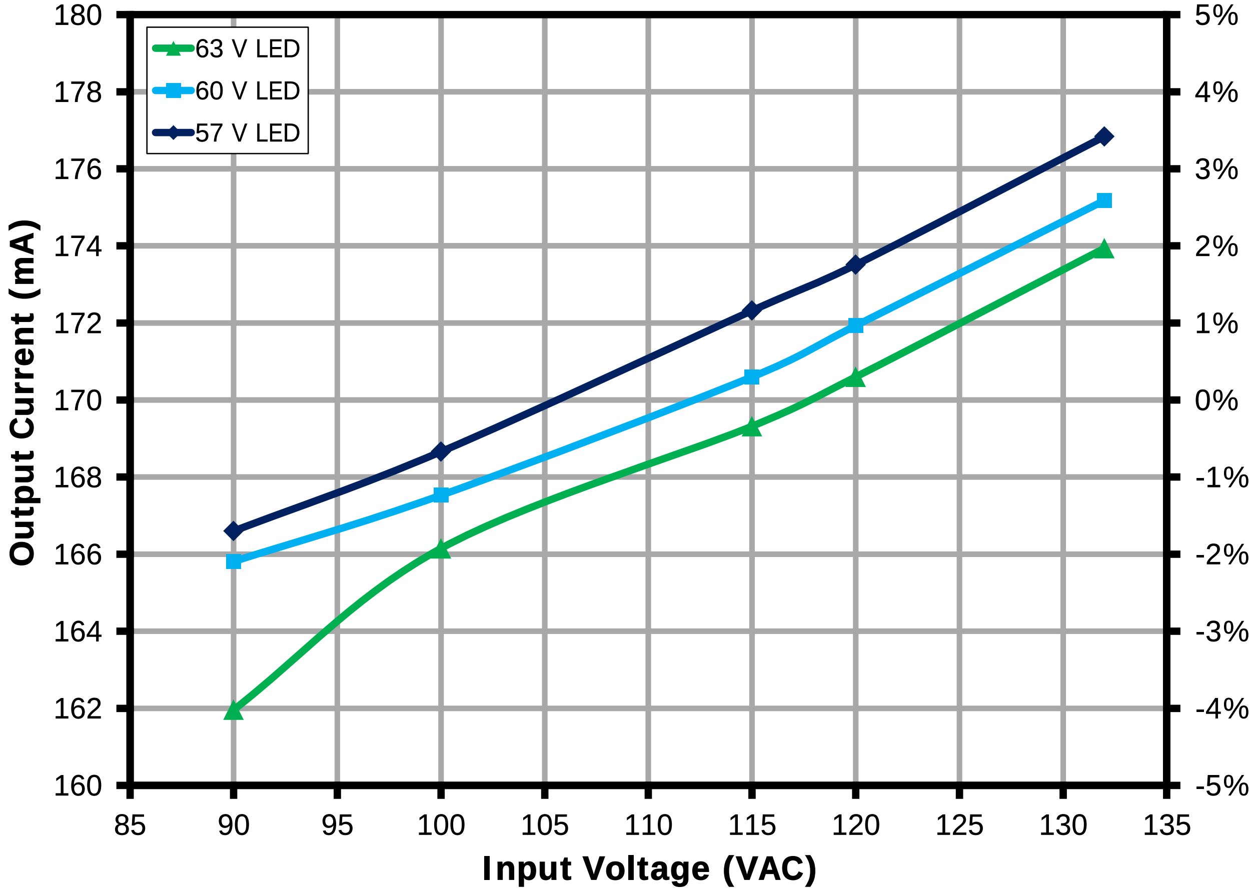

Figure 8 – Output Regulation vs. Input Line Voltage.

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8.3 Power Factor

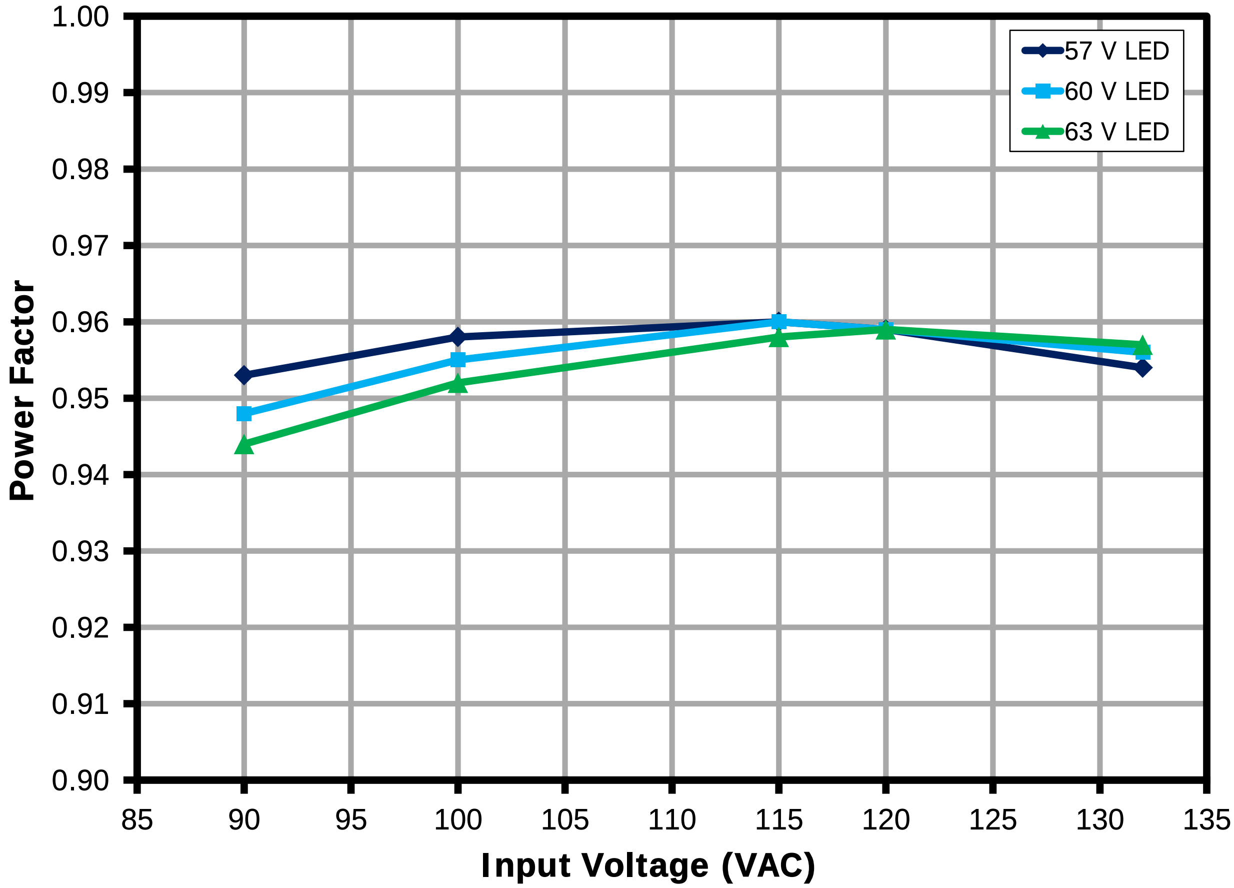

Figure 9 – Power Factor vs. Input Line Voltage.

8.4 %ATHD

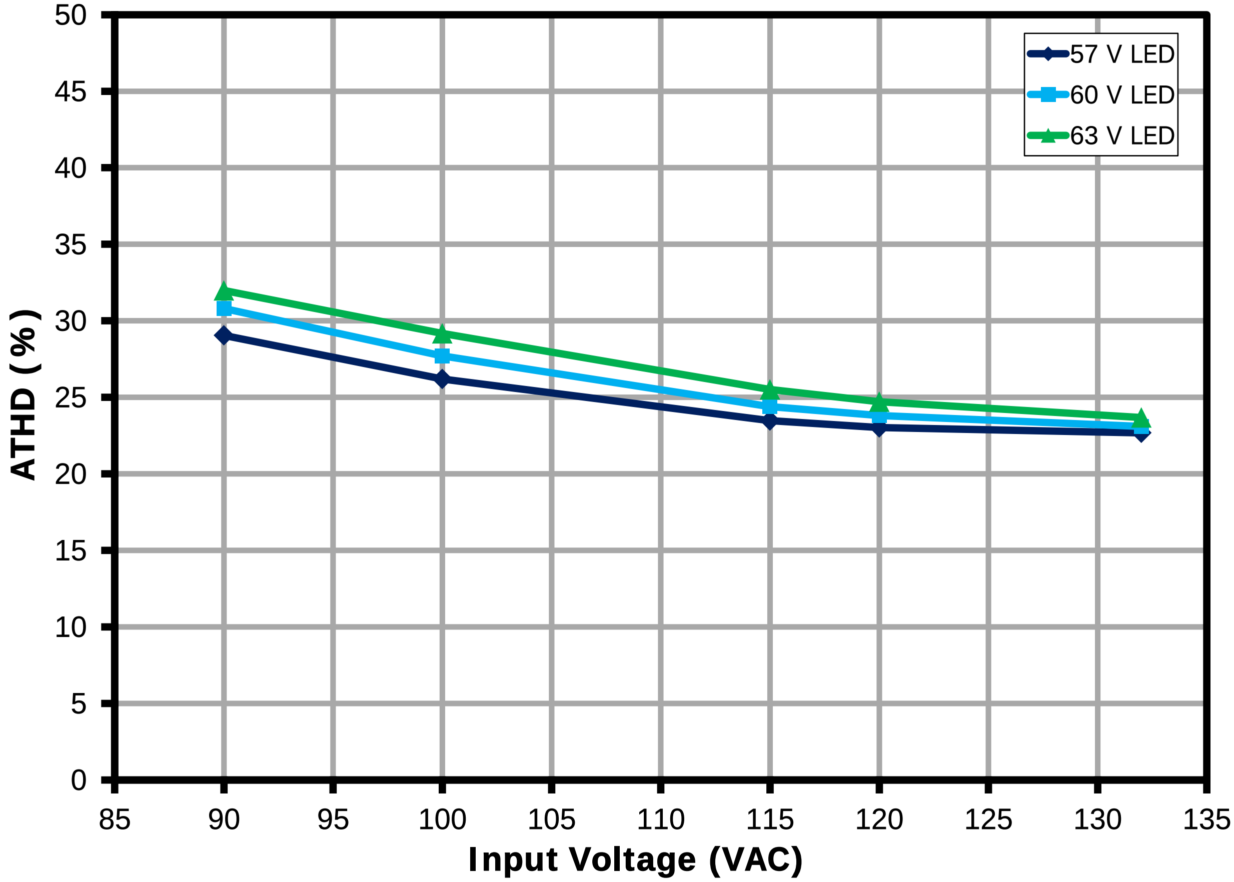

Figure 10 – %ATHD vs. Input Line Voltage.

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8.5 Harmonics

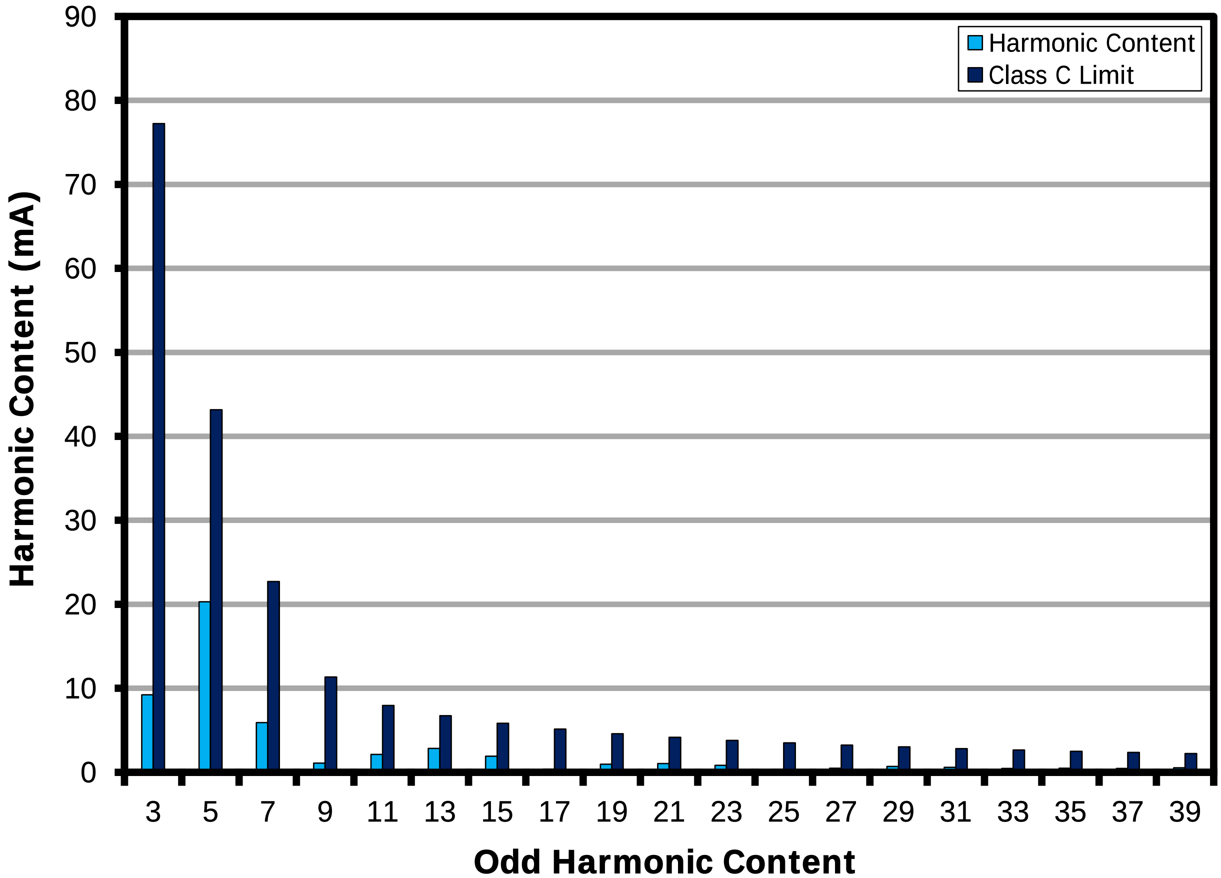

Figure 11 – Input Current Harmonics at 115 VAC, 60 Hz.

9 Test Data

9.1 Test Data, 57 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	90.00	126.16	10.82	0.953	29.05	56.11	166.60	9.37	86.58
100	60	99.93	113.28	10.85	0.958	26.19	56.20	168.66	9.49	87.51
115	60	115.01	99.81	11.02	0.960	23.47	56.34	172.32	9.72	88.21
120	60	119.97	96.38	11.09	0.959	23.03	56.38	173.51	9.80	88.33
132	60	131.95	89.87	11.31	0.954	22.68	56.51	176.84	10.01	88.47

9.2 Test Data, 60 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.99	133.41	11.38	0.948	30.81	59.25	165.81	9.84	86.46
100	60	99.93	119.18	11.38	0.955	27.71	59.30	167.53	9.95	87.46
115	60	115.00	104.21	11.50	0.960	24.39	59.42	170.60	10.15	88.26
120	60	119.97	100.63	11.58	0.959	23.81	59.47	171.93	10.24	88.40
132	60	131.95	93.59	11.80	0.956	23.09	59.60	175.18	10.45	88.59

9.3 Test Data, 63 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.99	137.43	11.68	0.944	31.98	62.25	161.96	10.10	86.47
100	60	99.92	124.86	11.87	0.952	29.17	62.42	166.15	10.39	87.47
115	60	114.99	108.89	12.00	0.958	25.51	62.54	169.32	10.60	88.36
120	60	119.96	105.02	12.08	0.959	24.71	62.58	170.60	10.69	88.52
132	60	131.94	97.56	12.31	0.957	23.68	62.73	173.94	10.92	88.73

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9.4 Harmonic Content at 115 VAC, 60 Hz, 60 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60	102.98	11.360	24.48%
Harmonic Content			**Class C Limit**	
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	96.02			
2	0.07	0.07%		
3	9.22	9.60%	77.25	Pass
5	20.31	21.15%	43.17	Pass
7	5.92	6.17%	22.72	Pass
9	1.09	1.14%	11.36	Pass
11	2.12	2.21%	7.95	Pass
13	2.84	2.96%	6.73	Pass
15	1.91	1.99%	5.83	Pass
17	0.39	0.41%	5.15	Pass
19	0.97	1.01%	4.60	Pass
21	1.04	1.08%	4.17	Pass
23	0.82	0.85%	3.80	Pass
25	0.34	0.35%	3.50	Pass
27	0.48	0.50%	3.24	Pass
29	0.70	0.73%	3.02	Pass
31	0.59	0.61%	2.82	Pass
33	0.47	0.49%	2.65	Pass
35	0.48	0.50%	2.50	Pass
37	0.47	0.49%	2.36	Pass
39	0.54	0.56%	2.24	Pass
41	0.36	0.37%		
43	0.61	0.64%		
45	0.48	0.50%		
47	0.40	0.42%		
49	0.35	0.36%		

10 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 115 VAC, 60 Hz line frequency, room temperature, and a nominal 60 V LED load.

10.1 Dimming Curve

Agilent 6812B AC source programmed as perfect leading edge dimmer, and Yokogawa WT310E for input and output measurements are used for this test.

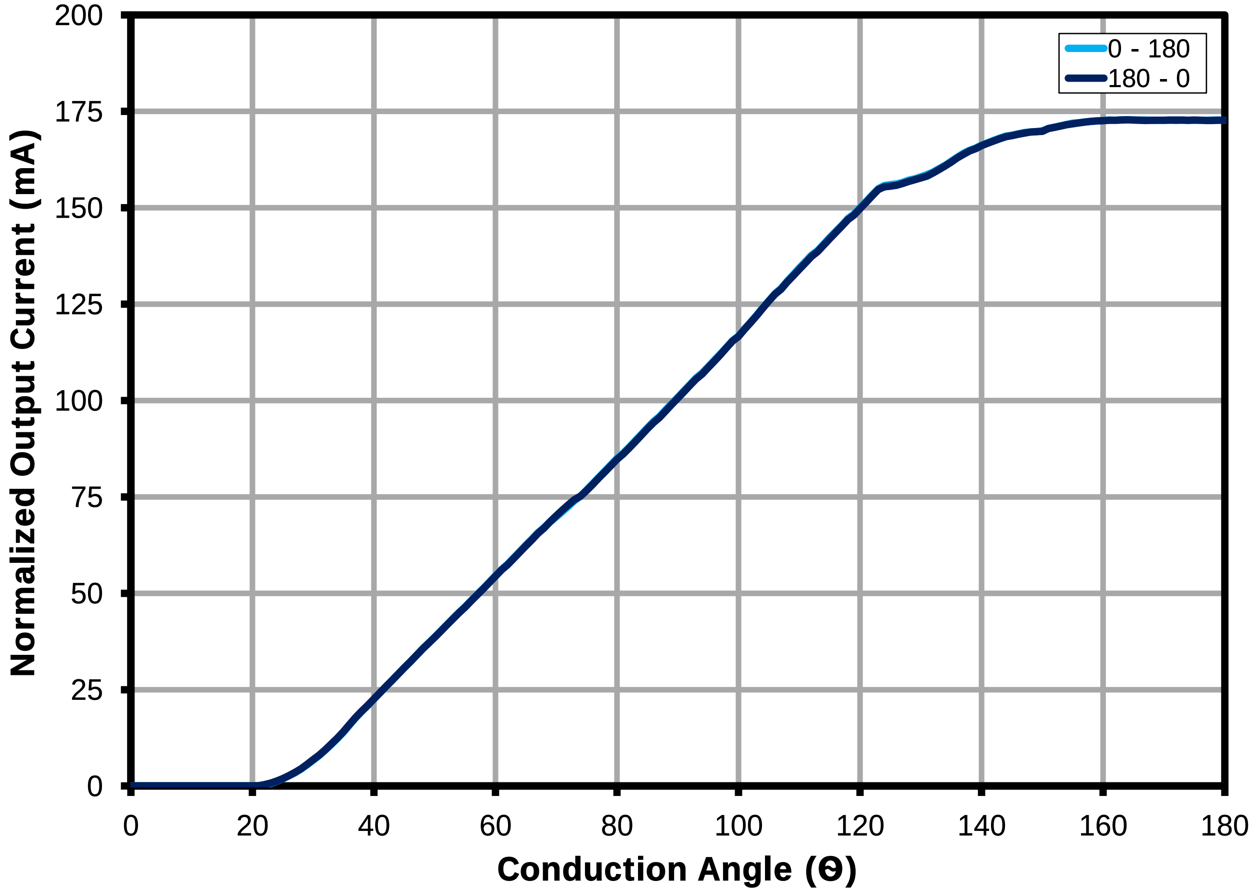

Figure 12 – Dimming Curve at 120 VAC, 60 Hz Input.

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10.2 Dimming Efficiency

Measurements were made using a programmable AC source to provide the leading edge chopped AC input.

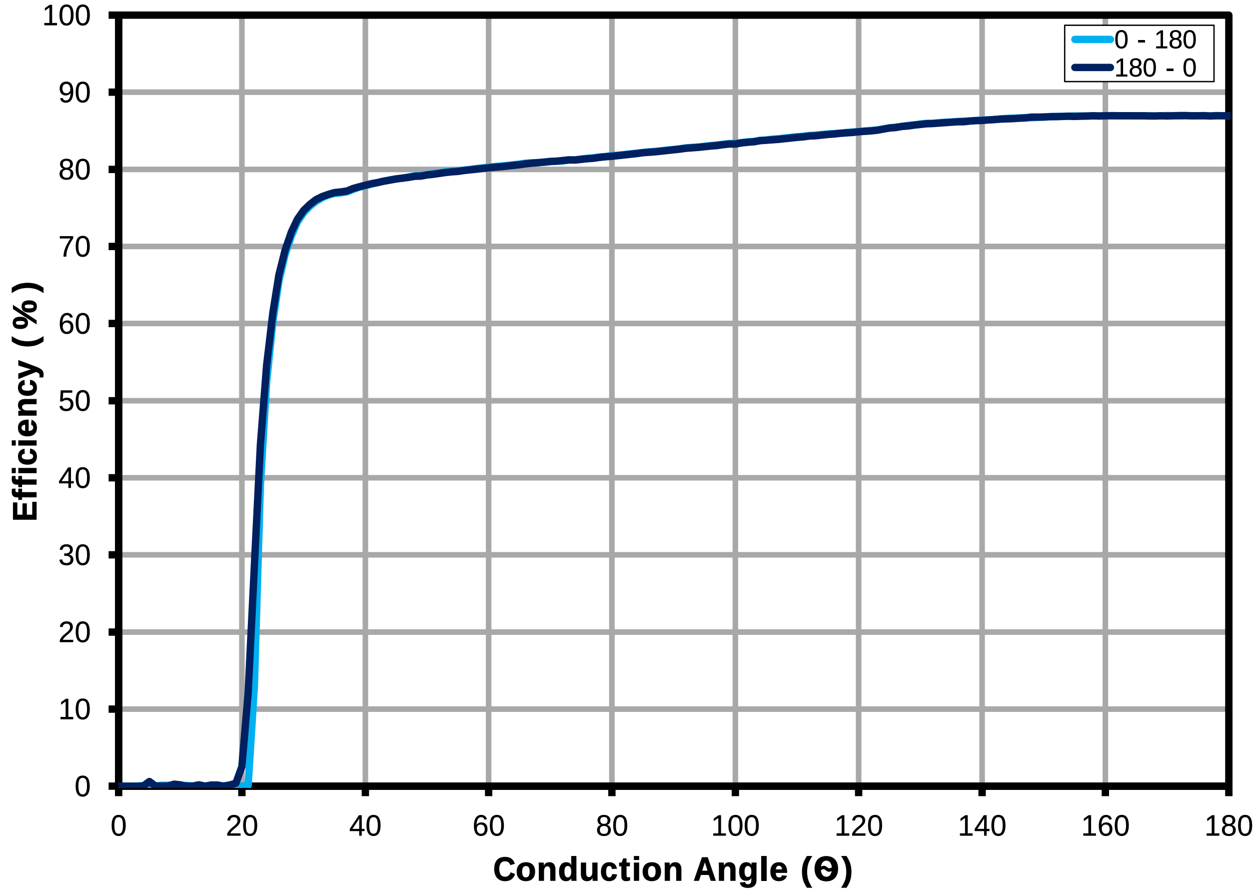

Figure 13 – Dimming Efficiency at 120 VAC, 60 Hz Input.

10.3 Driver Power Loss During Dimming

Measurements were made using a programmable AC source to provide the leading edge chopped AC input.

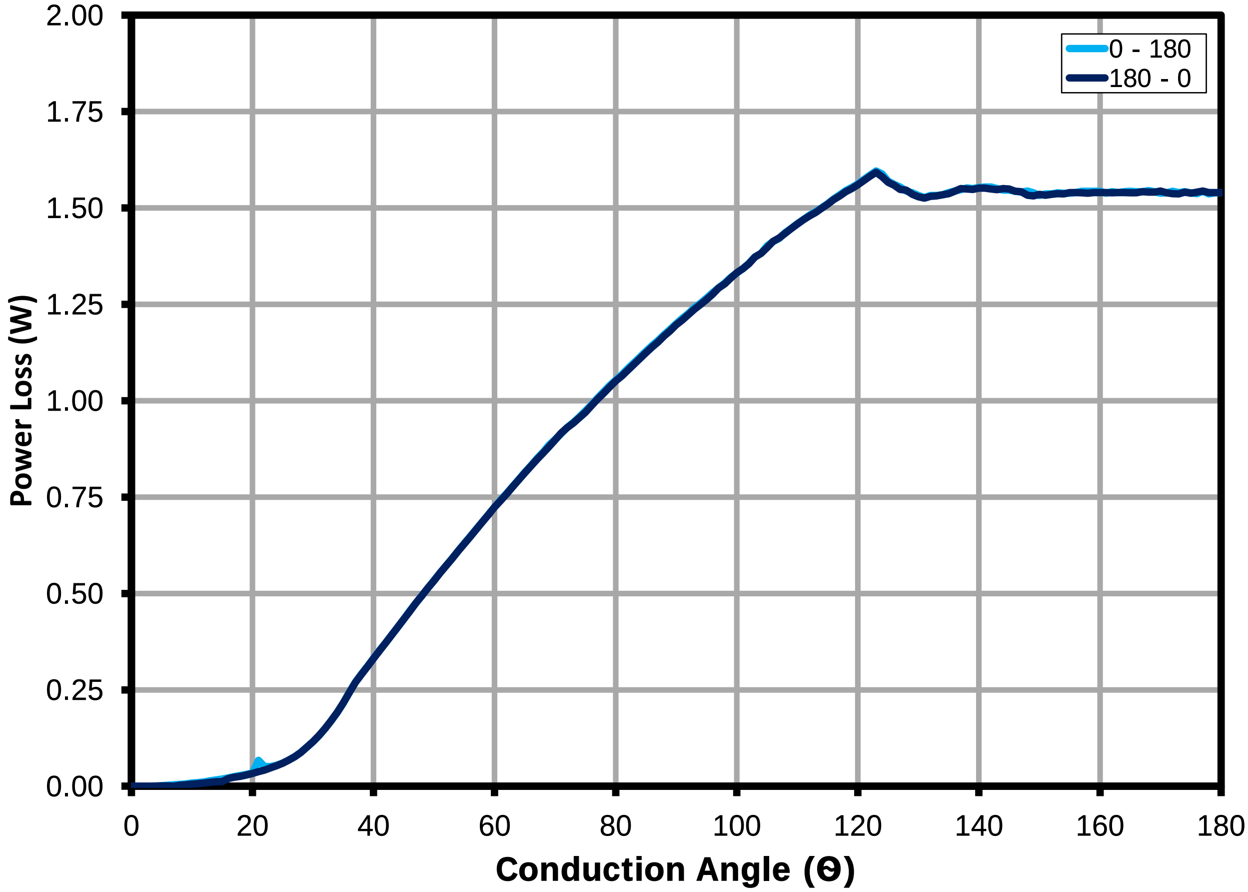

Figure 14 – Dimming Power Loss at 120 VAC, 60 Hz Input.

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10.4 Dimmer Compatibility List

The following dimmers were tested at 25 ºC ambient temperature, 60 V LED load with the following AC source:

1. AC programmable power source (Agilent 6812B) set at 120 V, 60 Hz
2. Utility line source (≈120 V, 60 Hz)

No.	Brand	Model	Type	Max (mA)	Min (mA)	Dimming Ratio
1	Lutron	AY-10PNL-WH	L	160	24	7
2	Lutron	DV-603P-WH	L	144	4.7	31
3	Lutron	DVWCL-153PH-WH	L	142	1.4	101
4	Lutron	CTCL-153P-WH	L	142	1.6	89
5	Leviton	R02-06613-PLW	L	165	5.3	31
6	Lutron	S-1000-WH	L	156	3	52
7	Lutron	S-103PNL-WH	L	144	15	10
8	Lutron	LGCL-153PLH-WH	L	142	1.8	79
9	Lutron	DVWCL-153PH-WH	L	142	2	71
10	Lutron	TGCL-153PH-WH	L	142	1.3	109
11	Lutron	CTCL-153PDH-WH	L	142	1.4	101
12	Leviton	IPL06	L	151	5	30
13	Leviton	6674	L	153	5	31
14	Legrand	H703PTCCCV6	L	154	4	39
15	Legrand	H1103PTCCCV6	L	154	4	39
16	Lutron	N-600-WH	L	154	8.8	18
17	Lutron	NT-603P-WH	L	155	8.4	18
18	Leviton	1PL06-10Z	L	151	5	30
19	Leviton	6672	L	157	9	17
20	Cooper	SI06P	L	156	2.3	68
21	Lutron	SLV-603P-WH	L	148	4.5	33
22	Lutron	TGCL-153PH-WH	L	142	1.3	109
23	Cooper	9530WS-K	L	171	2.4	71
24	Leviton	601-6631-1	L	150	3	50
25	Leviton	6633-PLW	L	165	2.5	66
26	GE	18023	L	163	1.7	96
27	Lutron	NT-600-WH	L	167	15	11
28	Legrand	HLV703PW	L	154	3.2	48
29	Leviton	TBL03	L	160	9	18
30	Lutron	DV-10P-WH	L	153	16	10

11 Thermal Performance

11.1 Thermal Performance Scan – 40°C Ambient

Figure 15 – Test Set-up Picture – Inside BR-30 Bulb Casing.

Unit inside BR-30 bulb casing was placed inside a box enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature was set to 40 ºC. Temperature was measured using type T thermocouple.

This power level (i.e. 10 W) in bulb application, full potting or selected potting on some components maybe necessary to manage temperature.

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11.1.1 Thermal Performance at 90 VAC, 60 V LED Load

Measurement	Internal Ambient	LYTSwitch-7 (U1)	Buck Inductor (L3)	Buck Diode (D1)	Output Capacitor (C3)	EMI Choke (L1)	Fuse (FR1)	Damper (R8)	Bleeder (R1)
Maximum	79.8	116.6	97.6	95.6	92.0	100.6	103.1	104.6	99.3
Final	79.8	116.6	97.6	95.6	92.0	100.6	103.1	104.6	99.3

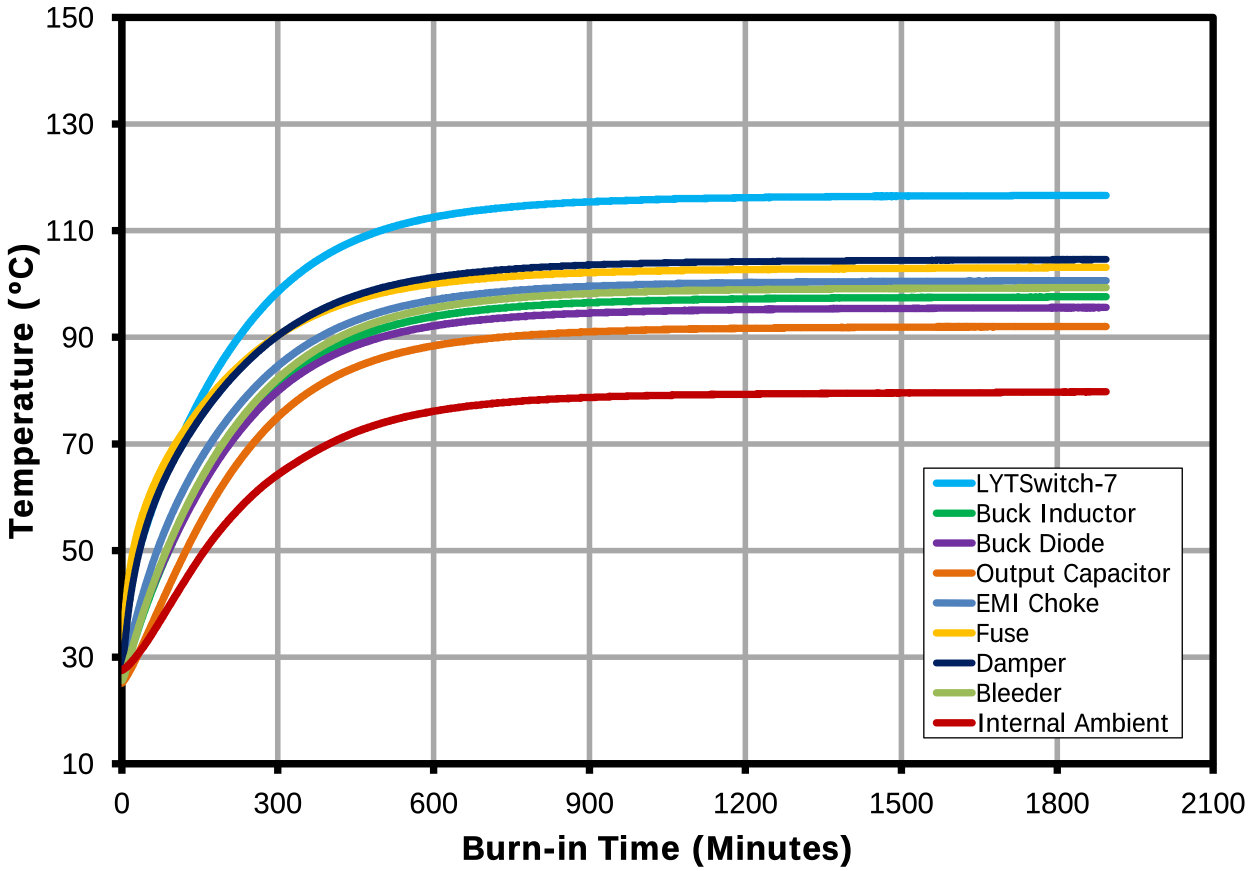

Figure 16 – Component Temperature at 90 VAC, 60 V LED Load, 40 ºC Ambient.

11.1.2 Thermal Performance at 115 VAC, 60 V LED Load

Measurement	Internal Ambient	LYTSwitch-7 (U1)	Buck Inductor (L3)	Buck Diode (D1)	Output Capacitor (C3)	EMI Choke (L1)	Fuse (FR1)	Damper (R8)	Bleeder (R1)
Maximum	80.3	112.7	100.7	97.3	93.7	92.5	91.1	94.0	98.5
Final	80.3	112.7	100.6	97.3	93.7	92.5	91.1	94	98.5

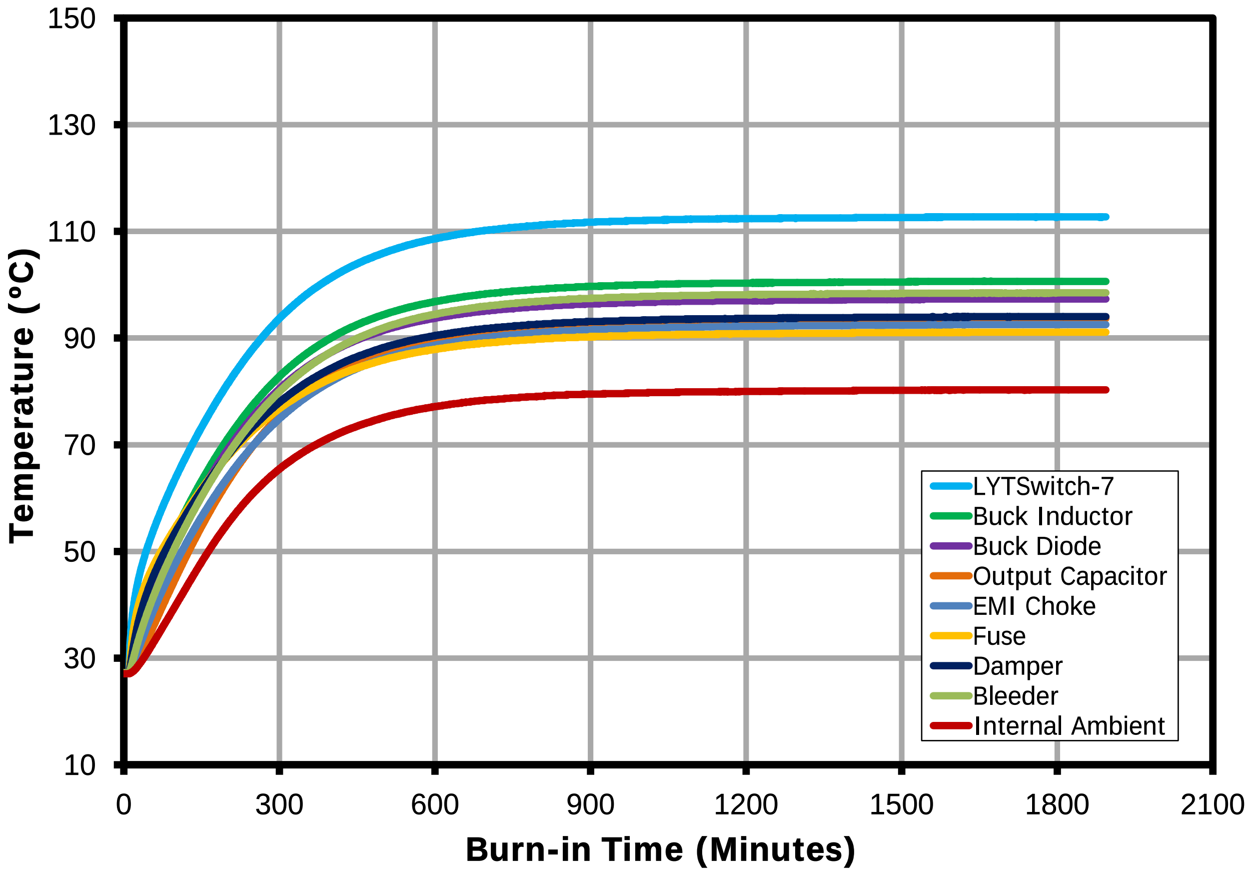

Figure 17 – Component Temperature at 115 VAC, 60 V LED Load, 40 °C Ambient.

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11.1.3 Thermal Performance at 132 VAC, 60 V LED Load

Measurement	Internal Ambient	LYTSwitch-7 (U1)	Buck Inductor (L3)	Buck Diode (D1)	Output Capacitor (C3)	EMI Choke (L1)	Fuse (FR1)	Damper (R8)	Bleeder (R1)
Maximum	82.2	114.8	104.5	100.3	96.4	91.9	88.8	92.4	101.3
Final	82.2	114.8	104.5	100.2	96.4	91.9	88.8	92.3	101.3

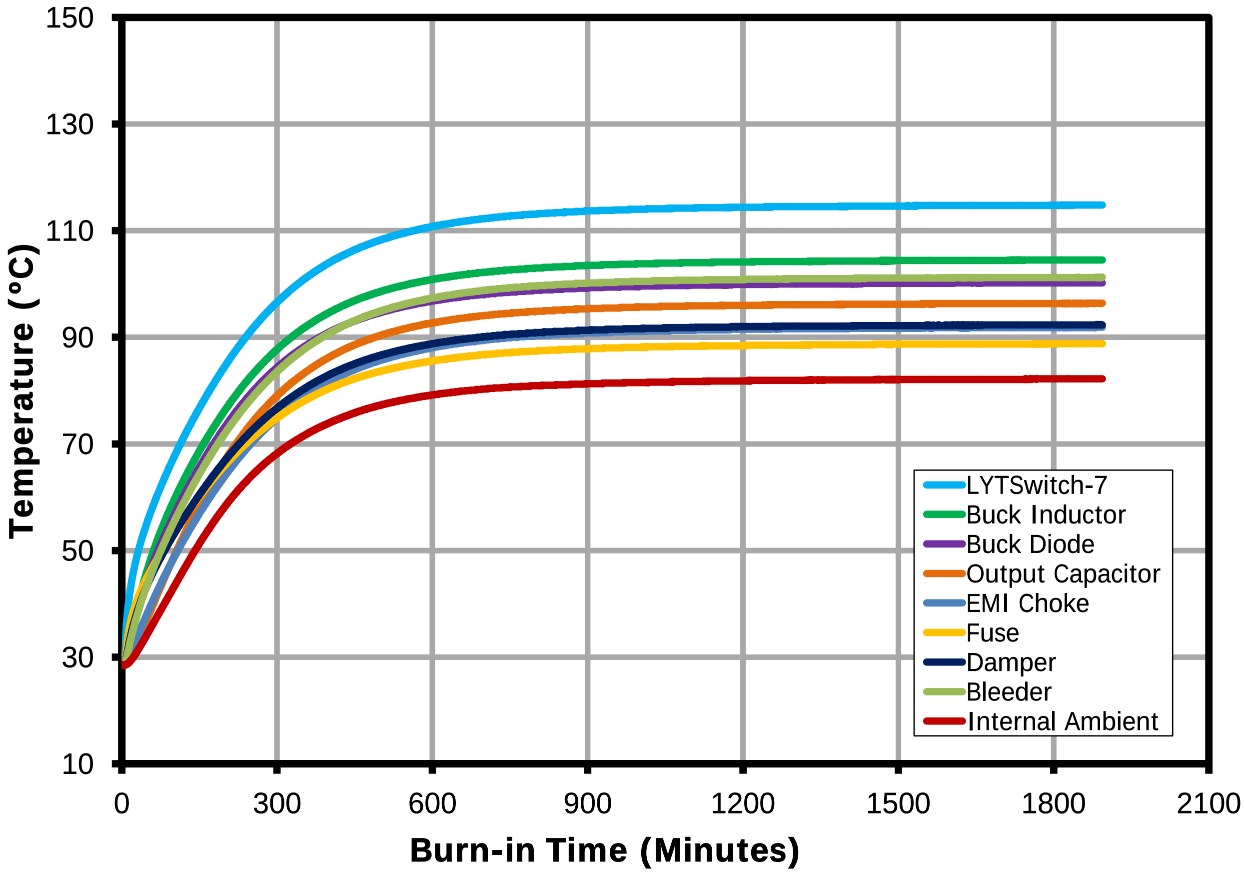

Figure 18 – Component Temperature at 132 VAC, 60 V LED Load, 40 °C Ambient.

11.1.4 Thermal Performance at 120 VAC, Dimming at Worst Power Loss Conduction Angle

Measurement	Internal Ambient	LYTSwitch-7 (U1)	Buck Inductor (L3)	Buck Diode (D1)	Output Capacitor (C3)	EMI Choke (L1)	Fuse (FR1)	Damper (R8)	Bleeder (R1)
Maximum	76.0	106.2	93.8	90.8	87.2	92.2	93.3	94.9	99.1
Final	75.9	106.2	93.8	90.8	87.2	92.2	93.3	94.9	99

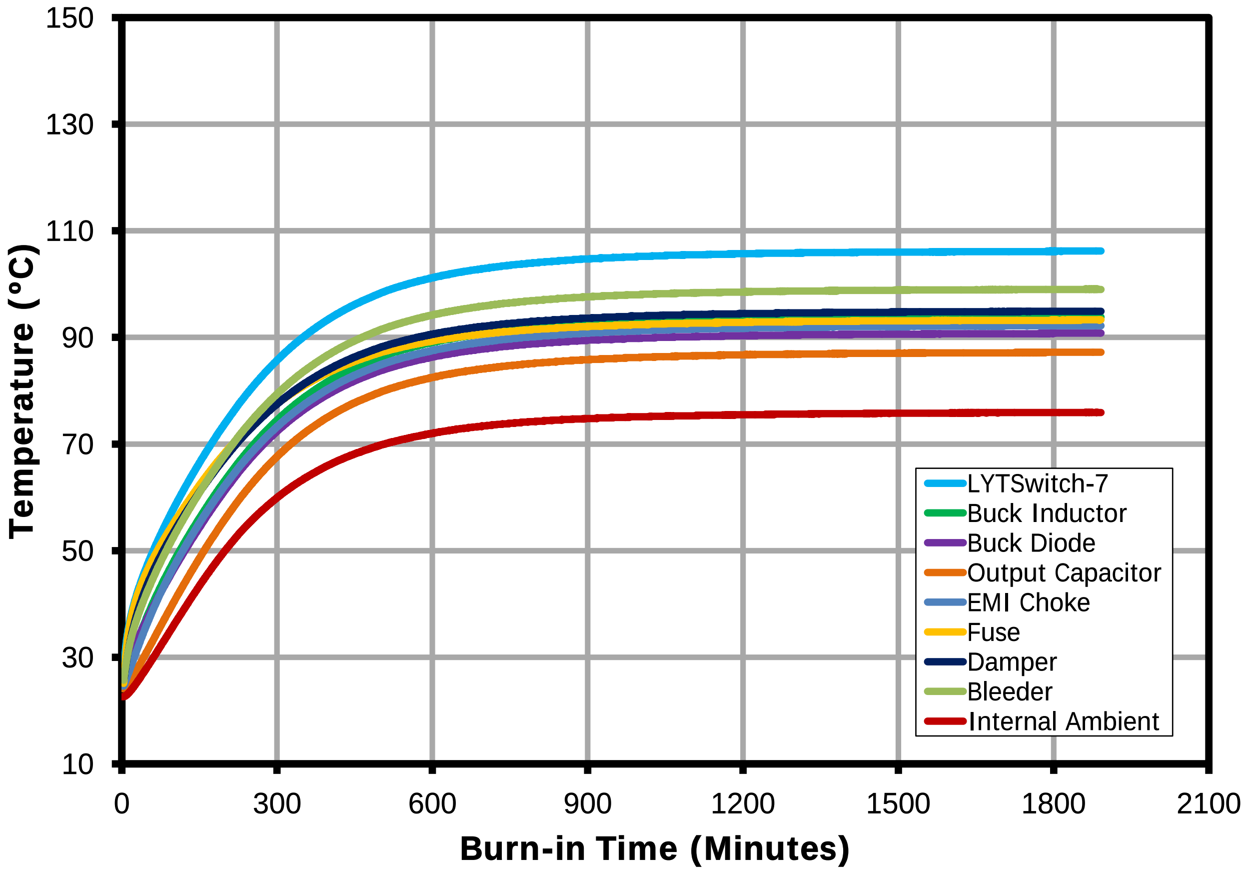

Figure 19 – Component Temperature at 120 VAC, Dimming at Worst Power Loss Conduction Angle, 40 ºC Ambient.

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12 Waveforms

12.1 Input Voltage and Input Current Waveforms

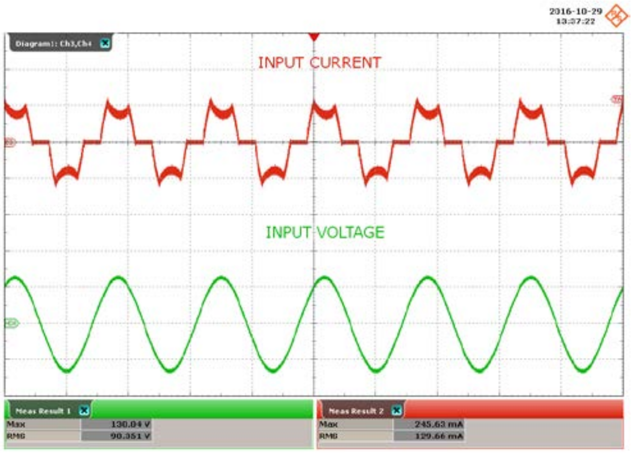

Figure 20 – 90 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{IN}: 246 mA_{PK}.
Peak V_{IN}: 130 V_{PK}.

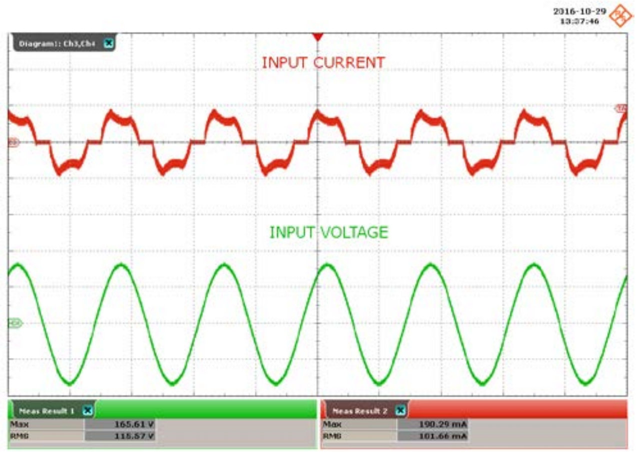

Figure 21 – 115 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{IN}: 190 mA_{PK}.
Peak V_{IN}: 165 V_{PK}.

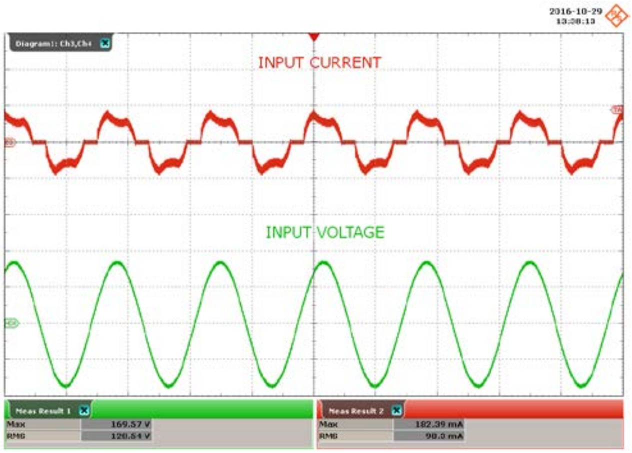

Figure 22 – 120 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{IN}: 182 mA_{PK}.
Peak V_{IN}: 170 V_{PK}.

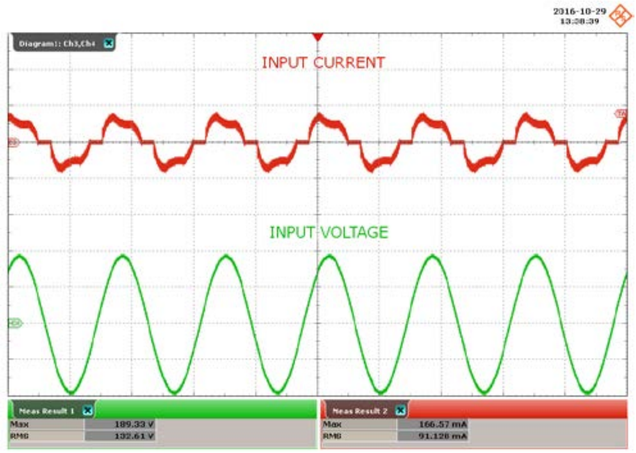

Figure 23 – 132 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{IN}: 167 mA_{PK}.
Peak V_{IN}: 189 V_{PK}.

12.2 Output Current Rise and Fall

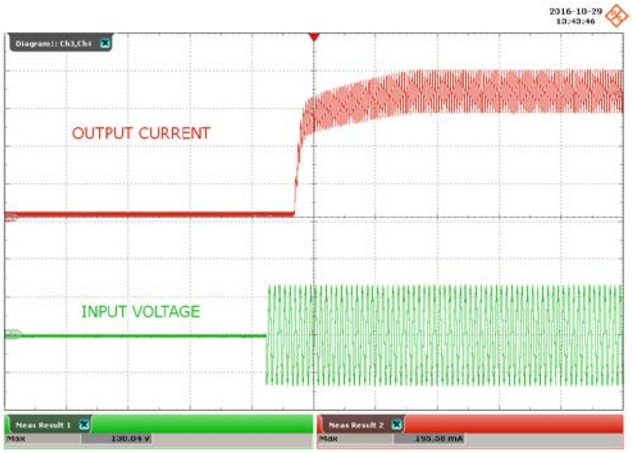

Figure 24 – 90 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 195 mA_{PK}.
Peak V_{IN}: 130 V_{PK}.

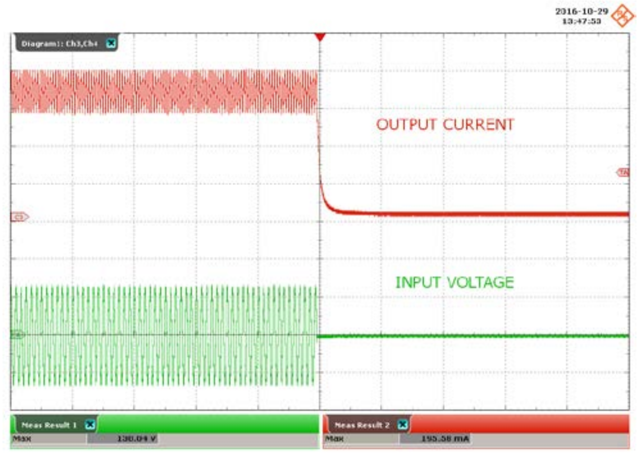

Figure 25 – 90 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 195 mA_{PK}.
Peak V_{IN}: 130 V_{PK}.

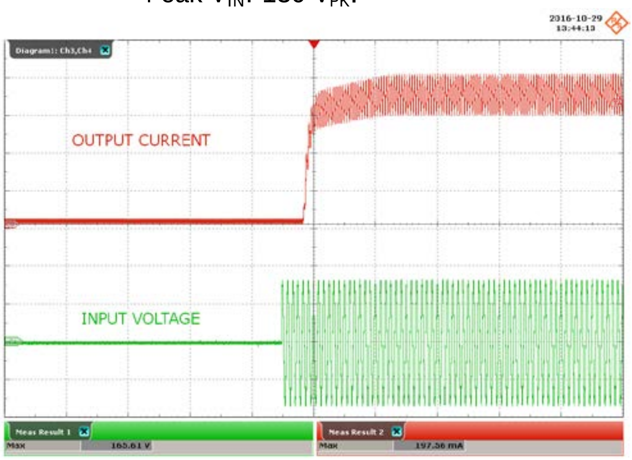

Figure 26 – 115 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 198 mA_{PK}.
Peak V_{IN}: 166 V_{PK}.

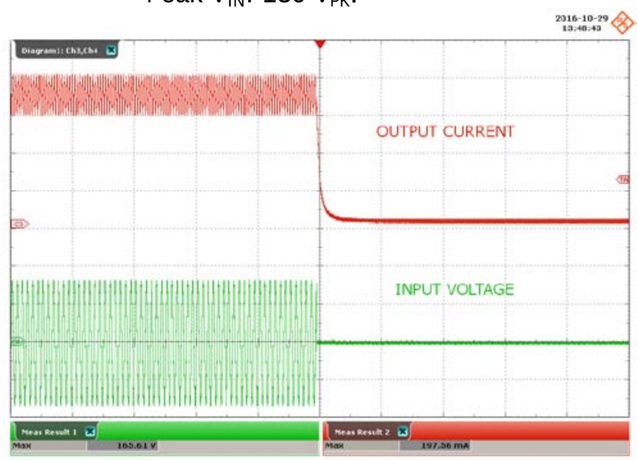

Figure 27 – 115 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 198 mA_{PK}.
Peak V_{IN}: 166 V_{PK}.

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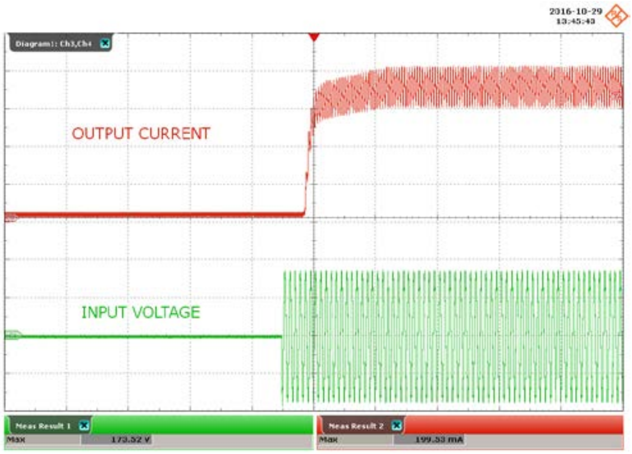

Figure 28 – 120 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 200 mA_{PK}.
Peak V_{IN}: 174 V_{PK}.

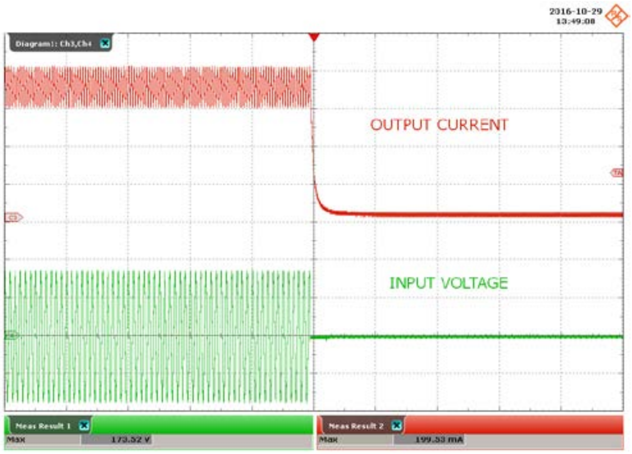

Figure 29 – 120 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 200 mA_{PK}.
Peak V_{IN}: 174 V_{PK}.

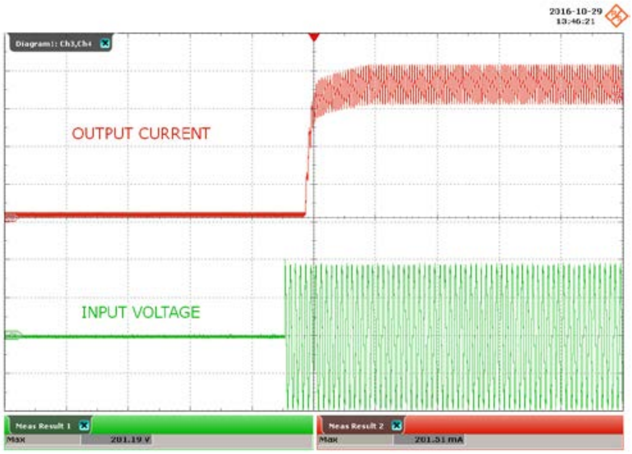

Figure 30 – 132 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 202 mA_{PK}.
Peak V_{IN}: 201 V_{PK}.

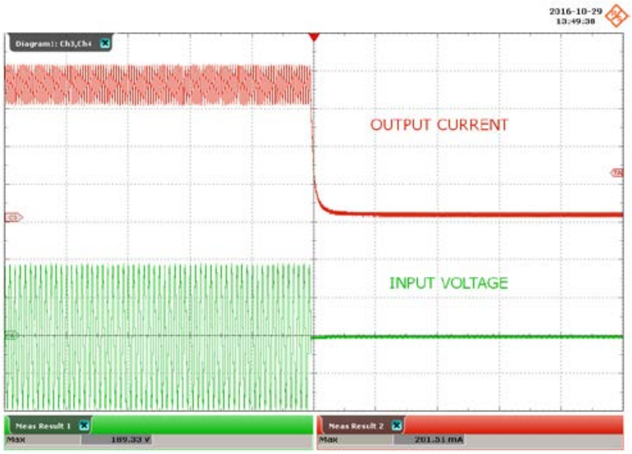

Figure 31 – 132 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.
Peak I_{OUT}: 202 mA_{PK}.
Peak V_{IN}: 200 V_{PK}.

12.3 Drain Voltage and Current in Normal Operation

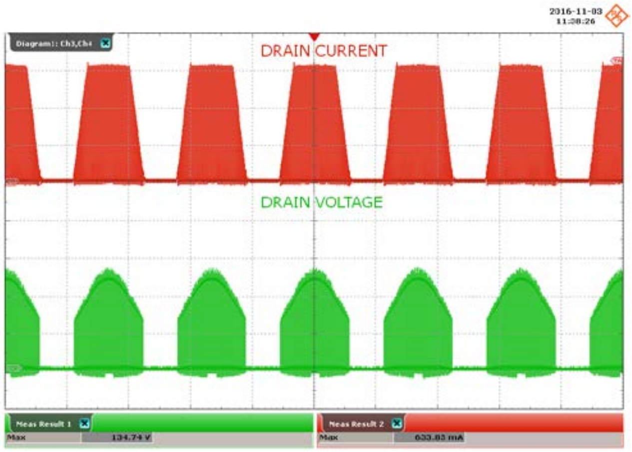

Figure 32 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 ms / div.
Peak I_{DRAIN}: 634 mA_{PK}.
Peak V_{DRAIN}: 135 V_{PK}.

Figure 33 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.
Peak I_{DRAIN}: 642 mA_{PK}.
Peak V_{DRAIN}: 103 V_{PK}.

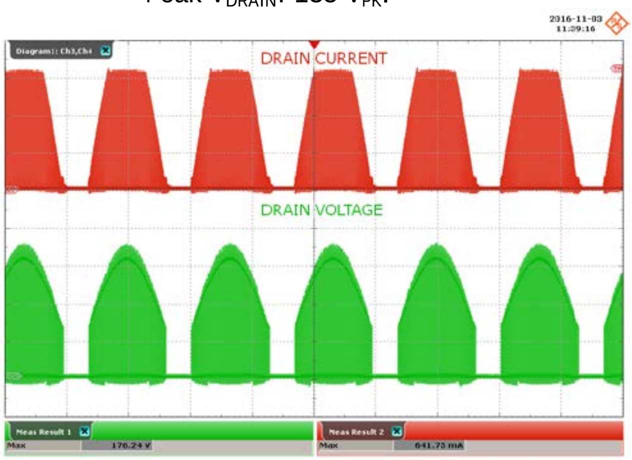

Figure 34 – 115 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.
Peak I_{DRAIN}: 642 mA_{PK}.
Peak V_{DRAIN}: 176 V_{PK}.

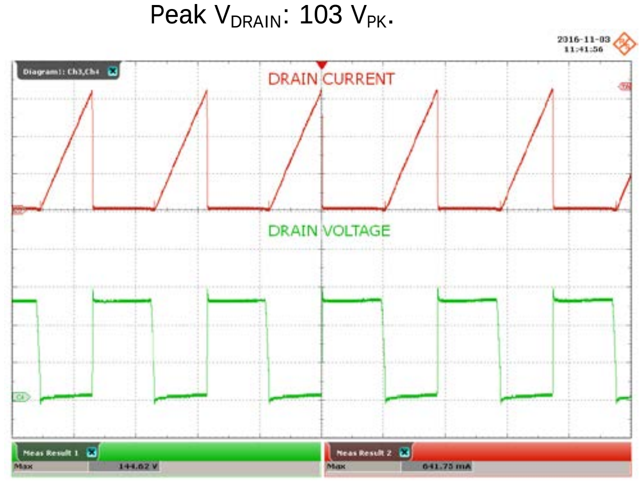

Figure 35 – 115 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.
Peak I_{DRAIN}: 642 A_{PK}.
Peak V_{DRAIN}: 144 V_{PK}.

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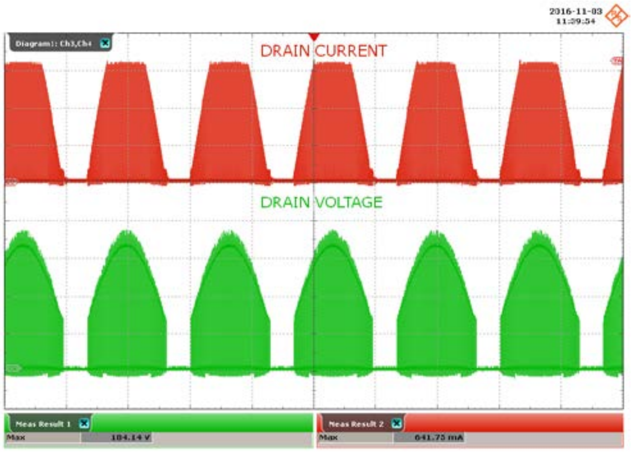

Figure 36 – 120 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 ms / div.
Peak I_{DRAIN}: 642 mA_{PK}.
Peak V_{DRAIN}: 184 V_{PK}.

Figure 37 – 120 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.
Peak I_{DRAIN}: 642 mA_{PK}.
Peak V_{DRAIN}: 155 V_{PK}.

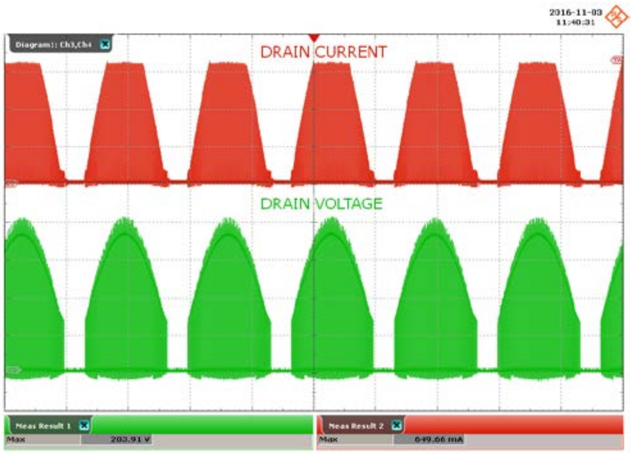

Figure 38 – 132 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 ms / div.
Peak I_{DRAIN}: 650 mA_{PK}.
Peak V_{DRAIN}: 204 V_{PK}.

Figure 39 – 132 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.
Peak I_{DRAIN}: 658 mA_{PK}.
Peak V_{DRAIN}: 204 V_{PK}.

12.4 Drain Voltage and Current Start-up Profile

Figure 40 – 90 VAC, 60 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms /div.
Peak I_{DRAIN}: 626 mA_{PK}.
Peak V_{DRAIN}: 141 V_{PK}.

Figure 41 – 90 VAC, 60 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs /div.
Peak I_{DRAIN}: 231 mA_{PK}.
Peak V_{DRAIN}: 115 V_{PK}.

Figure 42 – 132 VAC, 60 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms /div.
Peak I_{DRAIN}: 650 mA_{PK}.
Peak V_{DRAIN}: 208 V_{PK}.

Figure 43 – 132 VAC, 60 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs /div.
Peak I_{DRAIN}: 325 mA_{PK}.
Peak V_{DRAIN}: 162 V_{PK}.

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12.5 Drain Voltage and Current During Output Short-Circuit Condition

Figure 44 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.
Peak I_{DRAIN}: 976 mA_{PK}.
Peak V_{DRAIN}: 141 V_{PK}.

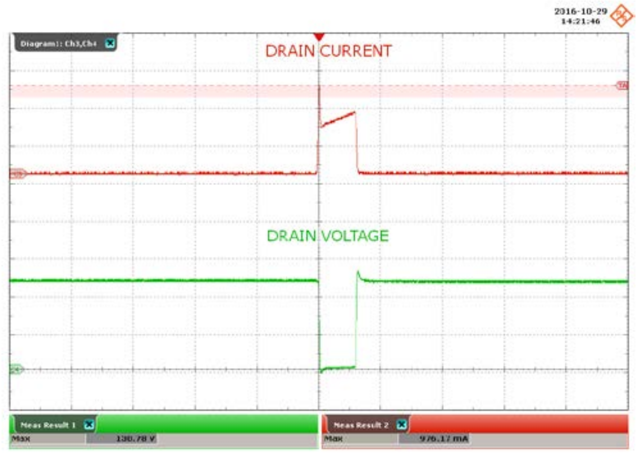

Figure 45 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs / div.
Peak I_{DRAIN}: 976 mA_{PK}.
Peak V_{DRAIN}: 131 V_{PK}.

Figure 46 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.02 A_{PK}.
Peak V_{DRAIN}: 204 V_{PK}.

Figure 47 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs / div.
Peak I_{DRAIN}: 1.04 A_{PK}.
Peak V_{DRAIN}: 206 V_{PK}.

V_{IN} (VAC)	Frequency (Hz)	P_{IN} (W)
90	60	0.939
132	60	0.535

12.6 Output Diode Voltage and Current in Normal Operation

Figure 48 – 90 VAC, 60 V LED Load.
Upper: I_{D3}, 200 mA / div.
Lower: V_{D3}, 50 V / div., 4 ms / div.
Peak I_{D3}: 626 mA_{PK}.
Peak V_{D3}: 124 V_{PK}.

Figure 49 – 90 VAC, 60 V LED Load.
Upper: I_{D3}, 200 mA / div.
Lower: V_{D3}, 50 V / div., 4 μs / div.
Peak I_{D3}: 642 mA_{PK}.
Peak V_{D3}: 124 V_{PK}.

Figure 50 – 132 VAC, 60 V LED Load.
Upper: I_{D3}, 200 mA / div.
Lower: V_{D3}, 50 V / div., 4 ms / div.
Peak I_{D3}: 666 mA_{PK}.
Peak V_{D3}: 187 V_{PK}.

Figure 51 – 132 VAC, 60 V LED Load.
Upper: V_{DRAIN}, 200 mA / div.
Lower: I_{DRAIN}, 50 V / div., 4 μs / div.
Peak I_{DRAIN}: 682 mA_{PK}.
Peak V_{DRAIN}: 160 V_{PK}.

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12.7 Output Voltage and Current – Open LED Load

Figure 52 – 90 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 500 ms / div.
Peak I_{OUT}: 192 mA_{PK}.
Peak V_{OUT}: 75.9 V_{PK}.

Figure 53 – 132 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 500 ms / div.
Peak I_{OUT}: 200 mA_{PK}.
Peak V_{OUT}: 70.3 V_{PK}.

Figure 54 – 90 VAC, 60 V LED Load,
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 500 ms / div.
Peak V_{OUT}: 75.8 V_{PK}.

Figure 55 – 132 VAC, 60 V LED Load,
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 500 ms / div.
Peak V_{OUT}: 70.3 V_{PK}.

12.8 Output Ripple Current

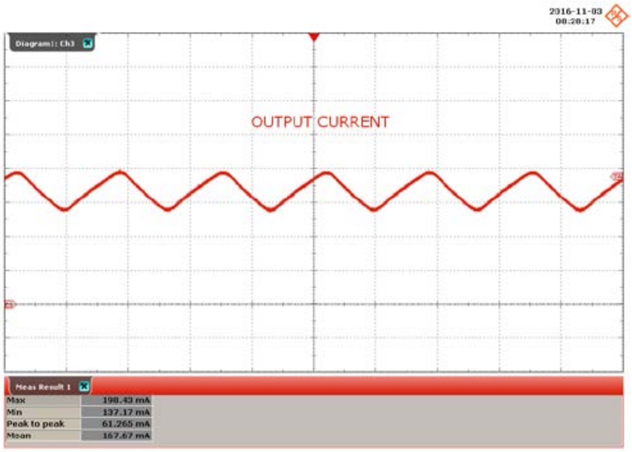

Figure 56 – 90 VAC, 60 Hz, 60 V LED Load.
I_{OUT}, 50 mA / div., 5 ms / div.

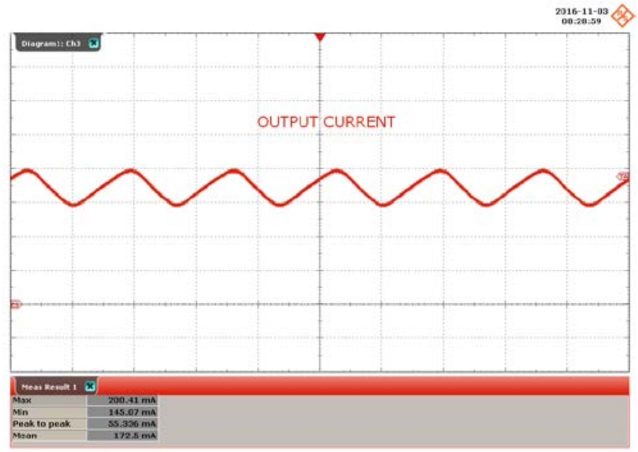

Figure 57 – 115 VAC, 60 Hz, 60 V LED Load.
I_{OUT}, 50 mA / div., 5 ms / div.

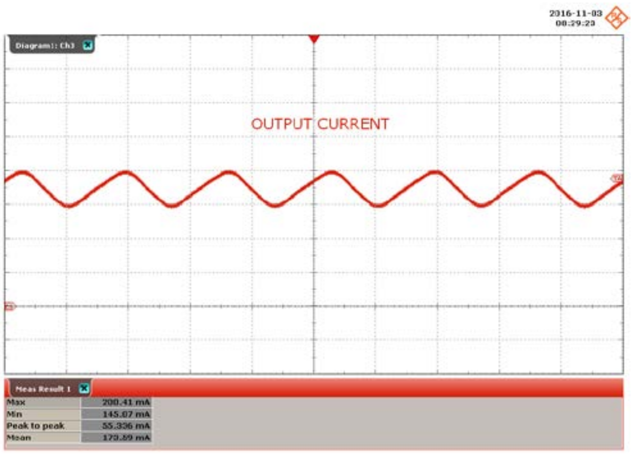

Figure 58 – 120 VAC, 60 Hz, 60 V LED Load.
I_{OUT}, 50 mA / div., 5 ms / div.

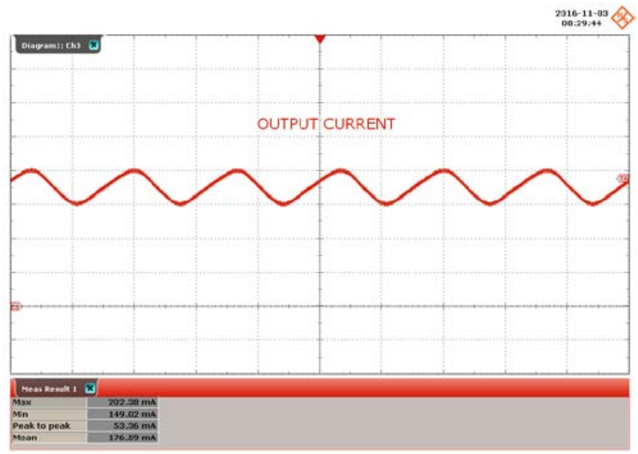

Figure 59 – 132 VAC, 60 Hz, 60 V LED Load.
I_{OUT}, 50 mA / div., 5 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	$I_{RP-P(PK-PK)}$ (mA)	I_{MEAN}	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{OUT(MAX)}$+$I_{OUT(MIN)}$)
90	198.43	137.17	61.26	167.67	0.36	18.26
115	200.41	145.07	55.34	172.50	0.32	16.02
120	200.41	145.07	55.34	173.59	0.32	16.02
132	202.38	149.02	53.36	176.59	0.30	15.18

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13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 60 V LED load
Dimmer: LUTRON CTCL-153P-WH

Figure 60 – 120º Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak V_{IN}: 173 V_{PK}.
V_{RMS}: 107 V.

Figure 61 – 90º Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak V_{IN}: 173 V_{PK}.
V_{RMS}: 86 V.

Figure 62 – 60º Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak V_{IN}: 118 V_{PK}.
V_{RMS}: 54 V.

Figure 63 – 45º Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak V_{IN}: 70 V_{PK}.
V_{RMS}: 43 V.

13.2 Output Current Waveforms – Leading Edge Dimmer

Input: 115 VAC, 60 Hz
Output: 60 V LED load
Dimmer: LEVITON 6672

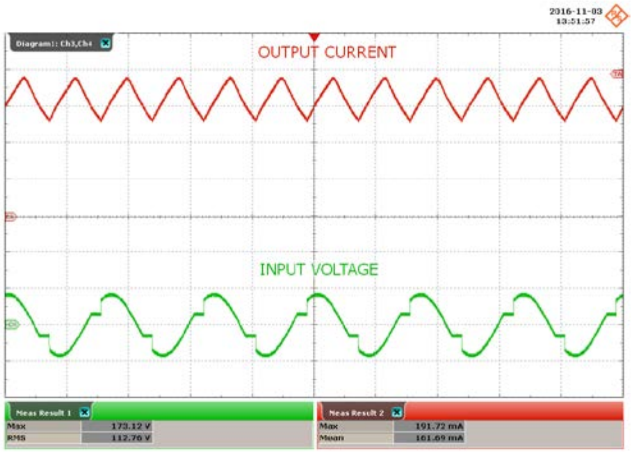

Figure 64 – 130° Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{OUT}: 191 mA_{PK}.
Peak V_{IN}: 173 V_{PK}.

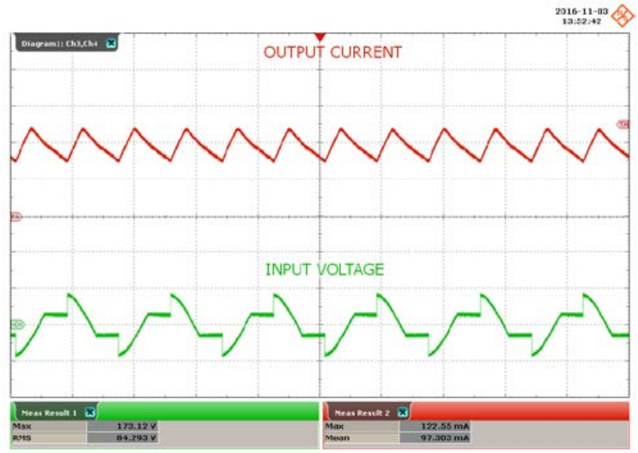

Figure 65 – 110° Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{OUT}: 173 mA_{PK}.
Peak V_{IN}: 122 V_{PK}.

Figure 66 – 90° Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{OUT}: 55 mA_{PK}.
Peak V_{IN}: 125 V_{PK}.

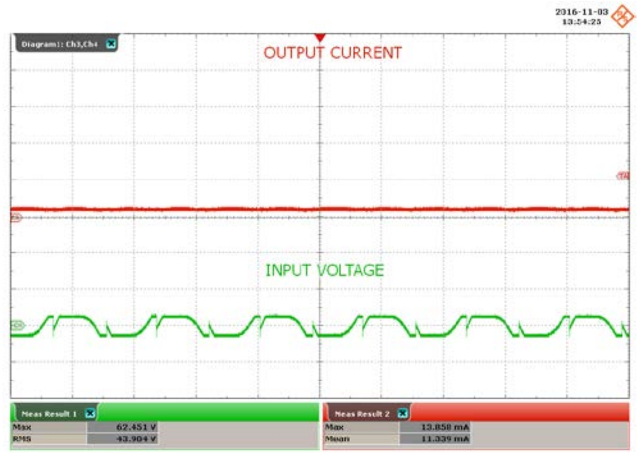

Figure 67 – 45° Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{OUT}: 14 mA_{PK}.
Peak V_{IN}: 62 V_{PK}.

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14 AC Cycling Test

Output current overshoot is within regulation during on - off cycling.

Figure 68 – 115 VAC, 60 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

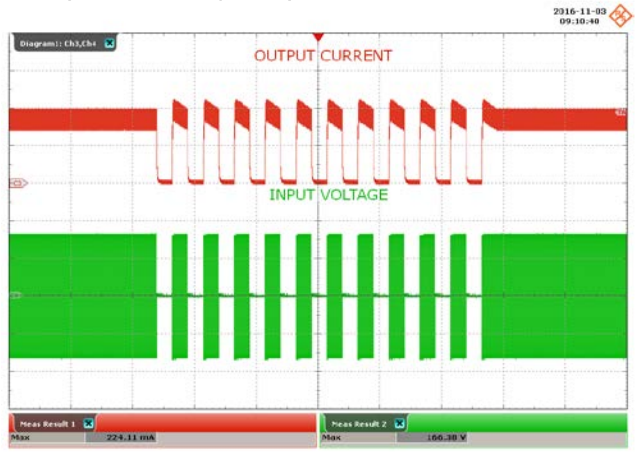

Figure 69 – 115 VAC, 60 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

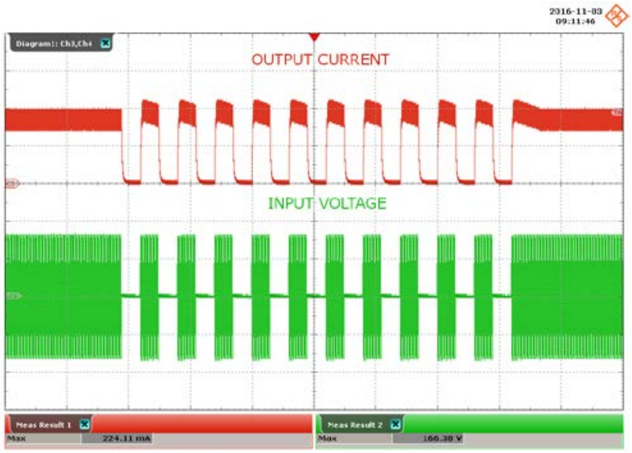

Figure 70 – 115 VAC, 60 V LED Load.
0.3 s On – 0.3 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

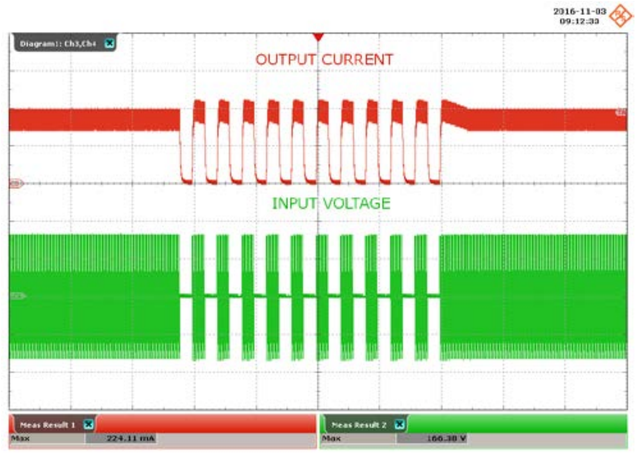

Figure 71 – 115 VAC, 60 V LED Load.
0.2 s On – 0.2 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

15 Conducted EMI

15.1 Test Set-up

15.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture, model A662003.
5. 60 V LED load with input voltage set at 115 VAC.

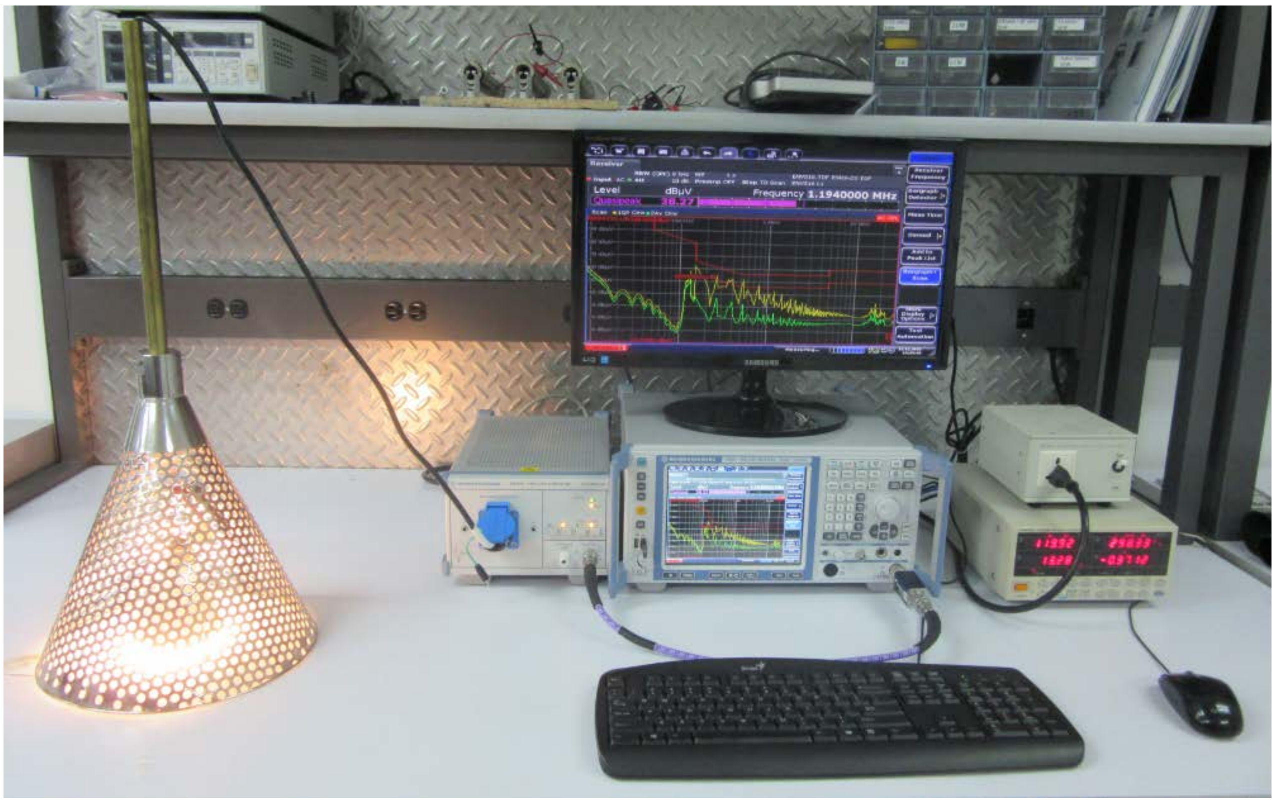

Figure 72 – Conducted EMI Test Set-up.

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15.2 EMI Test Result

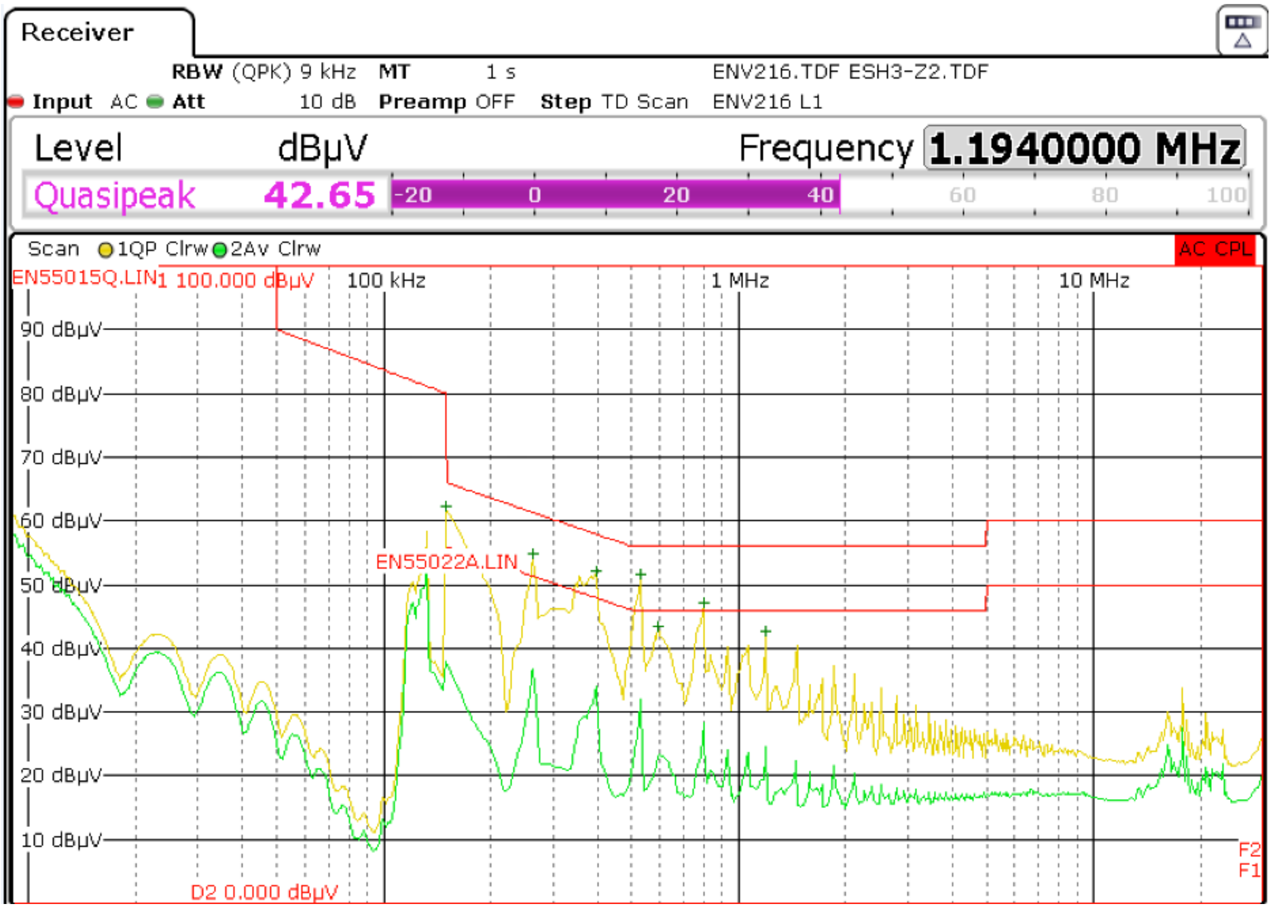

Figure 73 – Conducted EMI, 60V LED Load with Metal Cone Enclosure Grounded, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	150.0000 kHz	62.40 N	-3.60 dB
1 Quasi Peak	264.7500 kHz	54.79 N	-6.49 dB
1 Quasi Peak	397.5000 kHz	52.04 L1	-5.87 dB
1 Quasi Peak	530.2500 kHz	51.62 N	-4.38 dB
1 Quasi Peak	595.5000 kHz	43.54 L1	-12.46 dB
1 Quasi Peak	795.7500 kHz	47.25 L1	-8.75 dB
1 Quasi Peak	1.1940 MHz	42.63 N	-13.37 dB

Figure 74 – Conducted EMI, 60 V LED Load with Metal Cone Enclosure Grounded, Final Measurement Results.

16 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	115	L to N	0	Pass
-1000	115	L to N	0	Pass
+1000	115	L to N	90	Pass
-1000	115	L to N	90	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	115	L to N	0	Pass
-2500	115	L to N	0	Pass
+2500	115	L to N	90	Pass
-2500	115	L to N	90	Pass

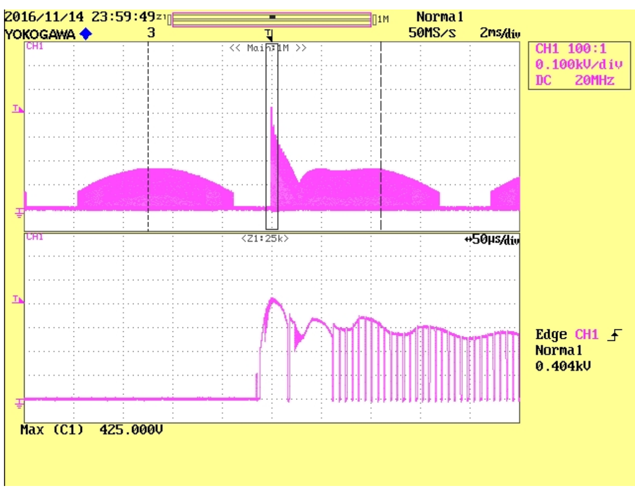

Figure 75 – +1000 kV Differential Surge, 90 ºC Phase.

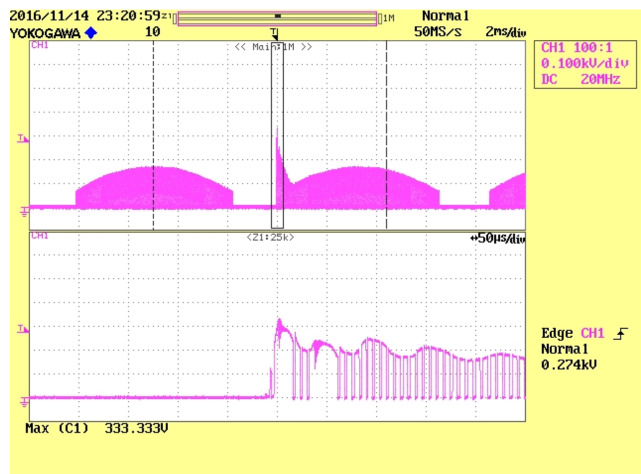

Figure 76 – +2500 kV Ring Wave, 90 ºC Phase.

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17 Brown-in / Brown-out Test

No failure of any component was seen during brownout test of 1 V / sec AC cut-in and cut-off.

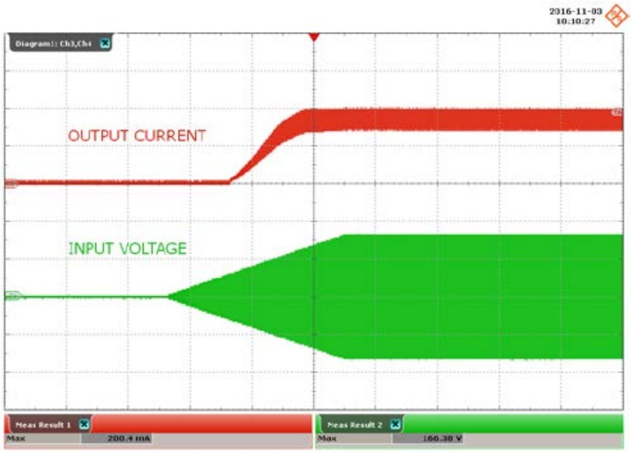

Figure 77 – Brown-In Test.
No Component Failures.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 40 s / div.

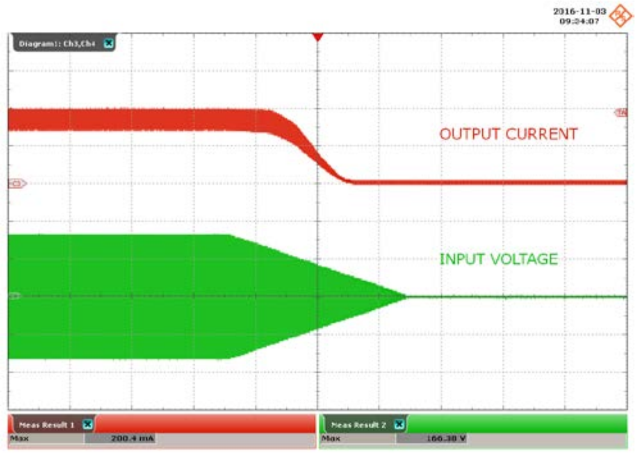

Figure 78 – Brown-Out Test.
No Component Failures.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 40 s / div.

18 Revision History

Date	Author	Revision	Description and Changes	Reviewed
13-Feb-17	AM/IB	1.0	Initial Release	Apps & Mktg

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