Design Example Report

Title	***11 W TRIAC Dimmable High Efficiency (>87%) Power Factor Corrected Non-Isolated Buck-Boost LED Driver Using LYTSwitch™-3 LYT3316D***
Specification	90 VAC – 132 VAC Input; 72 V_{TYP}, 155 mA_{TYP} Output
Application	A19 LED Bulb
Author	Applications Engineering Department
Document Number	DER-510
Date	March 1, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant LED current (CC) regulation, ±5%
- Highly energy efficient, >87% at 115 V
- 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
  - No load and output short-circuit protection
  - Thermal fold-back protection
  - No damage during line brown-out or brown-in conditions
- A-THD <10% at 120 VAC
- Meets IEC 2.5 kV ring wave, 1 kV differential surge
- Meets 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.

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1 Introduction

This engineering report describes a TRIAC dimmable, non-isolated buck-boost LED driver designed to drive a nominal LED voltage string of 72 V at 155 mA from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT3316D from the LYTSwitch-3 family of devices.

The LYTSwitch-3 is a TRIAC dimmable LED driver IC with a single stage PFC function and an accurate LED current control.

The DER-510 provides a single 11 W TRIAC dimmable constant current output. The key design goals were high efficiency, low component count and excellent dimming compatibility.

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

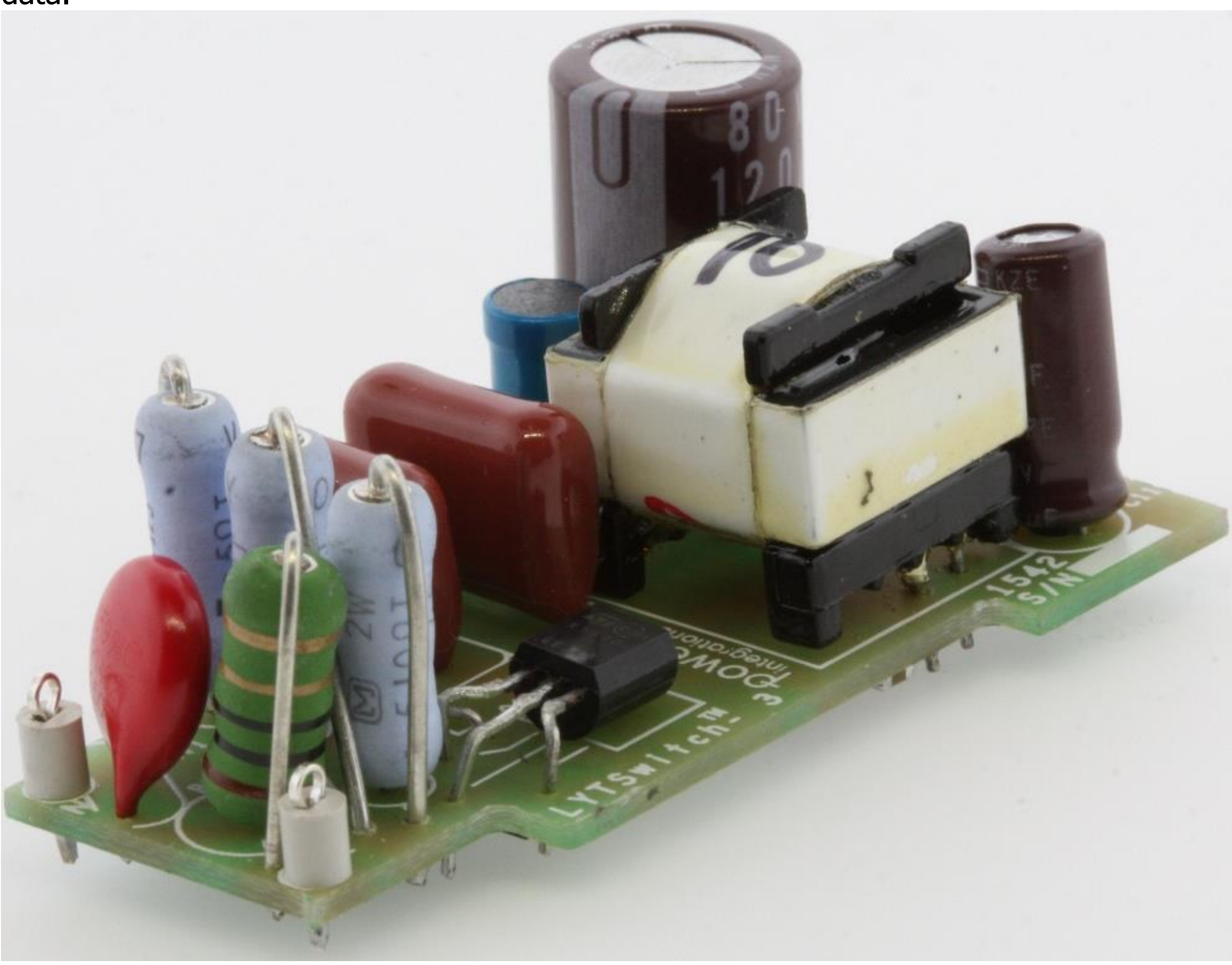

Figure 1 – Populated Circuit Board.

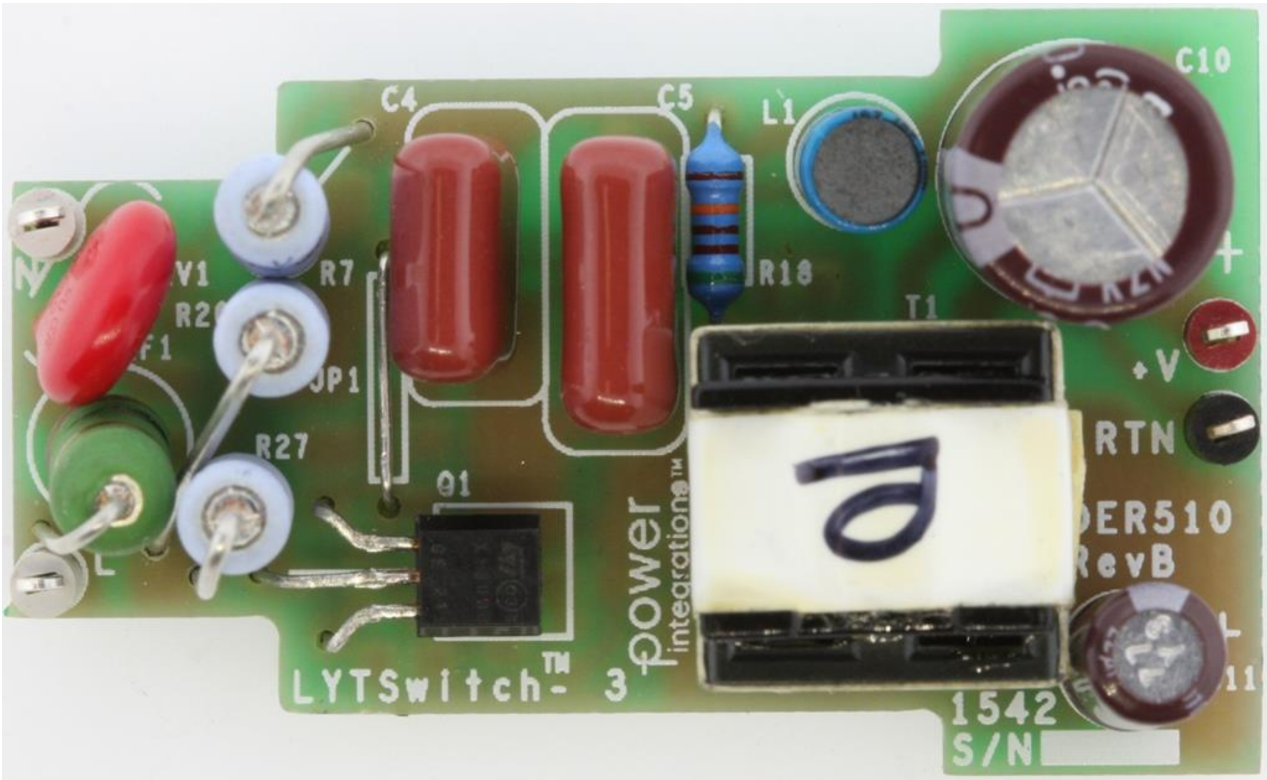

Figure 2 – Populated Circuit Board, Top View.

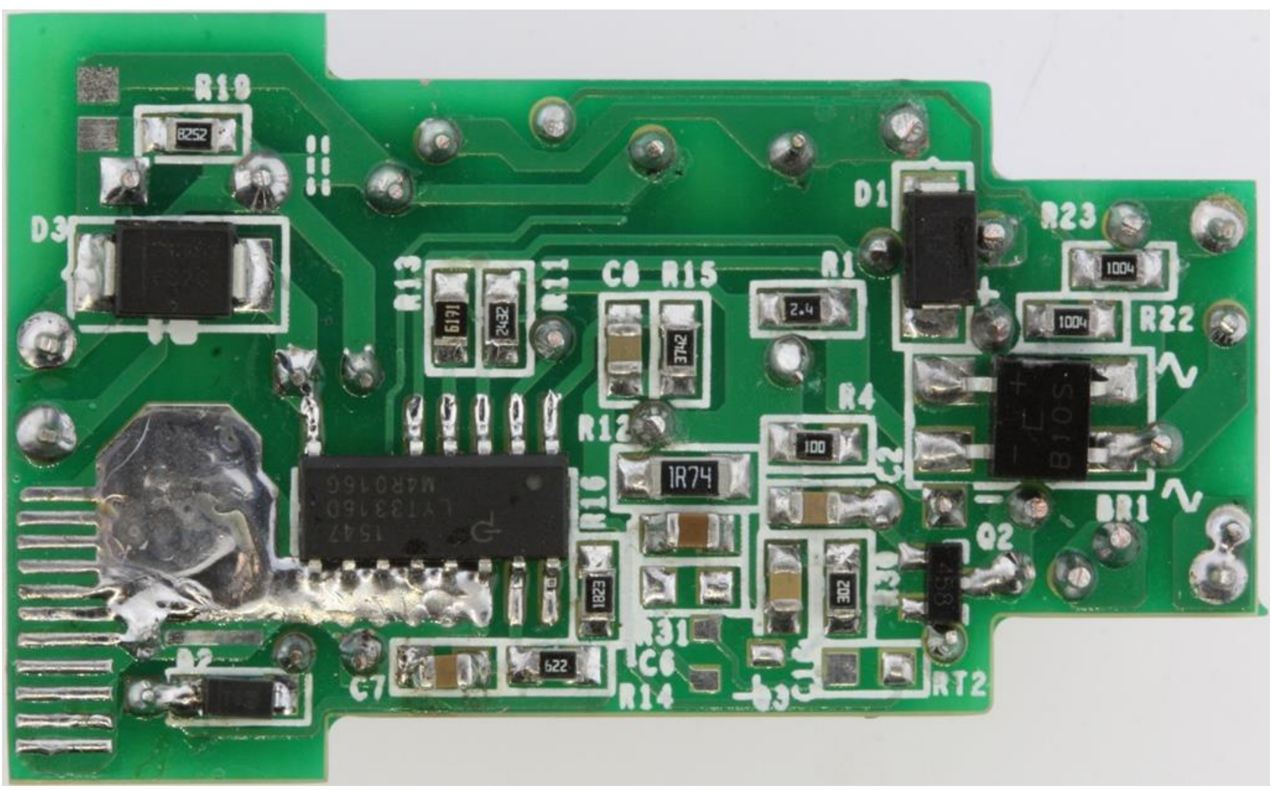

Figure 3 – Populated Circuit Board, Bottom View.

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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}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	69	72	74	V	
Output Current	I_{OUT}		155		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		11		W	
Efficiency						
Full Load	η		87		%	Measured at 115 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 115 VAC, 60 Hz.
Ambient Temperature	T_{AMB}			100	ºC	

2 Schematic

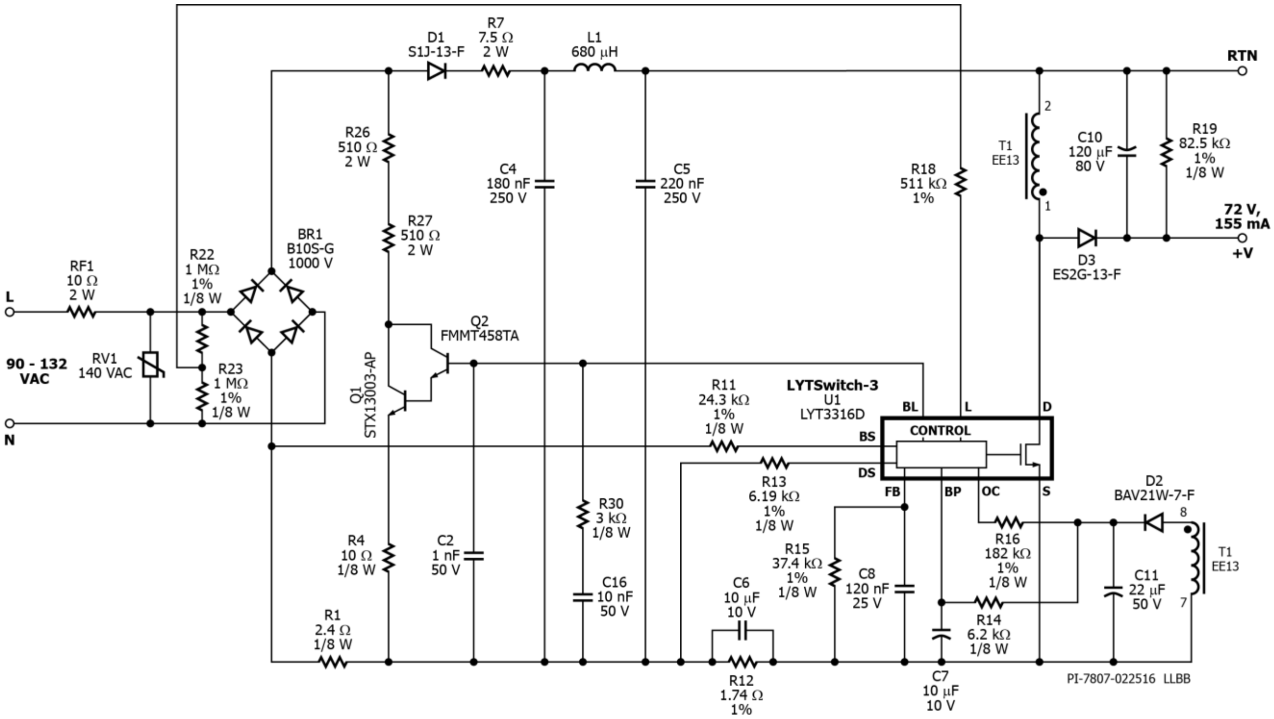

Figure 4 – Schematic.

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3 Circuit Description

The LYTSwitch-3 LYT3316D combines a high-voltage power MOSFET switch with a power supply controller in a single SO16 package. The LYTSwitch-3 controller provides a single-stage power factor correction, LED current control and dimming control.

3.1 Input Stage

Fusible resistor RF1 provides protection against component failure. It also helps dampen the inrush current ringing during start up and dimming operation. Varistor RV1 acts as a clamp to limit the maximum voltage spike on the primary during differential line surge events. A 140 VAC rated part was selected, being slightly above the maximum specified operating voltage (132 VAC).

The AC input is full wave rectified by BR1 to achieve good power factor and low THD.

3.2 EMI Filters

The Differential choke L1, together with the input filter capacitor C4 and C5 work as an EMI π filter. These EMI filters, together with the LYTSwitch-3 frequency jittering feature ensure compliance with the EN55015 Class B emission limit.

3.3 LYTSwitch-3 Primary Control Circuit

The topology is a buck-boost with a low-side switch. The primary winding finish terminal (no dot end) of the transformer (T1) is connected to the DC bus and the start (dotted end) terminal to the DRAIN (D) pin of the LYTSwitch-3 IC. During the on-time of the power MOSFET, current ramps through the primary winding, storing energy which is then delivered to the output load via output diode D3 during the power MOSFET off-time. Output capacitor C10 provides output voltage filtering minimizing the output LED ripple current.

Diode D2 and C11 deliver the primary bias supply for U1 from transformer auxiliary winding. The use of an external bias supply (via R14) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming condition.

Capacitor C7 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the IC. During start-up, the bypass capacitor C7 is charge to ~5.25 V from IC internal high-voltage current source connected to the D pin.

To provide input line voltage information to U1, the input AC voltage is sense directly before the bridge rectifier diode through sampling resistors R22 and R23. The (L) pin current set through resistor R18 is use to activate input OVP functions, to detect the presence of dimmer and to control the output LED current with respect to line.

With reference to the (FB) pin full conduction preset threshold of 300 mV, R12 senses the output LED current through U1 drain current and then fed into the U1 (DS) pin via

R13 to maintain the output constant current regulation. The capacitor C10 provides voltage filtering to generate a DC reference voltage and to reduce ripple voltage spike that could mistrigger the bleeder drive. The FB pin threshold is reduced linearly with respect to input conduction angle.

IC U1 (OC) pin senses the output voltage through R16 for the output OVP functions at open load and for optimized LED current regulation. Output OVP is activated with the IC latching off when the (OC) pin current exceeds the OV threshold.

3.4 TRIAC Phase Dimming Control with LYTSwitch-3 Smart Bleeder Drive

Due to the much lower power consumed by LED based lighting, the current drawn by the lamp is below the holding current of the TRIAC in many dimmers. This causes undesirable behavior such as limited dimming range and/or flicker. 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. This effect can cause similar undesirable behavior, as the ringing may cause the TRIAC current to fall below its holding current and turn off.

LYTSwitch-3 provides excellent dimming performance with its close loop smart bleeder to maintain the TRIAC holding current.

Transistor Q1, together with Q2 in Darlington connection, function as a high gain active bleeder switch. The active bleeder is modulated by the LYTSwitch-3 smart bleeder drive (BL) pin in a close loop system through sensing the input voltage and current.

Resistor R4, C2, R30 and C16 work as stabilizing network for the bleeder transistor for a more optimized dimming performance.

Resistor R1 senses the overall input current and fed to U1 (BS) pin through resistor R11. The overall current includes the active bleeder current and the U1 switch current. These current are sensed in order to keep the TRIAC current above its holding current level by modulating the bleeder dissipation in a closed loop system.

IC U1 (BL) pin drives the external bleeder switch in order to maintain the driver input current above the holding current of the TRIAC dimmer.

Fusible resistor RF1 and R7 dampens the driver input current ringing when TRIAC dimmer turns on. Diode D1 serves as a blocking diode to prevent current to be drawn from the input bulk capacitors C4 and C5 as the bleeder turns on.

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4 PCB Layout

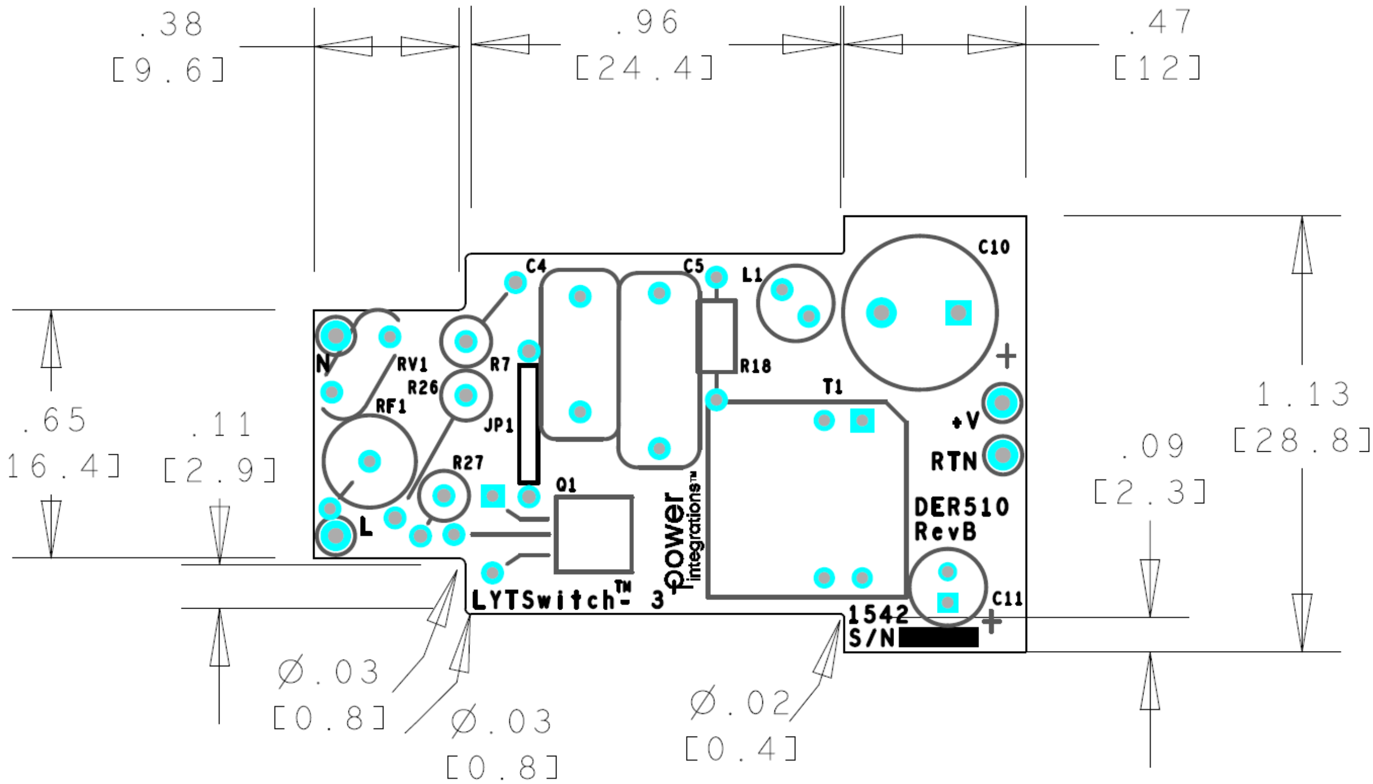

Figure 5 – Top Side.

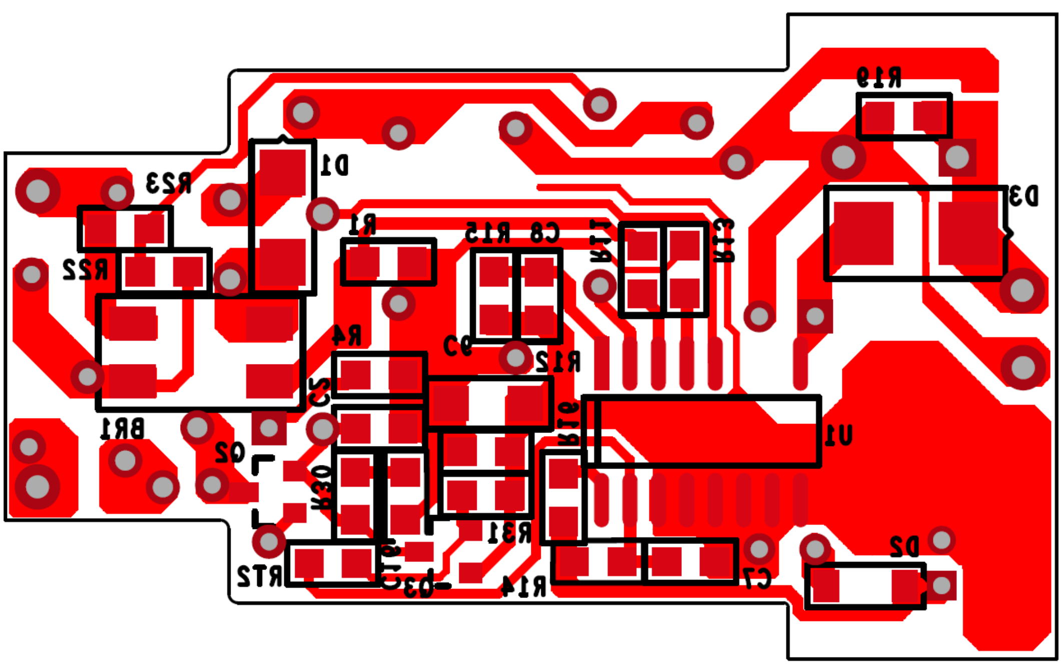

Figure 6 – Bottom Side.

5 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C2	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
3	1	C4	180 nF, 250 V, Film	ECQ-E2184KB	Panasonic
4	1	C5	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
5	1	C6	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
6	1	C7	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
7	1	C8	120 nF, 25 V, Ceramic, X7R, 0805	C0805C124K3RACTU	Kemet
8	1	C10	120 μF, 80 V, Electrolytic, Gen. Purpose, (10 x 17.5)	EKZN800ELL121MJ16S	United Chemi-con
9	1	C11	22 μF, 50 V, Electrolytic, Very Low ESR, 340 mΩ, (5 x 11)	EKZE500ELL220ME11D	Nippon Chemi-Con
10	1	C16	10 nF, 50 V, Ceramic, X7R, 0805	C0805C103K5RACTU	Kemet
11	1	D1	600 V, 1 A, Standard Recovery, SMA	S1J-13-F	Diodes, Inc.
12	1	D2	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
13	1	D3	400 V, 2 A, Superfast, 35 ns, DO-214A, SMB	ES2G-13-F	Diodes, Inc.
14	1	JP1	Wire Jumper, Non insulated, 30 AWG, 0.3 in	299/3 SV001	Alpha Wire
15	1	L1	680 μH, 0.25 A, 5.5 x 10.5 mm	SBC1-681-251	Tokin
16	1	Q1	NPN, Power BJT, 400 V, 1 A, TO-92	STX13003-AP	ST Micro
17	1	Q2	NPN, HP, 400 V, 225 mA, SOT23-3	FMMT458TA	Diodes-Zetex
18	1	R1	2.4 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ2R4V	Panasonic
19	1	R4	10 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
20	1	R7	7.5 Ω, 5%, 2 W, Metal Oxide	ERX-2SJ7R5	Panasonic
21	1	R11	24.3 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2432V	Panasonic
22	1	R12	1.74 Ω, 1%, 1/4 W, Thick Film, 1206	RC1206FR-071R74L	Yageo
23	1	R13	6.19 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6191V	Panasonic
24	1	R14	6.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ622V	Panasonic
25	1	R15	37.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3742V	Panasonic
26	1	R16	182 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1823V	Panasonic
27	1	R18	511 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-511K	Yageo
28	1	R19	82.5 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF8252V	Panasonic
29	1	R22	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
30	1	R23	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
31	1	R26	510 Ω, 5%, 2 W, Metal Oxide Film	ERG-2SJ511	Panasonic
32	1	R27	510 Ω, 5%, 2 W, Metal Oxide Film	ERG-2SJ511	Panasonic
33	1	R30	3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
34	1	RF1	10 Ω, 5%, 2 W, Wirewound, Fusible	FW20A10R0JA	Bourns
35	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
36	1	T1	Bobbin, EE13, Horizontal, 8 pins		Janohig Electronic
37	1	U1	LYTSwitch-3, SO-16C	LYT3316D	Power Integrations

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6 Inductor Specification

6.1 Electrical Diagram

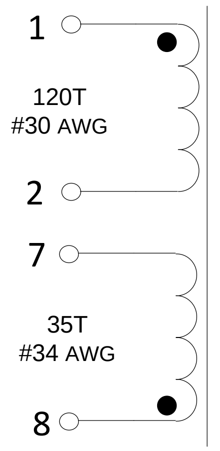

Figure 7 – Inductor Electrical Diagram.

6.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V pk-pk, 100 kHz switching frequency, between pin 1 and pin 2, with all other windings open.	400 μH
Tolerance	Tolerance of primary inductance.	±6%

6.3 Material List

Item	Description
[1]	Core: EE13.
[2]	Bobbin, EE13, Horizontal, 8 pins, Part No: 25-01017-00.
[3]	Magnet Wire: #30 AWG.
[4]	Magnet Wire: #34 AWG.
[5]	Transformer tape: 7.4 mm.
[6]	Transformer tape: 5.5 mm.

6.4 Inductor Build Diagram

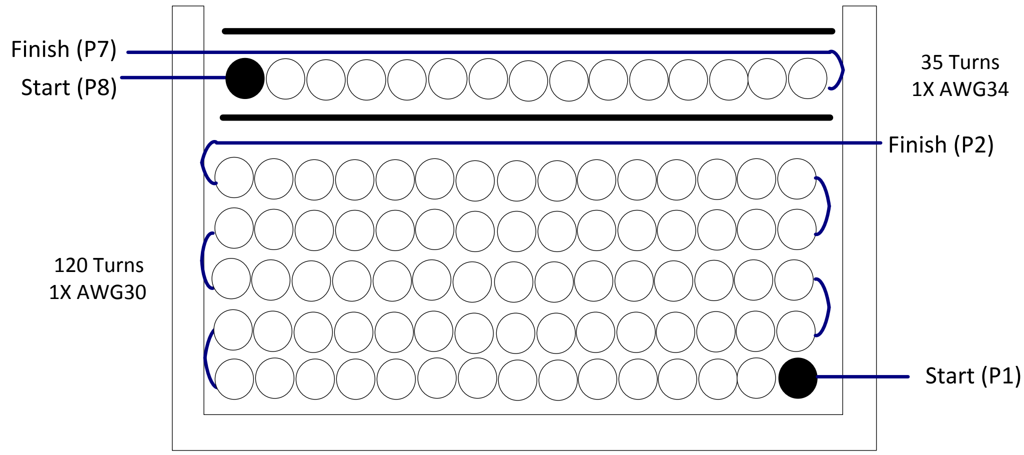

Figure 8 – Transformer Build Diagram.

6.5 Inductor Construction

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-4 is in the right side. The winding direction is clockwise.
Winding 1	Use wire item [3], start at pin 1 and wind 120 turns in 5 layers, then finish the winding on pin 2.
Insulation	Add 1 layer of tape, item [5], for insulation.
Winding 2	Use wire item [4], start at pin 8 and evenly wind 35 turns from left to right, then finish the winding on pin 7.
Insulation	Add 1 layer of tape, item [5], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 400 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 2 layer of tape, Item (6).
Bobbin and Core Tape	Center the core assembly across the bobbin then wrap with 1 layer of tape, Item (5).
Pins	Pull out Terminal pin no. 3,4, 5 and 6.
Finish	Dip the transformer assembly in varnish.

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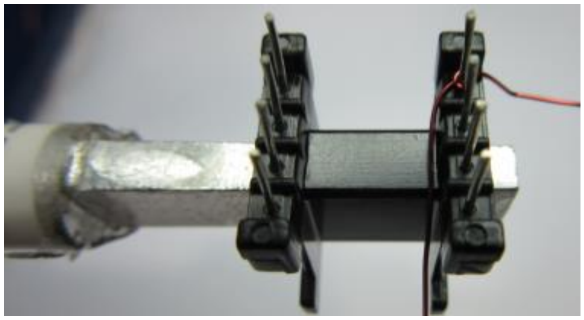
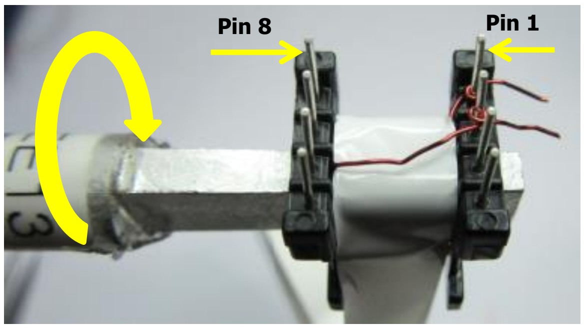
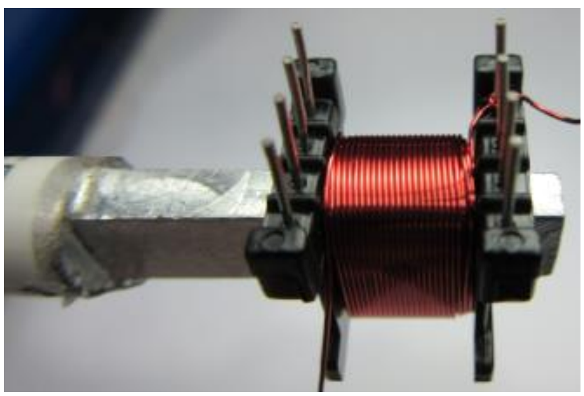
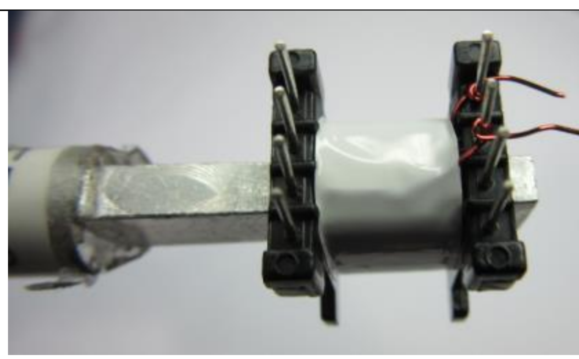
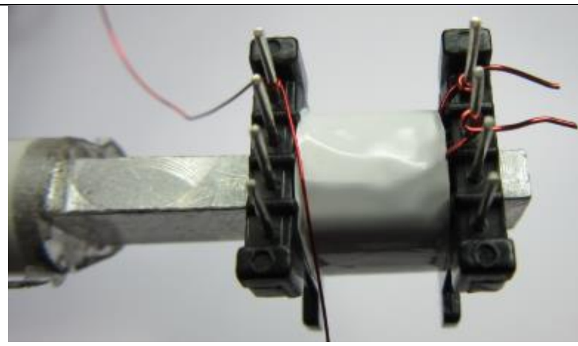
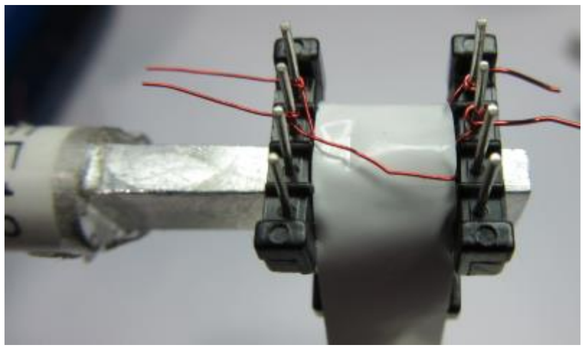
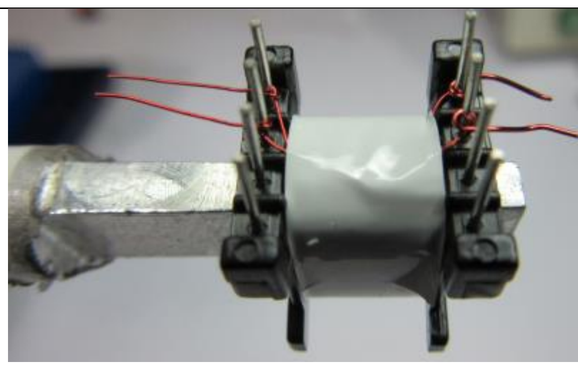
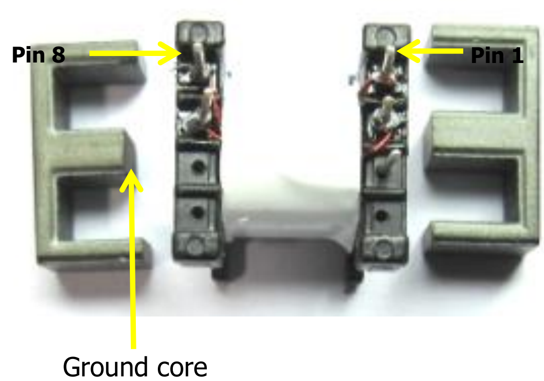
6.6 Winding Illustrations

Winding Directions	 	Bobbin is oriented on winder jig such that terminal pin 1-4 is in the right side. The winding direction is clockwise as illustrated on the right picture.
Winding 1		Use wire item [3], start at pin 1 and wind 120 turns in 5 layers, then finish the winding on pin 2.
Insulation		Add 1 layer of tape, item [5], for insulation.

Winding 2	 	Use wire item [4], start at pin 8 and evenly wind 35 turns from left to right, then finish the winding on pin 7.
Insulation		Add 1 layer of tape, item [5], for insulation.
Assemble Core		Assemble the 2 cores on the bobbin with the ground core place on pin 4-8 side. Wrap the cores with 2 layer of tape, Item (6).

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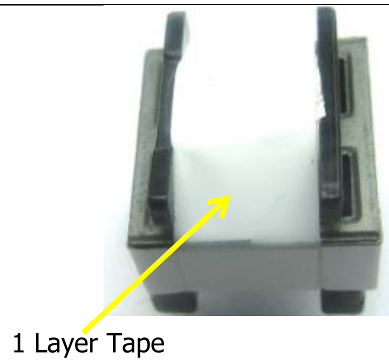
Bobbin and Core Tape		Center the core assembly across the bobbin then wrap with 1 layer of tape, Item (5).

7 Inductor Design Spreadsheet

ACDC_LYTSwitch-3-Buck_040915; Rev.0.94; Copyright Power Integrations 2015	INPUT	INFO	OUTPUT	UNIT	ACDC_LYTSwitch-3 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	90.00		90.00	V	Minimum AC Input Voltage
VACNOM			120.00	V	Typical AC Input Voltage
VACMAX	132.00		132.00	V	Maximum AC Input Voltage
FL	60.00		60.00	Hz	Minimum line frequency
VO_MIN			64.8	V	Guaranteed minimum VO that maintains output regulation
VO	72.0		72.0	V	Worst case normal operating output voltage
VO_OVP_MIN			86.7	V	Minimum Voltage at which output voltage protection may be activated
IO	155.0		155.0	mA	Average output current specification
n	0.87		0.87	%/100	Total power supply efficiency
Z			0.50		Loss allocation factor
PO			11.16	W	Total output power
VD			0.70	V	Output diode forward voltage drop
ENTER LYTSwitch-3 VARIABLES					
Select Breakdown Voltage	650		650	V	Choose between 650V and 725V
Device	LYT33X6		LYT33X6		Chosen LYTSwitch-3 Device
Final device code			LYT3316		
Select Dimming Curve Option	1		1		Dimming curve 1
RBS2			24	k-ohm	RBS2 resistor to select dimming curve
ILIMITMIN			1.769	A	Minimum device current limit
ILIMITTYP			1.902	A	Typical Current Limit
ILIMITMAX			2.035	A	Maximum Current Limit
TON			3.53	us	Expected on-time of MOSFET at low line and PO
FSW			120.0	kHz	Expected switching frequency at low line and PO
Duty Cycle			42.4	%	Expected operating duty cycle at low line and PO
IRMS			0.284	A	Nominal RMS current through the switch at low line
IPK			1.125	A	Worst Case Peak current
KDP			1.09		Ratio between off-time of switch and reset time of core at VACNOM
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type	EE13		EE13		Core Type
Core Part Number			PC40EE13-Z		If custom core is used - Enter part number here
Bobbin part number			BE-13		Bobbin Part number (if available)
AE			17.10	mm^2	Core Effective Cross Sectional Area
LE			30.20	mm	Core Effective Path Length
AL			1130	nH/T^2	Ungapped Core Effective Inductance
BW			7.40	mm	Bobbin Physical Winding Width
INDUCTOR DESIGN PARAMETERS					
LPMIN			380	uH	Minimum Inductance
LP	400		400	uH	Typical value of Primary Inductance
LP Tolerance	5.00		5	%	Tolerance of Primary Inductance
N	120.00		120	Turns	Number of Turns
ALG			28	nH/T^2	Gapped Core Effective Inductance
BM			2193	Gauss	Operating Flux Density. Maintain value below 3300 G
BP			4165	Gauss	Calculated Worst Case Peak Flux Density (BP < 4200 G)
BAC			1096	Gauss	Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)

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LG			0.774	mm	Gap Length (Lg > 0.1 mm)
Layers			4.8		Estimated number of winding layers
IL_RMS			0.465	A	Worst case RMS Current through the inductor
AWG			30	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			102	Cmils	Bare conductor effective area in circular mils
CMA			219	Cmils/A	Primary Winding Current Capacity (200 < CMA < 500)
Current Density (J)			9.13	A/mm^2	Inductor Winding Current density (3.8 < J < 9.75 A/mm^2)
Bias Section					
TURNS_BIAS			35.00	Turns	Number of turns of Bias Winding
VBIAS			20.00	V	Bias Voltage. Check performance at minimum VO and maximum VAC.
PIVBS			74.45	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at maximum VAC)
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			42.38	%	Duty cycle measured at minimum input voltage
IAVG			0.14	A	Input average current measured on the Mosfet at the minimum input voltage
IP			1.07	A	Peak Drain current at minimum input voltage
ISW_RMS			0.28	A	MOSFET RMS current measured at the minimum input voltage
ID_RMS			0.15	A	RMS current of freewheeling diode at minimum input voltage
IL_RMS			0.32	A	RMS current of the of the inductor at the minimum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
n_MEASURED			0.87		Measured efficiency (this value is used for resistor calculations only)
VBIAS_MEASURED			20.00	V	Bias voltage (across the bias capacitor) measured on a prototype unit
VOUT_MEASURED			72.00	V	Load voltage measured on a prototype unit
RDS_T			1.5547	ohm	Theoretical calculation for RDS sense resistor
RDS			1.54	ohm	Rds resistor calculation assuming E96 / 1%
CDS			10.00	uF	Cds Capacitor Calculation
ROVP			182.00	k-ohm	OC pin resistor (E96 / 1%)
RL			1.96	M-ohm	L pin resistor (E96 / 1%)
RFB_T			38878.84	ohm	Calculated value of RFB, using RDS_T
RFB			39.20	k-ohm	Feedback pin resistor (E96 / 1%)
CFB_T			154.33	nF	Feedback pin capacitor (for 6ms time constant)
CFB			150	nF	Feedback pin capacitor E12 standard value
RSUP			6.2	k-ohm	Bias supply resistor assuming 1mA current necessary to supply BP
VOLTAGE STRESS PARAMETERS					
VDRAIN			304	V	Estimated worst case drain voltage at VACMAX and VO_MAX
PIVD			301.5	V	Peak Inverse Voltage at VO_MAX on output diode
BLEEDER COMPONENTS					
I_HOLD			50.00	mA	Required bleeder holding current
RBS1			2.4	Ohm	Exact value of RBS1 resistor

8 Performance Data

All measurements were performed at room temperature using LED loads string. 60 minutes soak time was applied before measurement with AC Source turned-off for 3 seconds every succeeding input line measurement.

8.1 Efficiency

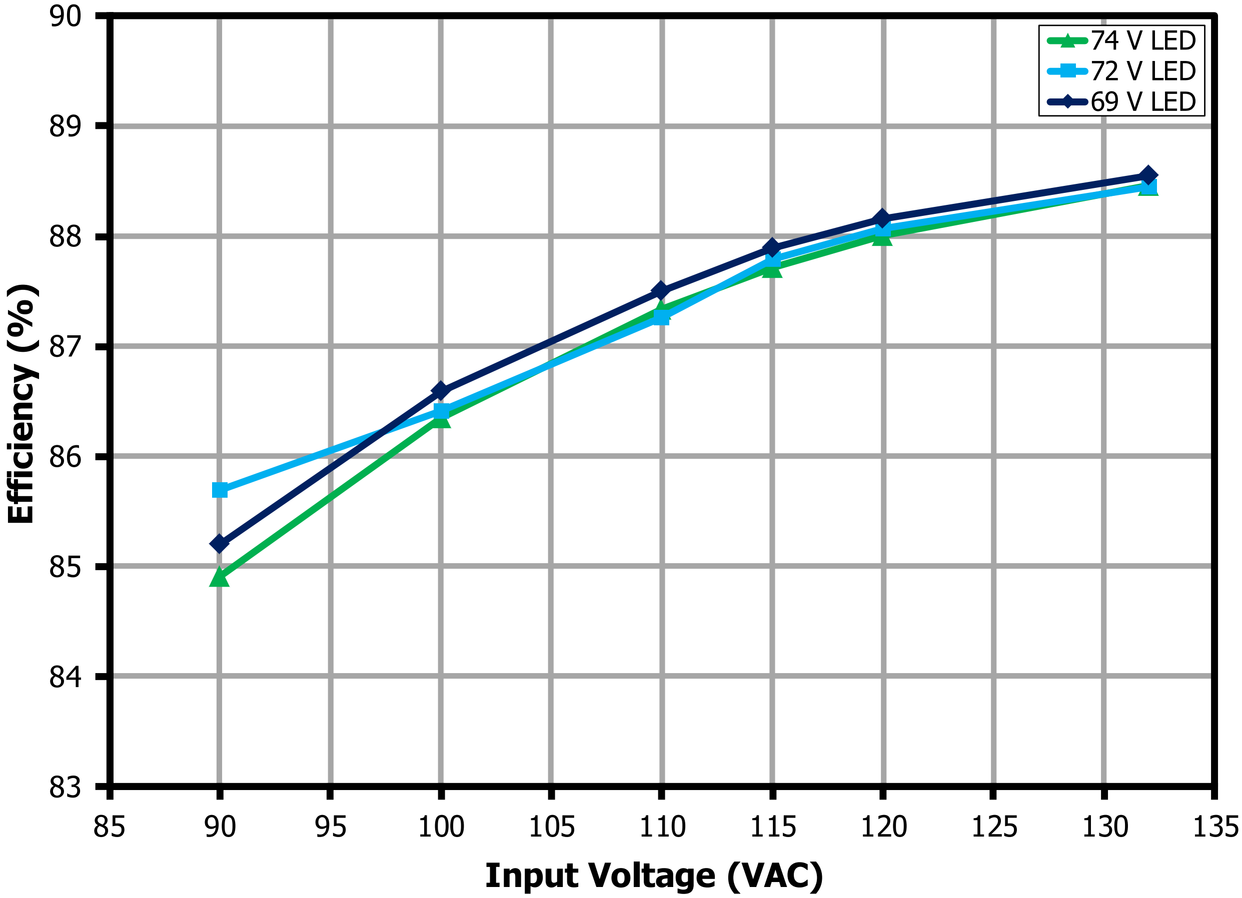

Figure 9 – Efficiency vs. Line and LED Load.

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8.2 Line Regulation

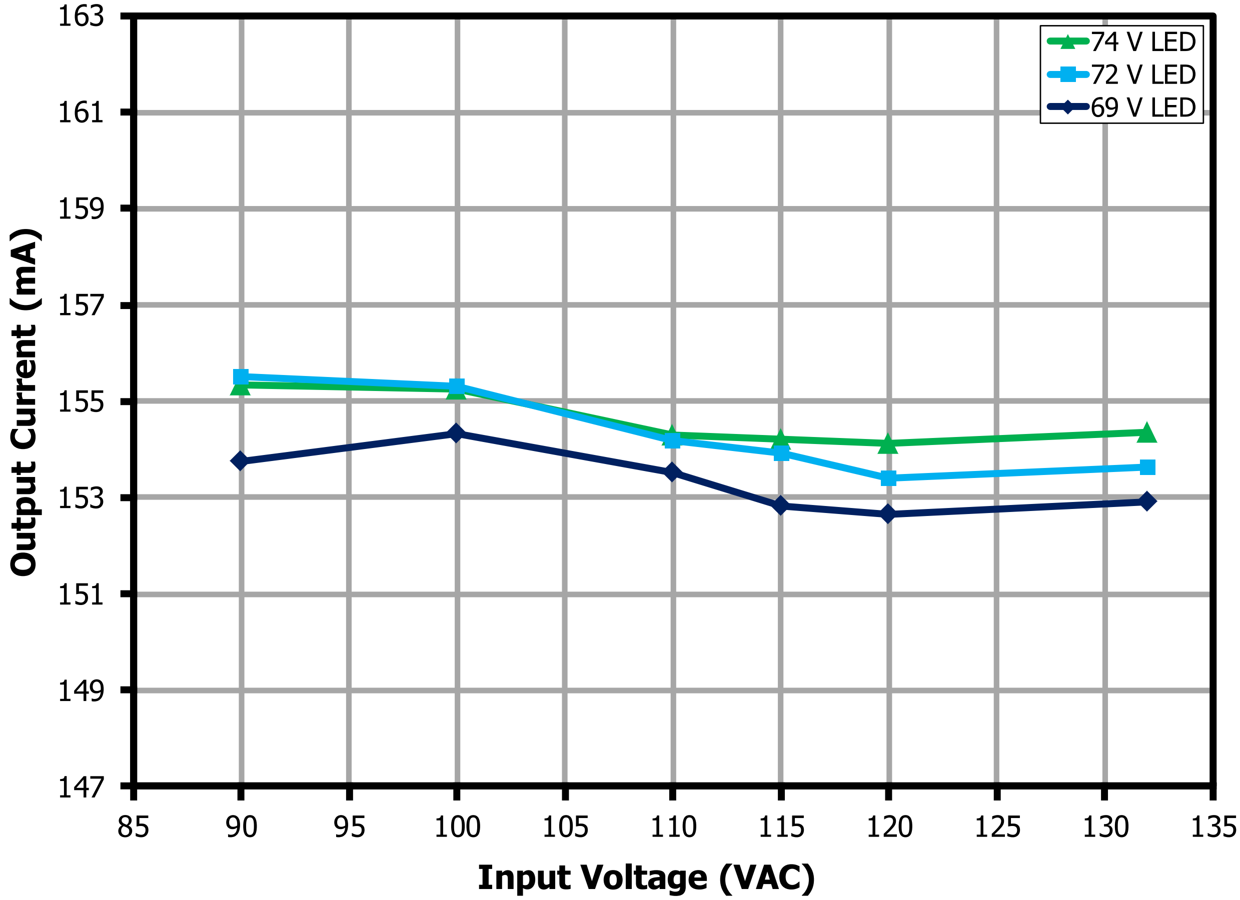

Figure 10 – Regulation vs. Line and LED Load.

8.3 Power Factor

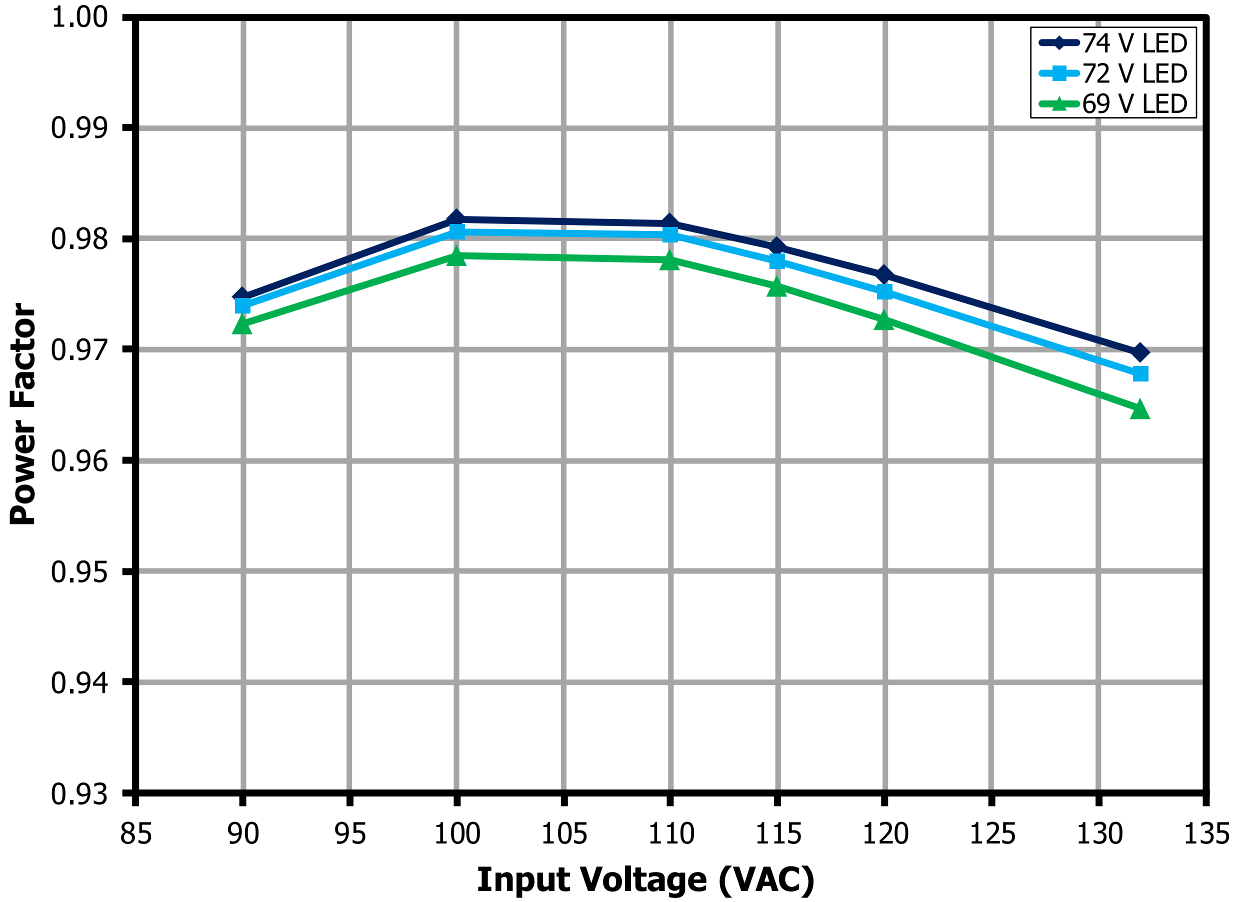

Figure 11 – Power Factor vs. Line and LED Load.

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8.4 %ATHD

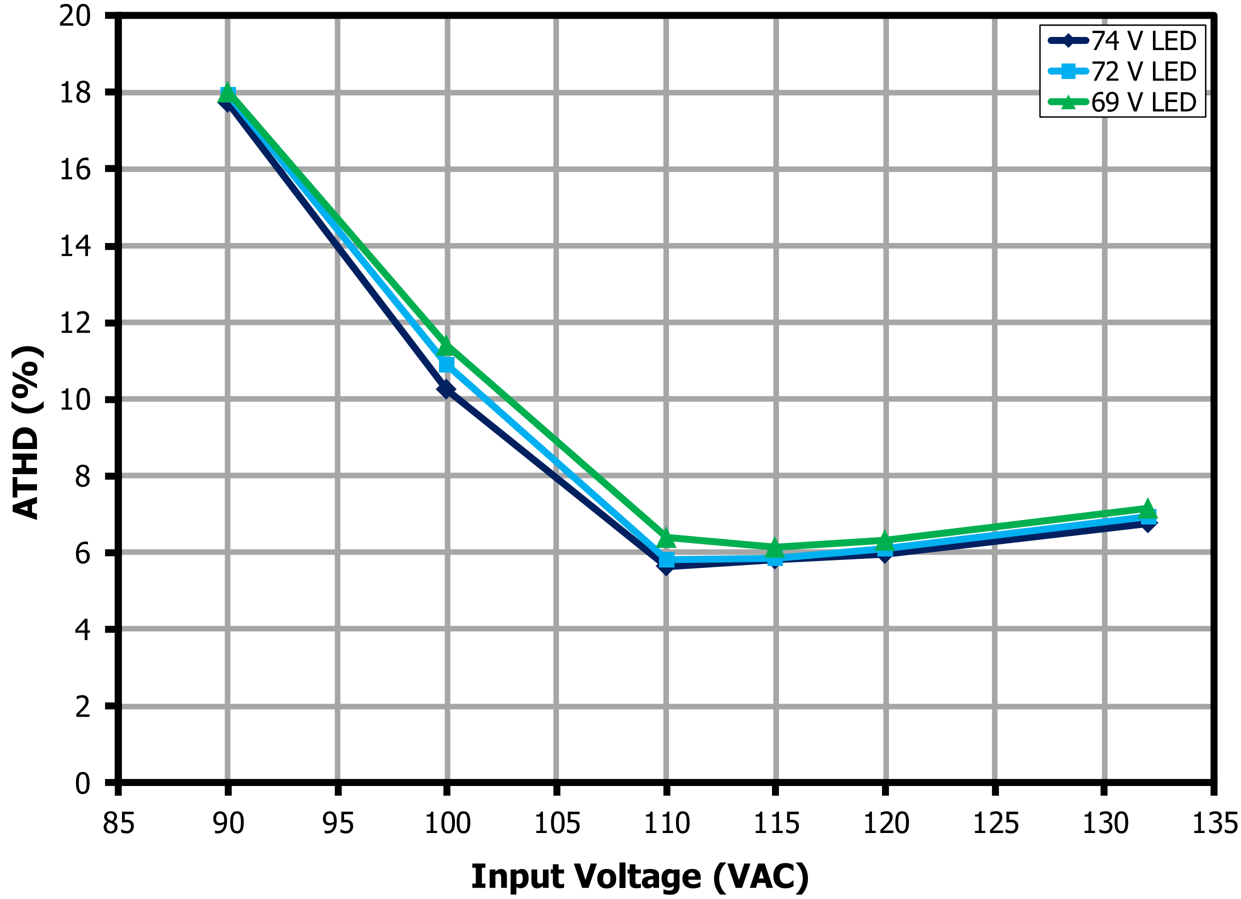

Figure 12 – %ATHD vs. Line and LED Load at 120 VAC, 60 Hz.

8.5 Harmonics

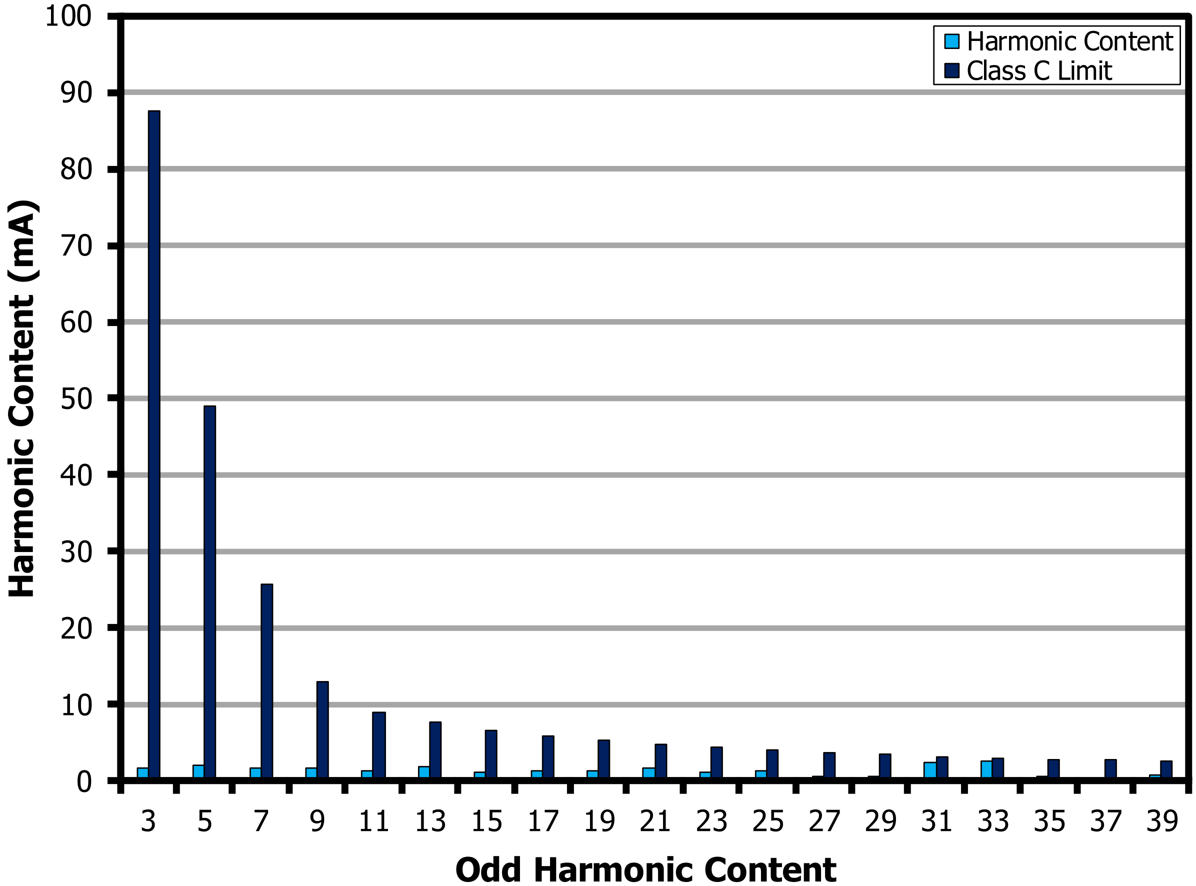

Figure 13 – 72 V LED Load Input Current Harmonics at 120 VAC, 60 Hz.

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9 Test Data

9.1 Test Data, 74 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	89.84	157.40	13.78	0.975	17.722	74.92	155.33	11.70	84.91
100	60	99.87	137.93	13.52	0.982	10.245	74.83	155.26	11.68	86.35
110	60	109.90	123.01	13.27	0.981	5.647	74.75	154.30	11.59	87.34
115	60	114.87	117.28	13.19	0.979	5.814	74.70	154.20	11.57	87.72
120	60	119.92	112.14	13.14	0.977	5.962	74.65	154.13	11.56	88.00
132	60	131.91	102.26	13.08	0.970	6.753	74.62	154.35	11.57	88.46

9.2 Test Data, 72 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	89.82	150.72	13.19	0.974	17.942	72.22	155.52	11.30	85.70
100	60	99.85	133.16	13.04	0.981	10.906	72.16	155.32	11.27	86.42
110	60	109.88	118.83	12.80	0.980	5.823	72.09	154.19	11.17	87.26
115	60	114.85	112.99	12.69	0.978	5.857	72.05	153.92	11.14	87.79
120	60	119.90	107.76	12.60	0.975	6.104	72.00	153.40	11.10	88.07
132	60	131.89	98.39	12.56	0.968	6.931	71.97	153.62	11.11	88.45

9.3 Test Data, 69 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	89.84	143.78	12.56	0.972	18.003	69.16	153.75	10.70	85.20
100	60	99.86	126.79	12.39	0.979	11.424	69.12	154.34	10.73	86.59
110	60	109.89	113.33	12.18	0.978	6.412	69.08	153.53	10.66	87.50
115	60	114.86	107.64	12.06	0.976	6.159	69.04	152.81	10.60	87.89
120	60	119.92	102.94	12.01	0.973	6.326	69.01	152.64	10.59	88.16
132	60	131.91	94.09	11.97	0.965	7.162	68.99	152.90	10.60	88.55

9.4 Test Data, Harmonic Content at 120 VAC with 72 V LED Load

Vin (V_{RMS})	Freq	Iin (mA_{RMS})	Pin (W)	PF	%THD
120	60	101.47	11.970	0.984	3.983
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	108.41				
2	0.09	0.08%		2.00%	Pass
3	1.68	1.55%	87.60	29.32%	Pass
5	2.00	1.84%	48.95	10.00%	Pass
7	1.63	1.50%	25.76	7.00%	Pass
9	1.60	1.48%	12.88	5.00%	Pass
11	1.37	1.26%	9.02	3.00%	Pass
13	1.92	1.77%	7.63	3.00%	Pass
15	1.21	1.12%	6.61	3.00%	Pass
17	1.22	1.13%	5.83	3.00%	Pass
19	1.31	1.21%	5.22	3.00%	Pass
21	1.74	1.61%	4.72	3.00%	Pass
23	1.08	1.00%	4.31	3.00%	Pass
25	1.30	1.20%	3.97	3.00%	Pass
27	0.50	0.46%	3.67	3.00%	Pass
29	0.54	0.50%	3.42	3.00%	Pass
31	2.33	2.15%	3.20	3.00%	Pass
33	2.54	2.34%	3.01	3.00%	Pass
35	0.63	0.58%	2.83	3.00%	Pass
37	0.18	0.17%	2.68	3.00%	Pass
39	0.67	0.62%	2.54	3.00%	Pass

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10 Dimming Performance Data

Dimming curve data were taken with an open frame LED driver unit at an input voltage of 120 VAC, 60 Hz and a 72 V nominal output LED load. Ambient temperature was 25 ºC.

10.1 Dimming Curve

Agilent 6812B AC source programmed as perfect leading edge dimmer

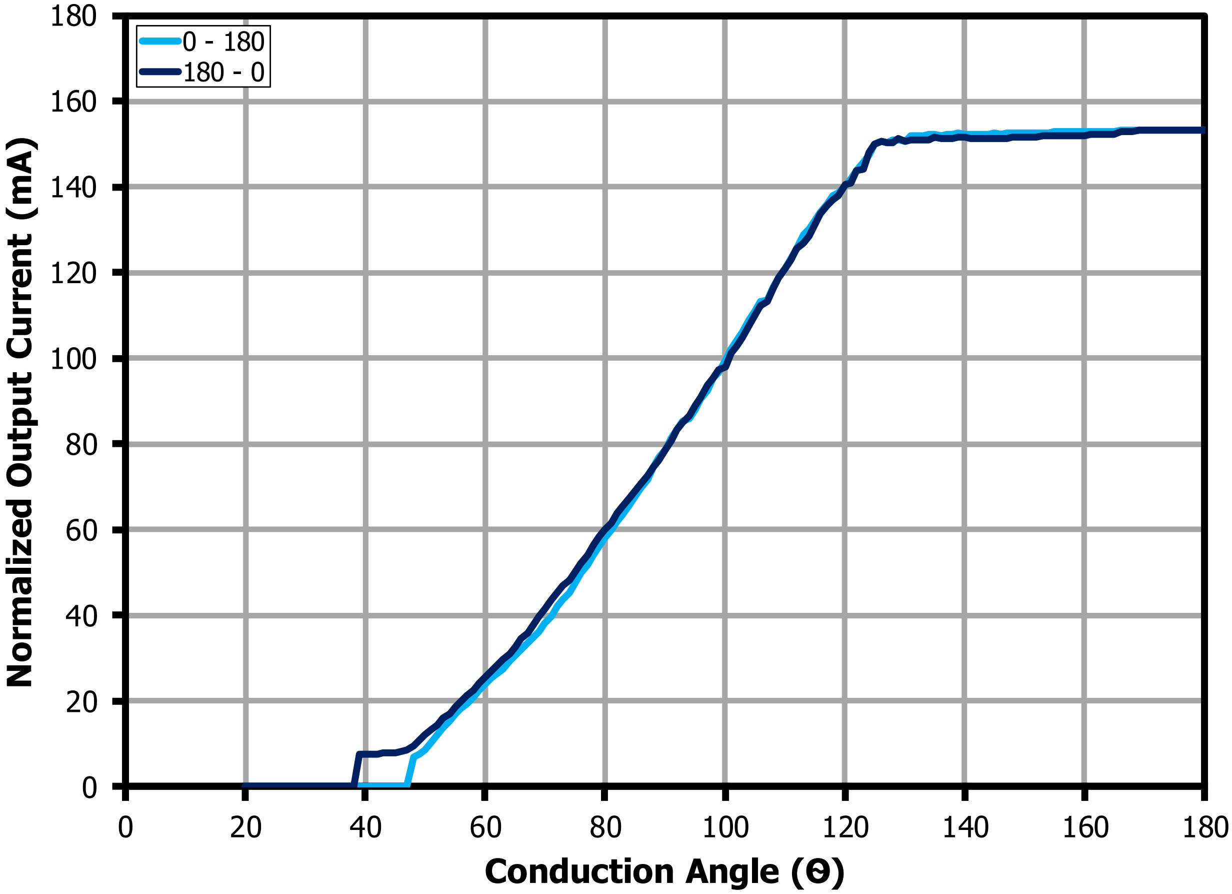

Figure 14 – Dimming Curve at 120 VAC, 60 Hz Input.

10.2 Dimming Efficiency

Measurement was made using a programmable AC source to provide the leading edge chopped AC input. For this test, the bleeder was already active.

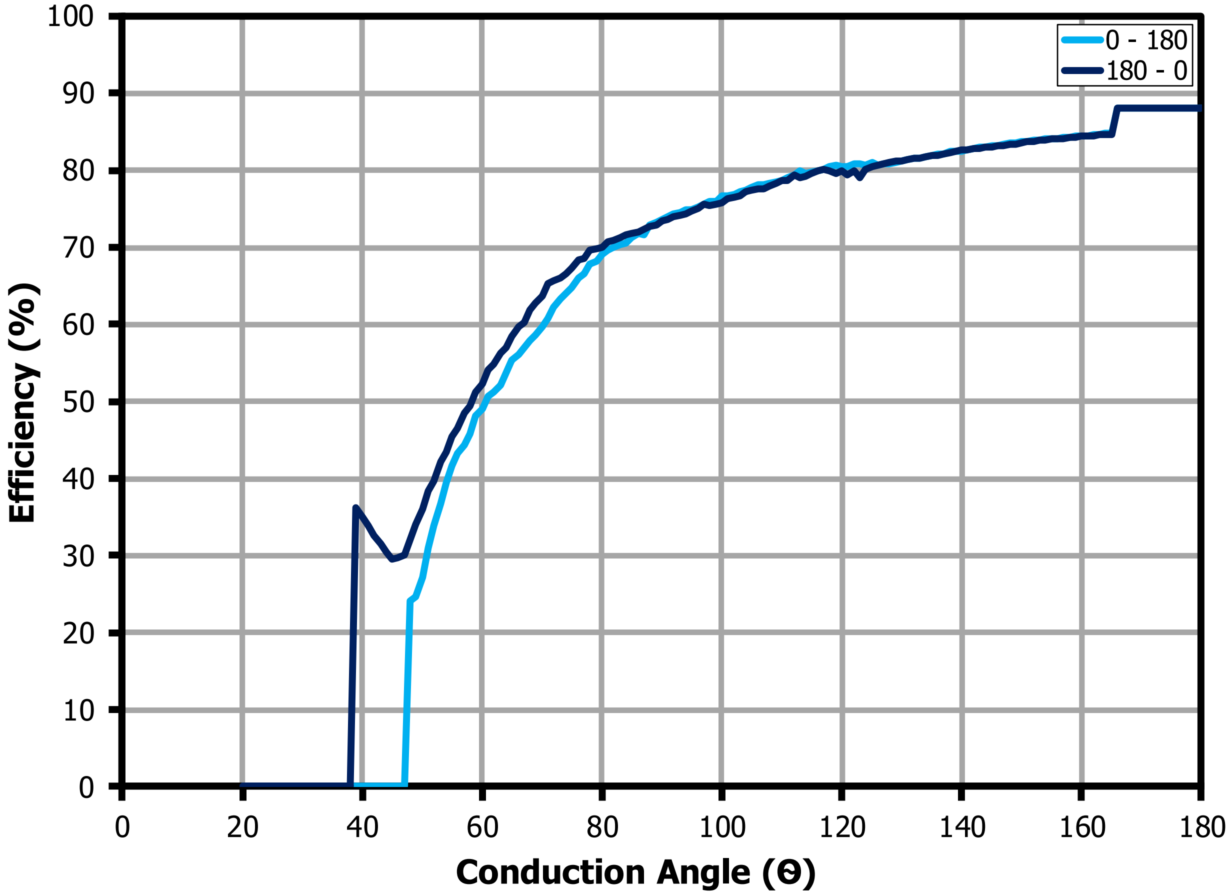

Figure 15 – Driver Efficiency at 120 VAC, 60 Hz Input.

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10.3 Driver Power Loss During Dimming

Measurement was made using a programmable AC source to provide the leading edge chopped AC input. For this test, the bleeder was already active.

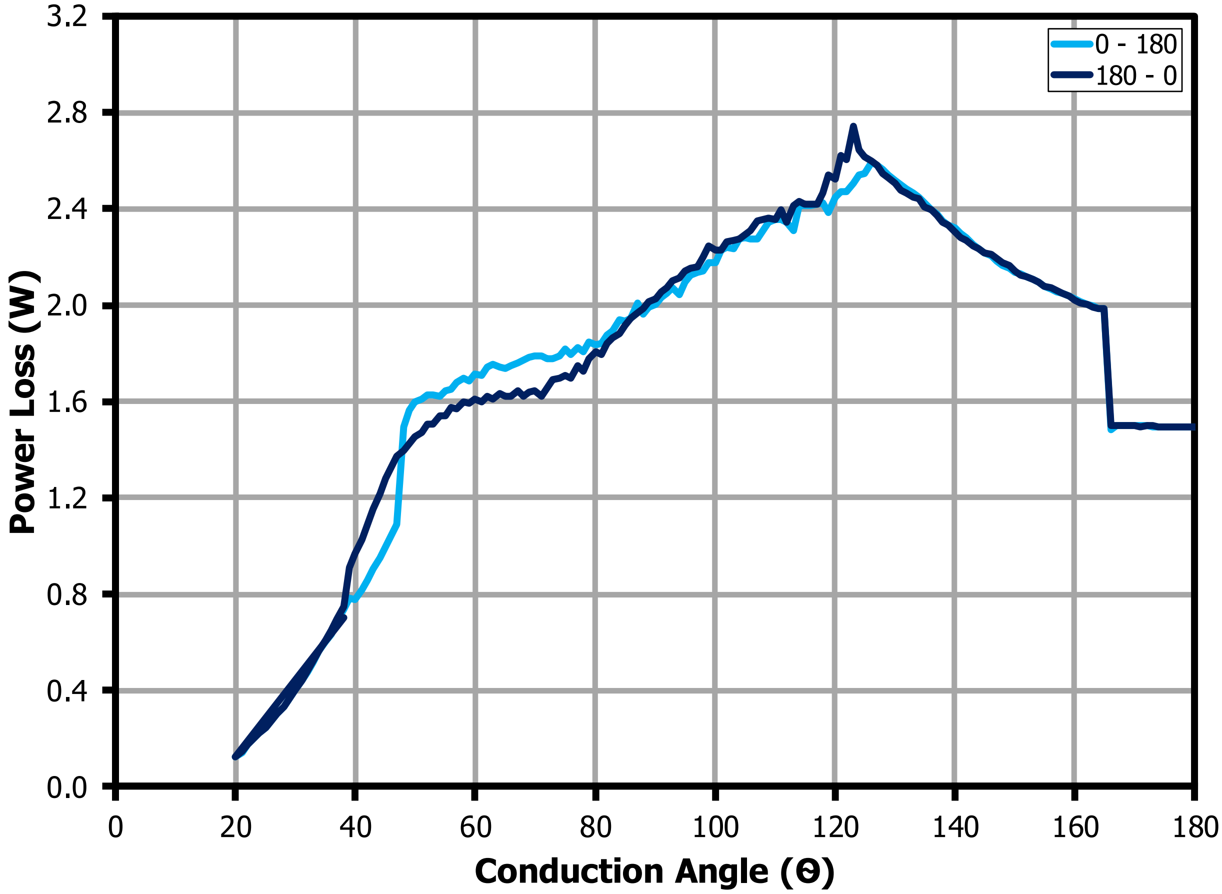

Figure 16 – Driver Power Loss at 120 VAC, 60 Hz Input.

10.4 Driver Compatibility List

The following dimmers were tested at 25 ºC ambient temperature at 120 VAC, 60 Hz using 72 V system LED Load.

No	Panel	Brand	Model	Type	Max. (mA)	Min. (mA)	Dimming Ratio
1	US Panel 1	LEVITON	9530WS-K	L	154.5	11.5	13
2	US Panel 1	LEVITON	601-6631-1	L	154.5	12	13
3	US Panel 1	LEVITON	6683	L	154.6	11	14
4	US Panel 1	LEVITON	1P106-1LZ	L	155	12	13
5	US Panel 1	LEVITON	6681	L	154	11	14
6	US Panel 1	LEVITON	6633_PLW	L	154	11	14
7	US Panel 2	G.E.	18019	L	154	12	13
8	US Panel 2	G.E.	18023	L	155	12	13
9	US Panel 2	G.E.	18022	L	154	12	13
10	US Panel 2	LUTRON	MRF2-6ND-120-BI	L	154	12	13
11	US Panel 2	LUTRON	RRD-6NA-WH	T	159	13	12
12	US Panel 2	LUTRON	D-600P-WH	L	155	11	14
13	US Panel 2	LUTRON	DVCL-153P-WH	L	154	11	14
14	US Panel 2	LUTRON	AY-600PNL-WH	L	154	11	14
15	US Panel 3	LUTRON	S-600P-WH	L	154	13	12
16	US Panel 3	LUTRON	LXELV-600PL-WH	T	155	15	10
17	US Panel 3	LUTRON	NTELV-300-WH	T	154	15	10
18	US Panel 3	LUTRON	NT-600-WH	L	154	12	13
19	US Panel 3	LUTRON	DVELV-300P-WH	T	155	12	13
20	US Panel 3	LUTRON	SELV-300P-WH	T	155	13	12
21	US Panel 3	LUTRON	CTCL-153P-WH	L	154	11	14
22	US Panel 9	LEGRAND	HCL453PTCCCV6	L	155	20	8
23	US Panel 9	LEVITON	1PE04-1LZ	T	163	14	12
24	US Panel 9	LUTRON	AYCL-153P-WH	L	155	13	12
25	US Panel 9	LUTRON	SCL-153P-WH	L	154	11.5	13
26	US Panel 9	LUTRON	RRD-10ND-WH	L	154	13	12
27	US Panel 9	LUTRON	RRD-6NA-WH	T	157	13	12
28	US Panel 9	LEVITON	VPM10-1LZ	L	154	13	12
29	US Panel 10	LUTRON	N-600-WH	L	156	12	13
30	US Panel 10	LUTRON	NTELV-600-WH	T	155	14.5	11
31	US Panel 10	LUTRON	NT-603P-WH	L	156	12	13
32	US Panel 10	LUTRON	DVF-103P-WH		154	30	5
33	US Panel 10	LEVITON	1PSD6-1LZ	L	154	12	13
34	US Panel 10	LEVITON	1PVD6-1LZ	L	155.4	12	13
35	US Panel 10	LEVITON	1PL06-10Z	L	153	13	12
36	US Panel 10	LEVITON	6672	L	153	11	14
37	US Panel 11	LEVITON	6674	L	155	11	14
38	US Panel 11	LEVITON	6641	L	154	11	14
39	US Panel 11	LEVITON	6602	L	155	11	14
40	US Panel 11	LEVITON	TBL03	L	155	12	13
41	US Panel 11	LEVITON	6615	T	158	11	11
42	US Panel 11	LUTRON	CTCL-153P-WH	L	155	13	13
43	PHILS-L1	LUTRON	AY-10PNL-WH	L	154	17	17
44	PHILS-L1	LUTRON	AY-603PG-WH	L	112	10	10
45	PHILS-L1	LUTRON	AY-603P-WH	L	153	13	13
46	PHILS-L1	LUTRON	AYLV-600P-WH	L	154	14	14
47	PHILS-L1	LUTRON	AYLV-603P-WH	L	155	14	14
48	PHILS-L1	LUTRON	GLV-600-IV	L	153	14	14
49	PHILS-L1	LUTRON	LG-600PH-WH	L	154	14	14

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50	PHILS-L2	LUTRON	DV-600P-WH	L	153	14	14
51	PHILS-L2	LUTRON	DV-603P-WH	L	155	14	14
52	PHILS-L2	LUTRON	DVLP-103P-WH	L	154	14	14
53	PHILS-L2	LUTRON	DVLP-10.WH	L	153	14	14
54	PHILS-L2	LUTRON	DVPDC-203P-WH	L	155	5	5
55	PHILS-L2	LUTRON	DVW-603PGH-WH	L	123	11	11
56	PHILS-L2	LUTRON	DVWCL-153PH-WH	L	154	14	14
57	PHILS-L2	LUTRON	GL-600-WH	L	153	14	14
58	PHILS-L2	LUTRON	LG-603PGH-WH	L	121	11	11
59	PHILS-L2	LUTRON	CTCL-153P-WH	L	154	15	15
60	PHILS-L3	LUTRON	MACL-153M-WH	L	148	13	13
61	PHILS-L3	LEVITON	R02-06613-PLW	L	155	14	14
62	PHILS-L3	LEVITON	R62-RP106-1LW	L	154	12	12
63	PHILS-L4	LUTRON	S-1000-WH	L	155	17	17
64	PHILS-L4	LUTRON	S-103PNL-WH	L	155	16	16
65	PHILS-L4	LUTRON	S-103P-WH	L	155	16	16
66	PHILS-L4	LUTRON	S-600P-WH	L	153	15	15
67	PHILS-L4	LUTRON	S-600-PNLH-WH	L	154	14	14
68	PHILS-L4	LUTRON	S-6000P-WH	L	154	14	14
69	PHILS-L4	LUTRON	S-6000-WH	L	156	14	14
70	PHILS-L4	LUTRON	S-603PGH-WH	L	120	15	15
71	PHILS-L4	LUTRON	S-603PNLH-WH	L	153	14	14
72	PHILS-L5	COOPER	S106P	L	155	14	14
73	PHILS-L5	COOPER	SLC03P-W-K-L	L	154	7	7
74	PHILS-L5	LUTRON	SLV600P-WH	L	153	13	13
75	PHILS-L5	LUTRON	SLV-603P-WH	L	155	14	14
76	PHILS-L5	LUTRON	SPSLV-1000-WH	T	154	14	14
77	PHILS-L5	LUTRON	TGCL-153PH-WH	L	152	13	13
78	PHILS-L5	LUTRON	TGLV-600PR	L	154	13	13
79	PHILS-L5	LEVITON	1P106	L	153	15	15
80	PHILS-L6	LEVITON	TTI06	L	154	14	14
81	PHILS-L6	LUTRON	SPSELV-600-WH	T	163	10	10
82	PHILS-L6	LUTRON	LGCL-153PLH-WH	L	153	12	12

11 Thermal Performance

11.1 Thermal Performance Scan – Open Frame Unit

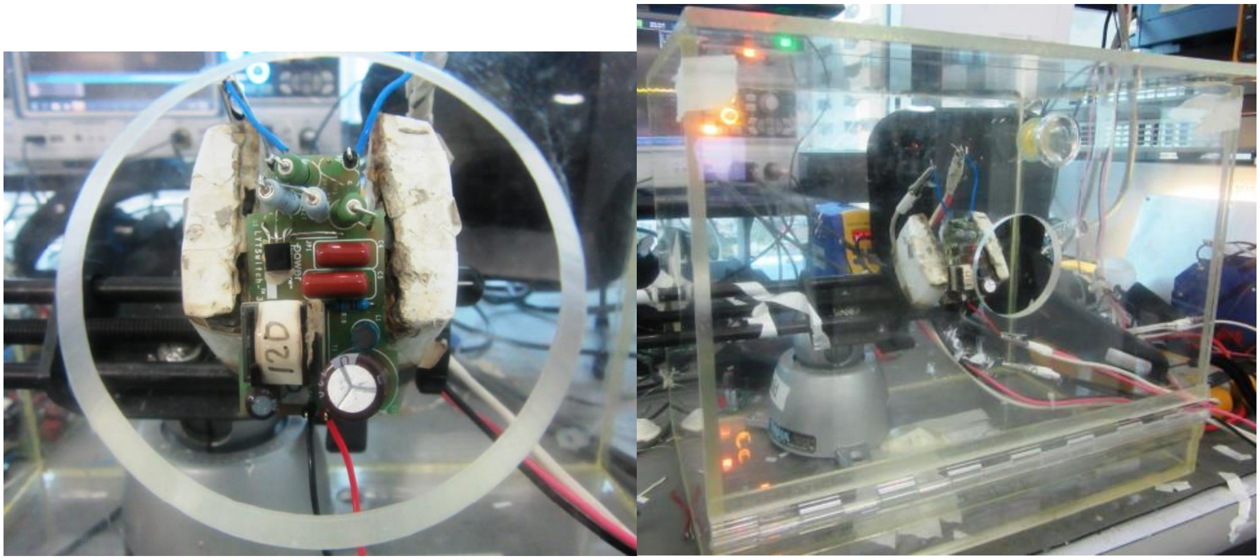

Figure 17 – Test Set-up Picture - Open Frame.

Unit in open frame was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR thermal camera.

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11.1.1 Thermal Scan During Non-Dimming at the Bottom Side

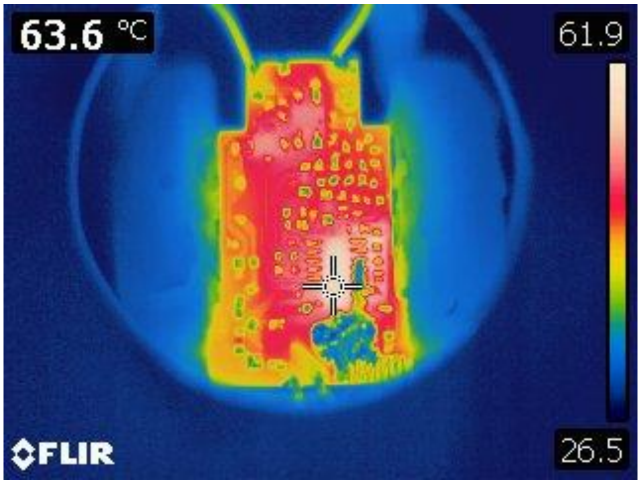

Figure 18 – 120 VAC, 72 V LED LOAD.
Spot 1: LYT3316D (U1): 63.6 ºC.

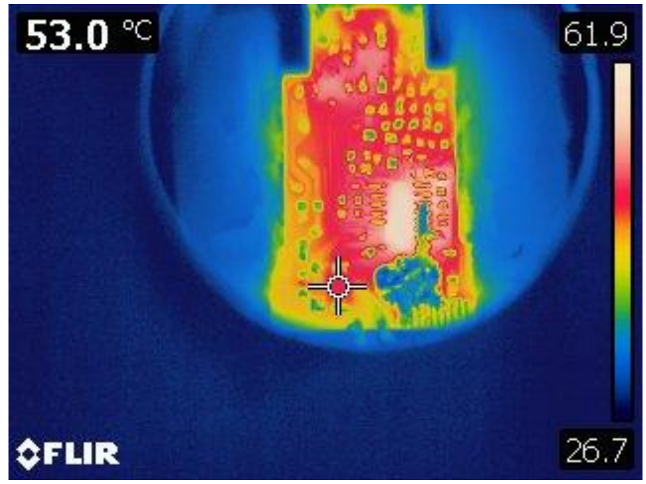

Figure 19 – 120 VAC, 72 V LED LOAD.
Spot 1: Output Diode (D3): 53 ºC.

11.1.2 Thermal Scan During Non-Dimming at the Top Side

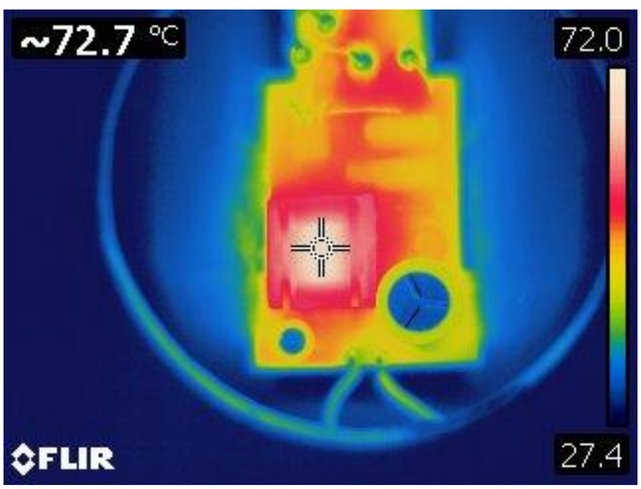

Figure 20 – 120 VAC, 72 V LED LOAD.
Spot 1: Transformer (T1): 72.7 ºC.

Figure 21 – 120 VAC, 72 V LED LOAD.
Spot 1: Fusible Resistor (RF1): 55.7 ºC.

11.1.3 Bleeder Thermal Performance During Dimming Operation

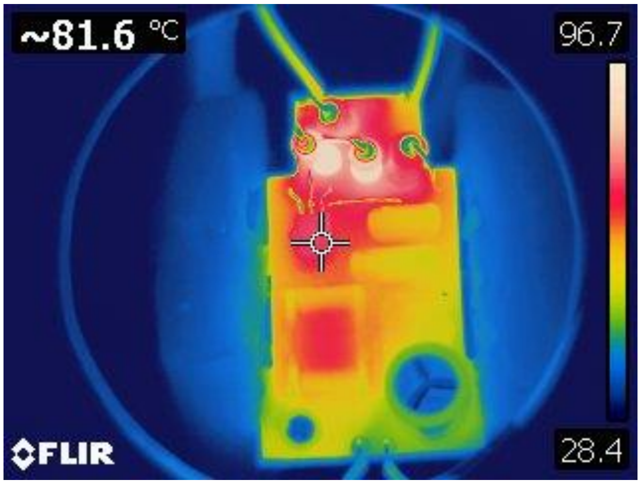

Figure 22 – 120 VAC, 72 V LED LOAD.
Spot 1: Bleeder Switch (Q1): 81.6 ºC.

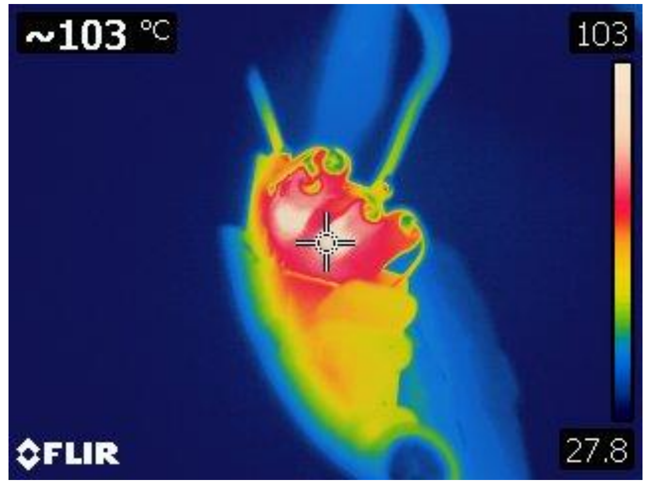

Figure 23 – 120 VAC, 72 V LED LOAD.
Spot 1: Bleeder Resistor (R27): 103 ºC.

11.1.4 Damper Thermal Performance During Dimming Operation

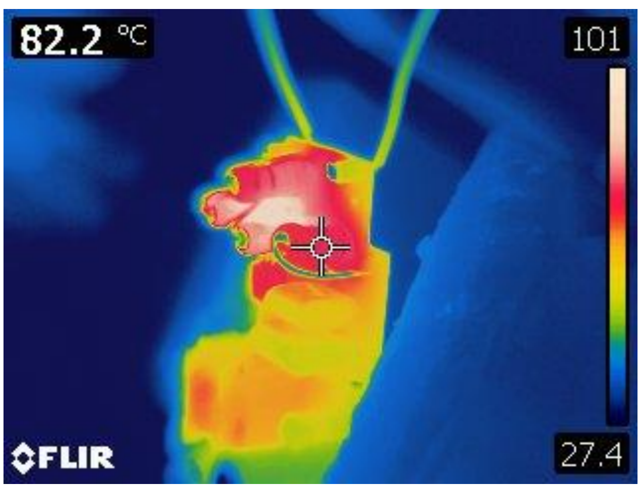

Figure 24 – 120 VAC, 72 V LED LOAD.
Spot 1: Damper Resistor (R7): 82.2 ºC.

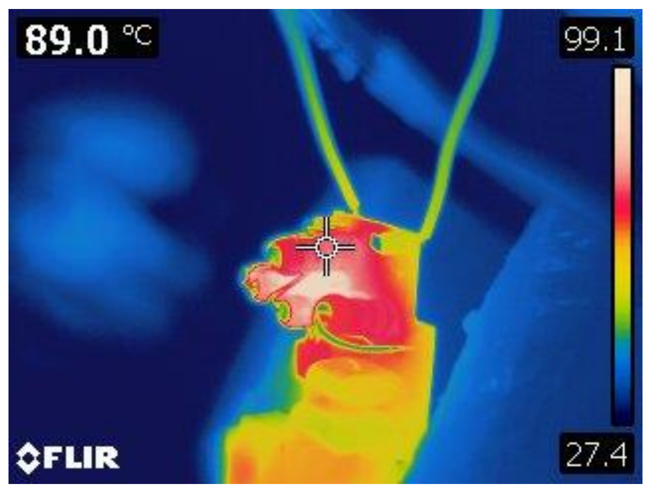

Figure 25 – 120 VAC, 72 V LED LOAD
Spot 1: Fusible Resistor (RF1): 89 ºC.

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11.2 Thermal Performance Using A19 Type LED Lamp

Thermal measurements were performed at 25 ºC room temperature using a 72 V A19 system LED bulb.

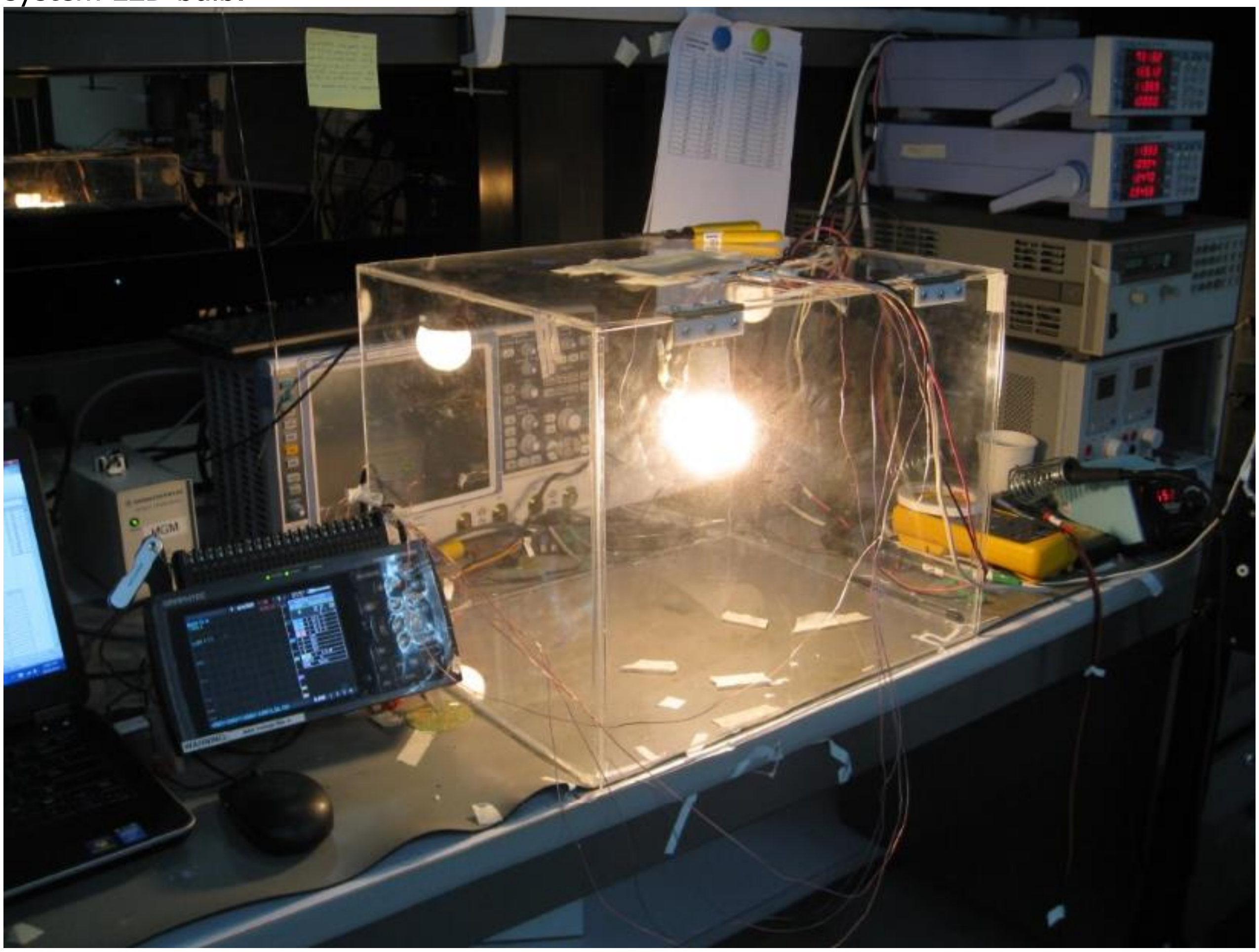

Figure 26 – Thermal Test Set-up Picture at 25 ºC Ambient.

Unit was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using a type T thermocouple wires.

11.2.1 Non-Dimming Thermal Performance at 120 VAC, 60 Hz

LED driver was burned in using A19 LED lamp for 5 hours.

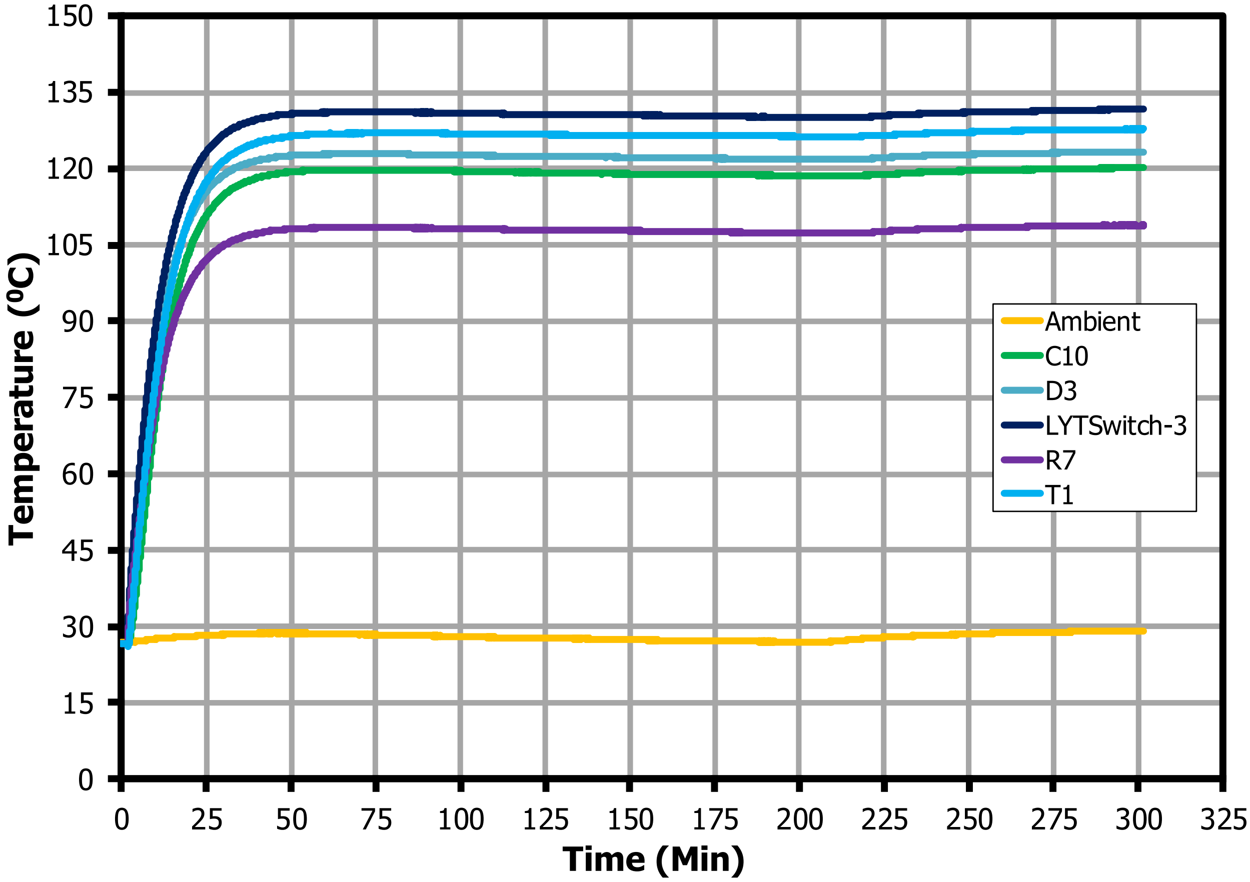

Figure 27 – Thermal Test during Non-Dimming at 120 VAC, 60 Hz.

Thermal Measurement	LYTSwitch-3 IC (ºC)	T1 (ºC)	C10 (ºC)	D3 (ºC)	R7 (ºC)	Ambient (ºC)
Maximum	131.6	127.8	120.1	123.3	108.9	29.1
Normalized	131.6	127.8	120.1	123.3	108.8	29.1

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11.2.2 Dimming Thermal Performance at 120 VAC with a 72 V LED Load

Set-up: LED driver was powered up with dimmer (LUTRON N-600-WH) at full conduction using A19 LED lamp at 26 ºC Ambient, input voltage is 120 VAC, 60 Hz (Agilent AC source).

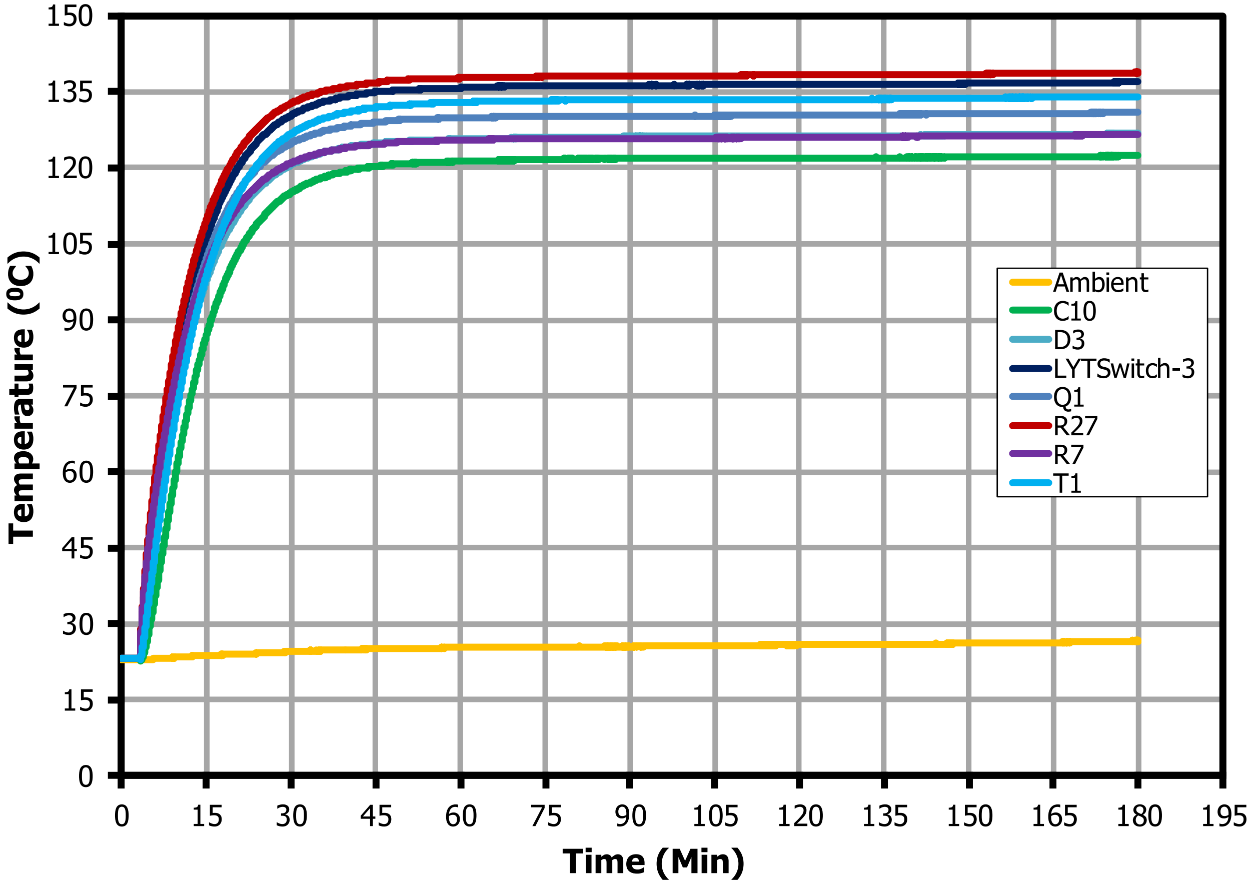

Figure 28 – Thermal Test during Dimming at 120 VAC, 60 Hz.

Thermal Measurement	LYTSwitch-3 IC (ºC)	T1 (ºC)	C10 (ºC)	D3 (ºC)	R7 (ºC)	Ambient (ºC)	Q1 (ºC)	R27 (ºC)
Maximum	137.0	134.1	122.5	126.8	126.6	26.7	131.0	138.9
Normalized	137.0	134.1	122.4	126.8	126.6	26.7	131	138.8

11.3 Lumen Test

The LED driver using A19 LED bulb was burned in for 5 hours at 25 ºC ambient temperature. The unit was placed inside acrylic plastic enclosure to prevent airflow.

11.3.1 Output Current Drift Measurement

Output current drifted by <5% based from initial measured output LED current.

Status	Output LED Current (mA)
Start	155.64
Finish	148.01
% Drift	4.902

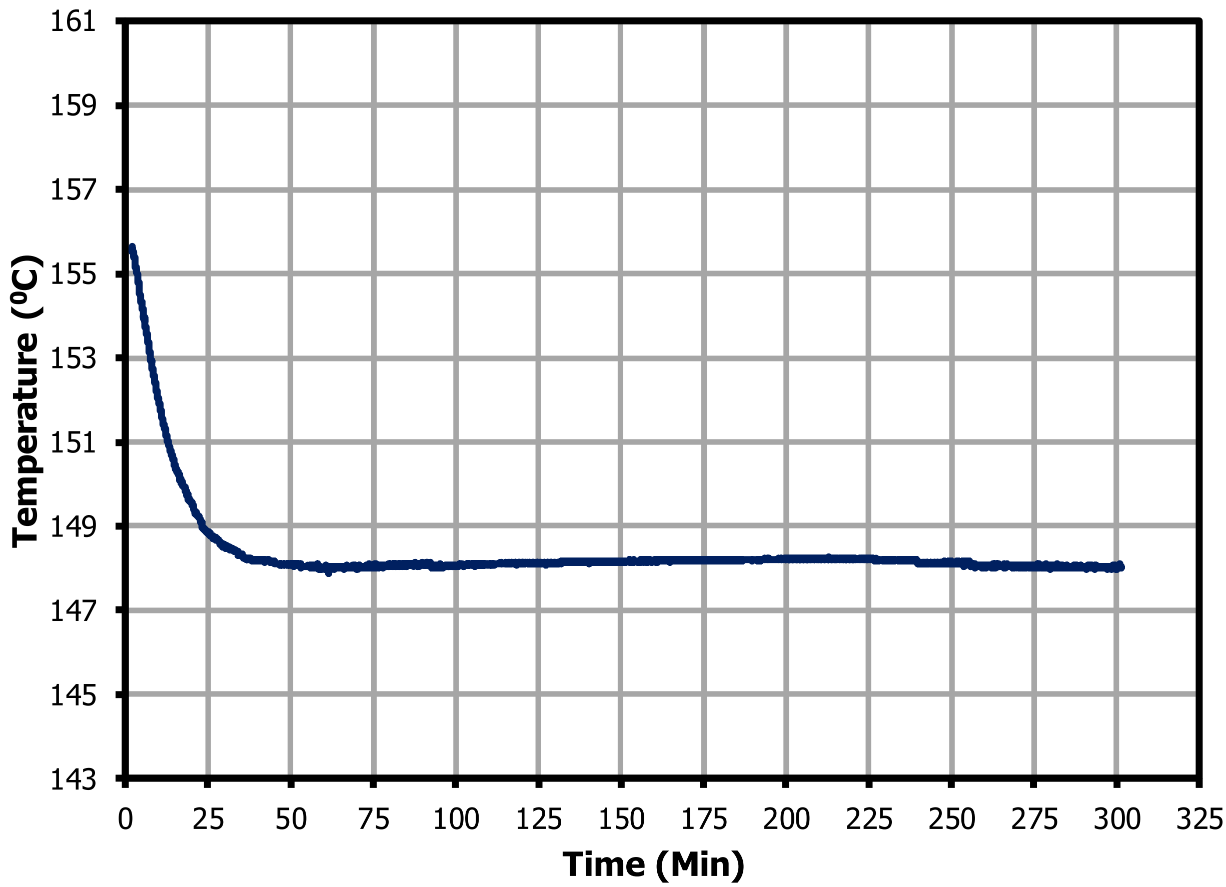

Figure 29 – Output Current Drift Plot at 120 VAC, 60 Hz.

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12 Waveforms

12.1 Input Voltage and Input Current Waveforms

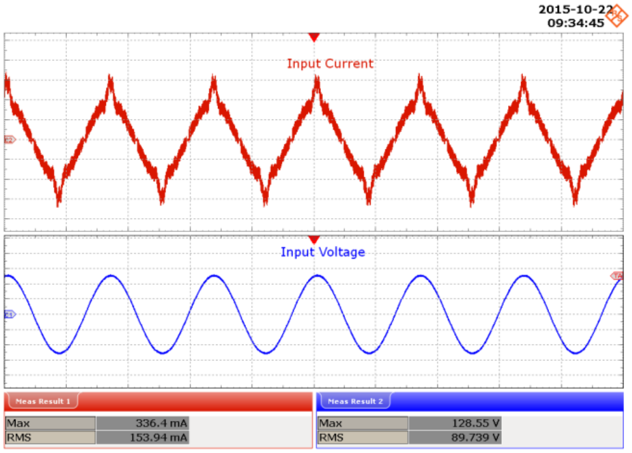

Figure 30 – 90 VAC, 72 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

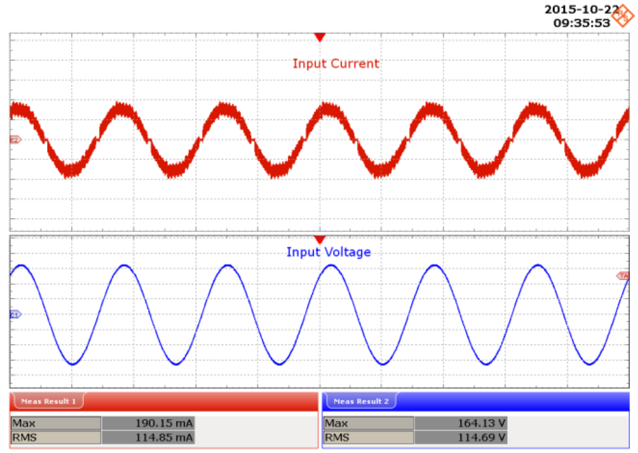

Figure 31 – 115 VAC, 72 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

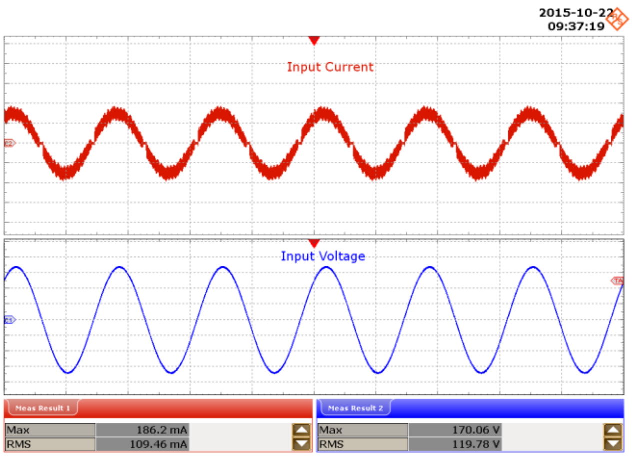

Figure 32 – 120 VAC, 72 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

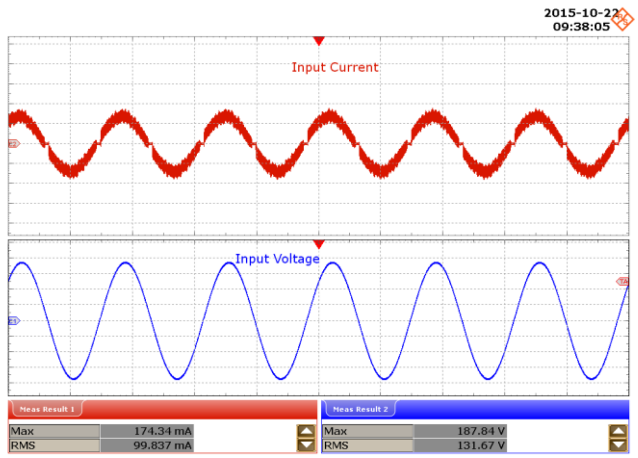

Figure 33 – 132 VAC, 72 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

12.2 Output Current Rise and Fall

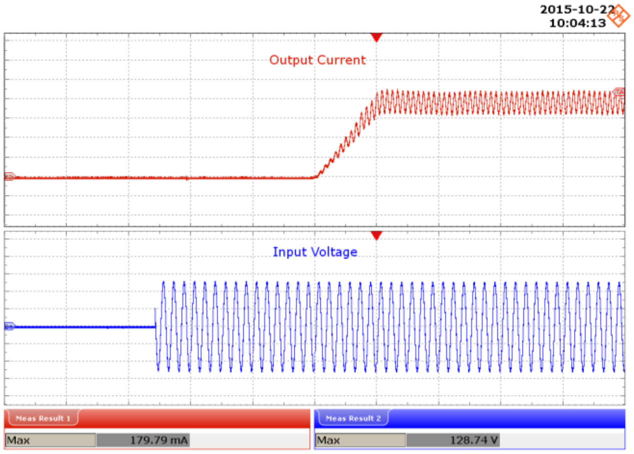

Figure 34 – 90 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

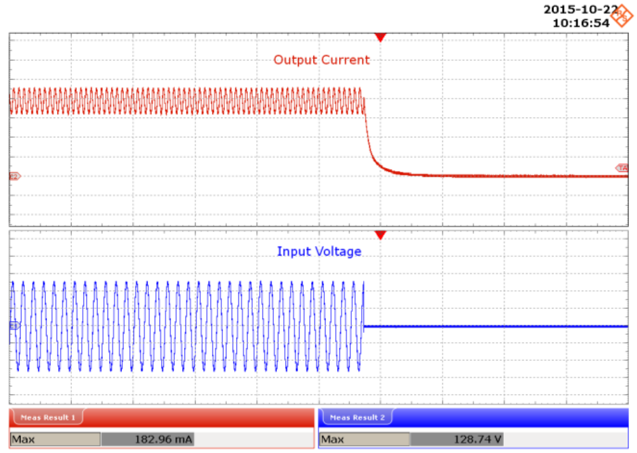

Figure 35 – 90 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

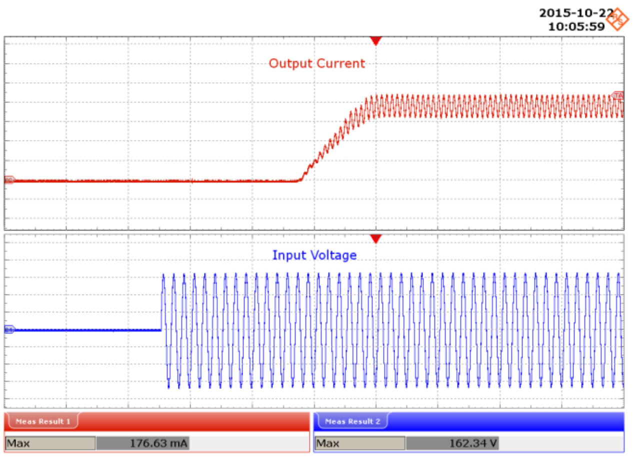

Figure 36 – 115 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

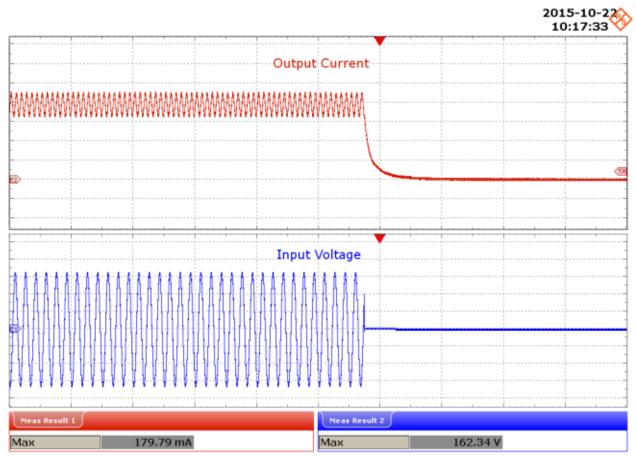

Figure 37 – 115 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

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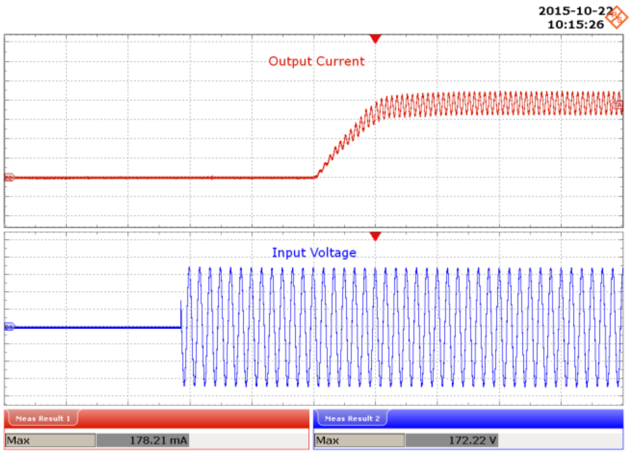

Figure 38 – 120 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

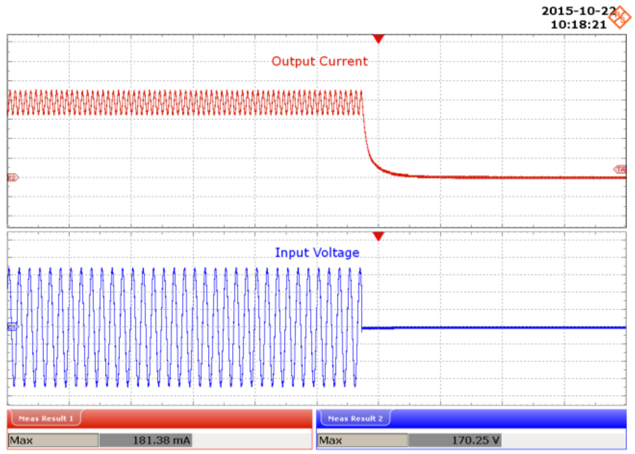

Figure 39 – 120 VAC, 72 V LED Load, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

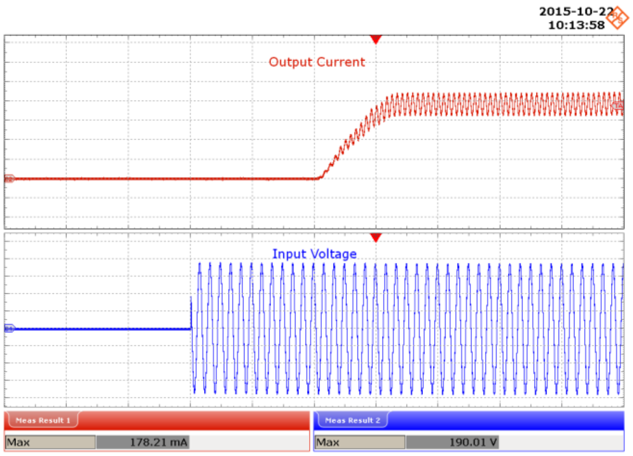

Figure 40 – 132 VAC, 72 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

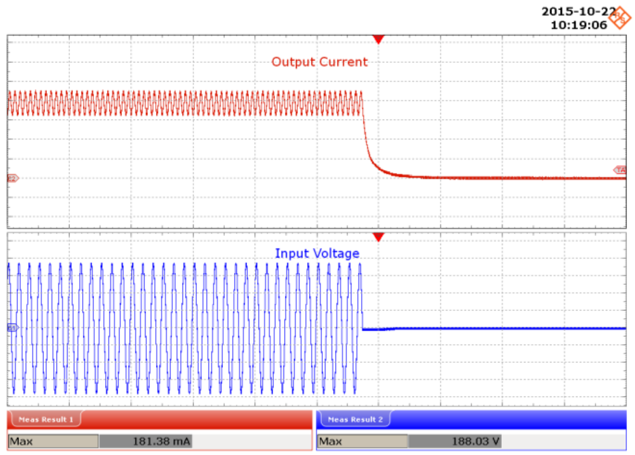

Figure 41 – 132 VAC, 72 V LED Load, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

12.3 Drain Voltage and Current in Normal Operation

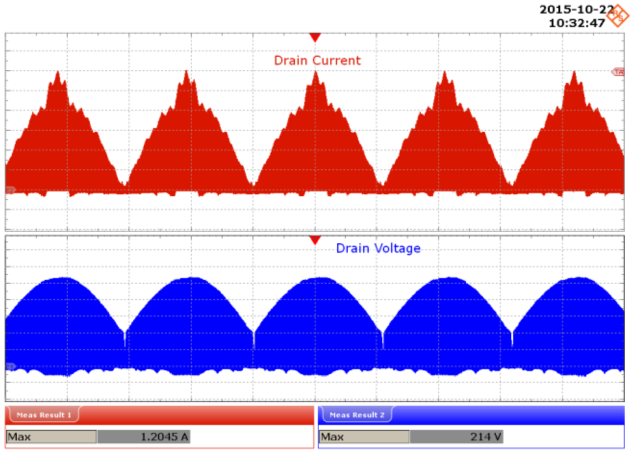

Figure 42 – 90 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

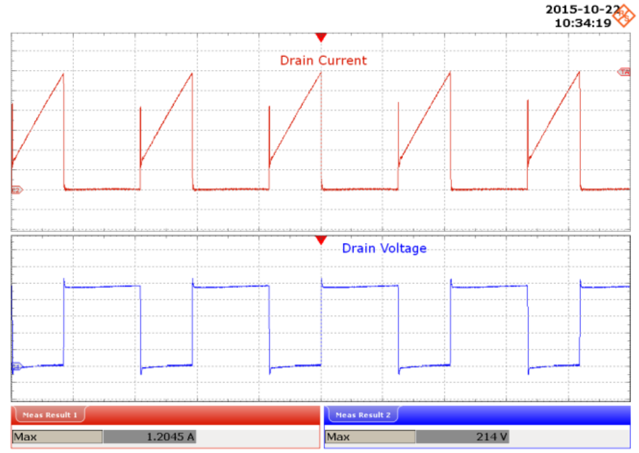

Figure 43 – 90 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 µs / div.

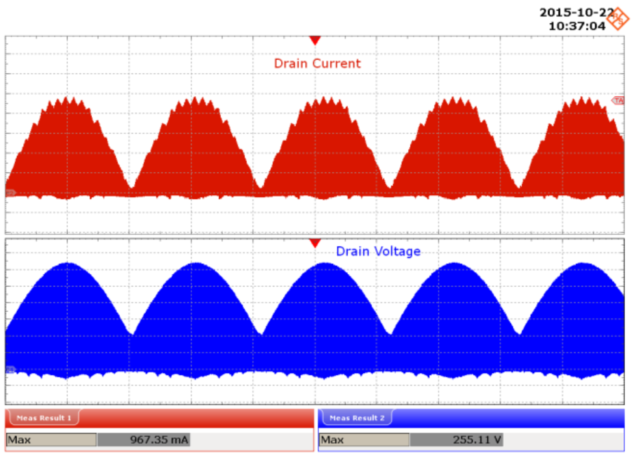

Figure 44 – 115 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

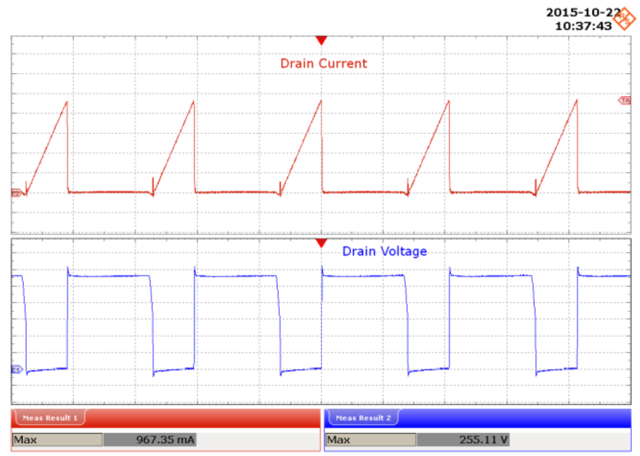

Figure 45 – 115 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 µs / div.

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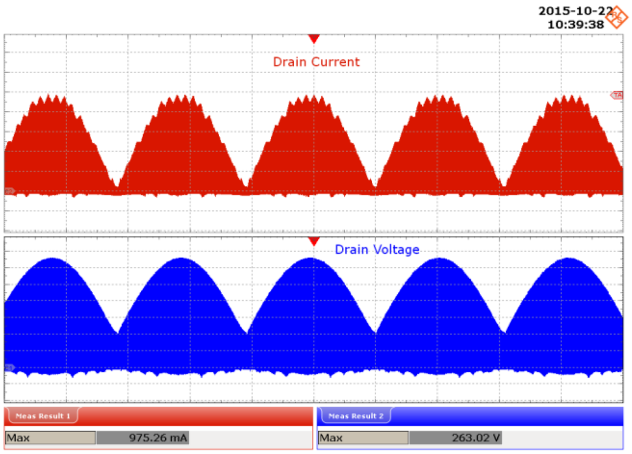

Figure 46 – 120 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

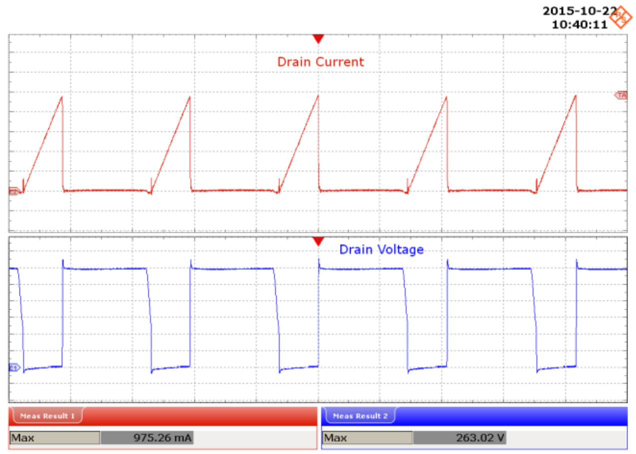

Figure 47 – 120 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

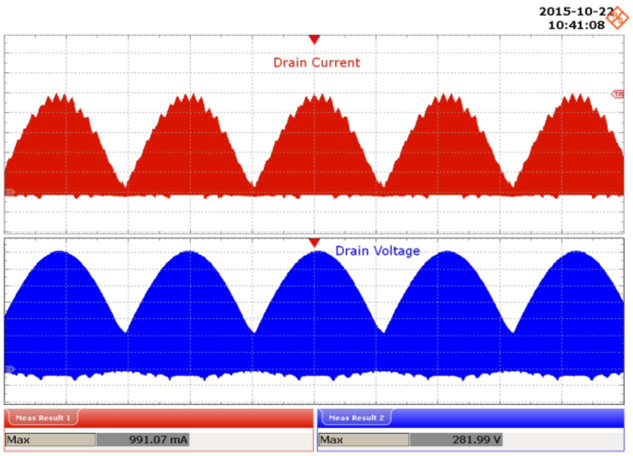

Figure 48 – 132 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

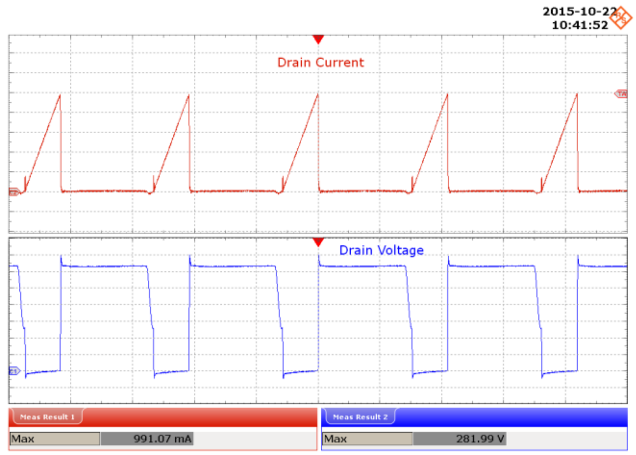

Figure 49 – 132 VAC, 72 V LED Load
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

12.4 Drain Voltage and Current Start-up Profile

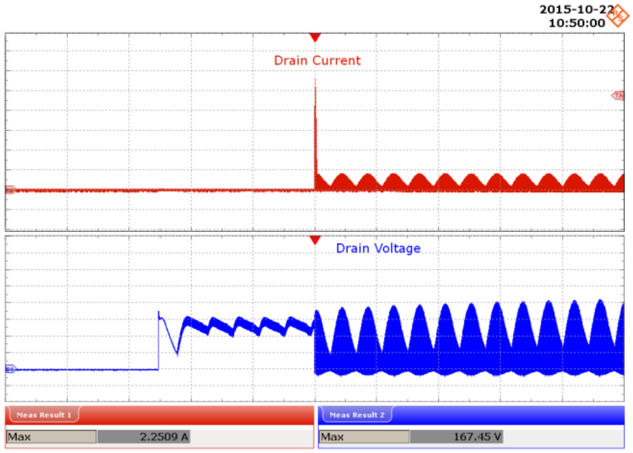

Figure 50 – 90 VAC, 72 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

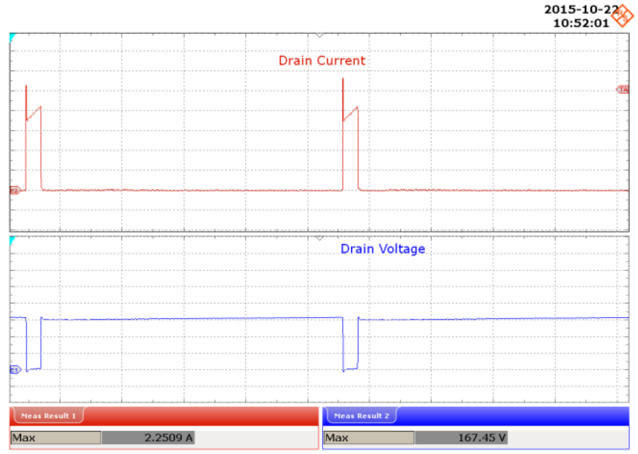

Figure 51 – 90 VAC, 72 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

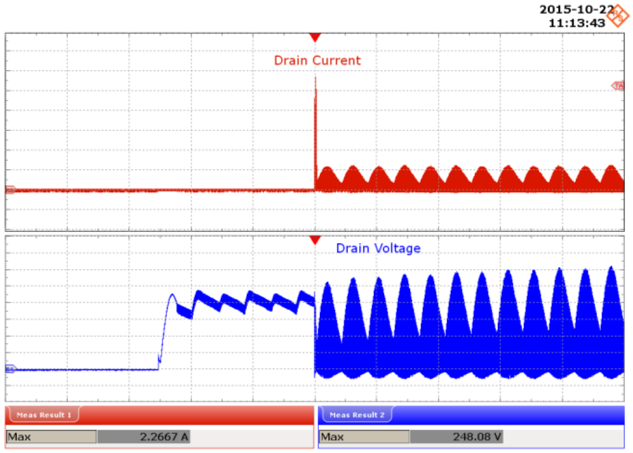

Figure 52 – 132 VAC, 72 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

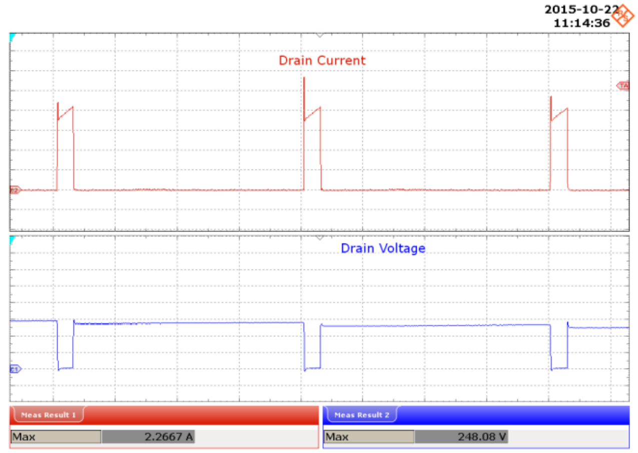

Figure 53 – 132 VAC, 72 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

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12.5 Drain Voltage and Current during Output Short-Circuit Condition

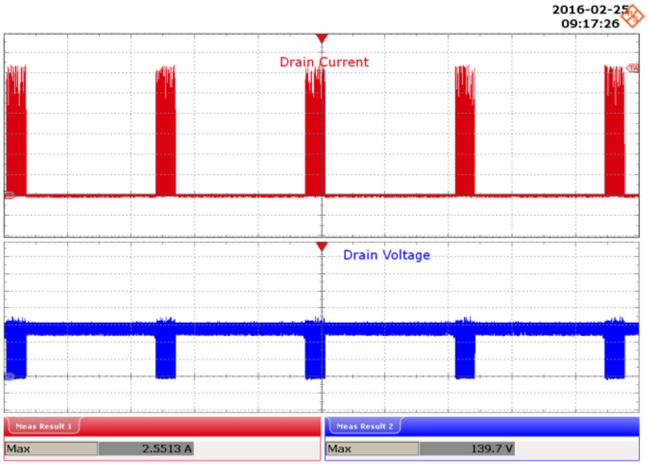

Figure 54 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1s / div.

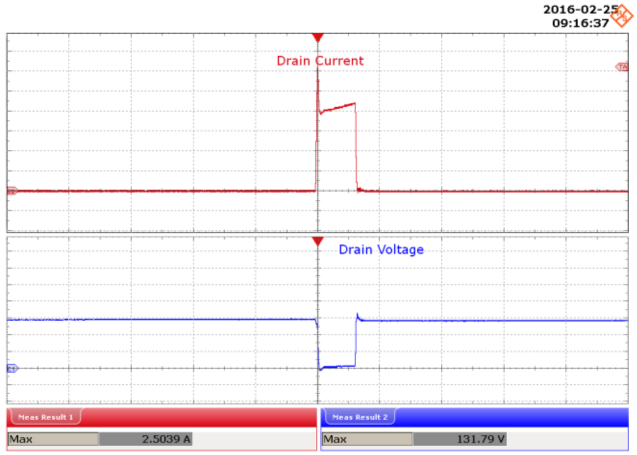

Figure 55 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 μs / div.

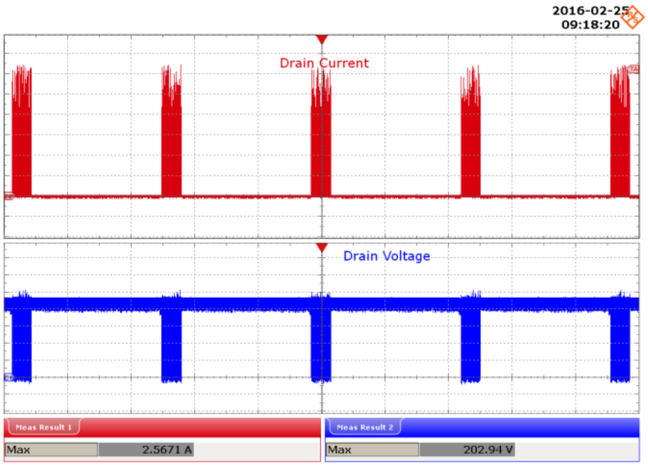

Figure 56 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1s / div.

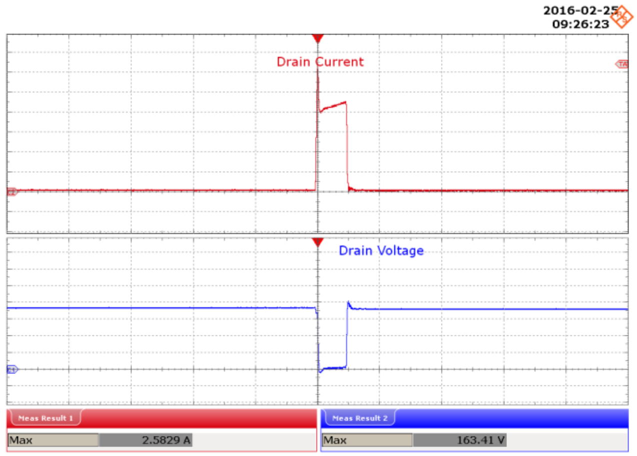

Figure 57 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 μs / div.

12.5.1 Output Voltage and Current – Open LED Load

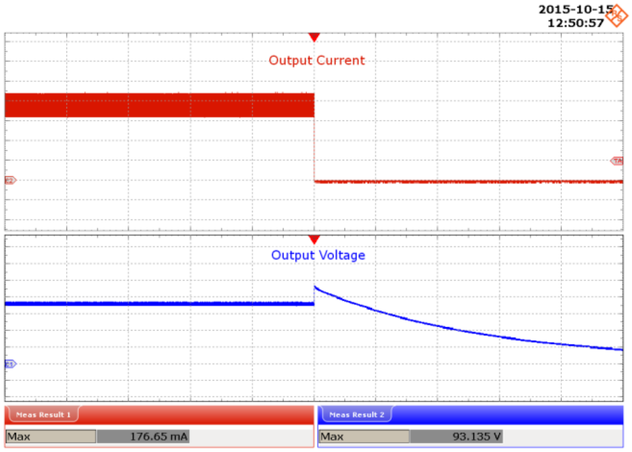

Figure 58 – 90 VAC, 72 V LED Load, Running Open Load. Upper: I_{OUT}, 40 mA / div. Lower: V_{OUT}, 20 V / div., 4 s / div.

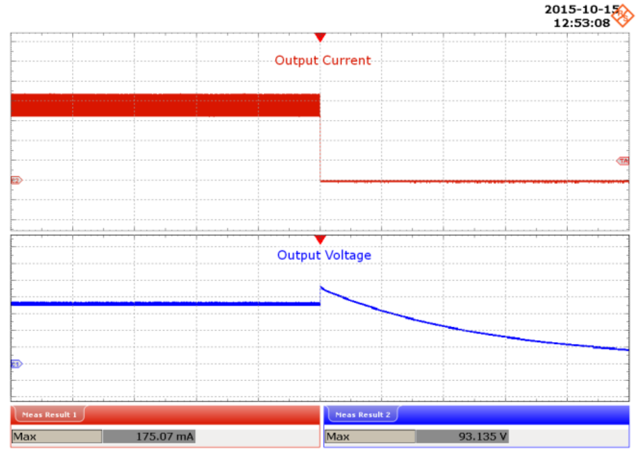

Figure 59 – 132 VAC, 72 V LED Load, Running Open Load. Upper: I_{OUT}, 40 mA / div. Lower: V_{OUT}, 20 V / div., 4 s / div.

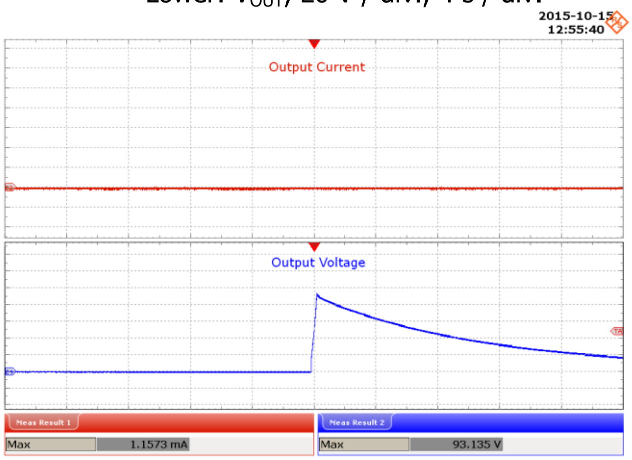

Figure 60 – 90 VAC, 72 V LED Load, Open Load Start-up. Upper: I_{OUT}, 40 mA / div. Lower: V_{OUT}, 20 V / div., 4 s / div.

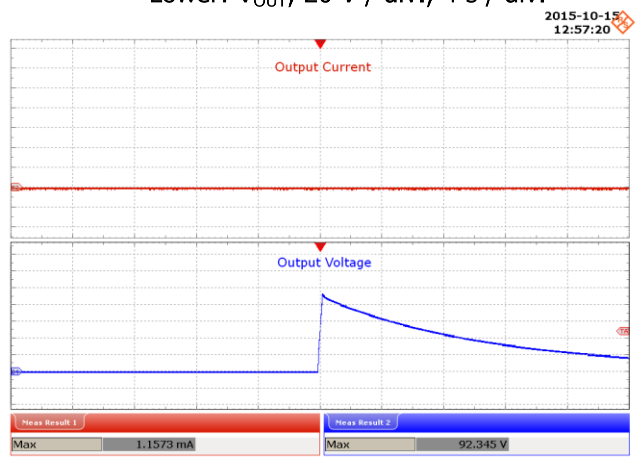

Figure 61 – 132 VAC, 72 V LED Load, Open Load Start-up. Upper: I_{OUT}, 40 mA / div. Lower: V_{OUT}, 20 V / div., 4 s / div.

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12.6 Output Ripple Current

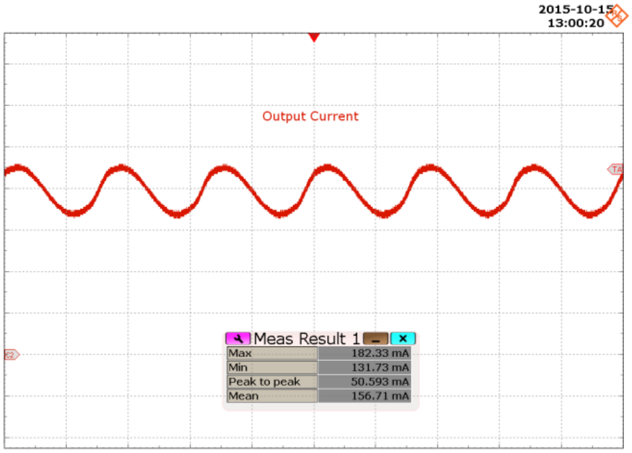

Figure 62 – 90 VAC, 60 Hz, 72 V LED Load.
Upper: I_{OUT}, 40 mA / div., 5 ms / div.

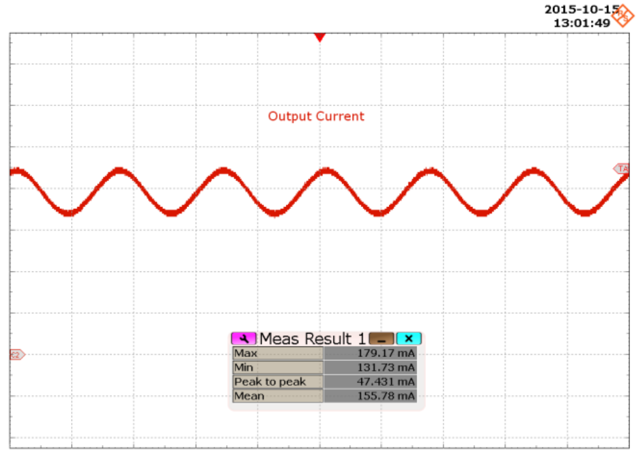

Figure 63 – 115 VAC, 60 Hz, 72 V LED Load.
Upper: I_{OUT}, 40 mA / div., 5 ms / div

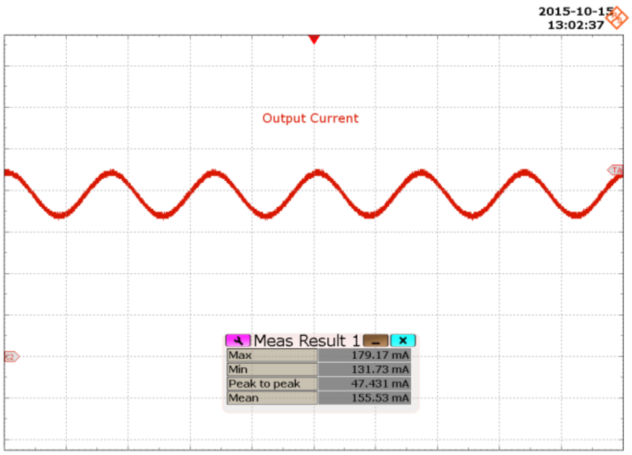

Figure 64 – 120 VAC, 60 Hz, 72 V LED Load.
Upper: I_{OUT}, 40 mA / div., 5 ms / div

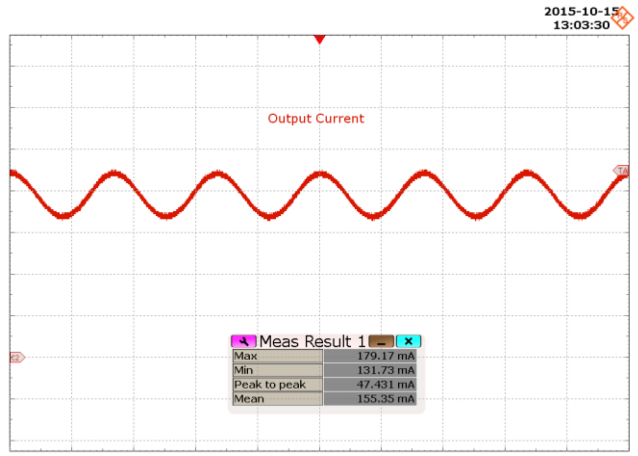

Figure 65 – 132 VAC, 60 Hz, 72 V LED Load.
Upper: I_{OUT}, 40 mA / div., 5 ms / div

V_{IN}	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN}	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}+I_{O(MIN)}$)
90 VAC	182.33	131.73	156.71	0.32	16.11
115VAC	179.17	131.73	155.78	0.30	15.26
120 VAC	179.17	131.73	155.53	0.31	15.26
132 VAC	179.17	131.73	155.35	0.31	15.26

13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 72 V LED load
Dimmer: Leviton 6681

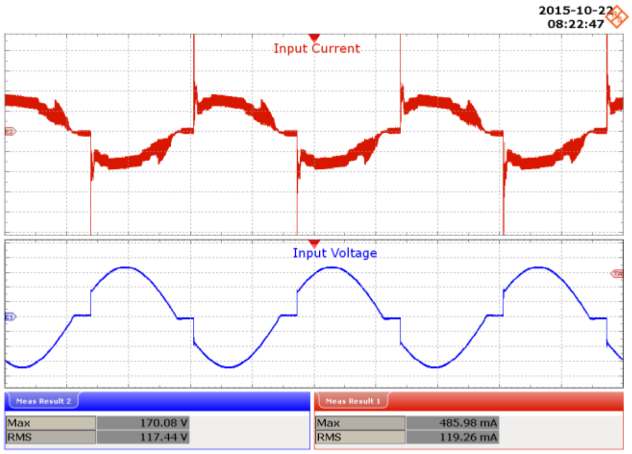

Figure 66 – 150º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

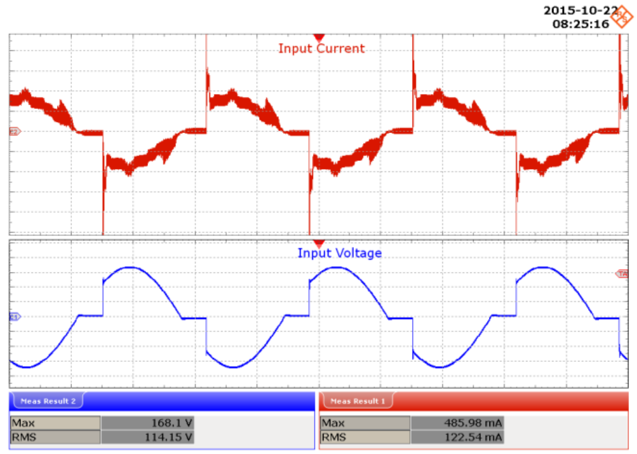

Figure 67 – 120º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

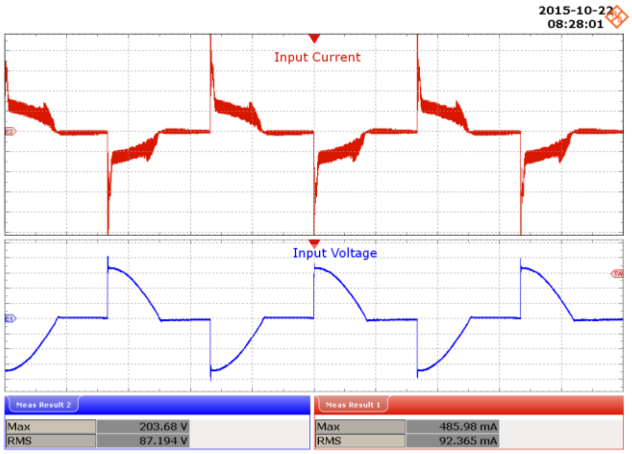

Figure 68 – 90º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

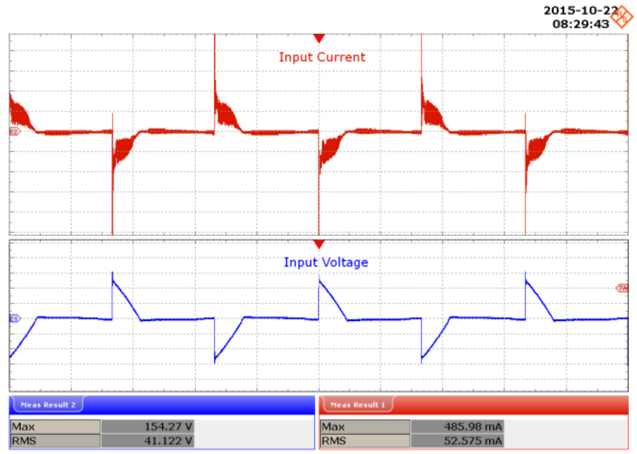

Figure 69 – 50º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

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13.2 Output Current Waveforms – Leading Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 72 V LED load
Dimmer: Leviton 6681

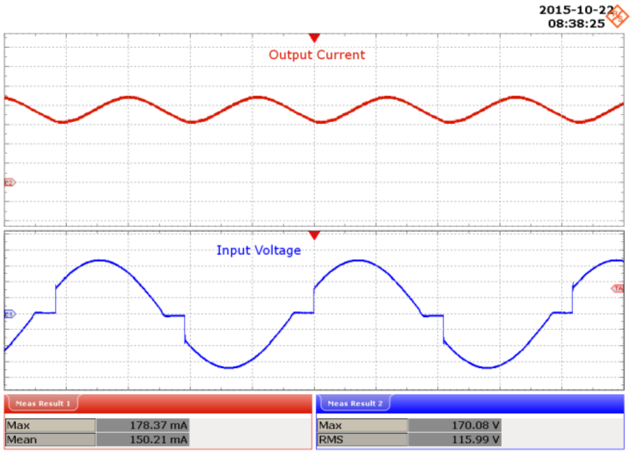

Figure 70 – 150º Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

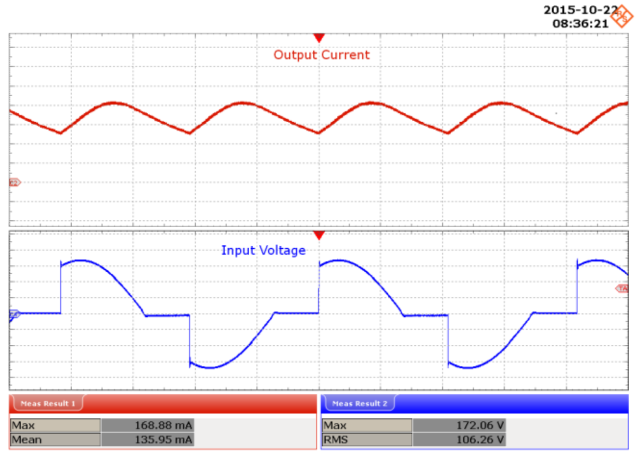

Figure 71 – 120º Conduction Angle.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

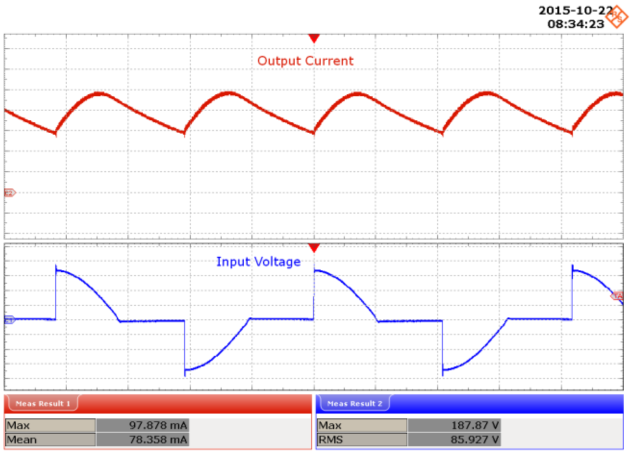

Figure 72 – 90º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

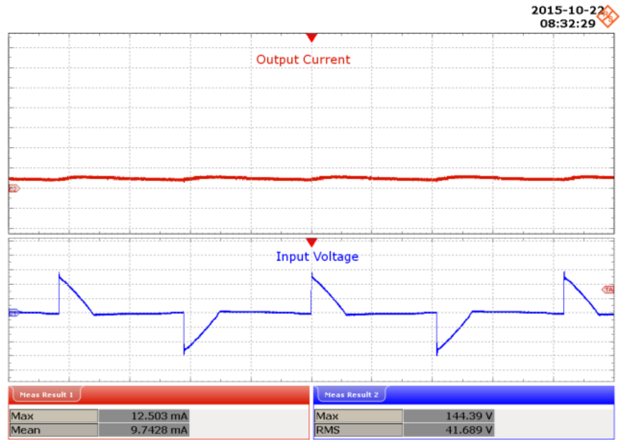

Figure 73 – 50º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

13.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 72 V LED Load
Dimmer: Lutron DVELV-300P-WH

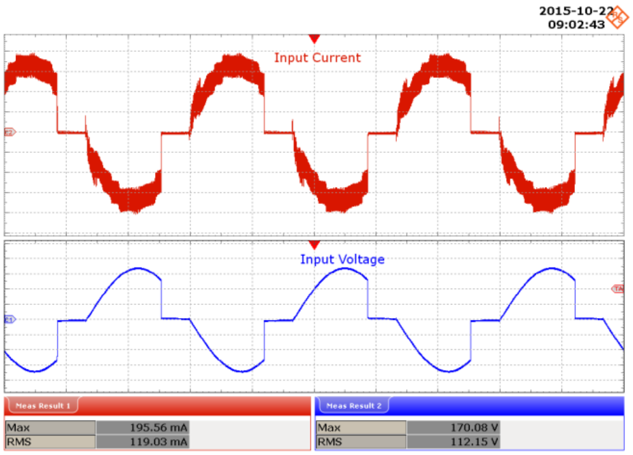

Figure 74 – 130º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

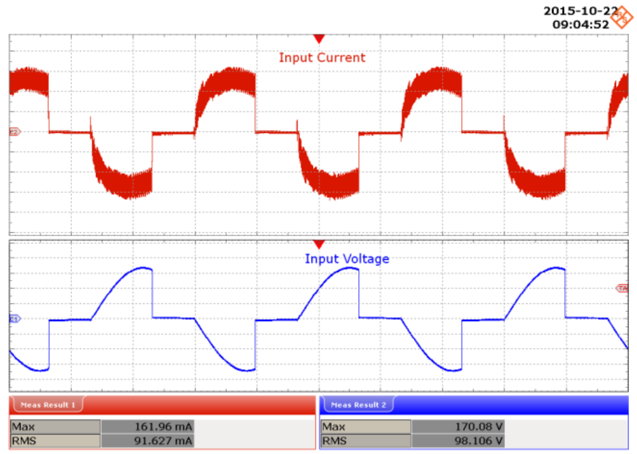

Figure 75 – 105º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

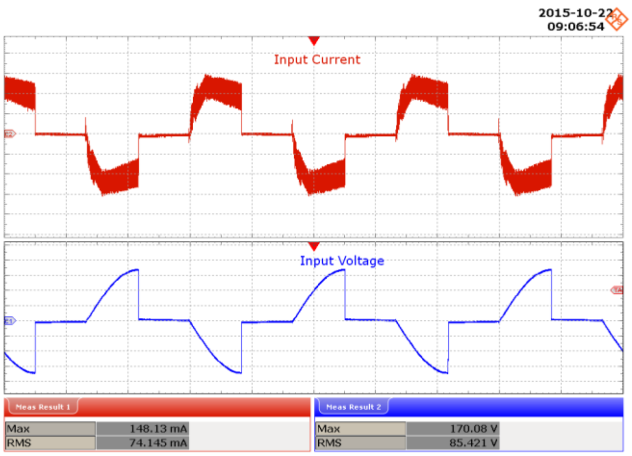

Figure 76 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

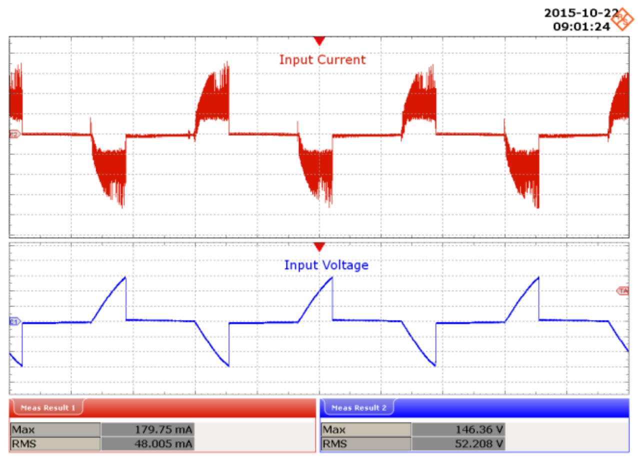

Figure 77 – 60º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

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13.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 72 V LED load
Dimmer: LUTRON DVELV-300P-WH

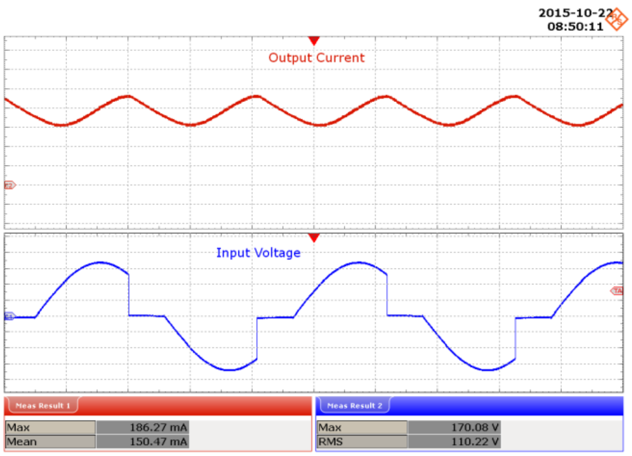

Figure 78 – 130º Conduction Angle.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

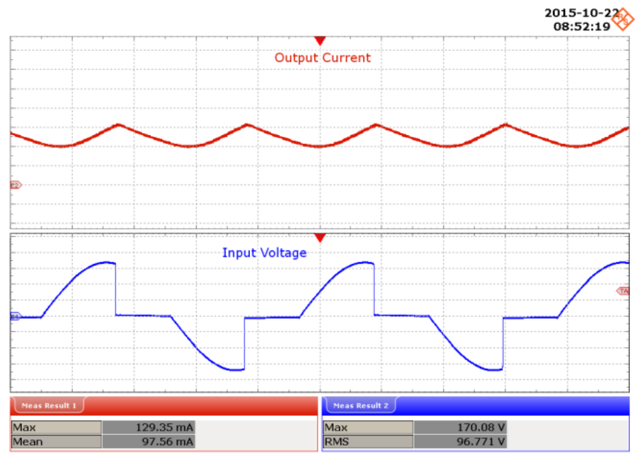

Figure 79 – 105º Conduction Angle.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

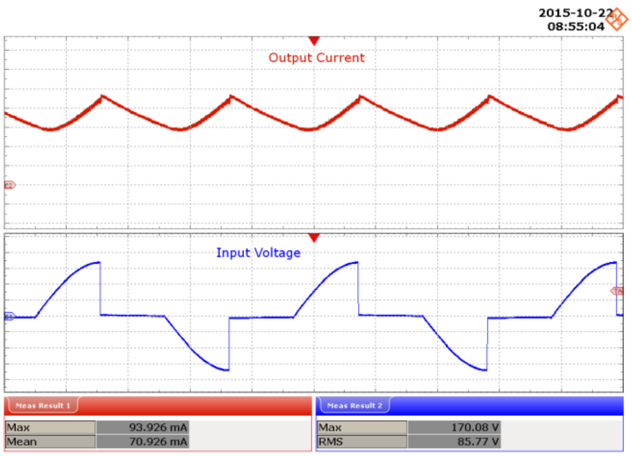

Figure 80 – 90º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

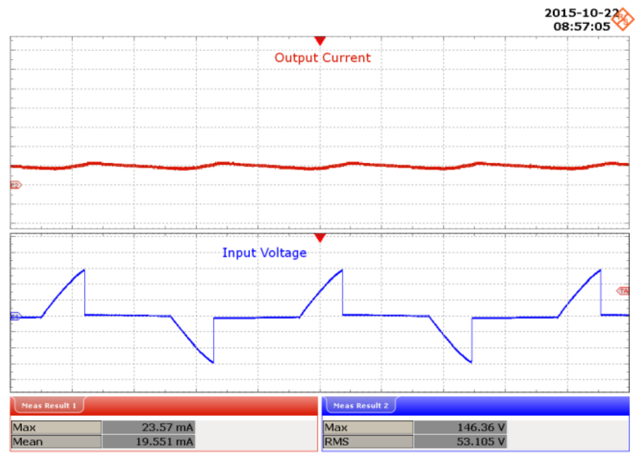

Figure 81 – 60º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

14 AC Cycling Test

No output current overshoot was observed during on - off cycling.

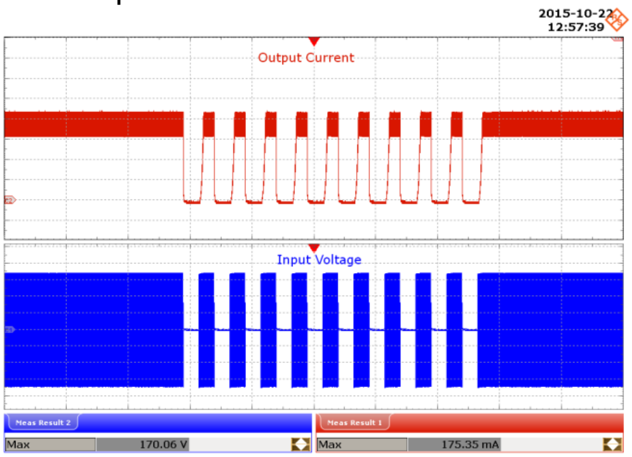

Figure 82 – 120 VAC, 72 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

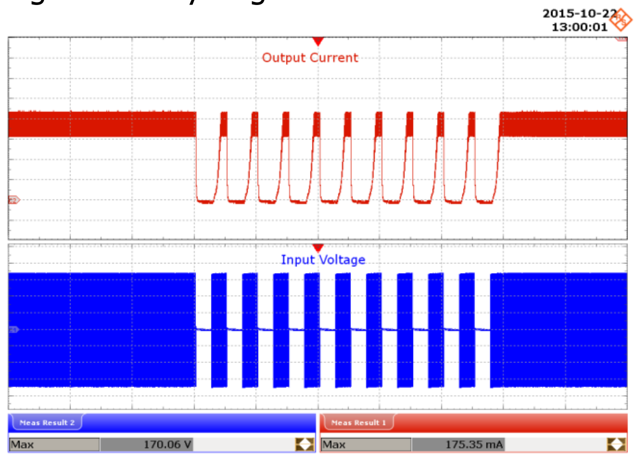

Figure 83 – 120 VAC, 72 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

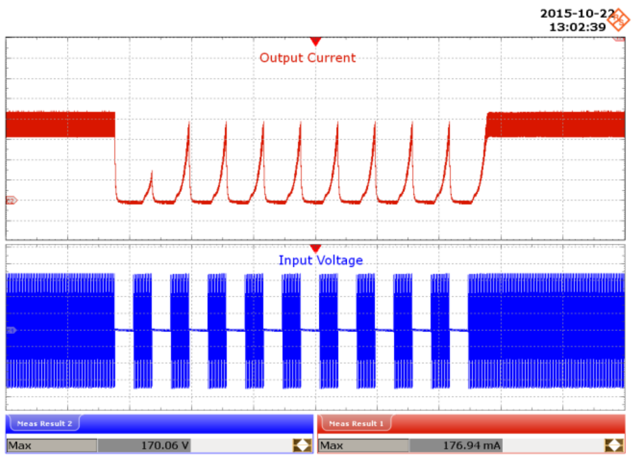

Figure 84 – 120 VAC, 72 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

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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.
5. 72 V LED load with input voltage set at 115 VAC.

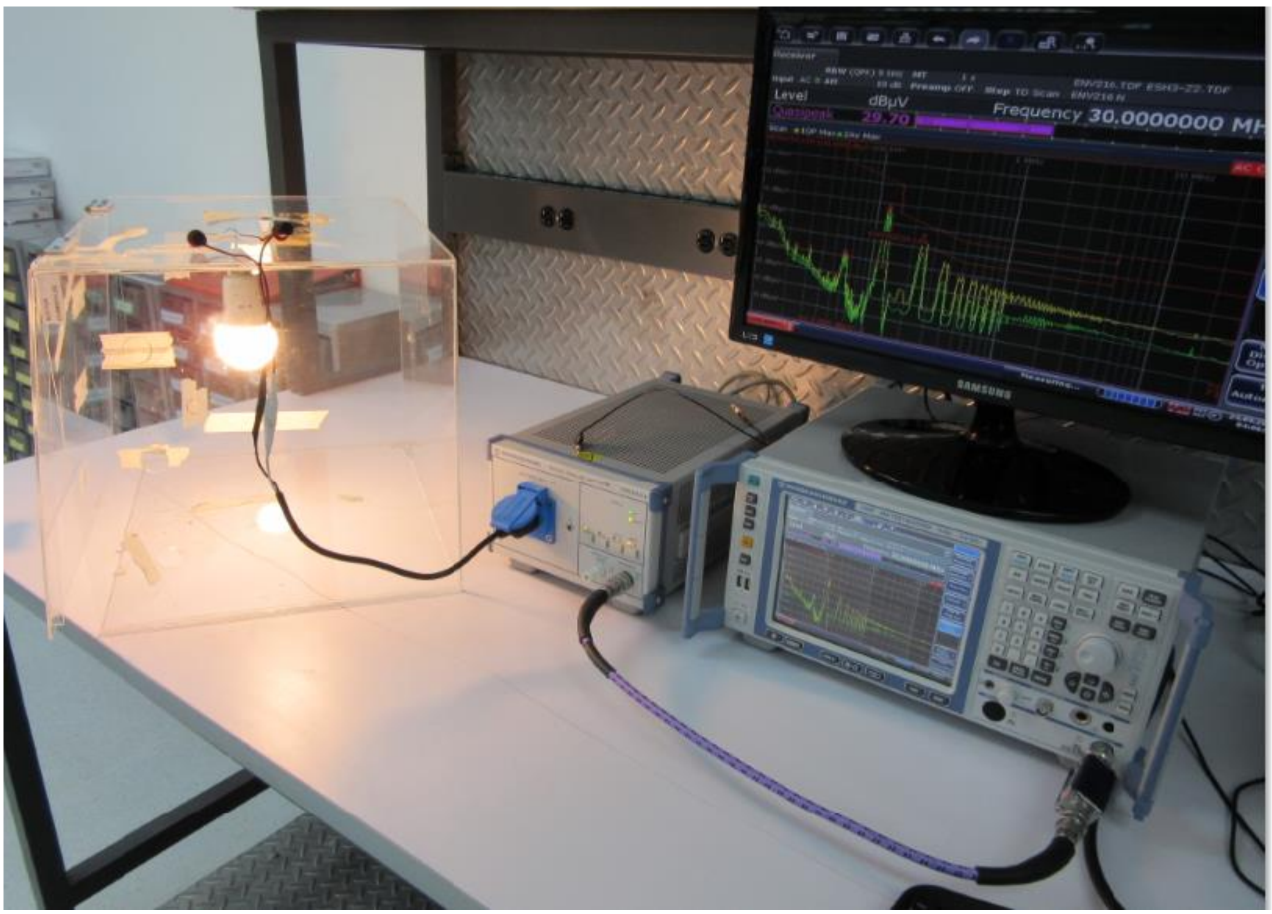

Figure 85 – Conducted EMI Test Set-up.

15.2 EMI Test Result

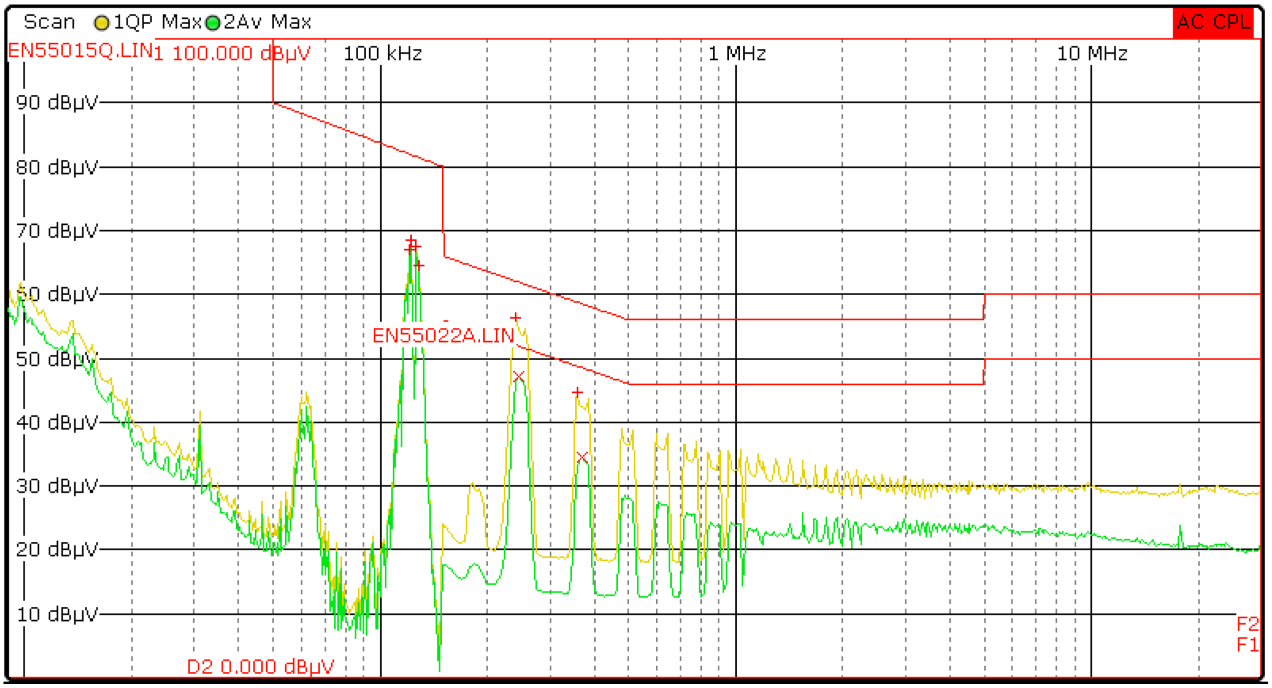

Figure 86 – Conducted EMI, 72 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	120.3500 kHz	66.91 N	-15.09 dB
1 Quasi Peak	122.3000 kHz	68.43 N	-13.43 dB
1 Quasi Peak	126.2000 kHz	67.43 N	-14.14 dB
1 Quasi Peak	128.1500 kHz	64.60 N	-16.83 dB
1 Quasi Peak	240.0000 kHz	56.31 N	-5.79 dB
2 Average	244.5000 kHz	47.03 N	-4.91 dB
1 Quasi Peak	359.2500 kHz	44.63 L1	-14.12 dB
2 Average	370.5000 kHz	34.47 N	-14.02 dB

Figure 87 – Conducted EMI at Line 1 and Neutral Line, 72 V LED Load, Final Measurement Results.

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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

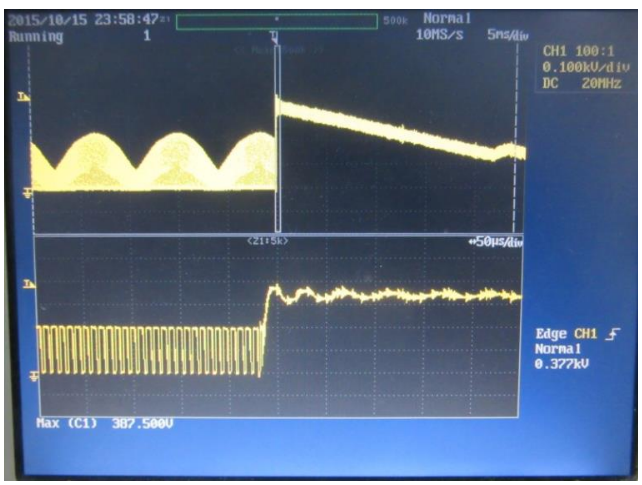

Figure 88 – +1000 kV Differential Surge, 90 °C Phase.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.
Peak V_{DRAIN}: 387.5 V.

17 Brown-in / Brown-out Test

No failure of any component was seen during brownout test of 0.5 V / sec AC cut-in and cut-off.

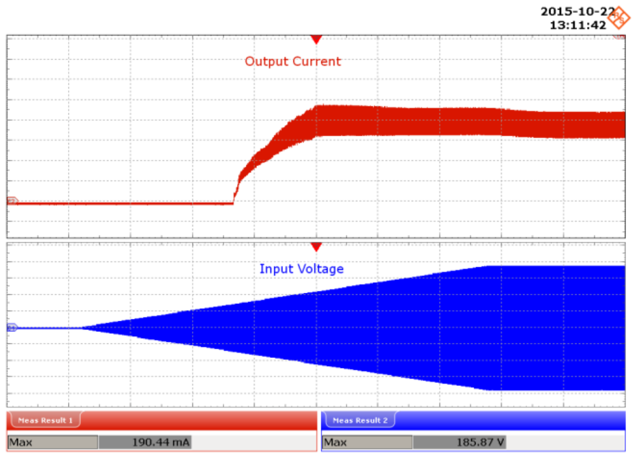

Figure 89 – Brown-in Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch1: V_{IN}, 50 V / div.
Ch2: I_{OUT}, 40 mA / div.
Time Scale: 40 s / div.

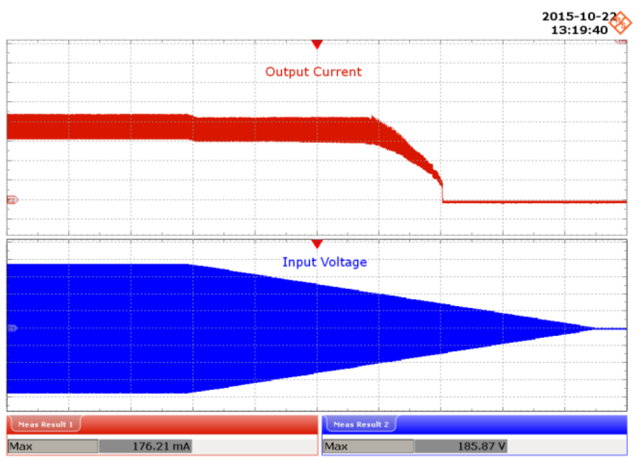

Figure 90 – Brown-out Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch1: V_{IN}, 50 V / div.
Ch2: I_{OUT}, 40 mA / div.
Time Scale: 40 s / div.

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18 Revision History

Date	Author	Revision	Description and Changes	Reviewed
01-Mar-16	MGM	1.0	Initial release	Apps & Mktg

For the latest updates, visit our website: www.power.com

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