Design Example Report

Title	***16.75 W Non-Dimmable, High Efficiency (>91%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1604D***
Specification	90 VAC – 132 VAC Input; 67 V_{TYP}, 250 mA_{TYP} Output
Application	Tube End
Author	Applications Engineering Department
Document Number	DER-541
Date	June 8, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <30% flicker percent requirement
- Highly energy efficient, >91% at 115 V
- Low cost and low component count for compact PCB solution
- Integrated Auto-restart protection features
  - No-load/ Open-load output
  - Output short-circuit
  - Line Surge or Line Over voltage
- Thermal foldback for power reduction
- Over Temperature Shutdown with hysteretic automatic power recovery
- No damage during line brown-out or brown-in conditions
- 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.

1 Introduction

This engineering report describes a low component count, non-isolated, non-dimmable LED driver in Buck topology, designed to drive a 67 V LED voltage string at 250 mA output current from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT1604D from the LYTSwitch-1 family of devices.

LYTSwitch-1 is a SO-8 package LED driver controller IC designed for non-isolated buck topology applications. The LYTSwitch-1 provides high efficiency, high power factor and accurate LED current regulation. LYTSwitch-1 incorporates a high-voltage power MOSFET and Variable Frequency / Variable On-Time, Critical Conduction Mode Control Engine for tight current regulation, high power factor and proprietary FET 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-541 offers a compact size solution for 16.75 W LED drivers ideal for bulb and tube-end applications. The key design goals were high efficiency, accurate constant current regulation and low component count.

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

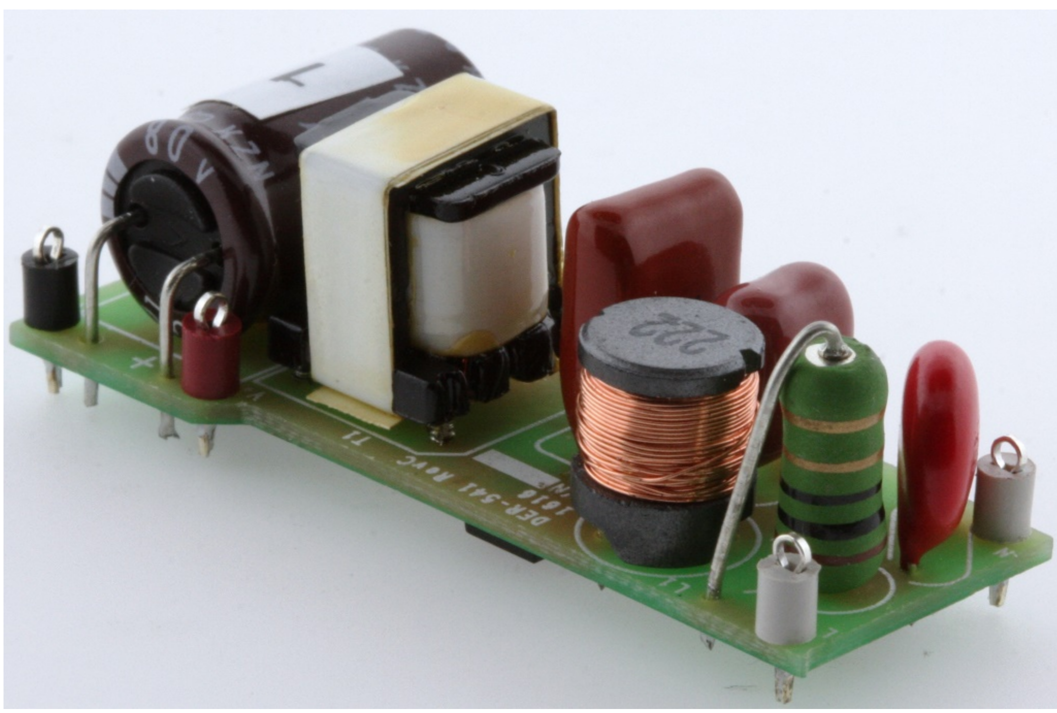

Figure 1 – Populated Circuit Board.

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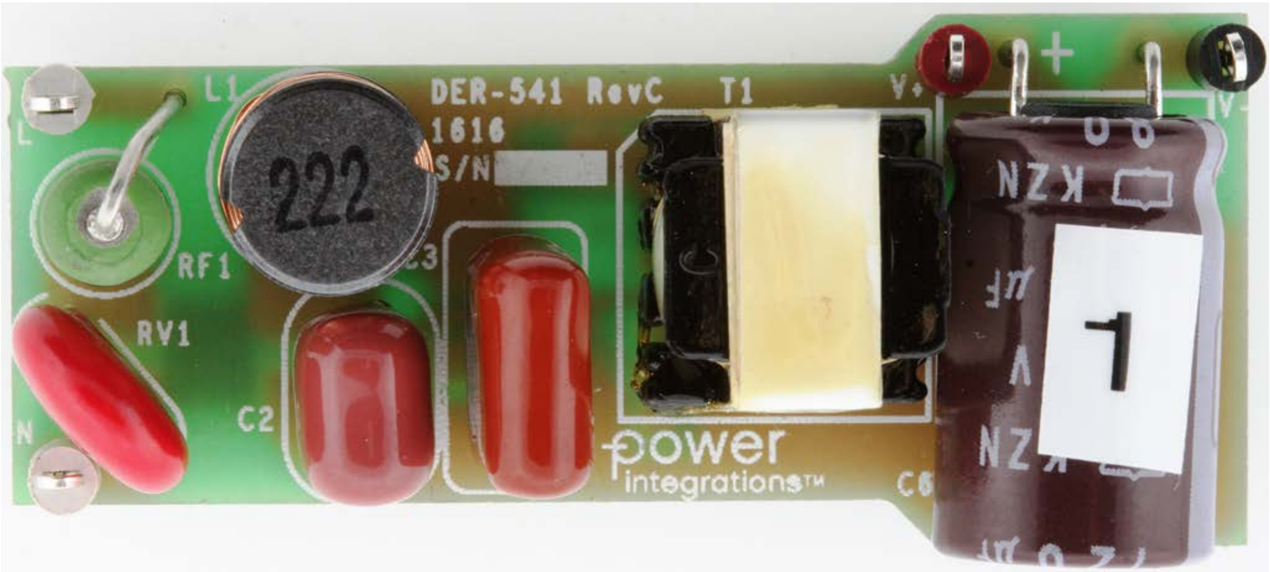

Figure 2 – Populated Circuit Board, Top View.

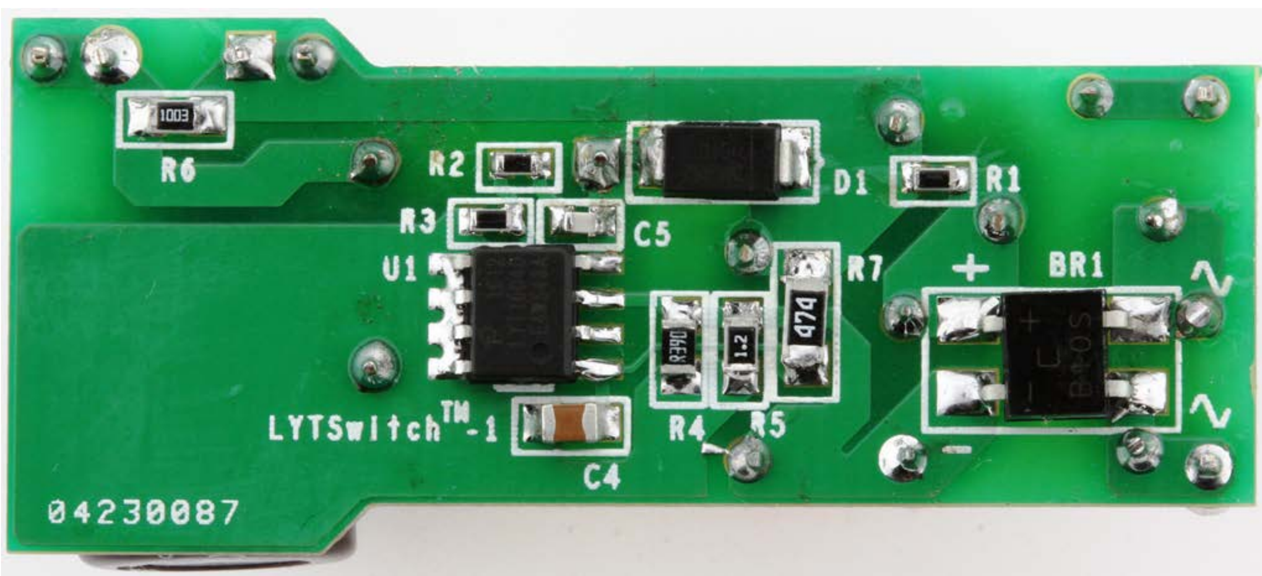

Figure 3 – Populated Circuit Board, Bottom View.

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}		67		V	
Output Current	I_{OUT}		250		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		16.75		W	
Efficiency						
Full Load	η		91		%	115 V / 50 Hz at 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 / 50 Hz.
Ambient Temperature	T_{AMB}		75		ºC	Free convection, sea level.

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3 Schematic

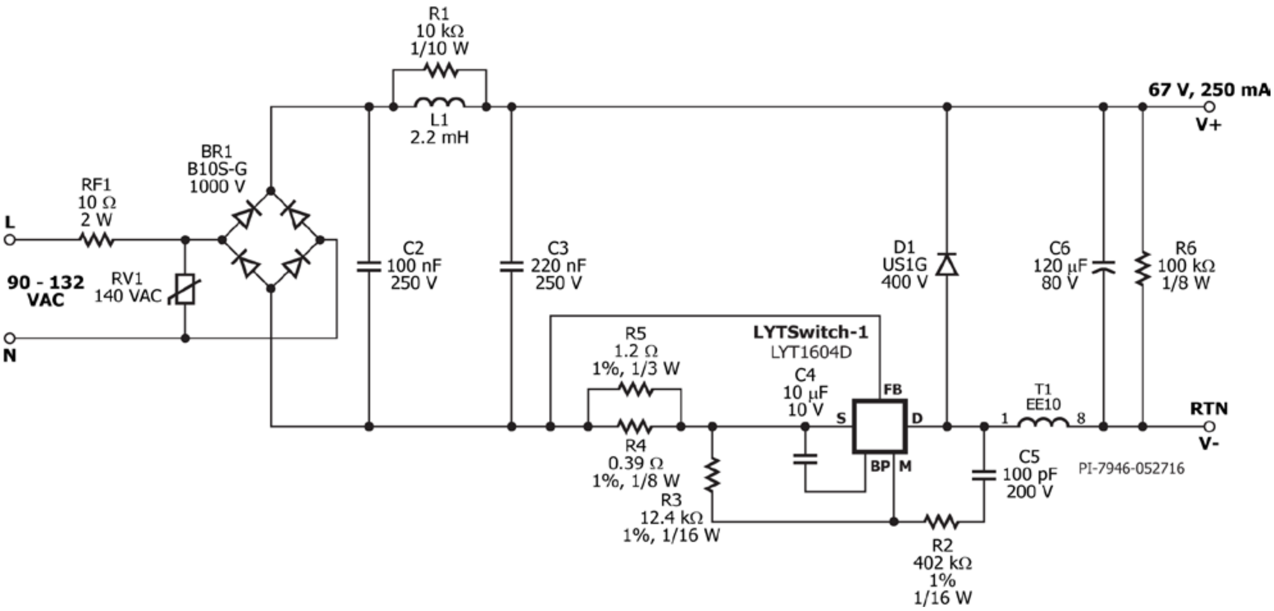

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-1 device (U1-LYT1604D) combines a high-voltage power FET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. LYT1604D is configured to drive a 67 V output non-isolated buck LED driver with 250 mA constant current output. The LYT1604D device was selected from the power table based on maximum output power (18 W for low line) in the datasheet.

4.1 *Input Stage*

The input fuse RF1 provides safety protection. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 140 V rated part was selected, being slightly above the maximum specified operating input voltage (132 V). The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD. For higher surge requirement such as > 1kV, C2 and L1 can be placed before the bridge rectifier BR1, but a safety X-capacitor is required for C2.

4.2 *EMI Filter*

Inductor L1 serves as differential choke. Inductor L1, C2 and C3 capacitors form as an emi pi filter which works to filter differential and common mode noise. Resistor R1 damps the resonance of L1 to make it more effective in blocking high frequency noise. LYTSwitch-1's variable frequency/on-time states and critical conduction code control engine limit 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-1 Control Circuit*

The LED driver circuit topology is a low side buck configuration, where the FET of U1 and the inductor L1 are connected to the ground rail. During the FET on time, current ramps through the inductor winding storing energy in the form of magnetic field which is then delivered to the output load via flywheel diode D1 during the FET off-time.

The output capacitor C6 provides output voltage ripple filtering to minimize the output ripple current. To avoid long ghosting effect of light output after power off, resistor R6 preload discharges the output capacitor voltage below the LED voltage.

Capacitor C4 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 charge the bypass capacitor C4 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 Vin < Vo, the value of capacitor should be large enough to keep the BP voltage above the $V_{BP\ (RESET)}$ reset value of 4.5 V. Recommended minimum value for the BP capacitor is 4.7 μF.

Constant output current regulation is achieved through the FEEDBACK (FB) pin directly sensing the drain current during the FET on-time using external current sense resistors

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(R_{FB}) R4 and R5 and comparing the voltage drop to a fixed internal reference voltage (V_{FB_REF}) of absolute value 280 mV typical.

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

Where: k is the ratio between I_{PK} and $I_{OUT;}$ such that k= 3 for LYT-14xx, and k= 3.6 for LYT-16xx)

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 over voltage event. When the internal 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 for the voltage across the inductor, i.e. (V_{IN}-V_{OUT}) and current flowing out of the M pin is defined by resistor R2, thus line over voltage detection is calculated as; where R2 is assumed to be 402 kΩ ±1%.

$$V_{LINE\_OVP} = I_{IOV} \times R2 + V_{OUT}$$

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 MOSFET of the IC.

The MULTIFUNCTION (M) pin also monitors the output for any overvoltage and undervoltage event. When the internal MOSFET is in off state, the output voltage is monitored through a coupling capacitor (C5) and divider resistors R2 and R3. 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 over voltage cut-off is typically 120% of the output voltage, which is equivalent to 2 V at the M pin (V_{OUT_OVP} = V_{OUT} x 2.4 V / 2 V). Resistor R2 is set to a fixed value of 402 kΩ ±1% and R3 will determine the output overvoltage limit. Any output short circuit at the output will be detected once the M-pin voltage falls below the undervoltage threshold (V_{OUV}) of 1 V typical, then the IC will inhibit switching instantaneously and initiate auto-restart to limit the average input less than 1 W, preventing any components from overheating.

R3 can be calculated as follows:

$R3 = 2\ V \times R2 / (V_{OUT} - 2\ V)$; this is applicable only to low-side configuration buck.

Another function of the MULTIFUNCTION (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.

5 PCB Layout

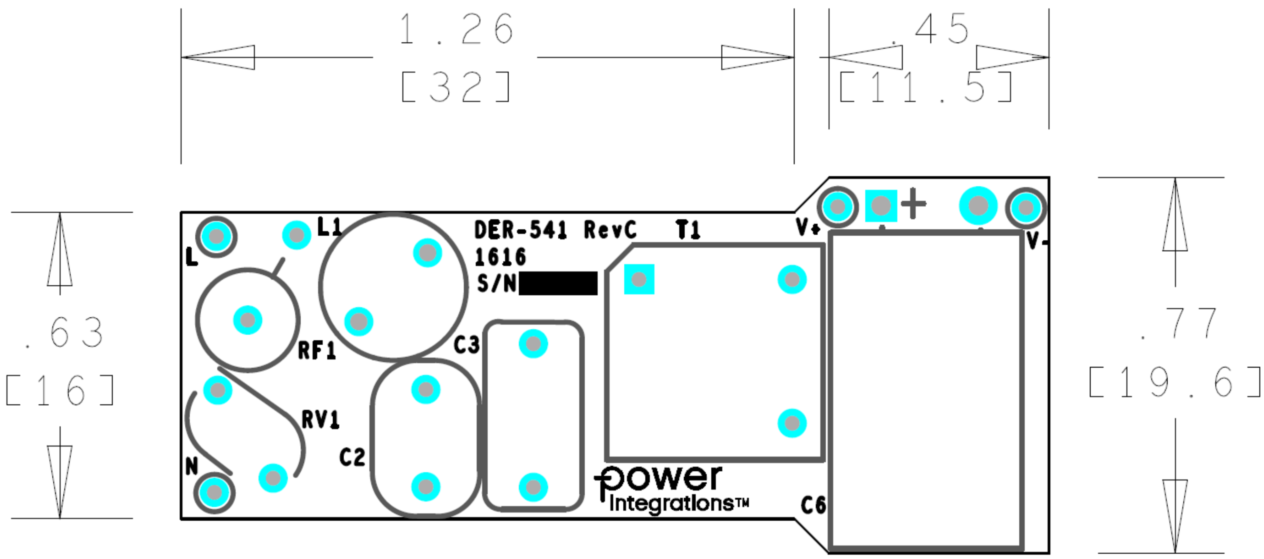

Figure 5 – Top Side.

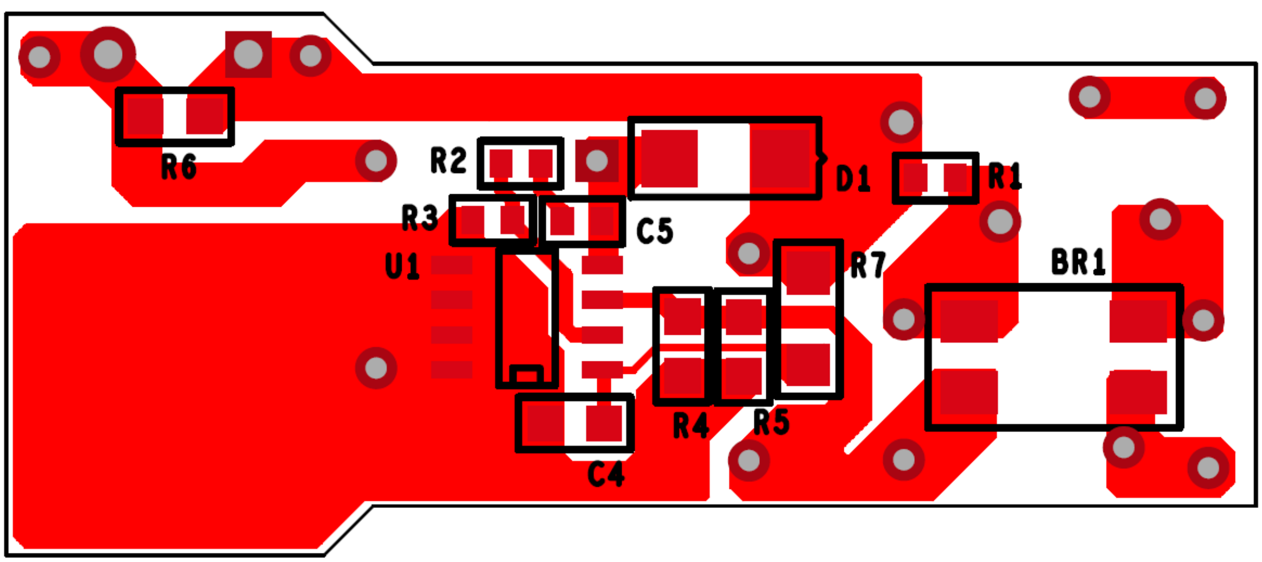

Figure 6 – Bottom Side.

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6 Bill of Materials

Item	Ref Des	QTY	Description	Mfg Part Number	Manufacturer
1	BR1	1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	C2	1	100 nF, 250 V, Film	ECQ-E2104KB	Panasonic
3	C3	1	220 nF, 250 V, 5%, Film	MEXID3220JJ	Duratech
4	C4	1	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
5	C5	1	100 pF 200 V, Ceramic, NPO, 0603	C0603C101J2GAC7867	Kemet
6	C6	1	120 μF, 80 V, Electrolytic, Gen. Purpose, (10 x 17.5)	EKZN800ELL121MJ16S	United Chemi-con
7	D1	1	Diode Ultrafast, GPP, 400 V, 1 A SMA	US1G-13-F	Diodes, Inc.
8	L1	1	2.2 mH, 0.19 A, Ferrite Core	CTCH895F-222K	CT Parts
9	R1	1	RES, 10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
10	R2	1	RES, 402 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4023V	Panasonic
11	R3	1	RES, 12.4 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1242V	Panasonic
12	R4	1	RES, SMD, 0.39 Ω, 1%, 1/8 W 0805	RL0805FR-070R39L	Yageo
13	R5	1	RES, SMD, 1.2 Ω, 1%, 1/3 W, 0805	ERJ-6BQF1R2V	Panasonic
14	R6	1	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
15	RF1	1	RES, 10 Ω, 2 W, Fusible/Flame Proof Wire Wound	CRF253-4 10R	Vitrohm
16	RV1	1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
17	T1	1	Bobbin, EE10, Vertical, 8 pins (10.2mm W x 10.4mm L x 9.7mm H)	EE-1016	Yulongxin
18	U1	1	LYTSwitch-1, Wide Range, 12W, 45V-65V, SO-8	LYT1604D	Power Integrations

7 Inductor Specification

7.1 *Electrical Diagram*

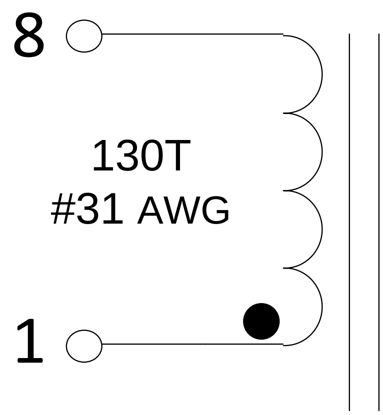

Figure 7 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 8, with all other windings open.	470 μH
Tolerance	Tolerance of Primary Inductance.	±7%

7.3 *Material List*

Item	Description
[1]	Core: EE10.
[2]	Bobbin: EE10, Vertical, 8 pins, Part no. 25-01068-00.
[3]	Magnet Wire: #31 AWG.
[4]	Polyester Tape: 7 mm.
[5]	Transformer Tape: 4 mm.

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7.4 *Inductor Build Diagram*

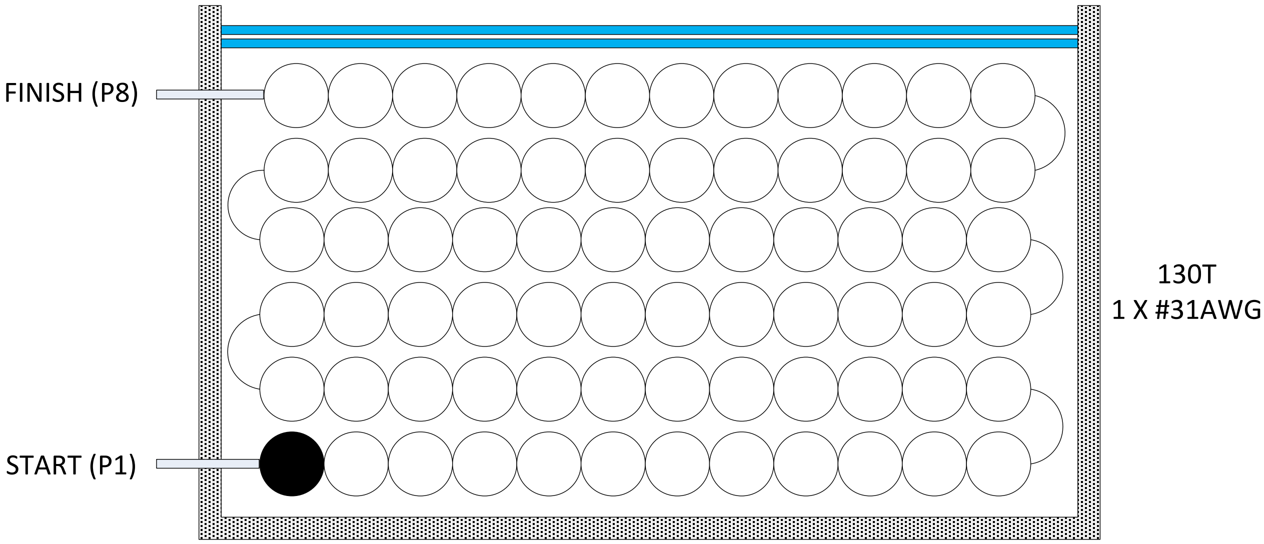
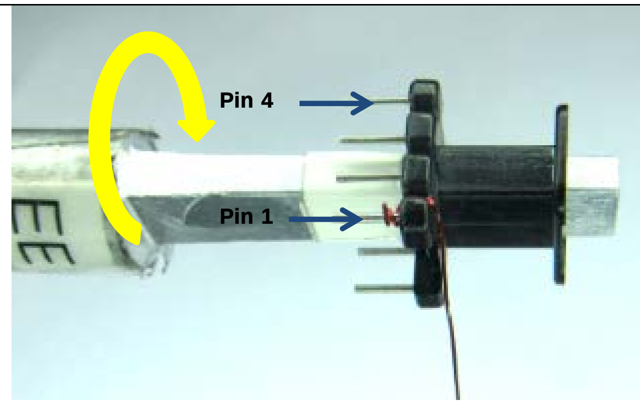
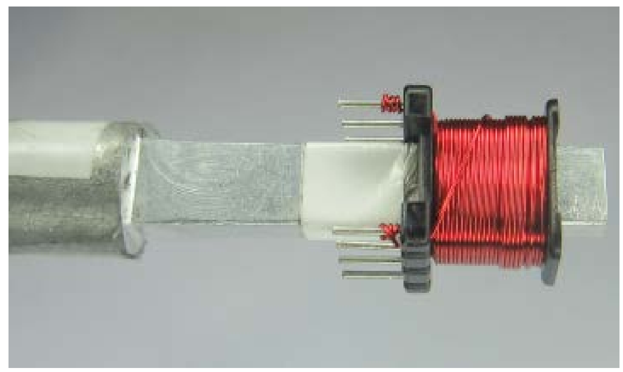
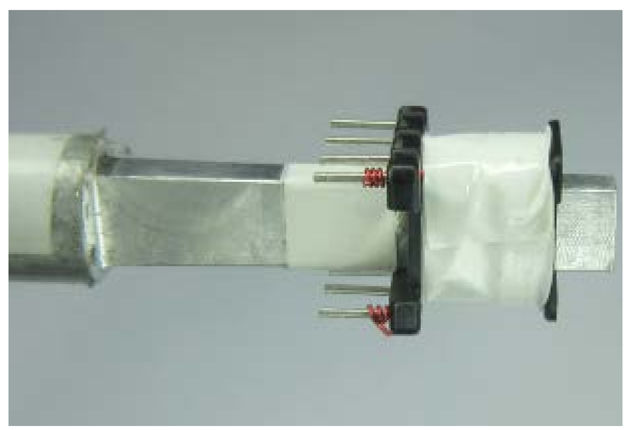


Figure 8 – Transformer Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-4 is in the left side. The winding direction is clockwise as shown in the figure.
Winding 1	Use wire item [3], start at pin 1 and wind 130 turns, then finish the winding on pin 8.
Insulation	Add 2 layer of tape, item [4], for insulation.
Terminal Pins	Pull out terminal pins 2-3 and pin 5-7.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 470 μH.
Core Assembly	Assemble the 2 cores on the bobbin with the ungapped core place on the terminal pin side as shown in the figure. Wrap the 2 cores with polyester tape item (5).
Finish	Dip the transformer assembly in 2:1 thinner and varnish solution.

7.6 *Winding Illustrations*

Winding Directions Bobbin is oriented on winder jig such that terminal pin 1-4 is in the Left side. The winding direction is clockwise as shown in the figure. **Winding 1** Use wire item [3], start at pin 1 and wind 130 turns, then finish the winding on pin 8.	 
Insulation Add 2 layer of tape, item [4], for insulation.	

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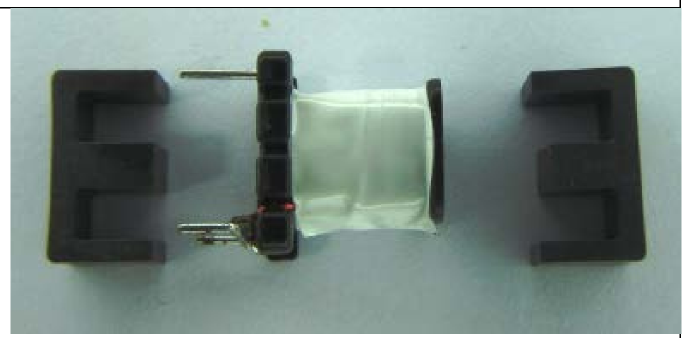
Terminal Pins Pull out terminal pins 2-3 and pin 5-7	
Core Grinding Grind the center leg of one core until it meets the nominal inductance of 470 μH. **Core Assembly** Assemble the 2 cores on the bobbin with the ungapped core place on the terminal pin side as shown in the figure. Wrap the 2 cores with polyester tape Item (5). See figure on the right side. **Finish** Dip the transformer assembly in 2:1 thinner and Varnish solution.	 

8 Inductor Design Spreadsheet

ACDC_LYTSwitch1_Buck_031816; Rev.0.1; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-1 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Low Line		AC line voltage range
VACMIN	90.00		90.00	Volts AC	Minimum AC line voltage
VACTYP			115.00	Volts AC	Typical AC line voltage
VACMAX	132.00		132.00	Volts AC	Maximum AC line voltage
fL	60.00		60.00	Hz	AC mains frequency
VO	67.00		67.00	Volts DC	Worst case normal operating output voltage
IO			0.250	Amperes	Average output current specification
EFFICIENCY	0.90		0.90		Efficiency estimate
PO			16.75	Watts	Continuous output power
VD			0.70	Volts DC	Output diode forward voltage drop
OPTIMIZATION PARAMETER	THD		THD		Parameter to be optimized
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE	725		725	Volts DC	Choose between 650V and 725V
GENERIC DEVICE	LYT1XX4D		LYT1XX4D		Generic LYTSwitch-1 device based on power
DEVICE CODE			LYT1604D		Actual LYTSwitch-1 device code
ILIMITMIN			1.59	Amperes	Minimum Current Limit
ILIMITTYP			1.71	Amperes	Typical Current Limit
ILIMITMAX			1.82	Amperes	Maximum Current Limit
TON			5.27	us	On-time during the fixed on-time region at VACTYP
FSW			93.14	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.83		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	EE10		EE10		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			12.10	mm^2	Core effective cross cectional area
LE			26.10	mm	Core effective path length
AL			850.00	nH/turn^2	Core ungapped effective inductance
AW			11.88	mm^2	Window Area of the bobbin
BW			6.60	mm	Bobbin physical winding width
MARGIN			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
LAYERS			6		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN_ABSOLUTE			128	uH	Absolute minimum design inductance
LP_TYP	470		470	uH	Typical design inductance
LP_TOLERANCE	7		7	%	Tolerance of the design inductance
LP_MAX			1022	uH	Absolue maximum design inductance
TURNS	130		130	Turns	Number of inductor turns
ALG			27.81	nH/turn^2	Inductance per turns squared
BMAX			3700	Gauss	Operating maximum flux density in the fixed peak current region
BMAX_ACTUAL			3453	Gauss	Actual saturation flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.529	mm	Core air gap
BWE			39.60	mm	Effective bobbin width
OD			0.30	mm	Outer diameter of the wire with insulation

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INS			0.053	mm	Wire insulation
DIA			0.252	mm	Outer diameter of the wire without insulation
AWG			31		AWG of the bare wire.
CM			81	Cmils	Bare wire circular mils
CMA			225.8	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			4.9	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR		Info	101.54%		Decrease the number of layers to ensure that the wire fits in the bobbin.
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.240	Amperes	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.900	Amperes	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.243	Amperes	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.261	Amperes	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.357	Amperes	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB (Non standard value)			0.333	Ohms	Non standard value of the feedback pin sense resistor
RFB (Standard 1% Value)			0.332	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Resistor					
RUPPER (Standard 1% Value)			402.00	kOhms	Standard 1% value of the upper (fixed) resistor on the M-pin divider network
RLOWER (Non standard value)			12.37	kOhms	Non standard value of the lower resistor on the M-pin divider network
RLOWER (Standard 1% Value)			12.40	kOhms	Standard 1% value of the lower resistor on the M-pin divider network
LOAD OVERVOLTAGE THRESHOLD			80.206	Volts DC	Load overvoltage threshold
LINE OVERVOLTAGE THRESHOLD			469.00	Volts DC	Line overvoltage threshold
VOLTAGE STRESS PARAMETERS					
VDRAIN			186.68	Volts DC	Estimated worst case drain voltage
PIVD			186.68	Volts DC	Output Rectifier Maximum Peak Inverse Voltage

9 Performance Data

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

9.1 *Efficiency*

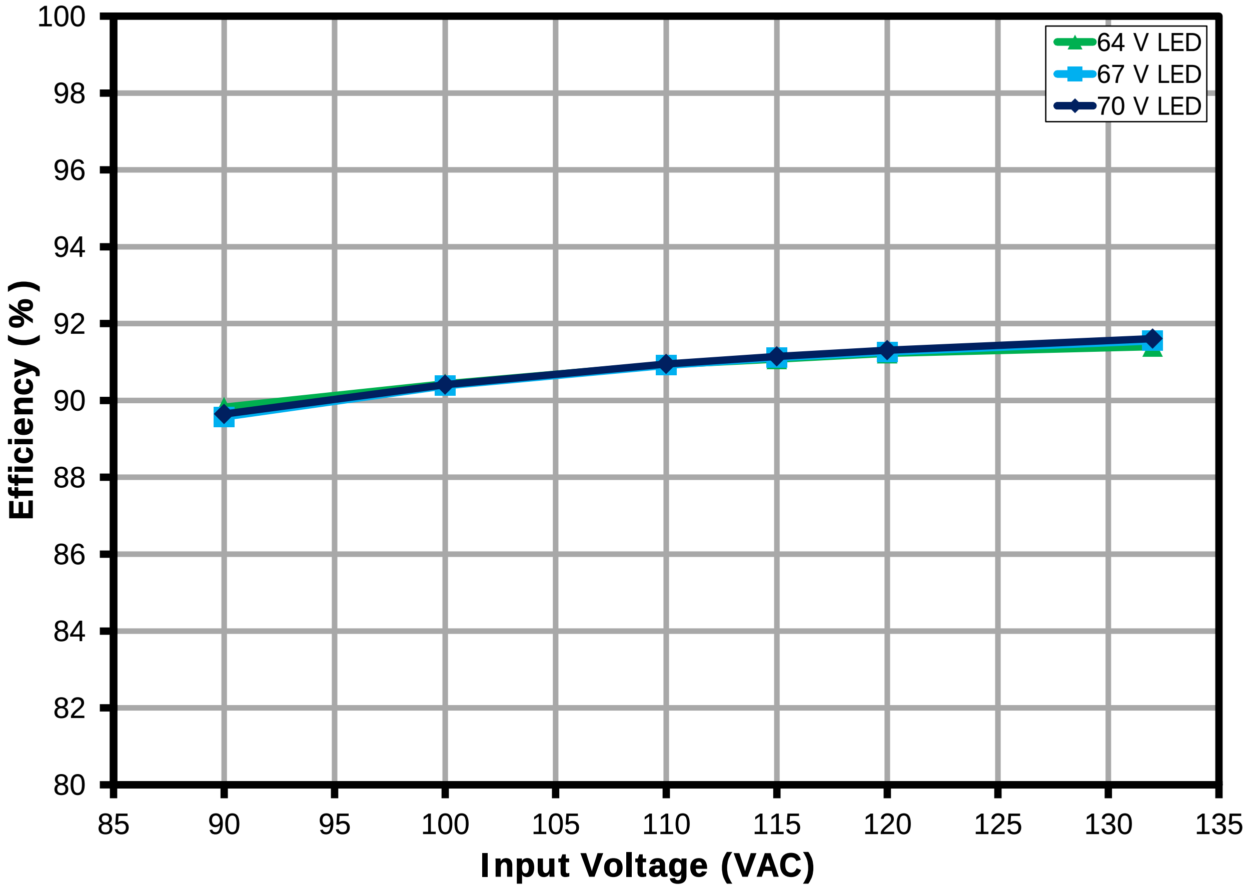

Figure 9 – Efficiency vs. Line and LED Load.

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9.2 *Line Regulation*

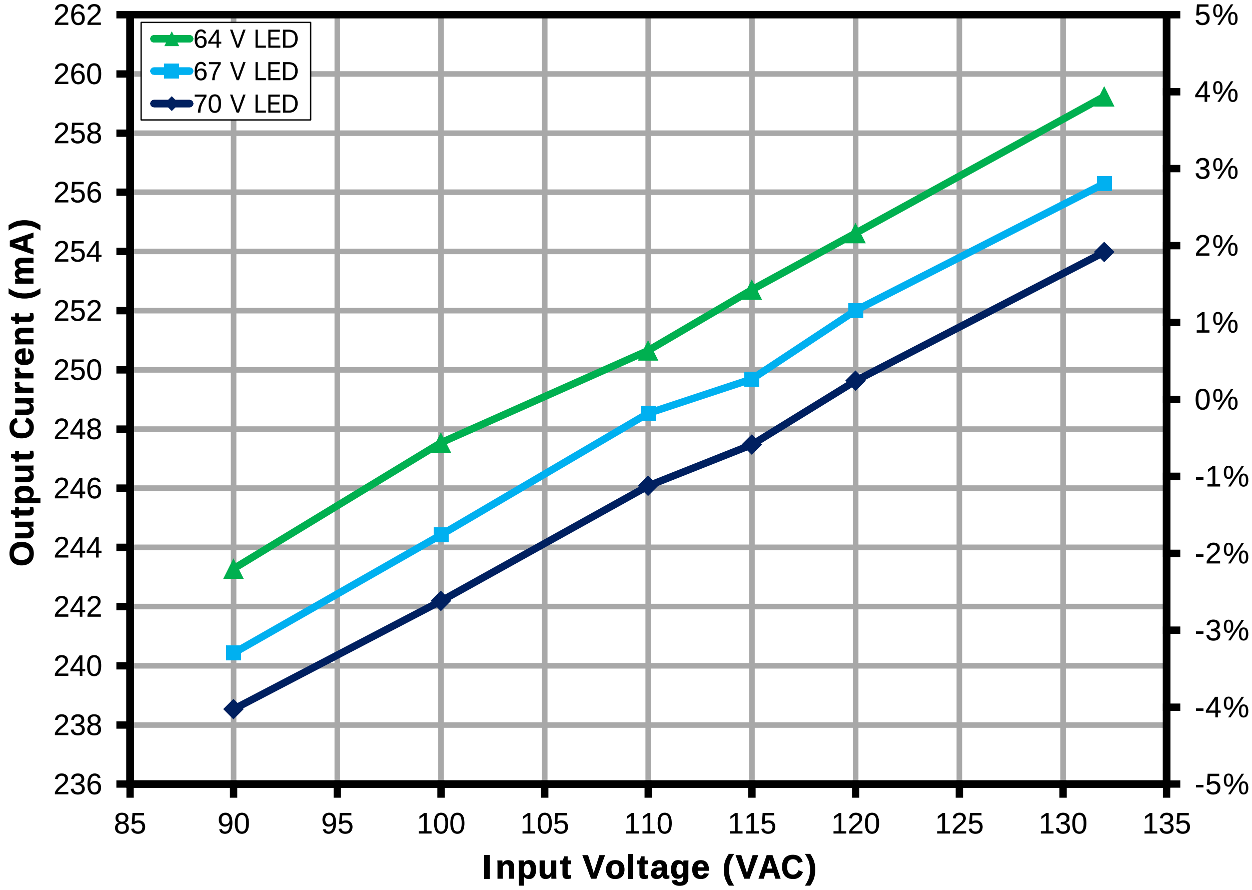

Figure 10 – Regulation vs. Line and LED Load.

9.3 *Power Factor*

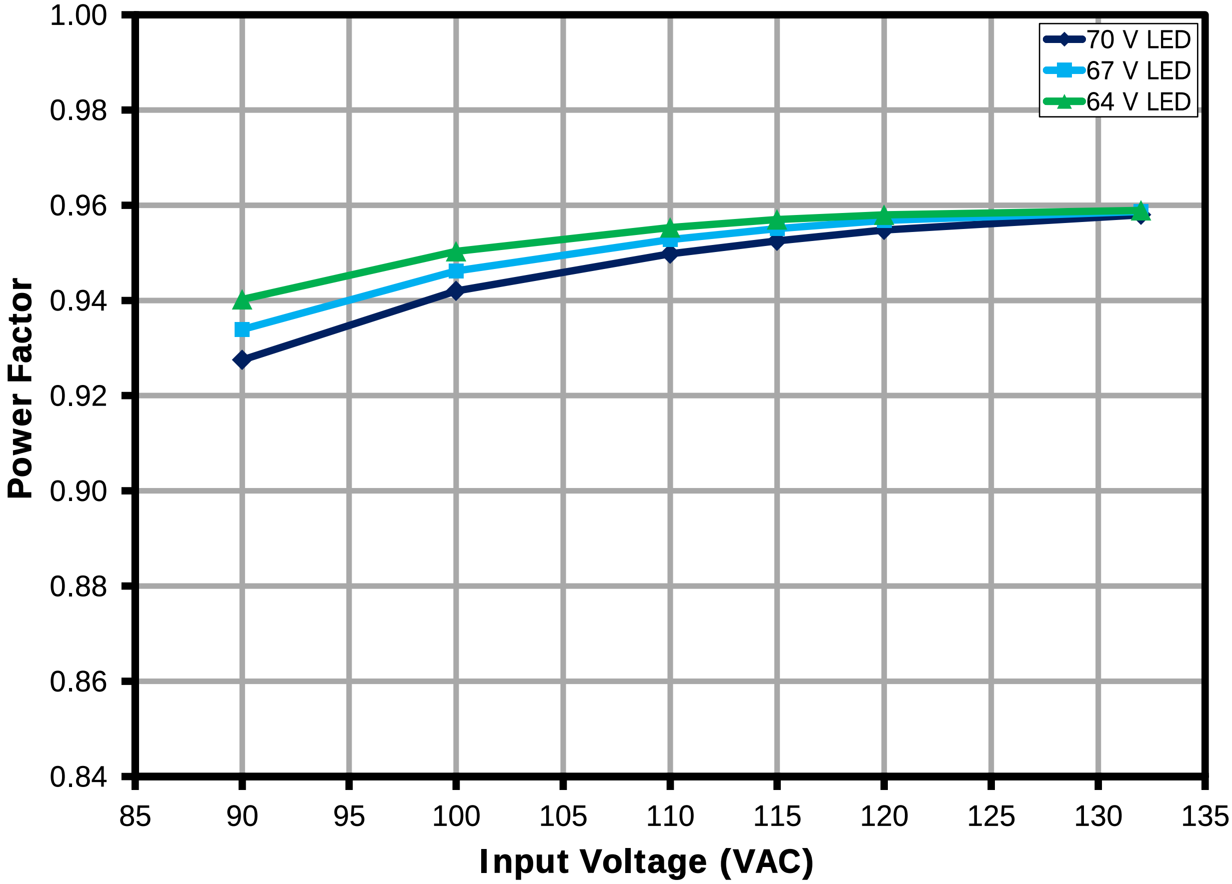

Figure 11 – Power Factor vs. Line and LED Load.

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9.4 *%ATHD*

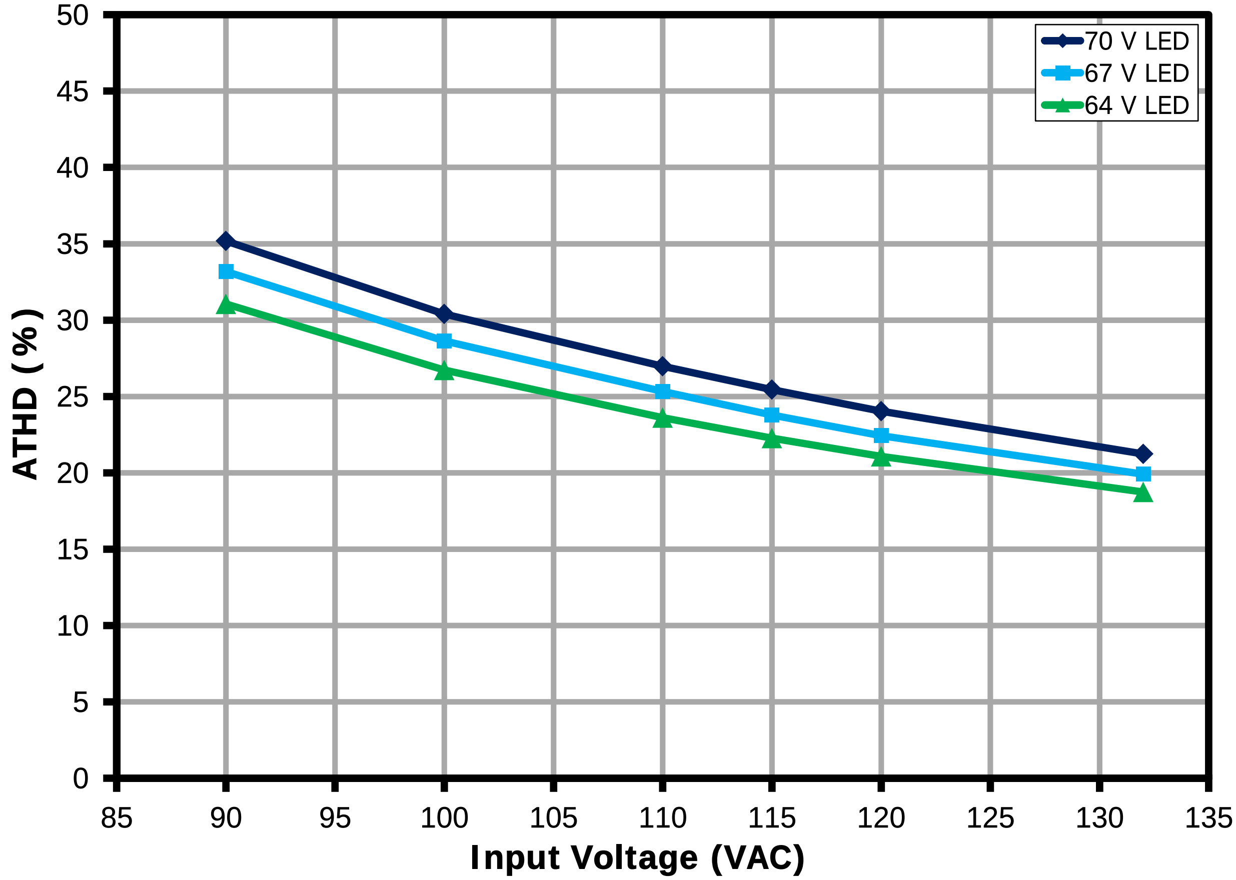

Figure 12 – %ATHD vs. Line and LED Load.

9.5 *Individual Harmonics Content*

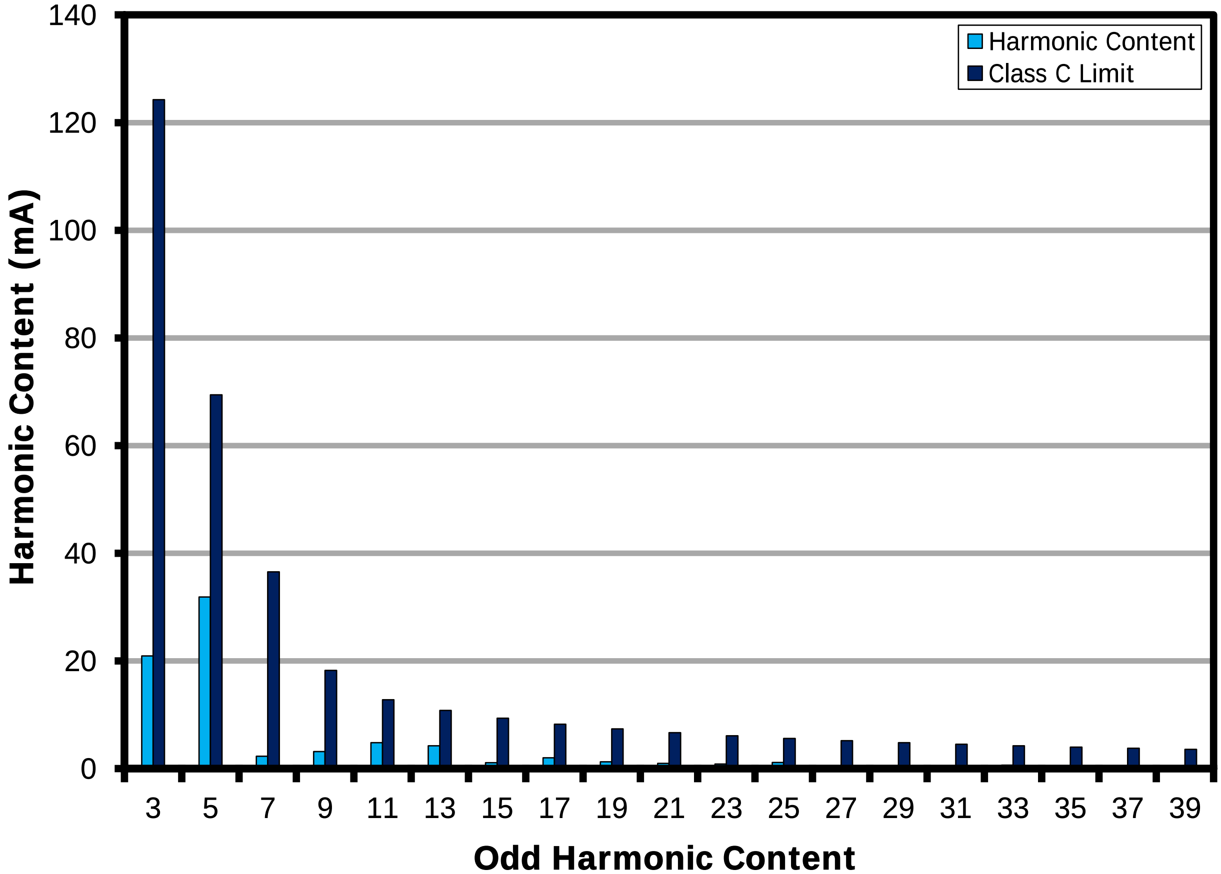

Figure 13 – 67 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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10 Test Data

10.1 *Test Data, 64 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	89.80	203.76	17.21	0.940	31.06	63.19	243.28	15.46	89.83
100	60	99.84	183.03	17.37	0.950	26.74	63.12	247.54	15.70	90.43
110	60	109.87	166.71	17.50	0.955	23.62	63.17	250.65	15.91	90.93
115	60	114.84	160.35	17.62	0.957	22.27	63.21	252.71	16.05	91.08
120	60	119.89	154.42	17.74	0.958	21.07	63.26	254.62	16.18	91.23
132	60	131.88	142.56	18.03	0.959	18.75	63.29	259.24	16.48	91.40

10.2 *Test Data, 67 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	89.80	213.87	17.94	0.934	33.19	66.49	240.43	16.07	89.57
100	60	99.83	190.85	18.03	0.946	28.64	66.35	244.42	16.29	90.38
110	60	109.86	174.21	18.24	0.953	25.33	66.41	248.53	16.58	90.91
115	60	114.83	166.56	18.27	0.955	23.79	66.37	249.69	16.64	91.11
120	60	119.89	160.53	18.41	0.957	22.43	66.40	252.01	16.80	91.26
132	60	131.88	147.89	18.70	0.959	19.90	66.52	256.30	17.12	91.55

10.3 *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	89.79	223.02	18.57	0.928	35.18	69.48	238.53	16.65	89.65
100	60	99.82	198.44	18.66	0.942	30.41	69.35	242.19	16.87	90.41
110	60	109.85	181.21	18.91	0.950	26.97	69.59	246.08	17.20	90.95
115	60	114.83	173.59	18.99	0.953	25.45	69.65	247.47	17.31	91.15
120	60	119.88	167.20	19.14	0.955	24.03	69.73	249.63	17.48	91.31
132	60	131.87	154.00	19.46	0.958	21.24	69.91	253.98	17.82	91.61

10.4 *Test Data, Harmonic Content at 115 VAC, 67 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60	166.60	18.272	23.805
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	159.28			
2	0.28	0.18%		
3	20.94	13.15%	124.25	Pass
5	31.87	20.01%	69.43	Pass
7	2.30	1.44%	36.54	Pass
9	3.17	1.99%	18.27	Pass
11	4.83	3.03%	12.79	Pass
13	4.24	2.66%	10.82	Pass
15	1.12	0.70%	9.38	Pass
17	2.03	1.27%	8.28	Pass
19	1.30	0.82%	7.40	Pass
21	1.01	0.63%	6.70	Pass
23	0.85	0.53%	6.12	Pass
25	1.14	0.72%	5.63	Pass
27	0.40	0.25%	5.21	Pass
29	0.26	0.16%	4.85	Pass
31	0.49	0.31%	4.54	Pass
33	0.67	0.42%	4.26	Pass
35	0.32	0.20%	4.02	Pass
37	0.15	0.09%	3.80	Pass
39	0.32	0.20%	3.61	Pass

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11 Thermal Performance

11.1 Thermal Performance Scan – Open Frame Unit

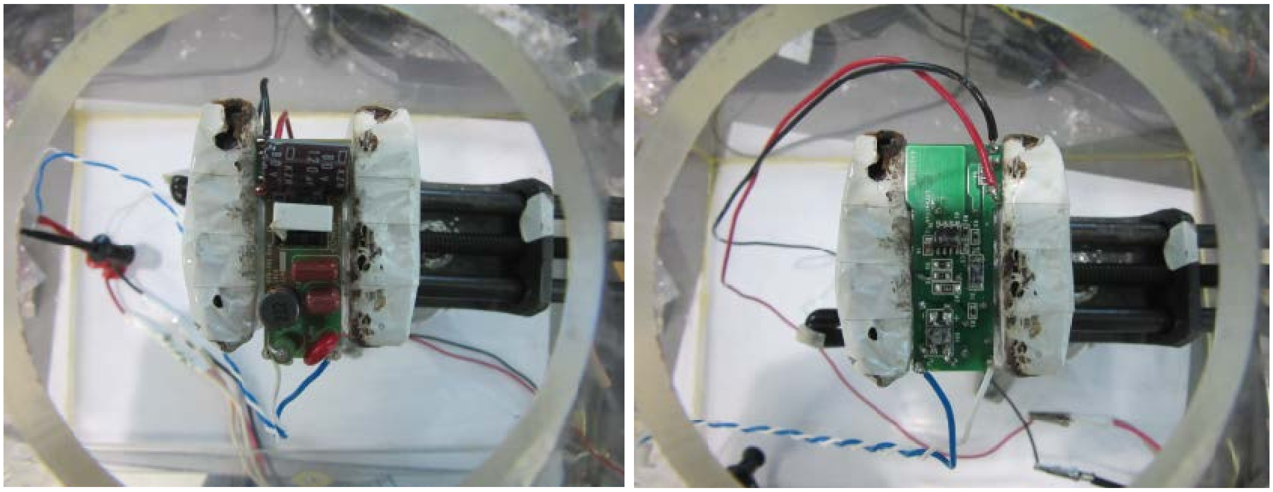

Figure 14 – Test Set-up Picture - Open Frame.

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. The ambient temperature is 25 ºC.

11.1.1 Thermal Scan at Normal Operation 115 V, 67 V LED Load

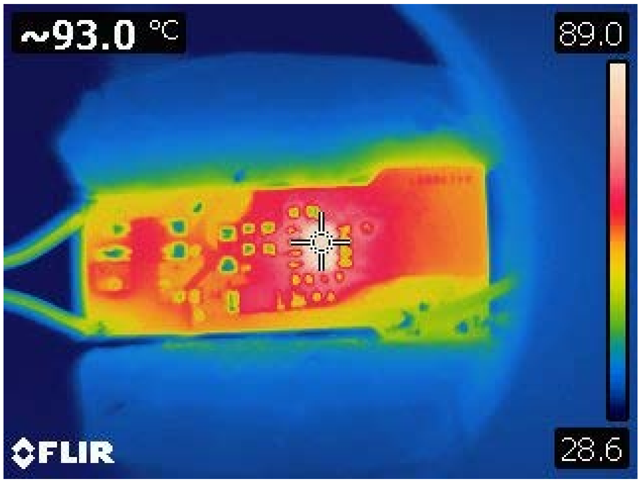

Figure 15 – 115 VAC, 67 V LED Load.
Spot 1: LYT1604D (U1): 93 ºC.

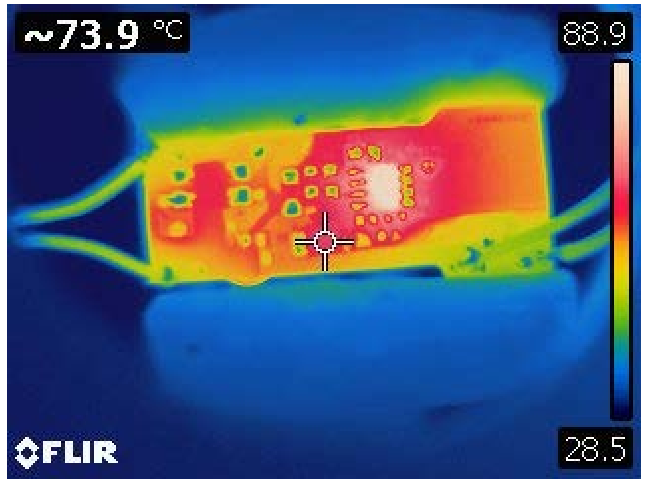

Figure 16 – 115 VAC, 67 V LED Load.
Spot 1: Flywheel Diode (D1): 73.9 ºC.

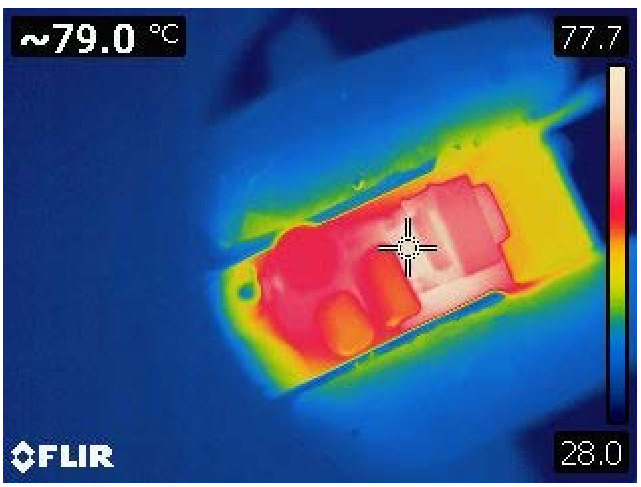

Figure 17 – 115 VAC, 67 V LED Load.
Spot 1: Inductor (T1): 79 ºC.

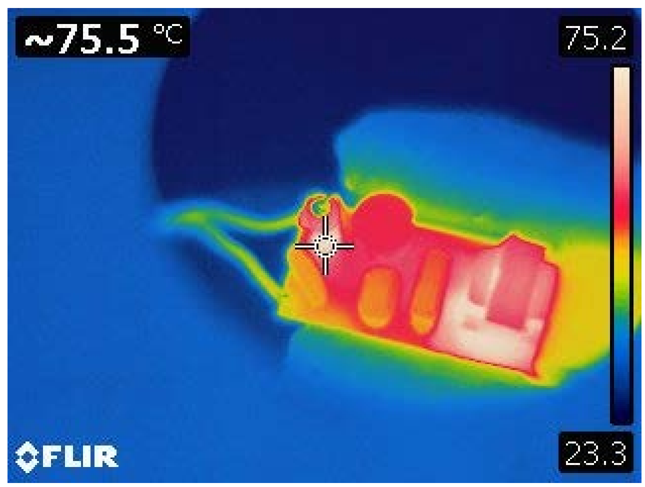

Figure 18 – 115 VAC, 67 V LED Load.
Spot 1: Fusible Resistor (RF1): 75.5 ºC.

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11.1.2 Thermal Scan During Output Short-Circuit at 115 VAC Input

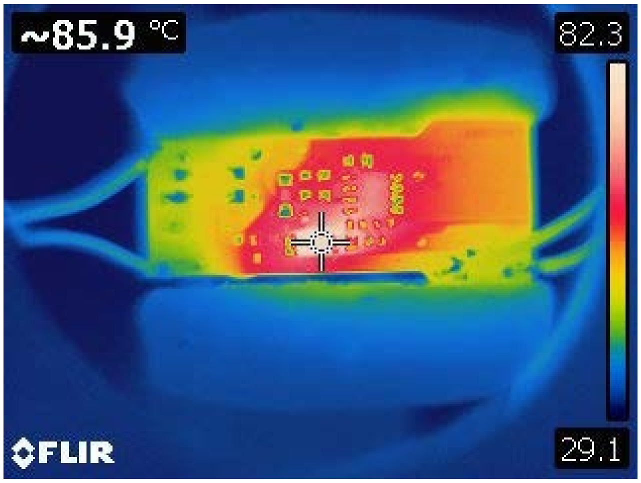

Figure 19 – 115 VAC, Output Short.
Spot 1: Flywheel Diode (D1): 86 ºC.

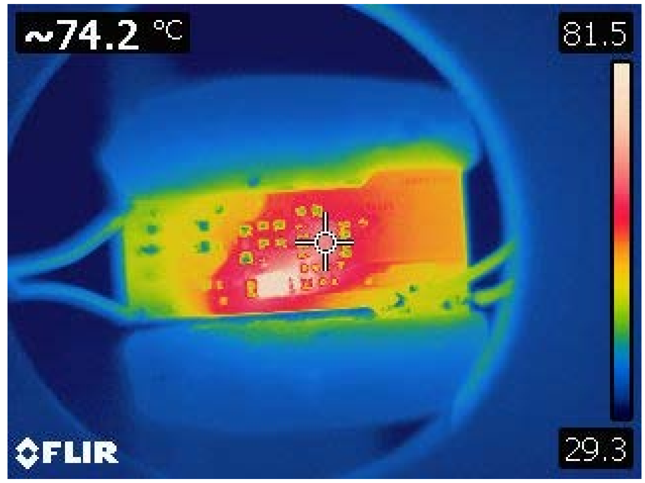

Figure 20 – 115 VAC, 67 V LED Load.
Spot 1: Inductor (T1): 74.2 ºC.

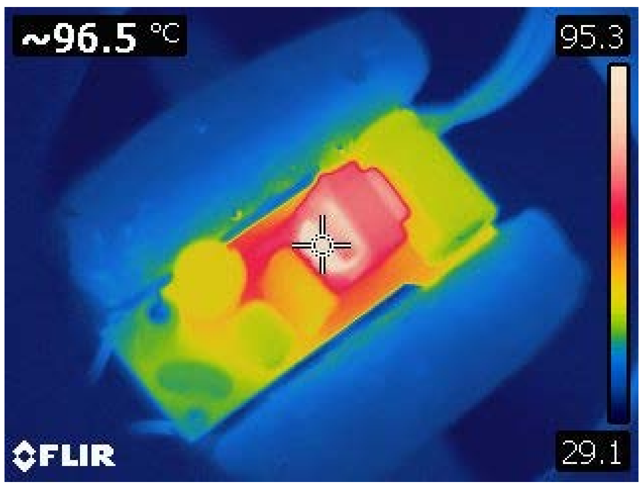

Figure 21 – 115 VAC, Output Short.
Spot 1: Flywheel Diode (D1): 97.5 ºC.

11.2 **Thermal Performance at 75 ºC Ambient**

Figure 22 – Test Set-up Picture Thermal at 75 ºC Ambient - Open Frame.

Unit in open frame was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 75 ºC. Temperature was measured using type T thermocouple.

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11.2.1 Thermal Performance at 115 VAC with a 67 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	BR1
Maximum (°C)	76.6	127.7	110.2	106.4	109.8	100.9
Final (°C)	76.4	127.6	110.1	106.3	109.5	100.6

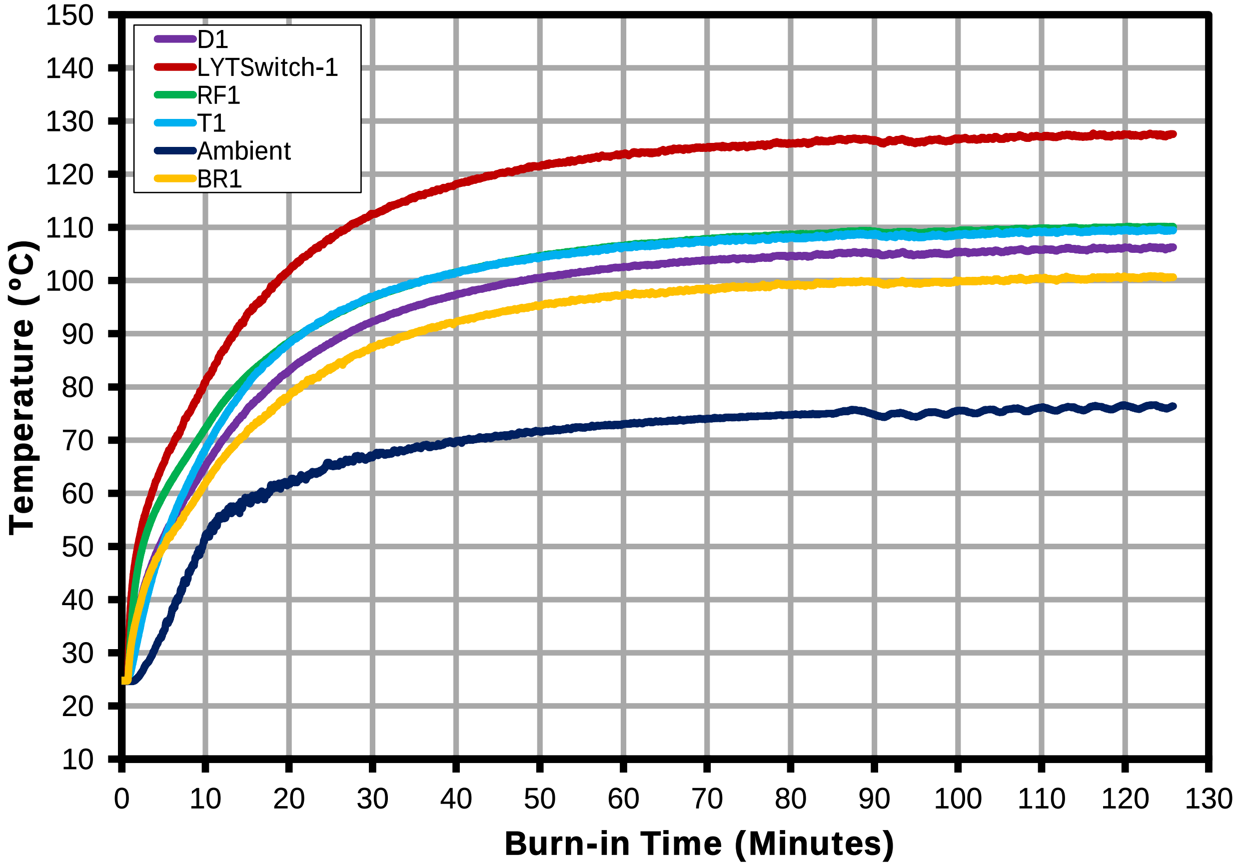

Figure 23 – Component Temperature at 115 VAC, 67 V LED Load, 75 ºC Ambient.

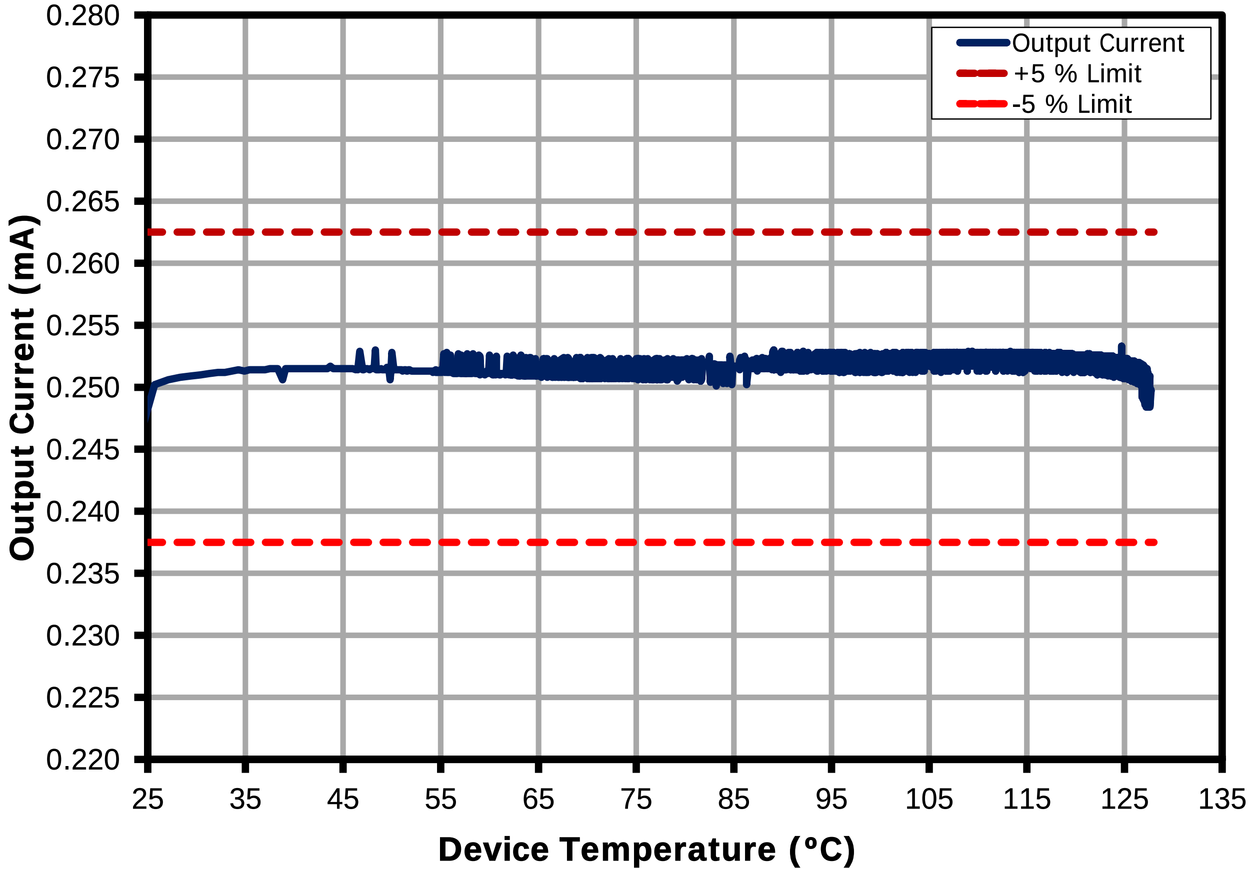

Figure 24 – Output Current vs. Device Temperature at 115 VAC, 67 V LED Load, 75 ºC Ambient.

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11.2.2 Thermal Performance at 90 VAC with a 67 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	BR1
Maximum (°C)	75.7	130.0	119.2	106.3	107.4	104.0
Final (°C)	75.6	129.8	119.2	106.1	107.3	103.9

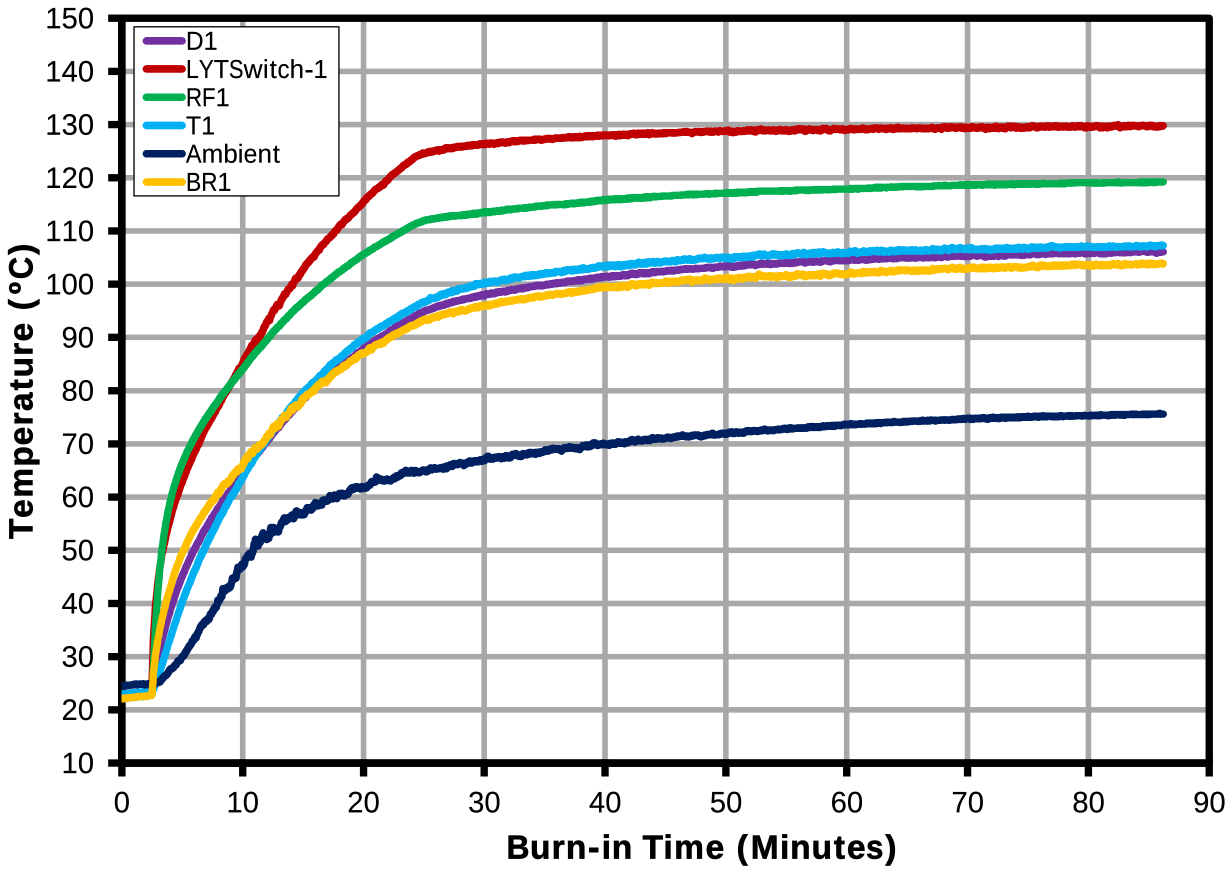

Figure 25 – Component Temperature at 90 VAC, 67 V LED Load, 75 ºC Ambient.

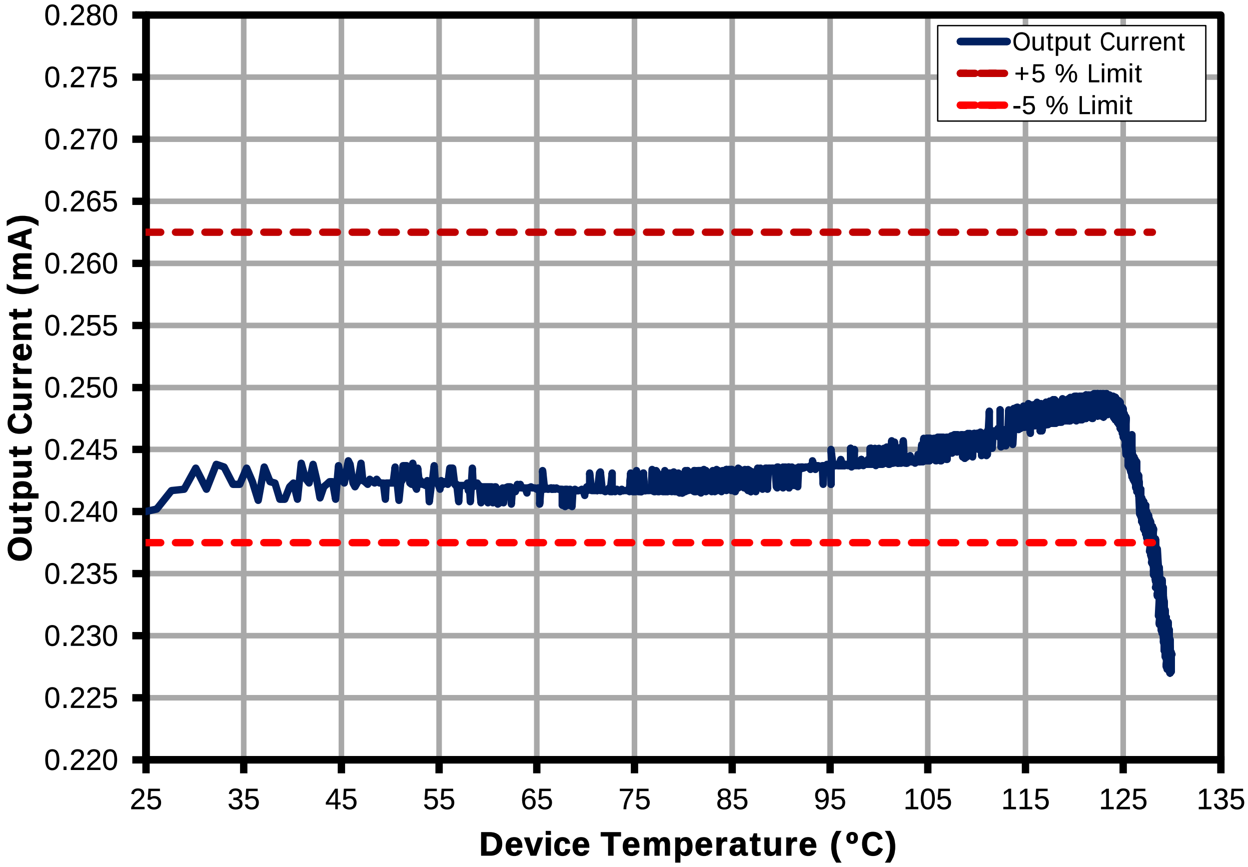

Figure 26 – Output Current vs. Device Temperature at 90 VAC, 67 V LED Load, 75 ºC Ambient.

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11.2.3 Thermal Performance at 132 VAC with a 67 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	BR1
Maximum (°C)	81.8	128.9	108.4	109.2	114.7	102.0
Final (°C)	76.5	124.7	105.6	105.7	110.5	98.8

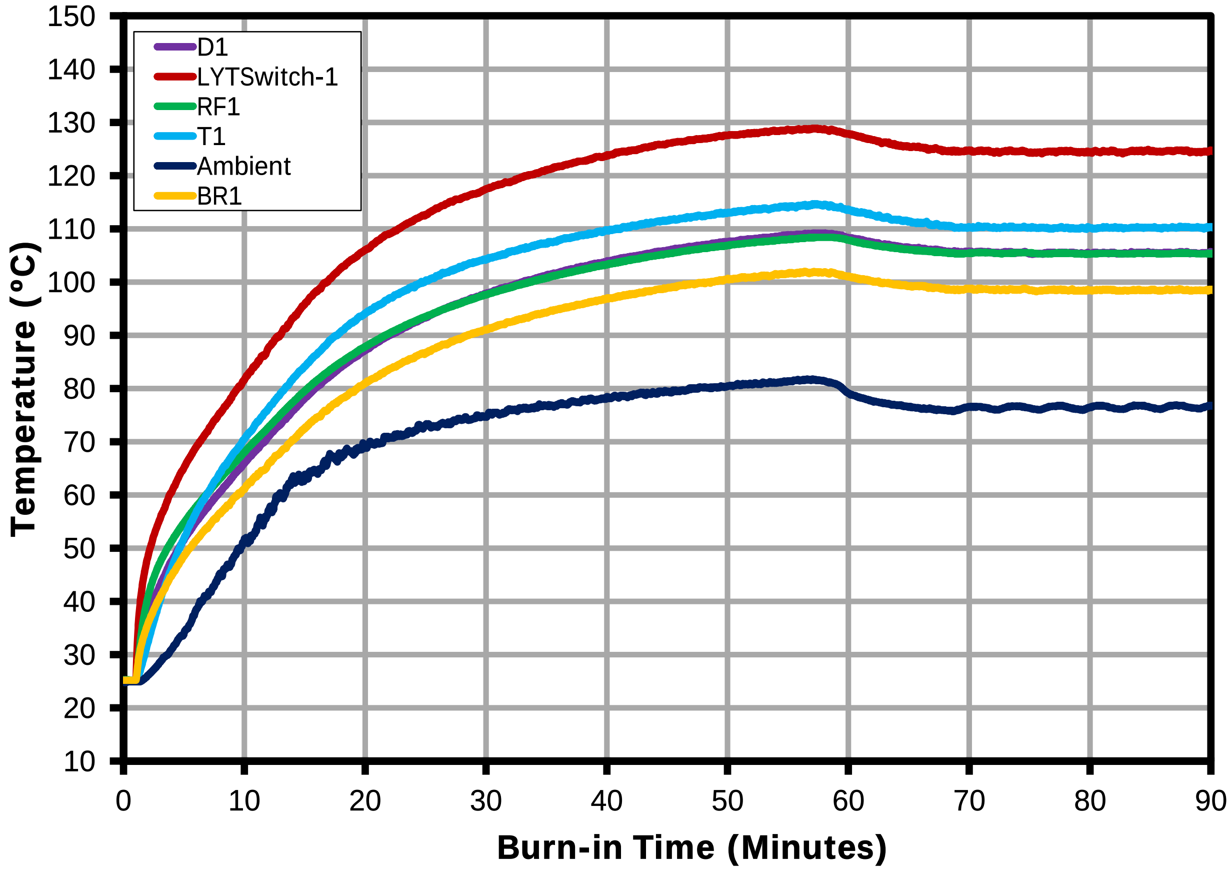

Figure 27 – Component Temperature at 132 VAC, 67 V LED Load, 75 ºC Ambient.

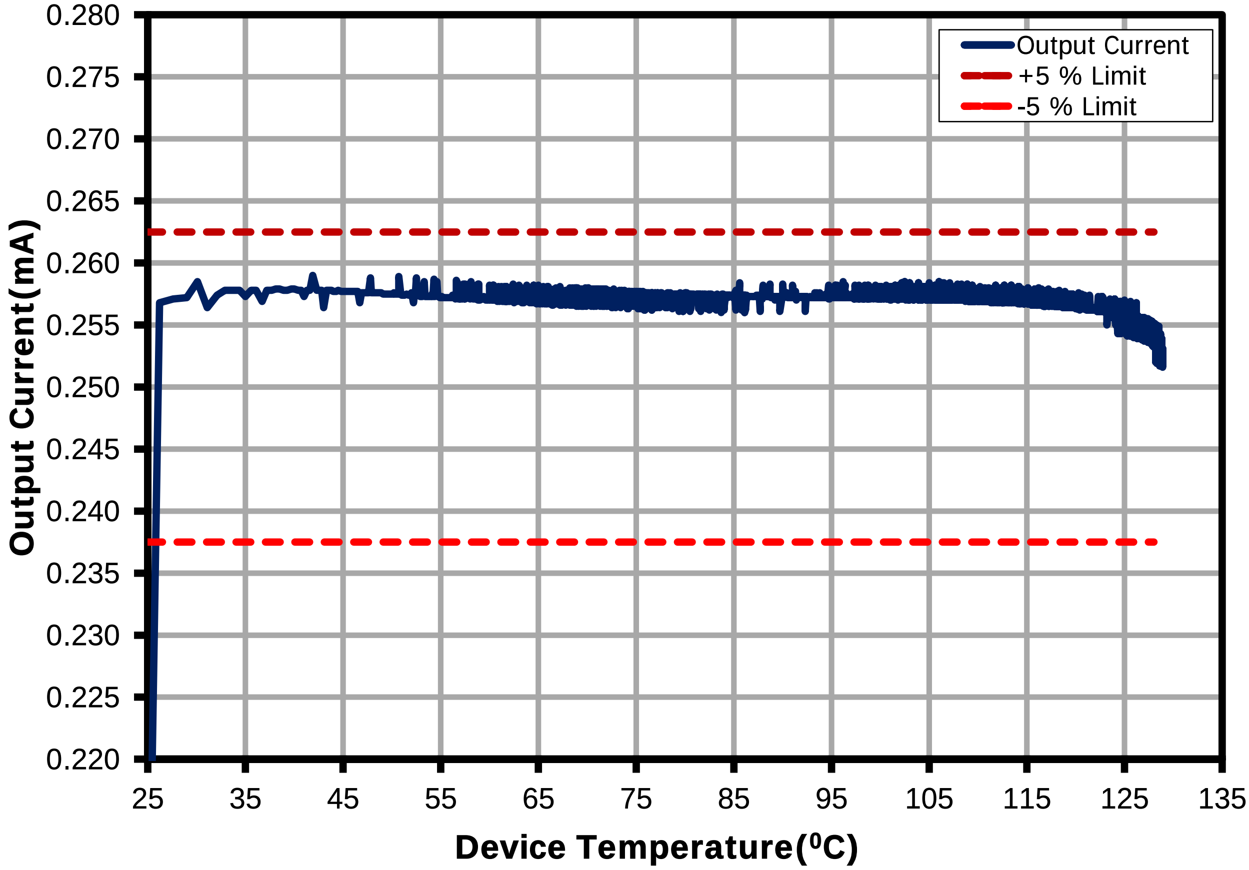

Figure 28 – Output Current vs. Device Temperature at 132 VAC, 67 V LED Load, 75 ºC Ambient.

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12 Waveforms

12.1 *Input Voltage and Input Current Waveforms*

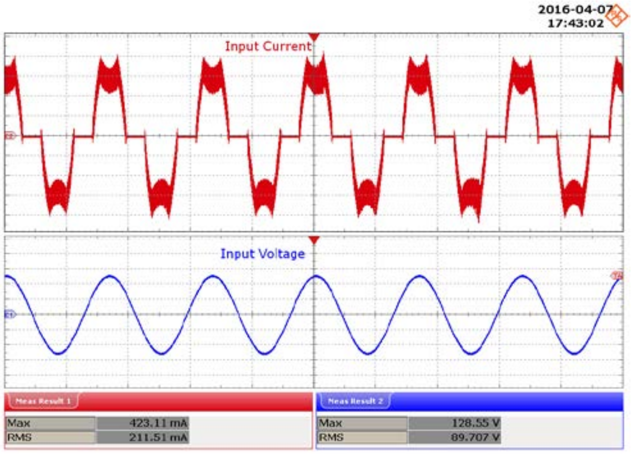

Figure 29 – 90 VAC, 67 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

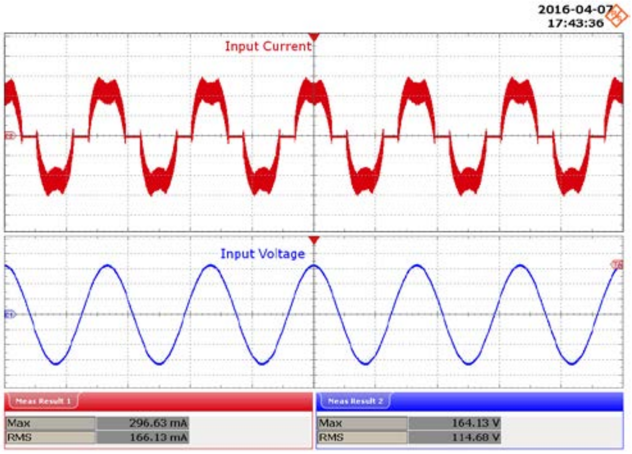

Figure 30 – 115 VAC, 67 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

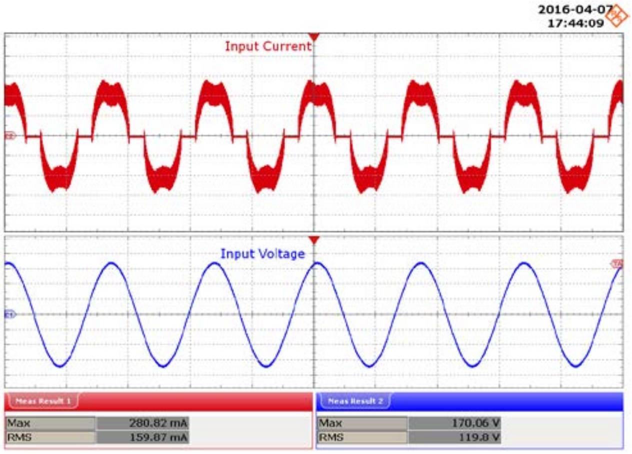

Figure 31 – 120 VAC, 67 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

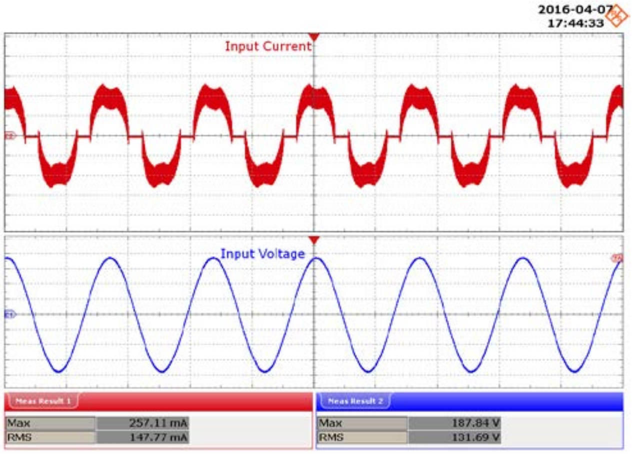

Figure 32 – 132 VAC, 67 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

12.2 *Start-up Profile*

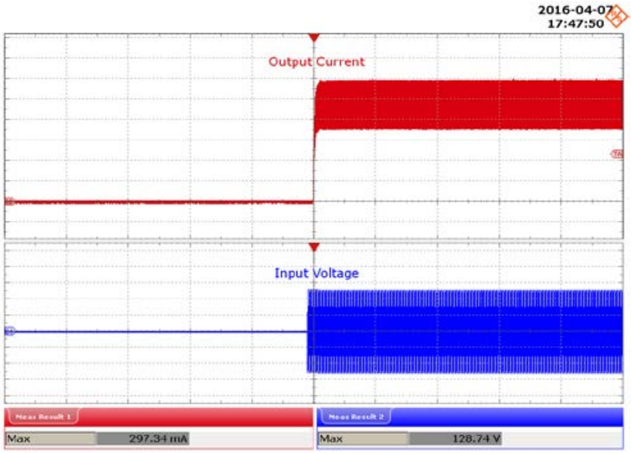

Figure 33 – 90 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

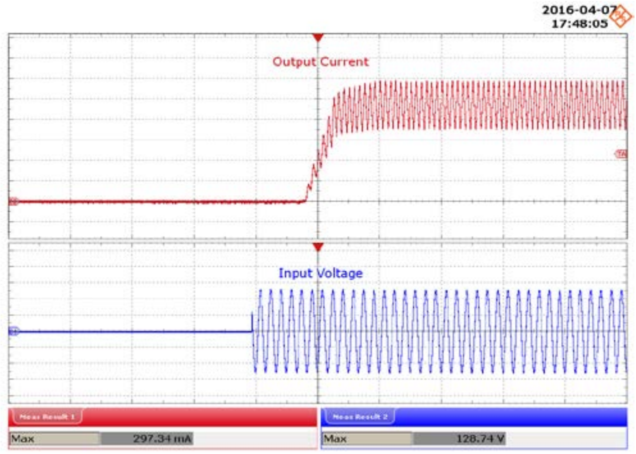

Figure 34 – 90 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

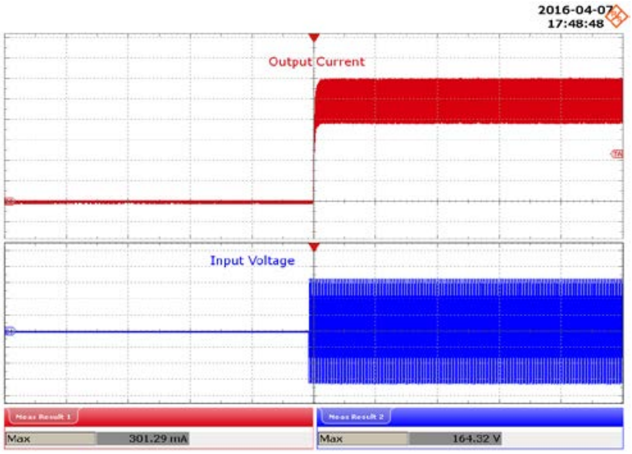

Figure 35 – 115 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 500 V / div., 1 s / div.

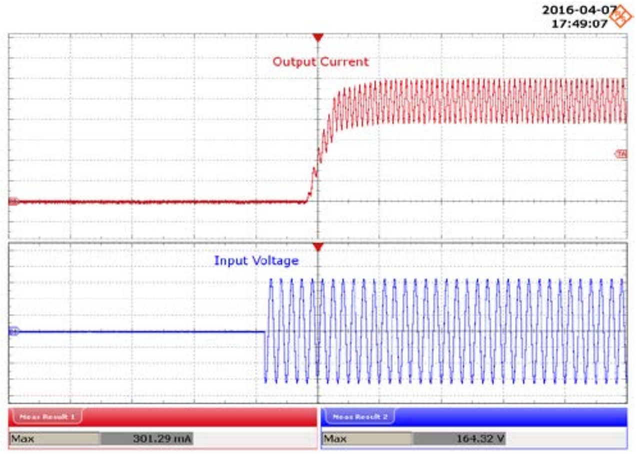

Figure 36 – 115 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

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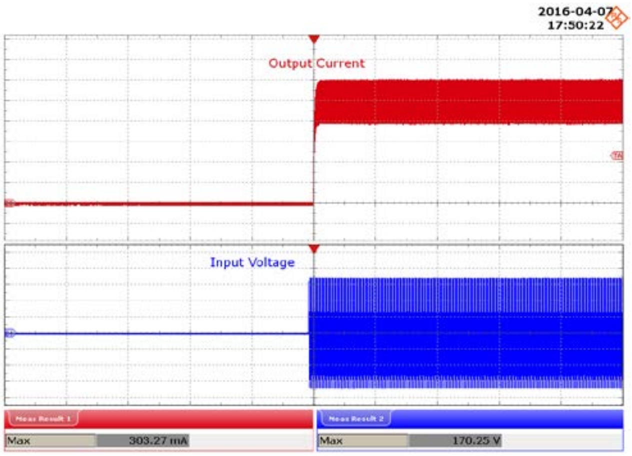

Figure 37 – 120 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

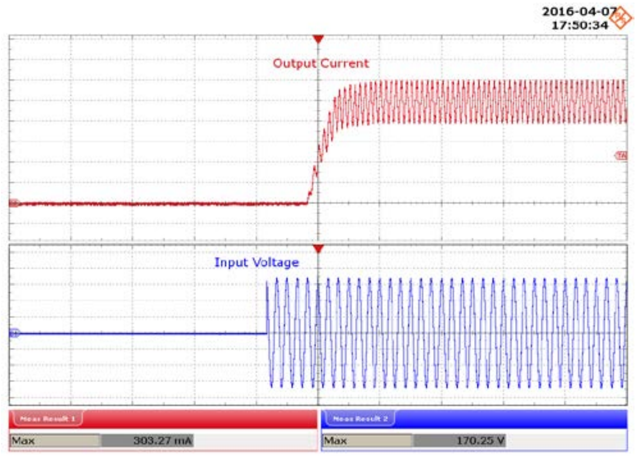

Figure 38 – 120 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

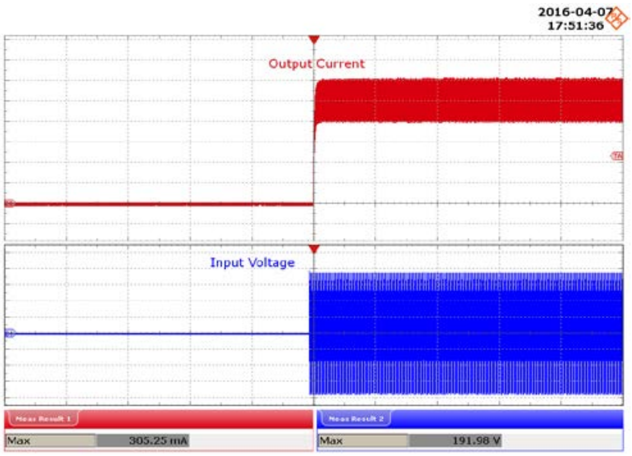

Figure 39 – 132 VAC, 67 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

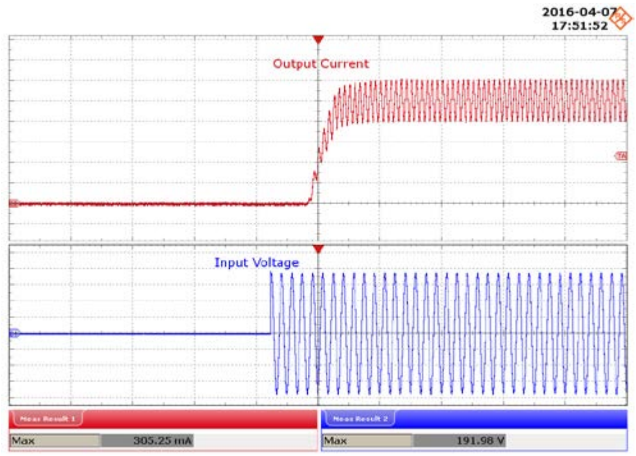

Figure 40 – 132 VAC, 67 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

12.3 *Output Current Fall*

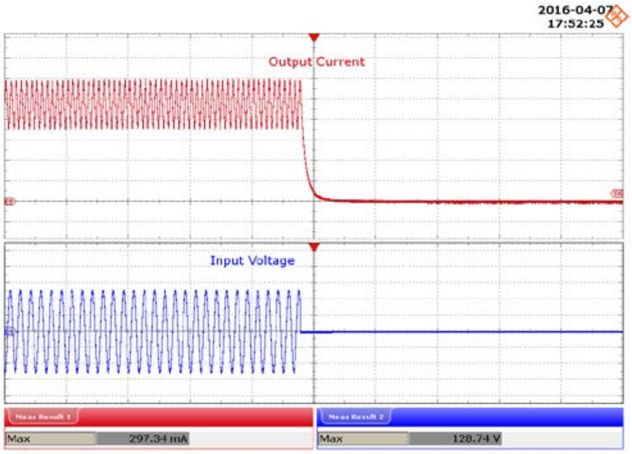

Figure 41 – 90 VAC, 67 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

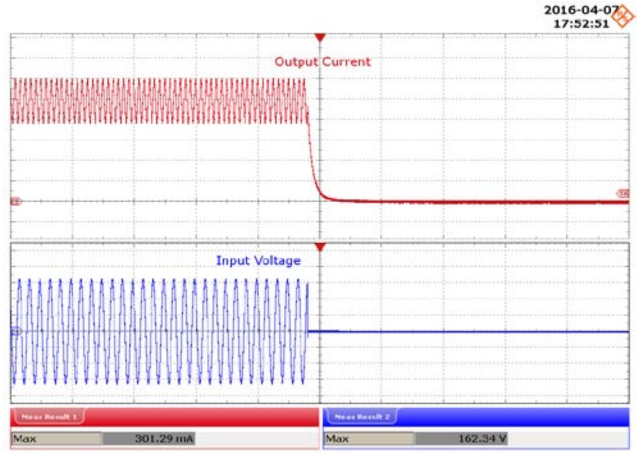

Figure 42 – 115 VAC, 67 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

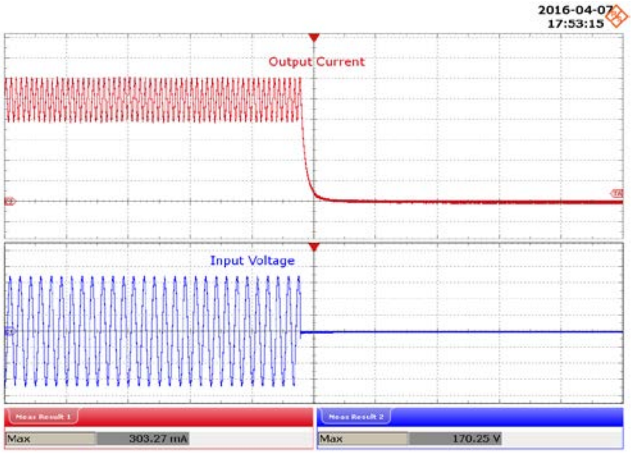

Figure 43 – 120 VAC, 67 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

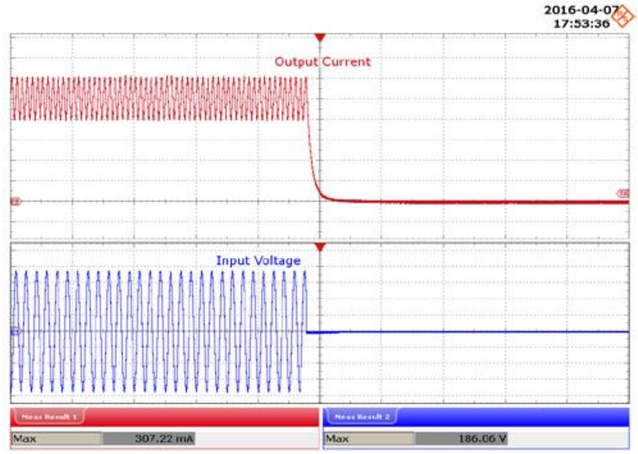

Figure 44 – 132 VAC, 67 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

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12.4 *Drain Voltage and Current in Normal Operation*

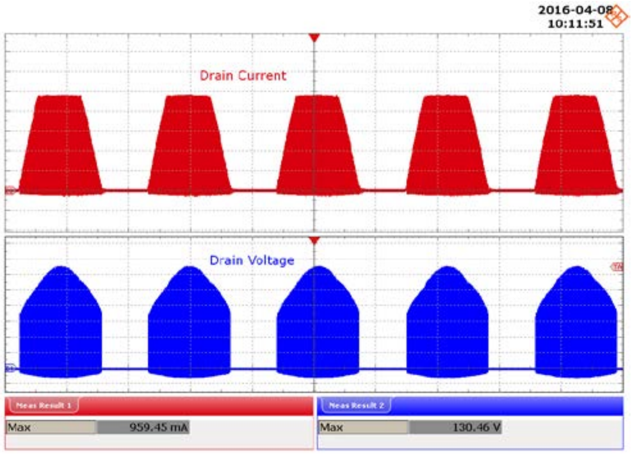

Figure 45 – 90 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 20 V / div., 4 ms / div.

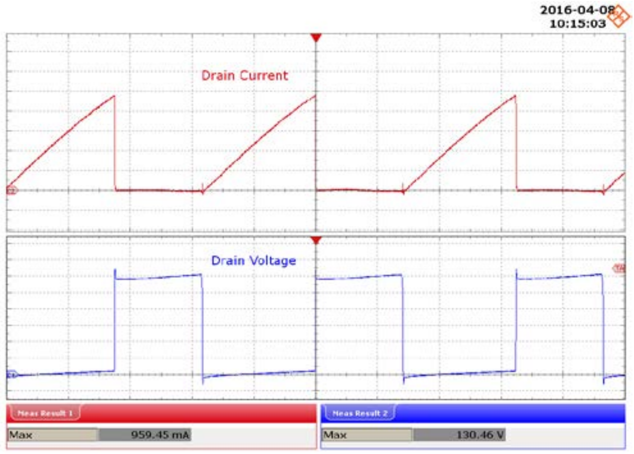

Figure 46 – 90 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 20 V / div., 5 μs / div.

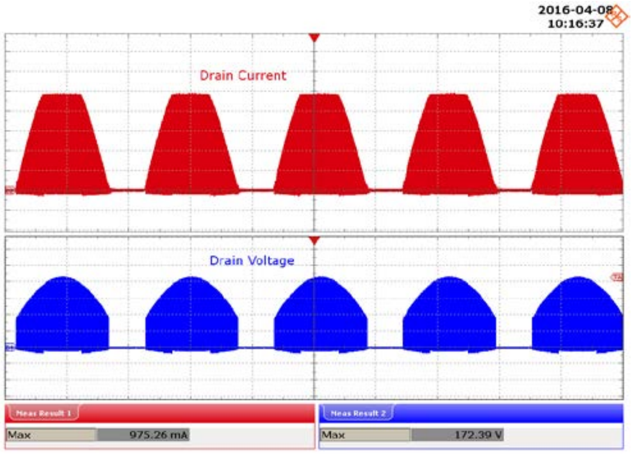

Figure 47 – 115 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

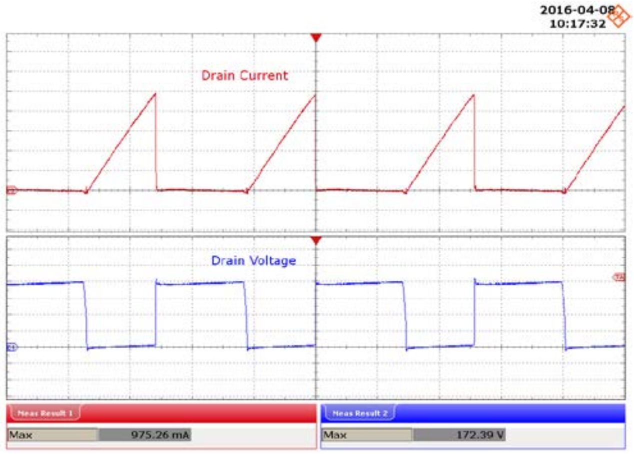

Figure 48 – 115 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

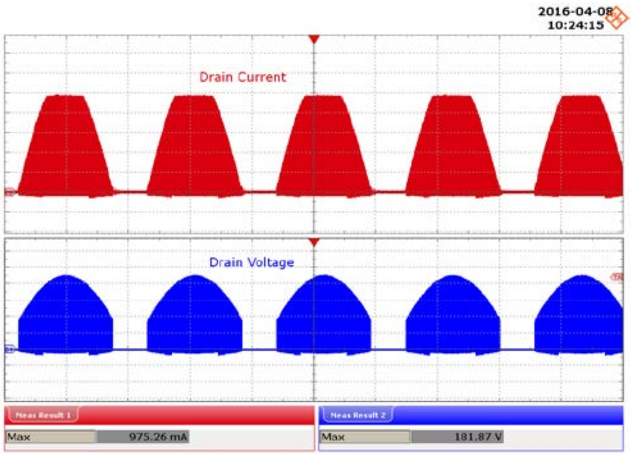

Figure 49 – 120 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

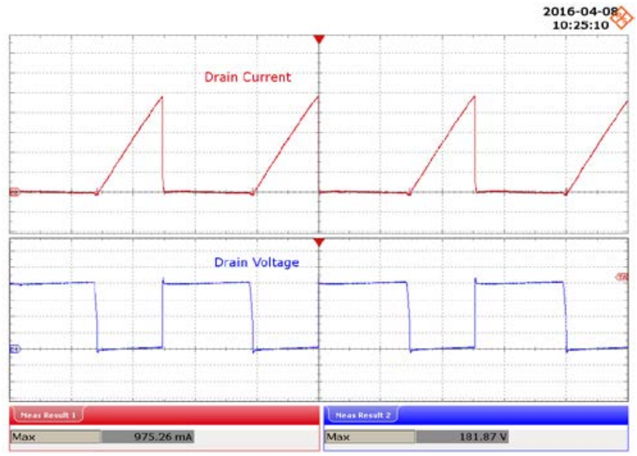

Figure 50 – 120 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

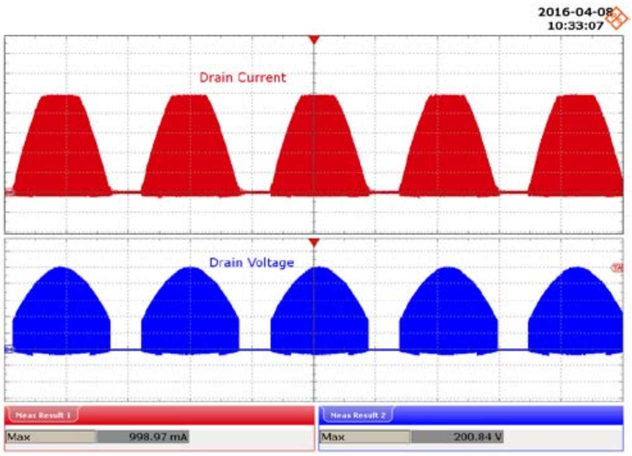

Figure 51 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

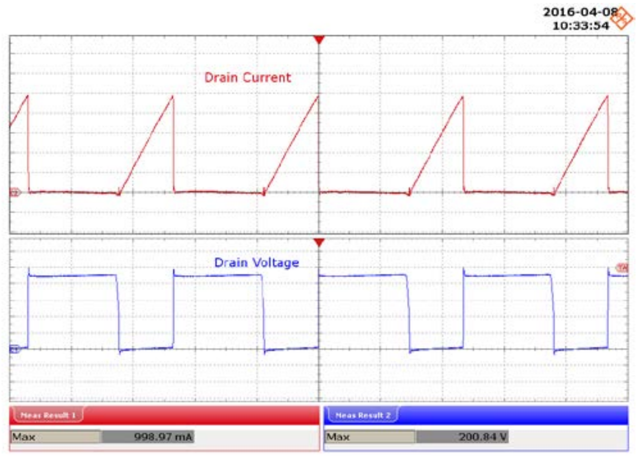

Figure 52 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

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12.5 *Drain Voltage and Current Start-up Profile*

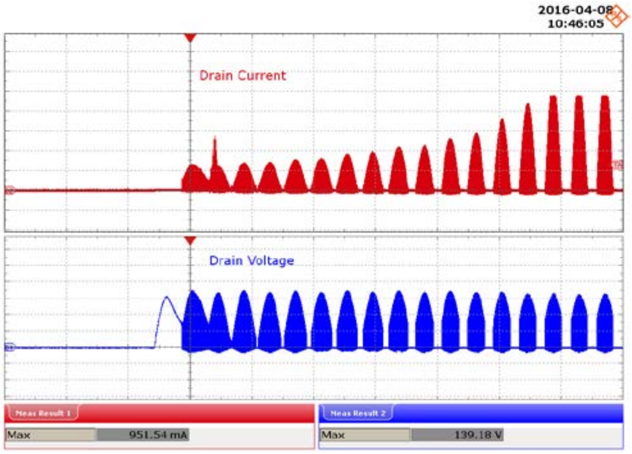

Figure 53 – 90 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

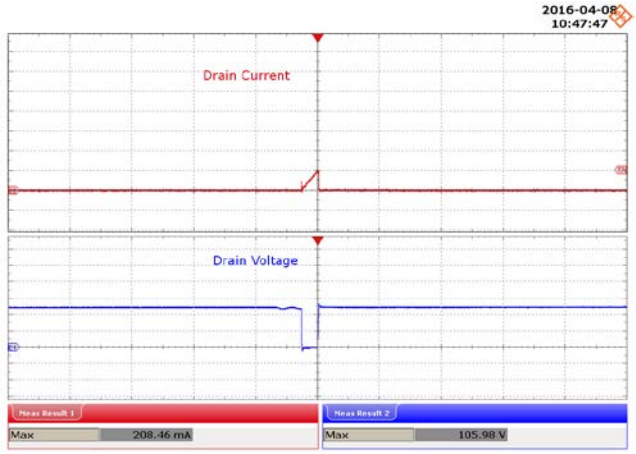

Figure 54 – 90 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

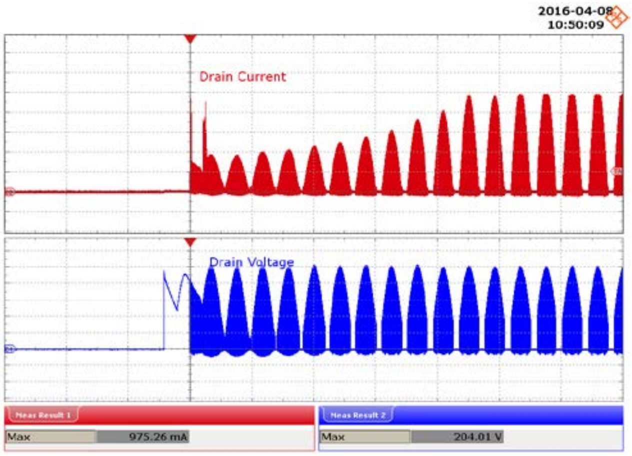

Figure 55 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

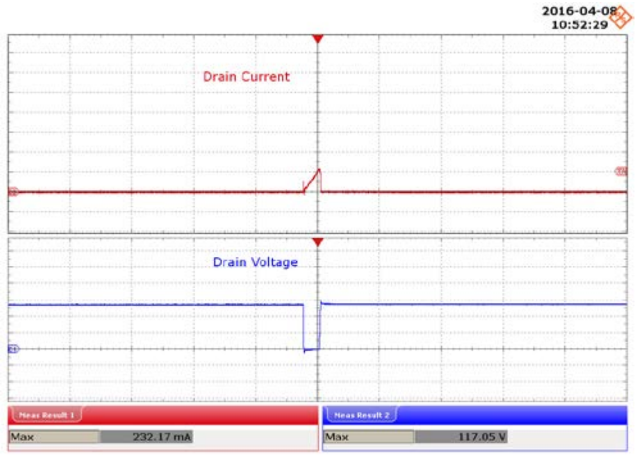

Figure 56 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

12.6 *Drain Voltage and Current During Output Short-Circuit*

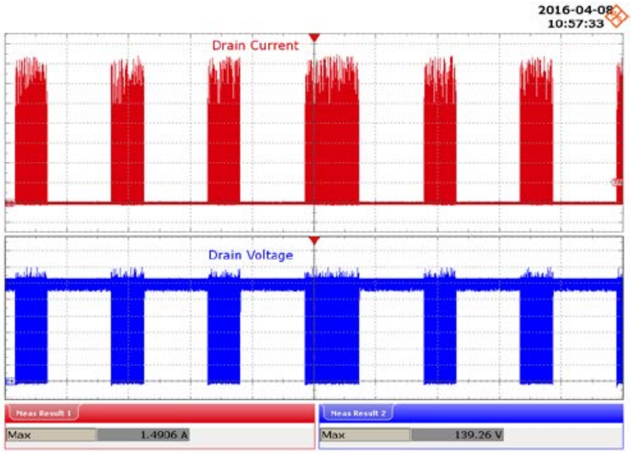

Figure 57 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 20 V / div., 1 s / div.

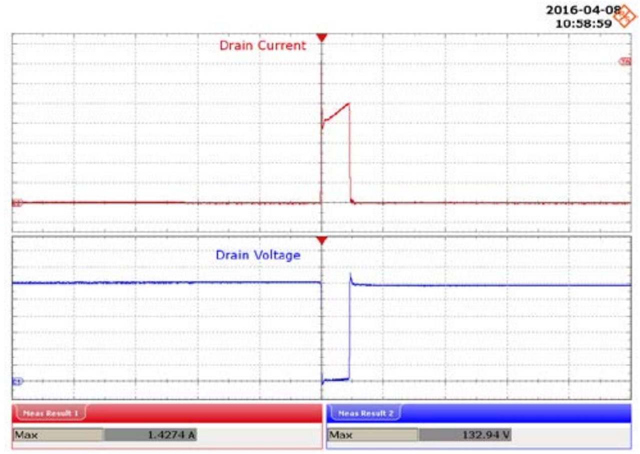

Figure 58 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 20 V / div., 2 μs / div.

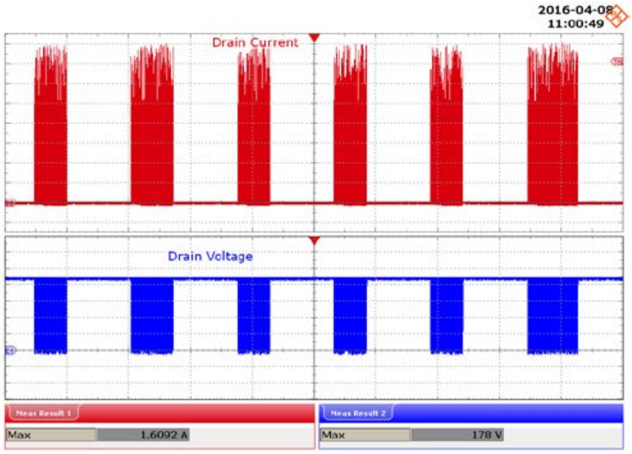

Figure 59 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

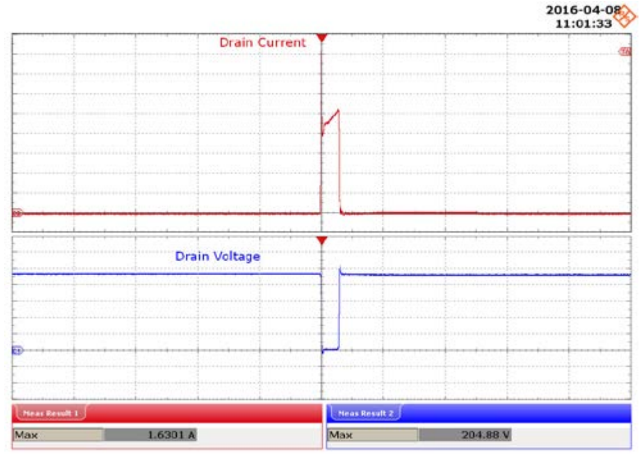

Figure 60 – 132 VAC, 67 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

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12.7 *Output Diode Voltage and Current in Normal Operation*

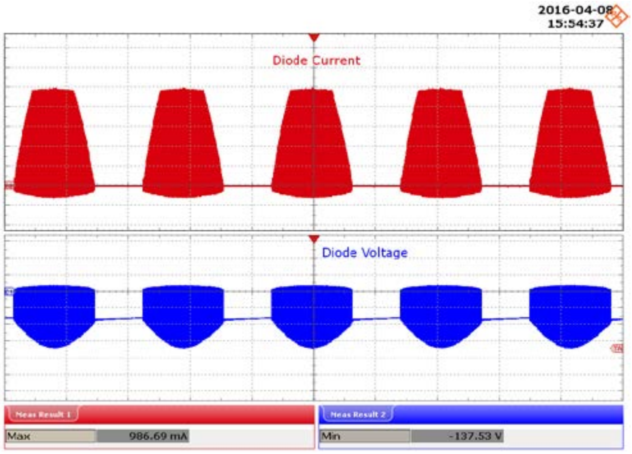

Figure 61 – 90 VAC, 67 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

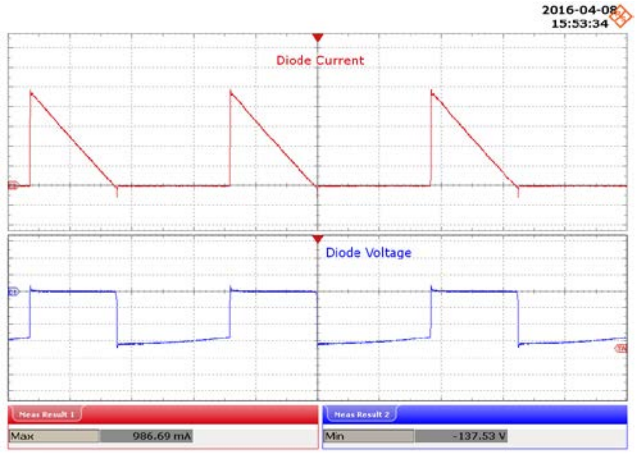

Figure 62 – 90 VAC, 67 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

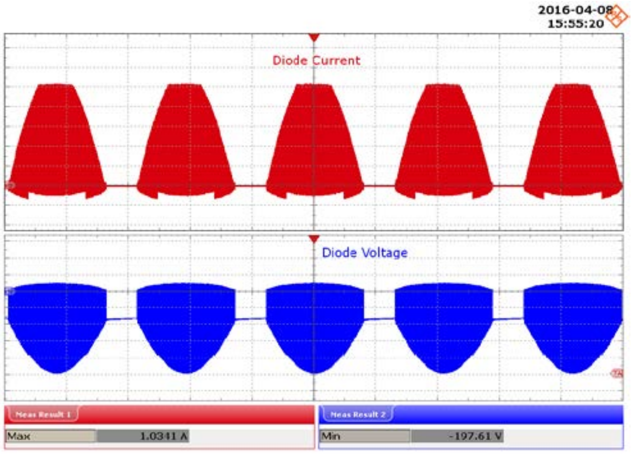

Figure 63 – 132 VAC, 67 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

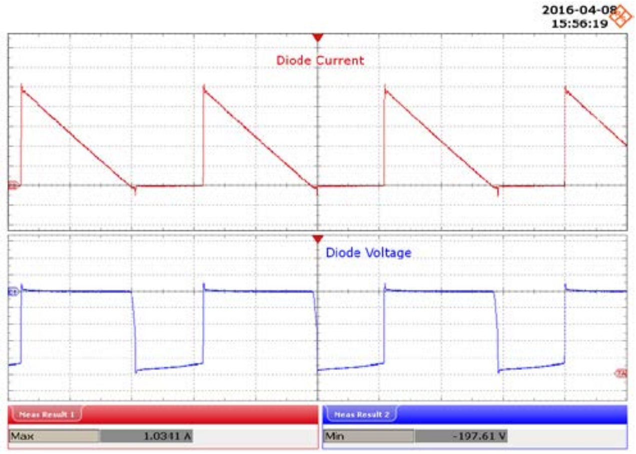

Figure 64 – 132 VAC, 67 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

12.8 *Output Voltage and Current – Open Output LED Load*

Maximum measured no-load output voltage is below the surge voltage rating of the output capacitor.

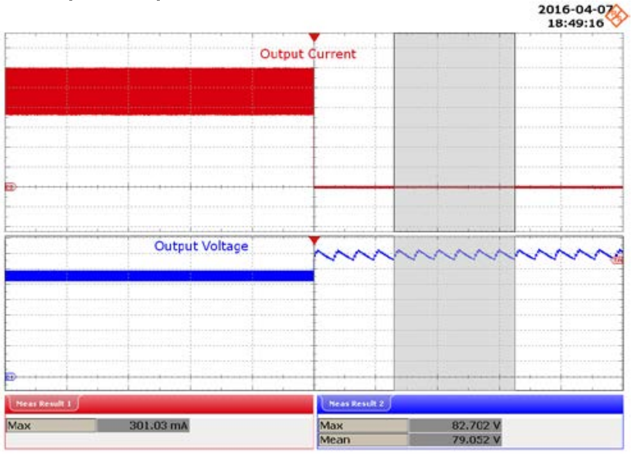

Figure 65 – 100 VAC, 67 V LED Load.
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

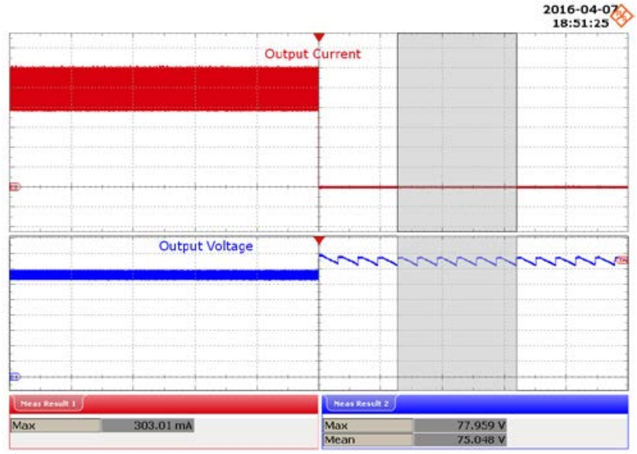

Figure 66 – 120 VAC, 67 V LED Load.
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

12.9 *Output Voltage and Current – Start-up at Open Output Load*

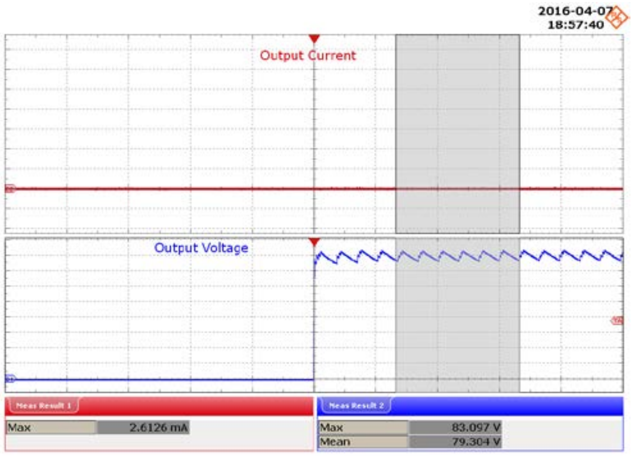

Figure 67 – 100 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

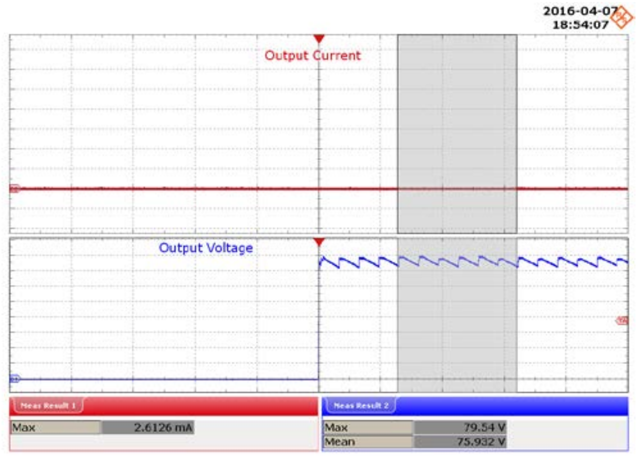

Figure 68 – 120 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

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12.10 *Output Ripple Current*

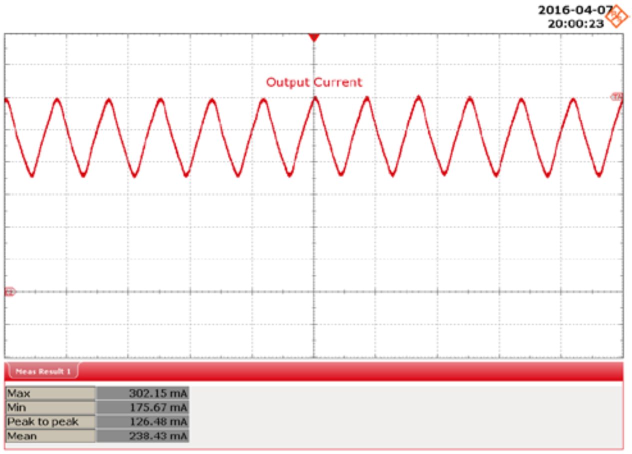

Figure 69 – 90 VAC, 60 Hz, 67 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

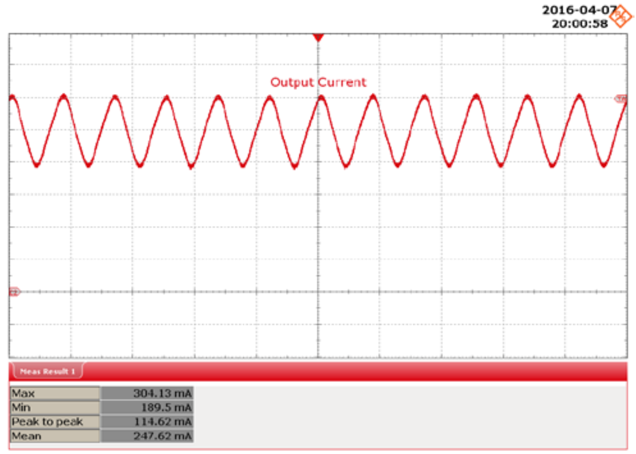

Figure 70 – 115 VAC, 60 Hz, 67 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

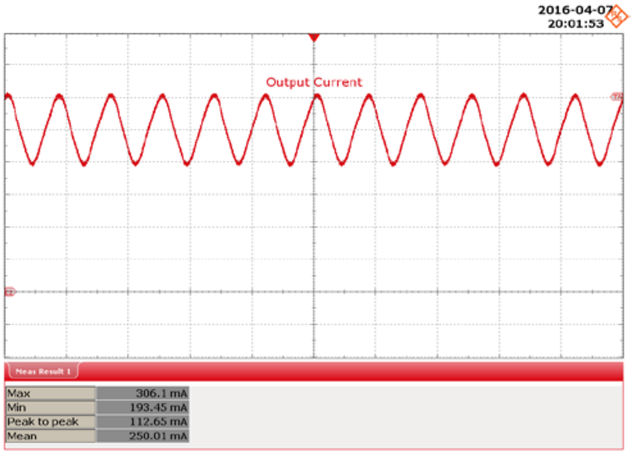

Figure 71 – 120 VAC, 60 Hz, 67 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

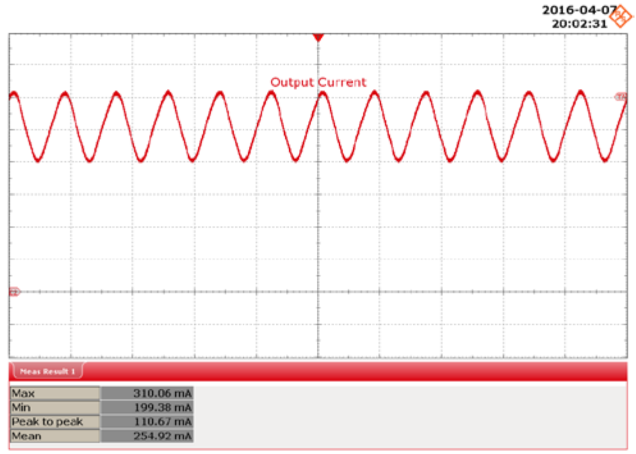

Figure 72 – 132 VAC, 60 Hz, 67 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (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	302	176	238.4	0.53	26.36
115	304	189.5	247.6	0.46	23.20
120	306	193.5	250	0.45	22.52
132	310	199.8	255	0.43	21.62

13 AC Cycling Test

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

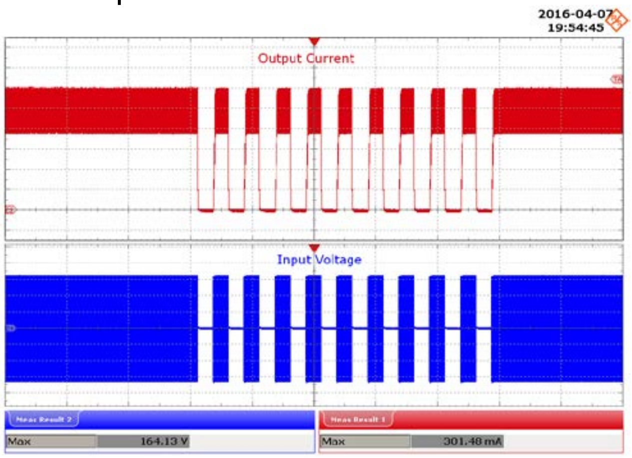

Figure 73 – 115 VAC, 67 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

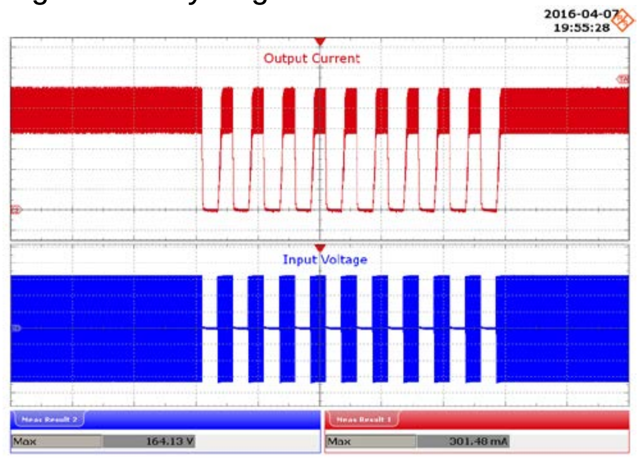

Figure 74 – 115 VAC, 67 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

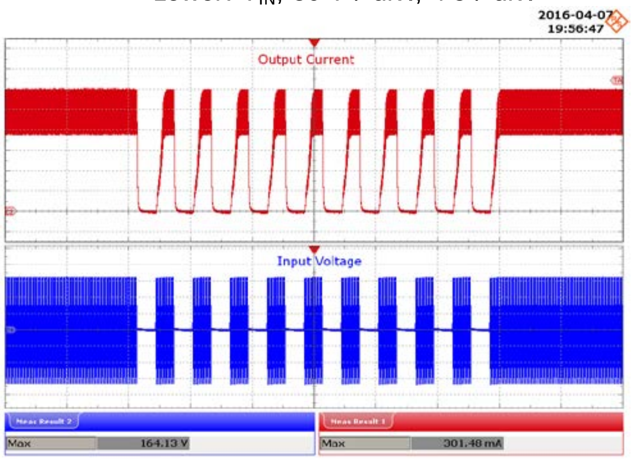

Figure 75 – 115 VAC, 67 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

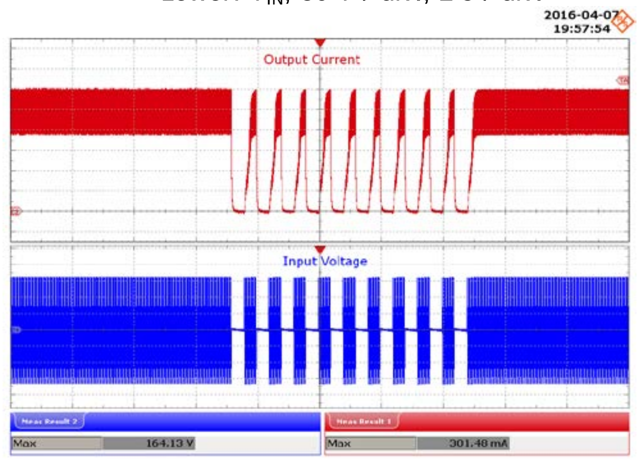

Figure 76 – 115 VAC, 67 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

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14 Conducted EMI

14.1 *Test Set-up*

14.1.1 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. 67 V LED load with input voltage set at 115 VAC.

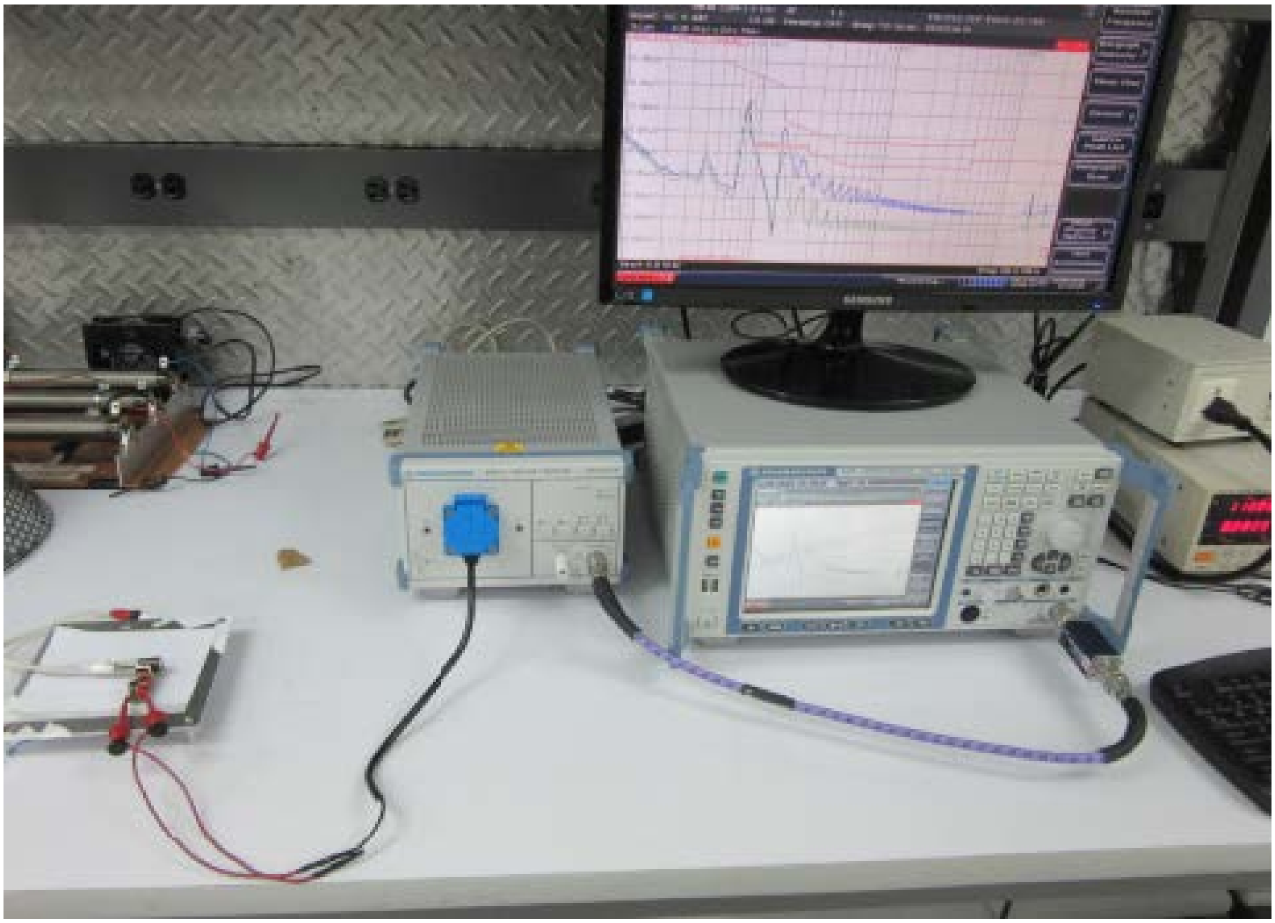

Figure 77 – Conducted EMI Test Set-up.

14.2 *EMI Test Result*

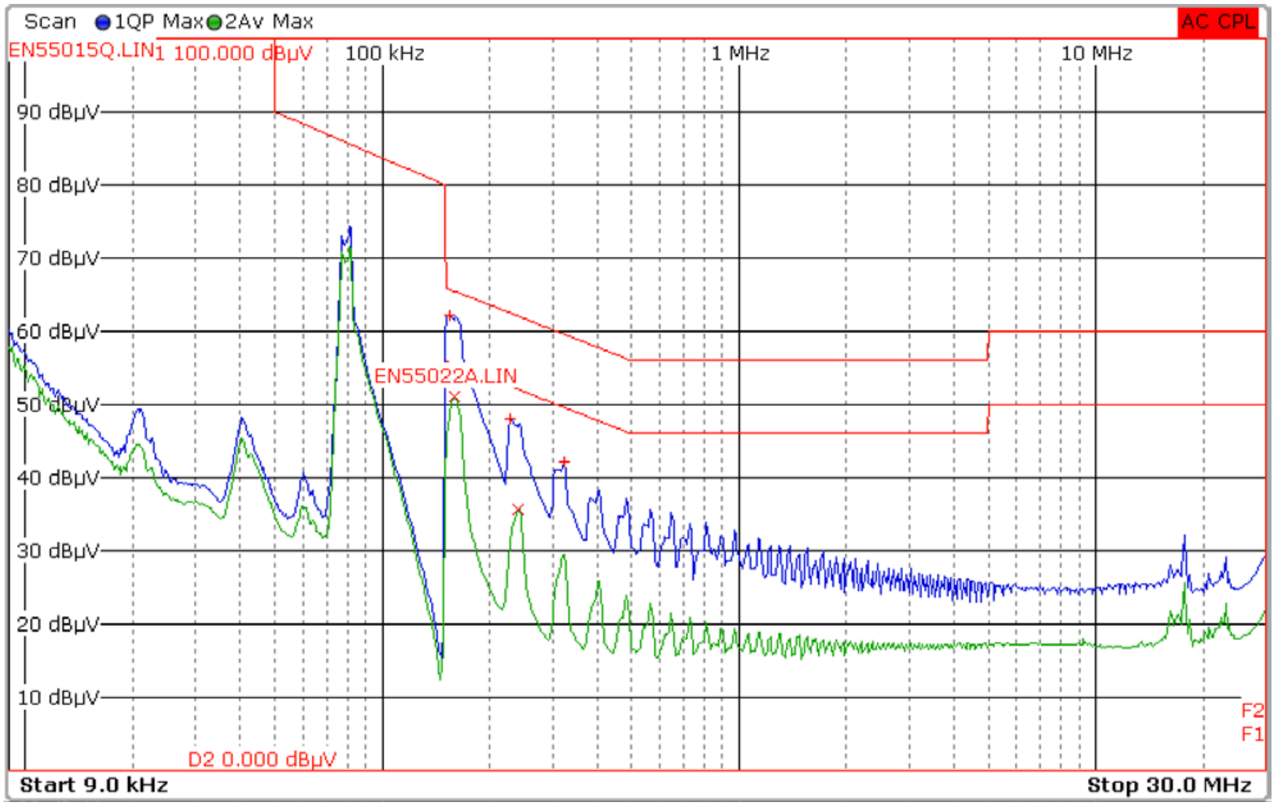

Figure 78 – Conducted EMI QP Scan at 67 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	154.5000 kHz	62.23 L1	-3.52 dB
2 Average	159.0000 kHz	51.03 L1	-4.49 dB
1 Quasi Peak	228.7500 kHz	48.01 L1	-14.48 dB
2 Average	240.0000 kHz	35.72 L1	-16.38 dB
1 Quasi Peak	323.2500 kHz	42.09 L1	-17.53 dB

Figure 79 – Conducted EMI Data at 115 VAC, 67 V LED Load.

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15 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	120	L to N	0	Pass
-1000	120	L to N	0	Pass
+1000	120	L to N	90	Pass
-1000	120	L to N	90	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	120	L to N	0	Pass
-2500	120	L to N	0	Pass
+2500	120	L to N	90	Pass
-2500	120	L to N	90	Pass

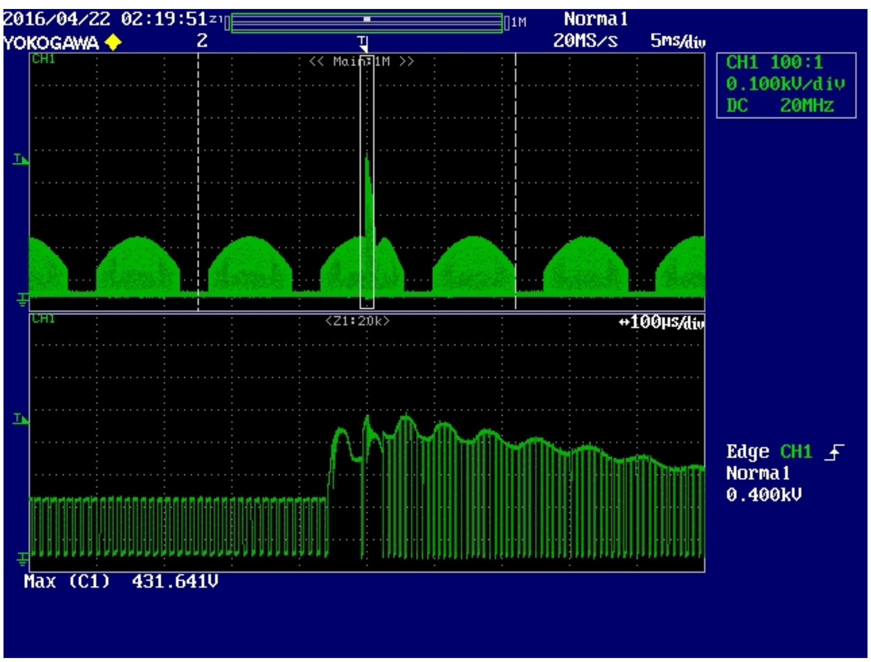

Figure 80 – +1000 kV Differential Surge, 90º Phase Angle.
V_{DRAIN}, 100 V / div., 5 m / div.
Peak V_{DRAIN}: 432 V.

16 Brown-in/Brown-out Test

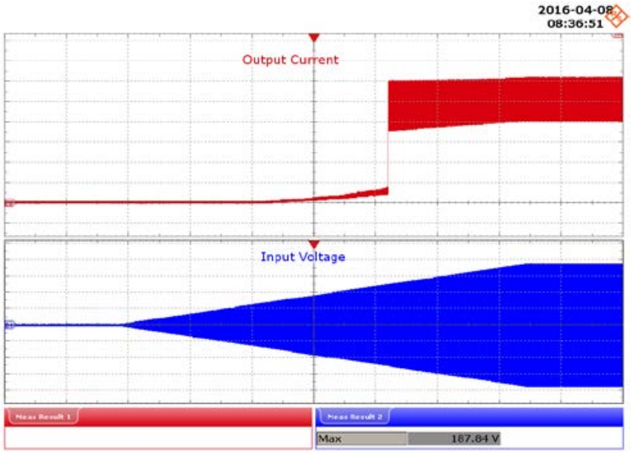

Figure 81 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

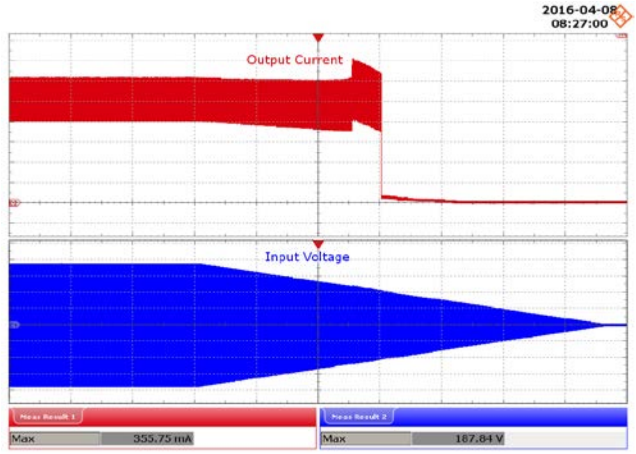

Figure 82 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

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17 Revision History

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

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