Design Example Report

Title	***20.4 W Non-Dimmable, High Efficiency (>94%), and Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1604D***
Specification	190 VAC – 300 VAC Input; 120 V, 170 mA Output
Application	T8 Tube End
Author	Applications Engineering Department
Document Number	DER-548
Date	June 30, 2016
Revision	1.1

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <30% flicker percent requirement
- Highly energy efficient, >93.5% over input range
- Low cost and low component count for compact PCB solution
  - Utilizes off-the-shelf Drum Core type inductor
- 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 cost, non-isolated non-dimmable buck LED driver designed to drive a 120 V LED voltage string at 170 mA output current from an input voltage range of 190 VAC to 300 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-548 offers a low cost compact size solution for 20 W LED drivers. The key design goals were high efficiency, accurate constant current regulation and low components count.

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

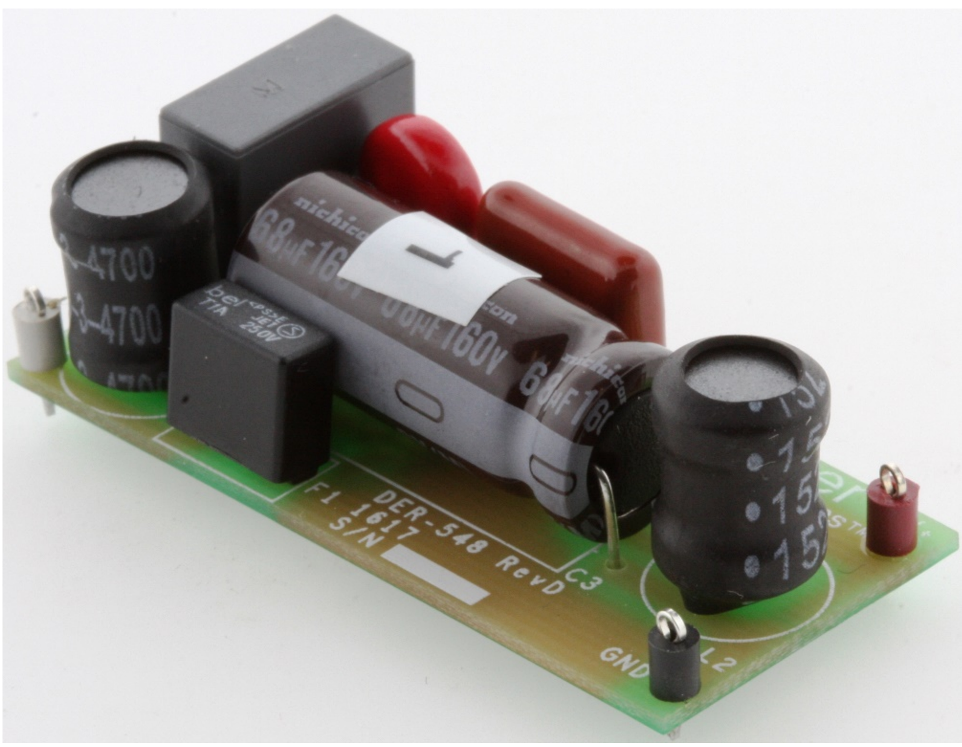

Figure 1 – Populated Circuit Board.

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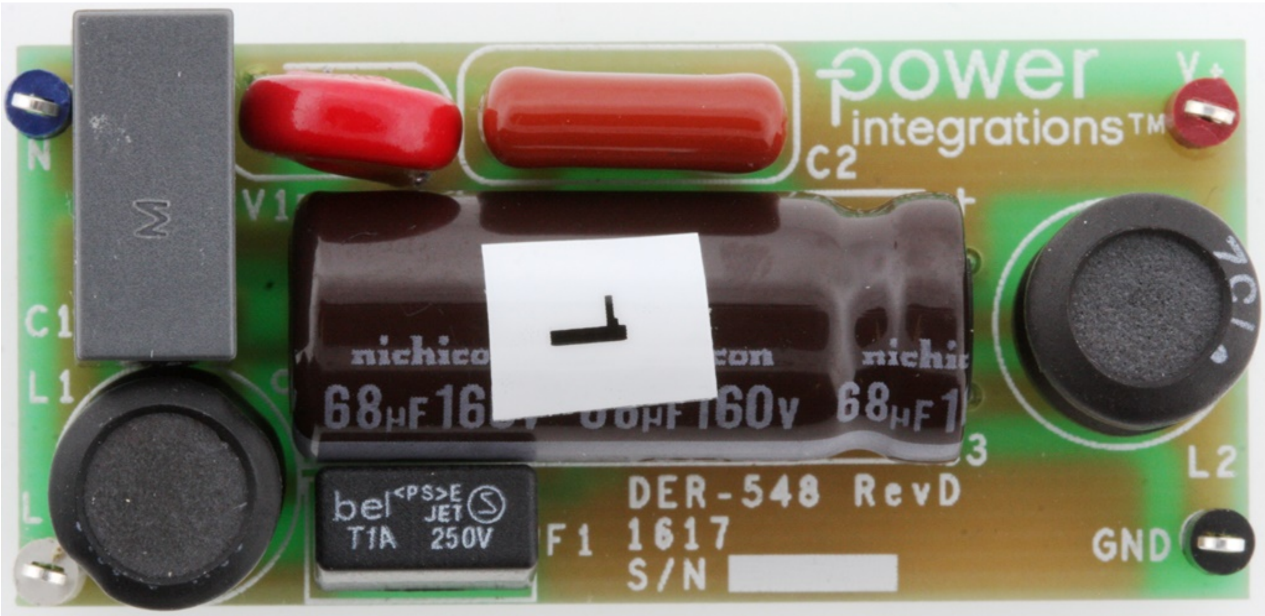

Figure 2 – Populated Circuit Board, Top View.

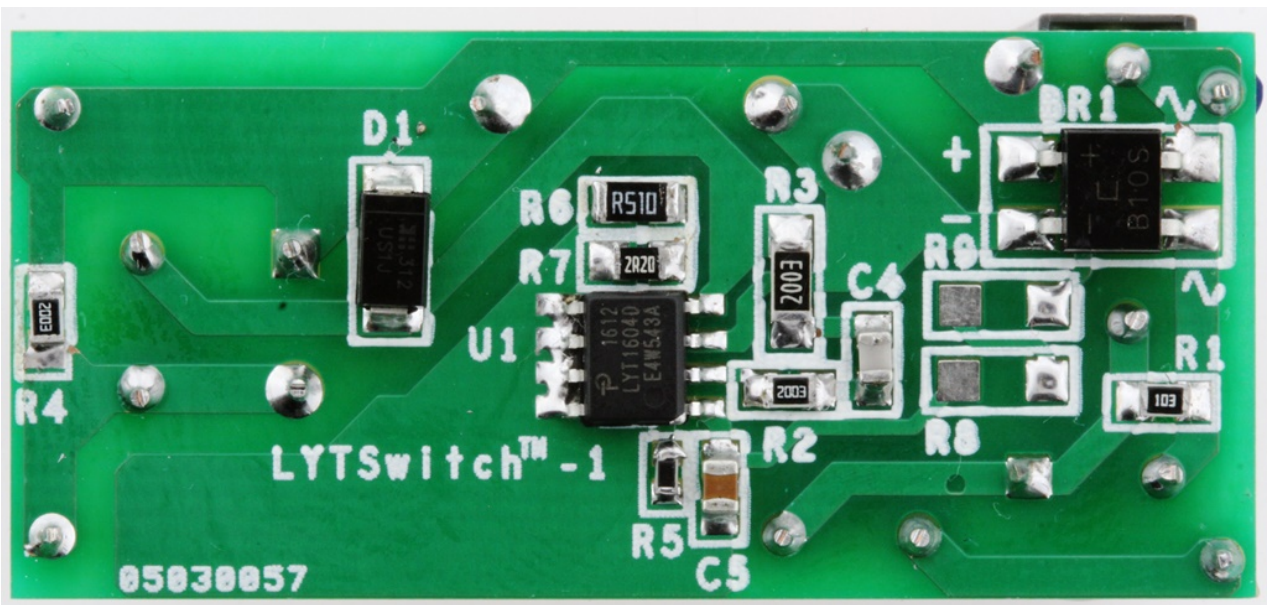

Figure 3 – Populated Circuit Board, Bottom View.

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}	190	230	300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		120		V	
Output Current	I_{OUT}		170		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		20.4		W	
Efficiency						
Full Load	η		94		%	230 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 230 VAC / 50 Hz.
Ambient Temperature	T_{AMB}		85		ºC	Free Convection, Sea Level.

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3 Schematic

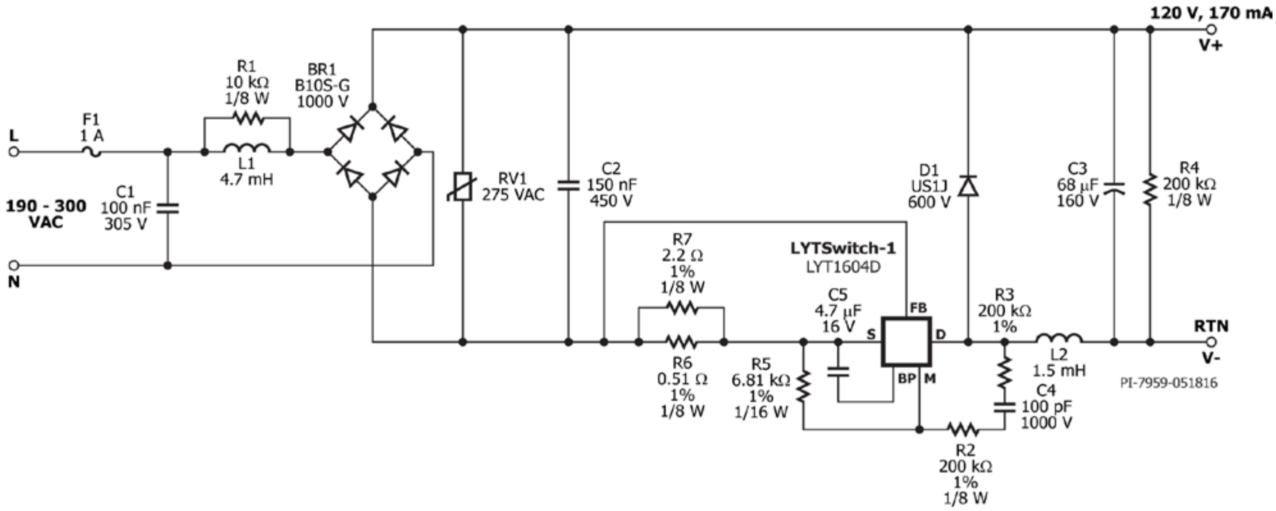

Figure 4 – Schematic.

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 120 V output non-isolated buck LED driver with 170 mA constant current output. The LYT1604D device was selected from the power table based on maximum output power of 22 W in the datasheet.

4.1 Input Stage

The input fuse F1 provides safety protection from component failures. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 275 VAC rated part was selected being with a maximum clamping voltage specification lower than the device drain voltage (710 V). The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD

The input fuse F1 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 275 VAC rated part was selected with a maximum clamping voltage specification of 710 VDC lower than the device drain voltage (725 V). The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD. For higher surge capability such as for this design > 1kV, C1 and L1 were placed before the bridge rectifier BR1, but a safety X-capacitor is required for C2, and the RV1 was placed after BR1.

4.2 EMI Filter

Inductor L1 serves as differential choke. Inductor L1, C1 and C2 capacitors form as an emi pi filter which works to filter differential and common mode noises. Resistor R1 damps the resonance of L1 to make it more effective in blocking high frequency noises. 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 internal mosfet of U1 and the power inductor L2 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.

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The output capacitor C3 provides output voltage ripple filtering to minimize the output ripple current. To avoid long ghosting effect of light output after power off, resistor R4 preload discharges the output capacitor voltage below the LED voltage.

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1, which provides power to the IC during the switch on time. The IC internal regulator draws power from high voltage DRAIN (D) pin and charge the bypass capacitor C5 during the power switch off time. The typical BP pin voltage is 5.22 V. To keep the IC operating normally especially during the dead zone, where 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 (R_{FB}) R6 and R7 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 LYT14xx, and k= 3.6 for LYT16xx)

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

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 resistors R2 and R3, thus line over voltage detection is calculated as; where R2+R3= R_{UPPER} is assumed to be 400 kΩ ±1%.

$$V_{LINE\_OVP} = I_{IOV} \times (R2+R3) + V_{OUT}$$

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.

MULTIFUNCTION (M) pin also monitors the output for any over voltage and under voltage event. When the internal mosfet is in off state, the output voltage is monitored through a coupling capacitor (C4) and divider resistors R_{UPPER} and R5. When an output open-load condition occurs, the voltage at the M pin will rise abruptly and when it exceeds the threshold of 2.4 V, the IC will inhibit switching instantaneously and initiate

auto-restart to limit the output voltage from further rising. The 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 R_{UPPER} is set to a fixed value of 400 kΩ ±1% and R5 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.

R5 can be calculated as follows;

$R5 = 2\ V \times R_{UPPER} / (V_{OUT} - 2\ V)$; 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.

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5 PCB Layout

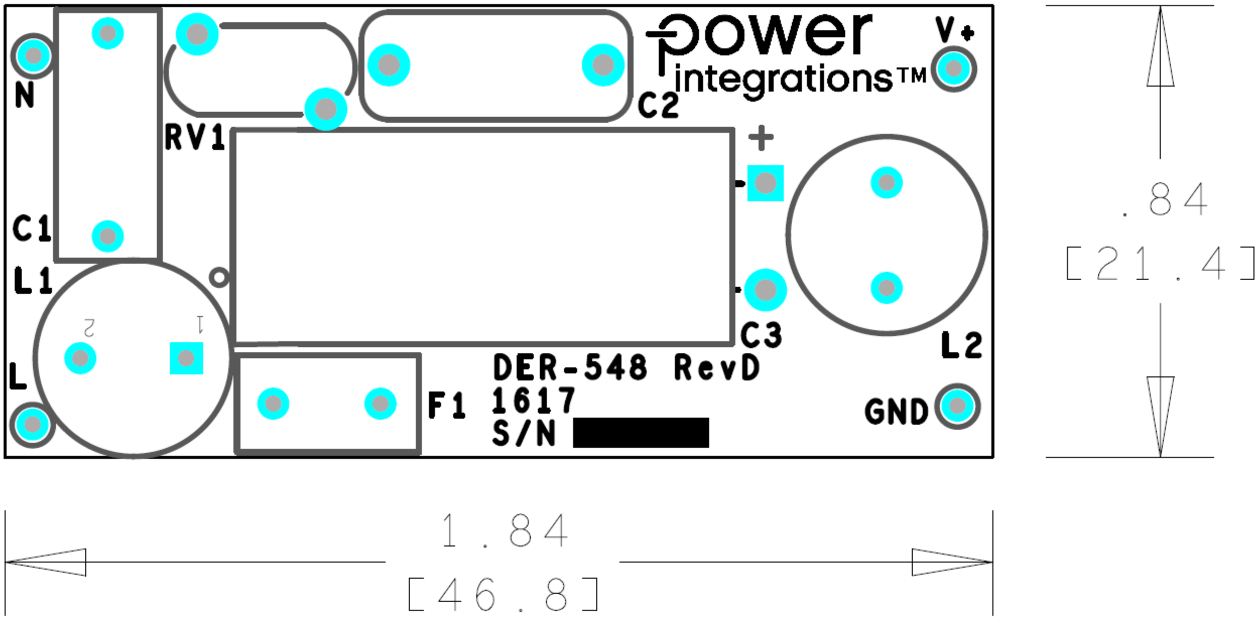

Figure 5 – Top Side.

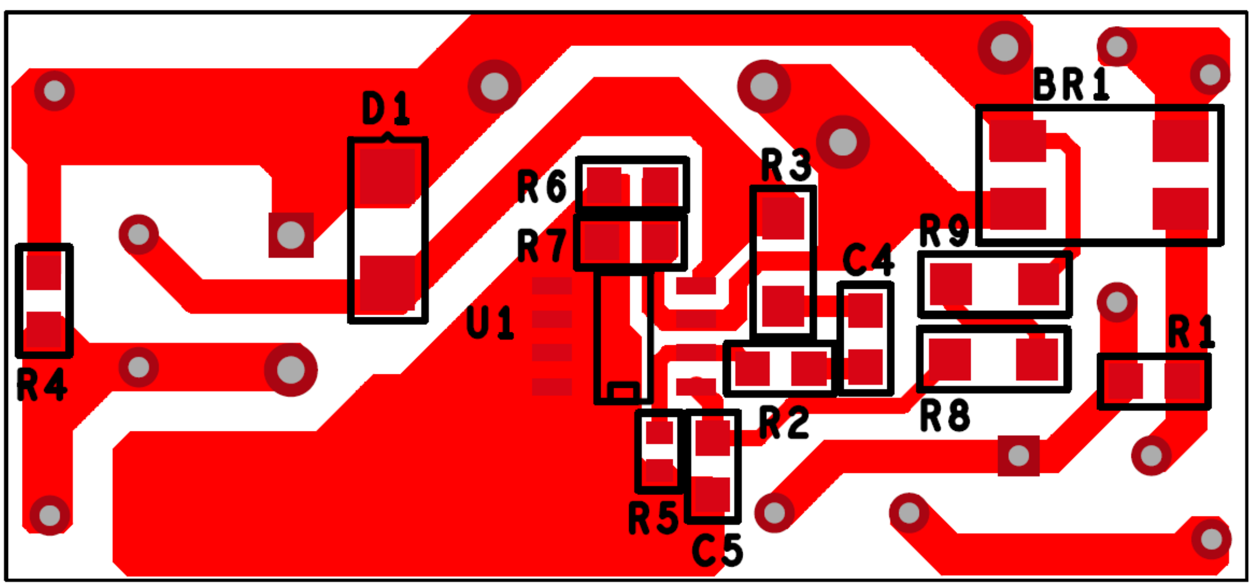

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Ref Des	QTY	Description	Mfg Part Number	Mfg
1	BR1	1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	C1	1	100 nF, 305 VAC, Film, X2	B32921C3104M	Epcos
3	C2	1	150 nF, 450 V, Film	MEXXF3150	Duratech
4	C3	1	68 μF, 20%, 160 V, CAP ALUM, RADIAL (10 x 26.5)	UCY2C680MPD1TD	Nichicon
5	C4	1	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
6	C5	1	4.7 μF, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KA73L	Murata
7	D1	1	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
8	F1	1	1 A, 250 V, Slow, Long Time Lag, RST 1	RST 1	Belfuse
9	L1	1	4.7 mH, 0.150 A, 20%	RL-5480-3-4700	Renco
10	L2	1	Inductor, Fixed, 1.5 mH, 430 mA, 3.8 Ω	RLB9012-152KL	Bourns
11	R1	1	RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
12	R2	1	RES, 200 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2003V	Panasonic
13	R3	1	RES, 200 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2003V	Panasonic
14	R4	1	RES, 200 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ204V	Panasonic
15	R5	1	RES, 6.81 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6811V	Panasonic
16	R6	1	RES, 0.51 Ω, 1%, 1/8 W 0805, SMD	RL0805FR-070R51L	Yageo
17	R7	1	RES, 2.2 Ω, 1%, 1/8 W, Thick Film, 0805	RC0805FR-072R2L	Yageo
18	RV1	1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
19	U1	1	LYTSwitch-1, Wide Range, 12 W, 45 V – 65 V, SO-8	LYT1604D	Power Integrations

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7 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			High Line		AC line voltage range
VACMIN	190.00		190.00	Volts AC	Minimum AC line voltage
VACTYP	245.00		245.00	Volts AC	Typical AC line voltage
VACMAX	300.00		300.00	Volts AC	Maximum AC line voltage
fL			50.00	Hz	AC mains frequency
VO	120.00		120.00	Volts DC	Worst case normal operating output voltage
IO	0.170		0.170	Amperes	Average output current specification
EFFICIENCY			0.85		Efficiency estimate
PO			20.40	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			4.34	us	On-time during the fixed on-time region at VACTYP
FSW			85.45	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.77		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	Off the shelf		Off the shelf		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			0.00	mm^2	Core effective cross cectional area
LE			0.00	mm	Core effective path length
AL			0.00	nH/turn^2	Core ungapped effective inductance
AW			0.00	mm^2	Window Area of the bobbin
BW			0.00	mm	Bobbin physical winding width
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			485	uH	Absolute minimum design inductance
LP_TYP	1500		1500	uH	Typical design inductance
LP_TOLERANCE			10	%	Tolerance of the design inductance
LP_MAX			4575	uH	Absolue maximum design inductance
TURNS			NA	Turns	Number of inductor turns
ALG			NA	nH/turn^2	Inductance per turns squared
BMAX			3700	Gauss	Operating maximum flux density in the fixed peak current region
BMAX_ACTUAL				Gauss	Actual saturation flux density in the fixed peak current region
BAC			NA	Gauss	AC flux density in the fixed peak current region
LG			NA	mm	Core air gap
BWE			NA	mm	Effective bobbin width
OD			NA	mm	Outer diameter of the wire with insulation
INS			NA	mm	Wire insulation

DIA			NA	mm	Outer diameter of the wire without insulation
AWG			NA		AWG of the bare wire.
CM			NA	Cmils	Bare wire circular mils
CMA			NA	Cmils/A	The wire is oversized for the design RMS current. Decrease the number of layers or wire outer diameter
CURRENT DENSITY			NA	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR			NA		NA
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.164	Amperes	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.612	Amperes	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.150	Amperes	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.187	Amperes	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.240	Amperes	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB (Non standard value)			0.490	Ohms	Non standard value of the feedback pin sense resistor
RFB (Standard 1% Value)			0.487	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)			6.81	kOhms	Non standard value of the lower resistor on the M-pin divider network
RLOWER (Standard 1% Value)			6.81	kOhms	Standard 1% value of the lower resistor on the M-pin divider network
LOAD OVERVOLTAGE THRESHOLD			144.074	Volts DC	Load overvoltage threshold
LINE OVERVOLTAGE THRESHOLD			522.00	Volts DC	Line overvoltage threshold
VOLTAGE STRESS PARAMETERS					
VDRAIN			424.26	Volts DC	Estimated worst case drain voltage
PIVD			424.26	Volts DC	Output Rectifier Maximum Peak Inverse Voltage

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8 Inductor Specification

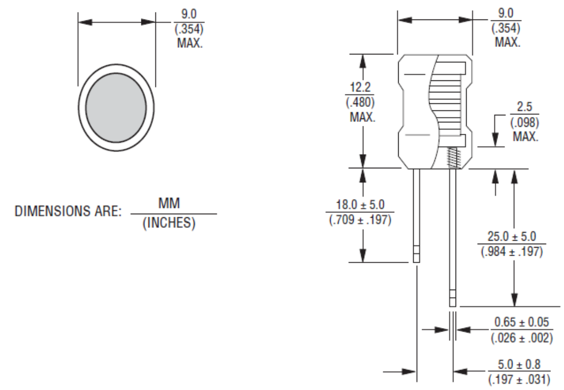
General Specifications

Inductance Drop at Rated Current (IDC).......5 %
Operating Temperature ....-55 °C to +125 °C
Storage Temperature ....-55 °C to +105 °C

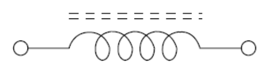
Materials

Core Material.......Ferrite DR core
Wire.......Enameled copper wire
Terminal ....Cu/AG/Sn
Tube.......Shrinkable tube 125 °C, 600 V

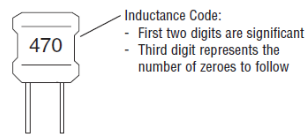
Product Dimensions



Electrical Schematic



Typical Part Marking



Electrical Characteristics

BOURNS Part No.	Inductance (uH)	Q ref.	Test freq. (MHz)		SRF (MHz) min.	RDC (ohms) max.	IDC (A) max.
			L	Q			
RLB9012-152KL	1500.0 ± 10 %	15	1K	0.252	1.10	3.800	0.43

9 Performance Data

All measurements were performed at room temperature using LED loads string. 1 minute soak time was applied before measurement.

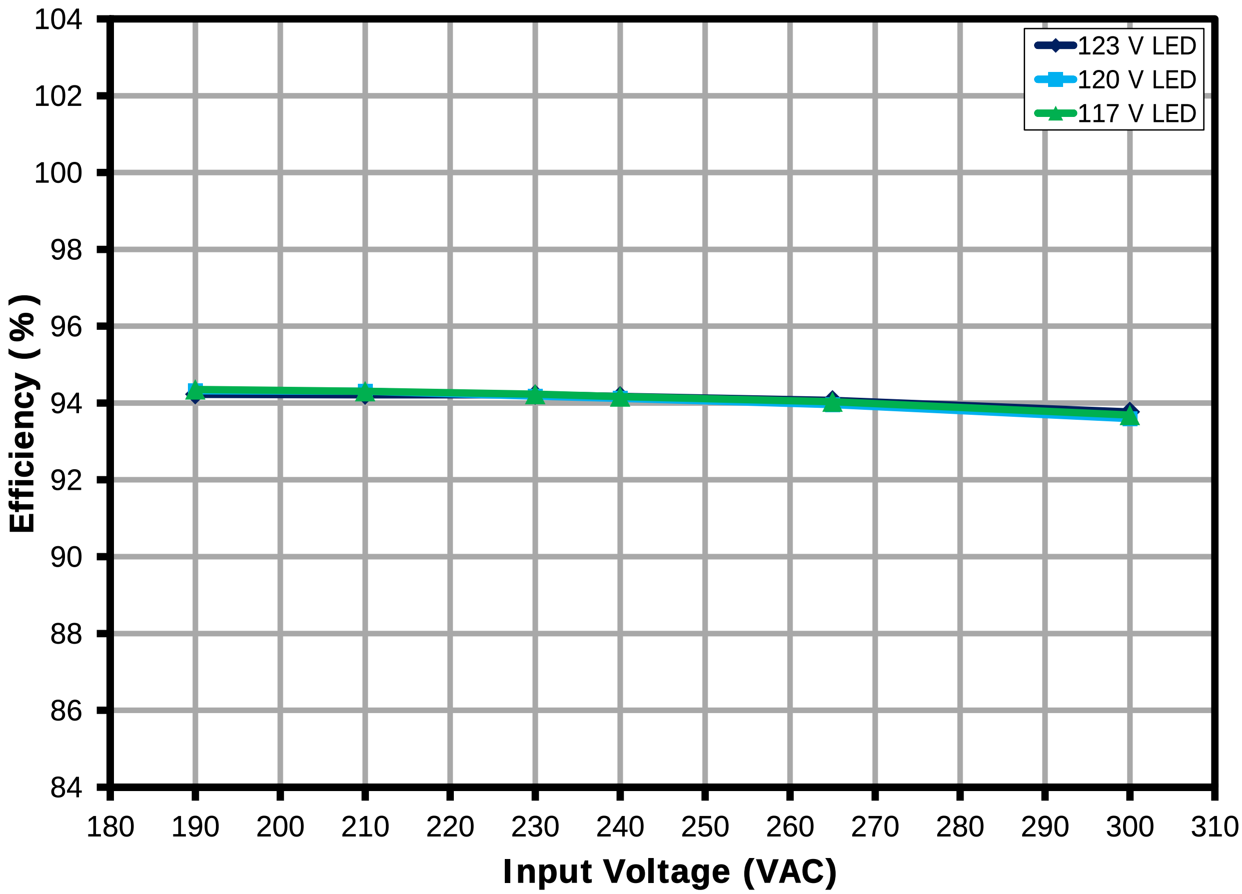


Figure 7 – Efficiency vs. Line and LED Load.

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9.1 Line Regulation

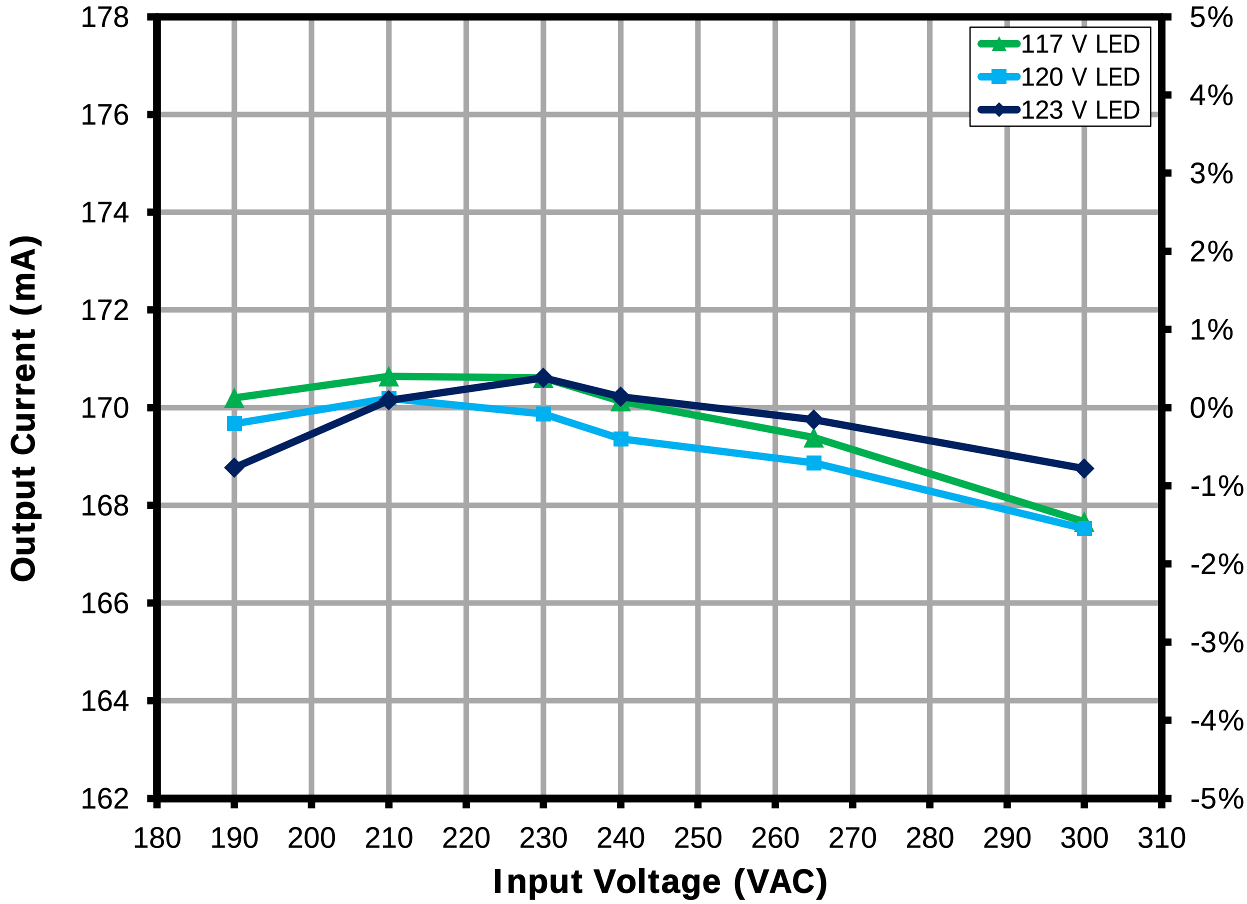

Figure 8 – Regulation vs. Line and LED Load.

9.2 Power Factor

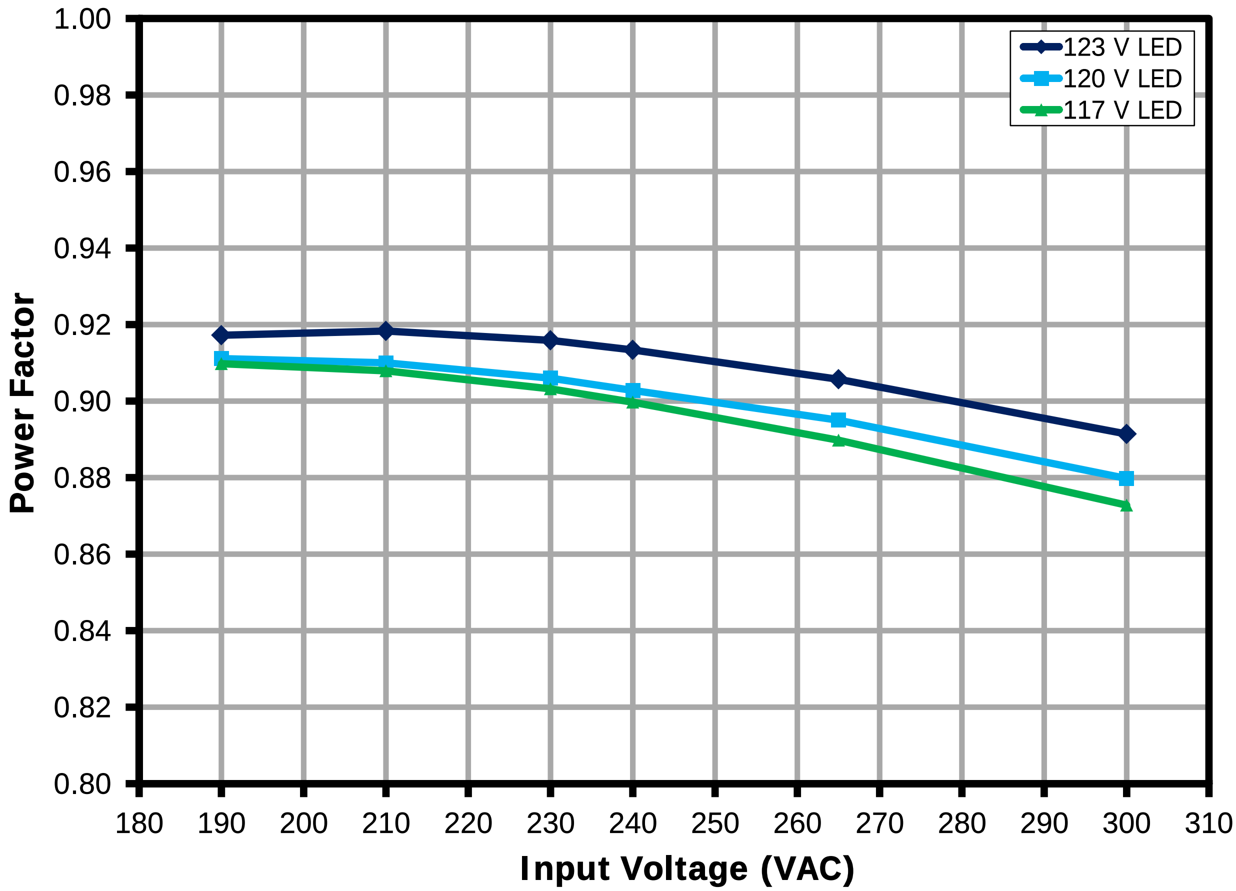

Figure 9 – Power Factor vs. Line and LED Load.

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9.3 %ATHD

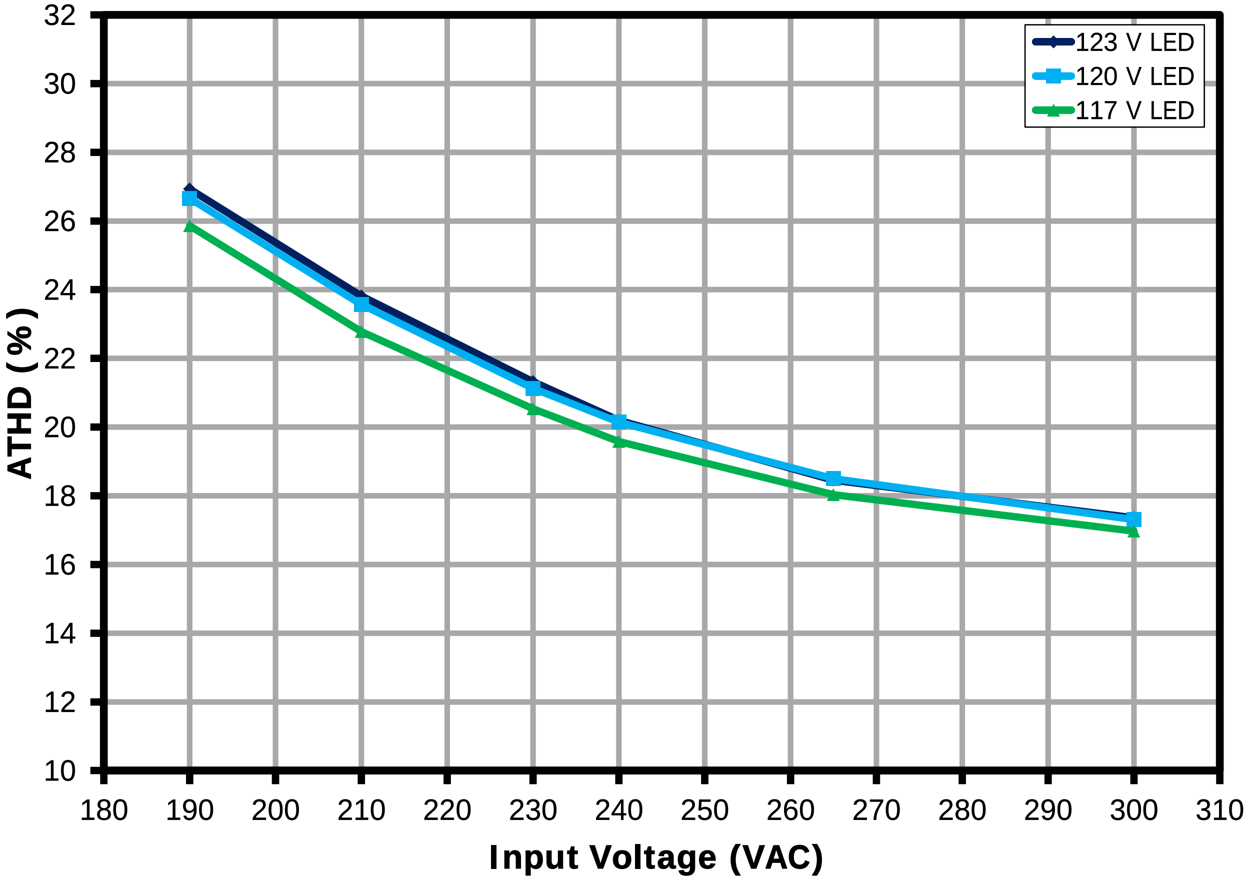

Figure 10 – %ATHD vs. Line and LED Load.

9.4 Individual Harmonics Content

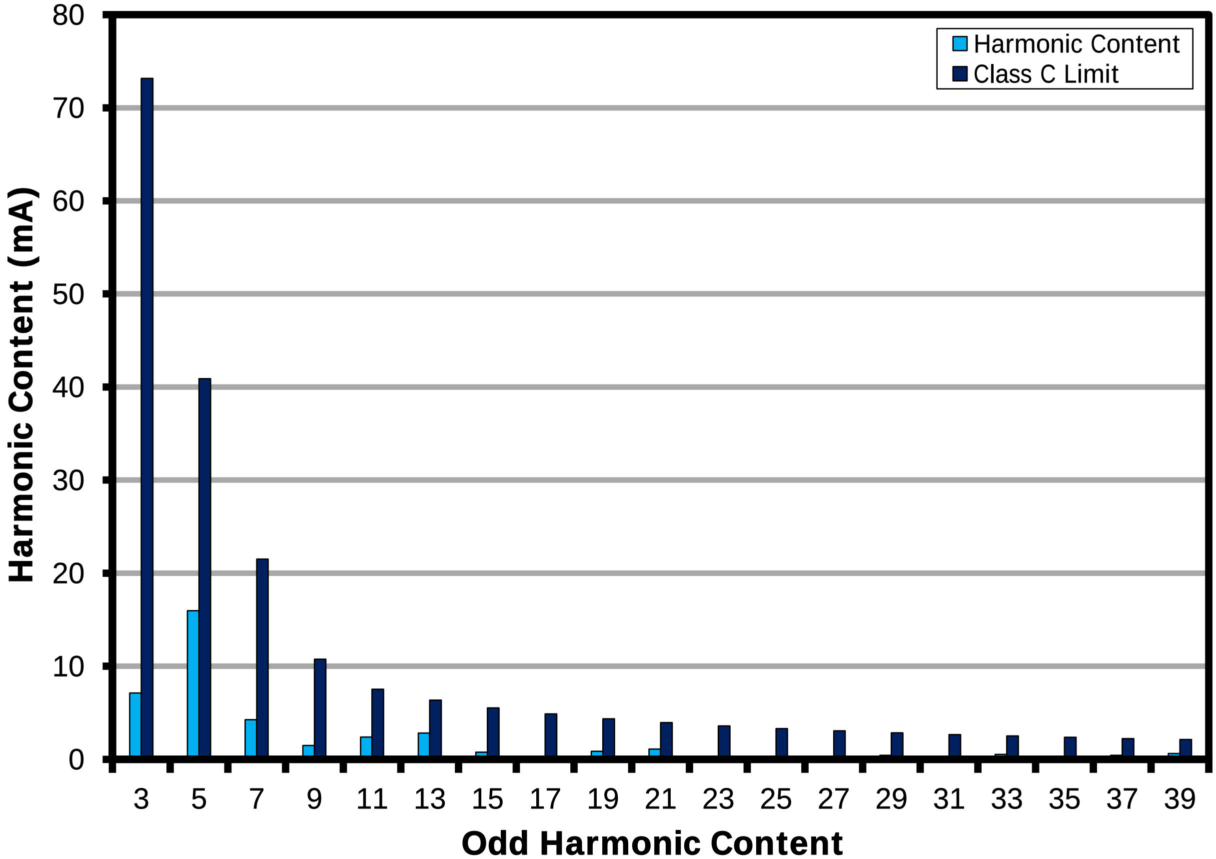

Figure 11 – 120 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10 Test Data

10.1 Test Data – 123 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)	
190	50	189.86	127.34	22.18	0.917	26.93	123.34	168.77	20.90	94.23
210	50	209.91	115.80	22.32	0.918	23.82	123.15	170.15	21.03	94.21
230	50	229.95	106.18	22.36	0.916	21.32	123.08	170.61	21.07	94.21
240	50	239.97	101.73	22.30	0.913	20.20	122.97	170.22	21.00	94.17
265	50	264.99	92.68	22.24	0.906	18.45	122.89	169.75	20.92	94.07
300	50	299.94	82.86	22.15	0.891	17.36	122.77	168.75	20.77	93.77

10.2 Test Data – 120 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)	
190	50	189.79	125.23	21.66	0.911	26.66	119.81	169.67	20.43	94.32
210	50	209.85	113.44	21.66	0.910	23.57	119.50	170.19	20.43	94.31
230	50	229.89	103.75	21.61	0.906	21.13	119.29	169.87	20.35	94.18
240	50	239.91	99.35	21.52	0.903	20.14	119.10	169.36	20.25	94.12
265	50	264.93	90.63	21.49	0.895	18.50	119.12	168.87	20.19	93.96
300	50	299.87	81.10	21.40	0.880	17.31	119.13	167.52	20.03	93.60

10.3 Test Data – 117 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)	
190	50	189.84	122.42	21.14	0.910	25.86	116.63	170.20	19.95	94.35
210	50	209.89	111.10	21.17	0.908	22.78	116.46	170.64	19.97	94.30
230	50	229.93	101.91	21.16	0.903	20.53	116.38	170.61	19.94	94.23
240	50	239.95	97.72	21.10	0.900	19.58	116.28	170.13	19.87	94.17
265	50	264.97	89.12	21.01	0.890	18.03	116.19	169.39	19.76	94.03
300	50	299.91	79.60	20.84	0.873	16.97	116.02	167.66	19.52	93.69

10.4 Test Data, Harmonic Content at 230 VAC with 120 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	99.35	21.518	20.144
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	90.67			
2	0.10	0.11%		
3	7.13	7.86%	73.16	Pass
5	15.98	17.62%	40.88	Pass
7	4.27	4.71%	21.52	Pass
9	1.48	1.63%	10.76	Pass
11	2.39	2.64%	7.53	Pass
13	2.83	3.12%	6.37	Pass
15	0.77	0.85%	5.52	Pass
17	0.24	0.26%	4.87	Pass
19	0.87	0.96%	4.36	Pass
21	1.12	1.24%	3.94	Pass
23	0.26	0.29%	3.60	Pass
25	0.10	0.11%	3.31	Pass
27	0.31	0.34%	3.07	Pass
29	0.43	0.47%	2.86	Pass
31	0.32	0.35%	2.67	Pass
33	0.54	0.60%	2.51	Pass
35	0.21	0.23%	2.37	Pass
37	0.44	0.49%	2.24	Pass
39	0.63	0.69%	2.12	Pass

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11 Thermal Performance

11.1 Thermal Performance Scan – Open Frame Unit

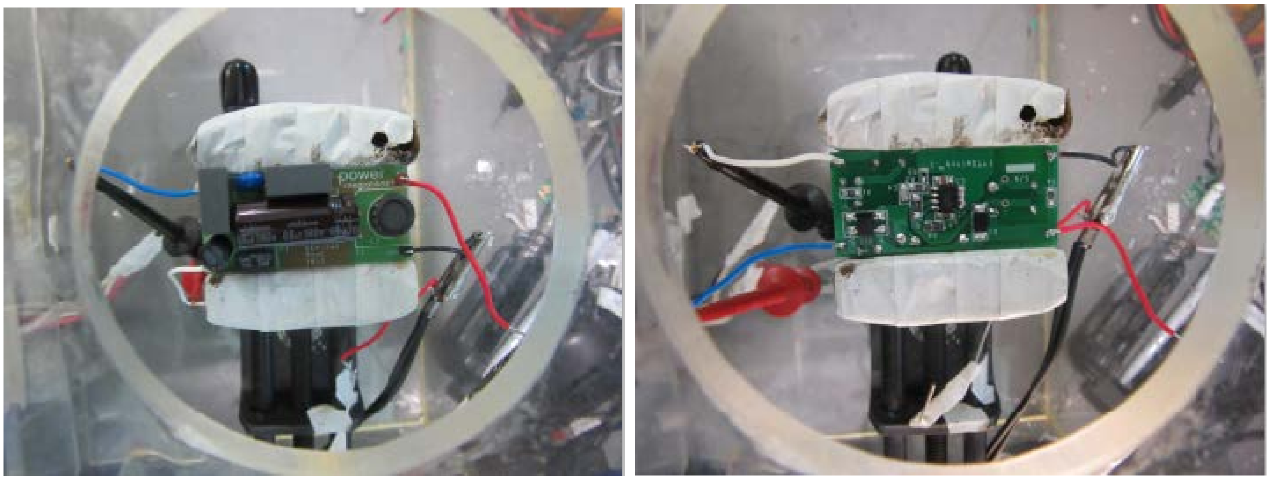

Figure 12 – Test Set-up Picture - Open Frame.

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.

11.1.1 Thermal Scan

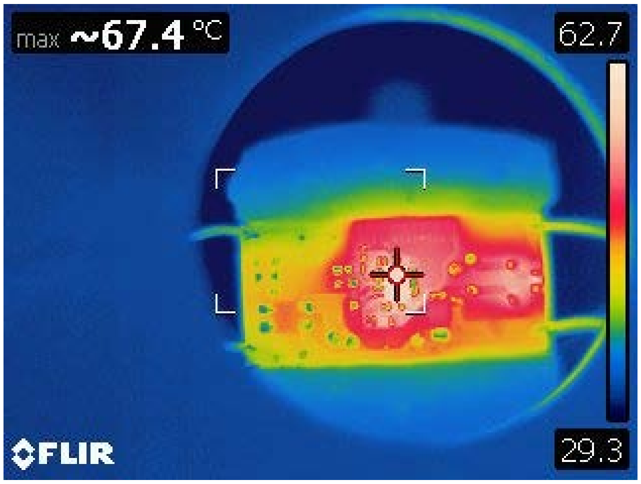

Figure 13 – 230 VAC, 120 V LED Load.
Spot 1: LYT1604D (U1): 67.4 ºC.

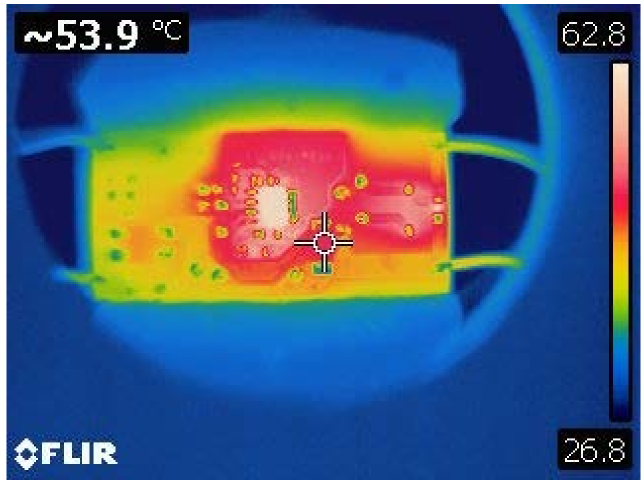

Figure 14 – 230 VAC, 120 V LED Load.
Spot 1: Flywheel Diode (D1): 53.9 ºC.

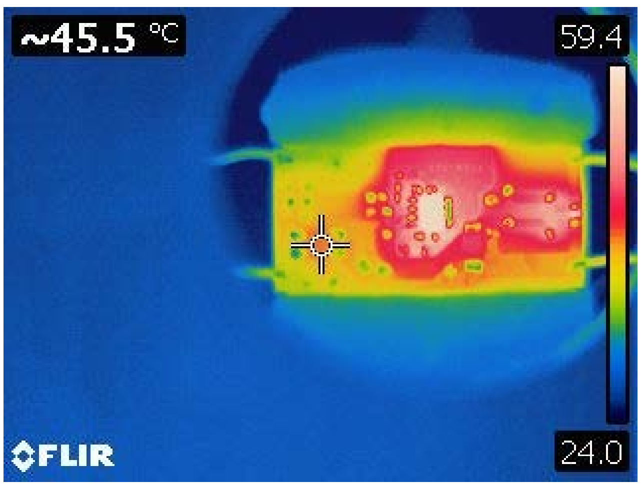

Figure 15 – 230 VAC, 120 V LED Load.
Spot 1: Bridge Diode (BR1): 45.5 ºC.

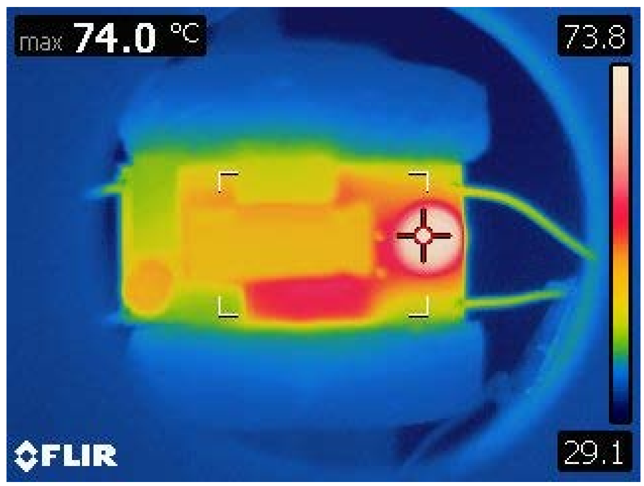

Figure 16 – 230 VAC, 120 V LED Load.
Spot 1: Buck Inductor (L2): 74 ºC.

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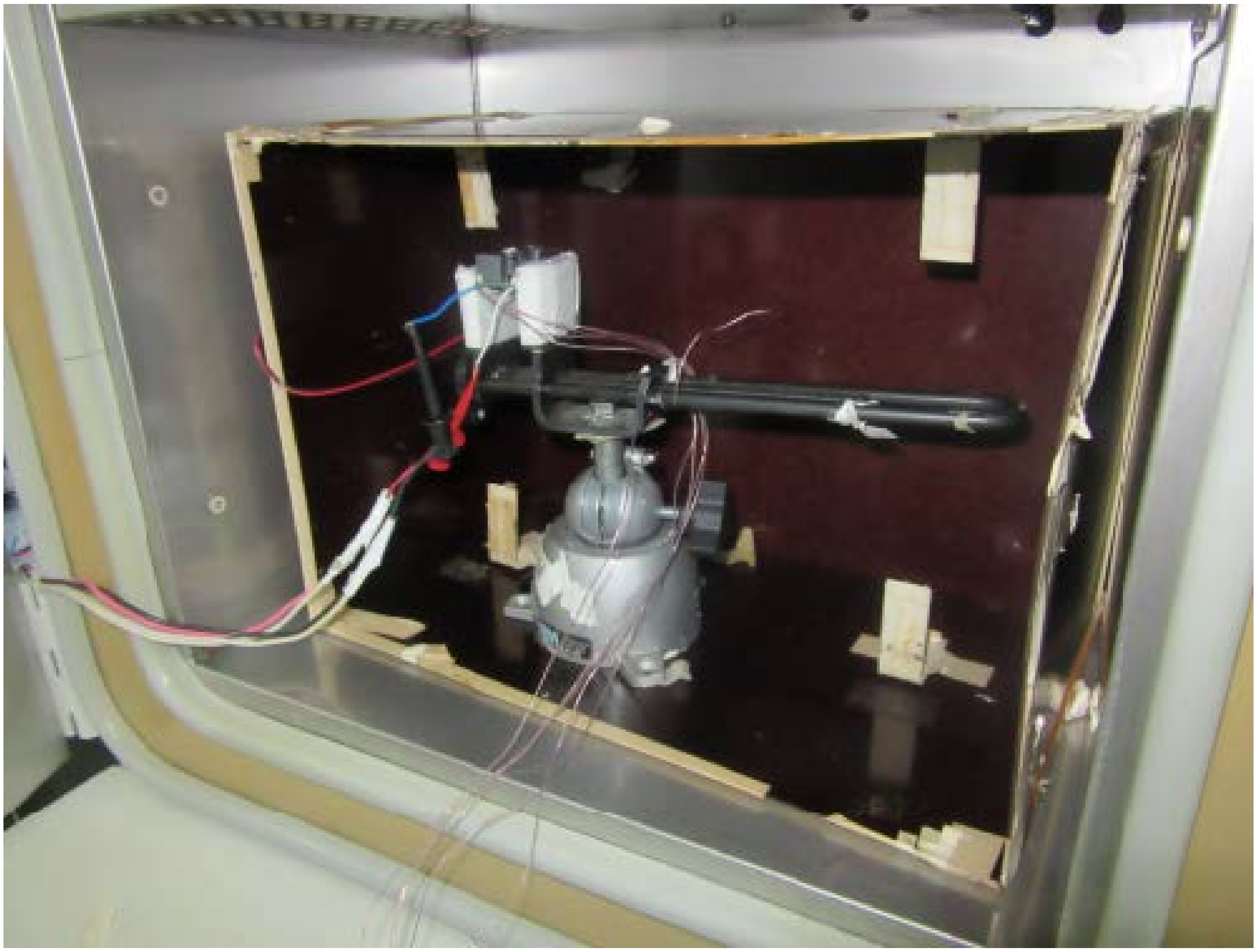
11.2 Thermal Performance at 85 ºC Ambient



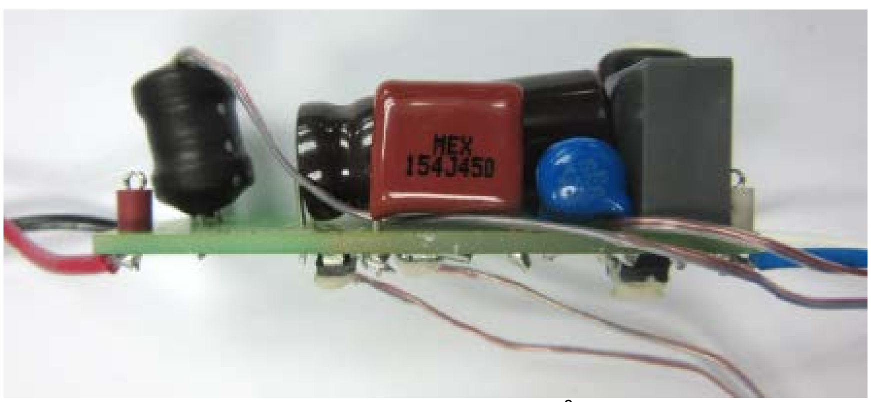


Figure 17 – Test Set-up Picture Thermal at 85^{0}C Ambient- Open Frame.

Unit in open frame was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 85 ºC. Temperature was measured using type T thermocouple.

11.2.1 Thermal Performance at 190 VAC with a 120 V LED Load

Measurement	Ambient	LYTSwitch-1	L2	D1	L1
Maximum (°C)	86.0	110.6	113.2	100.7	100.8
Final (°C)	85.9	110.6	112.9	100.6	100.8

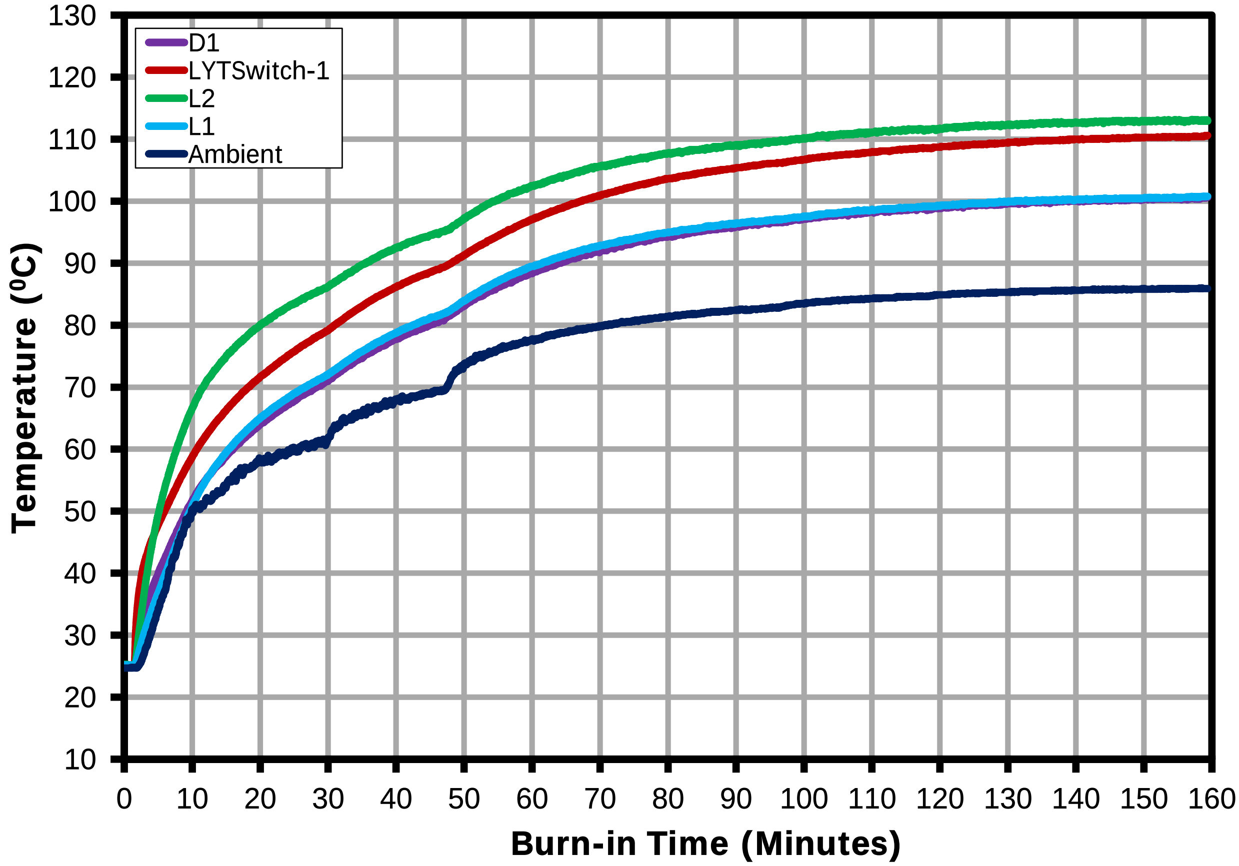


Figure 18 – Component Temperature at 190 VAC, 120 V LED Load, 85 °C Ambient.

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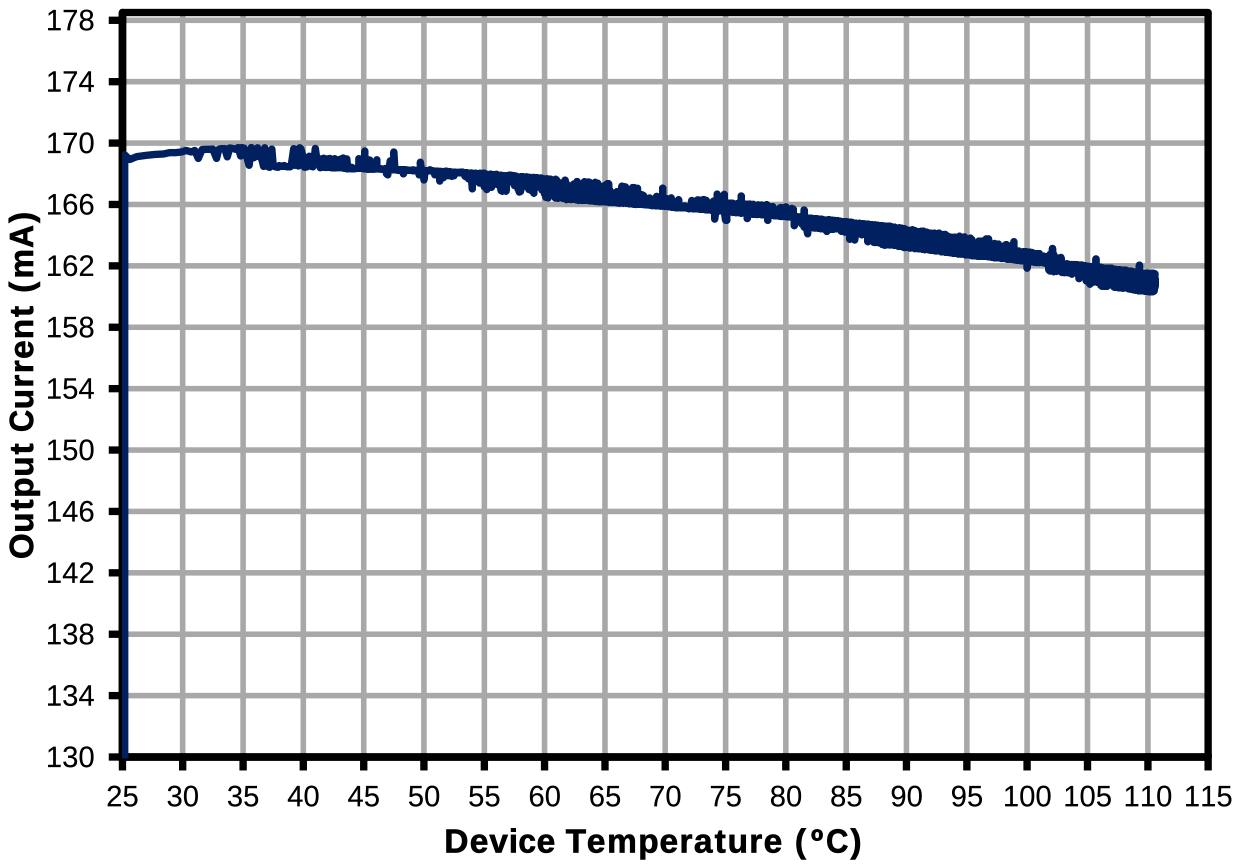

Figure 19 – Output Current vs. Device Temperature at 190 VAC, 120 V LED Load, 85 ºC Ambient.

11.2.2 Thermal Performance at 230 VAC with a 120 V LED Load

Measurement	Ambient	LYTSwitch-1	L2	D1	L1
Maximum (°C)	85.2	110.7	113.9	100.7	97.1
Final (°C)	85.2	110.7	113.5	100.5	97.0

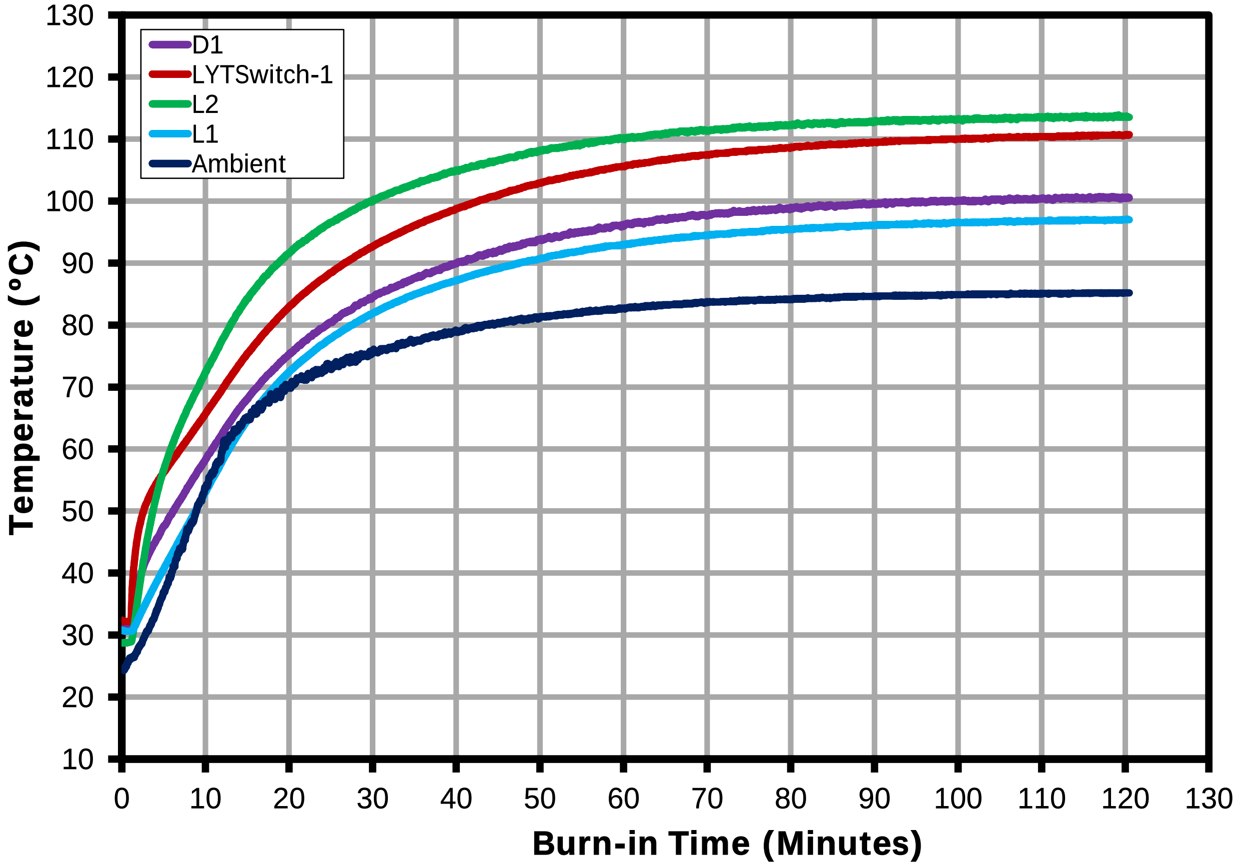

Figure 20 – Component Temperature at 230 VAC, 120 V LED Load, 85 ºC Ambient.

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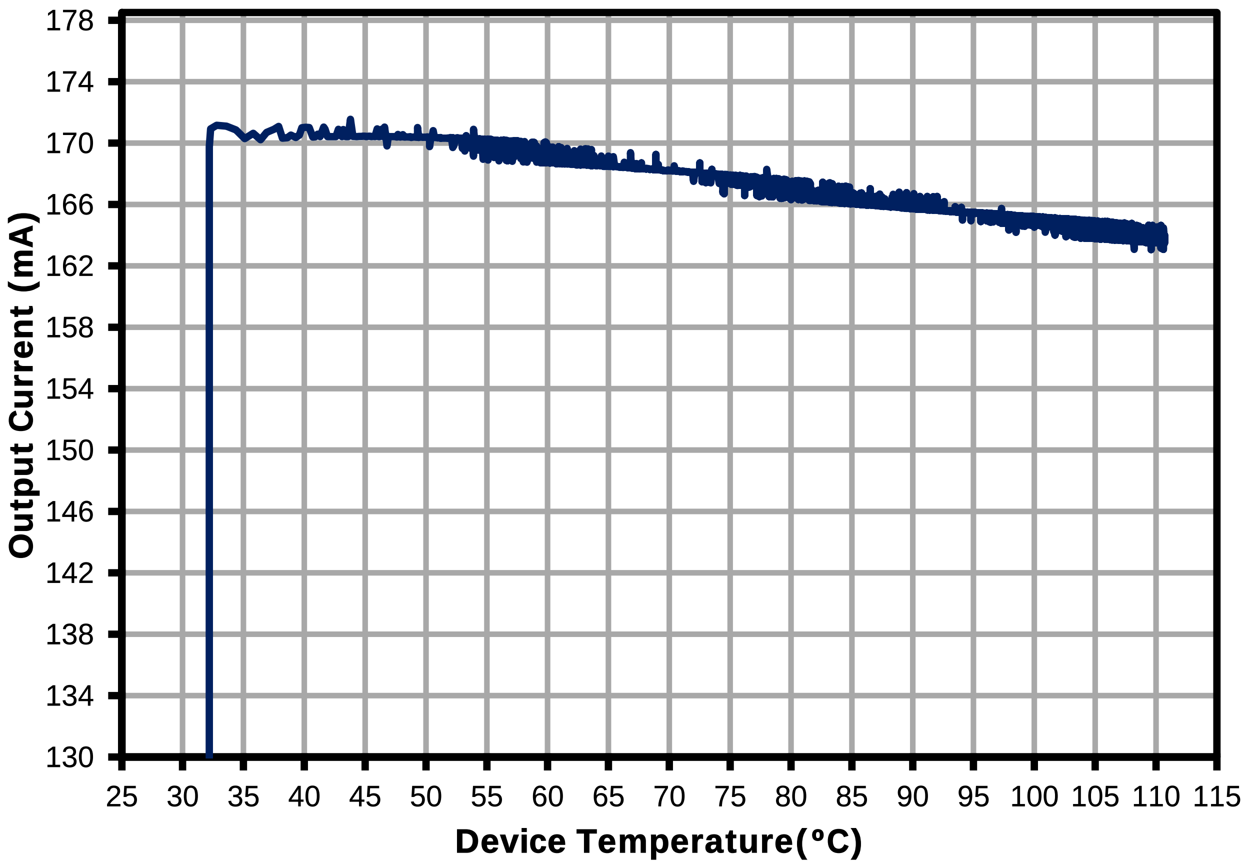

Figure 21 – Output Current vs. Device Temperature at 230 VAC, 120 V LED Load, 85 ºC Ambient.

11.2.3 Thermal Performance at 300 VAC with a 120 V LED Load

Measurement	Ambient	LYTSwitch-1	L2	D1	L1
Maximum (°C)	85.6	114.3	115.8	102.8	95.2
Final (°C)	85.6	114.2	115.6	102.5	95.1

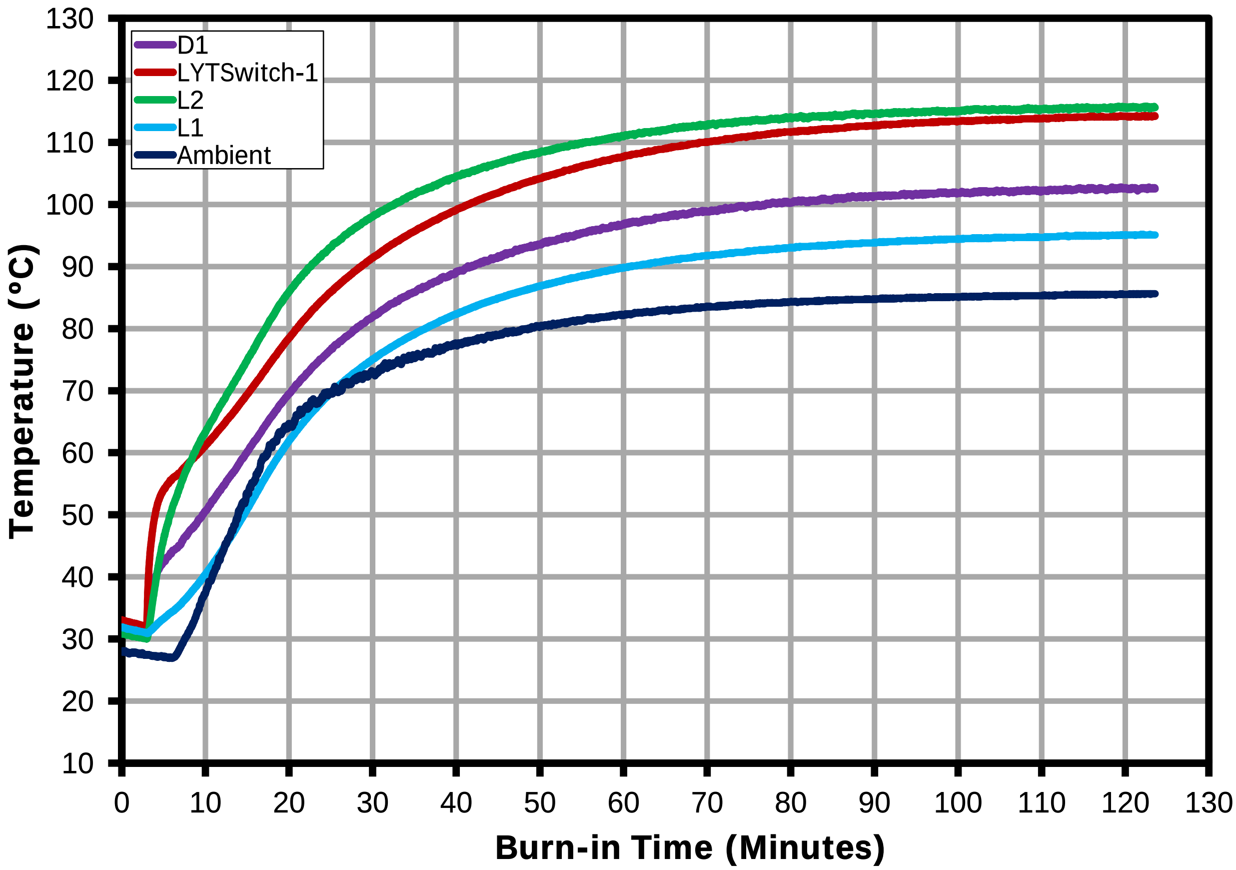

Figure 22 – Component Temperature at 300 VAC, 120 V LED Load, 85 ºC Ambient.

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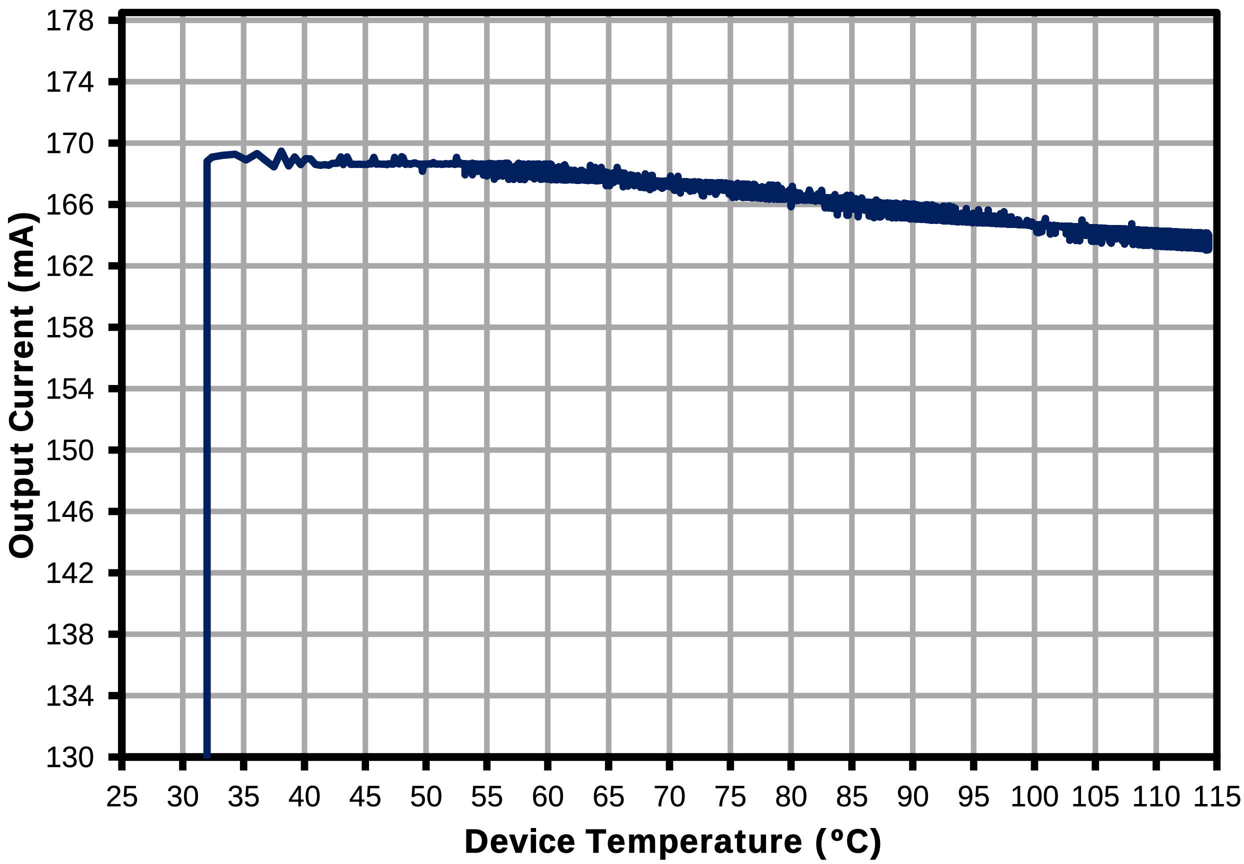

Figure 23 – Output Current vs. Device Temperature at 300 VAC, 120 V LED Load, 85 ºC Ambient.

12 Waveforms

12.1 Input Voltage and Input Current Waveforms

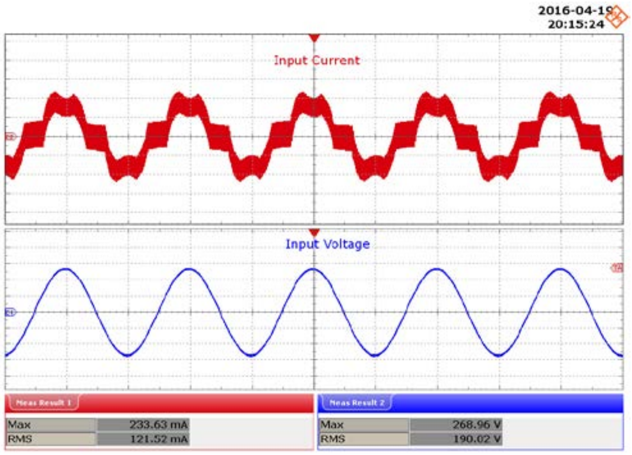

Figure 24 – 190 VAC, 120 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

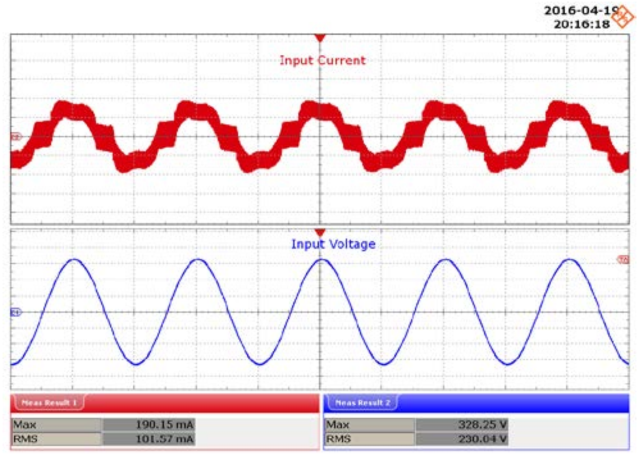

Figure 25 – 230 VAC, 120 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

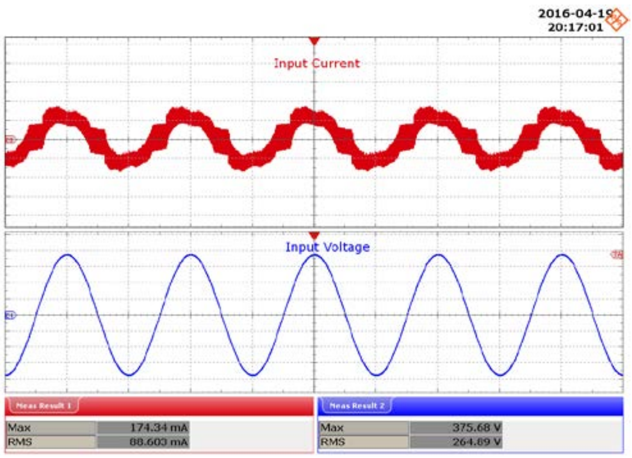

Figure 26 – 265 VAC, 120 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

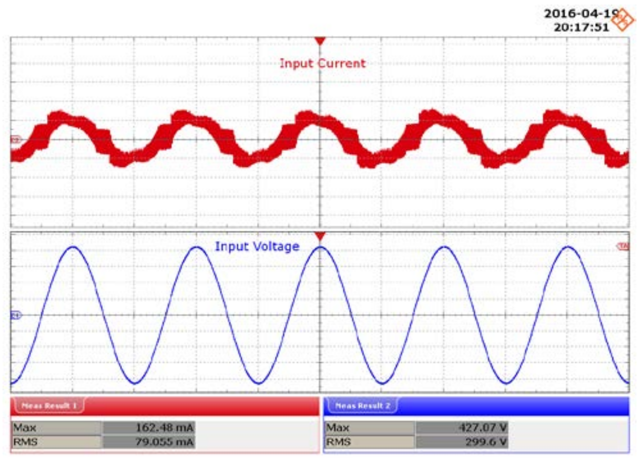

Figure 27 – 300 VAC, 120 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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12.2 Start-up Profile

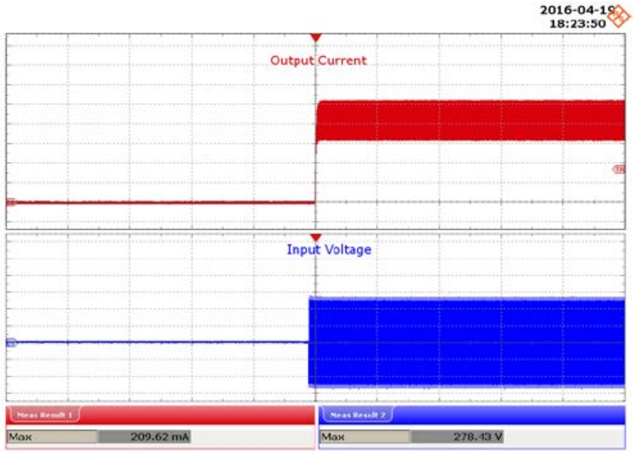

Figure 28 – 190 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

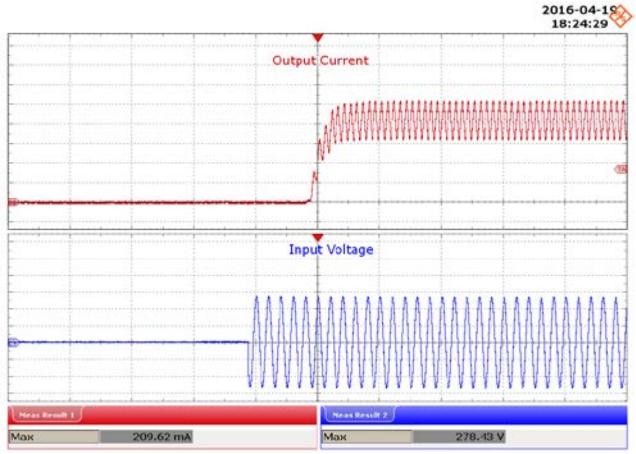

Figure 29 – 190 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

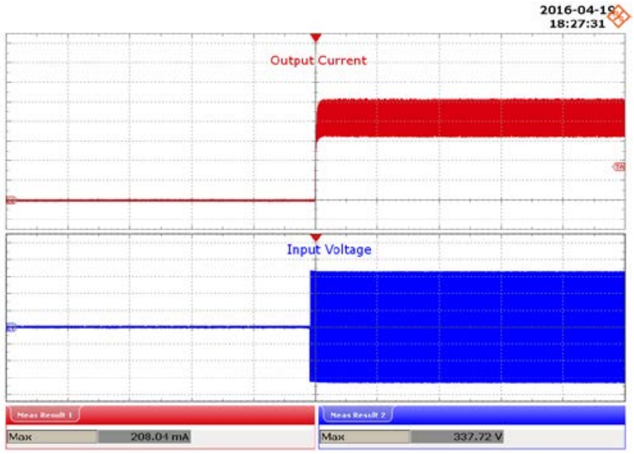

Figure 30 – 230 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

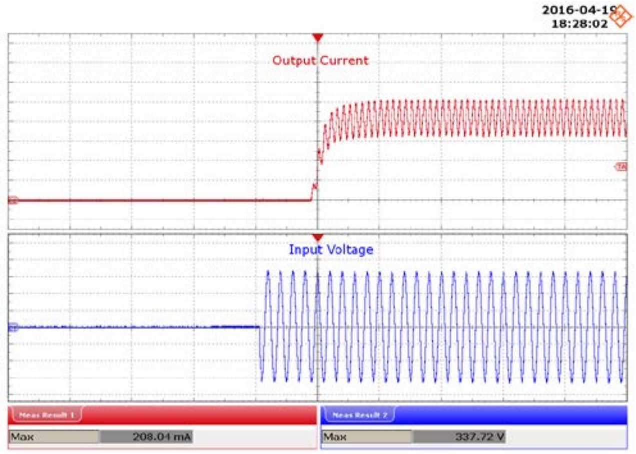

Figure 31 – 230 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

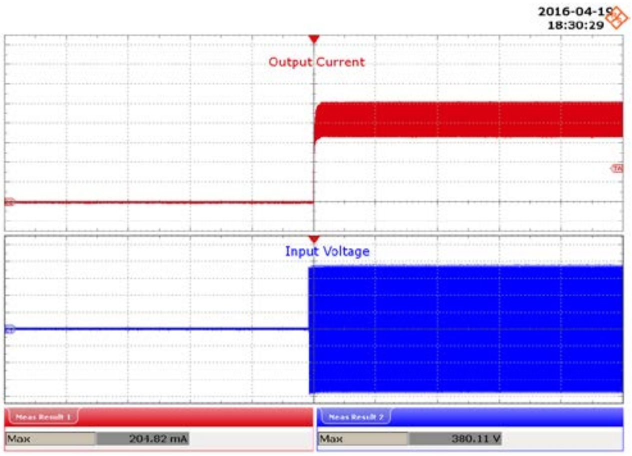

Figure 32 – 265 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

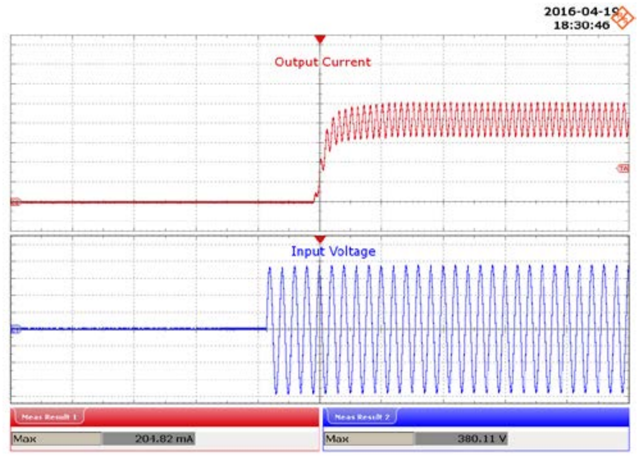

Figure 33 – 265 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

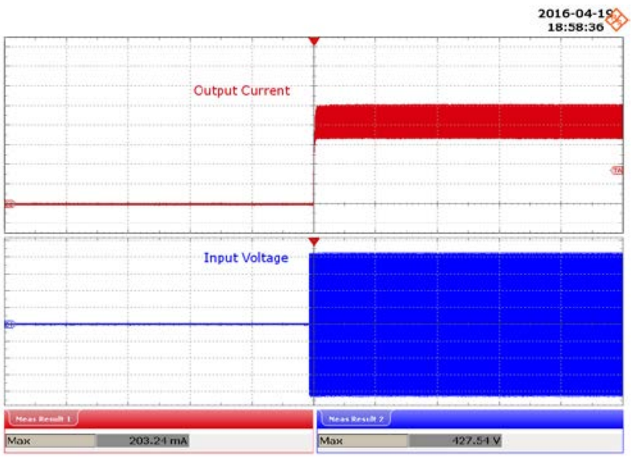

Figure 34 – 300 VAC, 120 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

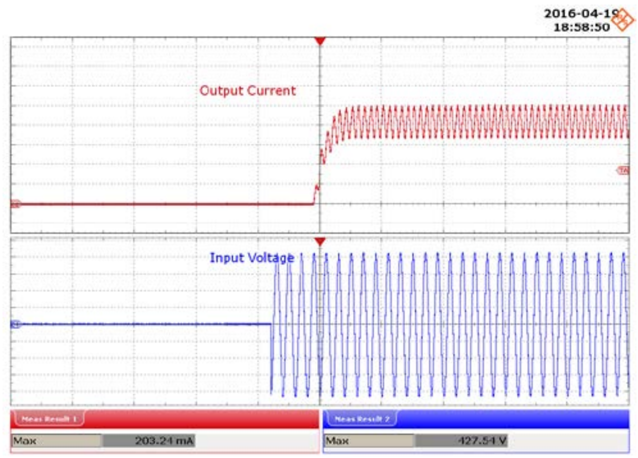

Figure 35 – 300 VAC, 120 V LED Load, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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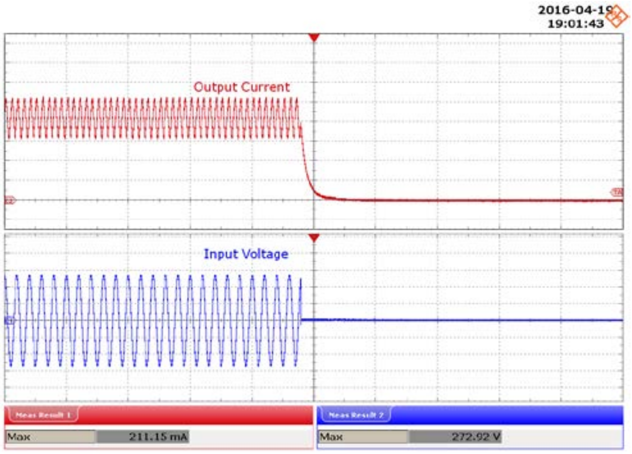
12.3 Output Current Fall



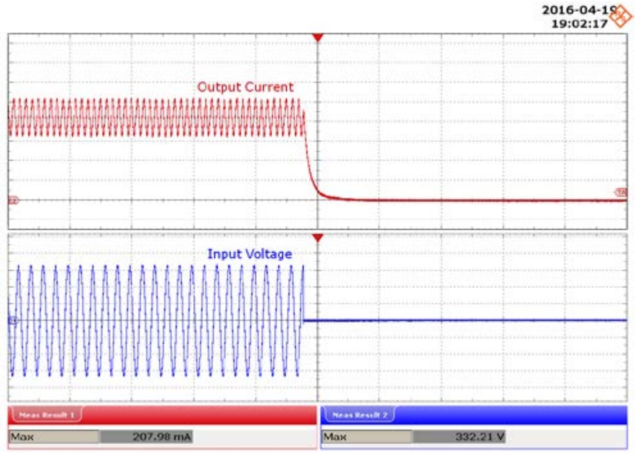
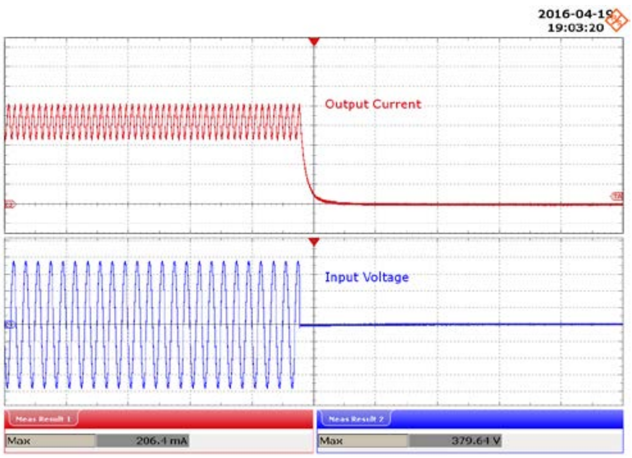


Figure 36 – 190 VAC, 120 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

Figure 37 – 230 VAC, 120 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.



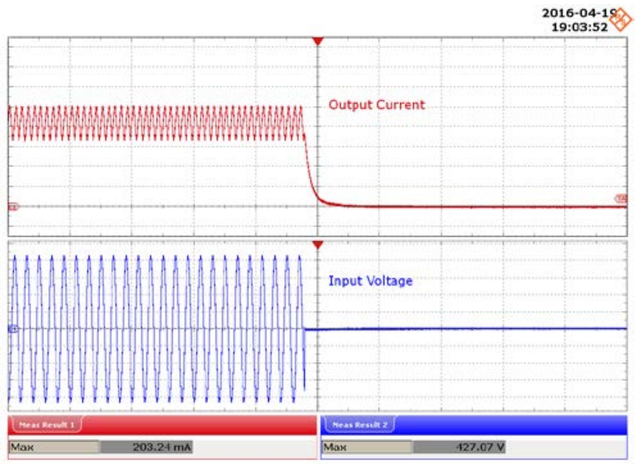


Figure 38 – 265 VAC, 120 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

Figure 39 – 300 VAC, 120 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

12.4 Drain Voltage and Current in Normal Operation

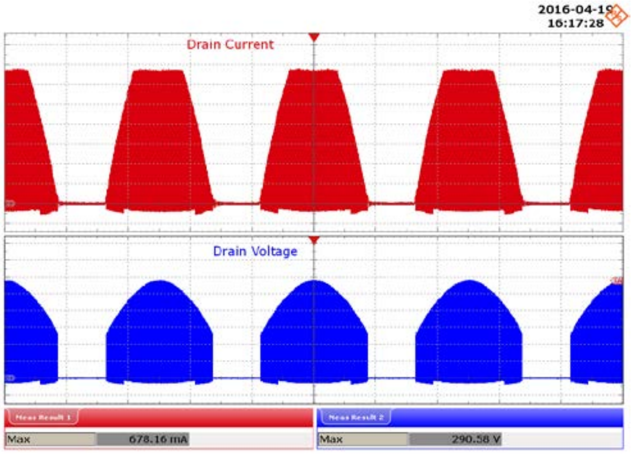


Figure 40 – 190 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

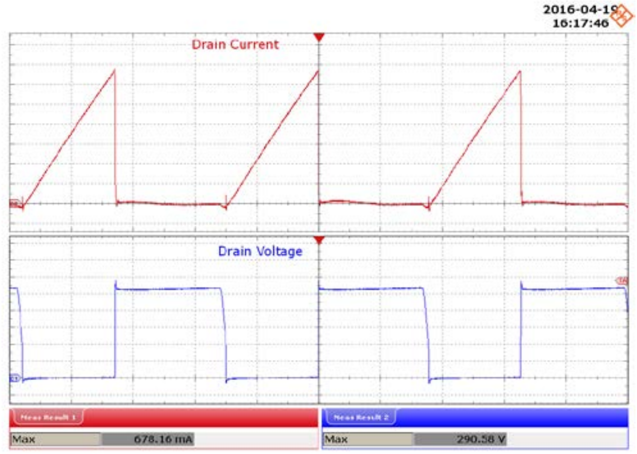


Figure 41 – 190 VAC, 120V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.

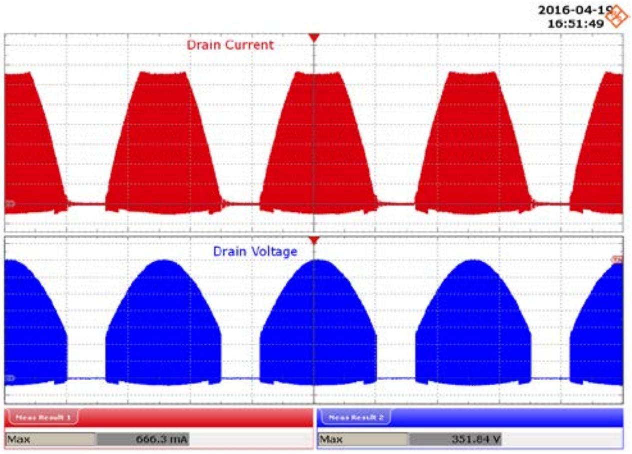


Figure 42 – 230 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

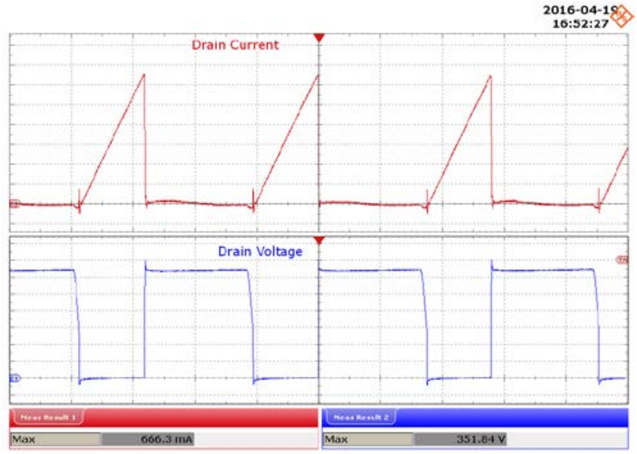


Figure 43 – 230 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.

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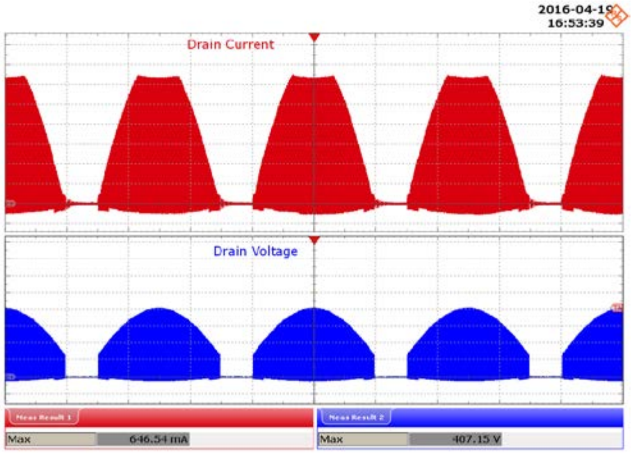

Figure 44 – 265 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

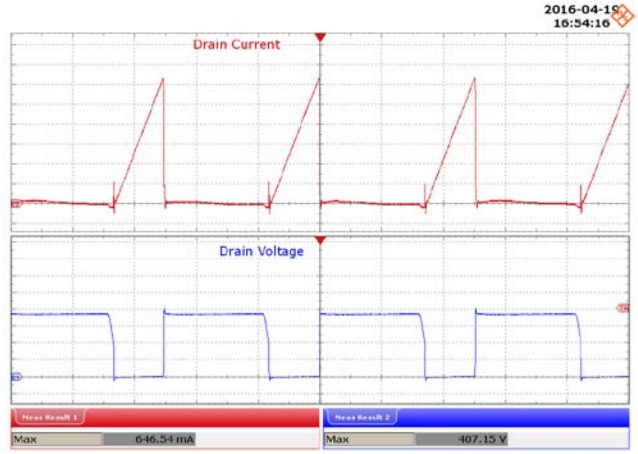

Figure 45 – 265 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

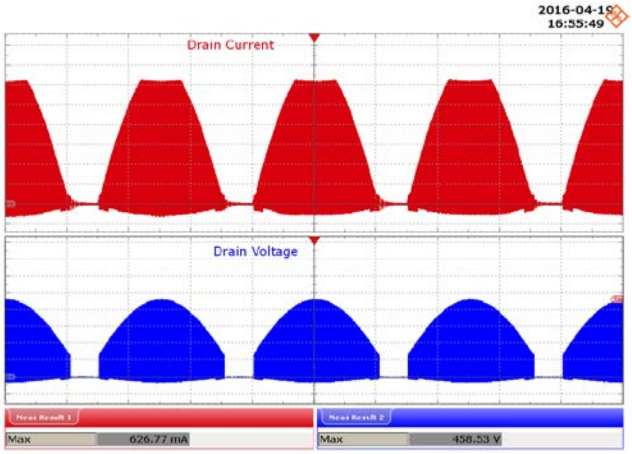

Figure 46 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

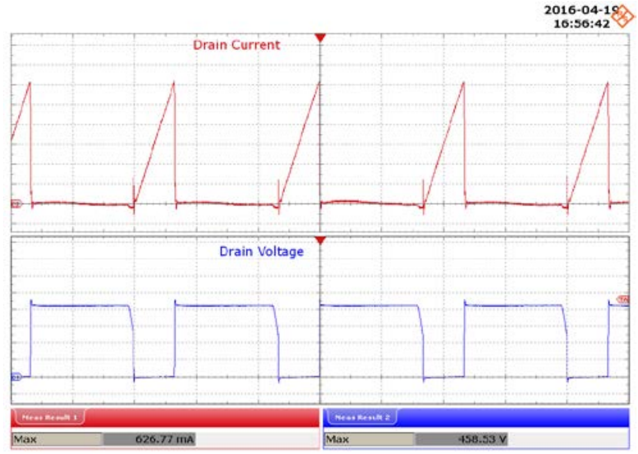

Figure 47 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

12.5 Drain Voltage and Current Start-up Profile

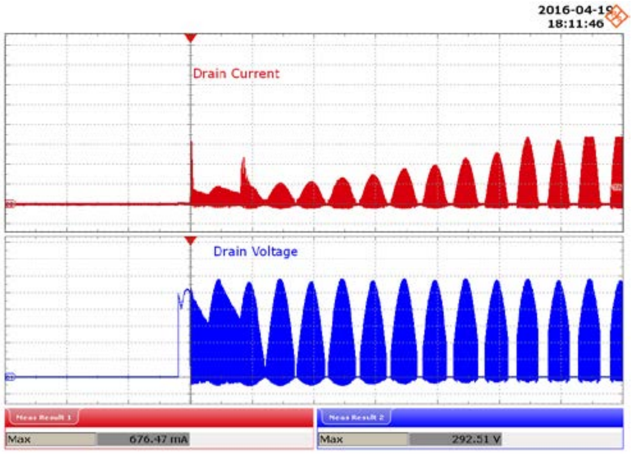

Figure 48 – 190 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms /div.

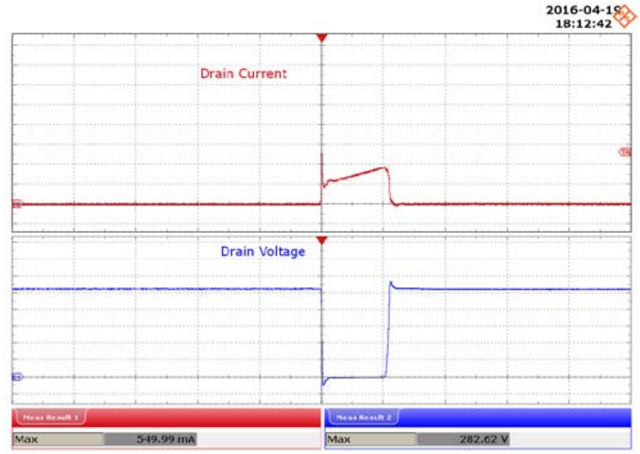

Figure 49 – 190 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 µs /div.

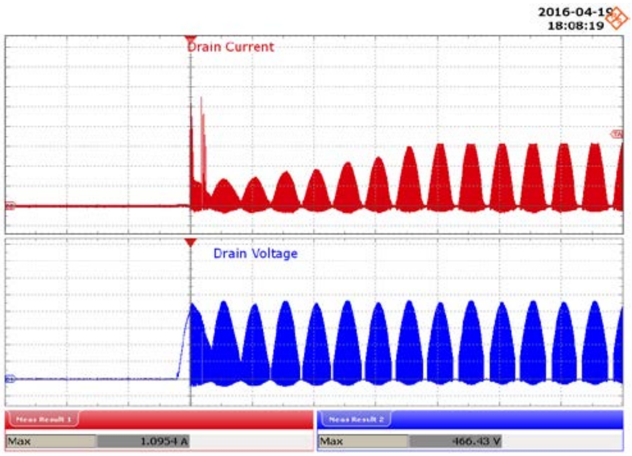

Figure 50 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms /div.

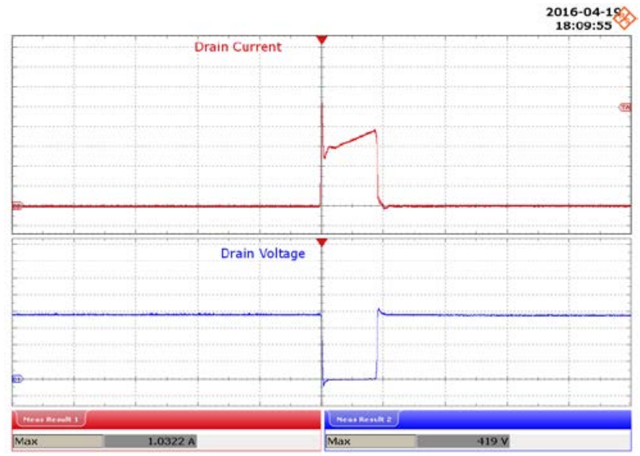

Figure 51 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 µs /div.

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12.6 Drain Voltage and Current at Output Short Circuit

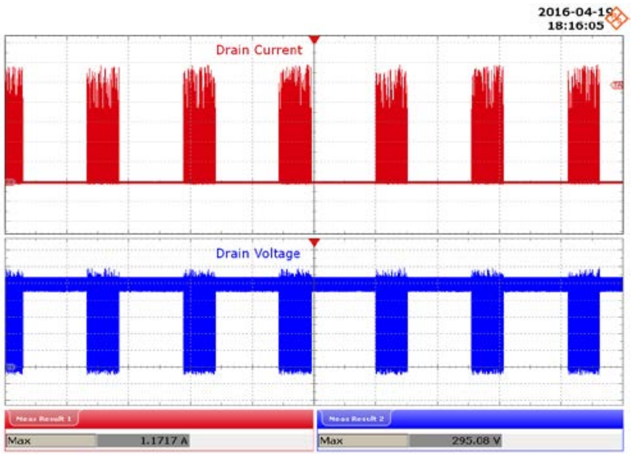

Figure 52 – 195 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s /div.

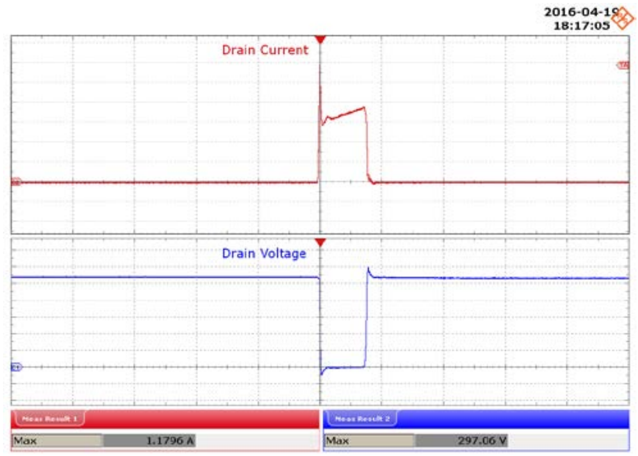

Figure 53 – 195 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 μs /div.

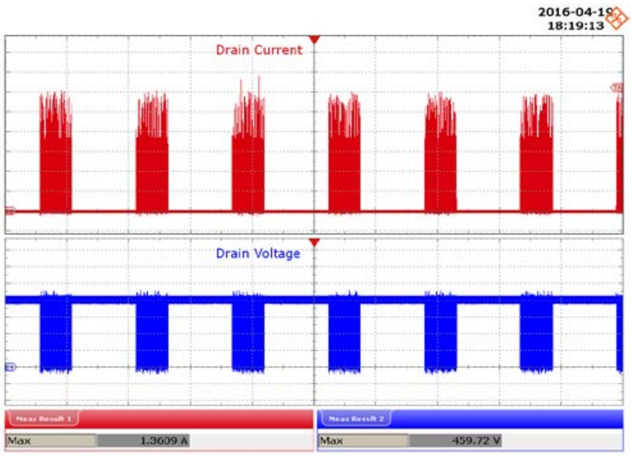

Figure 54 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms /div.

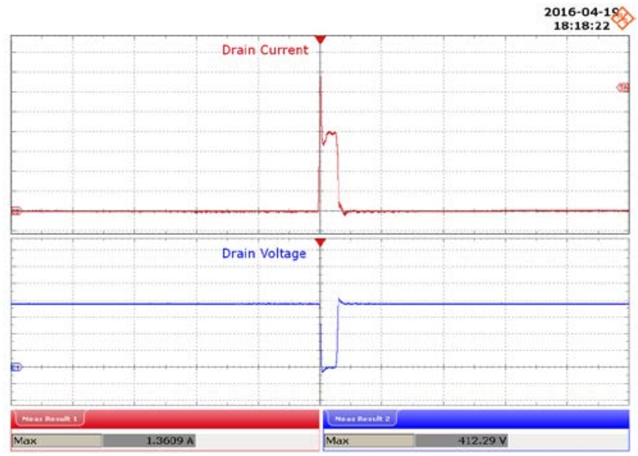

Figure 55 – 300 VAC, 120 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 μs /div.

12.7 Output Diode Voltage and Current in Normal Operation

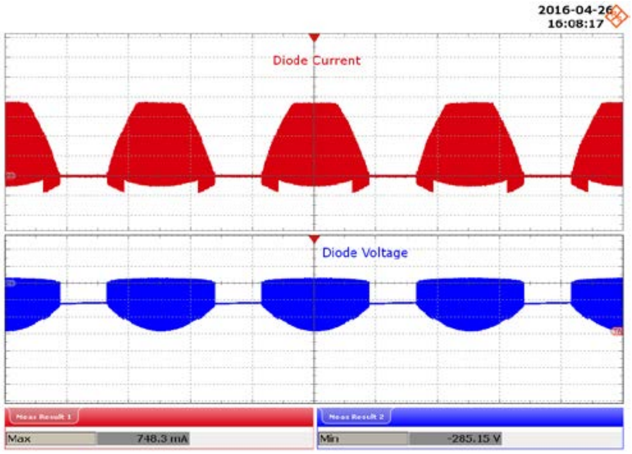

Figure 56 – 190 VAC, 120 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

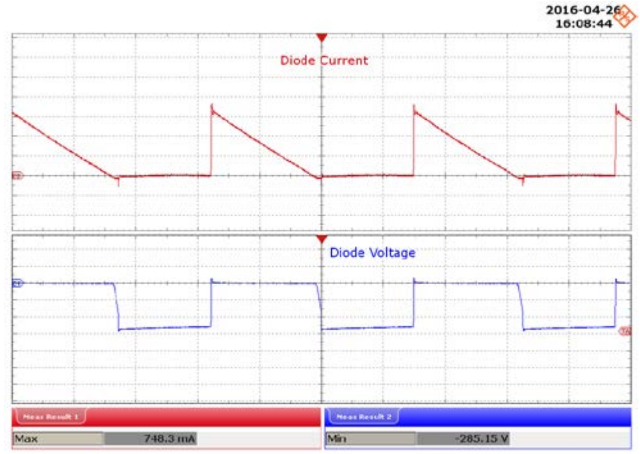

Figure 57 – 190 VAC, 120 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 5 μs / div.

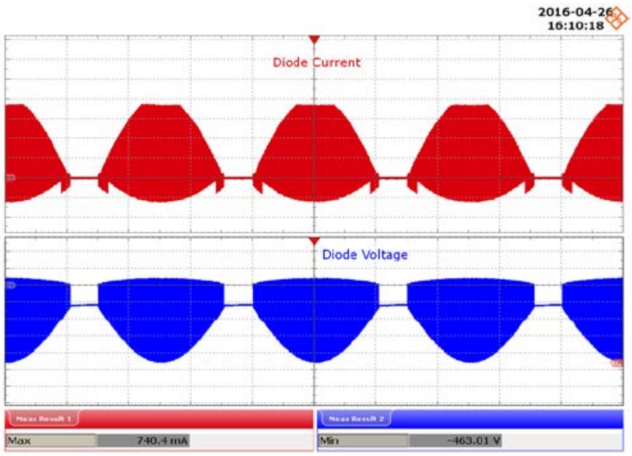

Figure 58 – 300 VAC, 120 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

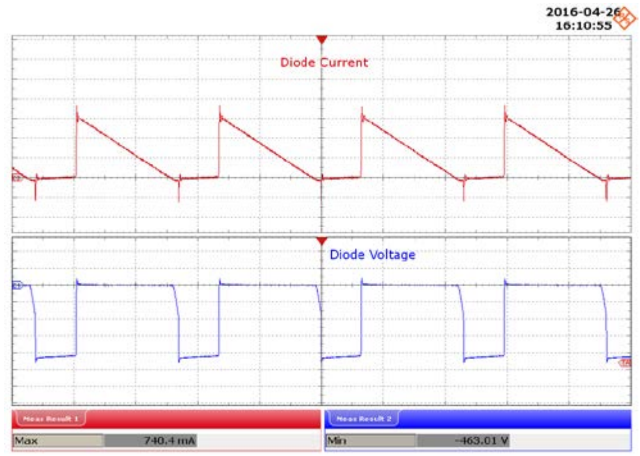

Figure 59 – 300 VAC, 120 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 5 μs / div.

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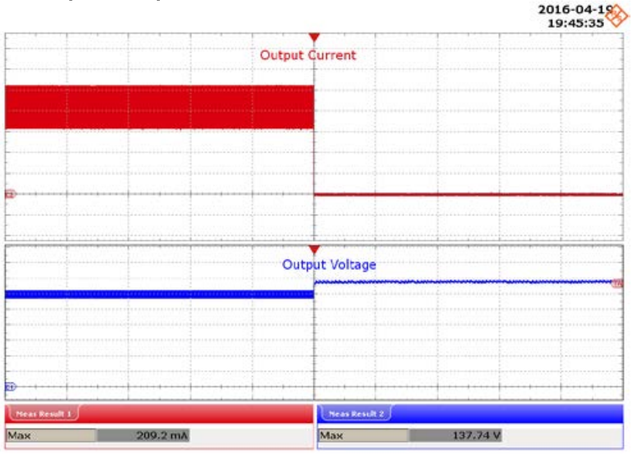
12.8 Output Voltage and Current – Open Output LED Load

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



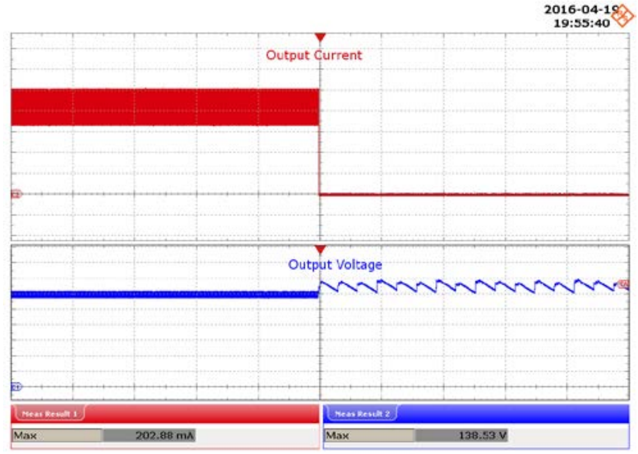
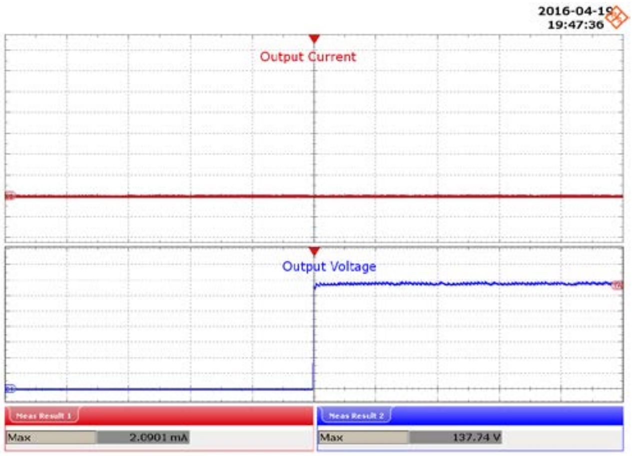


Figure 60 – 190 VAC, 120 V LED Load,
Running Open Load.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

Figure 61 – 300 VAC, 120 V LED Load,
Running Open Load.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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



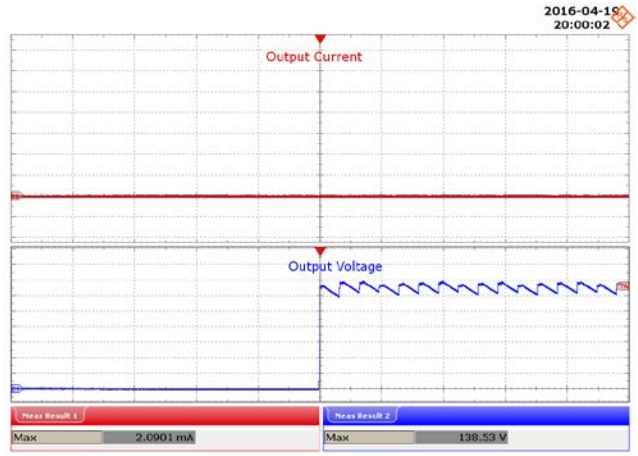


Figure 62 – 190VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

Figure 63 – 120 VAC, Open Load
Open Load Start-up.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

12.10 Output Ripple Current

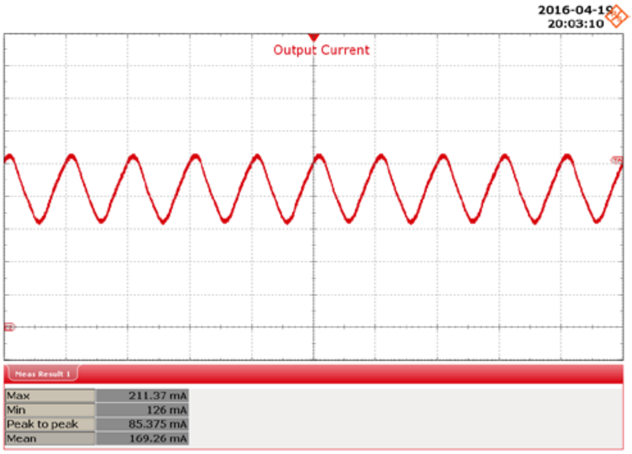


Figure 64 – 190 VAC, 50 Hz, 120 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

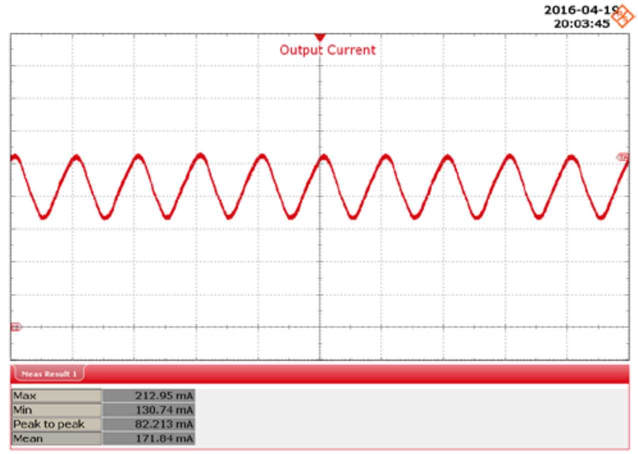


Figure 65 – 230 VAC, 60 Hz, 120 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

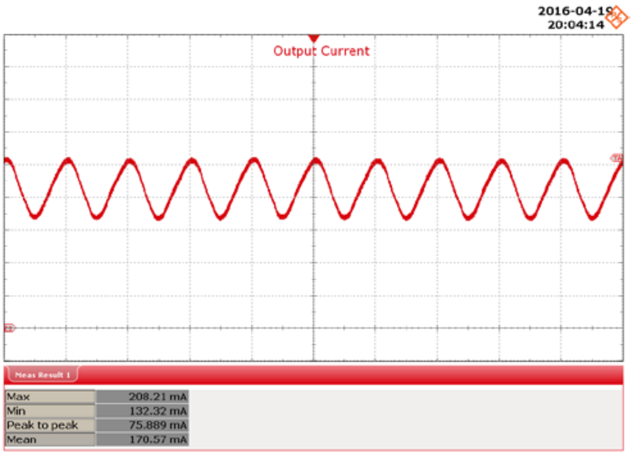


Figure 66 – 265 VAC, 60 Hz, 120 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

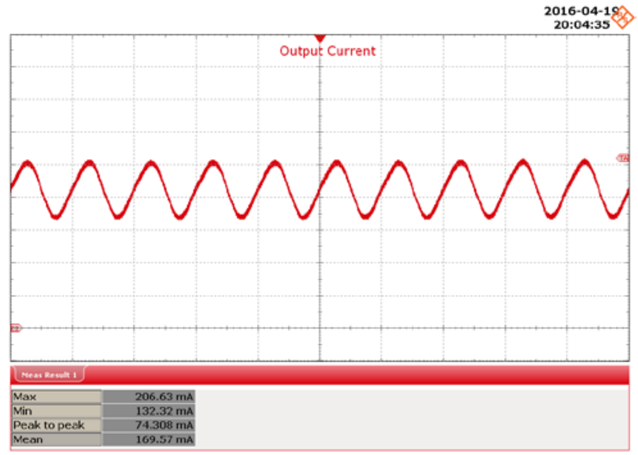


Figure 67 – 300 VAC, 60 Hz, 120 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

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} / $I_{O(MAX)}$+$I_{O(MIN)}$)
190	211.37	126	169.26	0.50	25.30
230	212.95	130.74	171.84	0.48	23.92
265	208.71	132.32	170.57	0.45	22.40
300	206.63	132.32	169.57	0.44	21.92

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13 AC Cycling Test

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

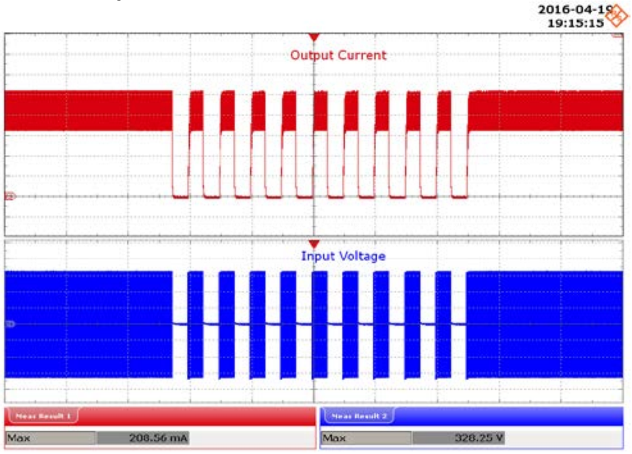

Figure 68 – 230 VAC, 120 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

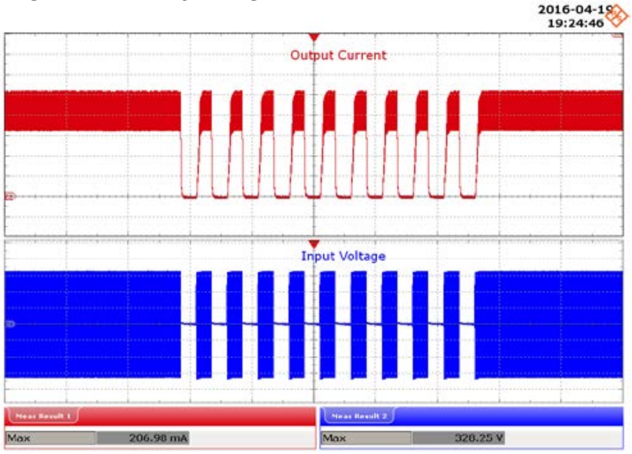

Figure 69 – 230 VAC, 120 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

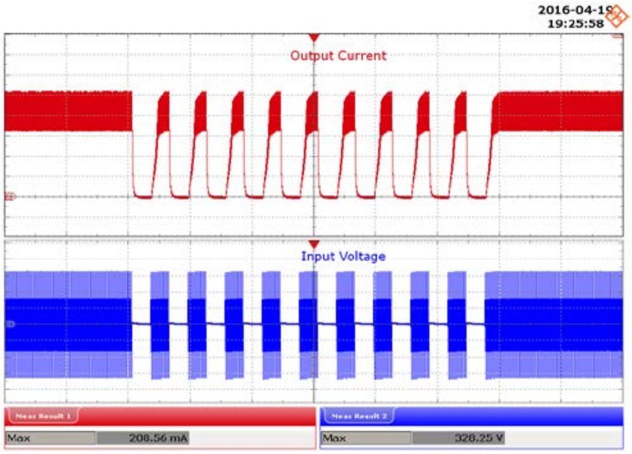

Figure 70 – 230 VAC, 120 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

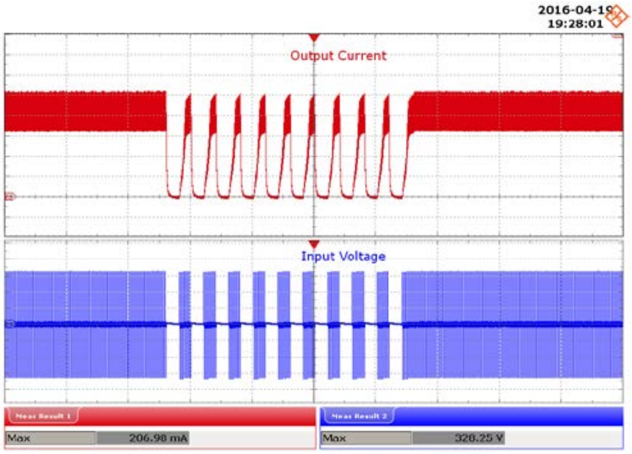

Figure 71 – 230 VAC, 120 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

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. 120 V LED load with input voltage set at 230 VAC.

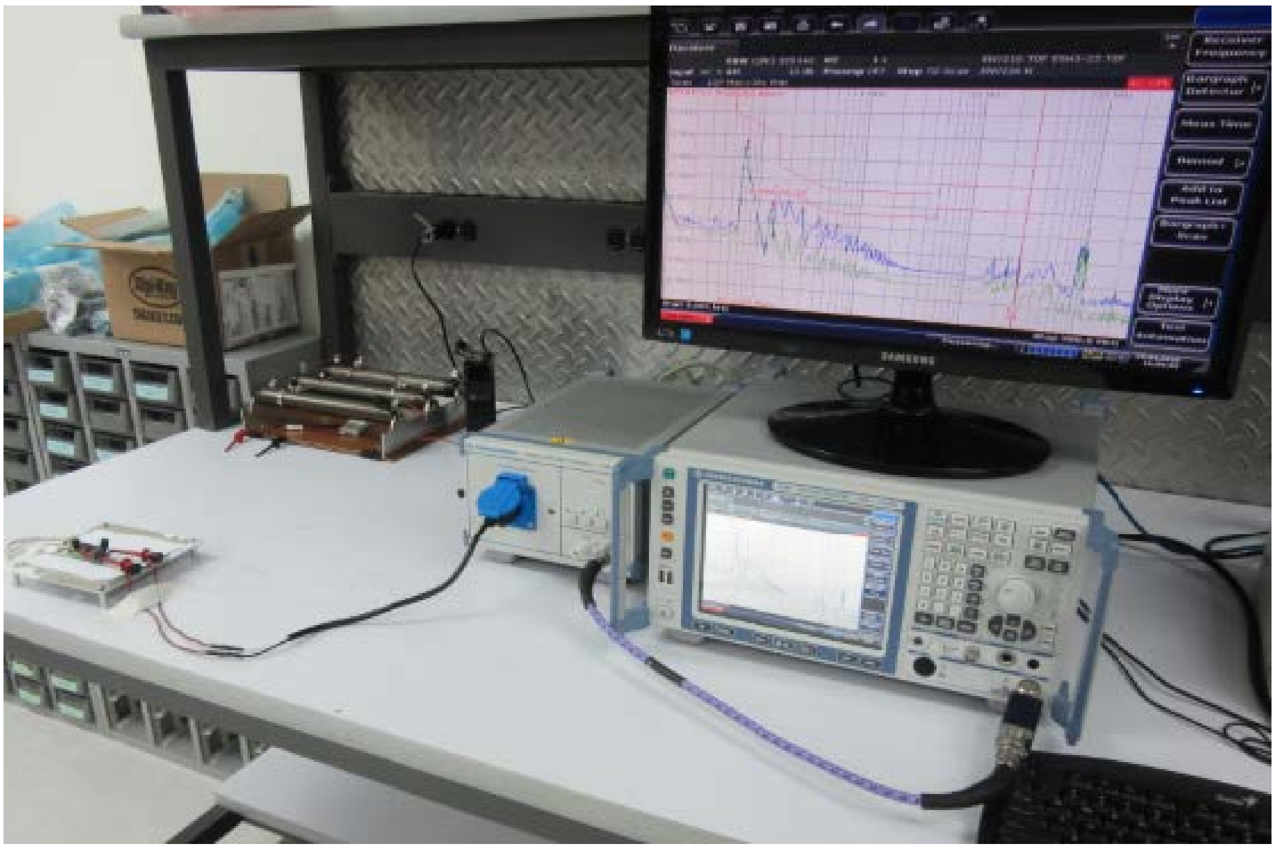

Figure 72 – Conducted EMI Test Set-up.

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14.2 EMI Test Result

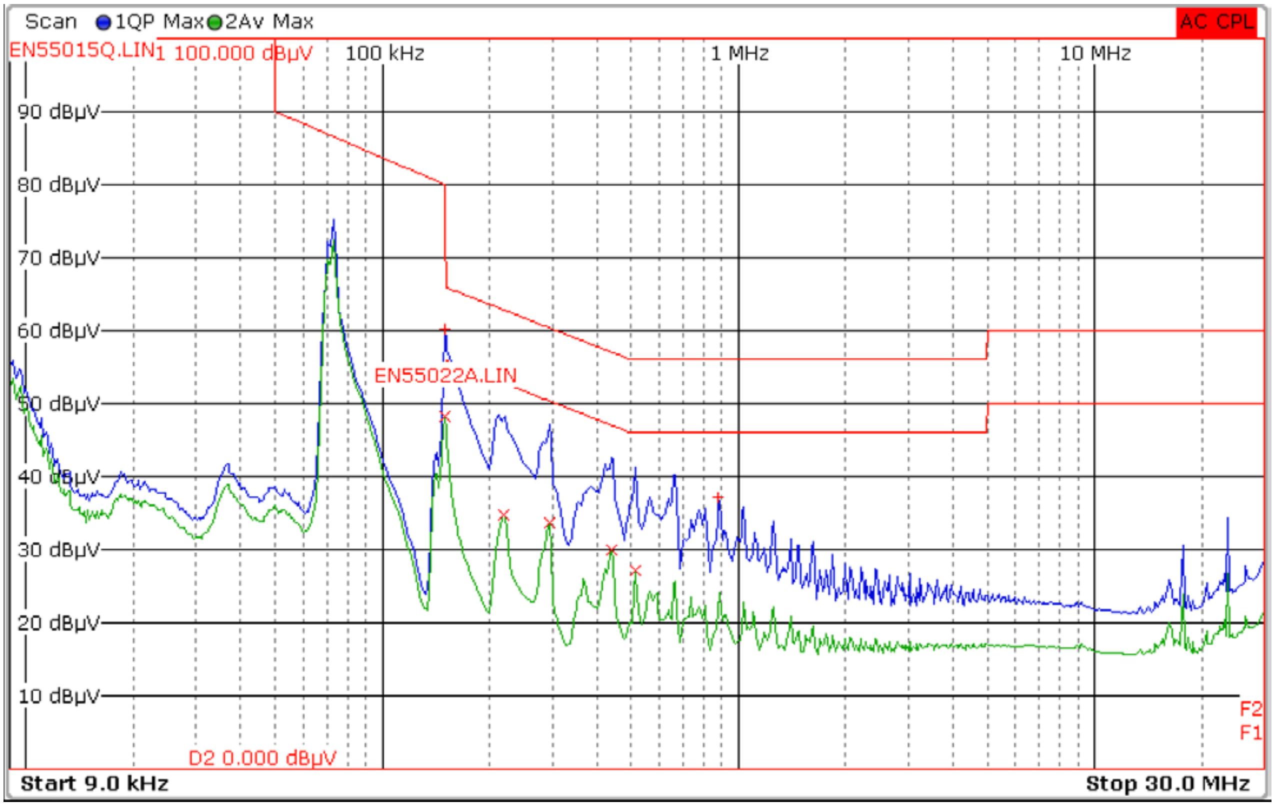

Figure 73 – Conducted EMI QP Scan at 120 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	150.0000 kHz	60.13 N	-5.87 dB
2 Average	150.0000 kHz	48.21 N	-7.79 dB
2 Average	294.0000 kHz	33.74 L1	-16.67 dB
2 Average	440.2500 kHz	30.00 L1	-17.06 dB
2 Average	219.7500 kHz	34.83 N	-18.00 dB
2 Average	514.5000 kHz	27.12 L1	-18.88 dB
1 Quasi Peak	881.2500 kHz	37.07 L1	-18.93 dB

Figure 74 – Conducted EMI Data at 230 VAC, 120 V LED Load.

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	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass
+2500	230	L to N	90	Pass
-2500	230	L to N	90	Pass

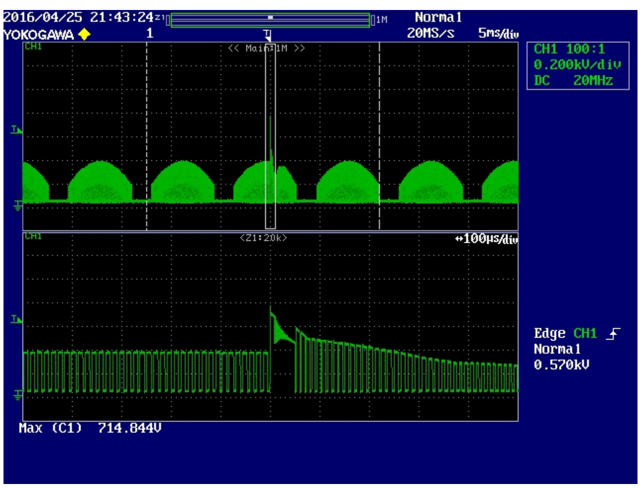

Figure 75 – +1 kV Differential Surge, 90º Phase Angle. Lower: V_{DRAIN}, 200 V / div., 5 ms /div. Peak V_{DRAIN}: 715 V.

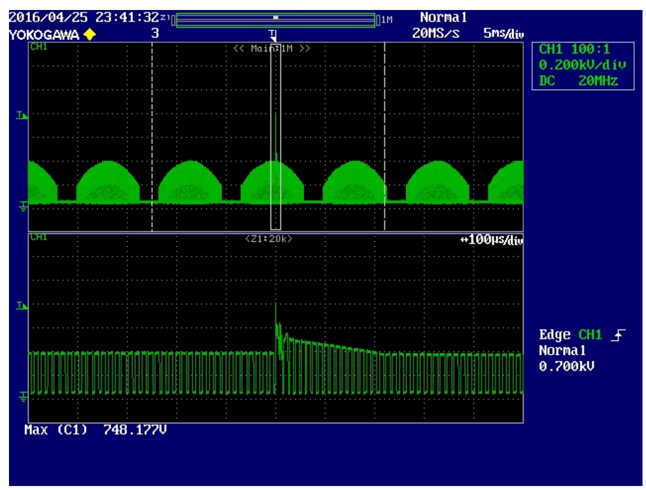

Figure 76 – +2.5 kV Ring Wave Surge, 90º Phase Angle. Lower: V_{DRAIN}, 200 V / div., 5 ms /div. Peak V_{DRAIN}: 748 V.

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16 Brown-in / Brown-out Test

No component failure and overheating were observed. The driver operates normally after the test.

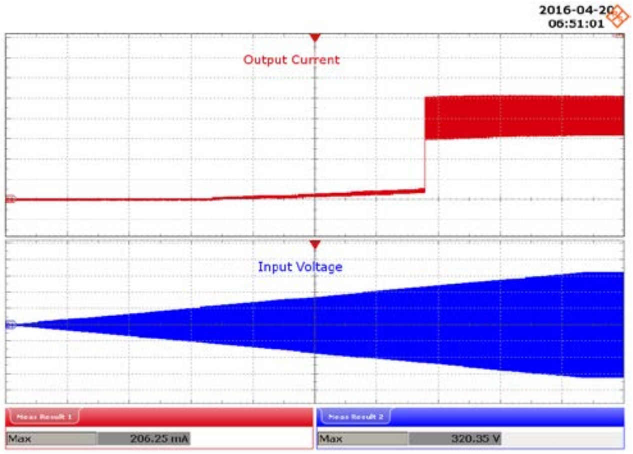

Figure 77 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 40 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

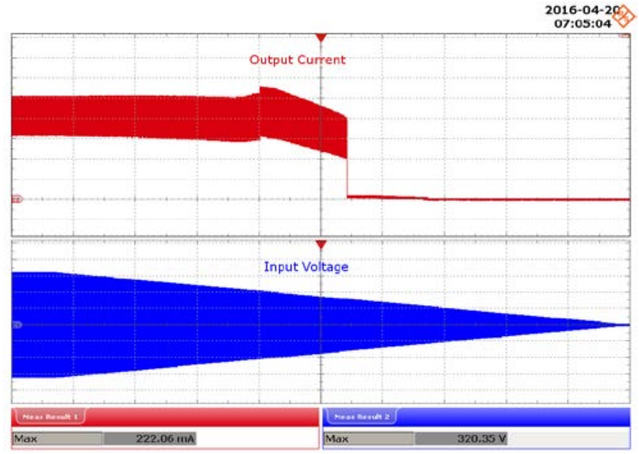

Figure 78 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 50 s / div.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
08-Jun-16	MGM	1.0	Initial Release	Apps & Mktg
30-Jun-16	KM	1.1	Fixed a Typo in the Power Supply Specification Table, Section 2. Updated Board Images.	

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