Design Example Report

Title	***10 W Dimmable, High Efficiency (>87%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-7 LYT7503D***
Specification	195 VAC – 265 VAC Input; 84 V, 120 mA Output
Application	A19 LED Bulb
Author	Applications Engineering Department
Document Number	DER-568
Date	August 13, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <25% flicker requirement
- Highly energy efficient, >87 % at 230 V
- Low cost and low component count for compact PCB solution
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers
- Integrated auto-restart protection features
  - No-load / open-load output
  - Output short-circuit
  - Line surge or line overvoltage
- Thermal fold-back 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, dimmable LED driver in buck topology, designed to drive an 84 V LED voltage string at 120 mA output current from an input voltage range of 195 VAC to 265 VAC. The LED driver utilizes the LYT7503D from the LYTSwitch-7 family of devices.

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

DER-568 offers a TRIAC dimmable, high power factor and low component count solution for 10 W LED bulbs. The key design goals were low component count, high power factor and excellent dimming compatibility.

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

Figure 1 – Populated Circuit Board.

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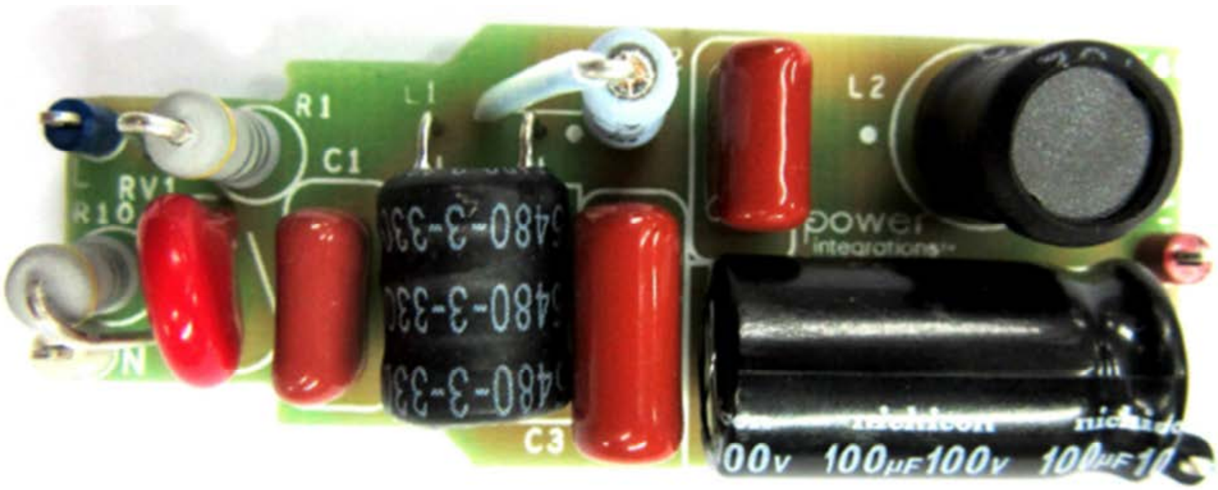

Figure 2 – Populated Circuit Board, Top View.

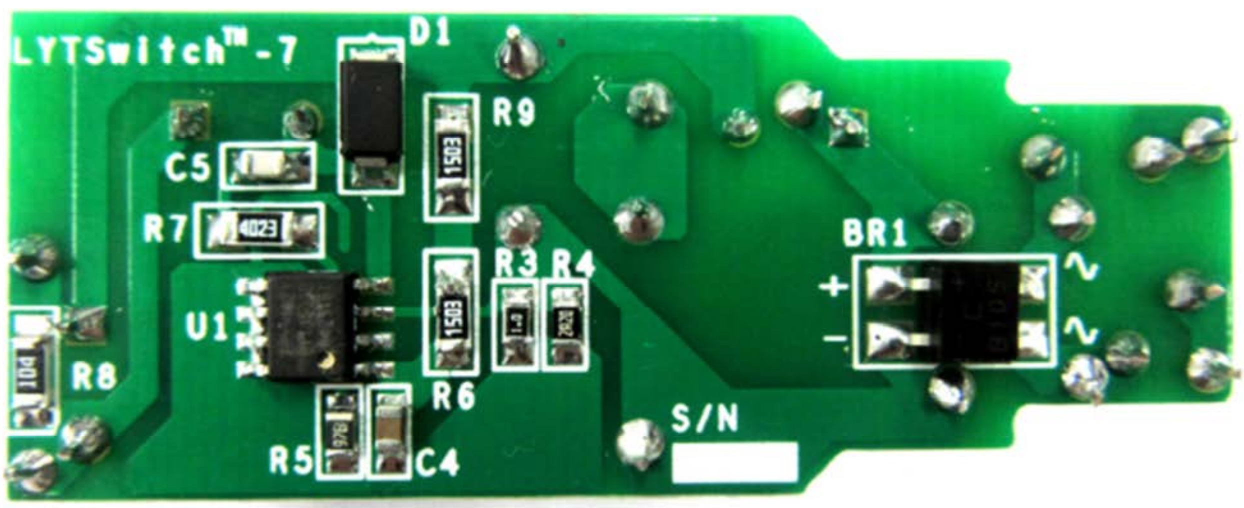

Figure 3 – Populated Circuit Board, Bottom View.

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}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		84		V	
Output Current	I_{OUT}		120		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		10		W	
Efficiency						
Full Load	η		87		%	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}			90	ºC	Free Convection, Sea Level, Open Frame.

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3 Schematic

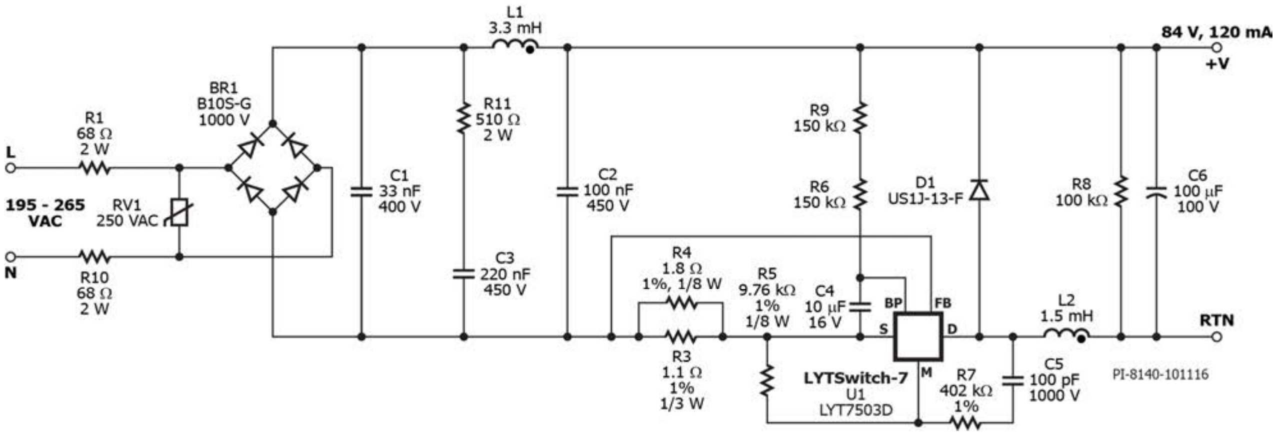

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-7 device (U1-LYT7503D) combines a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. The LYT7503D IC is configured to drive an 84 V output, TRIAC dimmable buck LED driver with 120 mA constant output current. The LYT7503D device was selected from the power table based on maximum output power (15 W for high line) in the data sheet.

4.1 *Input Stage*

The input fuse R1 and R10 provides safety protection. Varistor RV1 acts a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 250 V rated part was selected, being slightly above the nominal specified operating input voltage (230 V). The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD.

4.2 *EMI Filters*

Inductor L1 serves as differential choke. Inductor L1, C1 and C2 capacitors form an EMI pi filter which works to filter differential and common mode noise. LYTSwitch-7's variable frequency / on-time states and critical conduction code control engine limit RFI emission to significantly low levels which enables design to use simple EMI pi filter even for high power bulb and tube applications.

4.3 *LYTSwitch-7 Control Circuit*

The LED driver circuit topology is a low side buck configuration, where the MOSFET of U1 and the inductor L1 are connected to the ground rail. During the MOSFET 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 MOSFET 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 R8 preload discharges the output capacitor voltage below the LED voltage.

Capacitor C4 provides local decoupling for the BYPASS (BP) pin of U1, it also provides power to the IC during the switch on time. The IC internal regulator draws power from high voltage DRAIN (D) pin and charges the bypass capacitor 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 $V_{IN} < V_{OUT}$, the value of capacitor should be large enough to keep the BP pin voltage above the $V_{BP(RESET)}$ value of 4.5 V. Recommended minimum value for the BP pin capacitor is 4.7 μF.

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

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resistors (R_{FB}) R3 and R4 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}; k = 4 for LYT750x.

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

The MULTIFUNCTION (M) pin monitors the line for any line overvoltage event. When the internal MOSFET is in on-state, the M pin is shorted internally to SOURCE (S) pin in order to detect the rectified input line voltage derived from the voltage across the inductor, i.e. (V_{IN}-V_{OUT}) and current flowing out of the M pin is defined by resistor R5, thus line overvoltage detection is calculated as; where R7 is assumed to be 402 kΩ ±1%.

$$V_{LINE\_OVP} = I_{IOV} \times R5 + V_{OUT}$$

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 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 R5 and R7. When an output open-load condition occurs, the voltage at the M pin will rise abruptly and when it exceeds the threshold of 2.4 V, the IC will inhibit switching instantaneously and initiate auto-restart to limit the output voltage from further rising. The overvoltage cut-off is typically 120% of the output voltage, which is equivalent to 2 V at the M pin ($V_{OUT\_OVP} = V_{OUT} \times 2.4 V / 2 V$). Resistor R7 is set to a fixed value of 402 kΩ ±1% and R5 will determine the output overvoltage limit. Any 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 to less than 1 W, preventing any components from overheating.

R5 can be calculated as follows:

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

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

4.4 *TRIAC Phase Dimming Control*

The average output current control mechanism of the LYTSwitch-7 LYT7503D provides inherent dimming capability with TRIAC phase-cut dimmers. The peak current limit on-time duration varies with respect to dimming conduction angle providing a natural dimming performance.

Due to a much lower power consumed by LED based lighting, the current drawn by the lamp is below the holding current of the TRIAC in many dimmers. This causes undesirable behavior such as limited dimming range and/or flicker. RC passive damper (R11 and C3) serves as an impedance load to avoid the TRIAC current to fall below its holding current.

The relatively large impedance presented to the line by the LED allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This effect can cause similar undesirable behavior, as the ringing may cause the TRIAC current to fall below its holding current and turn off. Resistors R1 and R10 are needed to dampen the driver input current ringing when TRIAC dimmer turns on.

Pull-up resistors R6 and R9 is needed to maintain the BP pin voltage above the reset threshold (4.5 V) that may cause flickering and shimmering during minimum dimming conduction angle.

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5 PCB Layout

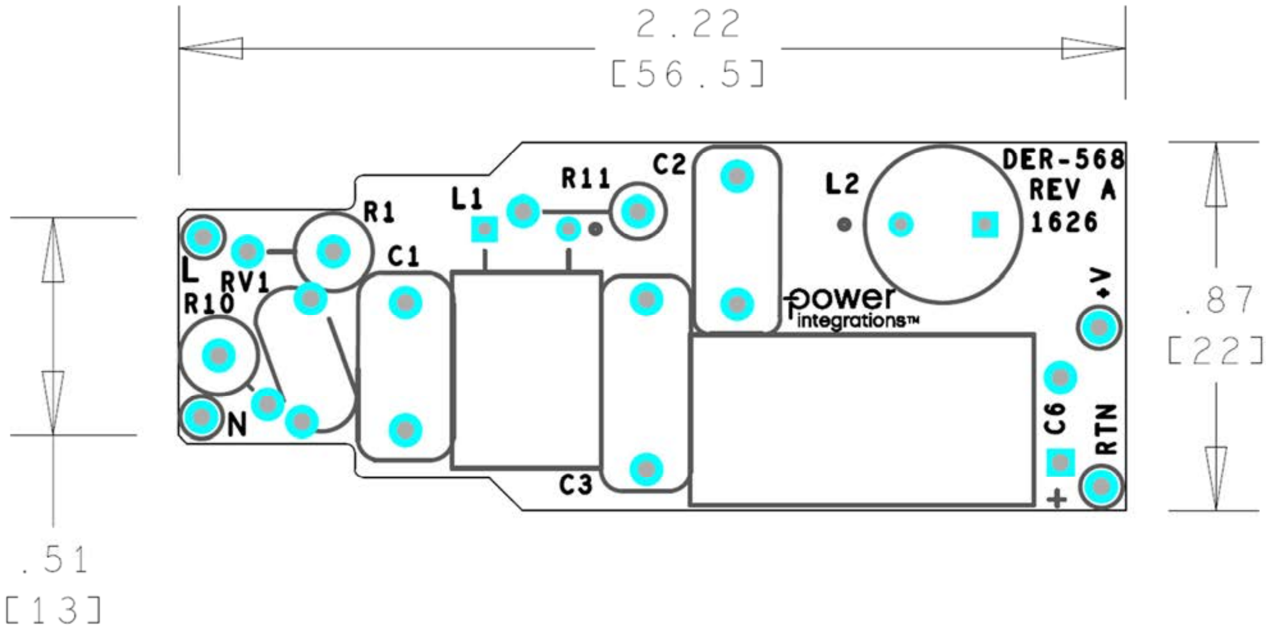

Figure 5 – Top Side.

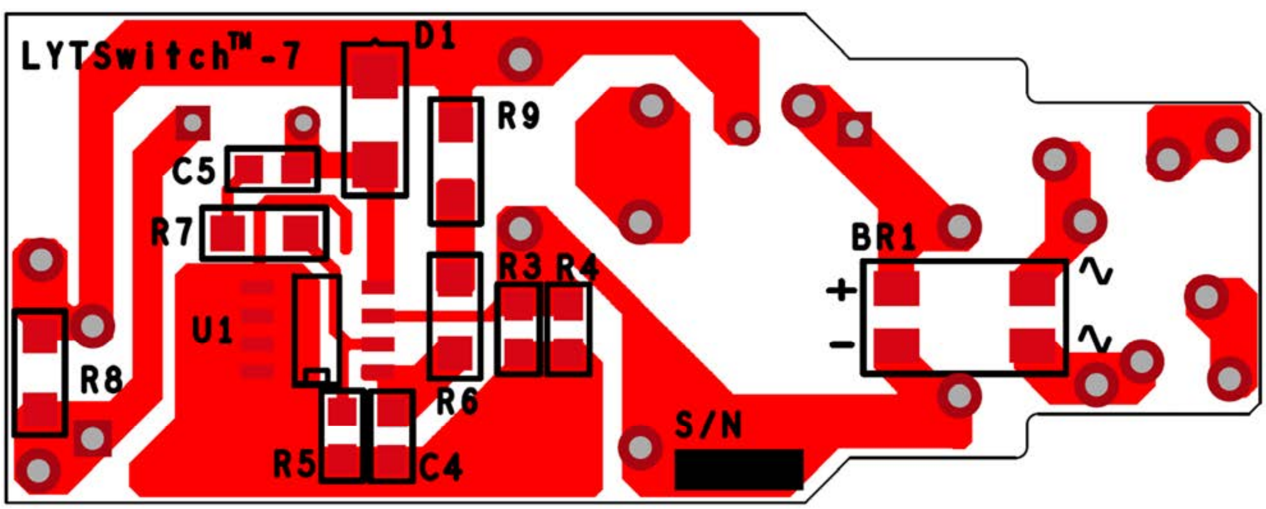

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Ref Des	Qty	Description	Mfg Part Number	Manufacturer
1	BR1	1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	C1	1	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
3	C2	1	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
4	C3	1	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
5	C4	1	10 μF, ±10%, 16V, X7R, Ceramic Capacitor	CL21B106KOQNNNG	Samsung
6	C5	1	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
7	C6	1	100 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 20)	UVZ2A101MPD	Nichicon
8	D1	1	Diode Ultrafast, SW 600 V, 1A, SMA	US1J-13-F	Diodes, Inc.
9	L1	1	3.3 mH, 0.150 A, 20%	RL-5480-3-3300	Renco
10	L2	1	INDUCTOR, FIXED, 1.5 MH, 430 mA, 3.8 Ω, TH	RLB9012-152KL	Bourns
11	R1	1	RES, 68 Ω, 2 W, 5%, AXIAL, Wirewound, Fusible, ±200 ppm/°C	ULW2-68RJA25	TT Electronics
12	R3	1	RES, SMD, 1.1 Ω, 1%, 1/3 W, 0805	ERJ-6BQF1R1V	Panasonic
13	R4	1	RES, SMD, 1.8 Ω, 1%, 1/8 W, 0805	CRCW08051R80FKEA	Vishay-Dale
14	R5	1	RES, 9.76 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9761V	Panasonic
15	R6	1	RES, 150 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ154V	Panasonic
16	R7	1	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
17	R8	1	RES, 100 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ104V	Panasonic
18	R9	1	RES, 150 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ154V	Panasonic
19	R10	1	RES, 68 Ω, 2 W, 5%, AXIAL, Wirewound, Fusible, ±200 ppm/°C	ULW2-68RJA25	TT Electronics
20	R11	1	RES, 510 Ω, 5%, 2 W, Metal Oxide Film	ERG-2SJ511	Panasonic
21	RV1	1	250 VAC, 21 J, 7 mm, RADIAL LA	V250LA4P	Littlefuse
22	U1	1	LYTSwitch-7, Dimmable, SO-8	LYT7503D	Power Integrations

Miscellaneous

Item	Ref Des	Qty	Description	Mfg Part Number	Manufacturer
1	+V	1	Test Point, RED,Miniature THRU-HOLE MOUNT	5000	Keystone
2	L	1	Test Point, BLK,Miniature THRU-HOLE MOUNT	5001	Keystone
3	N	1	Test Point, WHT,Miniature THRU-HOLE MOUNT	5002	Keystone
4	RTN	1	Test Point, BLK,Miniature THRU-HOLE MOUNT	5001	Keystone

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7 Inductor Specification

Off-the-shelf drum type inductor specification from magnetic manufacturer (Bourns).

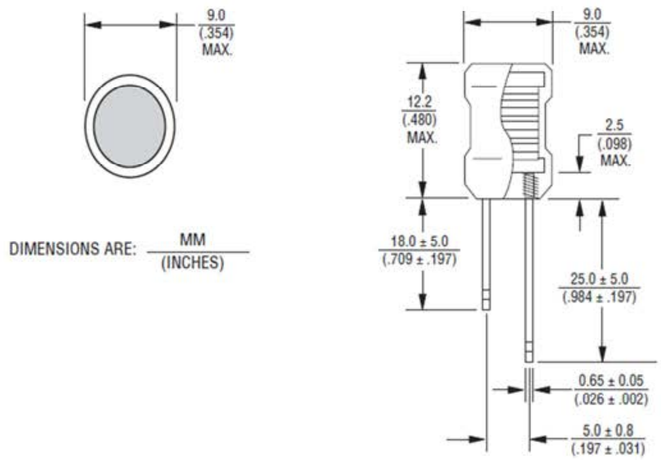
General Specifications

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

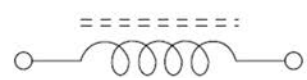
Materials

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

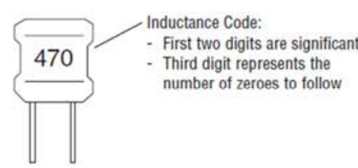
Product Dimensions



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

8 Performance Data

All measurements were performed at room temperature using LED load string. 2 minutes soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

8.1 *Efficiency*

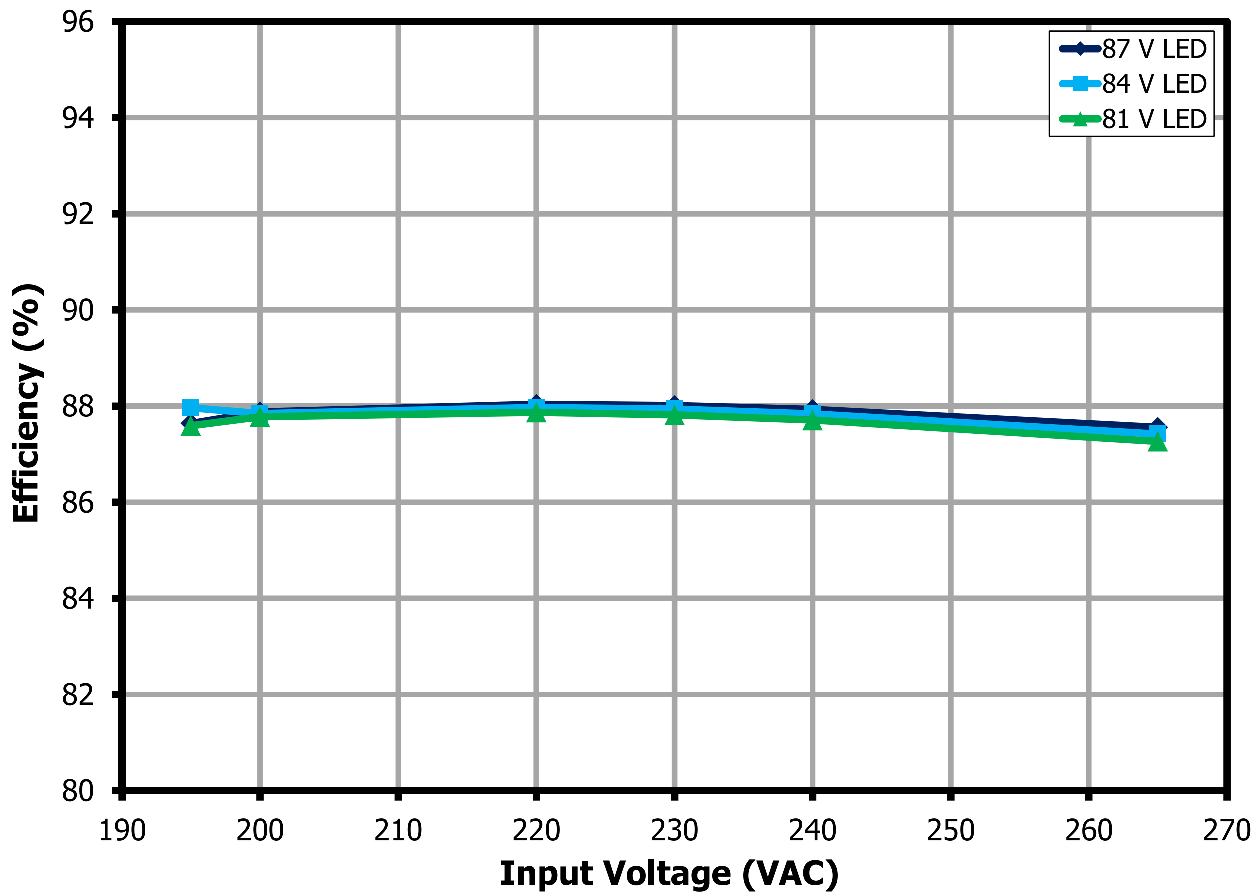


Figure 7 – Efficiency vs. Line and LED Load.

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8.2 *Line Regulation*

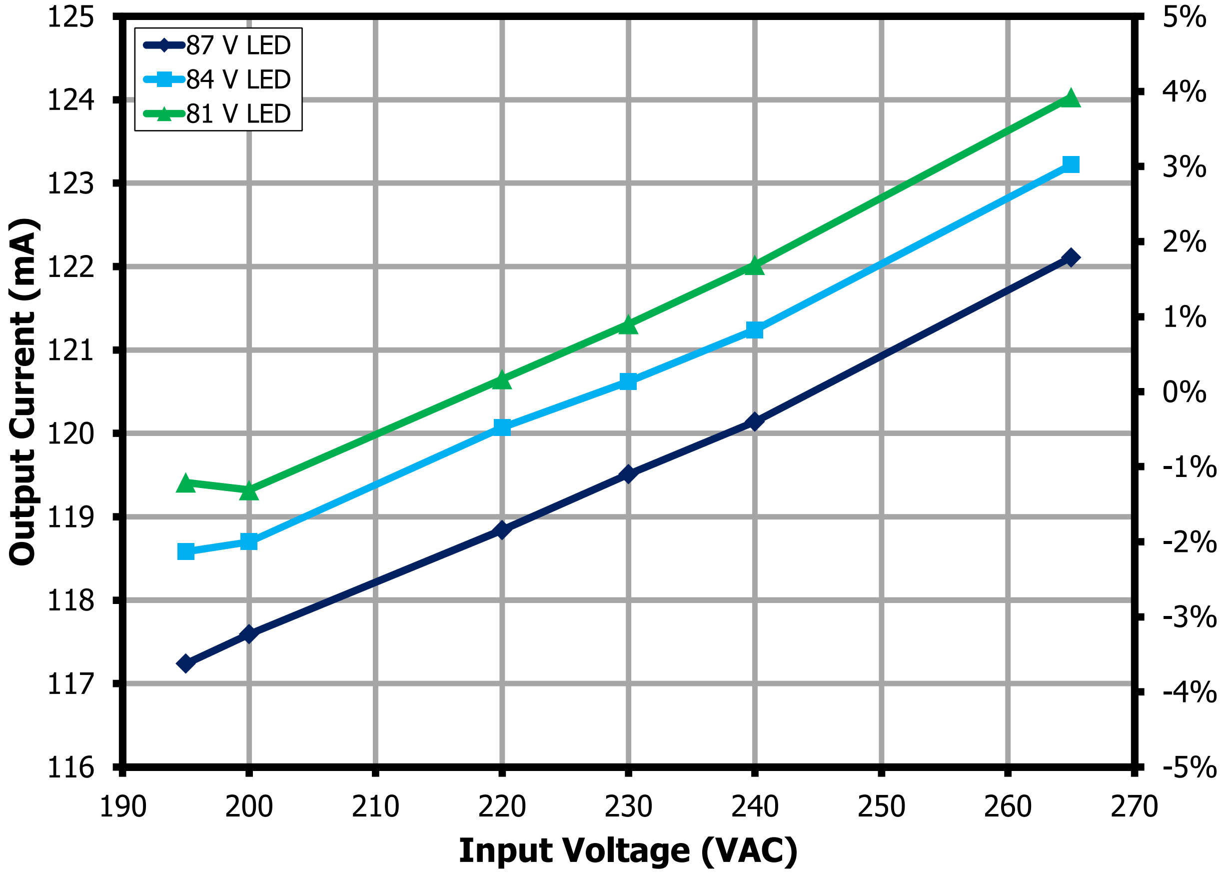

Figure 8 – Regulation vs. Line and LED Load.

8.3 *Power Factor*

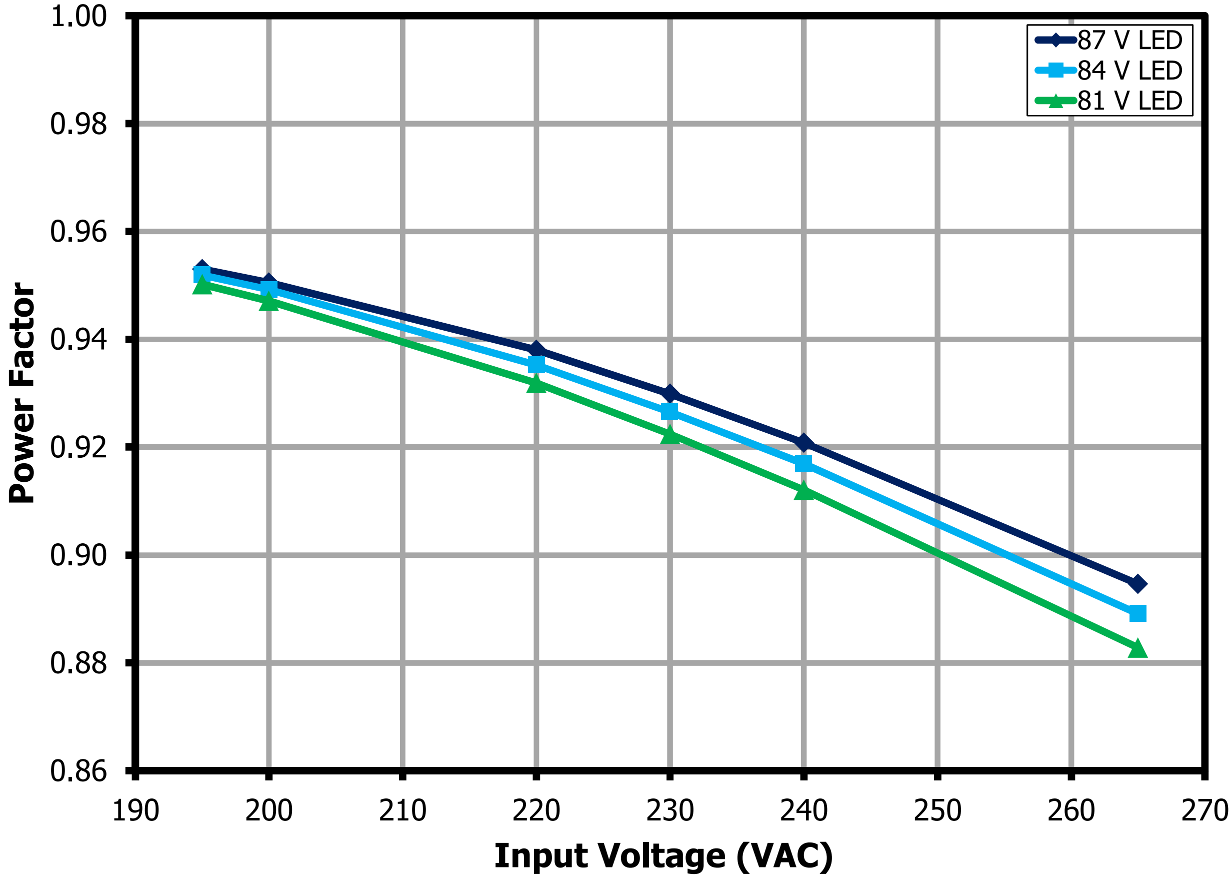

Figure 9 – Power Factor vs. Line and LED Load.

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8.4 ***%ATHD***

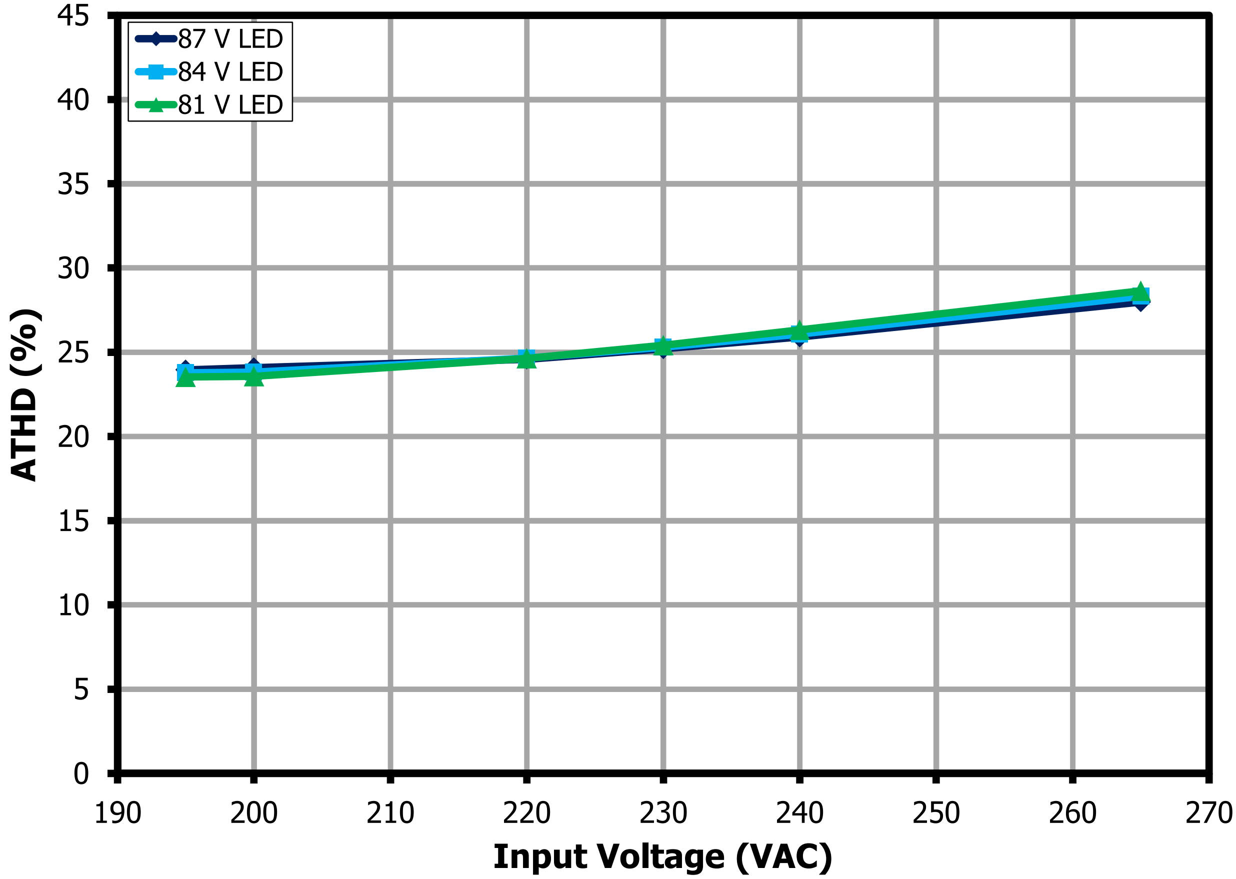

Figure 10 – % ATHD vs. Line and LED Load.

8.5 *Individual Harmonics Content*

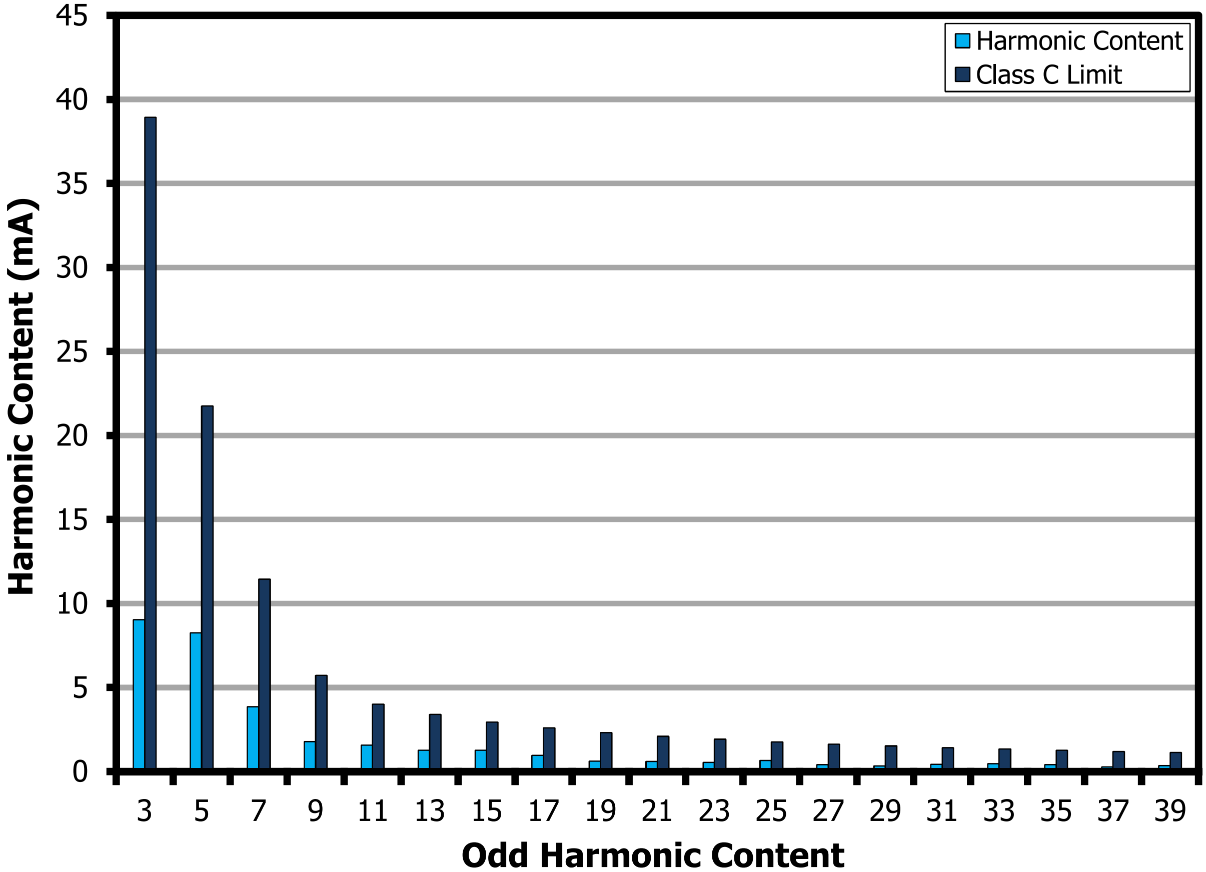

Figure 11 – 84 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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9 Test Data

9.1 *Test Data – 87 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)	
195	50	194.90	62.60	11.63	0.953	23.95	87.30	117.24	10.19	87.64
200	50	199.87	61.28	11.64	0.951	24.09	87.28	117.59	10.23	87.88
220	50	219.91	57.01	11.76	0.938	24.58	87.35	118.84	10.35	88.03
230	50	229.93	55.35	11.83	0.930	25.20	87.39	119.51	10.41	88.01
240	50	239.95	53.91	11.91	0.921	25.90	87.43	120.14	10.47	87.93
265	50	264.97	51.34	12.17	0.895	27.97	87.57	122.11	10.66	87.56

9.2 *Test Data – 84 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)	
195	50	194.83	61.10	11.33	0.952	23.79	84.43	118.58	9.97	87.96
200	50	199.87	59.93	11.37	0.949	23.81	84.40	118.70	9.99	87.84
220	50	219.91	55.83	11.48	0.935	24.65	84.47	120.07	10.10	87.97
230	50	229.93	54.25	11.56	0.927	25.29	84.50	120.62	10.16	87.94
240	50	239.95	52.88	11.63	0.917	26.07	84.53	121.24	10.22	87.84
265	50	264.97	50.47	11.89	0.889	28.31	84.66	123.22	10.39	87.42

9.3 *Test Data – 81 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)	
195	50	194.90	59.70	11.06	0.950	23.54	81.47	119.41	9.69	87.59
200	50	199.87	58.27	11.03	0.947	23.57	81.40	119.32	9.68	87.78
220	50	219.91	54.42	11.15	0.932	24.64	81.47	120.65	9.80	87.87
230	50	229.93	52.93	11.23	0.922	25.42	81.50	121.31	9.86	87.81
240	50	239.95	51.68	11.31	0.912	26.31	81.53	122.02	9.92	87.71
265	50	264.97	49.44	11.56	0.883	28.65	81.66	124.03	10.09	87.26

9.4 *Test Data – Individual Odd Harmonic Content*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	53.69	11.450	24.919

nth Order	mA Content	% Content	mA Limit <25 W	Remarks
1	51.76			
2	0.02	0.04%		
3	9.03	17.45%	38.93	Pass
5	8.25	15.94%	21.76	Pass
7	3.86	7.46%	11.45	Pass
9	1.77	3.42%	5.73	Pass
11	1.56	3.01%	4.01	Pass
13	1.27	2.45%	3.39	Pass
15	1.26	2.43%	2.94	Pass
17	0.96	1.85%	2.59	Pass
19	0.63	1.22%	2.32	Pass
21	0.60	1.16%	2.10	Pass
23	0.55	1.06%	1.92	Pass
25	0.65	1.26%	1.76	Pass
27	0.41	0.79%	1.63	Pass
29	0.33	0.64%	1.52	Pass
31	0.43	0.83%	1.42	Pass
33	0.47	0.91%	1.34	Pass
35	0.41	0.79%	1.26	Pass
37	0.28	0.54%	1.19	Pass
39	0.36	0.70%	1.13	Pass

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10 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 230 VAC, 50 Hz line frequency, room temperature, and a nominal 84 V LED load.

10.1 ***Dimming Curve***

Agilent 6812B AC source programmed as perfect leading edge dimmer

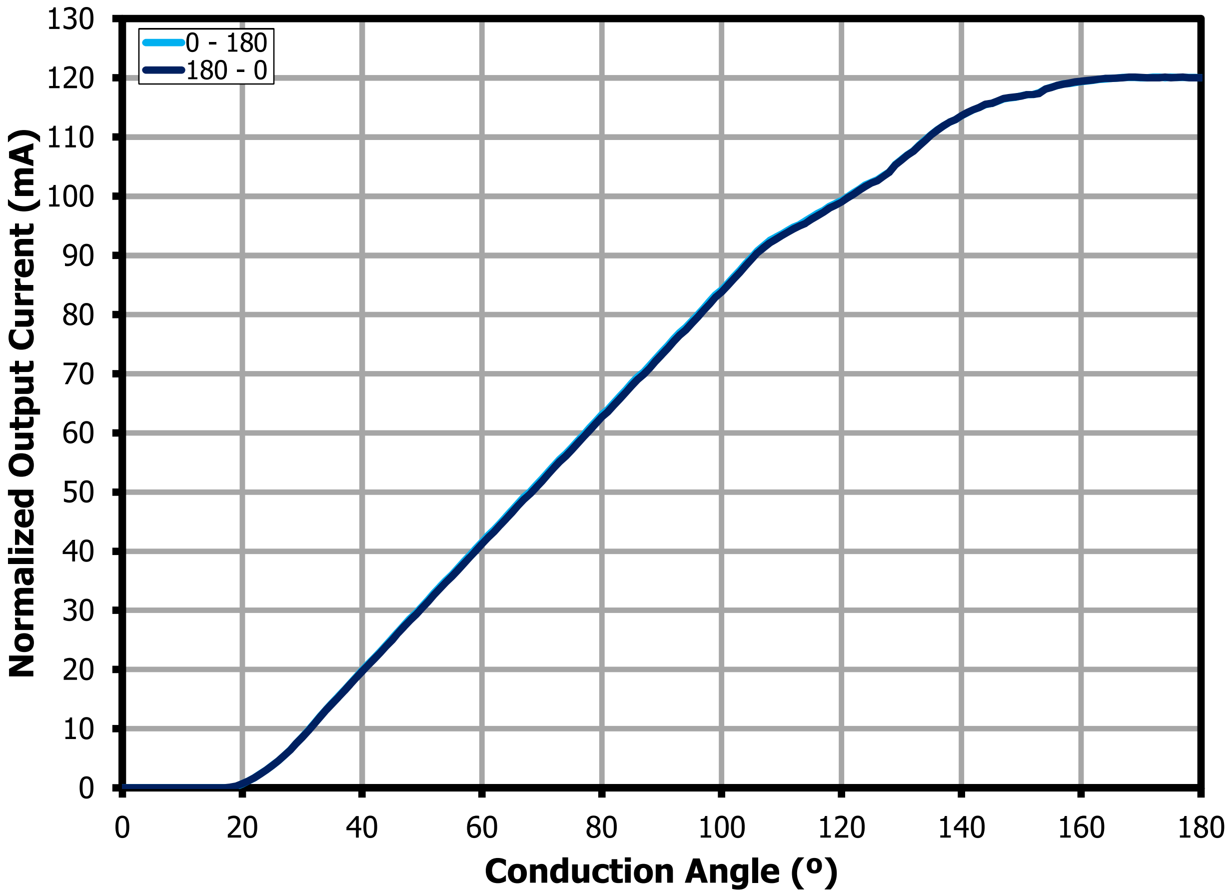

Figure 12 – Dimming Curve at 230 VAC, 50 Hz Input.

10.2 ***Dimming Efficiency***

Measurements were made using a programmable AC source to provide the leading edge chopped AC input. For this test, the damper is already active.

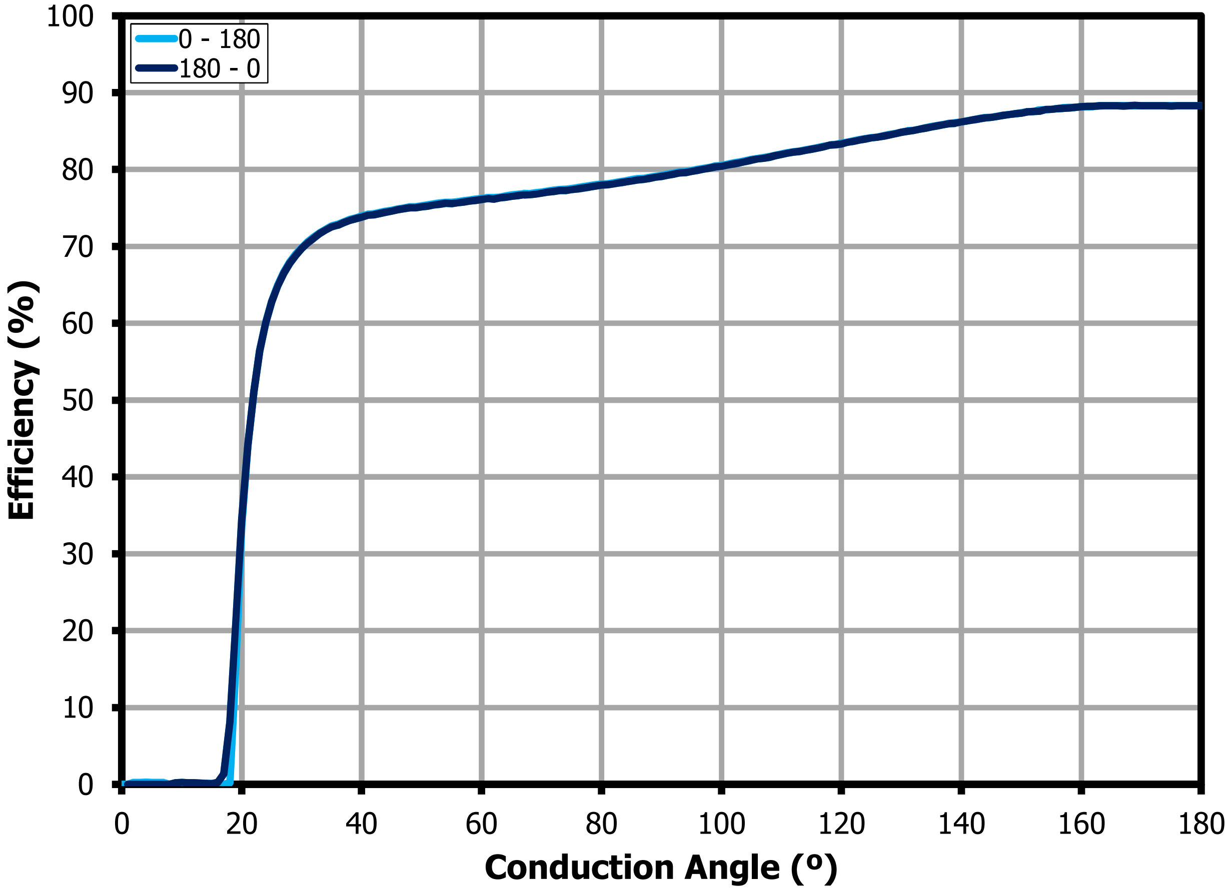

Figure 13 – Driver Efficiency at 230 VAC, 50 Hz Input.

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10.3 *Driver Power Loss during Dimming*

Measurements were made using a programmable AC source to provide the leading edge chopped AC input. For this test, the damper is already active.

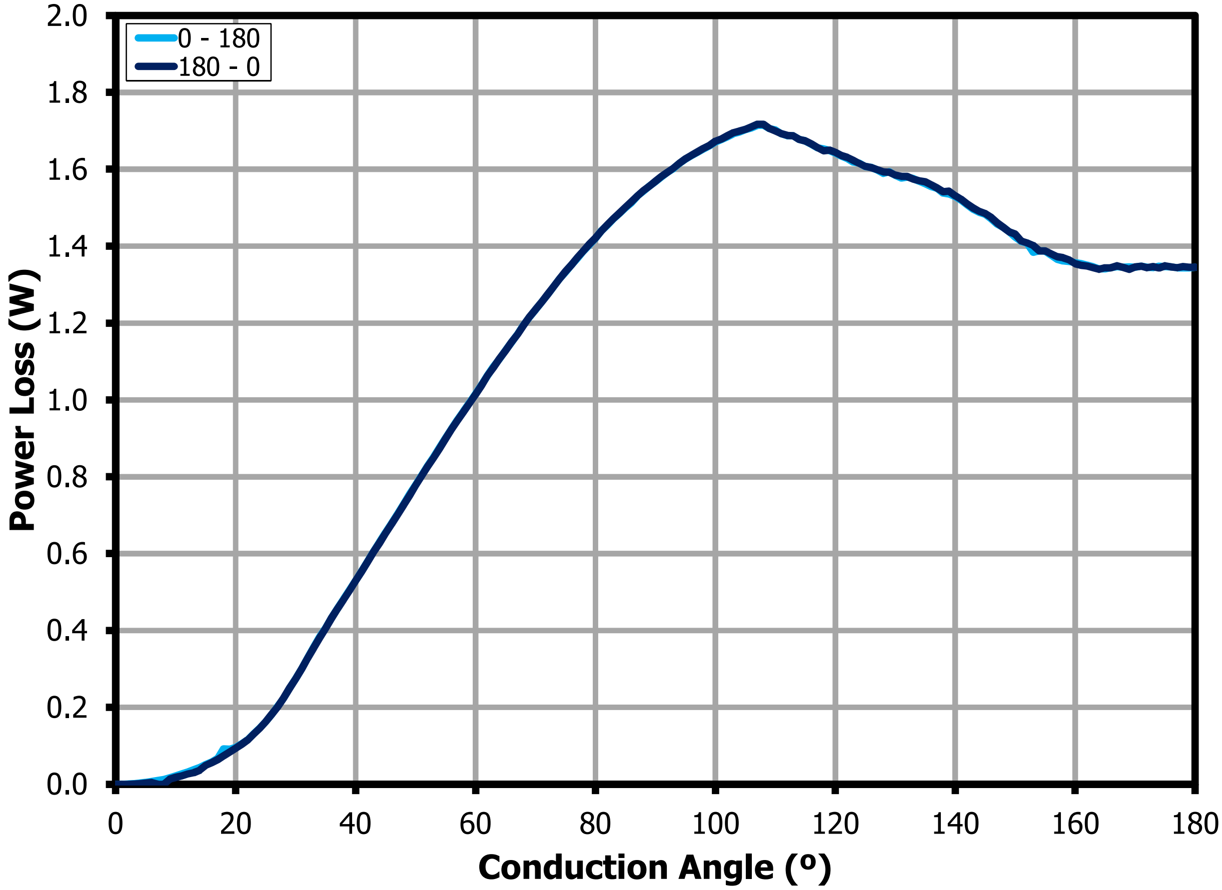

Figure 14 – Driver Power Loss at 230 VAC, 50 Hz Input.

10.4 *Dimmer Compatibility List*

The following dimmers were tested at 25 ºC ambient temperature with 230 V, 50 Hz line input and 84 V LED load.

No	Brand	Model	Type	Max (mA)	Min (mA)	Dimming Ratio
1	BERKER	2830	L	115.49	2.6	44.42
2	GIRA	0302 00	L	115	2.9	39.66
3	GIRA	2262 00	L	117	9.9	11.82
4	GIRA	0300 00	L	112	2.3	48.70
5	PEHA	433 HAB 0A	T	106	14.5	7.31
6	BERKER	2875	L	115.23	4	28.81
7	GIRA	226200-101	L	117.33	7.7	15.24
8	BTICINO	4402N	L	109.5	23.5	4.66
9	IKEA	EED200LRS	L	110	1	110.00
10	EAGLERISE	SED200LRS	L	118	1.5	78.67
11	EAGLERISE	SED300FHS	L	114	1.1	103.64
12	SCHNEIDER	ALB4X192	L	115.8	1.1	105.27
13	JUNG	266 GDE	L	115	2.7	42.59
14	JUNG	225 NVDE	L	114.5	5.5	20.82
15	BUSCH	2250 U	L	117	4.4	26.59
16	NIKO	310-01600	L	118	9.6	12.29
17	NIKO	310-01400	L	118.5	6.4	18.52
18	NIKO	310-01300	L	118	1.9	62.11
19	AU	DSP400X	L	113.2	1.1	102.91

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11 Thermal Performance

11.1 Thermal Scan at 25 ºC Ambient

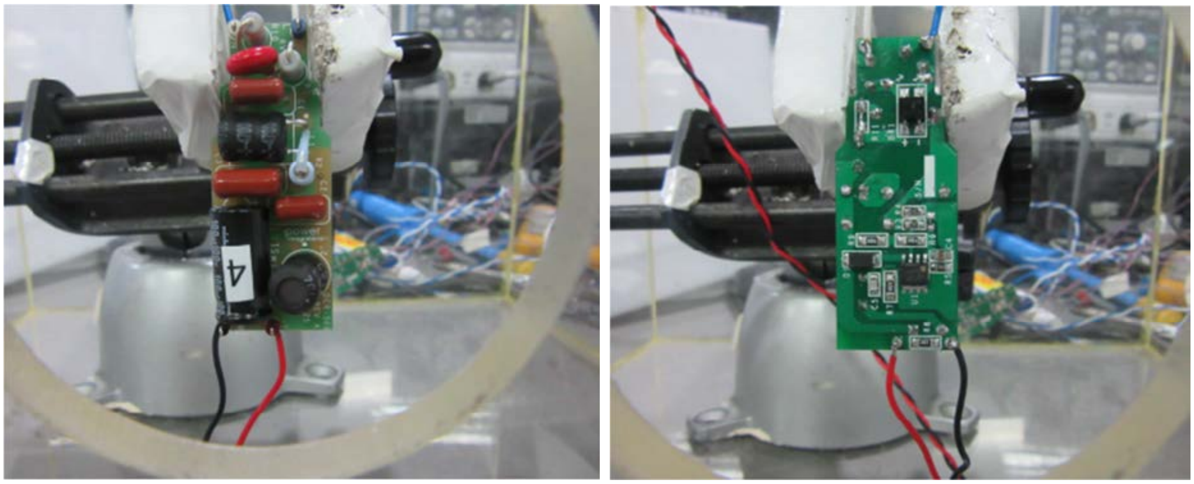

Figure 15 – Test Set-up Picture - Open Frame.

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 Non-Dimming Operation at 230 VAC

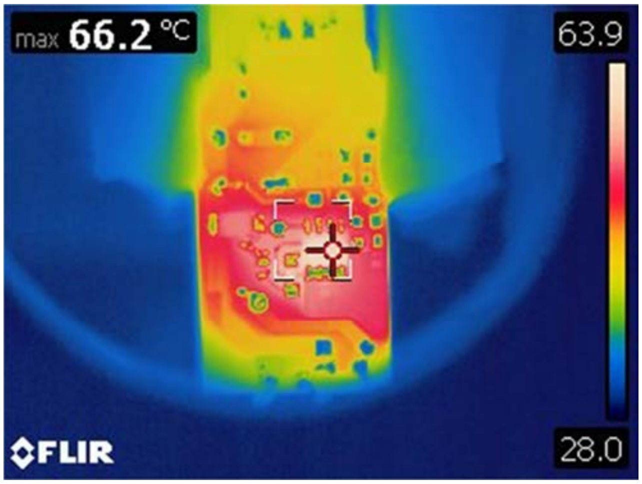

Figure 16 – 230 VAC, 84 V LED Load.
Spot 1: LYT7503D (U1): 66.2 ºC

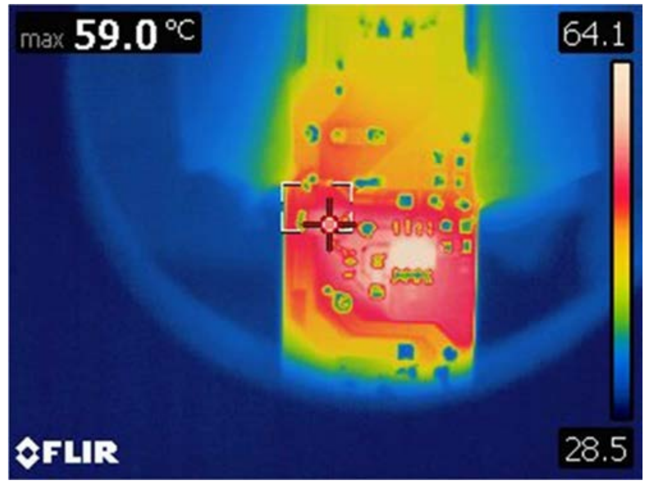

Figure 17 – 230 VAC, 84 V LED Load.
Spot 1: Flywheel Diode (D1): 59 ºC

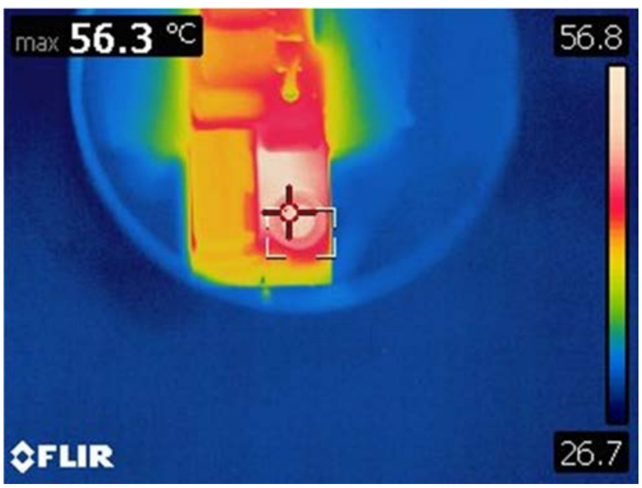

Figure 18 – 230 VAC, 84 V LED Load.
Spot 1: Buck Inductor (L2): 56.3 ºC.

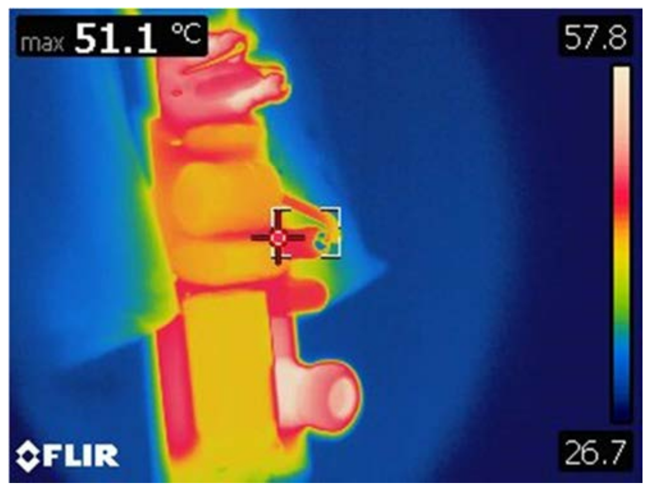

Figure 19 – 230 VAC, 84 V LED Load.
Spot 1: Damper (R11): 51.1 ºC.

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Figure 20 – 230 VAC, 84 V LED Load.
Spot 1: Damper Resistor (R10): 60.2 ºC.

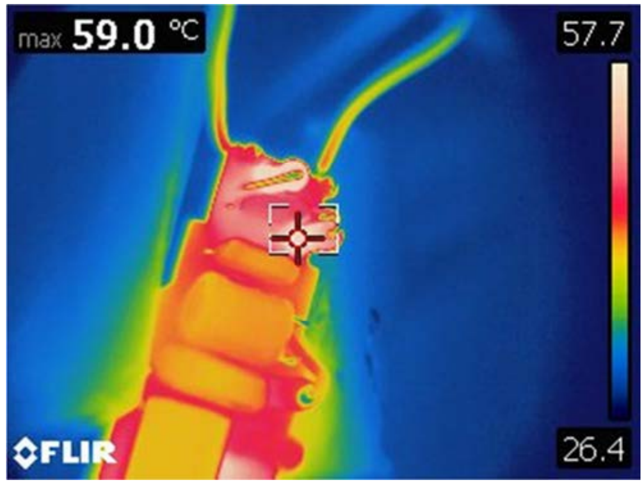

Figure 21 – 230 VAC, 84 V LED Load.
Spot 1: Fusible Resistor (R1): 59 ºC.

11.1.2 Dimming Operation at 110º Conduction Angle

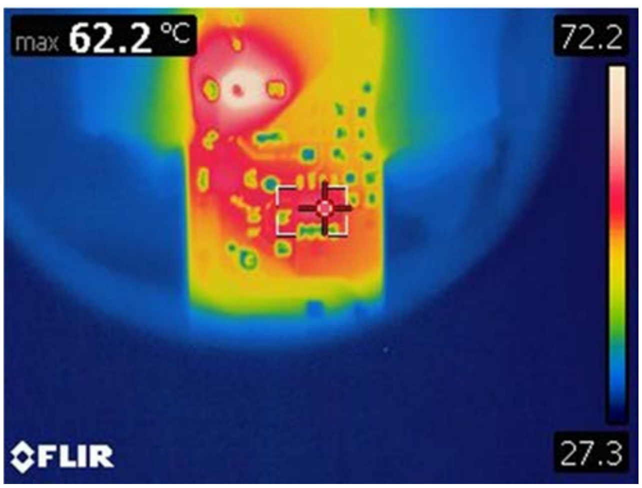

Figure 22 – 230 VAC, 84 V LED Load.
Spot 1: LYT7503D (U1): 62.2 ºC.

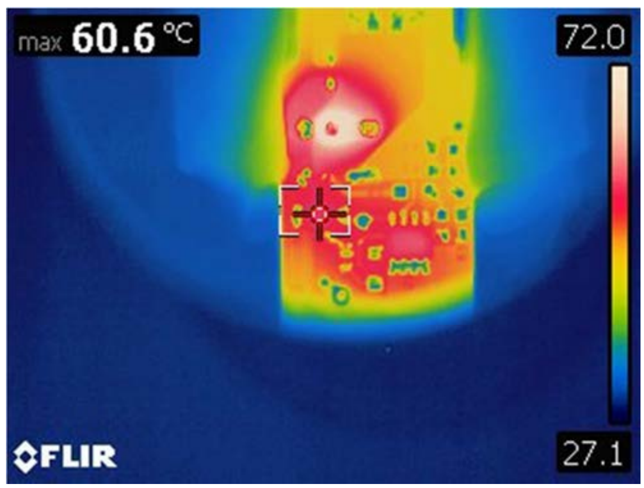

Figure 23 – 230 VAC, 84 V LED Load.
Spot 1: Flywheel Diode (D1): 60.6 ºC.

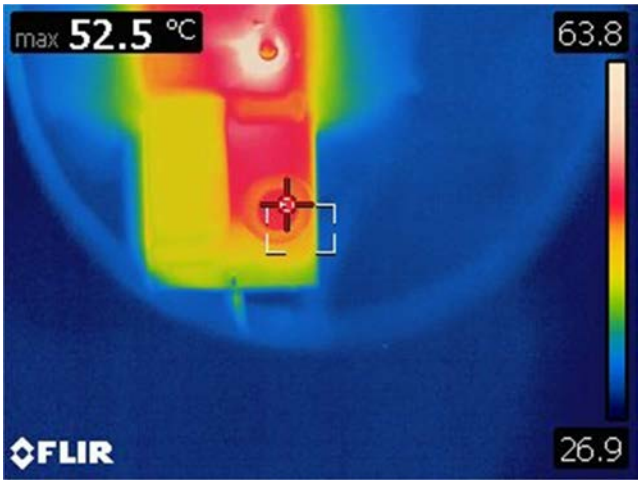

Figure 24 – 230 VAC, 84 V LED Load.
Spot 1: Buck Inductor (L2): 52.5 ºC.

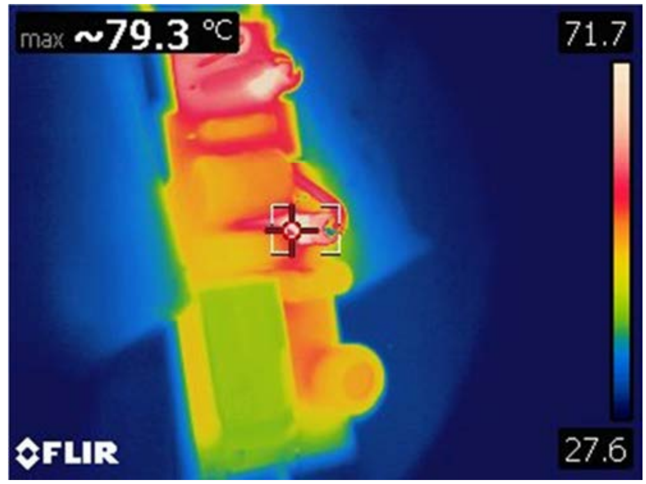

Figure 25 – 230 VAC, 84 V LED Load.
Spot 1: Damper (R11): 79.3 ºC.

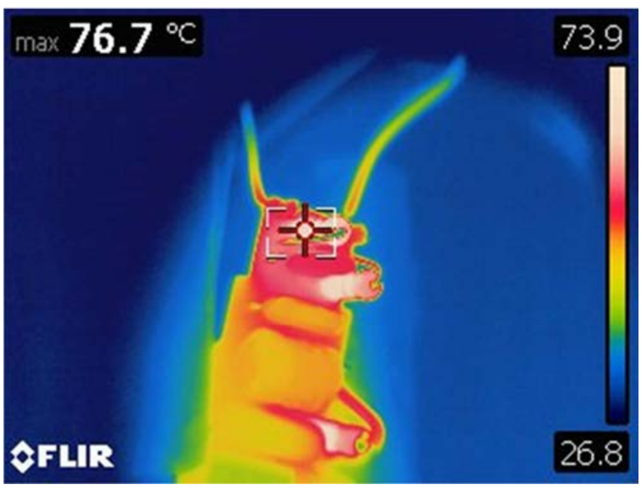

Figure 26 – 230 VAC, 84 V LED Load,
Spot 1: Damper Resistor (R10): 76.7 ºC.

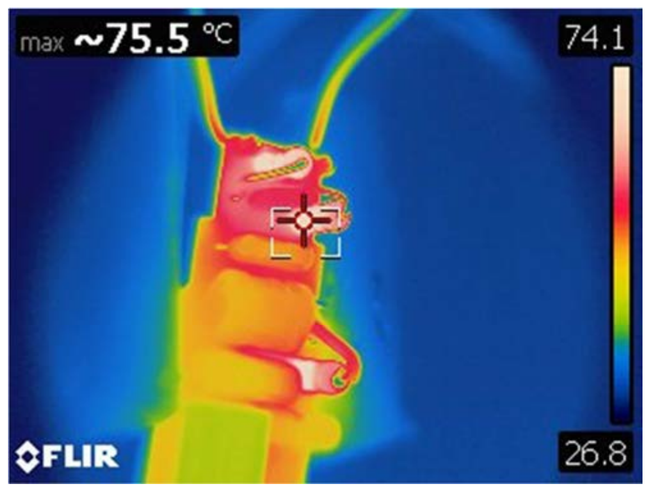

Figure 27 – 230 VAC, 84 V LED Load.
Spot 1: Fusible Resistor (R1): 75.5 ºC.

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11.2 **Thermal Performance at 90 ºC Ambient**

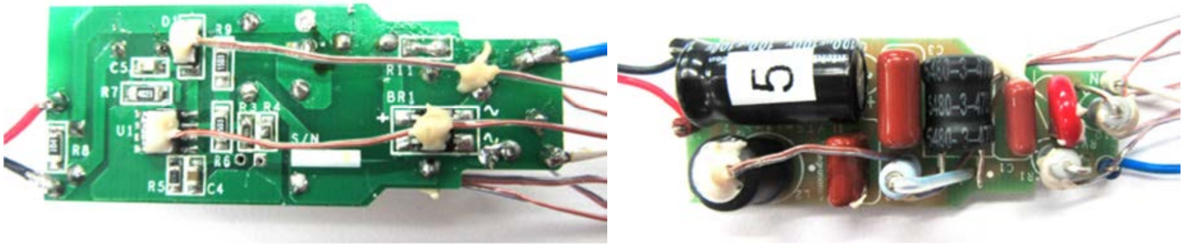

Figure 28 – Test Set-up Picture Thermal at 90 ºC Ambient- Open Frame.

Unit in open frame was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 90 ºC. Temperature was measured using type T thermocouple.

11.2.1 Non-Dimming at 195 VAC, 84 V LED Load

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	91.1	90.9
LYTSwitch-7	111.5	111.4
L2-Buck Inductor	110.2	110.1
R1-Fusible	112.5	112.4
R10-Damper	114.1	114.1
R11-Damper	105.5	105.5
D1-Flywheel Diode	111.5	111.5

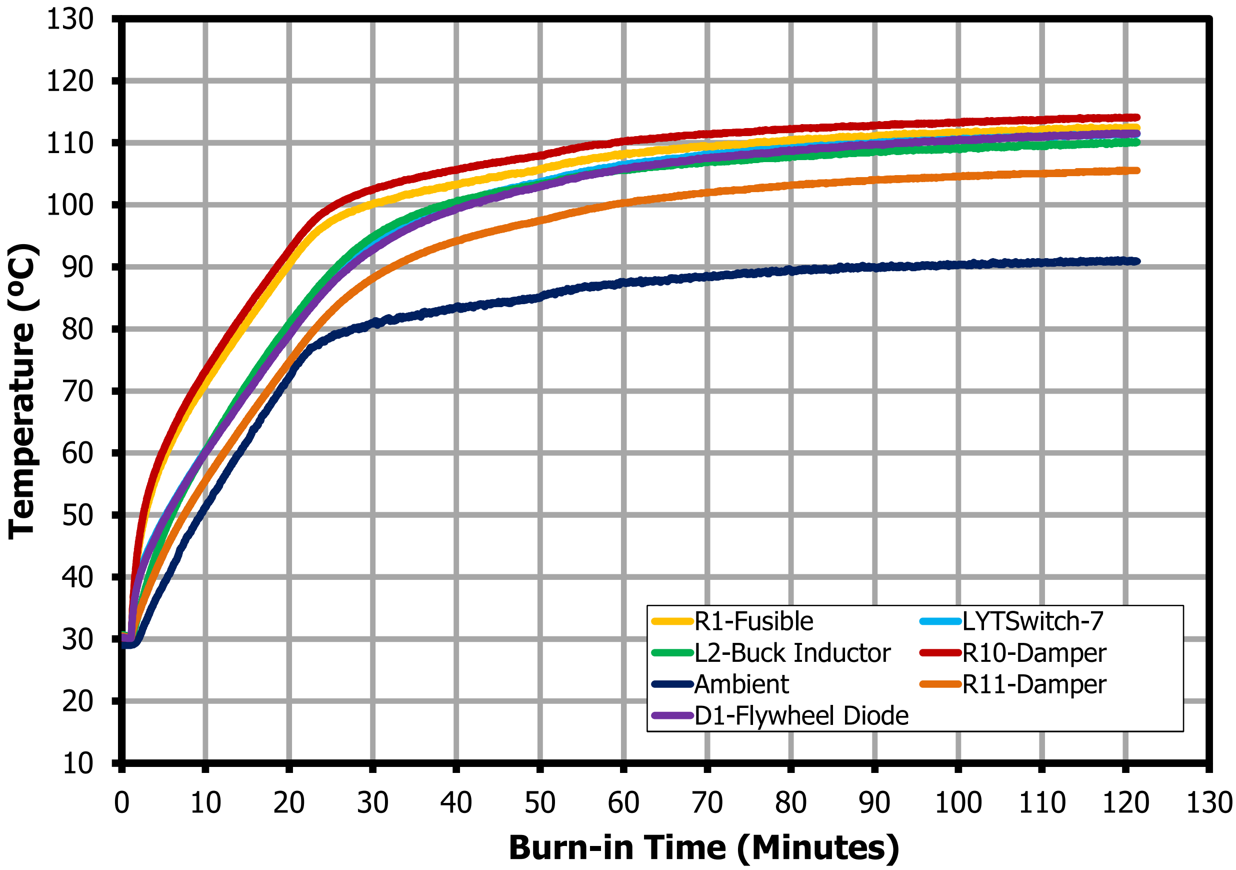

Figure 29 – Component Temperature at 195 VAC, 84 V LED Load, 90 ºC Ambient.

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11.2.2 Non-Dimming at 265 VAC, 84 V LED Load

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	90.9	90.8
LYT-7	111.8	111.3
L2-Buck Inductor	111.7	111.6
R1-Fusible	104.2	104.2
R10-Damper	101.9	101.8
R11-Damper	107.2	107.1
D1-Flywheel Diode	114.9	114.7

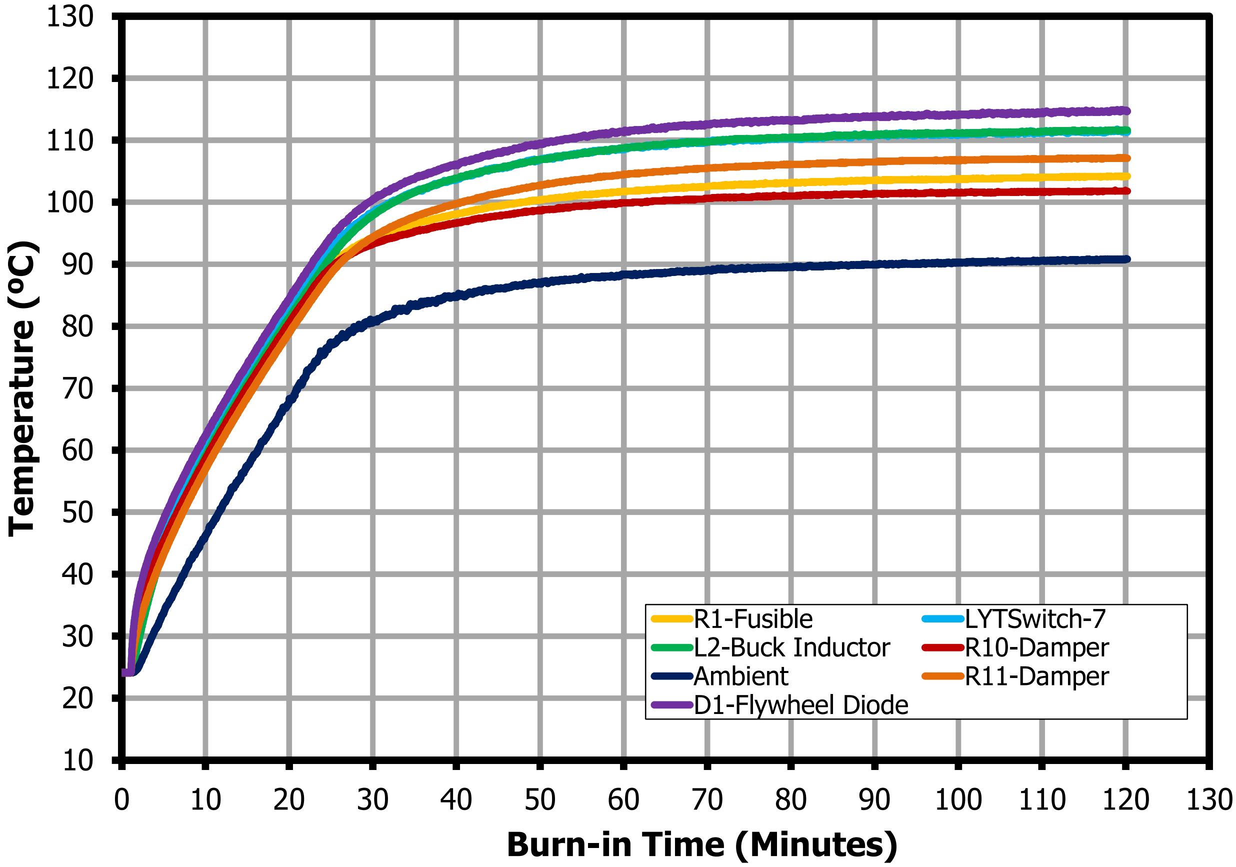

Figure 30 – Component Temperature at 265 VAC, 84 V LED Load, 90 ºC Ambient.

11.2.3 With Dimmer at 230 VAC and 110º Conduction Angle

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	91.4	91.3
LYT-7	112.0	111.8
L2-Buck Inductor	113.6	113.5
R1-Fusible	125.4	125.2
R10-Damper	124.8	124.6
R11-Damper	133.7	133.6
D1-Flywheel Diode	114.8	114.7

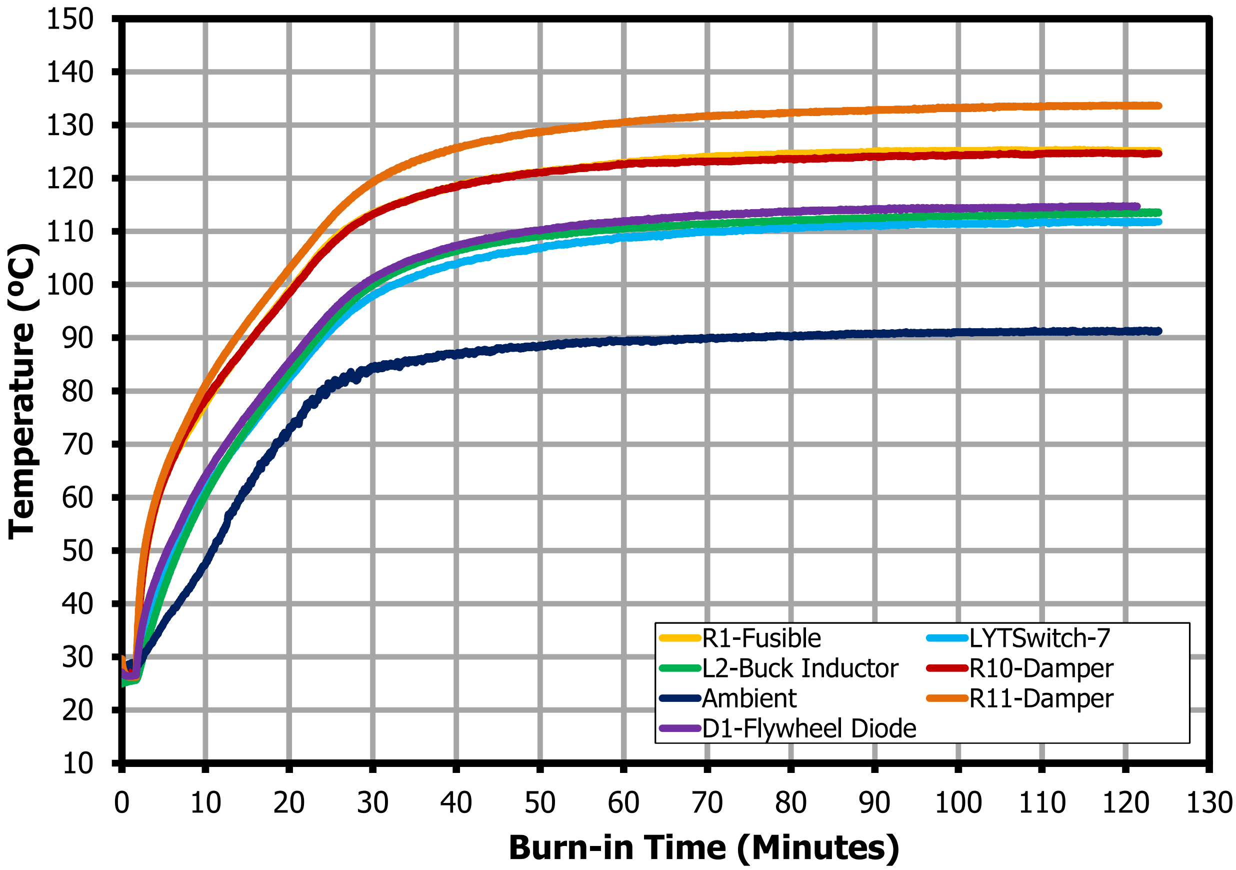

Figure 31 – Component Temperature with Dimmer at 230 VAC, 84 V LED Load, 90 ºC Ambient.

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12 Waveforms

12.1 *Input Voltage and Input Current Waveforms*

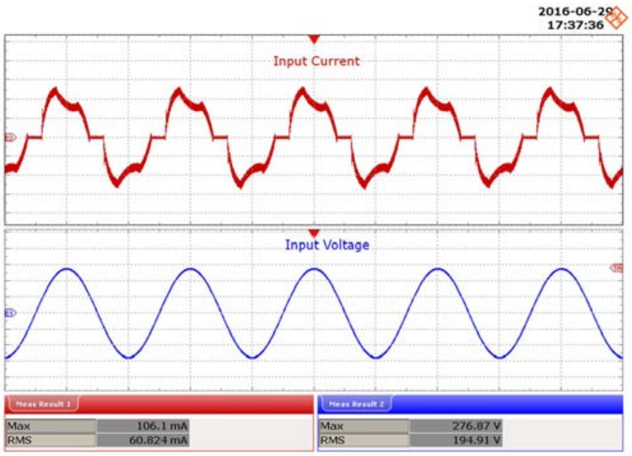

Figure 32 – 195 VAC, 84 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

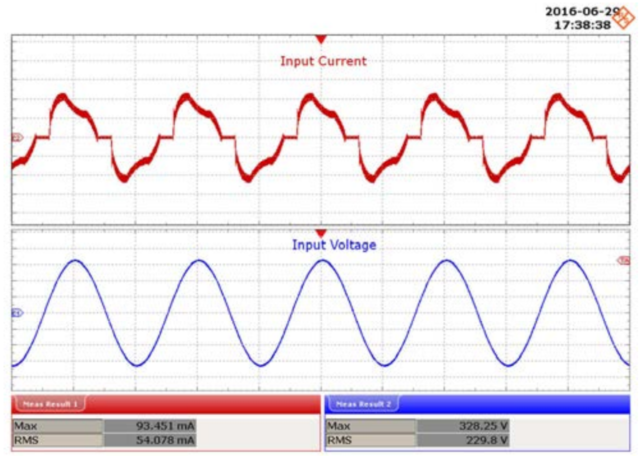

Figure 33 – 230 VAC, 84 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

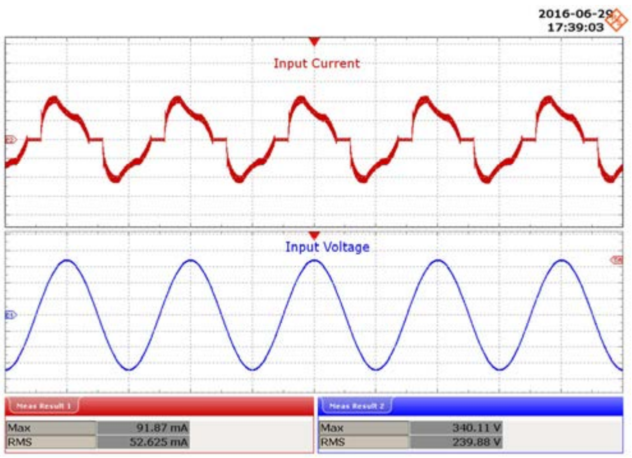

Figure 34 – 240 VAC, 84 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

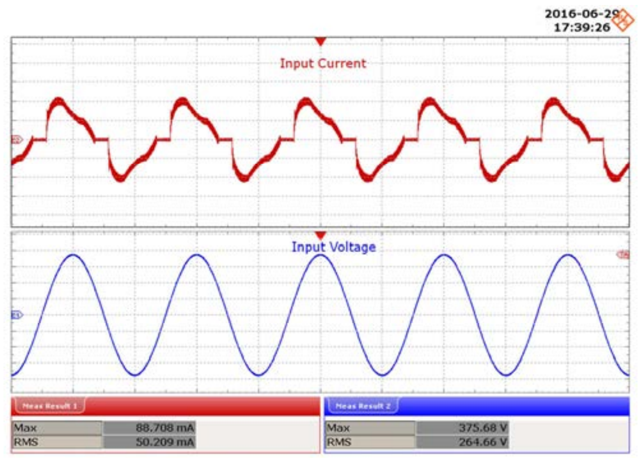

Figure 35 – 265 VAC, 84 V LED Load.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

12.2 *Input Voltage and Input Current Waveforms with Dimmer*

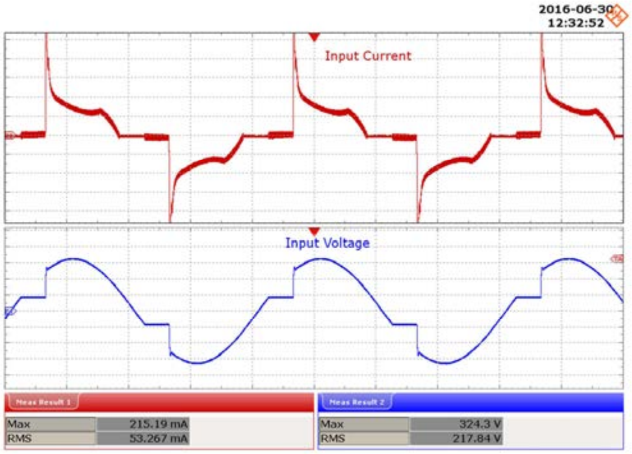

Figure 36 – 145º Conduction Angle, 84 V LED.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 5 ms / div.

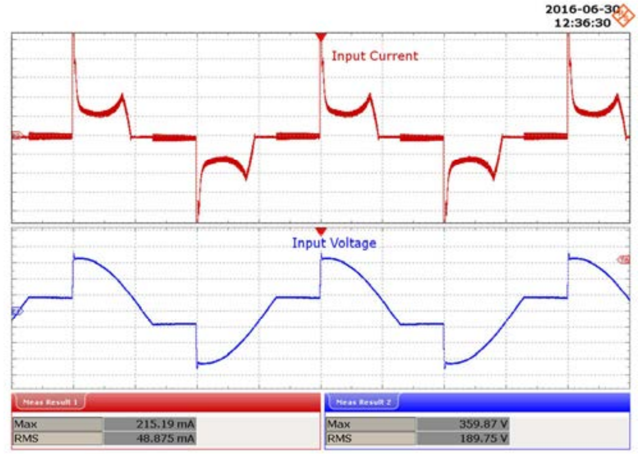

Figure 37 – 115º Conduction Angle, 84 V LED.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 5 ms / div.

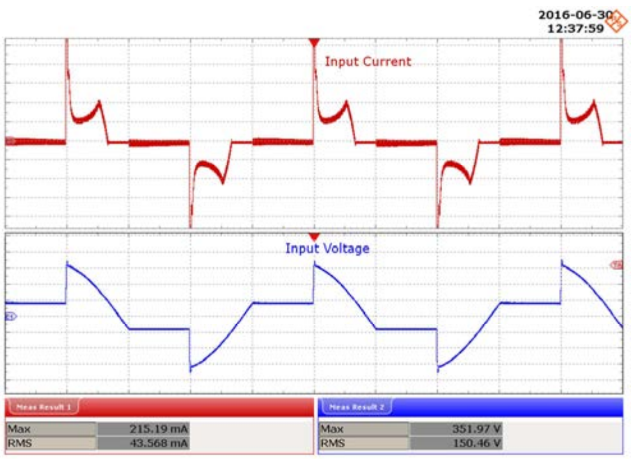

Figure 38 – 90º Conduction Angle, 84 V LED.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 5 ms / div.

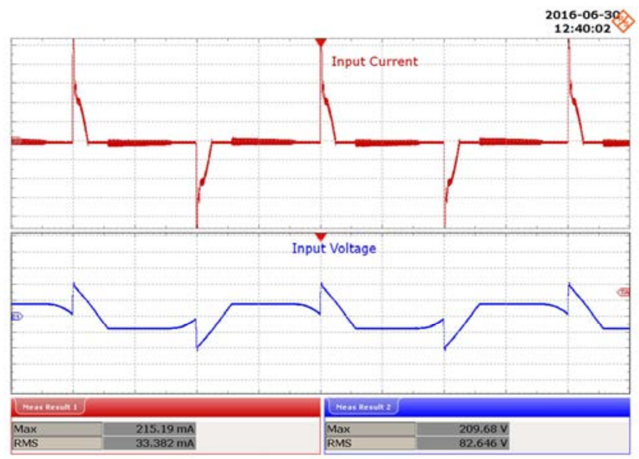

Figure 39 – 50º Conduction Angle, 84 V LED.
Upper: I_{IN}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 5 ms / div.

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12.3 *Start-up Profile*

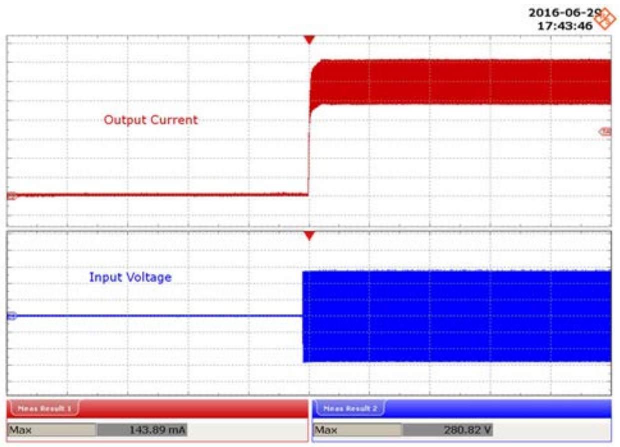

Figure 40 – 195 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

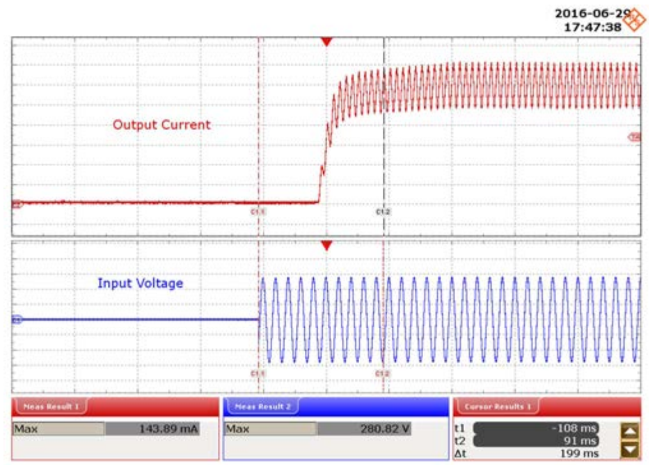

Figure 41 – 195 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Turn-on Time: 199 ms.

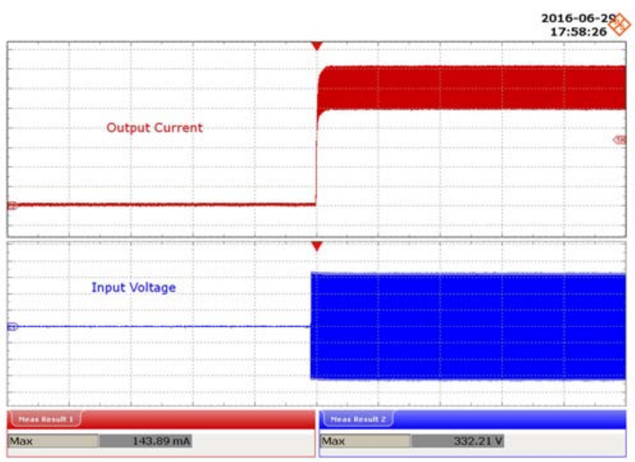

Figure 42 – 230 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

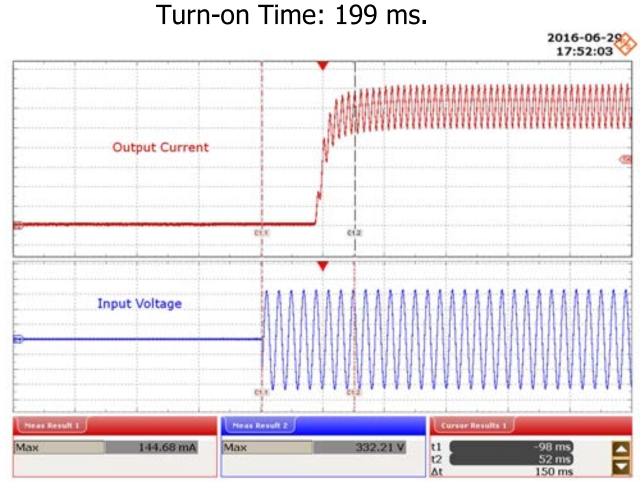

Figure 43 – 230 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Turn-on Time: 150 ms.

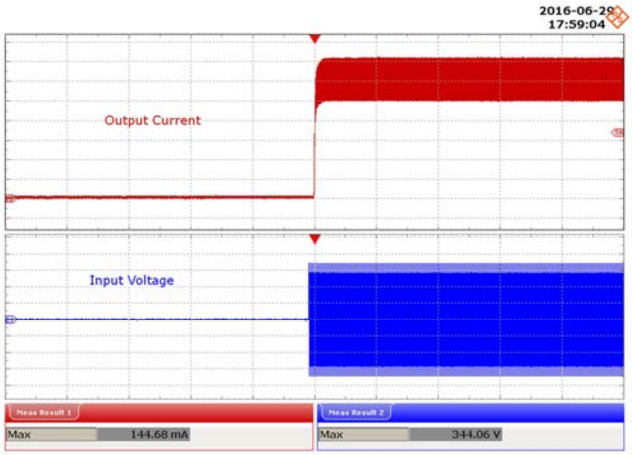

Figure 44 –240 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

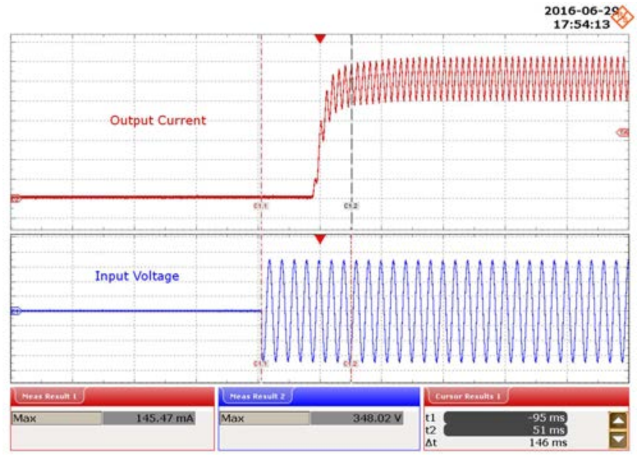

Figure 45 – 240 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Turn-on Time: 146 ms.

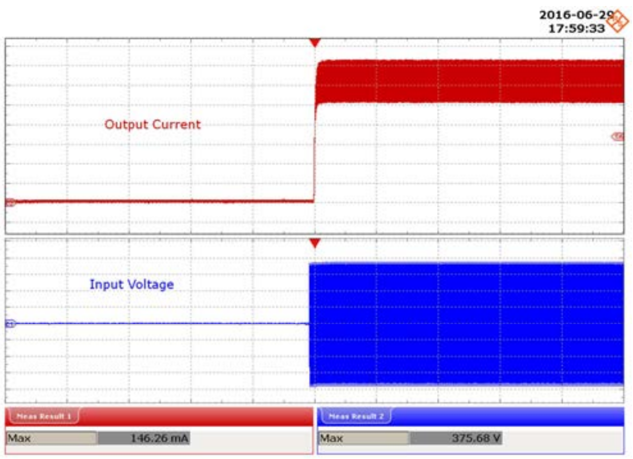

Figure 46 – 265 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

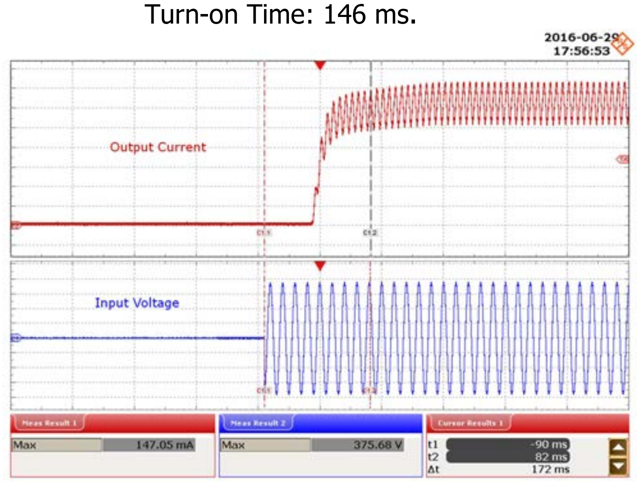

Figure 47 – 265 VAC, 84 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Turn-on Time: 172 ms.

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12.4 *Output Current Fall*

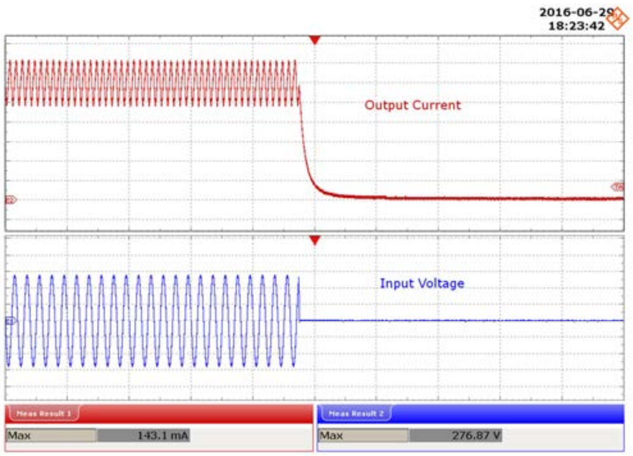

Figure 48 – 195 VAC, 84 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

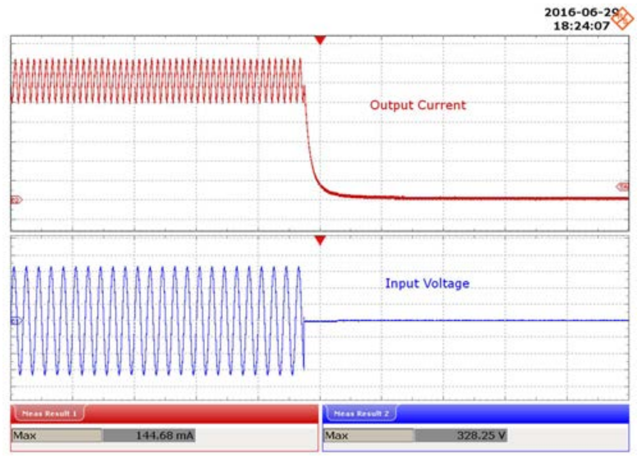

Figure 49 – 230 VAC, 84 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

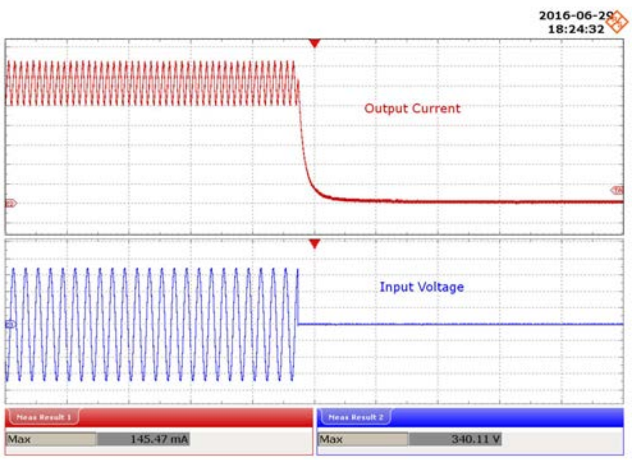

Figure 50 – 240 VAC, 84 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

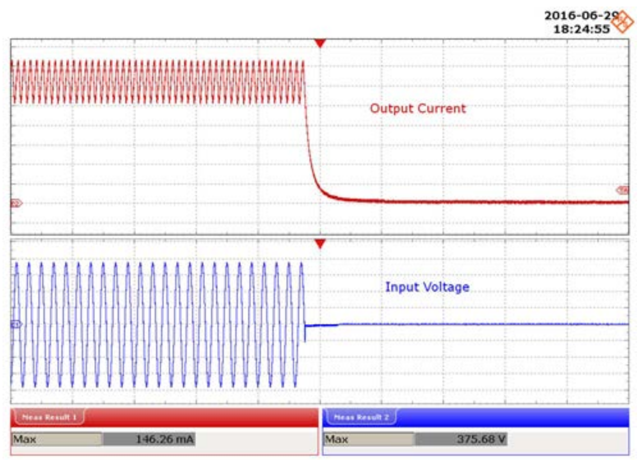

Figure 51 – 265 VAC, 84 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

12.5 *Input Voltage and Output Current with Dimmer*

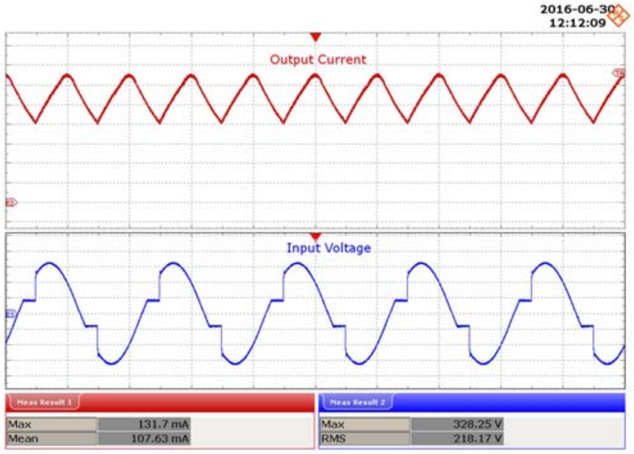

Figure 52 – 145º Conduction Angle, 84 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

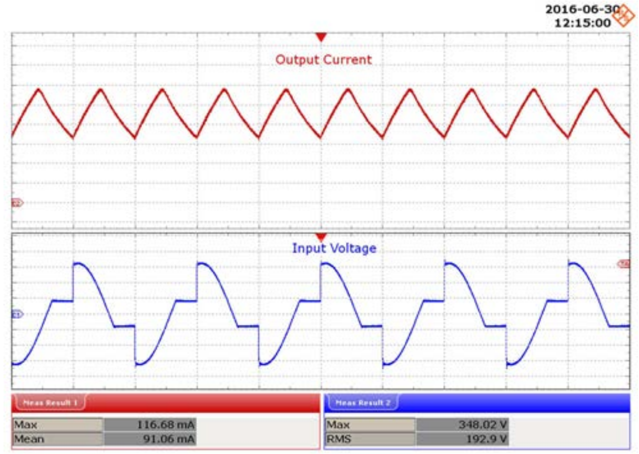

Figure 53 – 115º Conduction Angle, 84 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

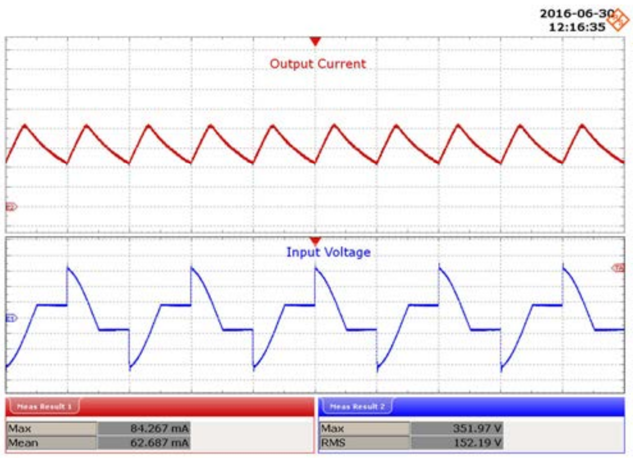

Figure 54 – 90º Conduction Angle, 84 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

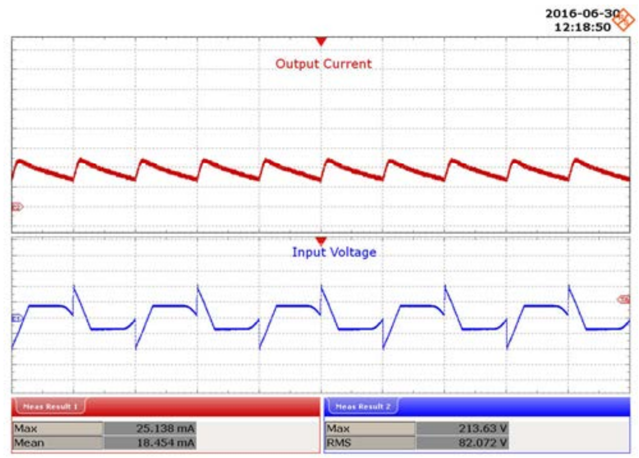

Figure 55 – 50º Conduction Angle, 84 V LED.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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12.6 *Drain Voltage and Current in Normal Operation*

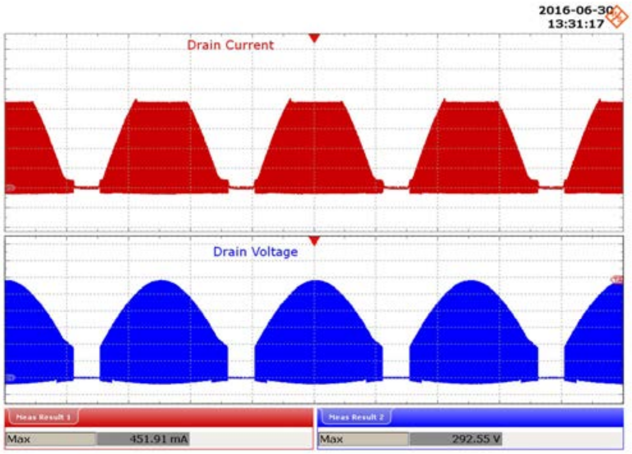

Figure 56 – 195 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 40 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

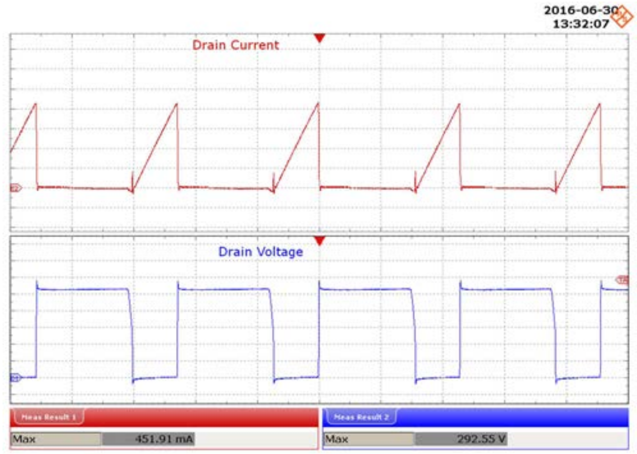

Figure 57 – 195 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 40 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

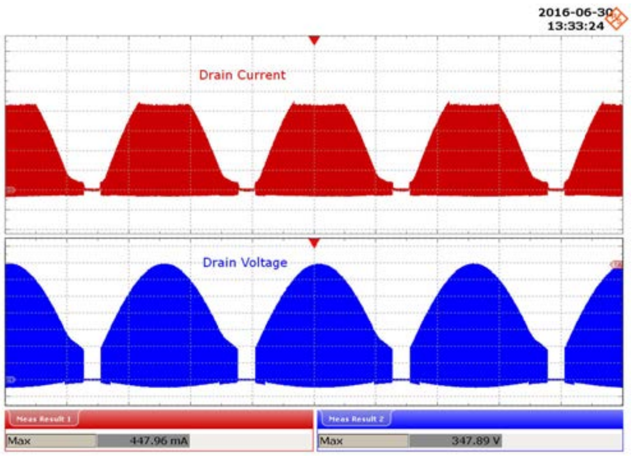

Figure 58 – 230 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 40 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

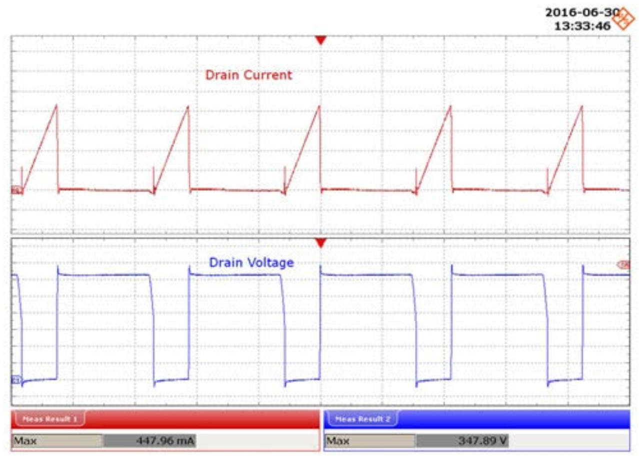

Figure 59 – 230 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 40 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

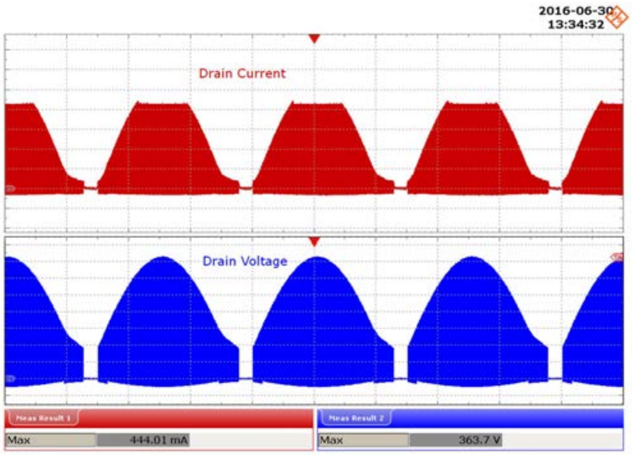

Figure 60 – 240 VAC, 84 V LED Load
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

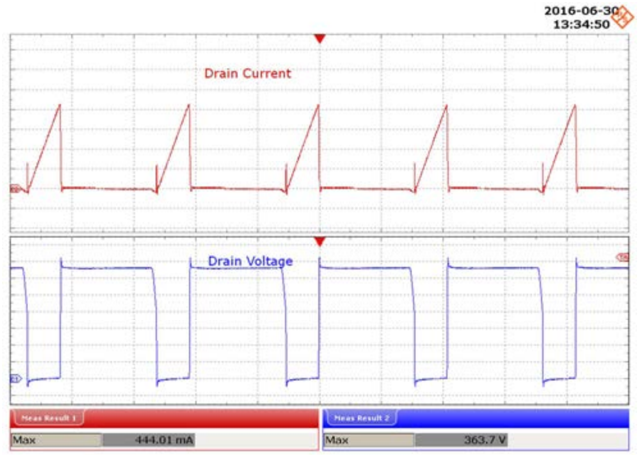

Figure 61 – 240 VAC, 84 V LED Load
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

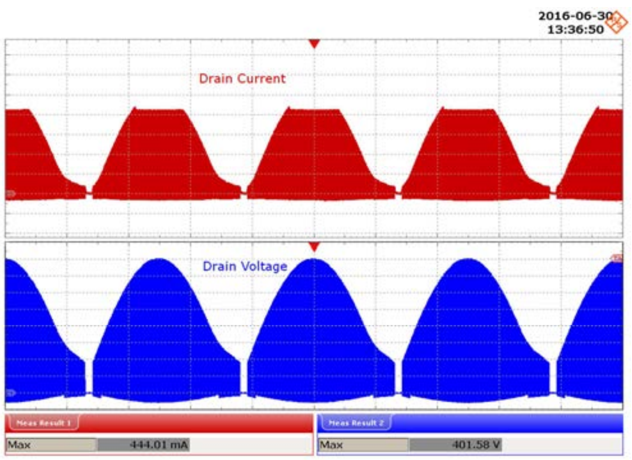

Figure 62 – 265 VAC, 84 V LED Load
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

Figure 63 – 265 VAC, 84 V LED Load
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

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12.7 *Drain Voltage and Current Start-up Profile*

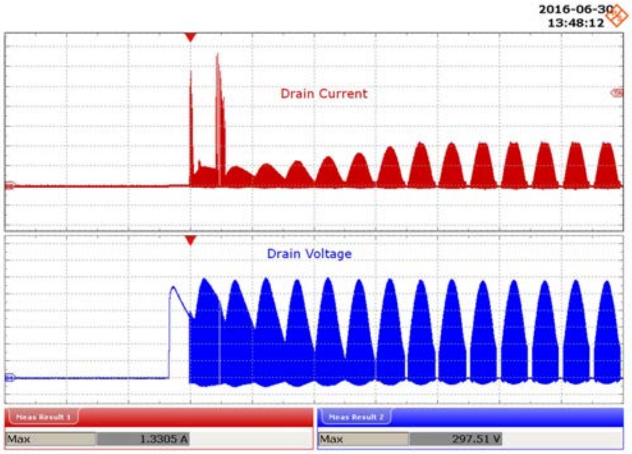

Figure 64 – 195 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

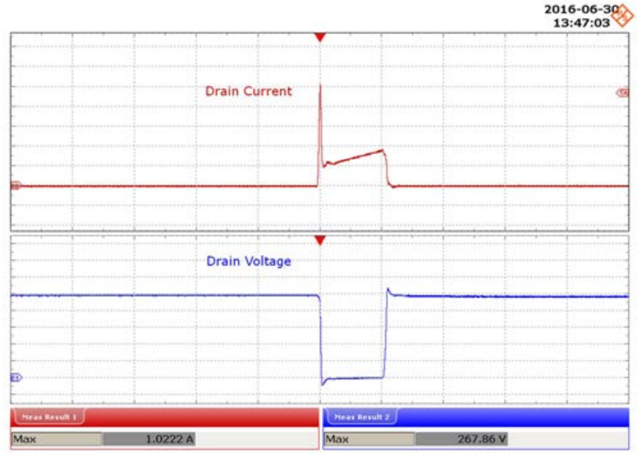

Figure 65 – 195 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 µs / div.

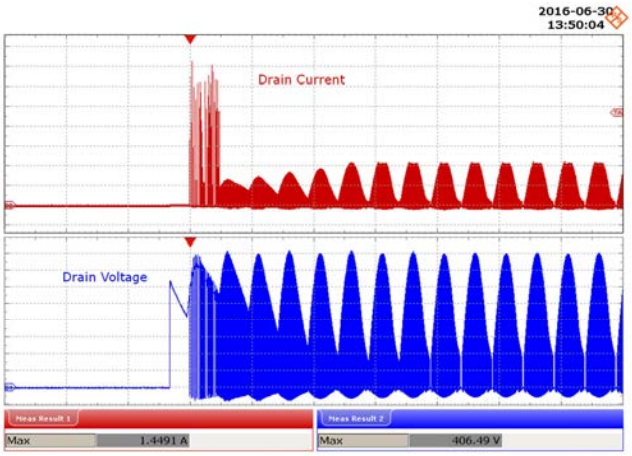

Figure 66 – 265 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

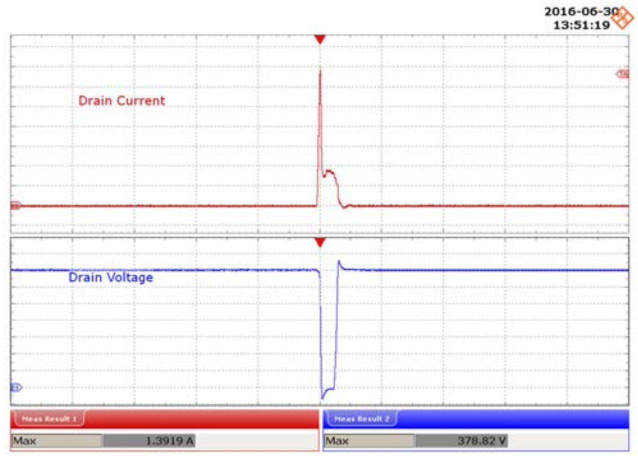

Figure 67 – 265 VAC, 84 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 µs / div.

12.8 ***Drain Voltage and Current at Output Short Circuit***

The device auto-restart mode short-circuit protection is activated during output short to lower the driver power dissipation (<1 W).

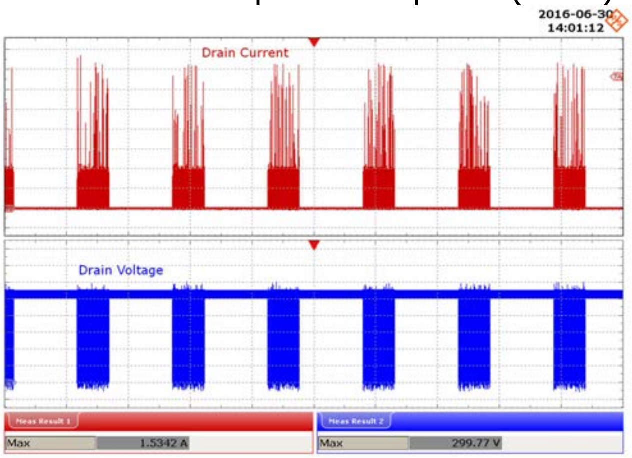

Figure 68 – 195 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s /div.

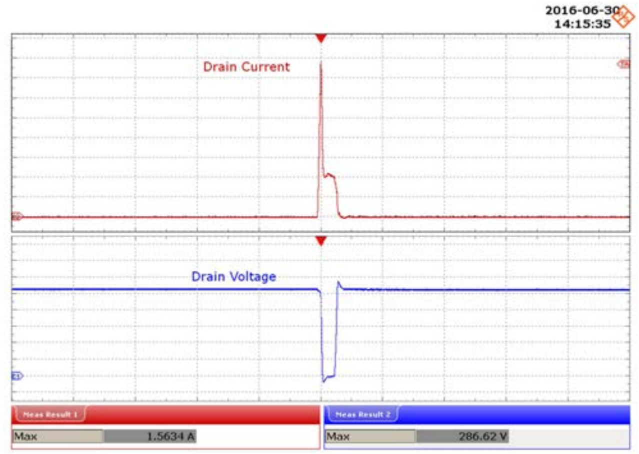

Figure 69 – 195 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 µs /div.

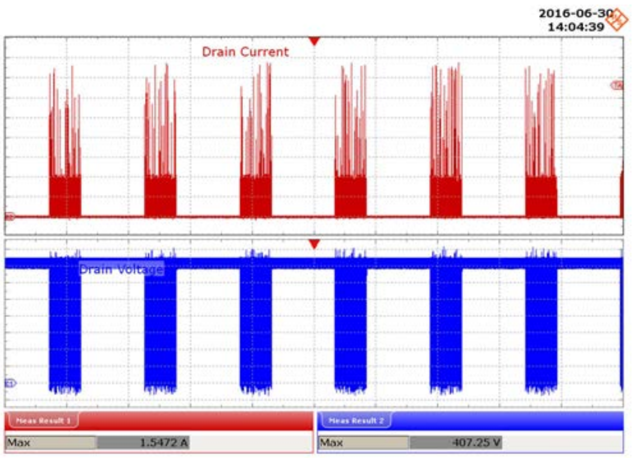

Figure 70 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms /div.

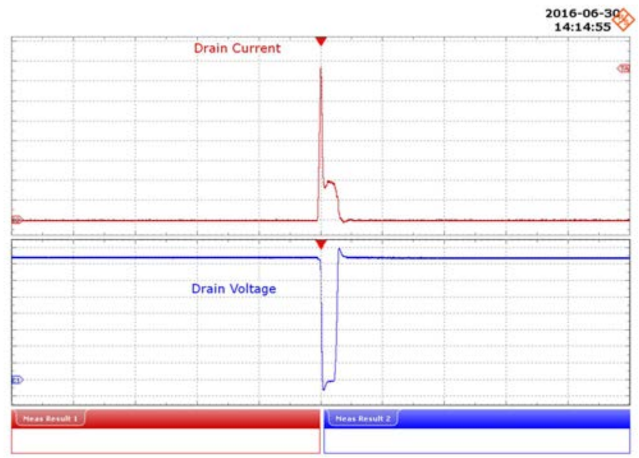

Figure 71 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 5 V / div., 1 µs /div.

Input Power at Shorted Output

Input		Input Measurement		
VAC (V_{RMS})	**Freq (Hz)**	**V (V_{RMS})**	**I (mA_{RMS})**	**P (W)**
195	50	194.97	4.05	0.364
230	50	229.98	4.44	0.493
240	50	239.99	4.52	0.531
265	50	265.01	4.67	0.612

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12.9 *Output Diode Voltage and Current in Normal Operation*

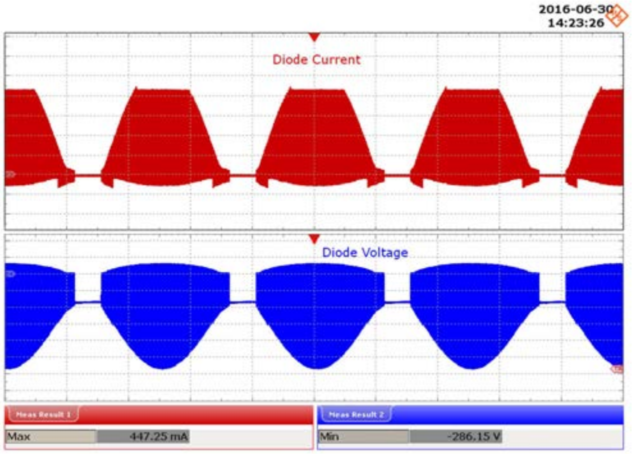

Figure 72 – 195 VAC, 84 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 4 ms / div.

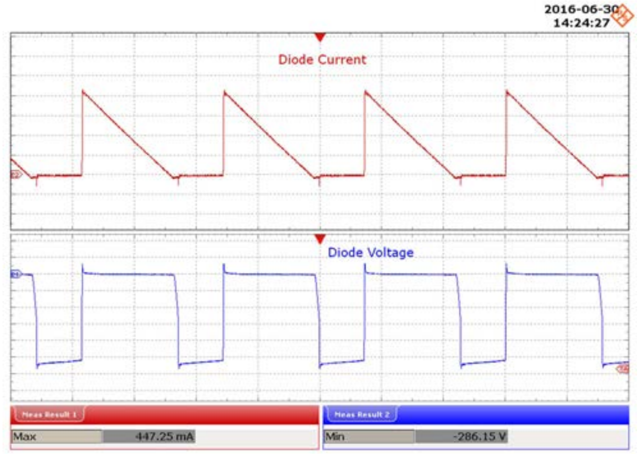

Figure 73 – 195 VAC, 84 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 5 µs / div.

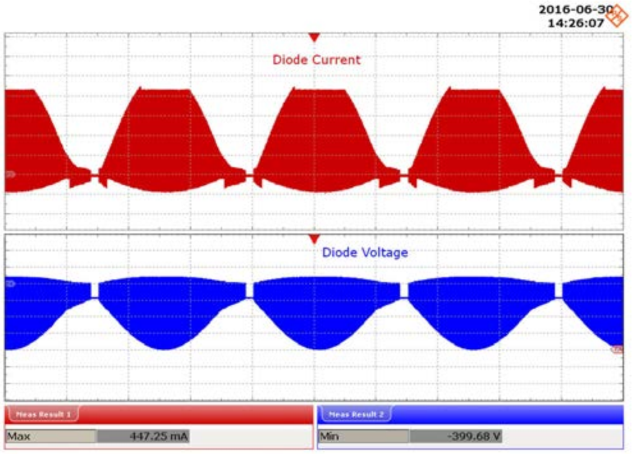

Figure 74 – 265 VAC, 84 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

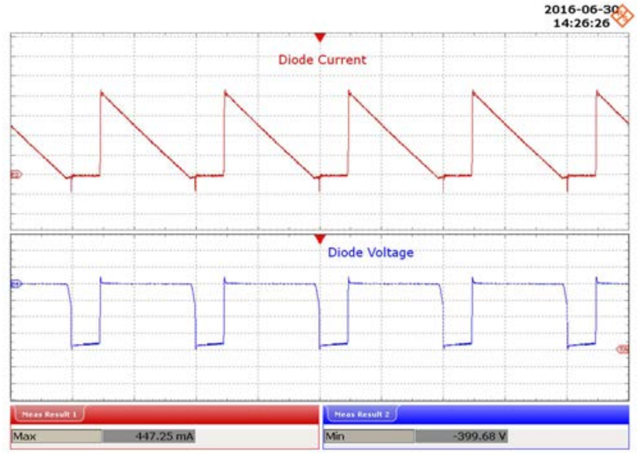

Figure 75 – 265 VAC, 84 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 100 V / div., 5 µs / div.

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

Maximum measured average no load output voltage is below the rated voltage of the output capacitor.

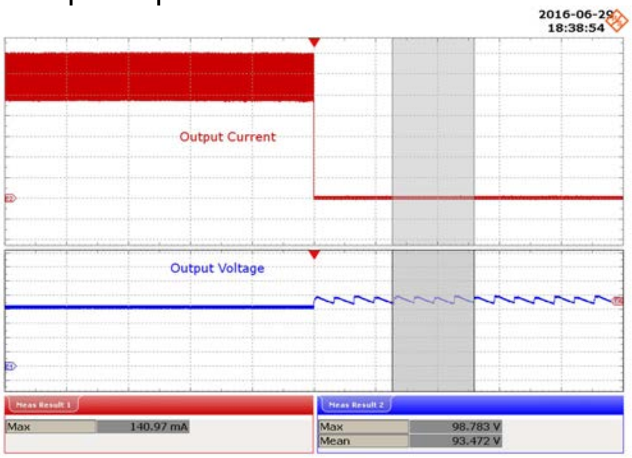

Figure 76 – 195 VAC, 84 V LED Load,
Running Open Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

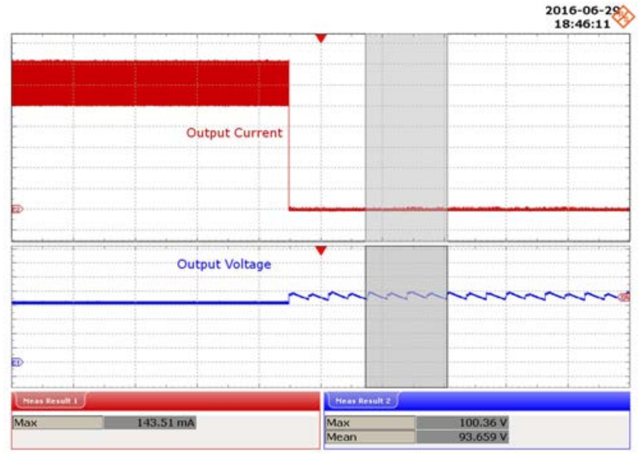

Figure 77 – 265 VAC, 84 V LED Load,
Running Open Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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

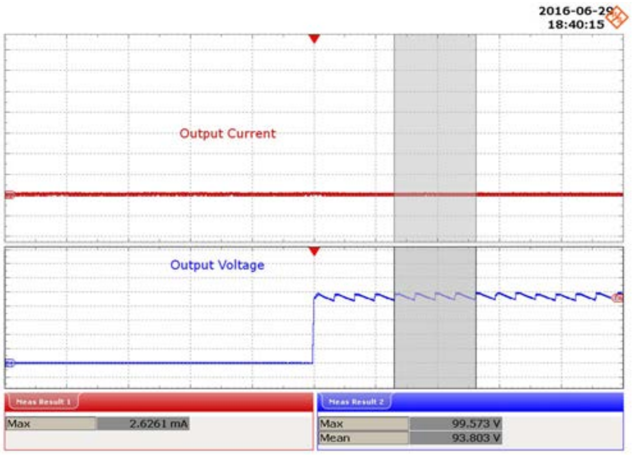

Figure 78 – 195 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

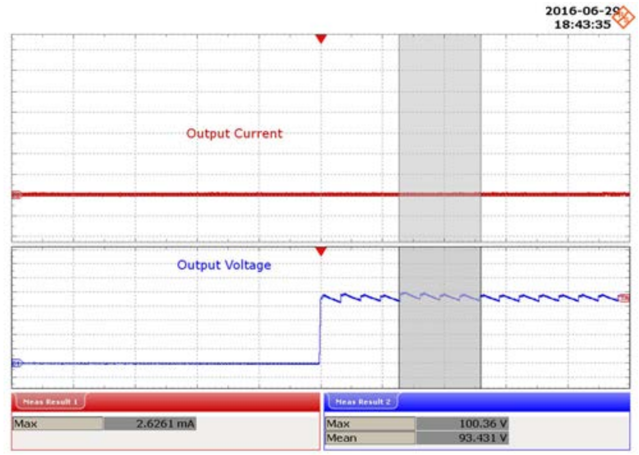

Figure 79 – 265 VAC, Open Load
Open Load Start-up.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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12.12 *Output Ripple Current at Non-Dimming Operation*

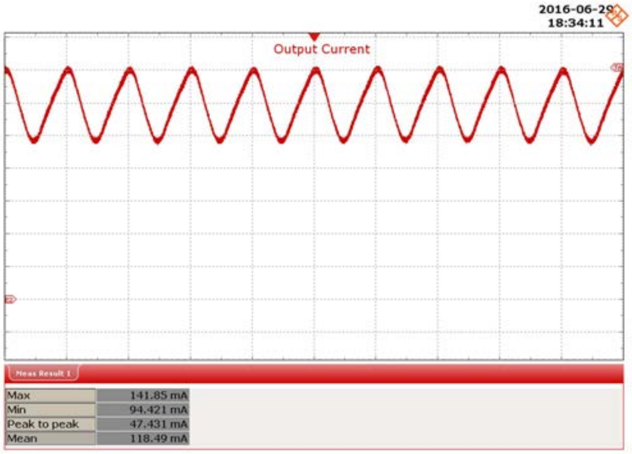

Figure 80 – 195 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

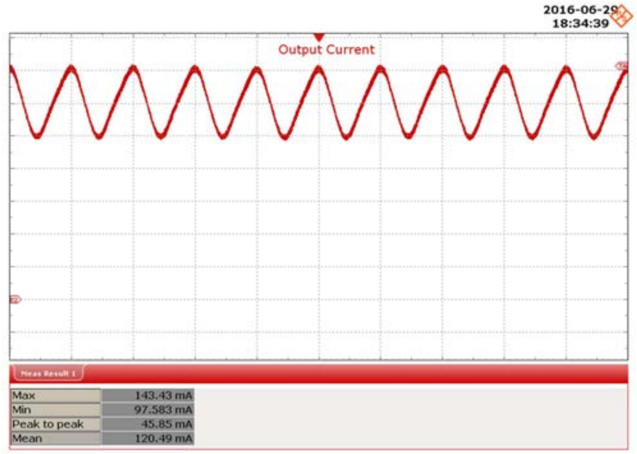

Figure 81 – 230 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

Figure 82 – 240 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

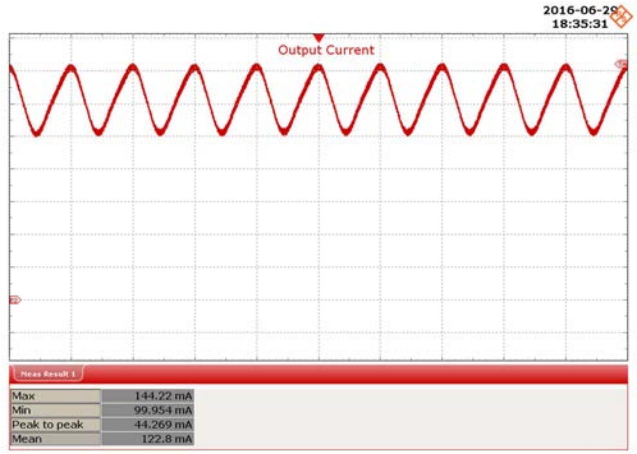

Figure 83 – 265 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P})/ (2 x I_{OUT})
195	141.85	94.42	118.49	20.01
230	143.43	97.58	120.49	19.03
240	143.43	98.37	121.15	18.60
265	144.42	99.95	122.8	18.11

12.13 *Output Ripple Current with Dimmer at Maximum Conduction Angle*

Dimmer: IKEA EED20PRS

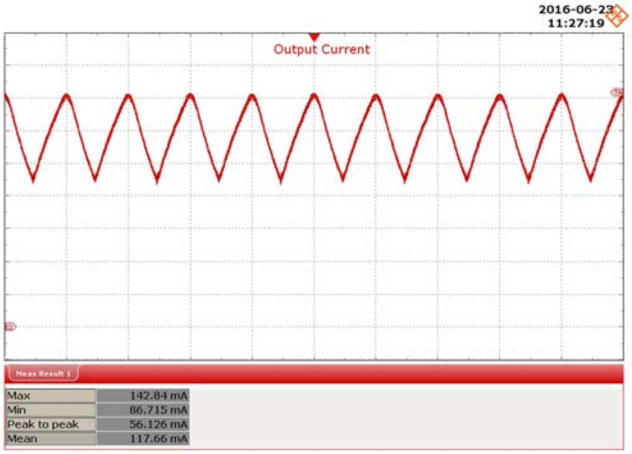

Figure 84 – 195 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

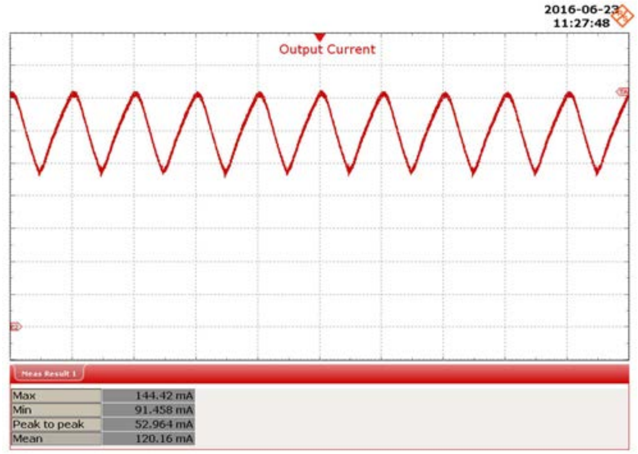

Figure 85 – 230 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

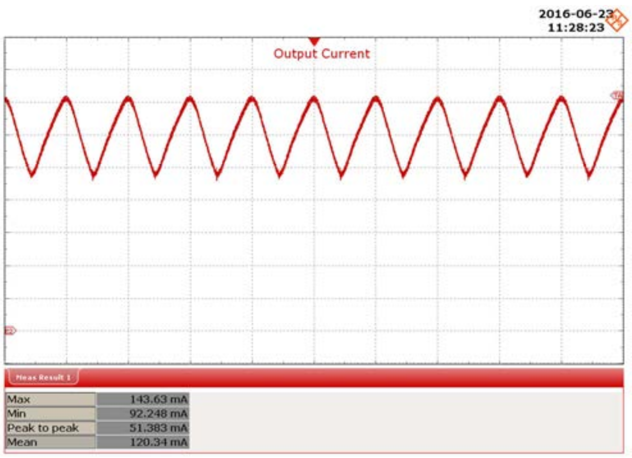

Figure 86 – 240 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

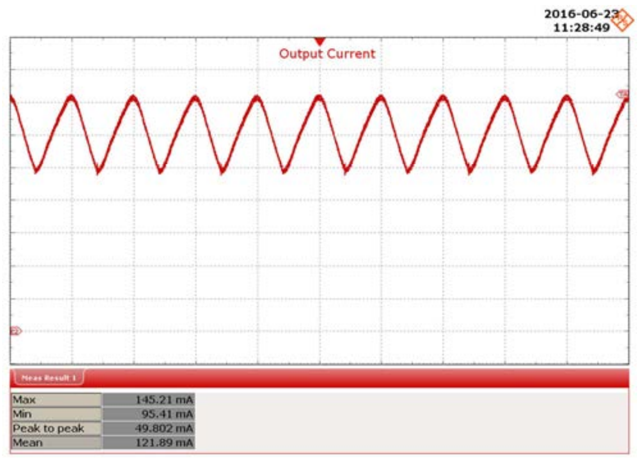

Figure 87 – 265 VAC, 50 Hz, 84 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P})/ (2 x I_{OUT})
195	142.84	86.72	117.7	23.84
230	144.42	91.5	120.16	22.02
240	143.63	92.3	120.34	21.33
265	145.21	95.41	121.89	20.43

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13 AC Cycling Test at Non Dimming

Output current recovers immediately after on/off cycling.

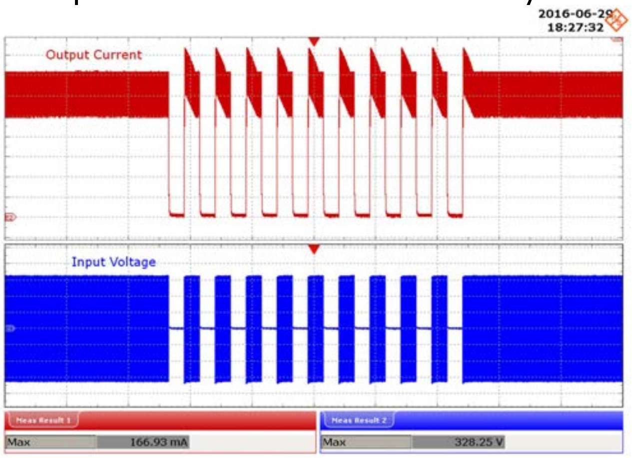

Figure 88 – 230 VAC, 84 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

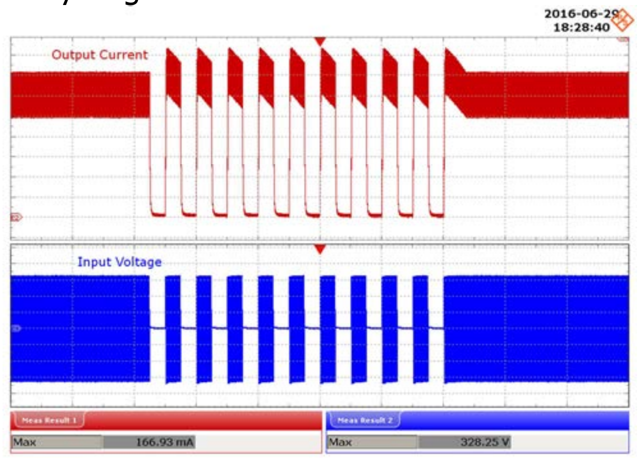

Figure 89 – 230 VAC, 84 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

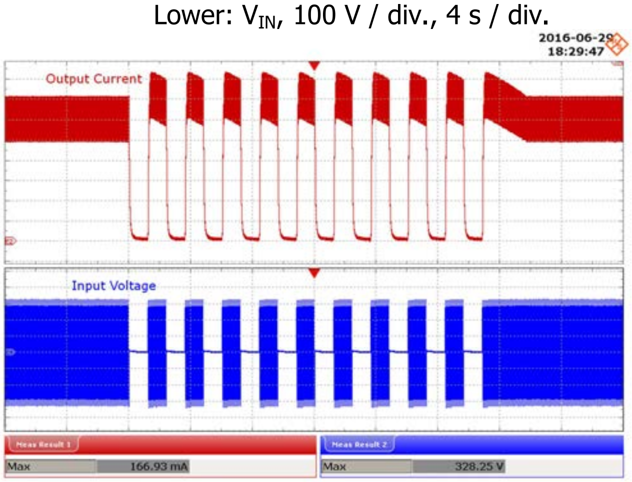

Figure 90 – 230 VAC, 84 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

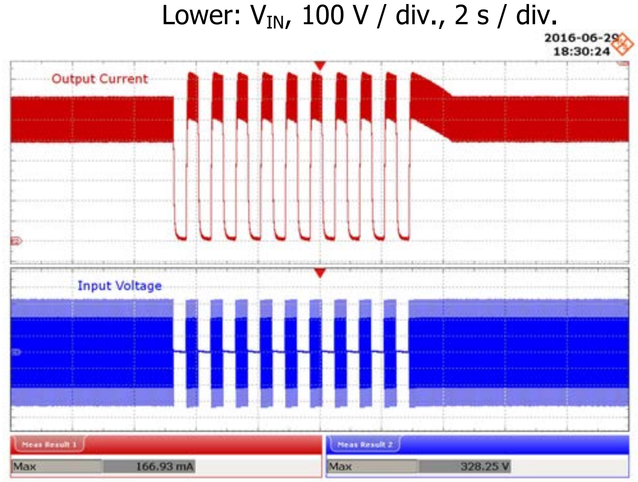

Figure 91 – 230 VAC, 84 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

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

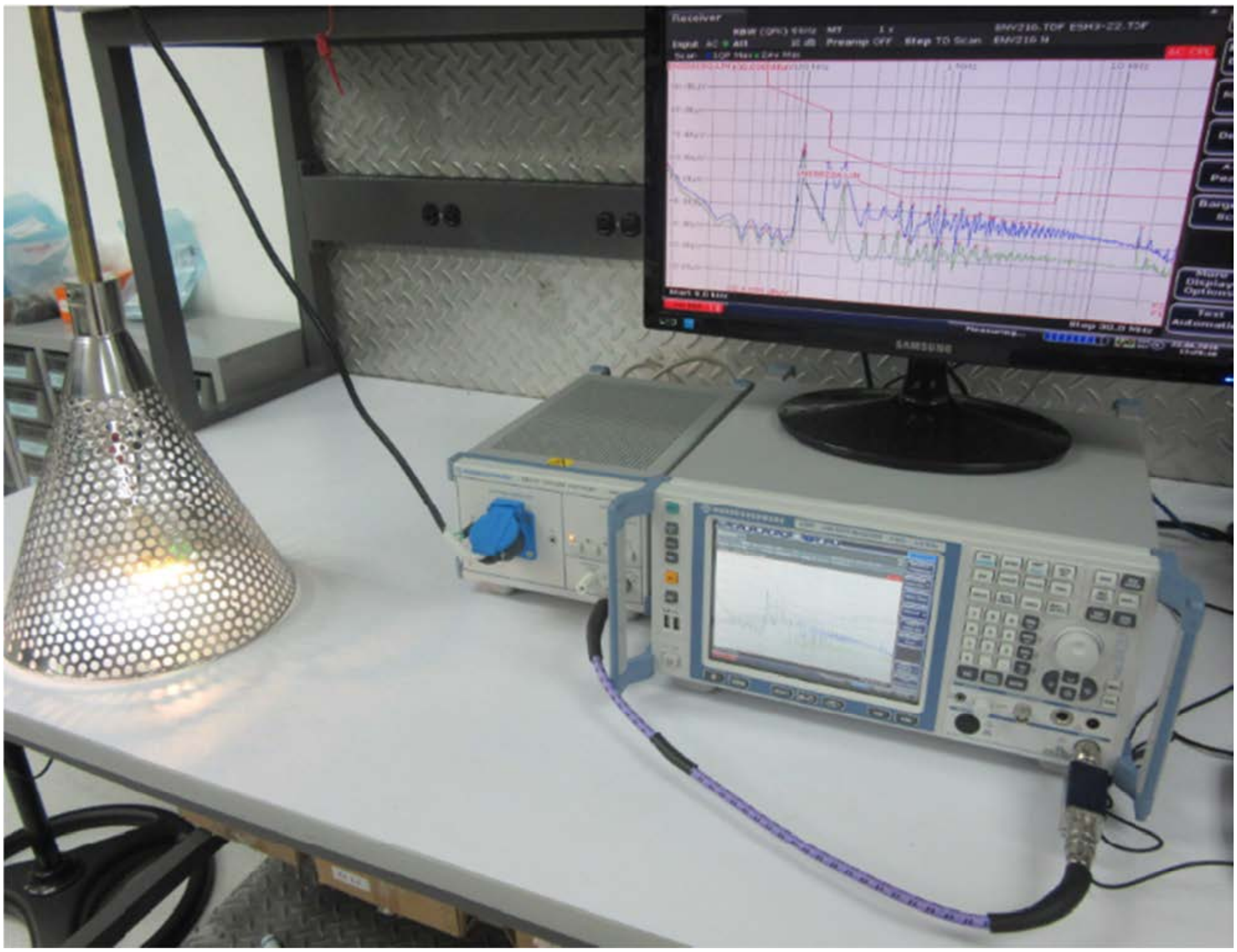

Figure 92 – Conducted EMI Test Set-up.

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14.2 *EMI Test Result*

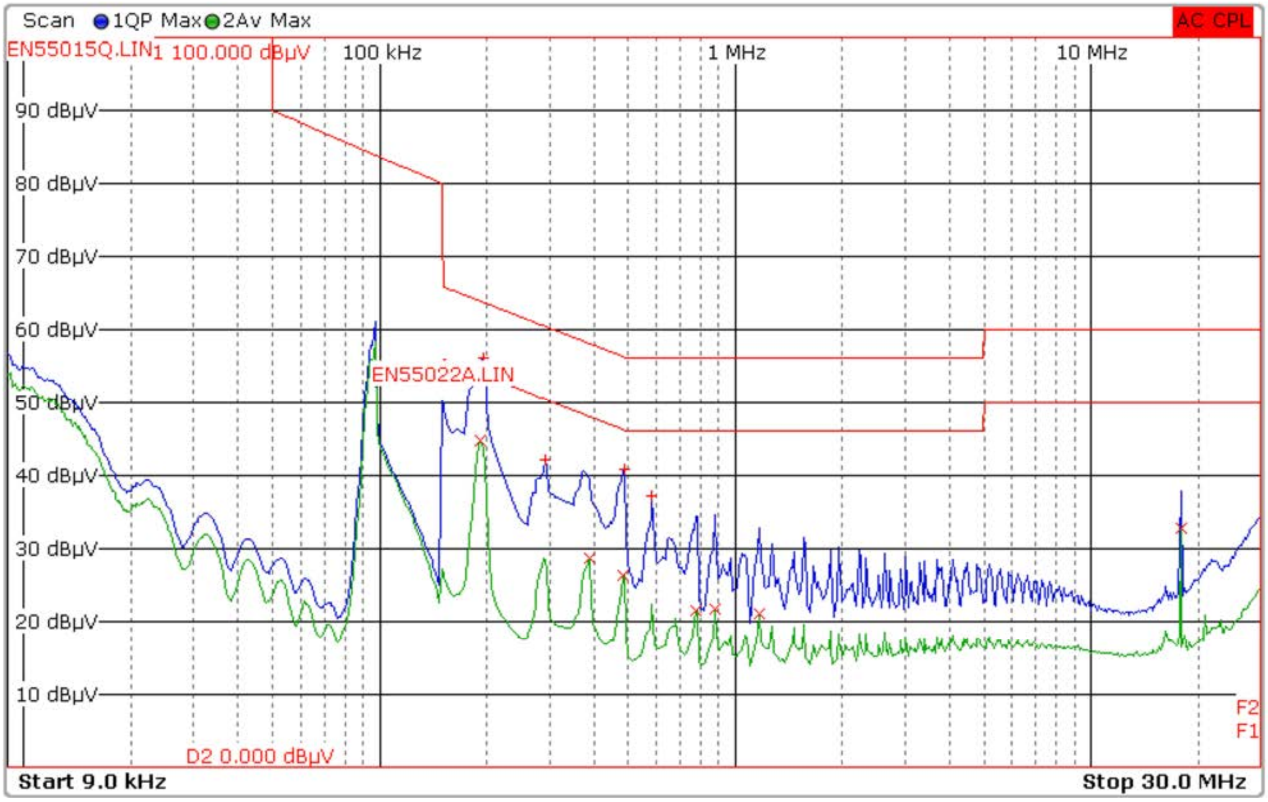

Figure 93 – Conducted EMI QP Scan at 84 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	192.7500 kHz	44.78 N	-9.14 dB
1 Quasi Peak	195.0000 kHz	56.16 N	-7.66 dB
1 Quasi Peak	291.7500 kHz	42.11 N	-18.36 dB
2 Average	388.5000 kHz	28.75 N	-19.35 dB
2 Average	485.2500 kHz	26.32 N	-19.93 dB
1 Quasi Peak	487.5000 kHz	40.97 N	-15.24 dB
1 Quasi Peak	584.2500 kHz	37.19 N	-18.81 dB
2 Average	777.7500 kHz	21.57 N	-24.43 dB
2 Average	876.7500 kHz	21.74 N	-24.26 dB
2 Average	1.1693 MHz	21.02 N	-24.98 dB
2 Average	17.9183 MHz	32.83 L1	-17.17 dB

Figure 94 – Conducted EMI Data at 230 VAC, 84 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.

15.1 *Differential Surge Test Results*

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

15.2 *Ring Wave Surge Test Results*

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

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15.3 *1 kV Differential Surge Test*

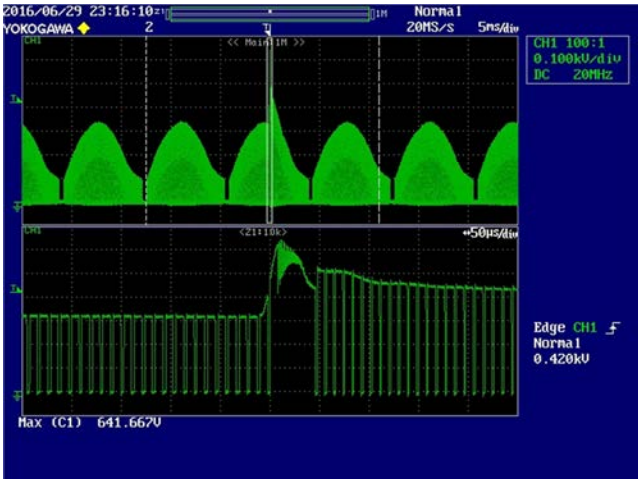

Figure 95 – +1 kV Differential Surge,
90º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 641.67 V.

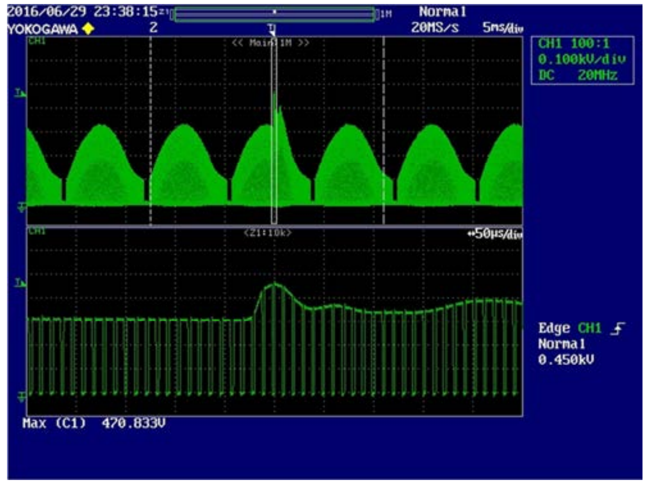

Figure 96 – -1 kV Ring Wave Surge,
90º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 470.83 V.

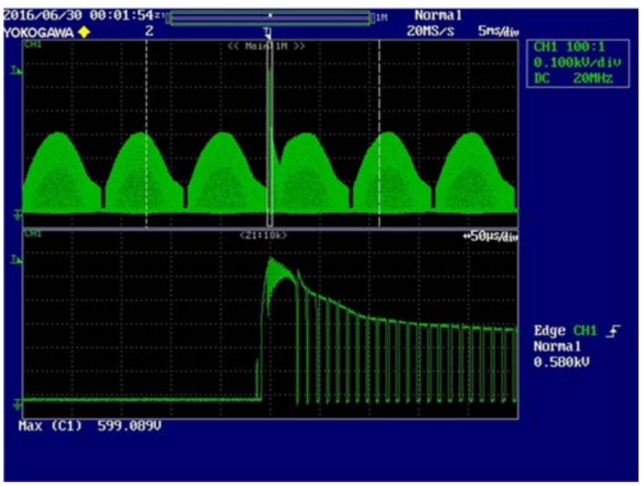

Figure 97 – +1 kV Differential Surge,
0º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 599 V.

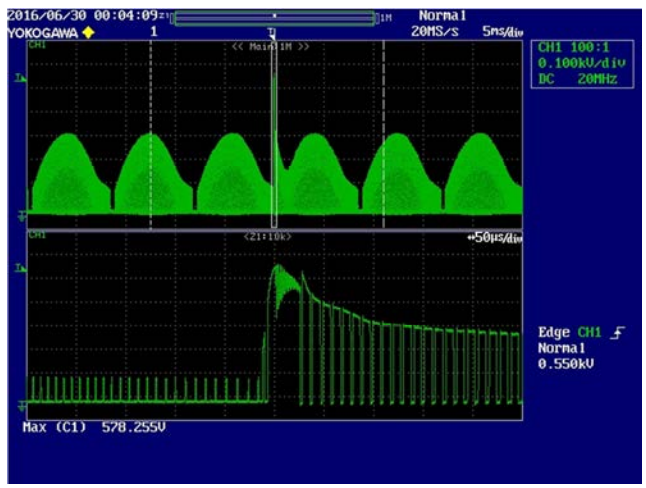

Figure 98 – -1 kV Ring Wave Surge,
0º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 578.25 V.

15.4 *2.5 kV Ring Wave Surge Test*

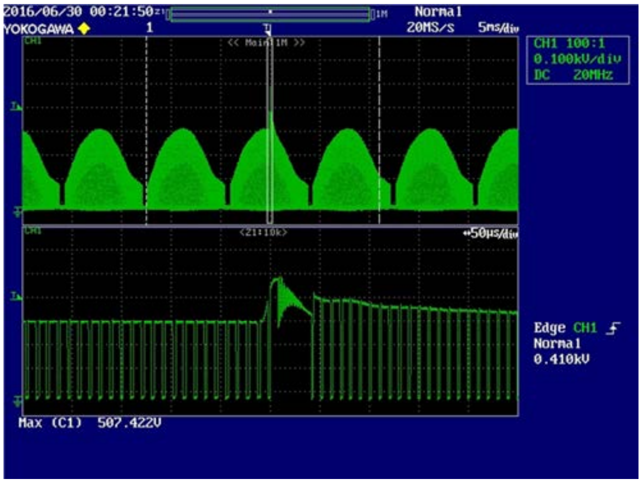

Figure 99 – +2.5 kV Ring Wave Surge,
90º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 507.42 V.

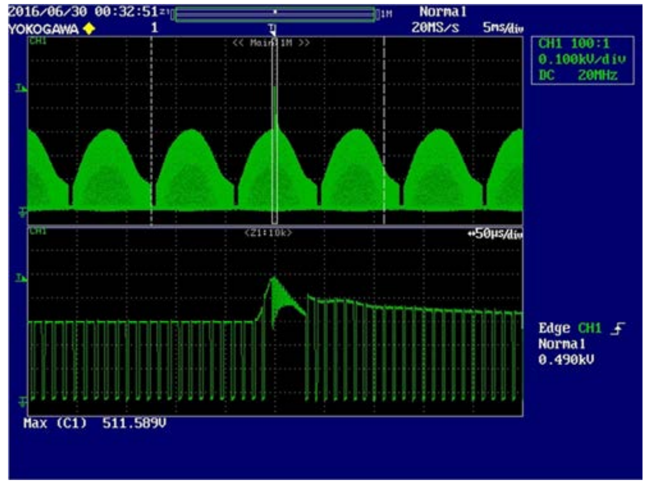

Figure 100 – -2.5 kV Ring Wave Surge,
90 º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 511.59 V.

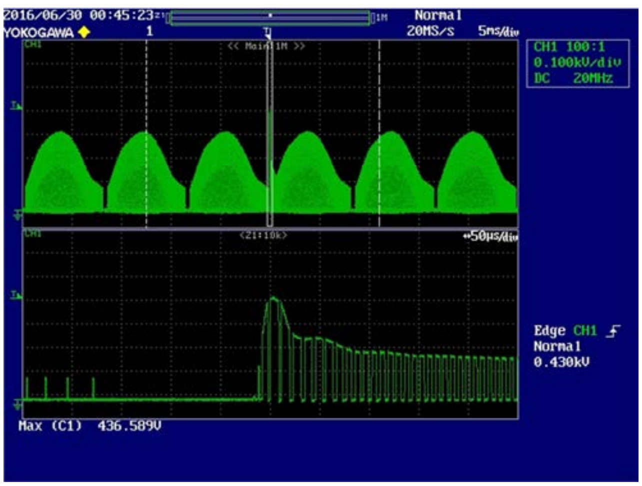

Figure 101 – +2.5 kV Ring Wave Surge,
0º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 436.75 V.

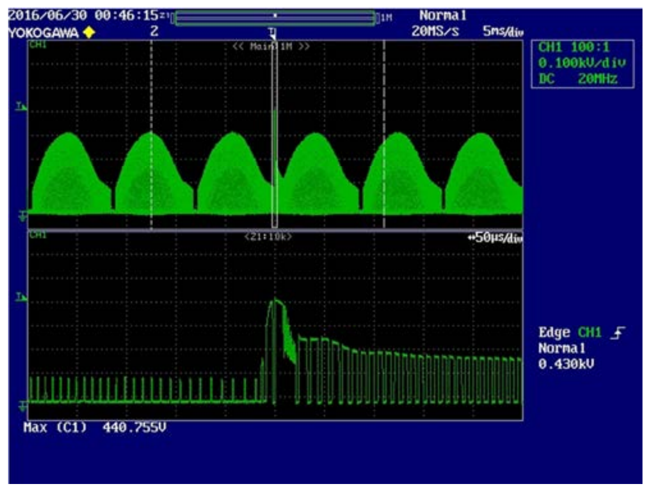

Figure 102 – -2.5 kV Ring Wave Surge,
0º Phase Angle.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 440.76 V.

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16 Brown-in / Brown-out Test

No abnormal output current overshoot, component overheating and component failure was observed during and after 0.5 V / s brown-in and brown-out test.

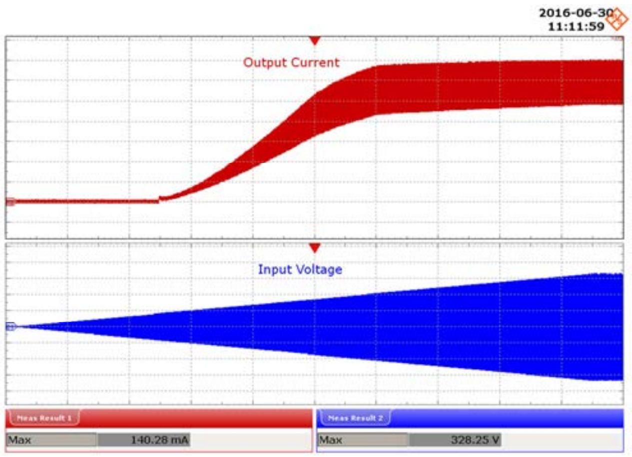

Figure 103 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

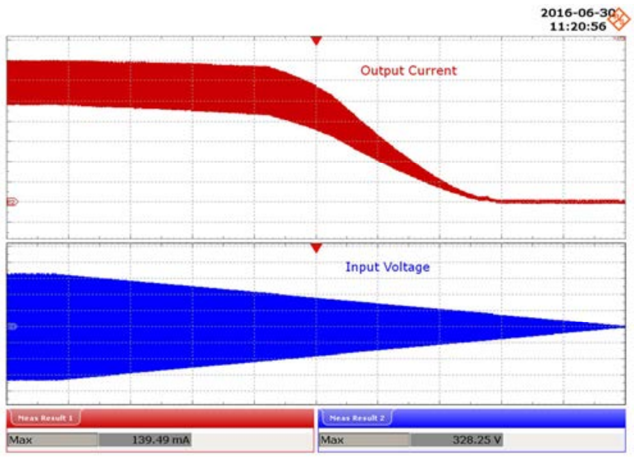

Figure 104 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

17 Revision History

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

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