Design Example Report

Title	***6.5 W Dimmable, High Efficiency (>86%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-7 LYT7503D***
Specification	90 VAC – 132 VAC Input; 52 V, 125 mA Output
Application	A19 LED Bulb
Author	Applications Engineering Department
Document Number	DER-539
Date	April 6, 2017
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <25% flicker percent requirement
- Highly energy efficient, >86 % at 115 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 52 V LED voltage string at 125 mA output current from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT7503D from the LYTSwitch-7 family of devices.

LYTSwitch-7 is a SO-8 package, TRIAC dimmable LED driver controller IC designed for non-isolated buck topology applications. The LYTSwitch-7 provides 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 tight 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-539 offers a TRIAC dimmable, high power factor and low components count solution for 6.5 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.

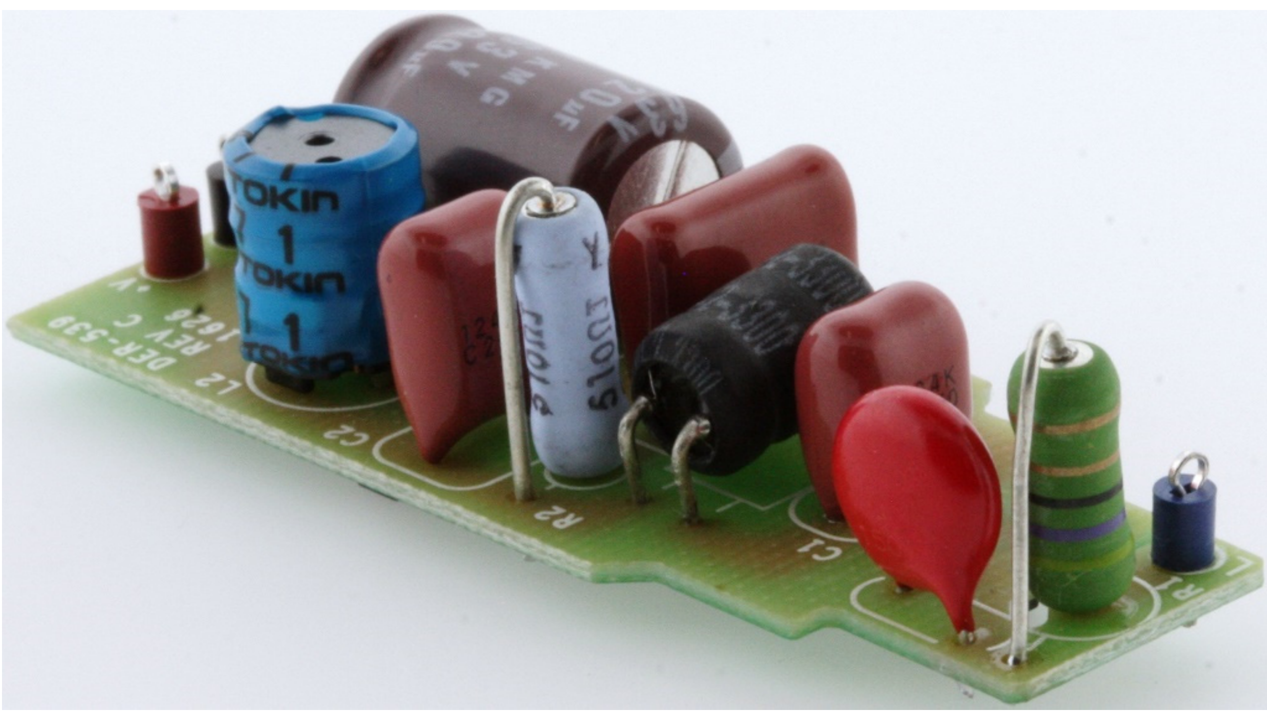

Figure 1 – Populated Circuit Board

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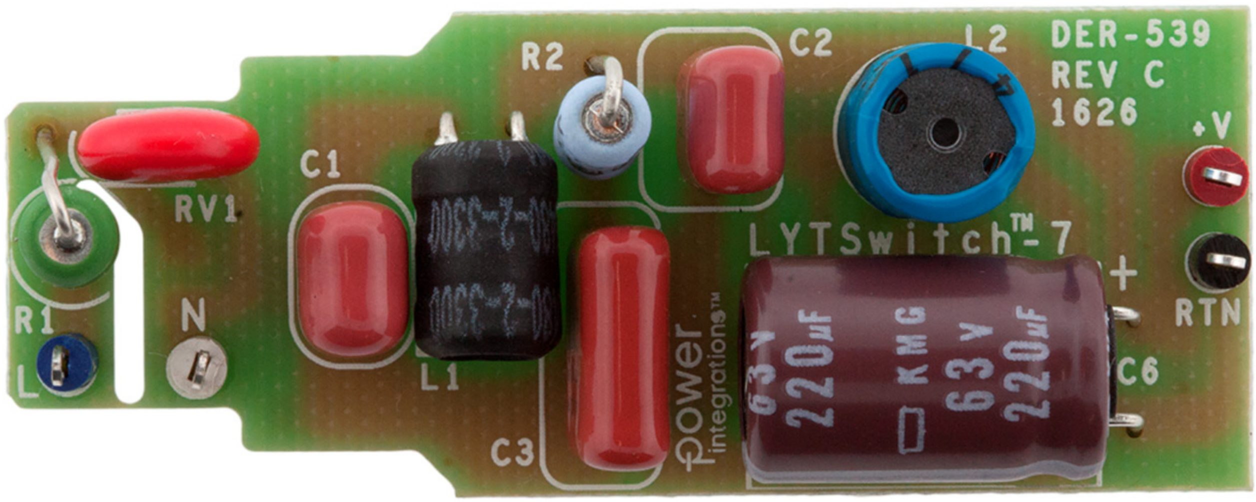

Figure 2 – Populated Circuit Board, Top View.

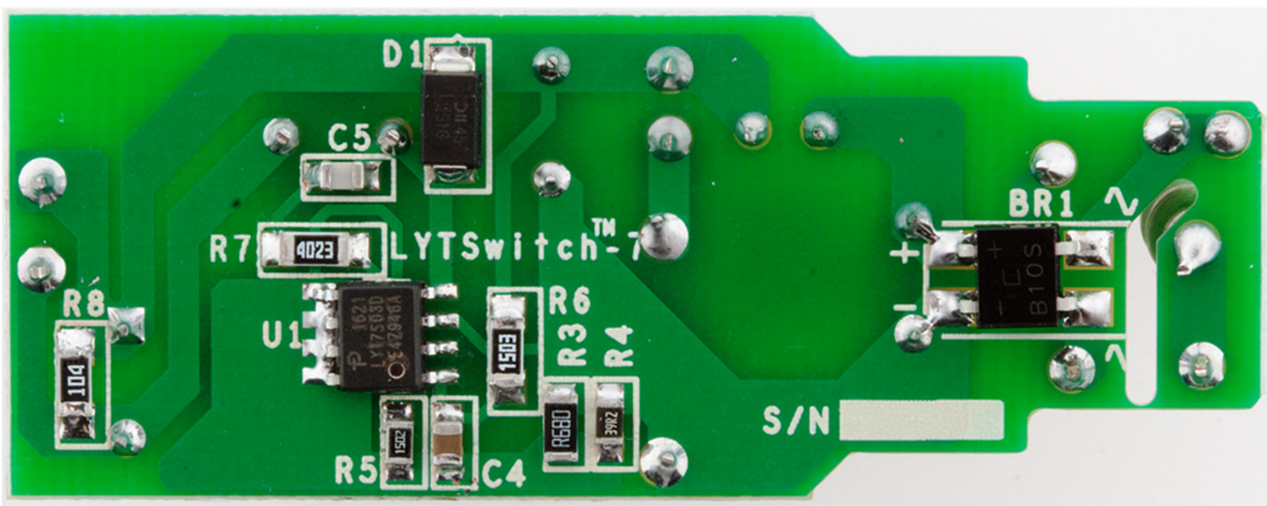

Figure 3 – Populated Circuit Board, Bottom View.

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}	90	115	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}		52		V	
Output Current	I_{OUT}		125		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		6.5		W	
Efficiency						
Full Load	η		86		%	115 V / 60Hz at 25 ºC
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 115 VAC / 60 Hz
Ambient Temperature	T_{AMB}			75	ºC	Free Convection, Sea Level.

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3 Schematic

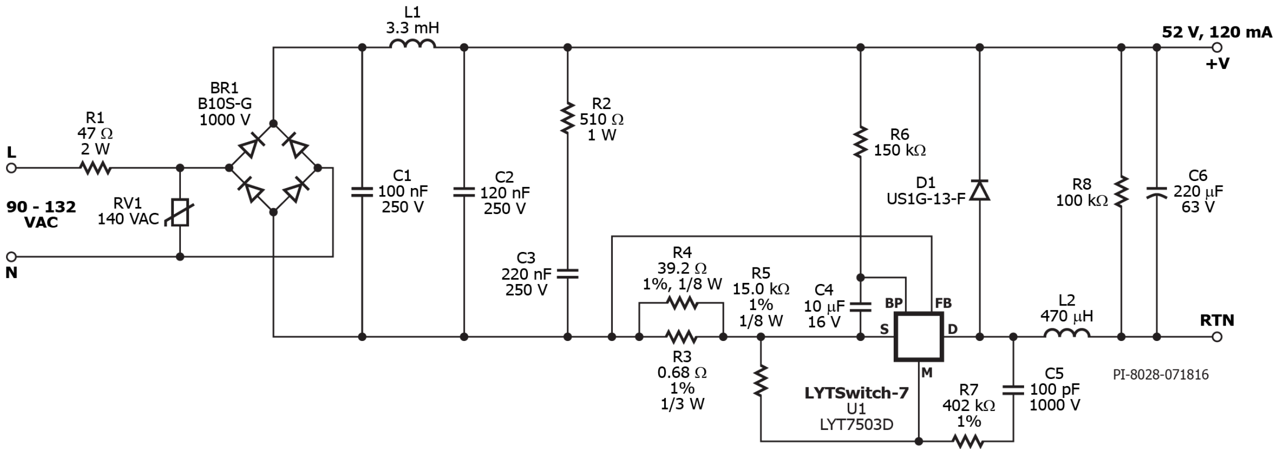

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-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 a 52 V output, TRIAC dimmable buck LED driver with 125 mA constant output current. The LYT7503D device was selected from the power table based on maximum output power (15 W) in the data sheet.

4.1 Input Stage

The input fuse R1 provides safety protection. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 140 V rated part was selected, being slightly above the nominal specified operating input voltage (120 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 mode 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, which provides power to the IC during the switch on time. The IC internal regulator draws power from high voltage DRAIN (D) pin and charge the bypass capacitor C4 during the power switch off time. The typical BP pin voltage is 5.22 V. To keep the IC operating normally especially during the dead zone, where $V_{IN} < V_{OUT}$, 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 = 3.6 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 for 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 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:

$R5 = 2\ V \times R7 / (V_{OUT} - 2\ V)$; 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 (R2 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. Fusible Resistor R1 is needed to dampen the driver input current ringing when TRIAC dimmer turns on.

Pull-up resistor R6 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

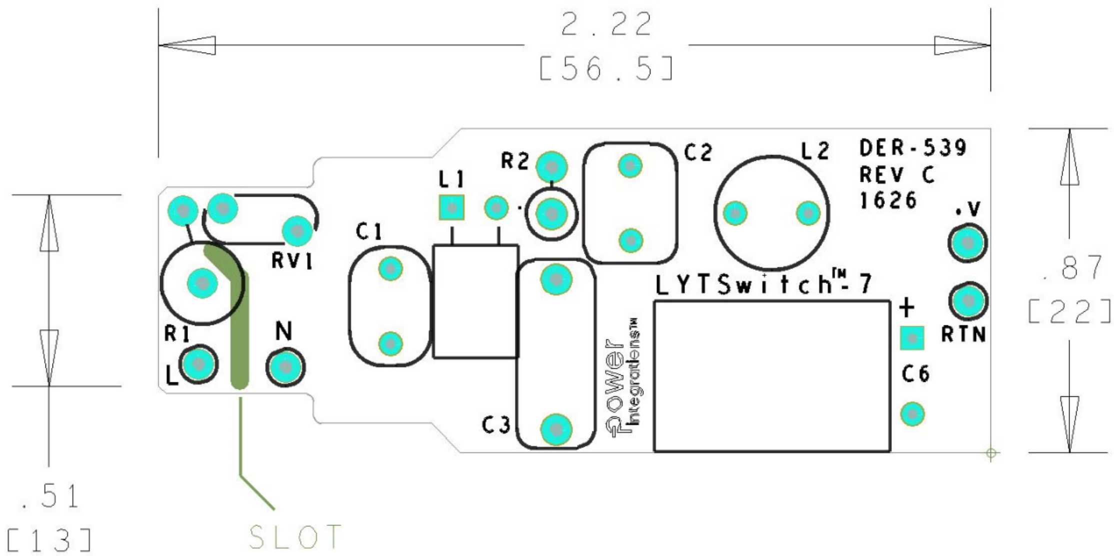

Figure 5 – Top Side.

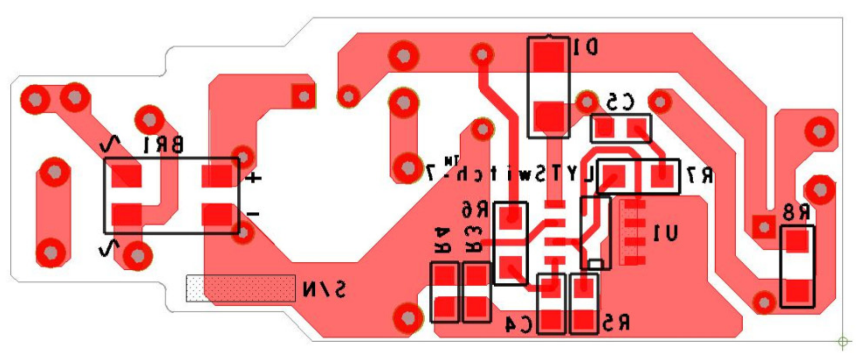

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	+V	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
2	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
3	1	C1	100 nF, 250 V, Film	ECQ-E2104KB	Panasonic
4	1	C2	120 nF, 250 V, Radial, Film	ECQ-E2124JB	Panasonic
5	1	C3	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
6	1	C4	10 μF, ±10%, 16 V, X7R, Ceramic Capacitor, -55°C ~ 125°C, Surface Mount, MLCC 0805 (2012 Metric), 0.079" L x 0.049" W (2.00 mm x 1.25 mm)	CL21B106KOQNNNG	Samsung
7	1	C5	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
8	1	C6	220 μF, 63 V, Electrolytic, (10 x 16)	EKMG630ELL221MJ16S	United Chemi-con
9	1	D1	Diode Ultrafast, GPP, 400 V, 1 A SMA	US1G-13-F	Diodes, Inc.
10	1	L	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
11	1	L1	3.3 mH, 0.095 A, 20%	RL-5480-2-3300	Renco
12	1	L2	470 μH, 0.49 A	SBC3-471-491	Tokin
13	1	N	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
14	1	R1	RES, 47 Ω, 5%, 2 W, Wire wound, Fusible	FW20A47R0JA	Bourns
15	1	R2	RES, 510, 5%, 1 W, Metal Oxide Film	ERG-1SJ511	Panasonic
16	1	R3	RES, 0.68 Ω 1/3W, 1%,Thick Film, 0805	RL1220S-R68-F	Susumu
17	1	R4	RES, 39.2 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF39R2V	Panasonic
18	1	R5	RES, 15 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1502V	Panasonic
19	1	R6	RES, 150 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ154V	Panasonic
20	1	R7	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
21	1	R8	RES, 100 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ104V	Panasonic
22	1	RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
23	1	RV1	140 VAC, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
24	1	U1	LYTSwitch-7, Dimmable, SO-8	LYT7503	Power Integrations

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7 Performance Data

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

7.1 Efficiency

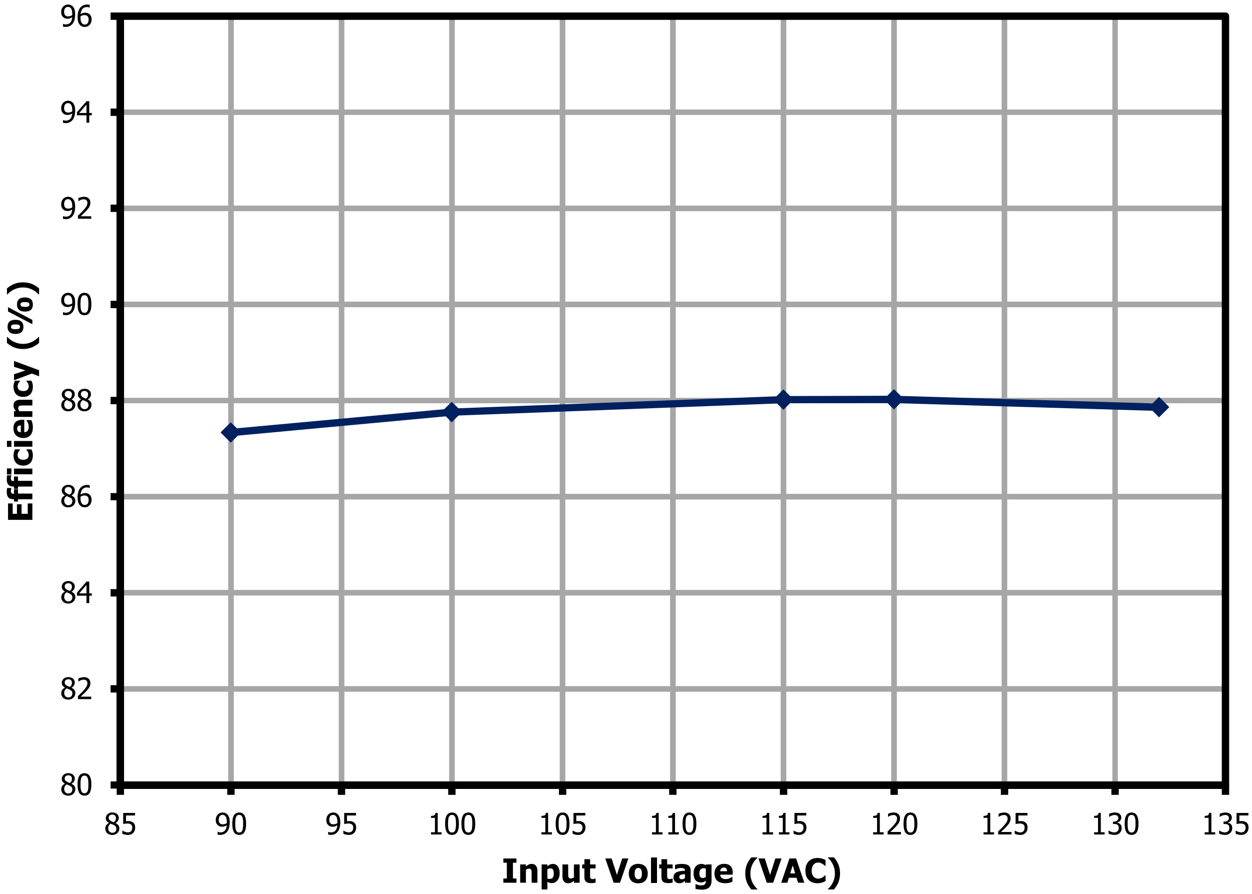

Figure 7 – Efficiency vs. Line and LED Load.

7.2 Line Regulation

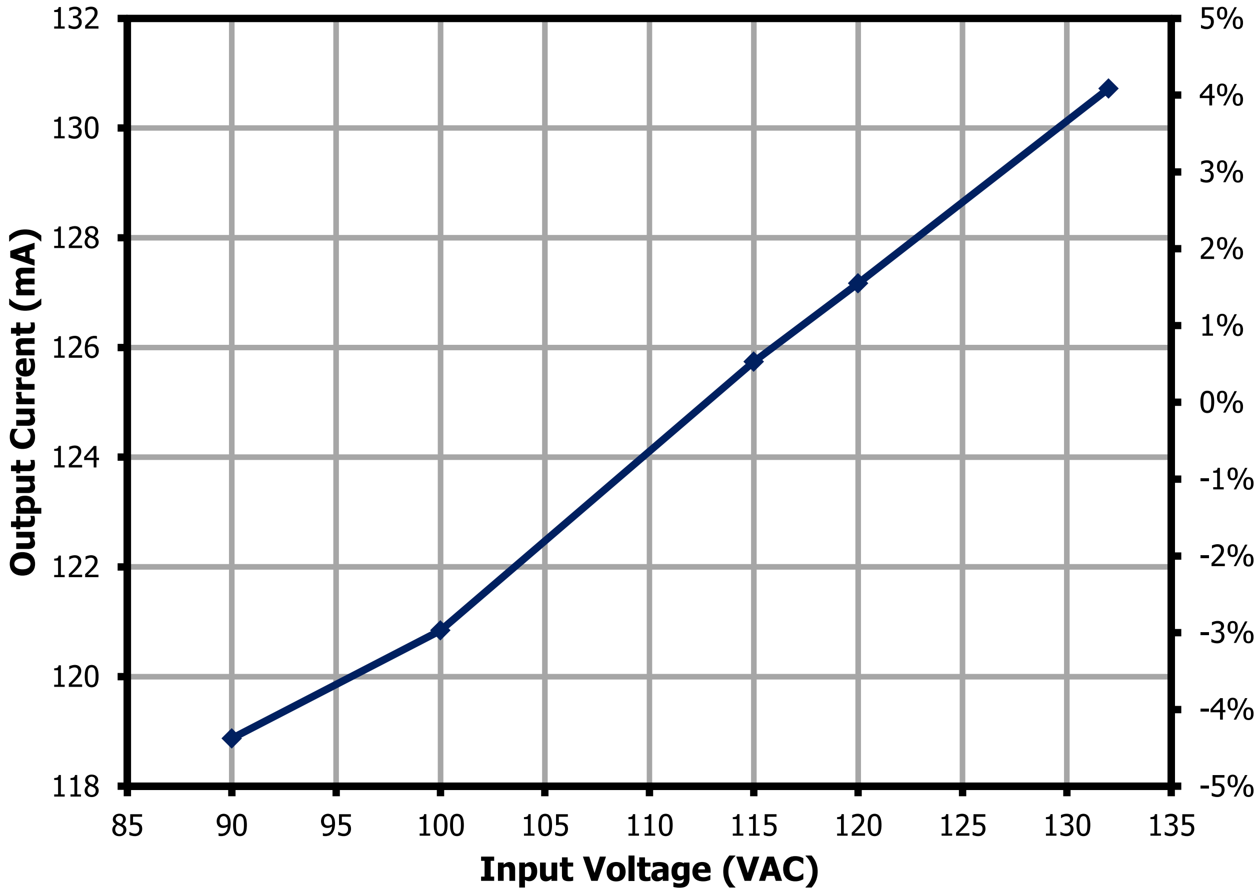

Figure 8 – Regulation vs. Line and LED Load.

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7.3 Power Factor

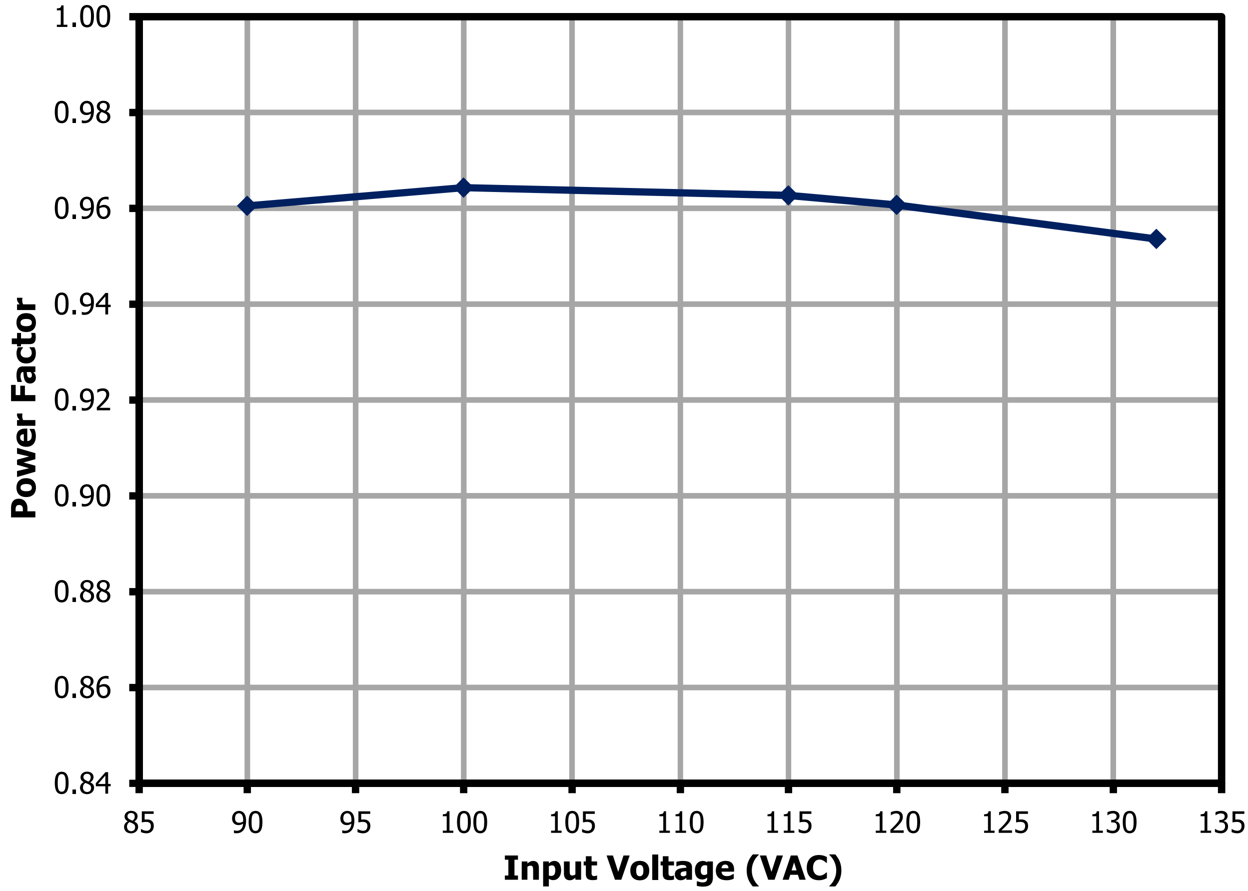

Figure 9 – Power Factor vs. Line and LED Load.

7.4 %ATHD

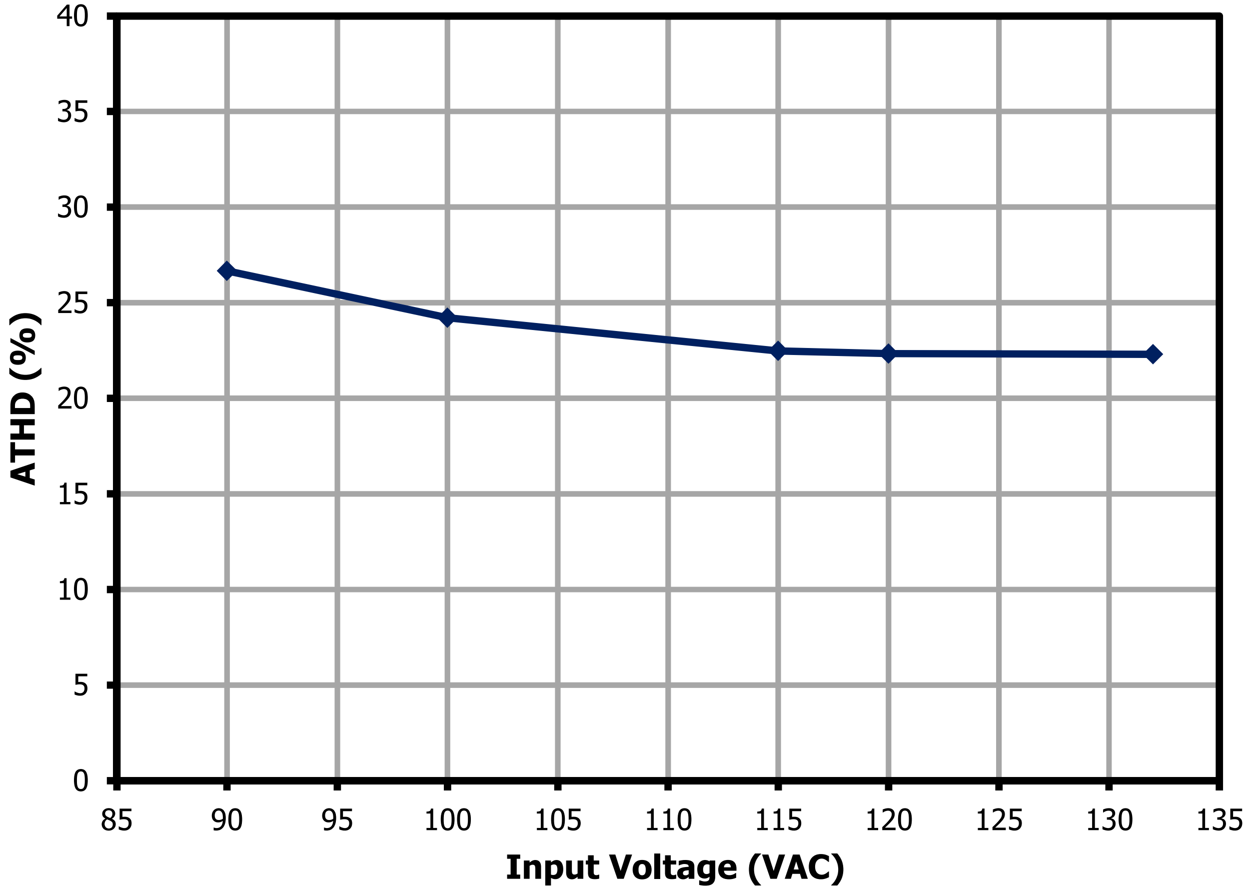

Figure 10 – %ATHD vs. Line and LED Load.

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7.5 Individual Harmonics Content

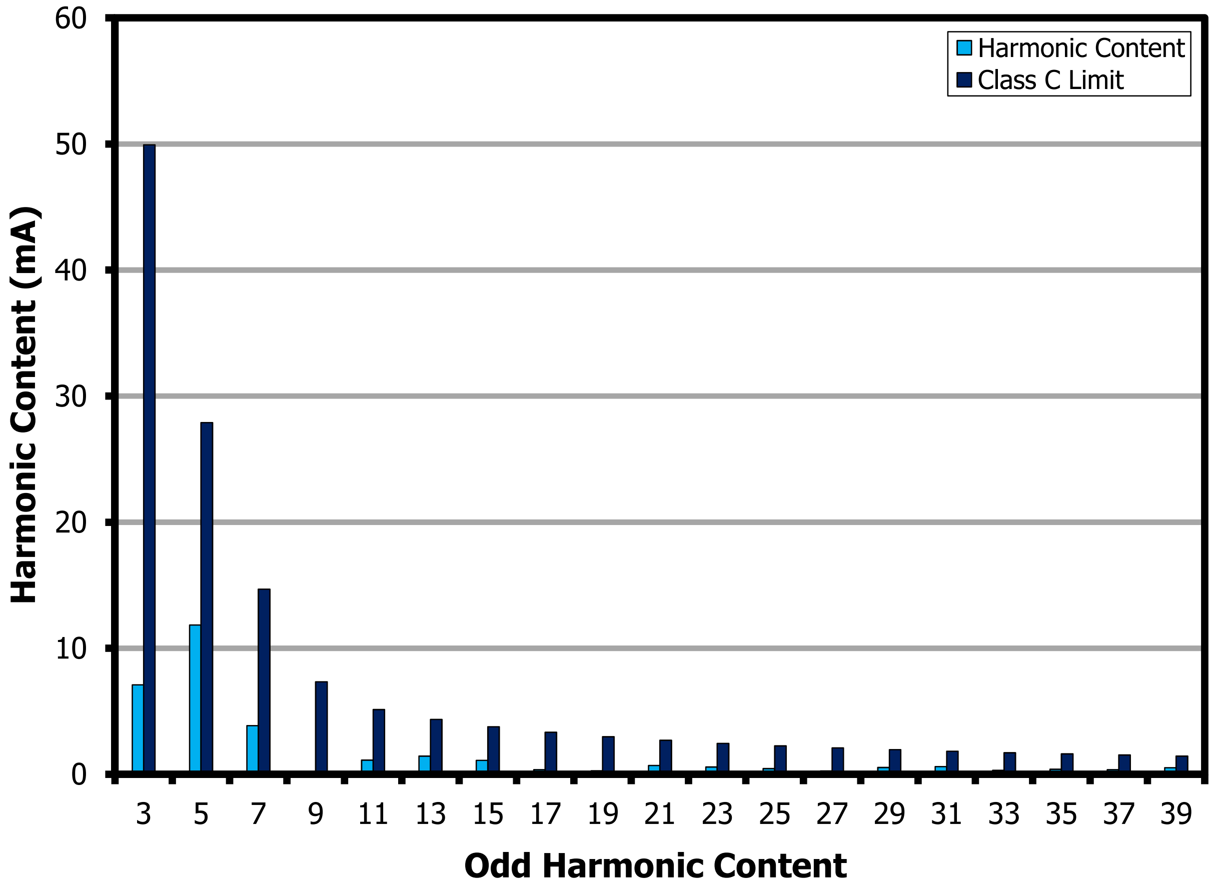

Figure 11 – 52 V LED Load Input Current Harmonics at 120 VAC, 60 Hz.

8 Test Data

8.1 Test Data, 52 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.90	82.10	7.09	0.961	26.67	52.03	118.87	6.19	87.33
100	60	99.92	74.55	7.18	0.964	24.21	52.12	120.84	6.30	87.76
115	60	114.92	67.65	7.48	0.963	22.48	52.34	125.74	6.59	88.02
120	60	119.97	65.74	7.58	0.961	22.33	52.40	127.17	6.67	88.02
132	60	131.96	62.20	7.83	0.954	22.30	52.56	130.72	6.88	87.86

8.2 Test Data, Harmonic Content at 120 VAC with 52 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
120	60	65.26	7.342	22.913
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	62.11			
2	0.10	0.16%		
3	7.09	11.42%	49.93	Pass
5	11.85	19.08%	27.90	Pass
7	3.86	6.21%	14.68	Pass
9	0.09	0.14%	7.34	Pass
11	1.13	1.82%	5.14	Pass
13	1.44	2.32%	4.35	Pass
15	1.11	1.79%	3.77	Pass
17	0.37	0.60%	3.33	Pass
19	0.28	0.45%	2.98	Pass
21	0.71	1.14%	2.69	Pass
23	0.58	0.93%	2.46	Pass
25	0.45	0.72%	2.26	Pass
27	0.26	0.42%	2.09	Pass
29	0.54	0.87%	1.95	Pass
31	0.62	1.00%	1.82	Pass
33	0.31	0.50%	1.71	Pass
35	0.40	0.64%	1.62	Pass
37	0.36	0.58%	1.53	Pass
39	0.52	0.84%	1.45	Pass

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9 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 120 VAC, 60 Hz line frequency, room temperature, and a nominal 52 V LED load.

9.1 Dimming Curve

Agilent 6812B AC source programmed as perfect leading edge dimmer.

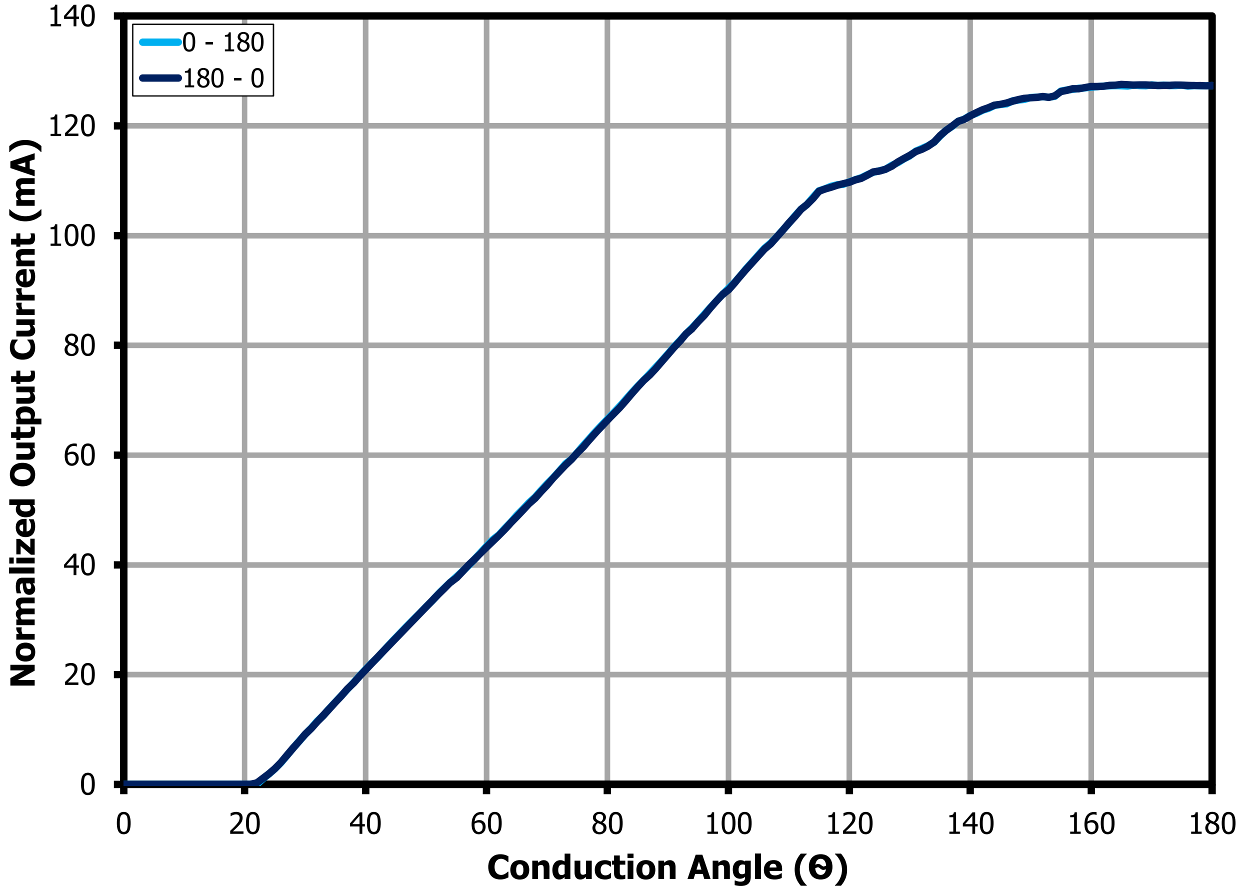

Figure 12 – Dimming Curve at 120 VAC, 60 Hz Input.

9.2 Dimming Efficiency

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

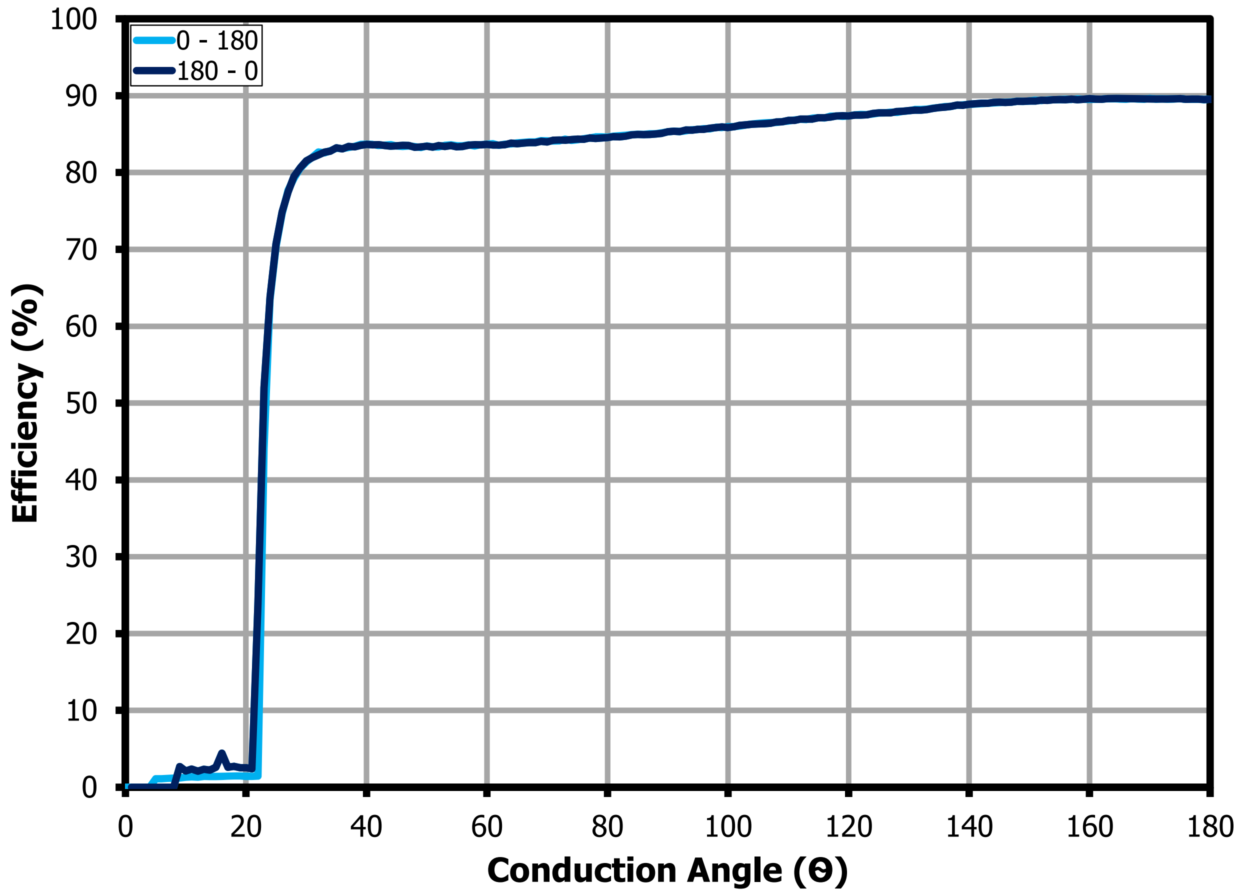

Figure 13 – Driver Efficiency at 120 VAC, 60 Hz Input.

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9.3 Driver Power Loss during Dimming

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

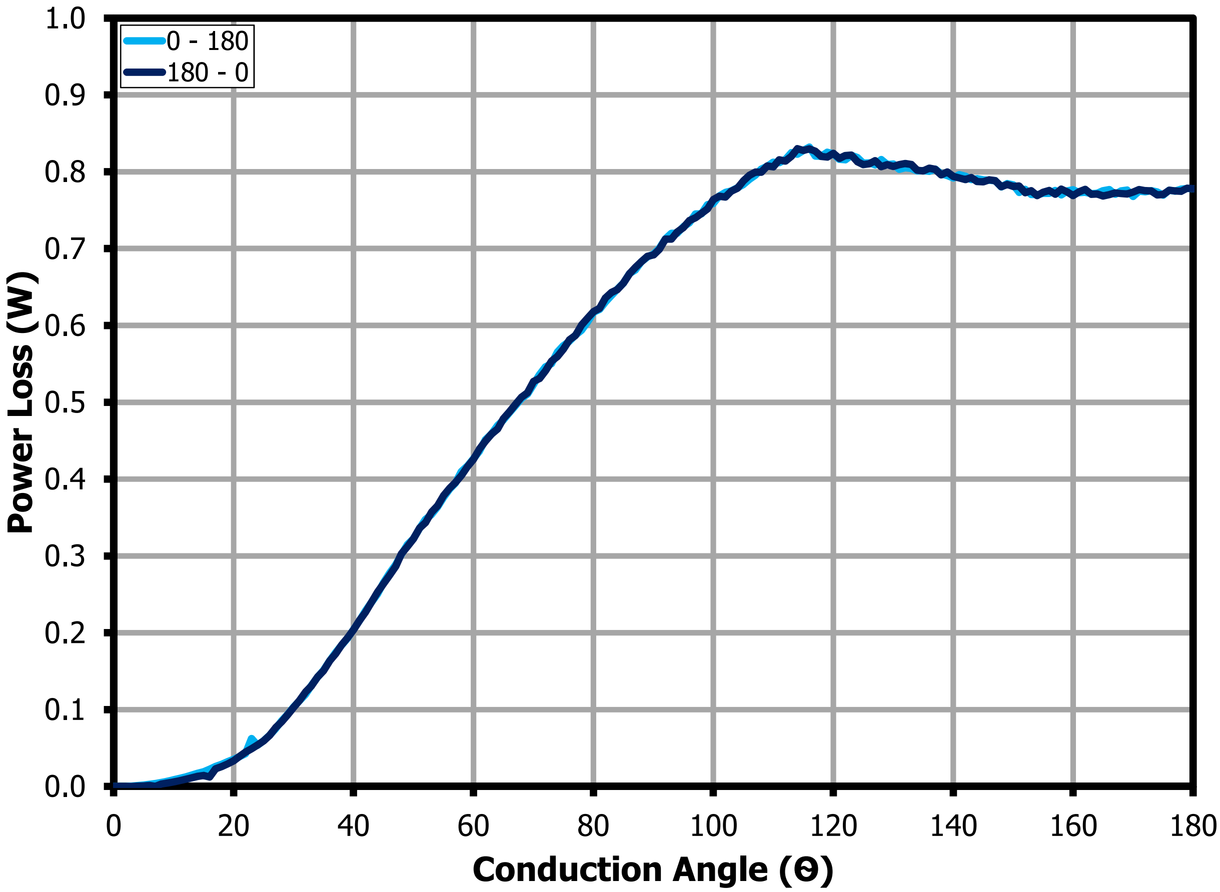

Figure 14 – Driver Power Loss at 120 VAC, 60 Hz Input.

9.4 Dimmer Compatibility List

The following dimmers were tested at 25 ºC ambient temperature with 115 V, 50 Hz line input and 52 V LED load.

No	Brand	Model	Type	Max (mA)	Min (mA)	Pop-on (mA)	Dimming Ratio
1	COOPER	R106PL-W-K	L	111	2	2	56
2	LEVITON	9530WS-K	L	122	2.4	3	51
3	LEVITON	601-6631-1	L	109	2.2	4	50
4	LEVITON	AT106-1LA	L	113	7	7	16
5	LEVITON	6683	L	120	3	3	40
6	LEVITON	1P106-1LZ	L	116	20	12	6
7	LEVITON	6681	L	120	2	2	60
8	LEVITON	6633_PLW	L	118	2.5	3	47
9	G.E.	18023	L	117	2	2	59
10	G.E.	18022	L	115	5	6	23
11	LUTRON	MRF2-6ND-120-BI	L	111	4	4	28
12	LUTRON	DVCL-153P-WH	L	106	3	3	35
13	LUTRON	AY-600PNL-WH	L	110	5	10	22
14	LUTRON	S-600P-WH	L	106	3	3	35
15	LUTRON	LXELV-600PL-WH	T	119	15	15	8
16	LUTRON	NTELV-300-WH	T	120	27	25	4
17	LUTRON	NT-600-WH	L	110	9.6	9.4	11
18	LUTRON	DVELV-300P-WH	T	121	14	15	9
19	LUTRON	SELV-300P-WH	T	122	15	15	8
20	LUTRON	LGCL-153PLH-WH	L	106	4	4	27
21	LUTRON	MACL-753-WH	L	98	1.5	2	65
22	LEGRAND	HCL453PTCCCV6	L	104	33	32.7	3
23	LEGRAND	H703PTCCCV6	L	110	4.22	4	26
24	LEGRAND	H1103PTCCCV6	L	110	4	4	28
25	LEVITON	1PM10-1LZ	L	98	4.8	5	20
26	LUTRON	AYCL-153P-WH	L	106	2	2	53
27	LUTRON	SCL-153P-WH	L	106	1.7	2	62
28	LUTRON	RRD-10ND-WH	L	115	4	4	29
29	LUTRON	RRD-6NA-WH	T	116	2.2	2	53
30	LUTRON	N-600-WH	L	110	8.8	12	13
31	LUTRON	NTELV-600-WH	T	121	26	24	5
32	LUTRON	NT-603P-WH	L	111	8	9	14
33	LUTRON	DV-10P-WH	L	109	15	15	7
34	LUTRON	MALV-600-WH	L	116	9	9	13
35	LUTRON	DVF-103P-WH	L	116	43	43	3
36	LEVITON	1PSD6-1LZ	L	111	16	15	7
37	LEVITON	1PVD6-1LZ	L	111	7	8	16
38	LEVITON	1PL06-10Z	L	112	5.3	5.2	21
39	LEVITON	6672	L	113	9	9	13
40	LEVITON	6674	L	112	6	6	19
41	LEGRAND	HLV703PW	L	110	4	4	28
42	LEVITON	6641	L	103	60	60	2

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No	Brand	Model	Type	Max (mA)	Min (mA)	Pop-on (mA)	Dimming Ratio
43	LEVITON	6602	L	120	1	14	120
44	LEVITON	TBL03	L	116	10	10	12
45	LUTRON	AY-10PNL-WH	L	117	22	23	5
46	LUTRON	AY-10P-WH	L	110	12	12	9
47	LUTRON	AY-603PG-WH	L	79	4.7	4.6	17
48	LUTRON	AYLV-600P-WH	L	110	4	4.7	28
49	LUTRON	AYLV-603P-WH	L	108	4.5	4.5	24
50	LUTRON	GLV-600-IV	L	112	4.6	4.5	24
51	LUTRON	LG-600PH-WH	L	108	4.5	4.5	24
52	LUTRON	DV-600P-WH	L	107	4.3	4.3	25
53	LUTRON	DV-603P-WH	L	108	4.6	4.6	23
54	LUTRON	DVLP-10.WH	L	106	5.6	5.6	19
55	LUTRON	DVPDC-203P-WH	L	110	40	40	3
56	LUTRON	DVW-603PGH-WH	L	82	4.5	4.5	18
57	LUTRON	GL-600-WH	L	105	2	2	53
58	LUTRON	LG-603PGH-WH	L	81	4.7	4.7	17
59	LUTRON	CTCL-153P-WH	L	106	2	2	53
60	LUTRON	MA-1000-WH	L	120	14.5	13	8
61	LUTRON	MACL-153M-WH	L	97.6	2	2	49
62	LUTRON	NT-1000	L	111	6.6	6	17
63	LEVITON	R02-06613-PLW	L	119	5.3	5.3	22
64	LEVITON	R62-RP106-1LW	L	119	3	2	40
65	LUTRON	S-1000-WH	L	112	3	3	37
66	LUTRON	S-103PNL-WH	L	107	15	15	7
67	LUTRON	S-103P-WH	L	106	18	17	6
68	LUTRON	S-10P-WH	L	105	14.5	14.4	7
69	LUTRON	S-600PH-WH	L	106.5	3	3	36
70	LUTRON	S-600-PNLH-WH	L	109	3	3	36
71	LUTRON	S-6000P-WH	L	107	3	3	36
72	LUTRON	S-6000-WH	L	100	1	2	100
73	LUTRON	S-603PGH-WH	L	78	3	3	26
74	LUTRON	S-603PNLH-WH	L	109	3.2	4	34
75	LUTRON	DVWCL-153PH-WH	L	106	2.7	3	39
76	LUTRON	TGCL-153PH-WH	L	107	1.8	2	59
77	LUTRON	D-600PH-DK	L	101	1	2	101
78	COOPER	DAL06P-C2	L	116	20	20	6
79	COOPER	SAL06P	L	120	17	3	7
80	LEVITON	IPL06	L	111	6	6	19
81	COOPER	S106P	L	112	2.4	3	47
82	COOPER	SLC03P-W-K-L	L	109	58	58	2
83	LUTRON	SLV600P-WH	L	109	4.5	3	24
84	LUTRON	SLV-603P-WH	L	109	4.5	4	24
85	LUTRON	SPSLV-1000-WH	T	123	18	17	7
86	LUTRON	TG-10PR-WH	L	109	12	11	9
87	LUTRON	TGLV-600PR	L	109	4.7	15	23
88	LEVITON	1P106	L	110	5	5	22
89	LEVITON	TTI06	L	114	7	7	16
90	LUTRON	SPSELV-600-WH	T	118	21	21	6

10 Thermal Performance

10.1 Thermal Scan at 25 ºC Ambient

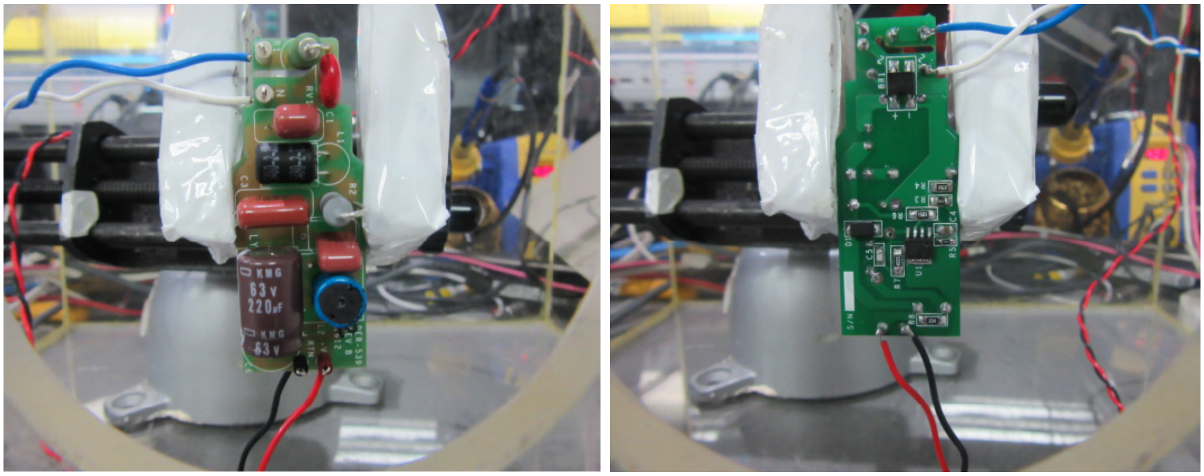

Figure 15 – Test Set-up Picture - Open Frame.

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.

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10.1.1 Non-Dimming Operation at 115 VAC

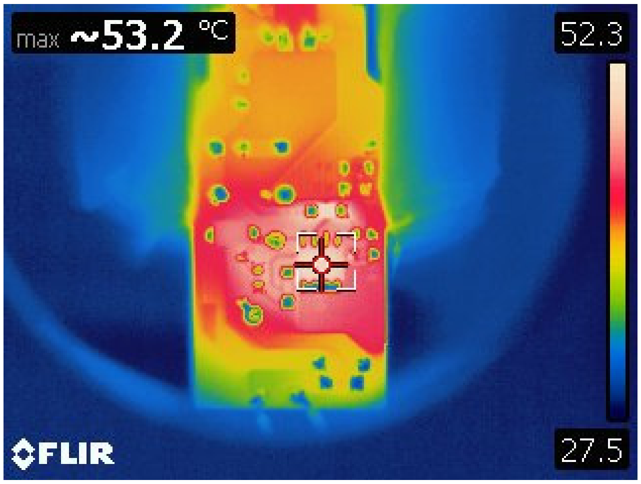

Figure 16 – 115 VAC, 52 V LED Load.
Spot 1: LYT7503D (U1): 53.2 ºC

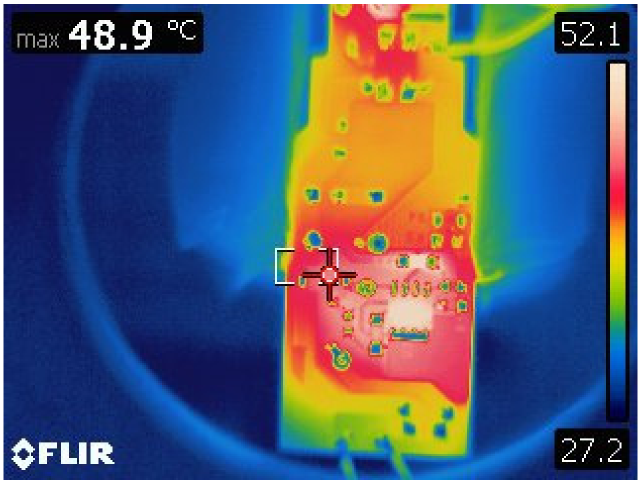

Figure 17 – 115 VAC, 52 V LED Load.
Spot 1: Flywheel Diode (D1): 48.9 ºC.

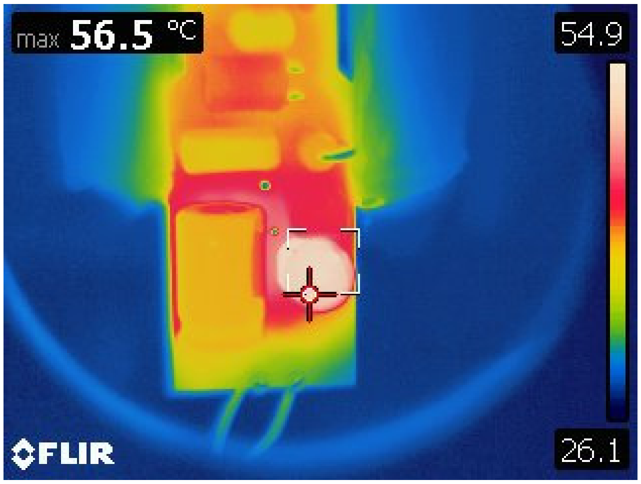

Figure 18 – 115 VAC, 52 V LED Load.
Spot 1: Buck Inductor (L2): 56.5 ºC.

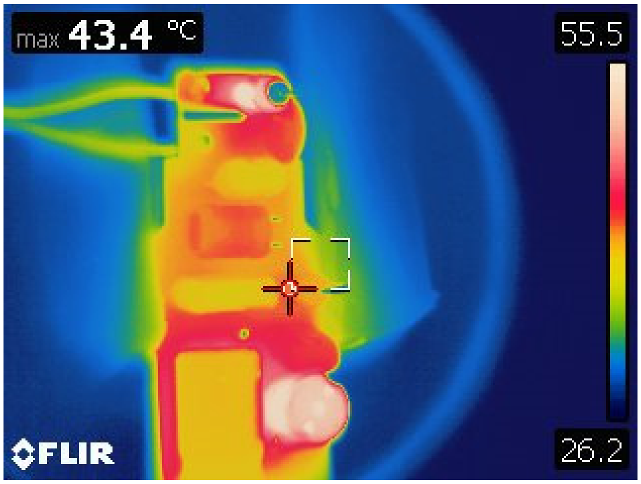

Figure 19 – 115 VAC, 52 V LED Load.
Spot 1: Damper (R2): 43.4 ºC.

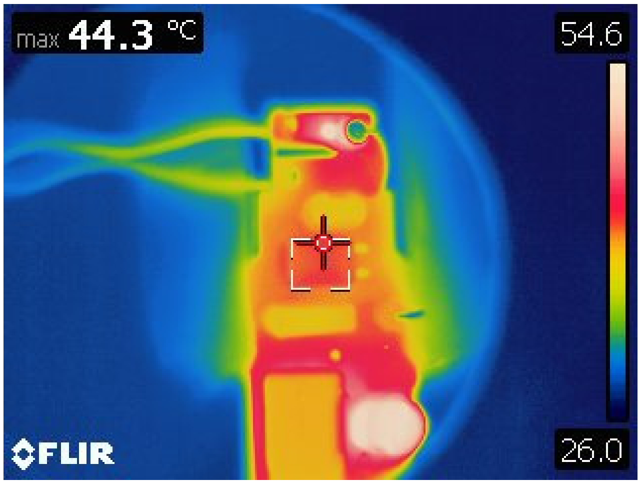

Figure 20 – 115 VAC, 52 V LED Load.
Spot 1: Differential Choke (L1): 44.3 ºC.

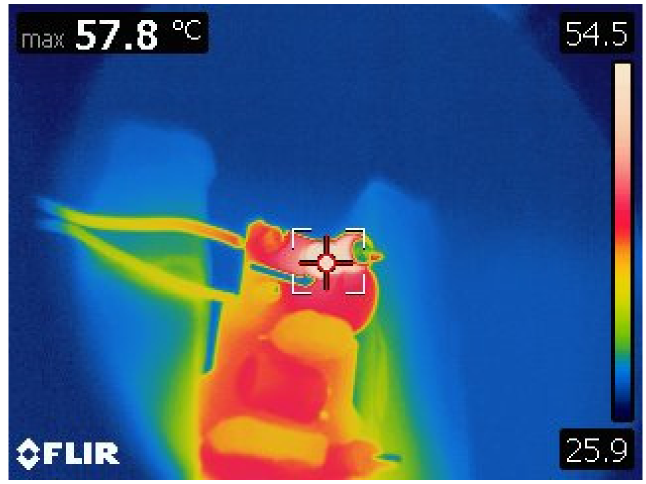

Figure 21 – 115 VAC, 52 V LED Load.
Spot 1: Fusible Resistor (R1): 57.8 ºC.

10.1.2 Dimming Operation at 115º Conduction Angle

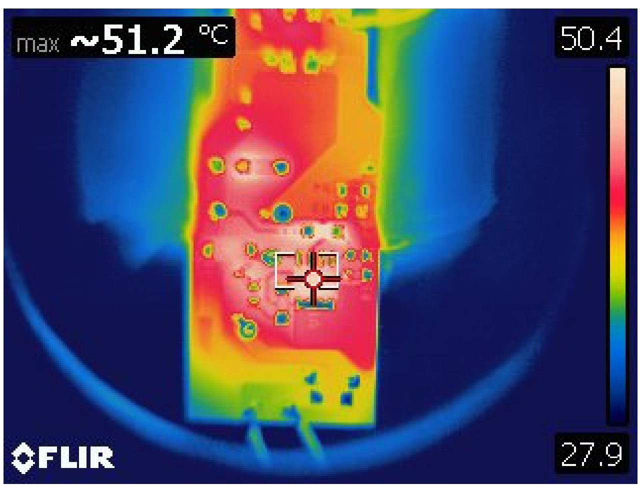

Figure 22 – 115 VAC, 52 V LED Load.
Spot 1: LYT7503D (U1): 51.2 ºC.

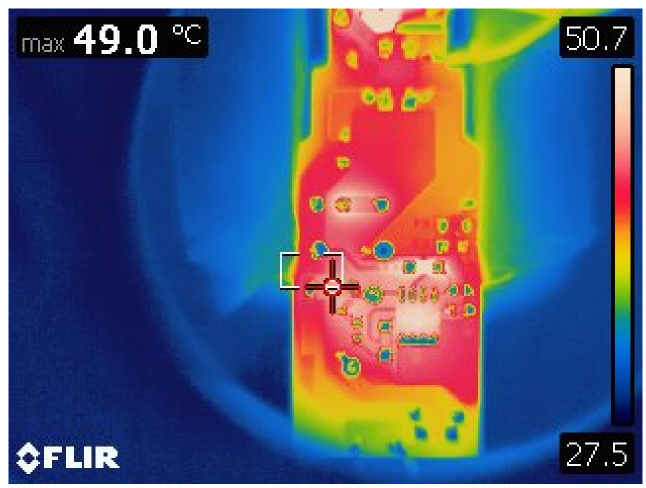

Figure 23 – 115 VAC, 52 V LED Load.
Spot 1: Flywheel Diode (D1): 49 ºC.

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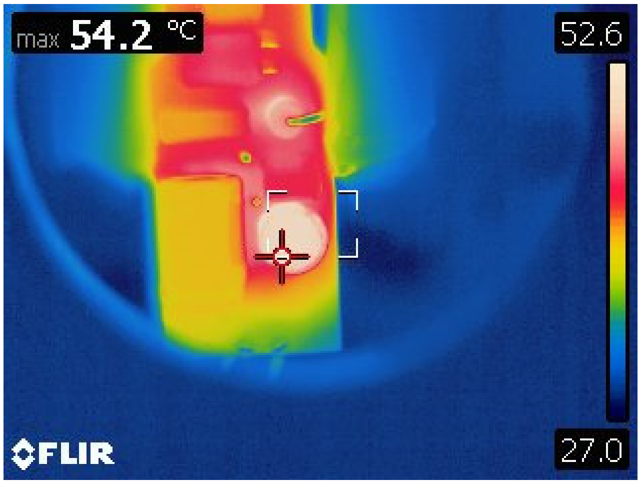

Figure 24 – 115 VAC, 52 V LED Load.
Spot 1: Buck Inductor (L2): 54.2 ºC.

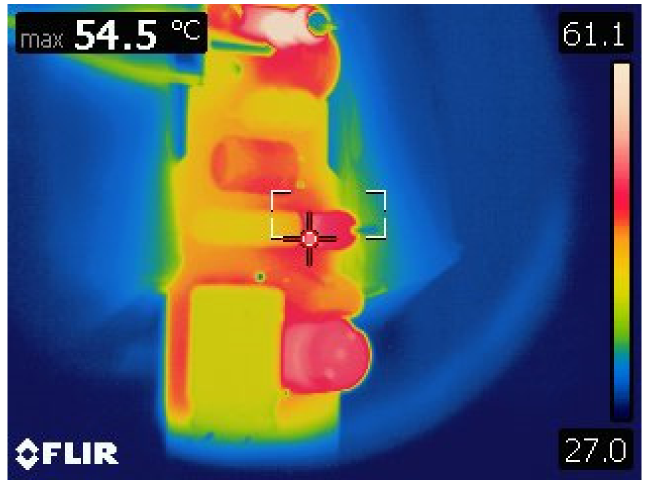

Figure 25 – 115 VAC, 52 V LED Load.
Spot 1: Damper (R2): 54.5 ºC.

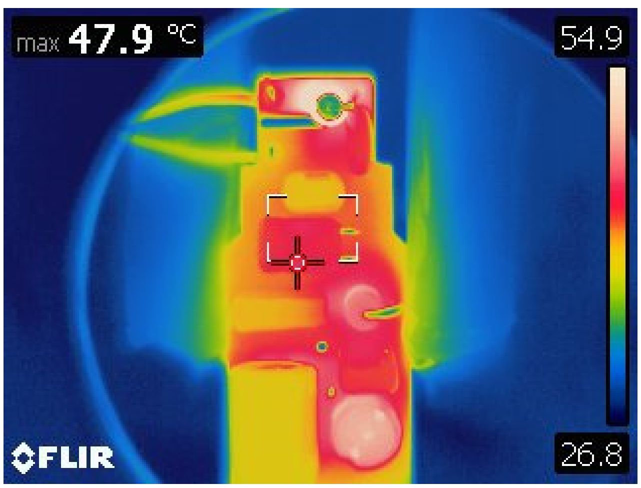

Figure 26 – 115 VAC, 52 V LED Load.
Spot 1: Differential Choke (L1): 47.9 ºC.

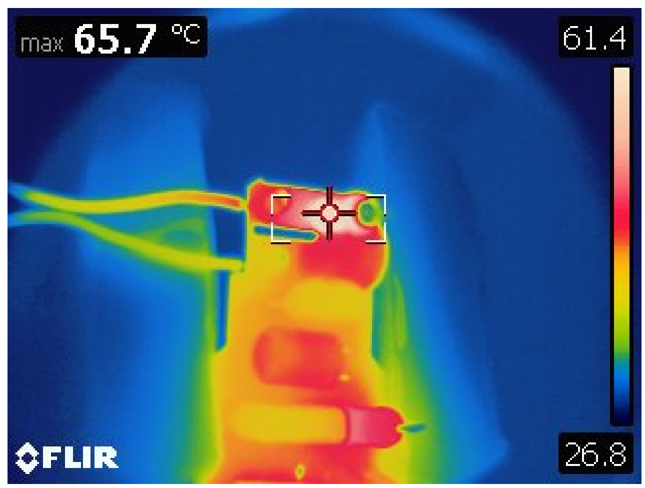

Figure 27 – 115 VAC, 52 V LED Load.
Spot 1: Fusible Resistor (R1): 75.5 ºC.

10.2 Thermal Performance at 90 ºC Ambient

Figure 28 – Test Set-up Picture Thermal at 75 ºC Ambient - Open Frame.

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

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10.2.1 Non-Dimming at 90 VAC, 52 V LED Load

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	76.3	76.3
LYTSwitch-7	95.4	95.4
L2-Buck Inductor	95.0	95.0
R1-Fusible	102.2	102.2
R2-Damper	88.2	88.2
D1-Flywheel Diode	93.0	93.0

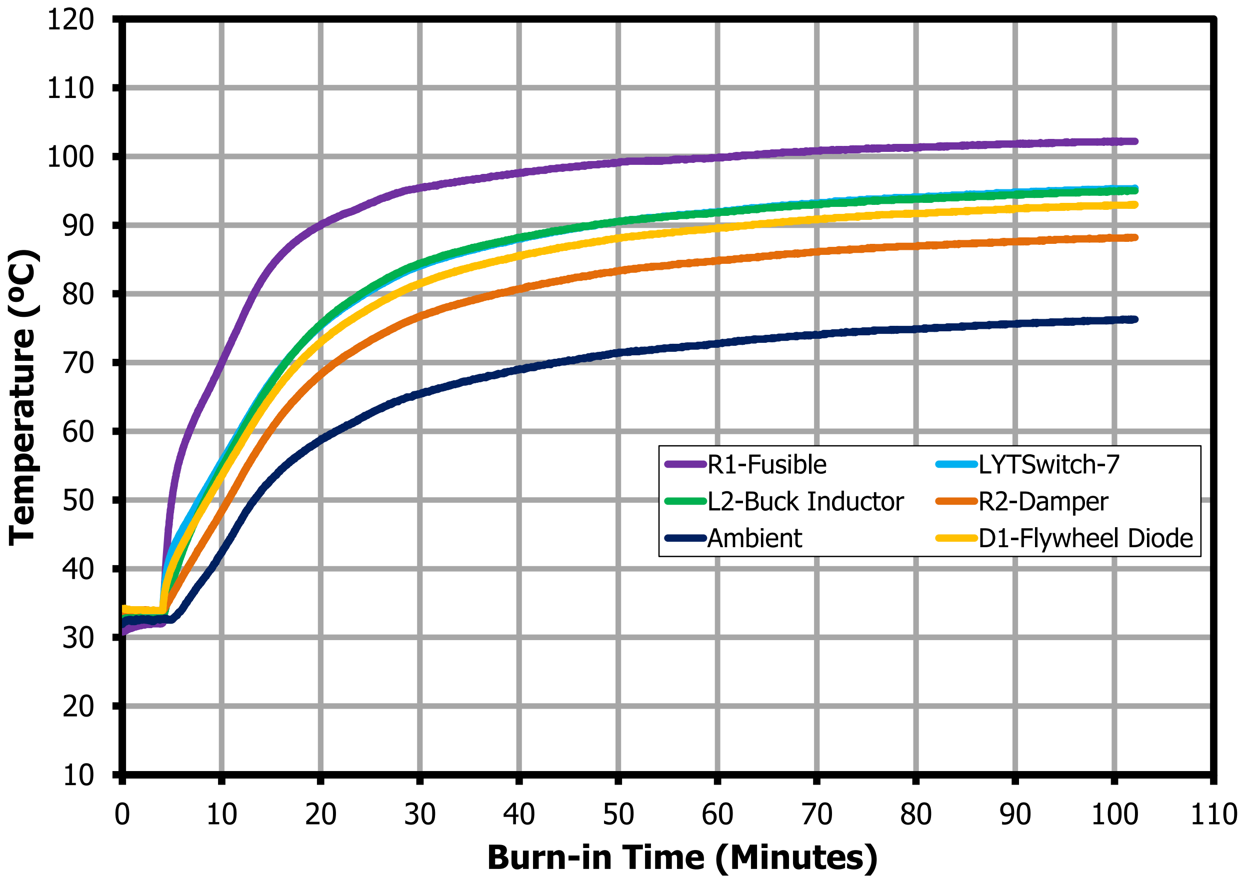

Figure 29 – Component Temperature at 90 VAC, 52 V LED Load, 75 ºC Ambient.

10.2.2 Non-Dimming at 115 VAC, 52 V LED Load

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	76.1	76.1
LYTSwitch-7	98.3	98.3
L2-Buck Inductor	100.8	100.8
R1-Fusible	96.6	96.6
R2-Damper	91.2	91.1
D1-Flywheel Diode	97.6	97.6

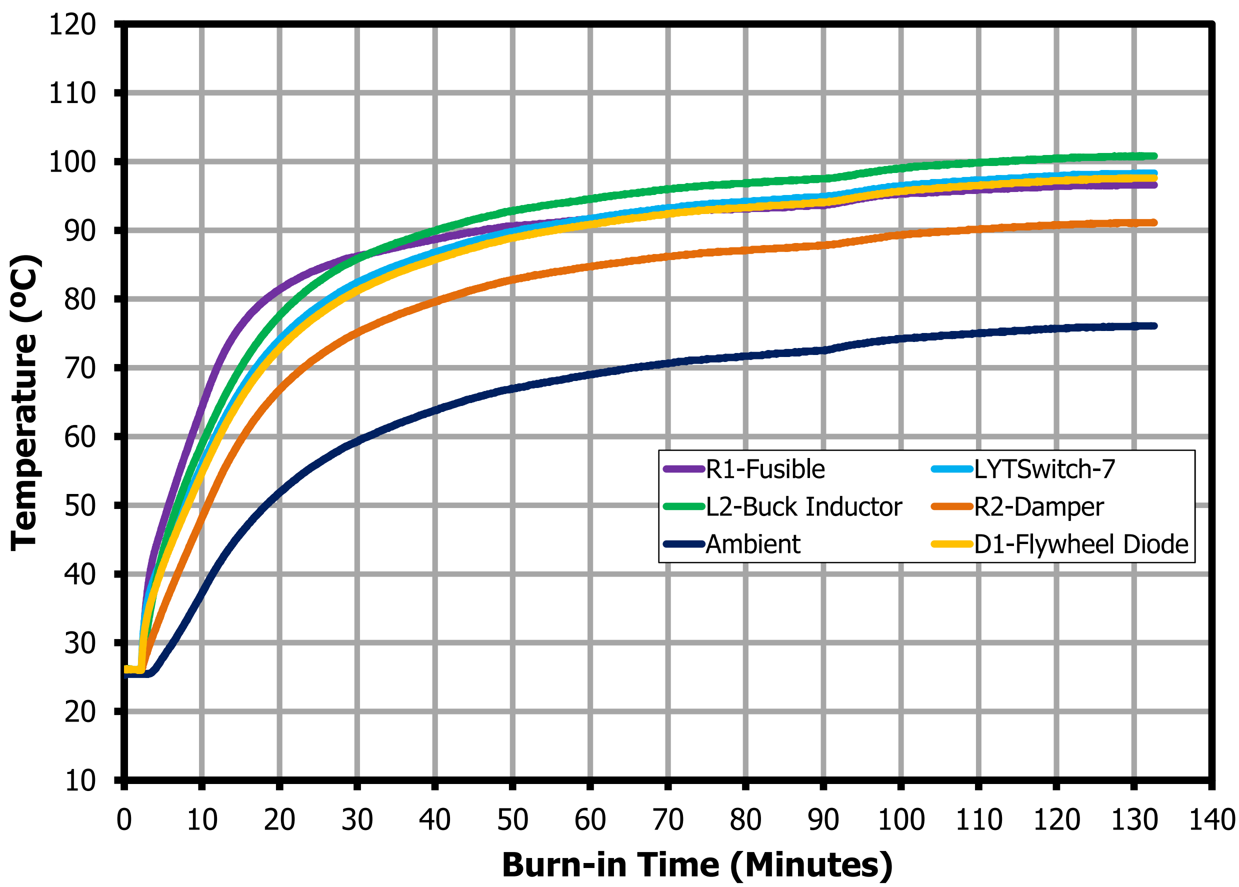

Figure 30 – Component Temperature at 115 VAC, 52 V LED Load, 75 ºC Ambient.

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10.2.3 Non-Dimming at 132 VAC, 52 V LED Load

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	75.6	75.6
LYTSwitch-7	100.1	100.0
L2-Buck Inductor	104.1	104.1
R1-Fusible	94.1	94.0
R2-Damper	92.6	92.6
D1-Flywheel Diode	100.2	100.2

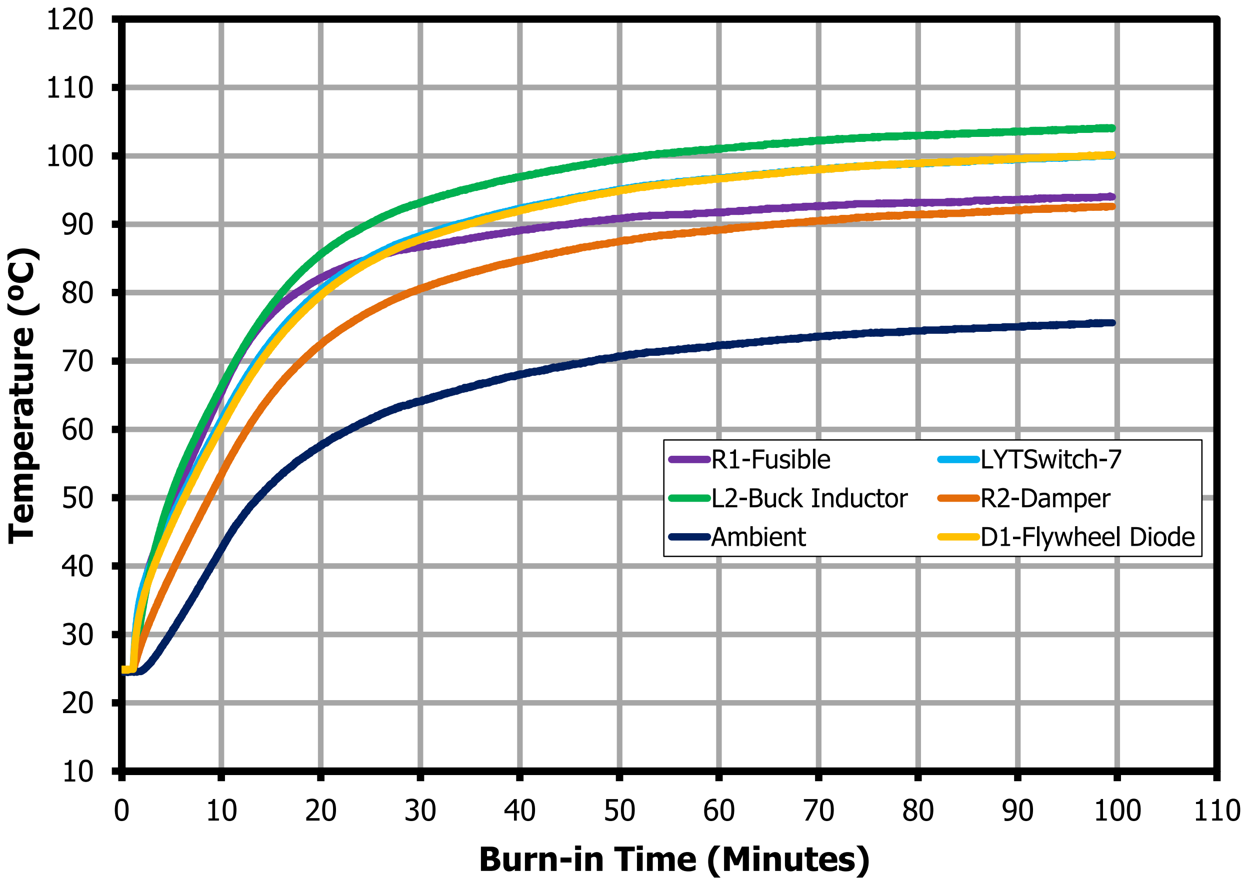

Figure 31 – Component Temperature at 132 VAC, 52 V LED Load, 75 ºC Ambient.

10.2.4 With Dimmer at 120 VAC and 115º Conduction Angle

Components	Thermal Measurements (ºC)	
	Maximum	Final
Ambient	76.8	76.8
LYTSwitch-7	96.8	96.7
L2-Buck Inductor	98.6	98.6
R1-Fusible	102.9	102.8
R2-Damper	99.7	99.7
D1-Flywheel Diode	96.7	96.6

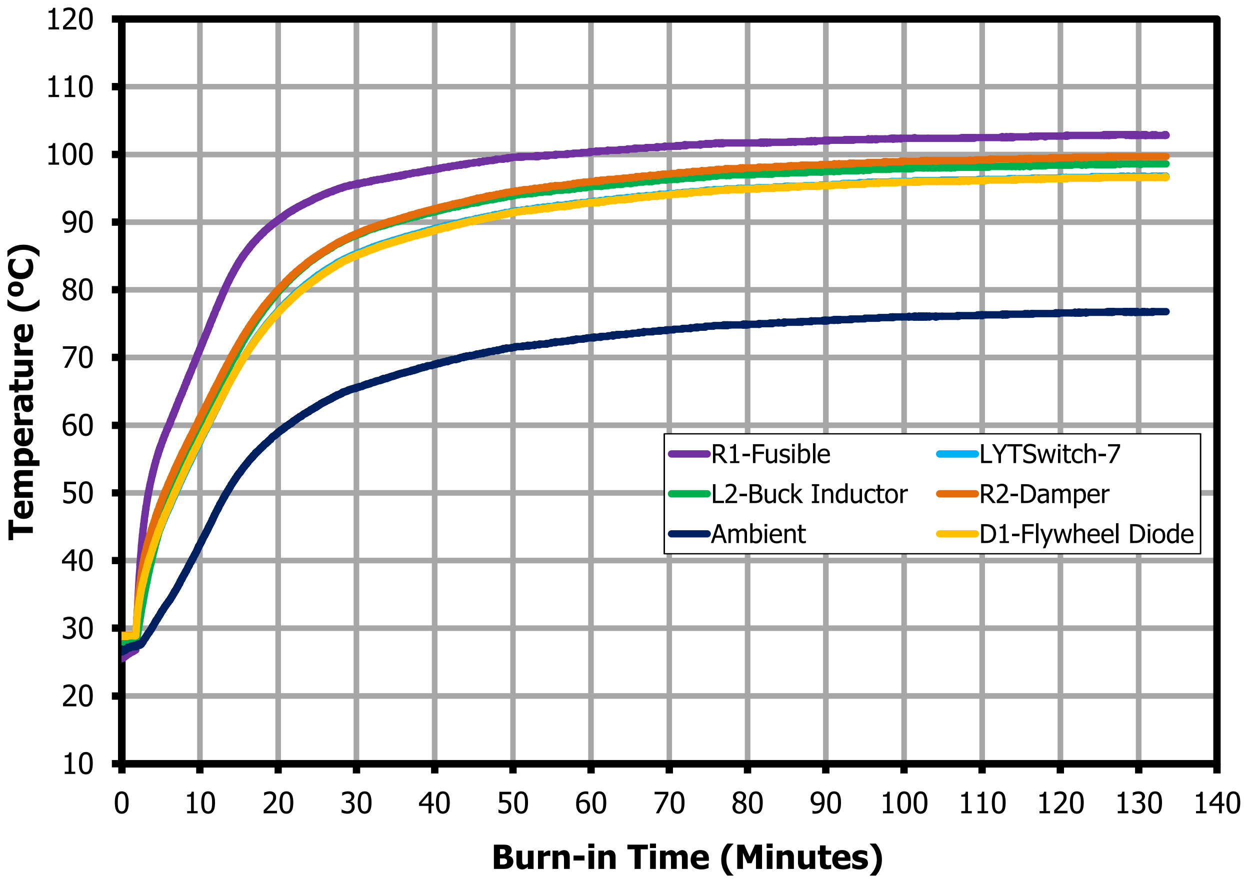

Figure 32 – Component Temperature with Dimmer at 120 VAC, 52 V LED Load, 75 ºC Ambient.

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11 Waveforms

11.1 Input Voltage and Input Current Waveforms

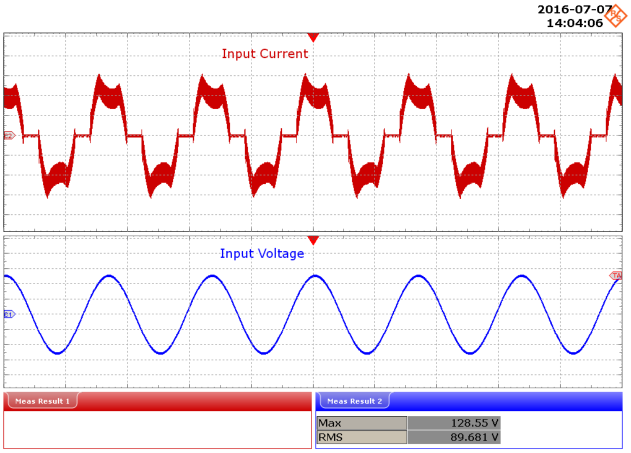

Figure 33 – 90 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

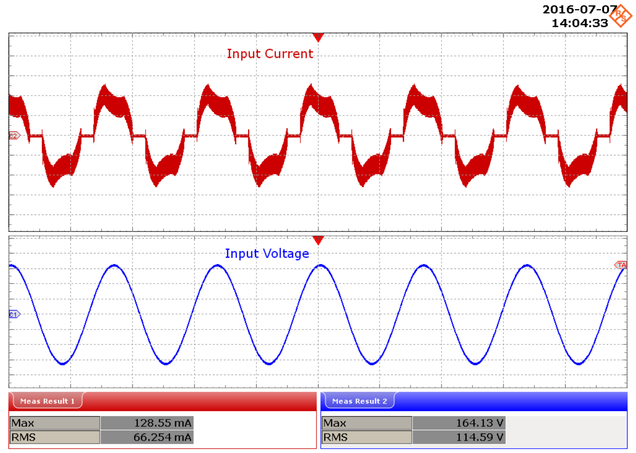

Figure 34 – 115 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

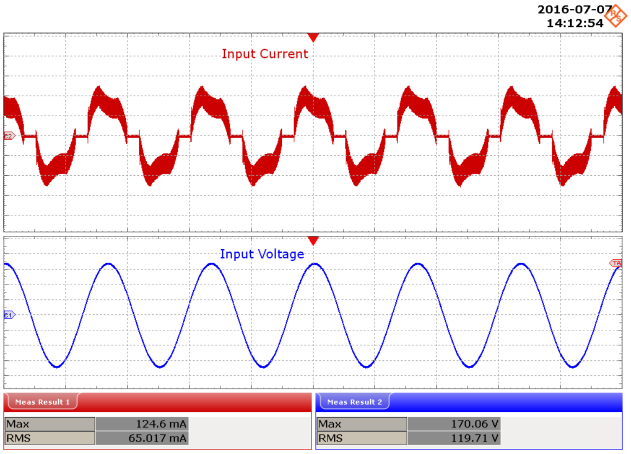

Figure 35 – 120 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

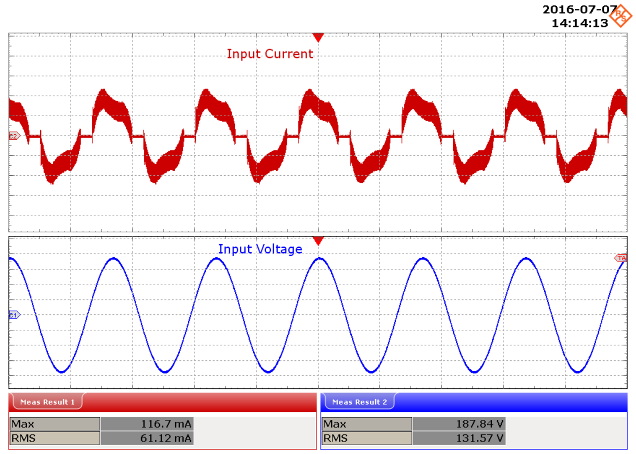

Figure 36 – 132 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

11.2 Input Voltage and Input Current Waveforms with Dimmer

V_{IN}: 120 V / 60 Hz
Dimmer: Leviton IP106-1LZ

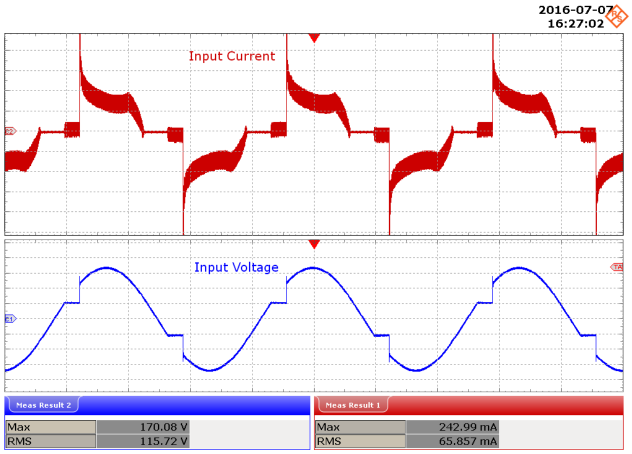

Figure 37 – 155º Conduction Angle, 52 V LED.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

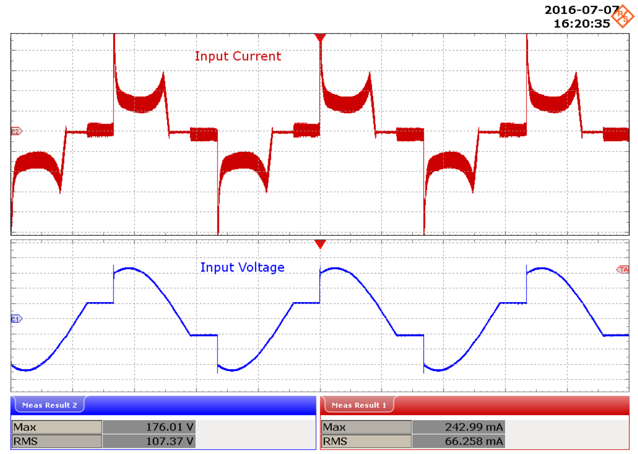

Figure 38 – 135º Conduction Angle, 52 V LED.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

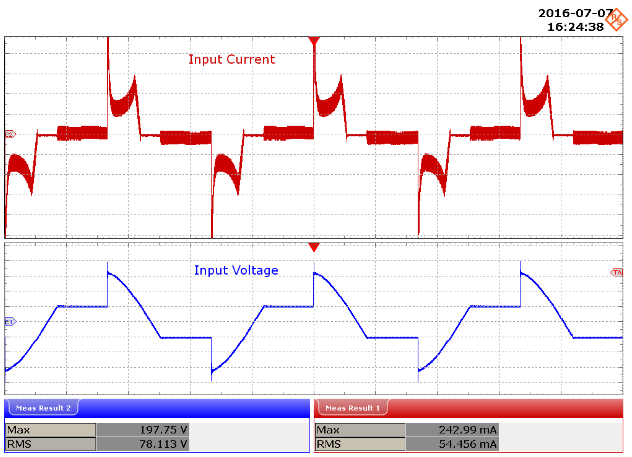

Figure 39 – 90º Conduction Angle, 52 V LED.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

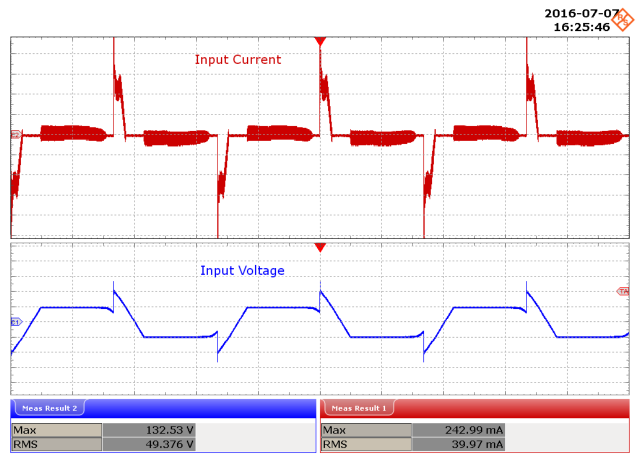

Figure 40 – 55º Conduction Angle, 52 V LED.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 5 ms / div.

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11.3 Start-up Profile

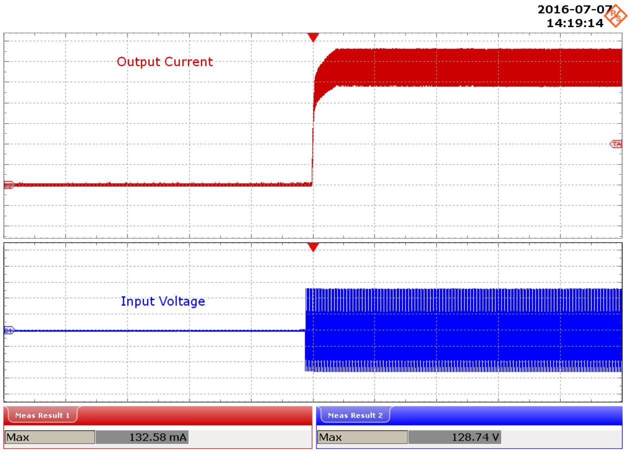

Figure 41 – 90 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

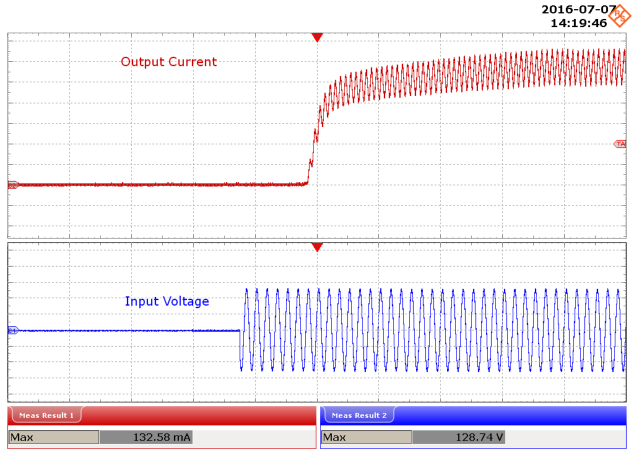

Figure 42 – 90 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Turn on Time: 223 ms.

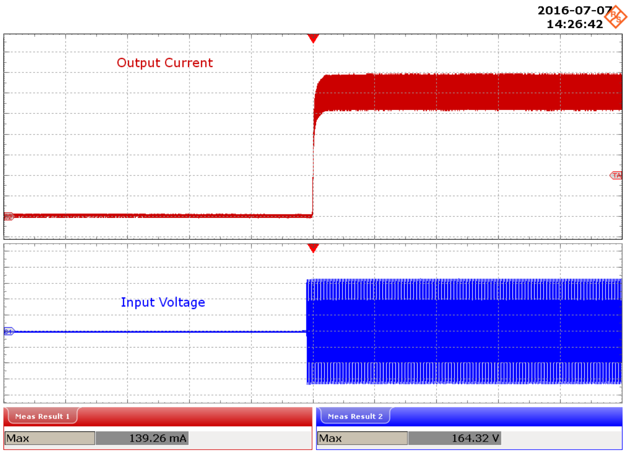

Figure 43 – 115 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

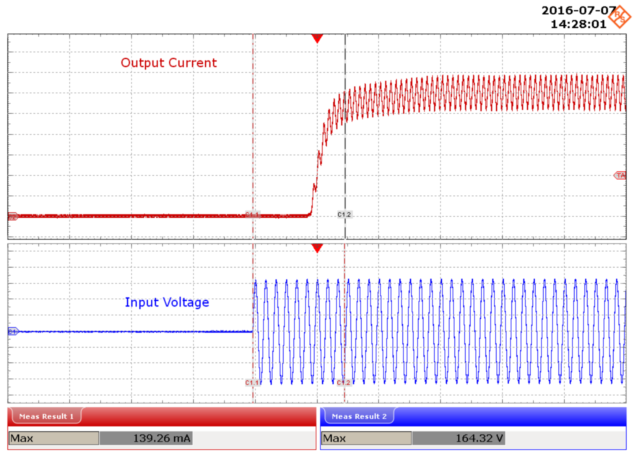

Figure 44 – 115 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Turn on Time: 149 ms.

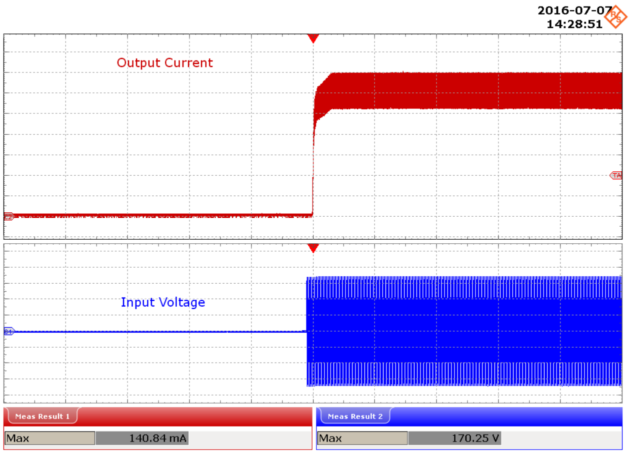

Figure 45 –120 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

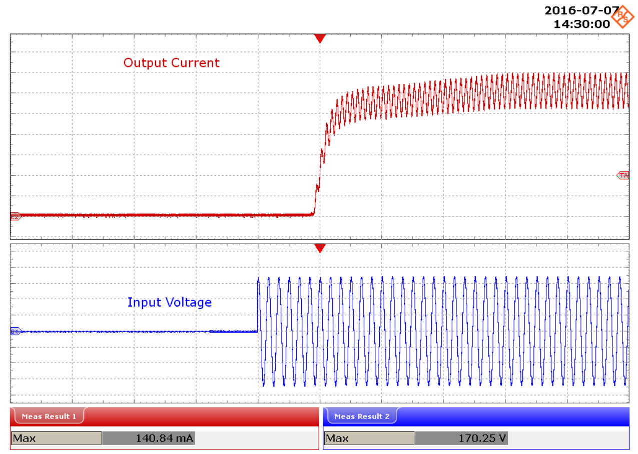

Figure 46 – 120 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Turn on Time: 154 ms.

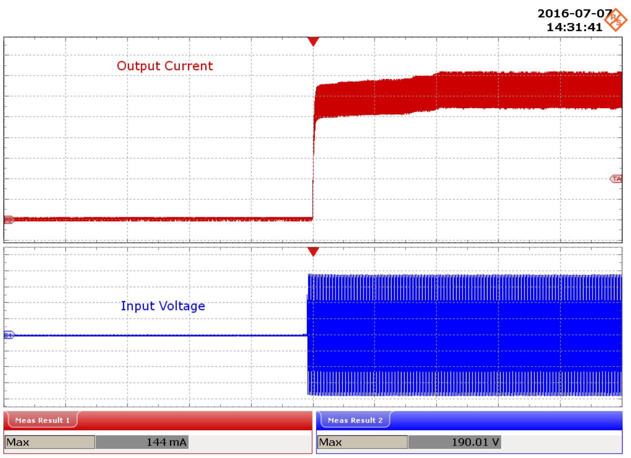

Figure 47 – 132 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

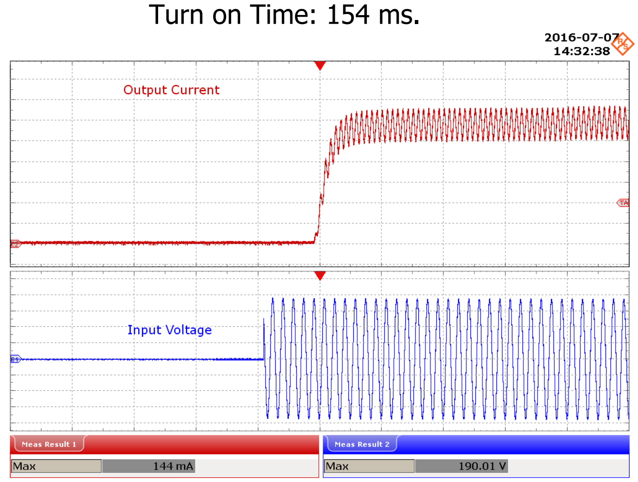

Figure 48 – 132 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Turn on Time: 142 ms.

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11.4 Output Current Fall

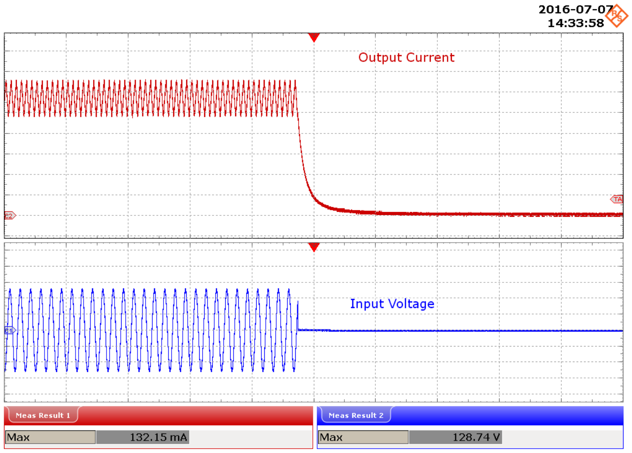

Figure 49 – 90 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

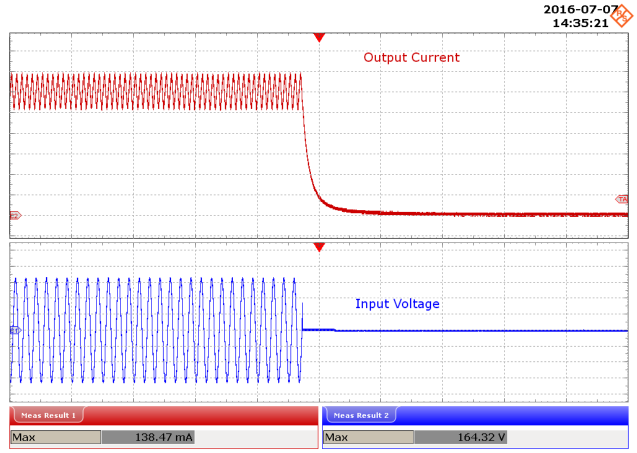

Figure 50 – 115 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

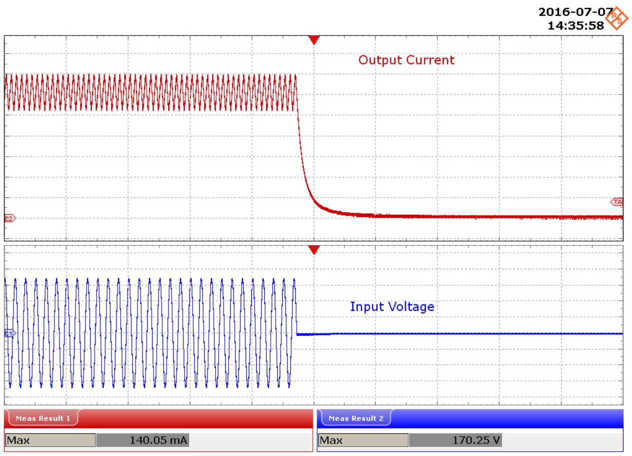

Figure 51 – 120 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

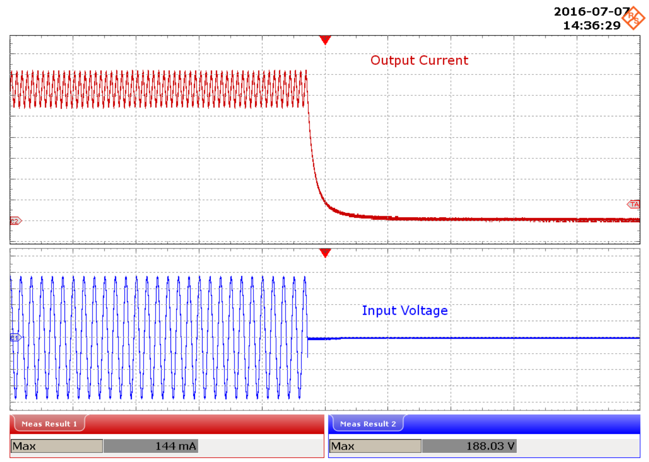

Figure 52 – 132 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

11.5 Output Voltage and Current with Dimmer

V_{IN}: 120 V / 60 Hz
Dimmer: Leviton IP106-1LZ

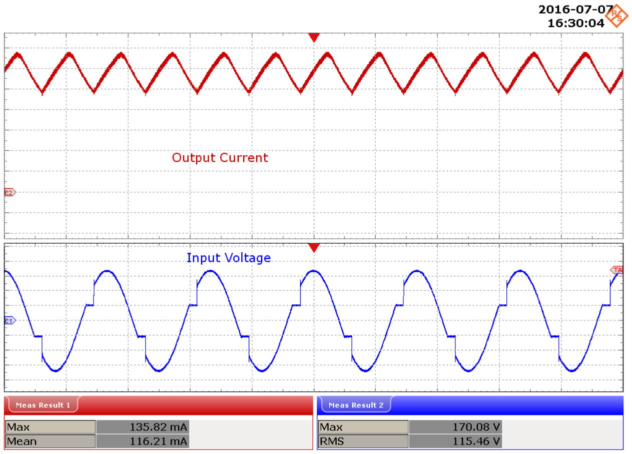

Figure 53 – 155º Conduction Angle, 52 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

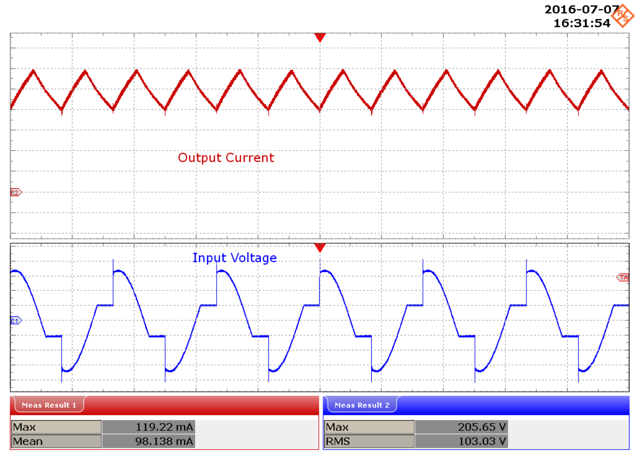

Figure 54 – 120º Conduction Angle, 52 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

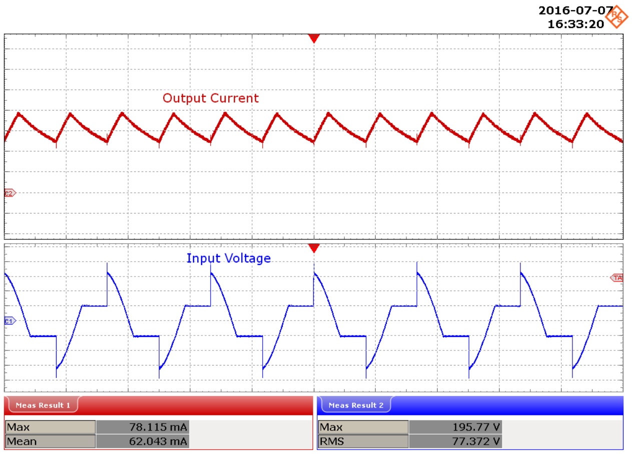

Figure 55 – 90º Conduction Angle, 52 V LED.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

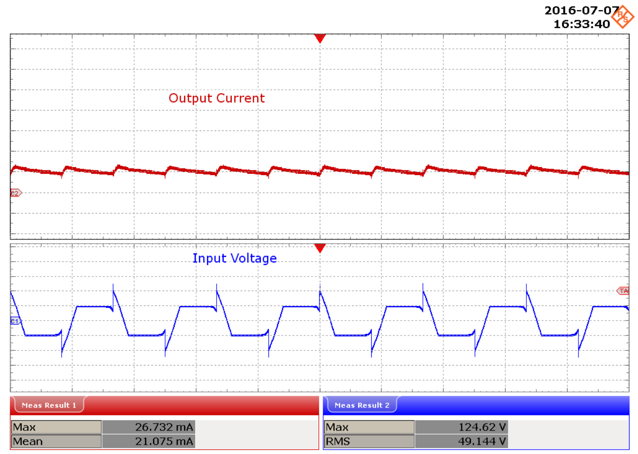

Figure 56 – 55º Conduction Angle, 52 V LED.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

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11.6 Drain Voltage and Current in Normal Operation

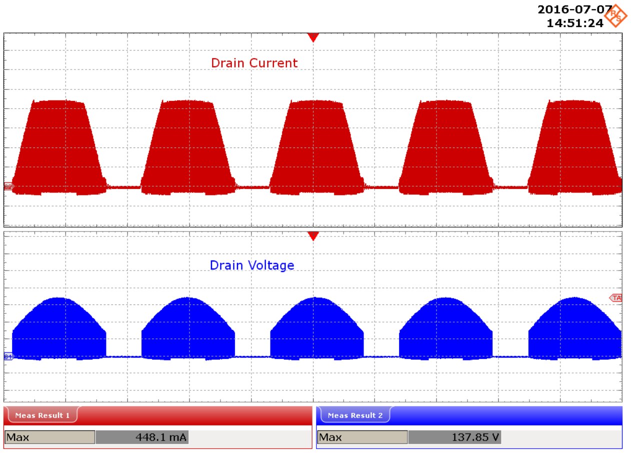

Figure 57 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

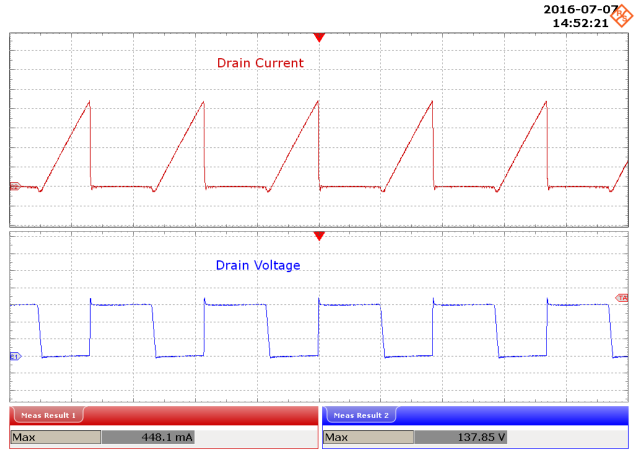

Figure 58 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

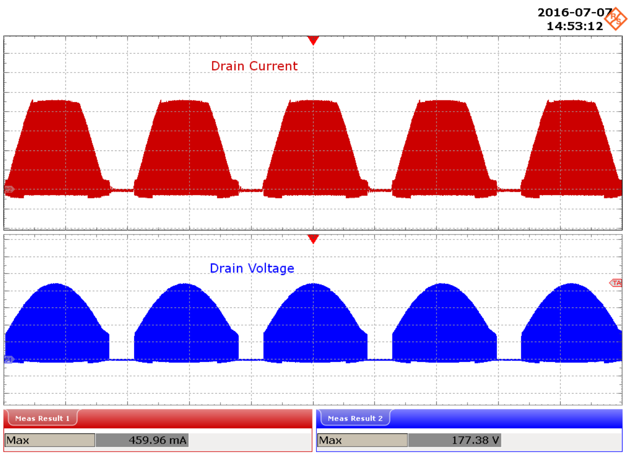

Figure 59 – 115 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

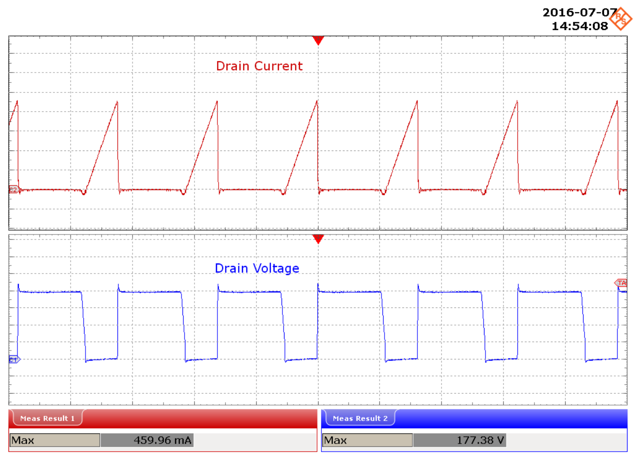

Figure 60 – 115 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 μs / div.

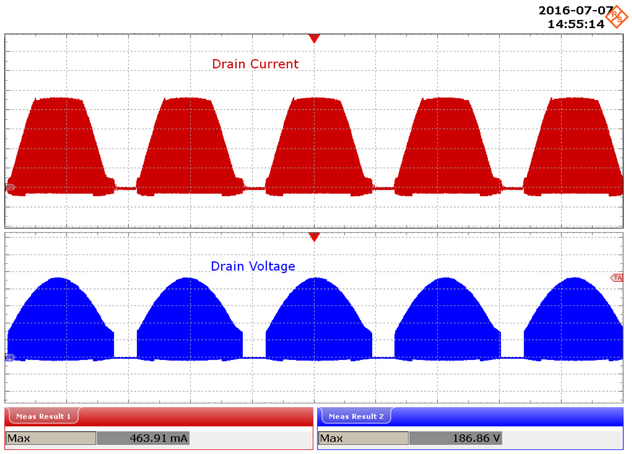

Figure 61 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

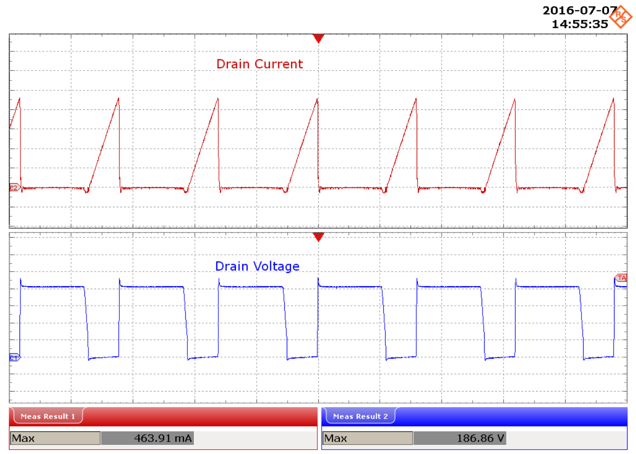

Figure 62 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs / div.

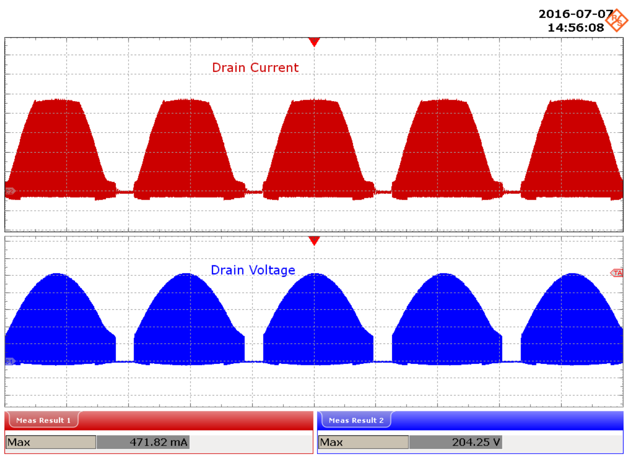

Figure 63 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

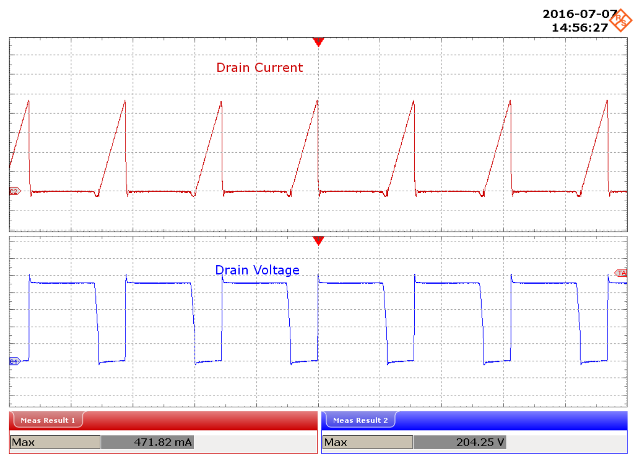

Figure 64 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs / div.

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11.7 Drain Voltage and Current Start-up Profile

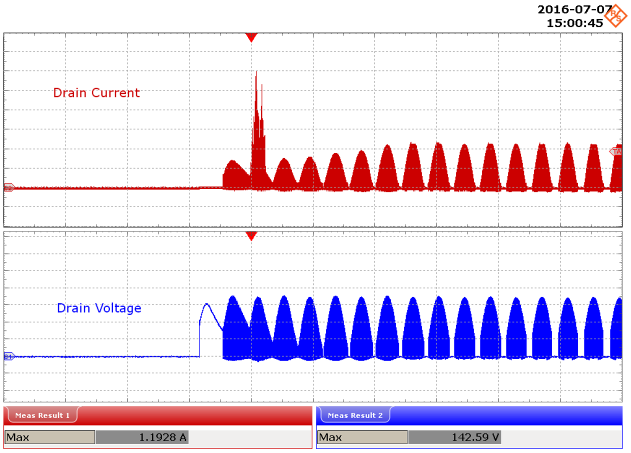

Figure 65 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms /div.

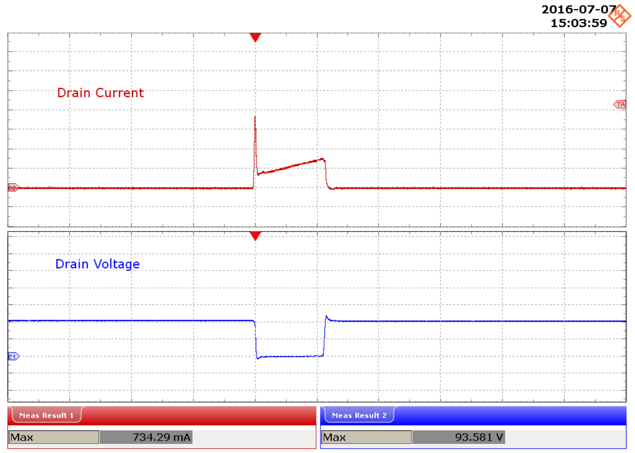

Figure 66 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 μs /div.

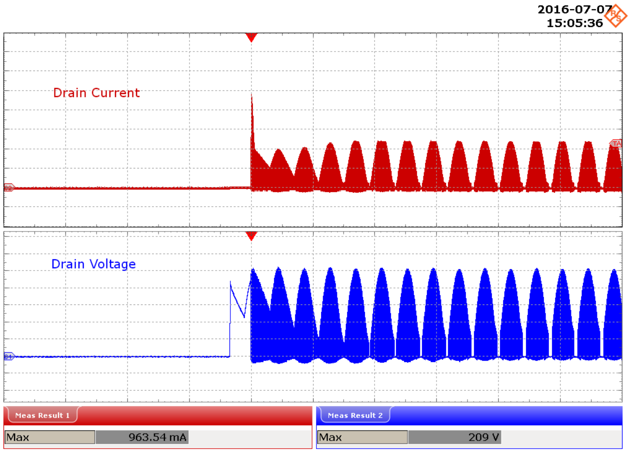

Figure 67 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms /div.

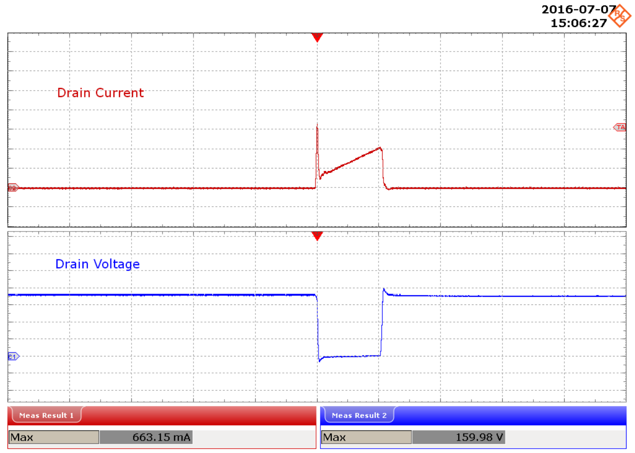

Figure 68 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 μs /div.

11.8 Drain Voltage and Current at Output Short-Circuit

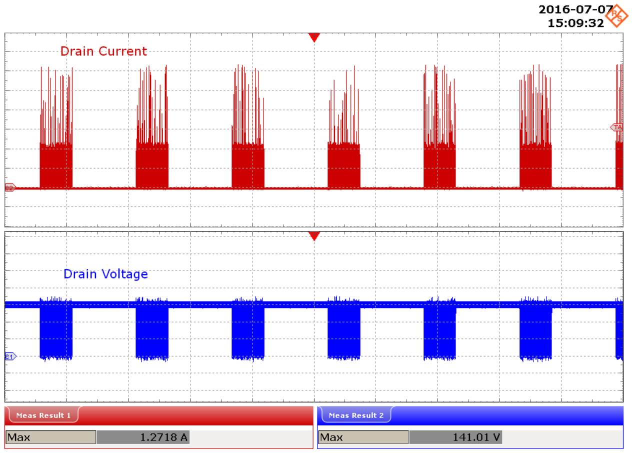

Figure 69 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s /div.

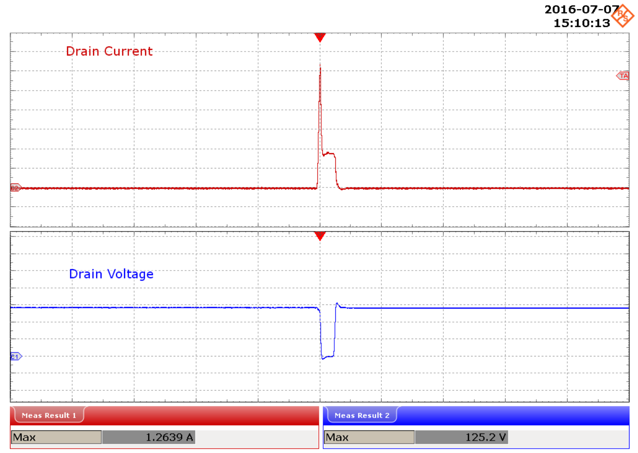

Figure 70 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 µs /div.

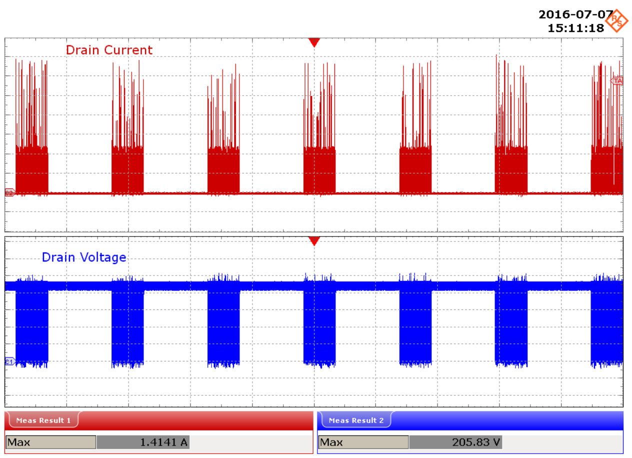

Figure 71 – 132 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1s /div.

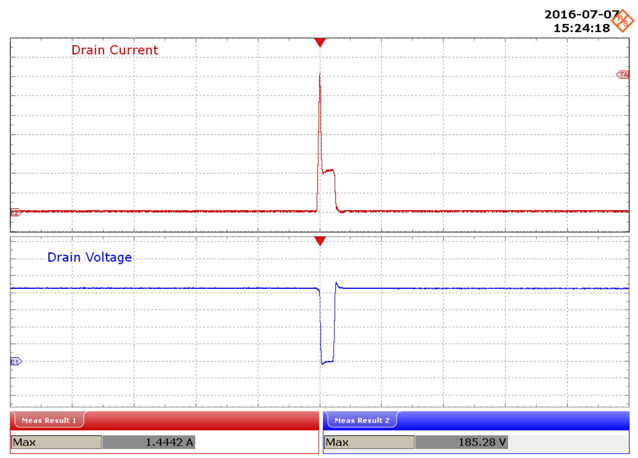

Figure 72 – 132 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 µs /div.

11.8.1 Input Power at Output Short-Circuit

Input		Input Measurement		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)
90	60	89.94	8.57	0.23
115	60	114.94	6.77	0.21
120	60	120.00	6.77	0.23
132	60	131.98	6.81	0.27

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11.9 Output Diode Voltage and Current in Normal Operation

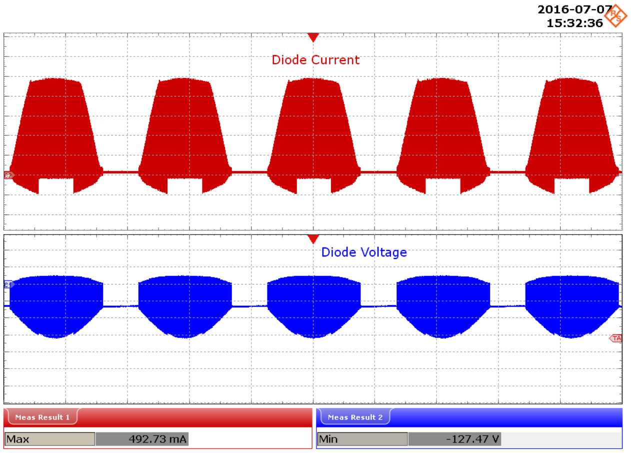

Figure 73 – 90 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

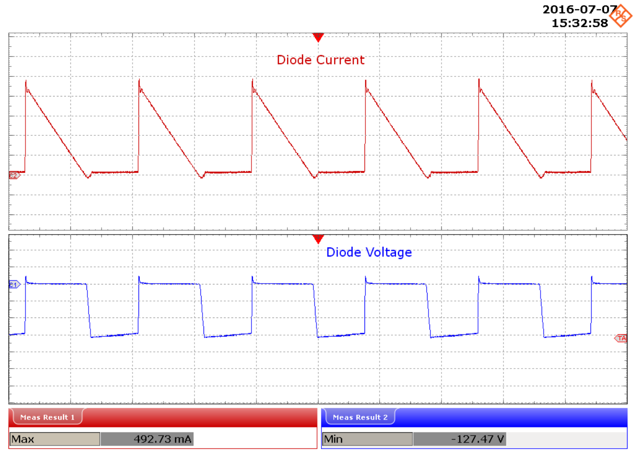

Figure 74 – 90 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

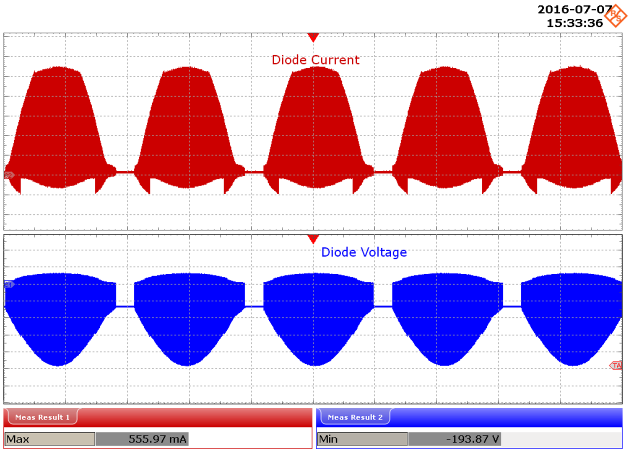

Figure 75 – 132 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

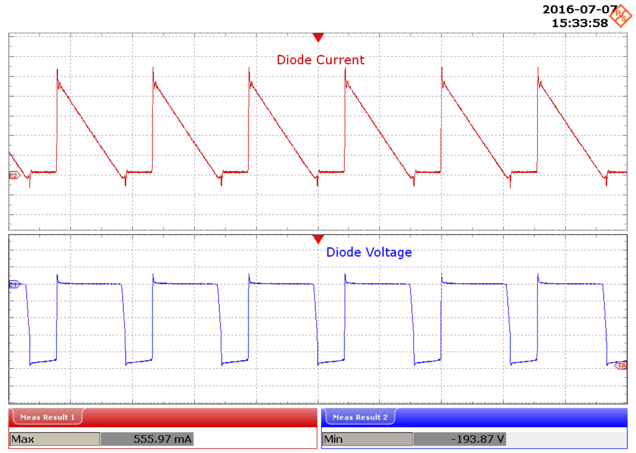

Figure 76 – 132 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

11.10 Output Voltage and Current – Open Output LED Load

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

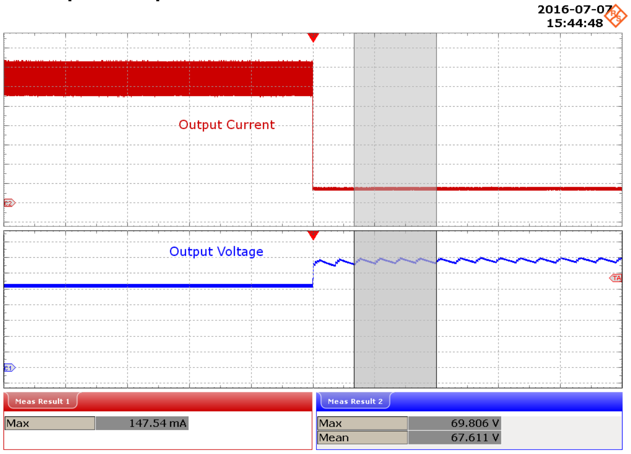

Figure 77 – 90 VAC, 52 V LED Load, Running Open Load. Upper: I_{OUT}, 20 mA / div. Lower: V_{OUT}, 10 V / div., 4 s / div.

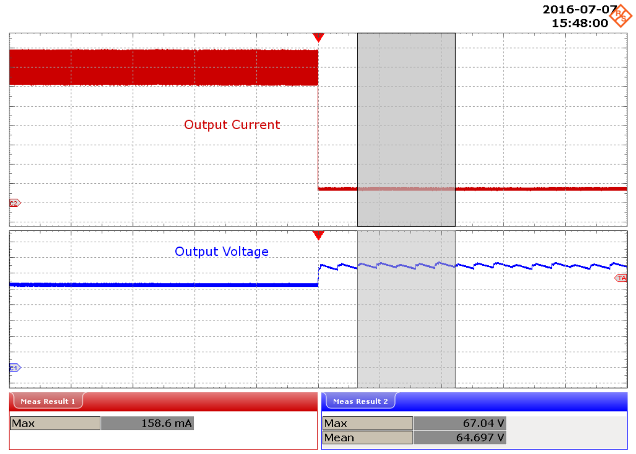

Figure 78 – 132 VAC, 52 V LED Load, Running Open Load. Upper: I_{OUT}, 20 mA / div. Lower: V_{OUT}, 10 V / div., 4 s / div.

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

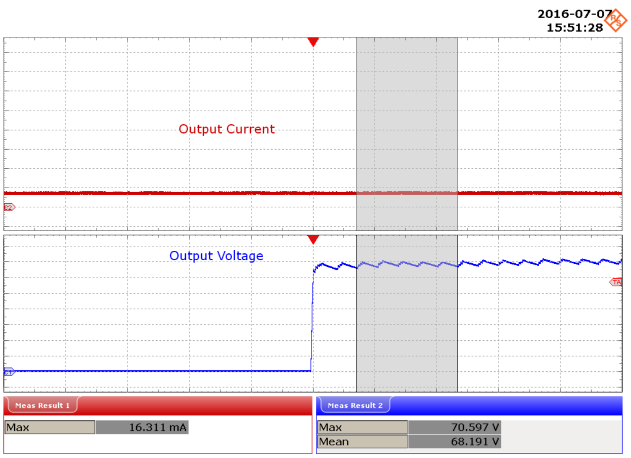

Figure 79 – 90 VAC, Open Load, Open Load Start-up. Upper: I_{OUT}, 20 mA / div. Lower: V_{OUT}, 10 V / div., 4 s / div.

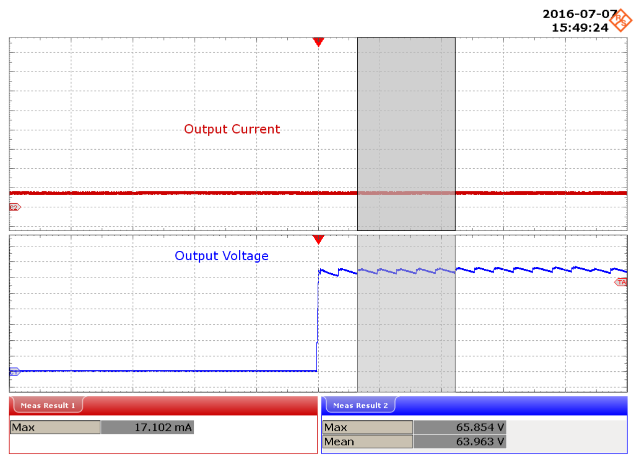

Figure 80 – 132 VAC, Open Load, Open Load Start-up. Upper: I_{OUT}, 20 mA / div. Lower: V_{OUT}, 10 V / div., 4 s / div.

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11.12 Output Ripple Current at Non-Dimming Operation

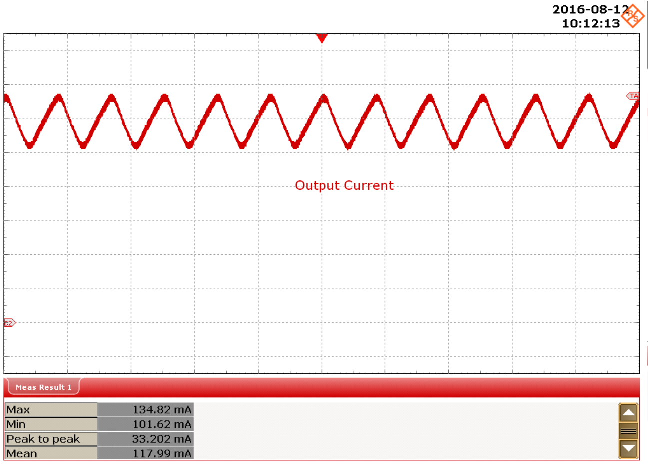

Figure 81 – 90 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

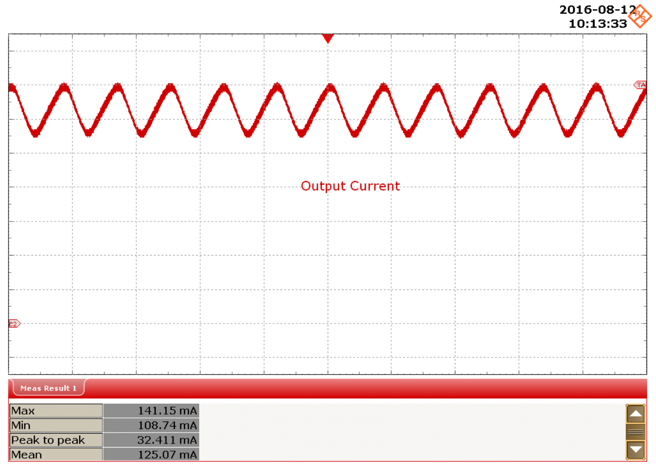

Figure 82 – 115 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

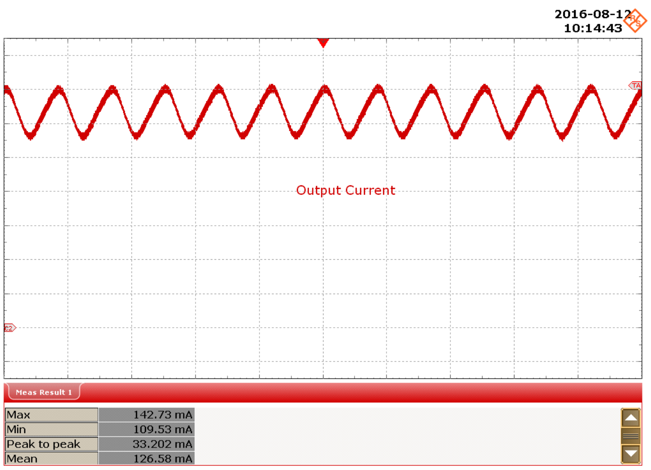

Figure 83 – 120 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

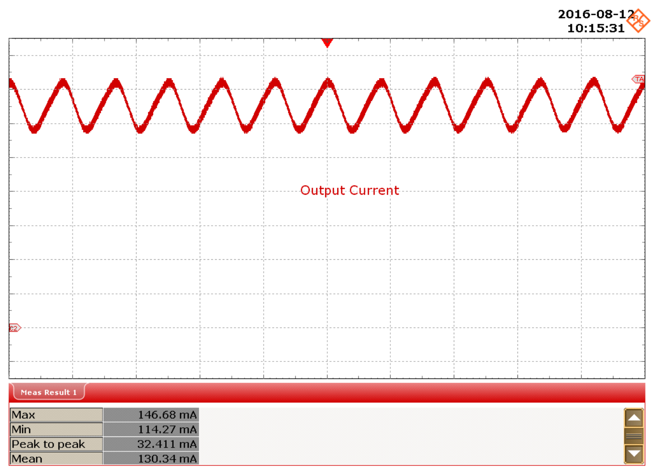

Figure 84 – 132 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}$+$I_{O(MIN)}$)
90	134.82	101.62	118	14.07
115	141.15	108.74	125	12.96
120	142.73	109.53	126.58	13.11
132	146.68	114.27	130.34	12.43

11.13 Output Ripple Current with Dimmer at Maximum Conduction Angle

Dimmer: Leviton IP106-1LZ

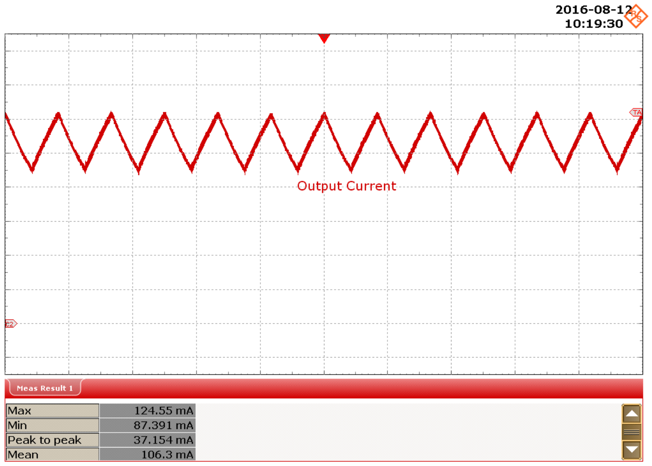

Figure 85 – 90 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

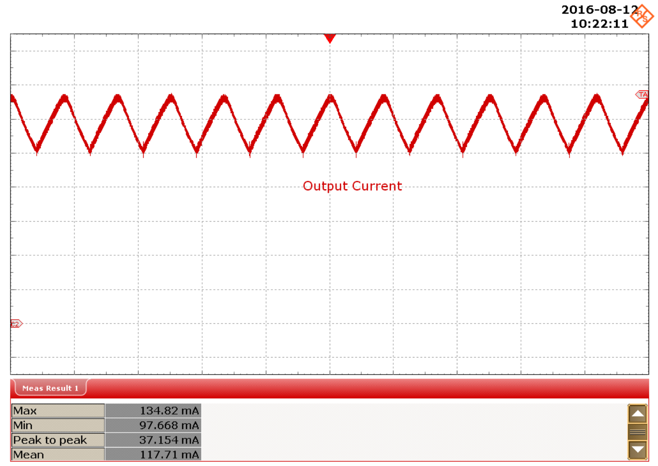

Figure 86 – 115 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

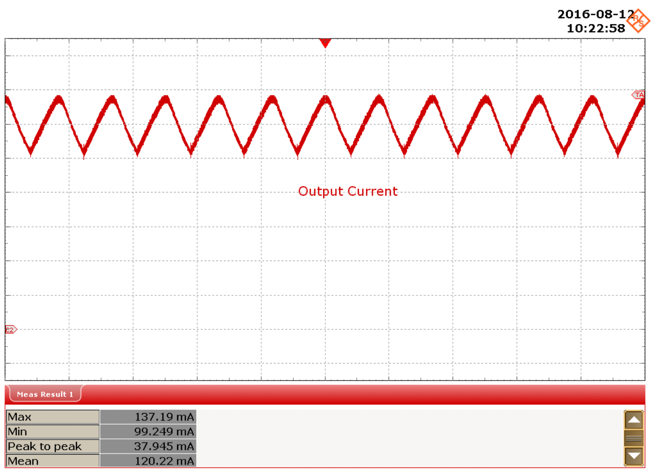

Figure 87 – 120 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

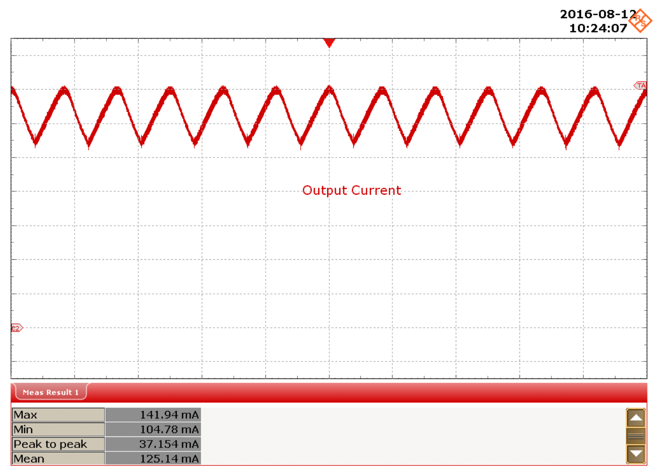

Figure 88 – 132 VAC, 50 Hz, 52 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}$+$I_{O(MIN)}$)
90	124.55	87.39	106.3	17.48
115	134.82	97.67	117.7	15.78
120	137.19	99.25	120.22	15.78
132	142	104.78	125	14.89

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12 AC Cycling Test at Non-Dimming

Output current recovers immediately after on/off cycling.

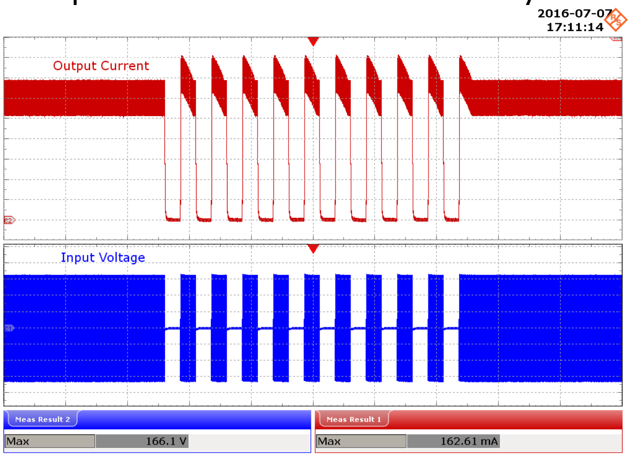

Figure 89 – 115 VAC, 52 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

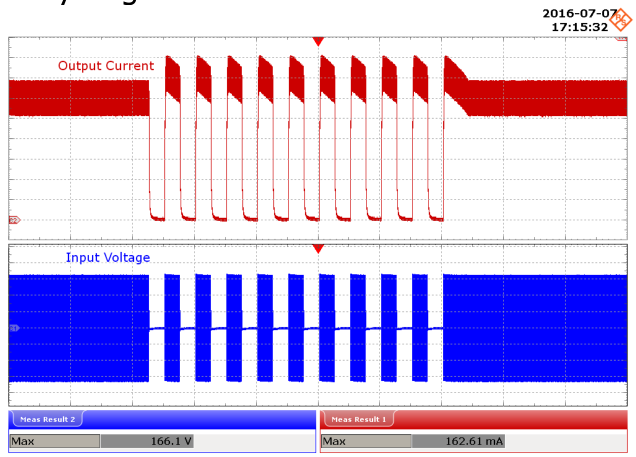

Figure 90 – 115 VAC, 52 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

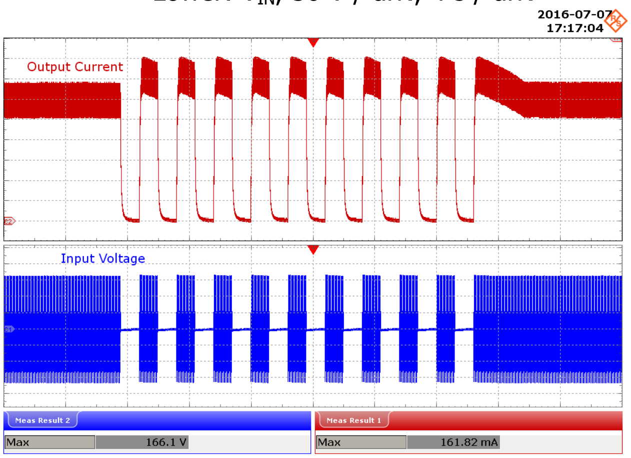

Figure 91 – 115 VAC, 52 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

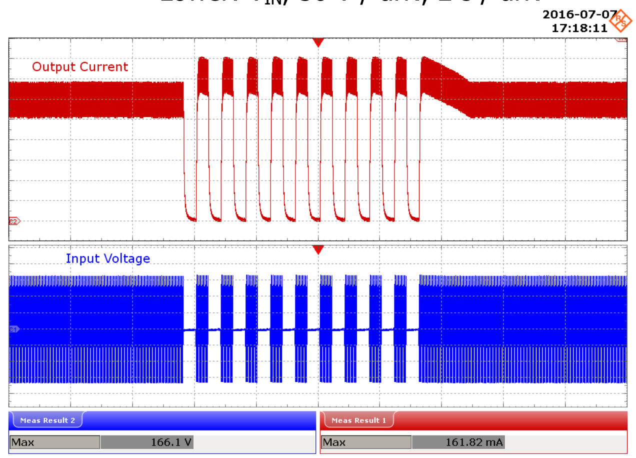

Figure 92 – 115 VAC, 52 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

13 Conducted EMI

13.1 Test Set-up

13.1.1 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. 52 V LED load with input voltage set at 115 VAC.

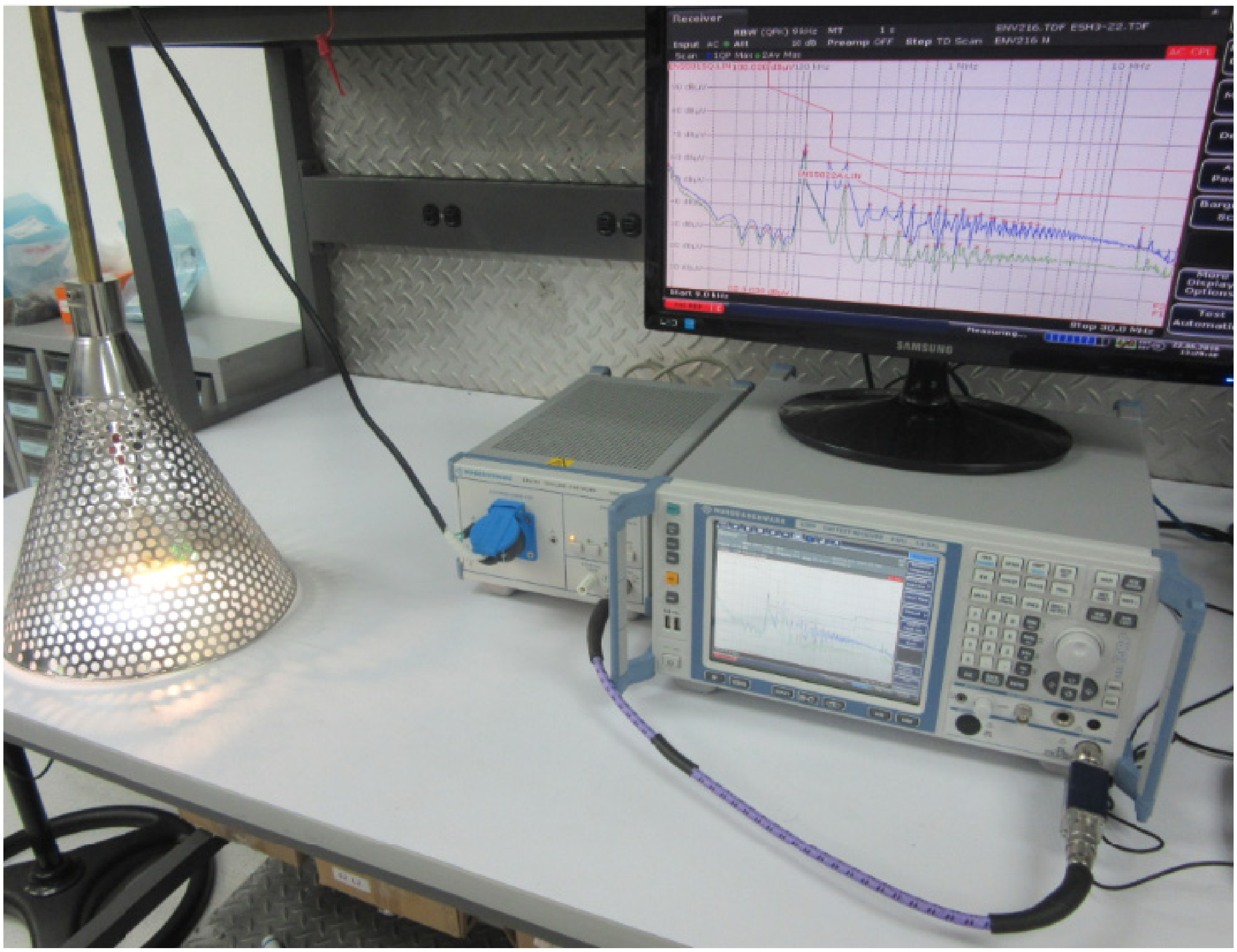

Figure 93 – Conducted EMI Test Set-up.

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13.2 EMI Test Result

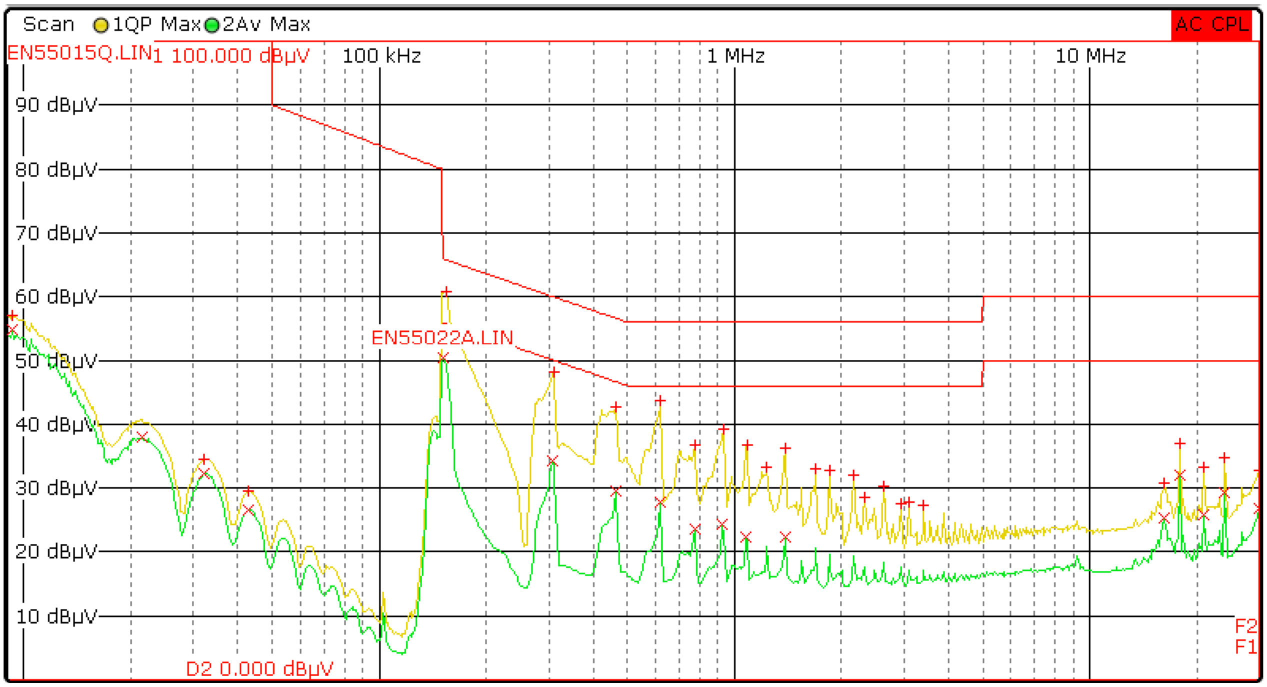

Figure 94 – Conducted EMI QP Scan at 52 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	154.5000 kHz	60.77 L1	-4.98 dB
2 Average	152.2500 kHz	50.31 L1	-5.57 dB
1 Quasi Peak	309.7500 kHz	48.17 L1	-11.81 dB
1 Quasi Peak	618.0000 kHz	43.62 L1	-12.38 dB
1 Quasi Peak	462.7500 kHz	42.78 L1	-13.86 dB
2 Average	307.5000 kHz	34.33 L1	-15.71 dB
1 Quasi Peak	928.5000 kHz	39.26 L1	-16.74 dB
2 Average	462.7500 kHz	29.47 L1	-17.17 dB
2 Average	17.9143 MHz	32.00 L1	-18.00 dB
2 Average	618.0000 kHz	27.90 L1	-18.10 dB
1 Quasi Peak	1.0838 MHz	36.83 L1	-19.17 dB
1 Quasi Peak	773.2500 kHz	36.71 L1	-19.29 dB
1 Quasi Peak	1.3920 MHz	36.33 L1	-19.67 dB
2 Average	23.8858 MHz	29.25 L1	-20.75 dB

Figure 95 – Conducted EMI Data at 115 VAC, 52 V LED Load.

14 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.

14.1 Differential Surge Test Results

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

14.2 Ring Wave Surge Test Results

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

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14.3 1 kV Differential Surge Test

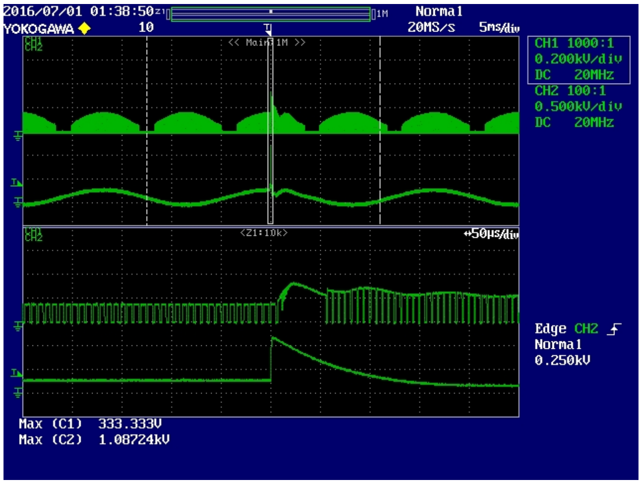

Figure 96 – (+)1 kV Differential Surge,
90º Phase Angle.
CH1: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 333.33 V.

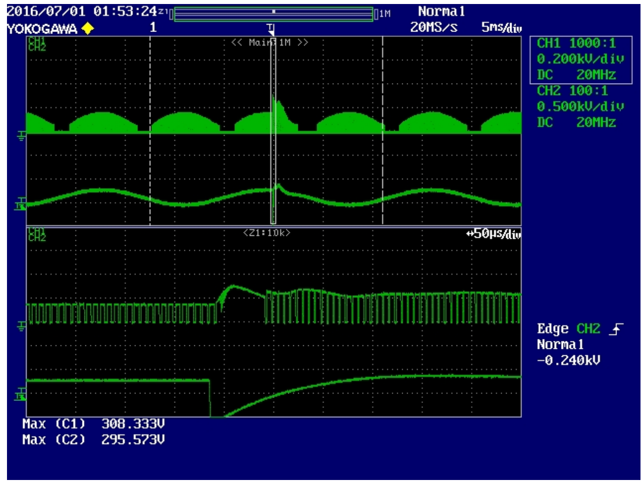

Figure 97 – (-1) kV Ring Wave Surge,
90º Phase Angle.
CH1: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 308.33 V.

14.4 2.5 kV Ring Wave Surge Test

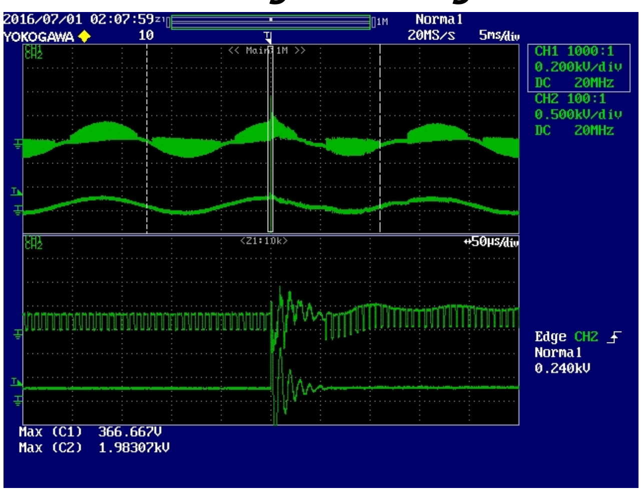

Figure 98 – (+) 2.5 kV Ring Wave Surge,
90º Phase Angle.
CH1: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}: 366.67 V.

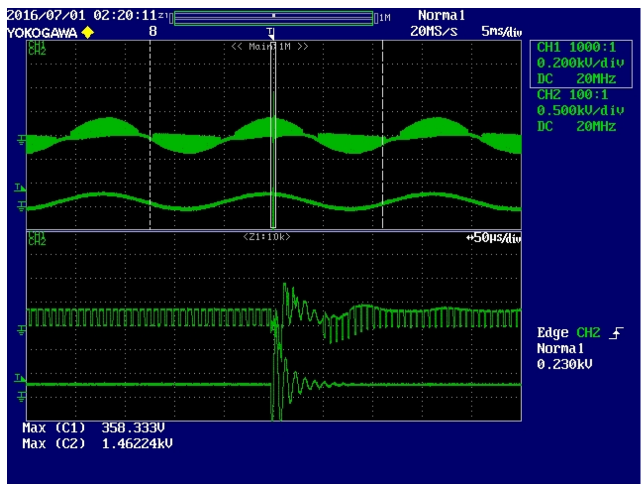

Figure 99 – (-) 2.5 kV Ring Wave Surge,
90º Phase Angle.
CH1: V_{DRAIN}, 100 V / div., 5 ms / div.
Peak V_{DRAIN}:358.33 V.

15 Brown-in / Brown-out Test

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

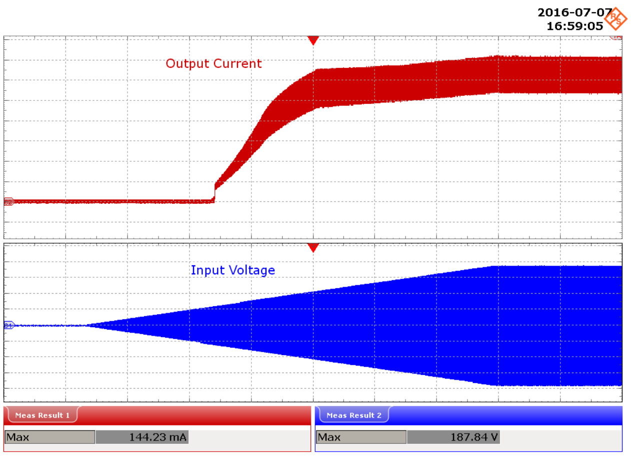

Figure 100 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

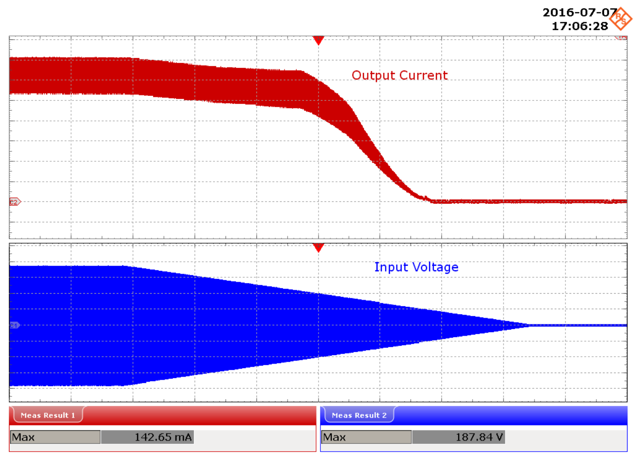

Figure 101 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

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16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
19-Jul-16	AM	1.0	Initial Release.	Apps & Mktg
06-Apr-17	AM	1.1	Updated sections 4.3, 7.1-7.4, 8.1, 9.1-9.3, 11.12-11.13 and changed to 6.5 W.	

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