Design Example Report

Title	***6.5 W, Low-Line Input, Non-dimmable, Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1603D***
Specification	90 VAC – 132 VAC Input; 52 V_{TYP}, 125 mA_{TYP} Output
Application	A19 LED Bulb
Author	Applications Engineering Department
Document Number	DER-553
Date	November 8, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <30% flicker requirement
- Highly energy efficient, 90% at 90 V to 132 V
- Low cost and low component count for compact PCB solution
- Uses standard "off the shelf" drum choke
- Integrated protection features
    - No-load output protection
    - Output short-circuit protection
    - Overcurrent protection
    - Thermal fold-back protection
    - Over temperature protection
    - 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

The engineering report is about a low cost, non-dimmable and non-isolated buck LED driver which is designed to drive a 52 V LED load at 125 mA output current from low line input voltage range of 90 VAC to 132 VAC. The LYT1603D from the LYTSwitch-1 family is utilized by this LED driver.

LYTSwitch-1 ICs are a family of low cost single-stage PFC ICs with integrated SO-8 package LED driver controllers. This IC is designed for non-isolated buck topology applications. LYTSwitch-1 ICs supply high efficiency, low power factor and accurate LED output current regulation. LYTSwitch-1 ICs have an integrated high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode control engine for accurate current regulation, high power factor and better power MOSFET utilization. The IC also has integrated protection features such as accurate output overvoltage protection (OVP), thermal fold-back using junction thermal sensing, low input power output short-circuit protection and overcurrent protection (OCP).

DER-553 offers an efficient and low cost compact size solution for mostly for 6.5 W LED driver applications. High efficiency, accurate constant current regulation and low components count were the target design goals.

This document is composed of the power supply specification, schematic, bill of materials (BOM), printed circuit layout, design spreadsheet, and performance data.

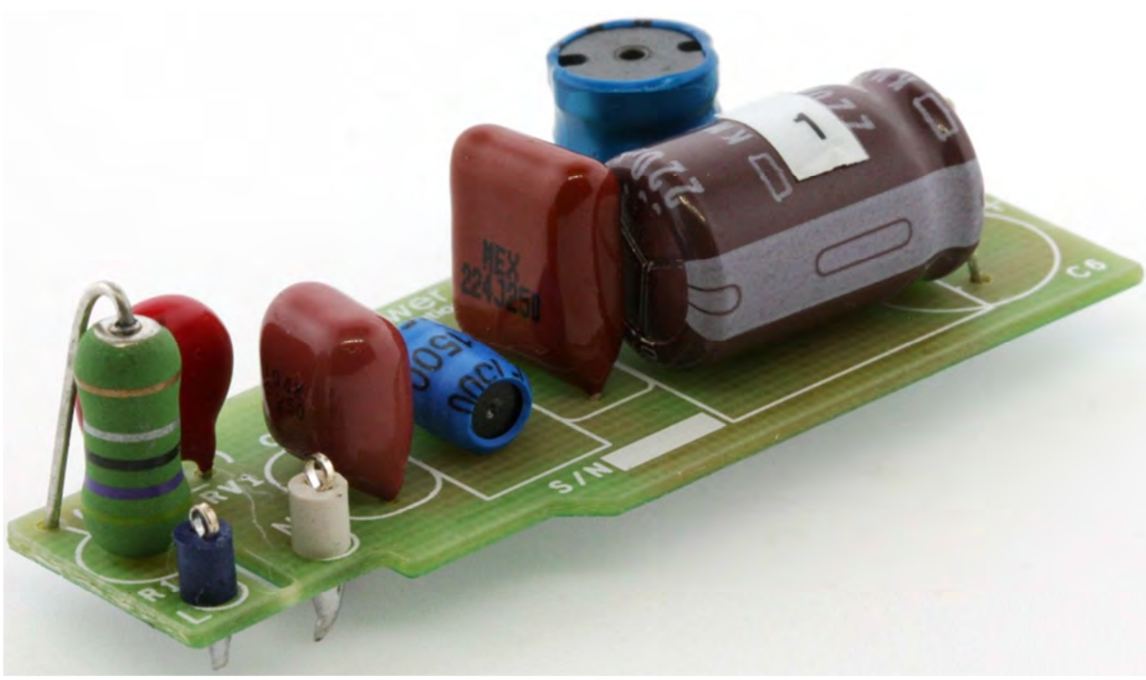

Figure 1 – Populated Circuit Board.

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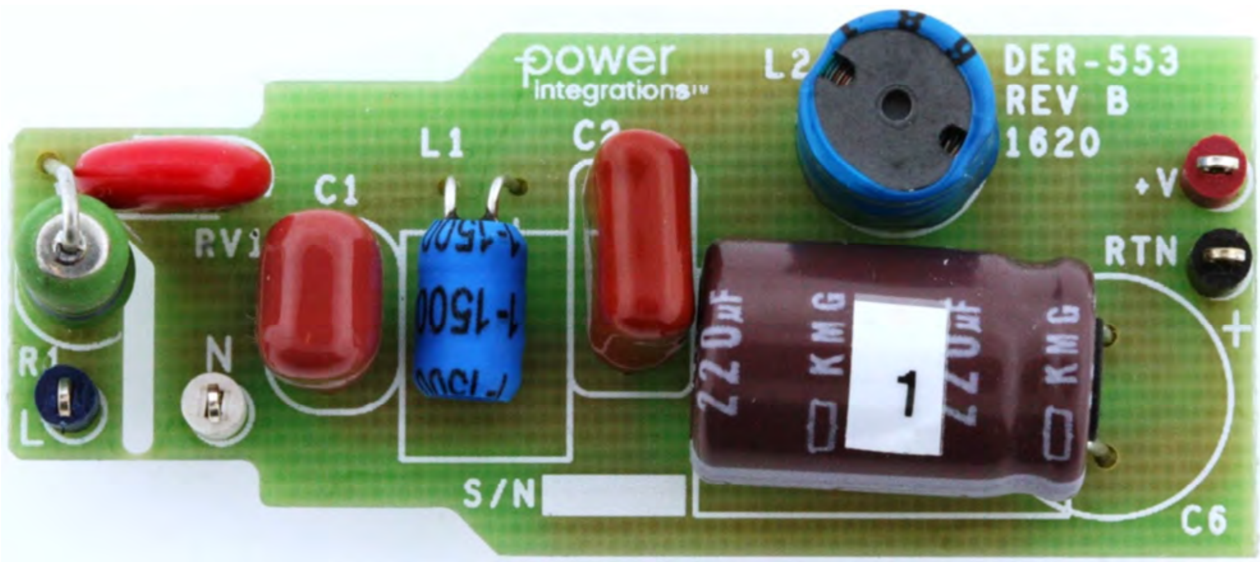

Figure 2 – Populated Circuit Board, Top View.

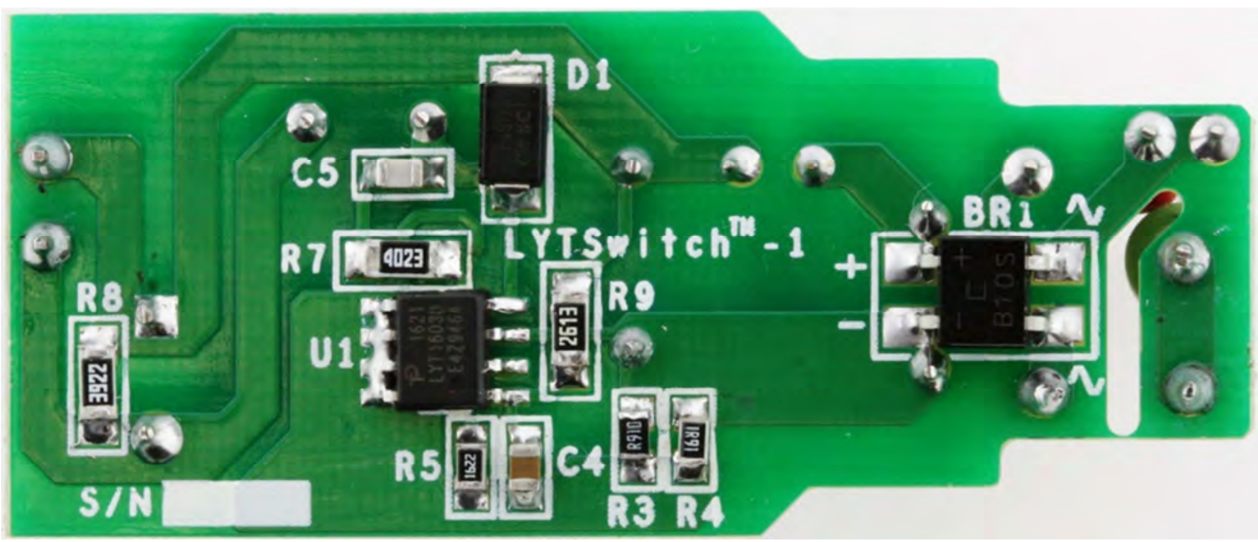

Figure 3 – Populated Circuit Board, Bottom View.

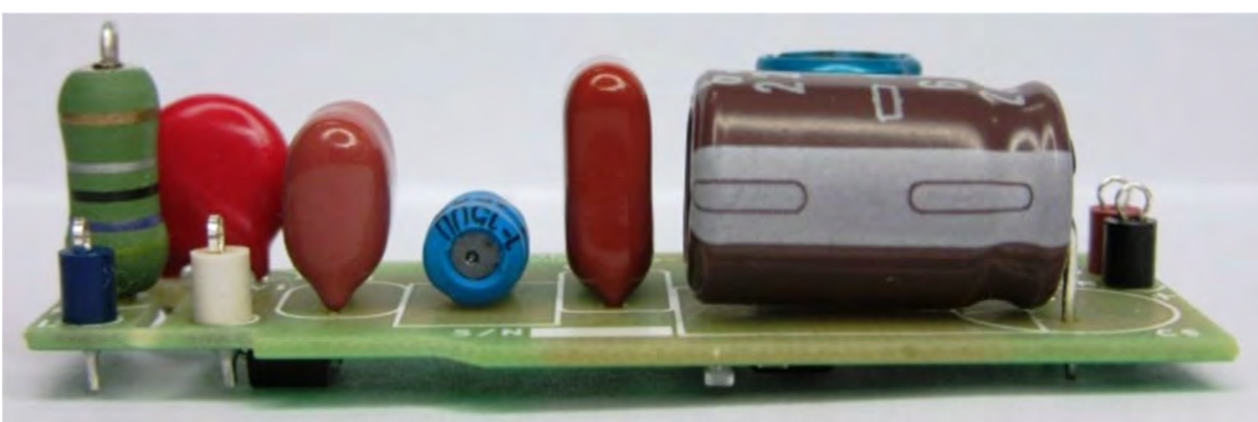

Figure 4 – Populated Circuit Board, Side View.

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		90		%	90 - 132 V / 60 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 90 - 115 VAC / 60 Hz.
Ambient Temperature	T_{AMB}			70	°C	Free Convection, Sea Level.

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3 Schematic

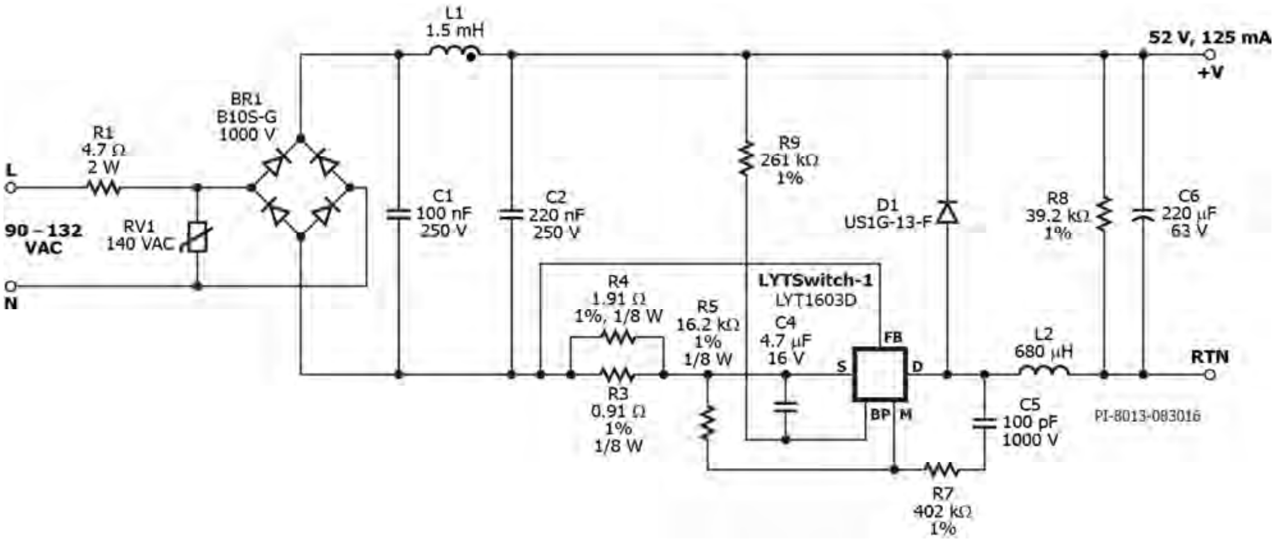

Figure 5 – Schematic.

4 Circuit Description

The LYTSwitch-1 IC (LYT1603D-U1) has an integrated high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. LYT1603D is designed to drive a 6.5 W, 52 V, 125 mA non-isolated and non-dimmable buck LED driver. LYT1603D IC was selected from the device options table according on the maximum output power of 8 W for low line and the output voltage range of 45 V to 65 V.

4.1 *Input Stage*

The input fusible resistor R1 serves as a safety protection from input component failures. Varistor RV1 (140 V rated slightly above 132 V) acts as a voltage clamp which limits the voltage spikes on the primary at the events of line transient surge. The full wave bridge rectifier BR1 provides good power factor and low total harmonic distortion.

4.2 *EMI Filter*

After the rectified AC input voltage an EMI π filter circuit is cascaded. The circuit is composed of a drum choke inductor L1 and input filter capacitors C1 and C2. Drum choke inductor for the EMI inductor L1 is used for its low cost. The EMI filter, together with the LYTSwitch-1 variable frequency / variable on-time and critical conduction mode control engine ensures compliance with the EN55015 Class B emission limit.

Note that the orientation of the EMI inductor L1 affects the EMI performance. The phase dot of inductor L1 on the schematic diagram indicates the starting point of where the drum choke was winded while the non-dotted side of the inductor is where the winding has finished. Based on the EMI tests done for DER-553, this orientation on the schematic has the best performance (the phase dot part of the inductor is connected to the 2nd input filter capacitor C2).

Also L1 and L2 should have an enough distance with each other in layout consideration to avoid any magnetic field interference produced by each inductor. There will be a significant external field that can cause adverse coupling. Another solution to minimize the effect of coupling is to align the inductor's axes at a right angle orientation. Based on the EMI tests done for DER-553, axially mounting L1 gave a better EMI performance.

4.3 *LYTSwitch-1 Control Circuit*

The LED driver circuit topology is a low side buck where both the power MOSFET of U1 and the drum choke inductor L2 are connected at the ground rail. A drum choke inductor for L2 was used for its low cost. During on time, the Drain current flows through the drum choke inductor L2, storing energy in the form of magnetic field which is then delivered to the output load via flywheel diode D1 during the power MOSFET off-time.

The output capacitor C6 is used as a filter to minimize the output current ripple. At power off the pre-load resistor R8 fully discharges the output capacitor.

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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 ~5.25 V. The value of capacitor should be large enough to keep BP pin voltage above reset value $V_{BP(RESET)}$ ~4.6 V, when controller is switching at maximum frequency or $T_{ON(MAX)}$ conditions. An additional pull-up resistor R9 helps maintains the BP pin voltage above the $V_{BP(RESET)}$ ~4.6 V threshold during on/off power cycling at low line input voltage (90 V).

Constant output current regulation is achieved through inductor force peak current limit and the device constant ratio (0.75). The FEEDBACK (FB) pin directly senses the drain or inductor current when the power MOSFET is on using external current sense resistors R3 and R4. This is to set a constant inductor peak current I_{PK} by comparing the sensed voltage with the reference current limit threshold ($V_{FBth} \geq 0.28$ V, $I_{PK} = 0.28$ V / R_{SENSE}). Output LED current is computed as $I_{LED} = I_{PK} / 4.666$ for the LYT1603D device.

When the power MOSFET is on, the MULTIFUNCTION (M) pin provides line OVP detection. The M pin is shorted internally to SOURCE (S) pin to detect line OVP based on voltage across the inductor (V_{IN}-V_{OUT}) and current flowing out of the M pin defined resistor R5, $I_M = (V_{IN}-V_{OUT}) / R7$. The M pin line OVP current threshold is $I_{MOVL} = 1$ mA_{TYP}.

When the power MOSFET is at off-state, the M pin provides zero current detection (ZCD) and output OVP detection through decoupling capacitor C5 and sampling resistors R5 and R7. The ZCD is to guarantee critical conduction mode operation which means that the power MOSFET must be turned on immediately once inductor has been demagnetized. The inductor demagnetization is sensed when the voltage across the inductor begins to collapse towards zero as flywheel diode (D1) conduction expires. The ZCD threshold is when M pin voltage is V_M <0.25 V (negative edge triggered). The OVP detection is achieved through R5 and R7 voltage divider network. The OVP threshold is set at 120% of steady state value (2.0 V). Resistor R7 is set to fixed value of 402 kΩ ±1% to minimize power loss during power MOSFET on-time duration and ease of OVL detection for all output voltage designs.

In case of output short-circuit, pulse skipping mode is enabled when SOA event is triggered. If output short-circuit persists for more than 2 SOA events then 100 ms auto-restart delay is enabled before the next switching attempt. If SOA fault persists following two 100 ms auto-restart attempts then the delay is increased to 1 s.

5 PCB Layout

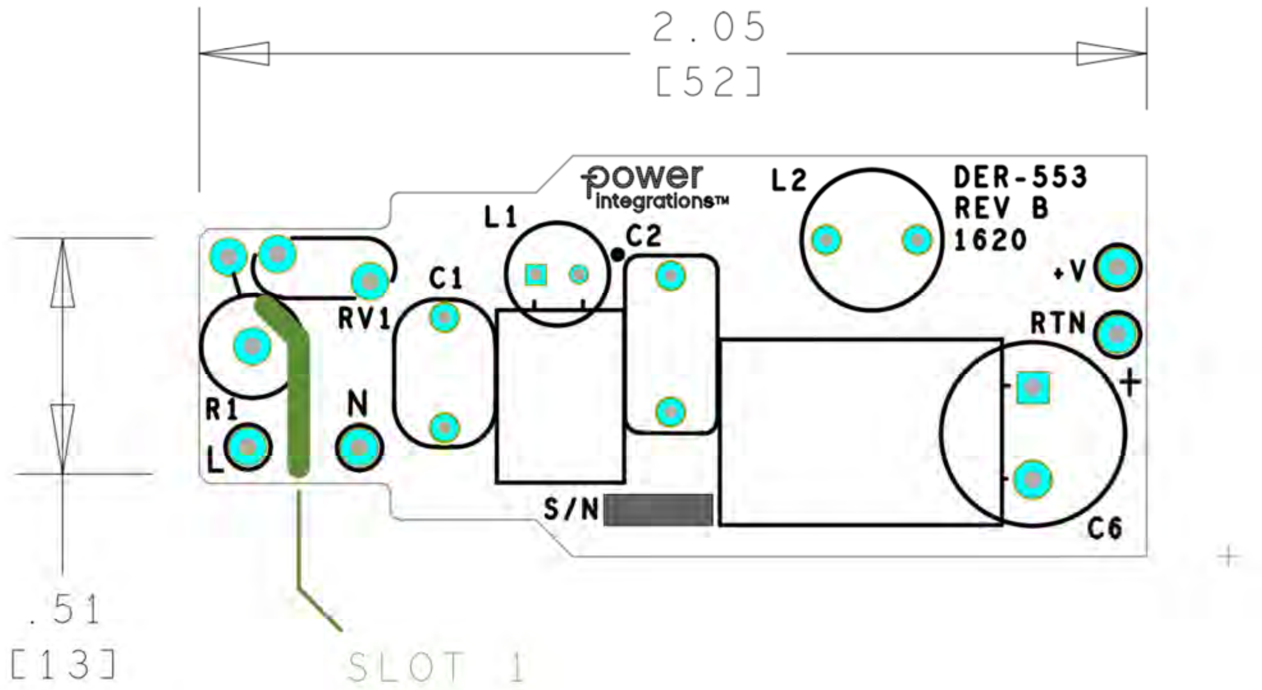

Figure 6 – Top Side

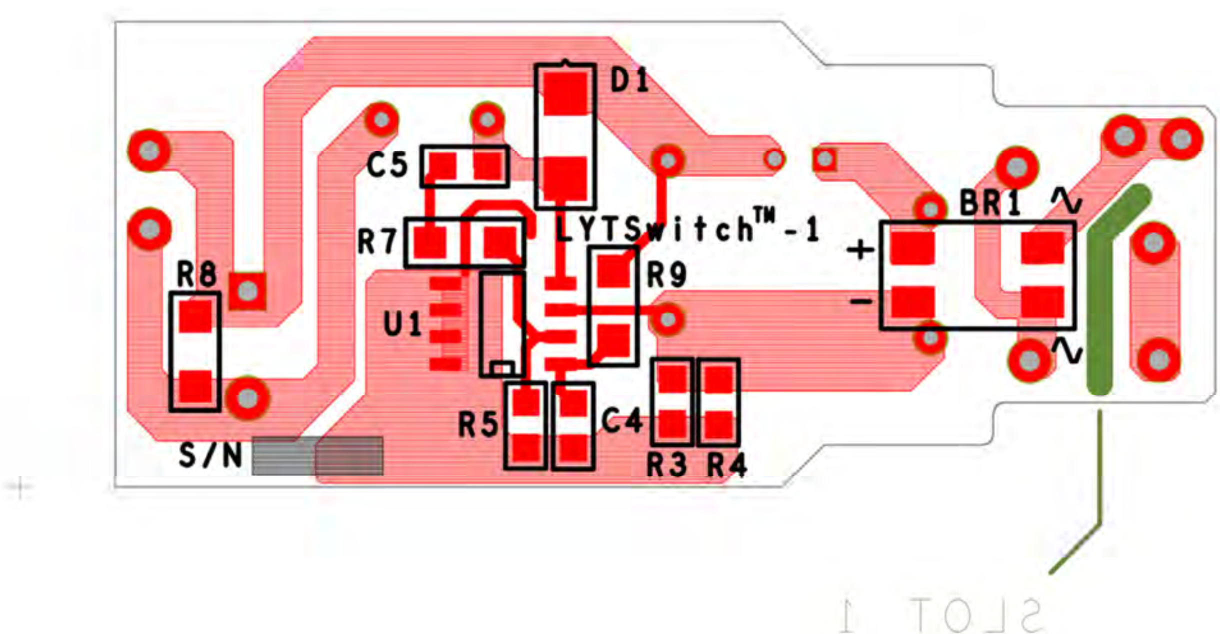

Figure 7 – Bottom Side.

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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	220 nF, 250V, 5%, Film	MEXID3220JJ	Duratech
5	1	C4	4.7 µF, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KA73L	Murata
6	1	C5	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
7	1	C6	220 µF, 63 V, Electrolytic, (10 x 16)	EKMG630ELL221MJ16S	United Chemi-con
8	1	D1	Diode Ultrafast, GPP, 400 V, 1 A SMA	US1G-13-F	Diodes, Inc
9	2	L RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
10	1	L1	1.5 mH, Mini-Drum, High Current	RL-5480HC-1-1500	Renco
11	1	L2	680 µH, 0.36 A	SBC3-681-361	Tokin
12	1	N	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
13	1	R1	RES, 4.7 Ω, 5%, 2 W, Wire wound, Fusible	FW20A4R70JA	Bourns
14	1	R3	RES, 0.91 Ω, 1%, 1/8 W, Thick Film, 0805	RL0805FR-070R91L	Yageo
15	1	R4	RES, 1.91 Ω, 1%, 1/8 W, Thick Film, 0805	RC0805FR-071R91L	Yageo
16	1	R5	RES, 16.2 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1622V	Panasonic
17	1	R7	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
18	1	R8	RES, 39.2 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3922V	Panasonic
19	1	R9	RES, 261 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2613V	Panasonic
20	1	RV1	140 VAC, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
21	1	U1	LYTSwitch-1, Wide Range, 8W, 45V-65V, SO-8	LYT1603D	Power Integrations

7 PIXls Design Spreadsheet

ACDC_LYTSwitch1_Buck _080516; Rev.1.1; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-1 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Low Line		AC line voltage range
VACMIN	90		90	V	Minimum AC line voltage
VACTYP	115		115	V	Typical AC line voltage
VACMAX	132		132	V	Maximum AC line voltage
FL	50		50	Hz	AC mains frequency
VO	52		52	V	Output Voltage
IO	125		125	mA	Average output current specification
EFFICIENCY			0.90		Efficiency estimate
PO			6.50	W	Continuous output power
VD	0.70		0.70	V	Output diode forward voltage drop
OPTIMIZATION PARAMETER	THD		THD		BOM selects IC with lowest peak current. THD selects IC for lowest THD.
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	V	This Spreadsheet supports 725V device only
DEVICE	LYT1x03D		LYT1603D		Actual LYTSwitch-1 device
ILIMITMIN			1.06	A	Minimum Current Limit
ILIMITTYP			1.15	A	Typical Current Limit
ILIMITMAX			1.24	A	Maximum Current Limit
TON			2	us	On-time during the fixed on-time region at VACTYP
FSW			116	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.69		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	Off the shelf		Off the shelf		Enter Transformer Core
CUSTOM CORE NAME	30-00025-00				If custom core is used - Enter part number here
AE			0.00	mm^2	Core effective cross cectional area
LE			0.00	mm	Core effective path length
AL			0.00	nH/turn^2	Core ungapped effective inductance
AW			0.00	mm^2	Window Area of the bobbin
BW			0.00	mm	Bobbin physical winding width
LAYERS			6.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN			292	uH	Absolute minimum design inductance
LP_TYP	680		680	uH	Typical design inductance
LP_TOLERANCE			10	%	Tolerance of the design inductance
LP_MAX			5340	uH	Absolue maximum design inductance
TURNS			NA	Turns	Number of inductor turns
ALG			NA	nH/turn^2	Inductance per turns squared
BMAX			NA	Gauss	
BAC			NA	Gauss	AC flux density in the fixed peak current region
LG			NA	mm	Core air gap
BWE			NA	mm	Effective bobbin width
OD			NA	mm	Outer diameter of the wire with insulation
INS			NA	mm	Wire insulation
DIA			NA	mm	Outer diameter of the wire without insulation
AWG			NA		AWG of the bare wire.
CM			NA	Cmils	Bare wire circular mils
CMA			NA	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			NA	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR			NA		Area of the bobbin occupied by wire

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CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.11	A	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.45	A	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.10	A	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.13	A	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.16	A	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.622	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.619	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Components					
BUCK_CONFIG	Low Side Buck				Buck Topology Switch Configuration
RUPPER	402.00		402.00	kOhms	Use 1% tolerance
RLOWER	16.20	Info	16.20	kOhms	!!Info. The Rlower value provided is higher than calculated. For low-side buck, this could falsely trigger OVP at high input voltage and wide LED tolerance.Please verify on the bench.
VO_OVP			61.3	V	VO overvoltage threshold
Line_OVP			454	V	Line overvoltage threshold
CC			100	pF	Coupling Capacitor for Low Side Buck Configuration
RPRELOAD			52	kOhms	Minimum Output Preload Resistor
CBP			4.7	uF	BP Capacitor
VOLTAGE STRESS PARAMETERS					
VDRAIN			187	V	Estimated worst case drain voltage
PIVD			187	V	Output Rectifier Maximum Peak Inverse Voltage

8 Performance Data

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

8.1 *Efficiency*

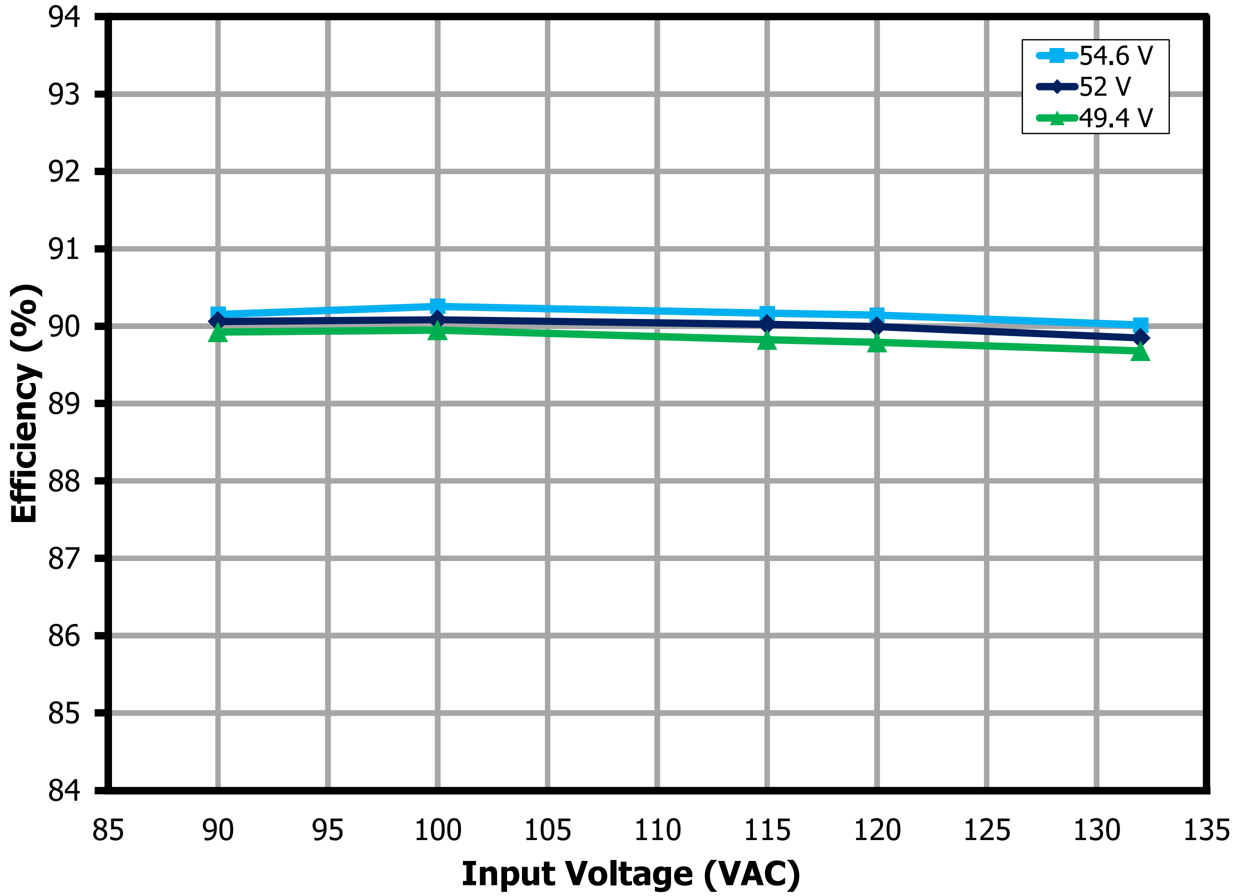

Figure 8 – Efficiency vs. Load-Line.

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8.2 *Line Regulation*

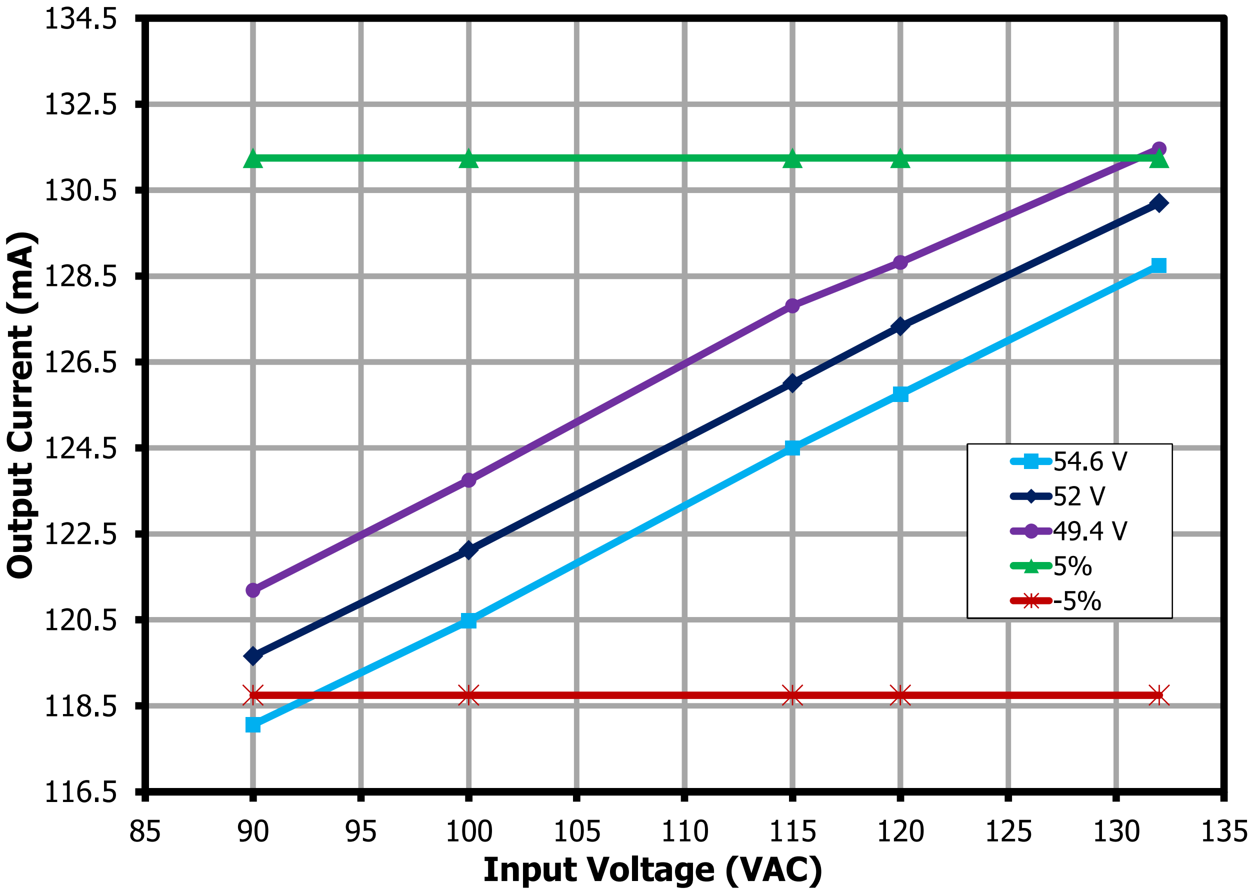

Figure 9 – Regulation vs. Load-Line.

8.3 *Power Factor*

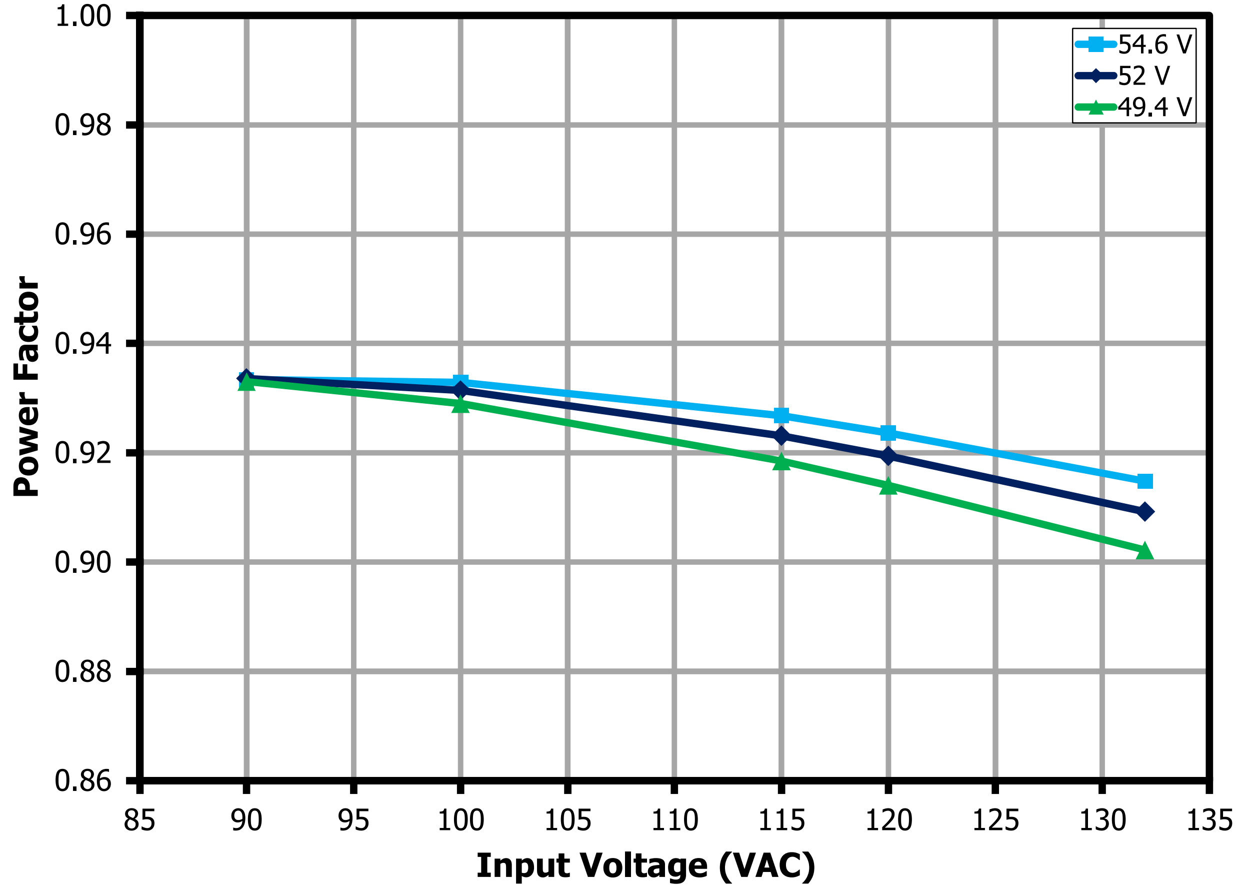

Figure 10 – Power Factor vs. Load-Line.

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8.4 *%ATHD*

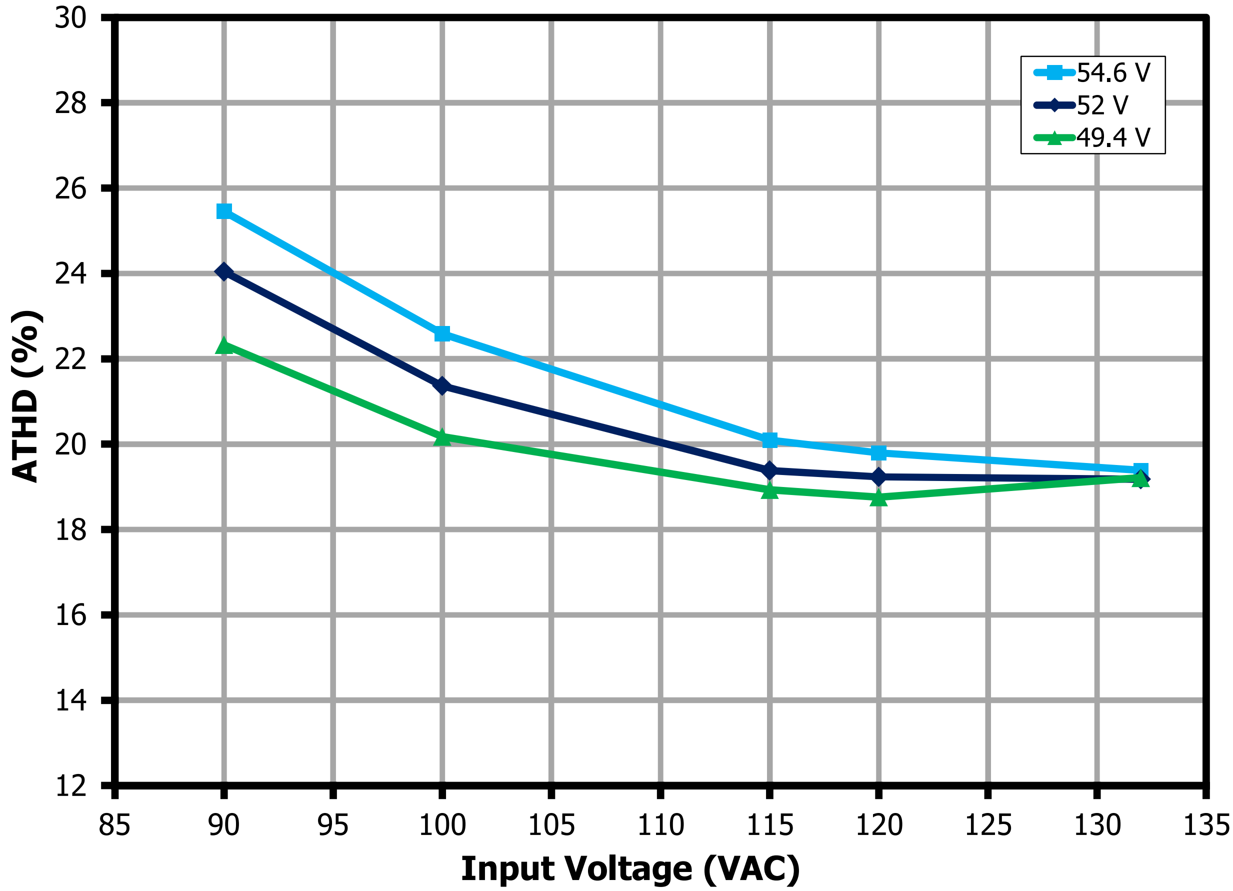

Figure 11 – %ATHD vs. Load-Line.

8.5 *Individual Harmonics Content*

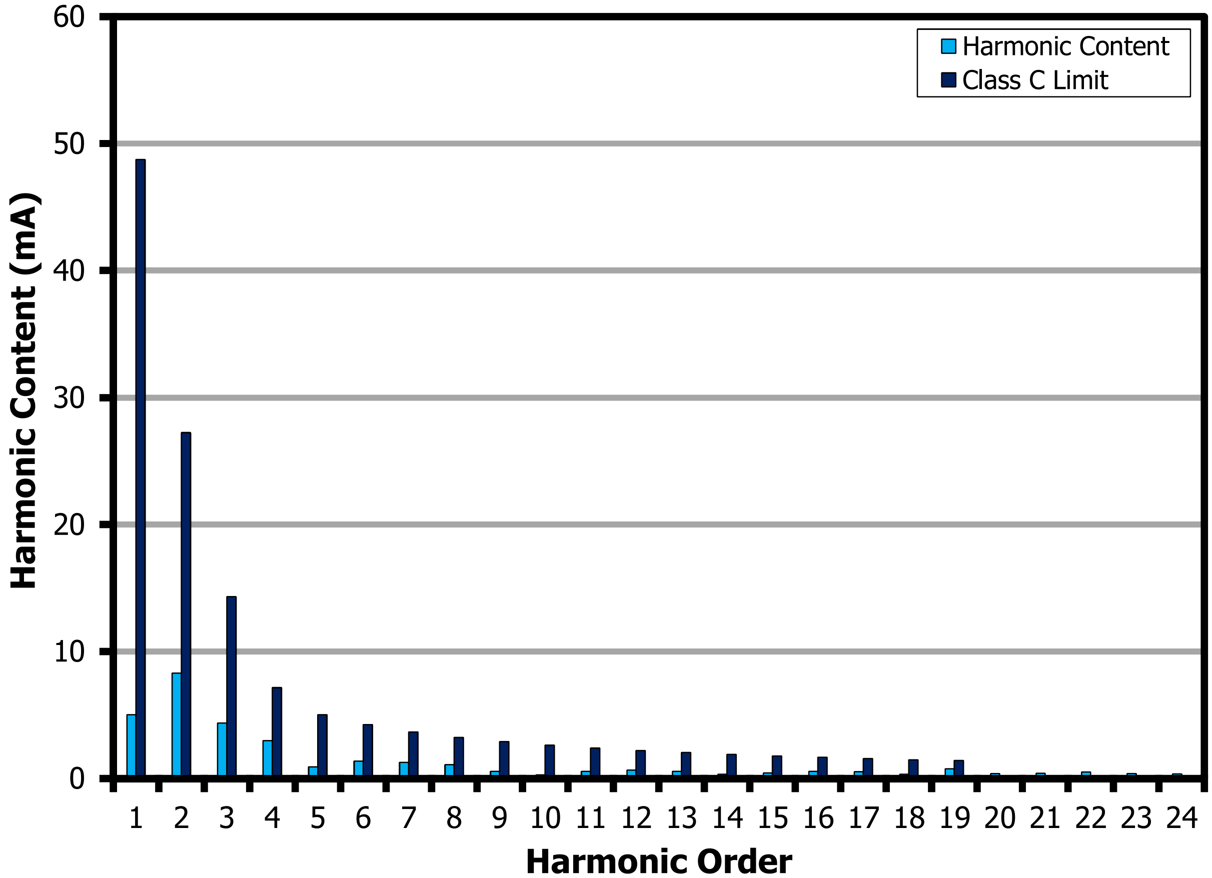

Figure 12 – 52 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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9 Test Data

9.1 *Test Data, 49.4 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	89.89	79.36	6.66	0.933	22.33	49.38	121.19	5.99	89.92
100	60	99.91	73.55	6.83	0.929	20.18	49.58	123.75	6.14	89.95
115	60	114.90	67.25	7.10	0.919	18.93	49.90	127.81	6.38	89.83
120	60	119.95	65.44	7.17	0.914	18.76	49.99	128.82	6.44	89.79
132	60	131.94	61.82	7.36	0.902	19.21	50.19	131.46	6.60	89.68

9.2 *Test Data, Harmonic Content at 115 VAC, 49.4 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60.00	65.44	7.1740	0.9140
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	60.3			
2	0.08	0.22%		
3	5.02	8.20%	48.729	Pass
5	8.31	13.96%	27.231	Pass
7	4.37	7.37%	14.332	Pass
9	2.99	4.72%	7.166	Pass
11	0.92	1.47%	5.0162	Pass
13	1.38	2.34%	4.2445	Pass
15	1.27	2.14%	3.6785	Pass
17	1.11	1.82%	3.2458	Pass
19	0.57	0.61%	2.9041	Pass
21	0.28	0.46%	2.6275	Pass
23	0.58	0.88%	2.3991	Pass
25	0.66	1.03%	2.2071	Pass
27	0.56	0.89%	2.0436	Pass
29	0.35	0.43%	1.9027	Pass
31	0.43	0.63%	1.7799	Pass
33	0.57	0.86%	1.6721	Pass
35	0.55	0.68%	1.5765	Pass
37	0.35	0.40%	1.4913	Pass
39	0.77	0.89%	1.4148	Pass

9.3 *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	89.87	82.35	6.91	0.934	24.04	51.99	119.66	6.22	90.06
100	60	99.90	76.07	7.08	0.931	21.37	52.20	122.12	6.38	90.08
115	60	114.89	69.38	7.36	0.923	19.38	52.52	126.01	6.62	90.02
120	60	119.94	67.56	7.45	0.919	19.24	52.63	127.33	6.70	89.99
132	60	131.92	63.88	7.66	0.909	19.18	52.87	130.20	6.89	89.85

9.4 *Test Data, Harmonic Content at 115 VAC, 52 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60.00	67.56	7.4490	0.9194
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	62.72			
2	0.05	0.06%		
3	5.06	8.07%	50.6464	Pass
5	9.48	15.04%	28.3024	Pass
7	4.35	6.98%	14.896	Pass
9	2.53	4.21%	7.448	Pass
11	0.84	1.26%	5.2136	Pass
13	1.71	2.84%	4.4115077	Pass
15	1.32	2.06%	3.8233067	Pass
17	0.91	1.37%	3.3735059	Pass
19	0.3	0.40%	3.0184	Pass
21	0.43	0.64%	2.7309333	Pass
23	0.6	0.91%	2.4934609	Pass
25	0.65	0.91%	2.293984	Pass
27	0.51	0.64%	2.1240593	Pass
29	0.2	0.30%	1.9775724	Pass
31	0.54	0.64%	1.8499871	Pass
33	0.74	0.72%	1.7378667	Pass
35	0.52	0.65%	1.63856	Pass
37	0.5	0.78%	1.5499892	Pass
39	0.48	1.02%	1.4705026	Pass

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9.5 *Test Data, 54.6 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	89.85	85.22	7.15	0.933	25.45	54.58	118.06	6.45	90.15
100	60	99.88	78.53	7.32	0.933	22.59	54.79	120.48	6.60	90.26
115	60	114.87	71.55	7.62	0.927	20.093	55.15	124.50	6.87	90.17
120	60	119.93	69.61	7.71	0.924	19.80	55.26	125.75	6.95	90.14
132	60	131.91	65.82	7.94	0.915	19.38	55.52	128.75	7.15	90.01

9.6 *Test Data, Harmonic Content at 115 VAC, 54.6 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60.00	69.61	7.7110	0.9236
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	64.83			
2	0.02	0.00%		
3	5.31	0.08%	52.428	Pass
5	10.4	0.16%	29.298	Pass
7	4.26	0.07%	15.42	Pass
9	2.07	0.03%	7.71	Pass
11	1.09	0.02%	5.397	Pass
13	1.97	0.03%	4.5666923	Pass
15	1.27	0.02%	3.9578	Pass
17	0.76	0.01%	3.4921765	Pass
19	0.23	0.00%	3.1245789	Pass
21	0.57	0.01%	2.827	Pass
23	0.73	0.01%	2.5811739	Pass
25	0.62	0.01%	2.37468	Pass
27	0.35	0.00%	2.1987778	Pass
29	0.44	0.01%	2.0471379	Pass
31	0.7	0.01%	1.9150645	Pass
33	0.58	0.01%	1.799	Pass
35	0.38	0.00%	1.6962	Pass
37	0.66	0.01%	1.6045135	Pass
39	0.43	0.01%	1.5222308	Pass

10 Thermal Performance

10.1 Thermal Performance Scan

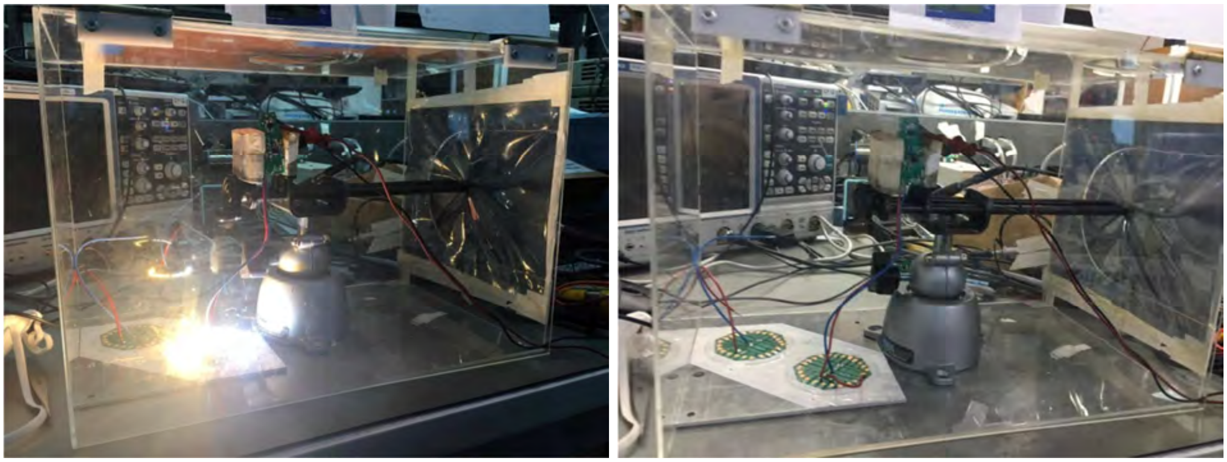

Figure 13 – Test Set-up.

Unit was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR thermal camera. The ambient temperature is 25 ºC.

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10.1.1 Thermal Scan at Normal Operation 115 V, 52 V LED Load

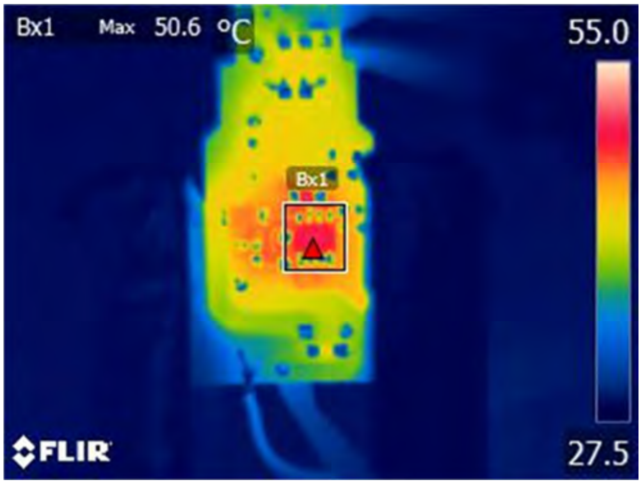

Figure 14 – 115 VAC, 52 V LED Load.
Spot 1: LYT1603D (U1): 50.6 ºC.

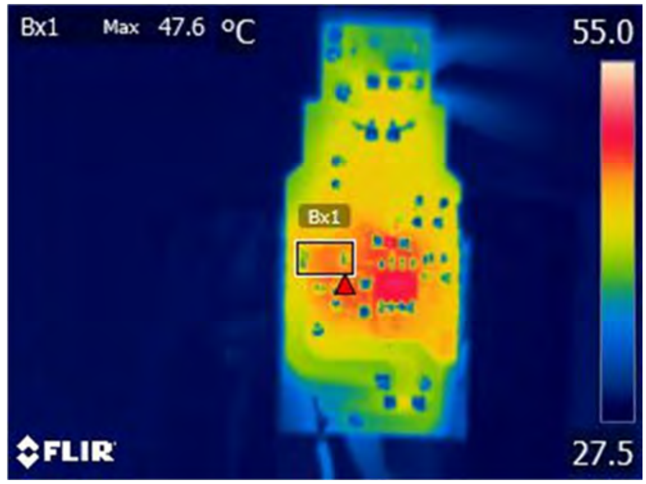

Figure 15 – 115 VAC, 52 V LED Load.
Spot 1: Flywheel Diode (D1): 47.6 ºC.

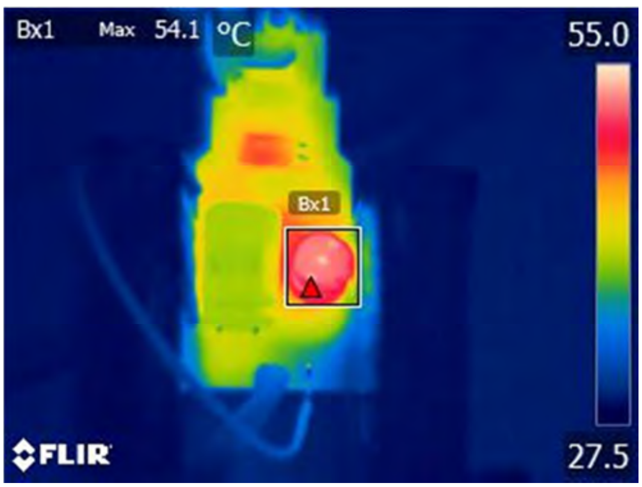

Figure 16 – 115 VAC, 52 V LED Load.
Spot 1: Drum Choke (L2): 54.1 ºC.

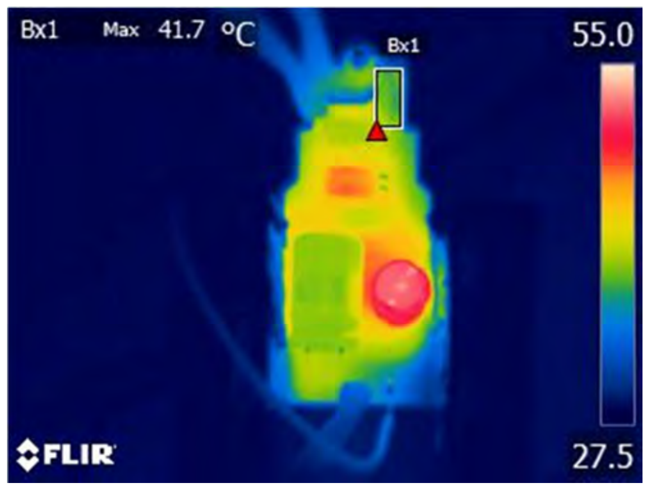

Figure 17 – 115 VAC, 52 V LED Load.
Spot 1: Varistor (RV1): 41.7 ºC.

10.1.2 Thermal Scan during Output Short-Circuit at 115 VAC Input

Figure 18 – 115 VAC, Output Short.
Spot 1: LYT1603D (U1): 39.3 ºC.

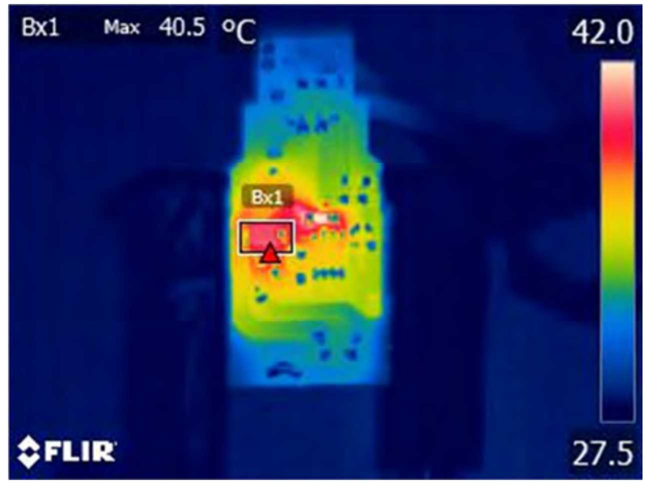

Figure 19 – 115 VAC, Output Short.
Spot 1: Flywheel Diode (D1): 40.5 ºC.

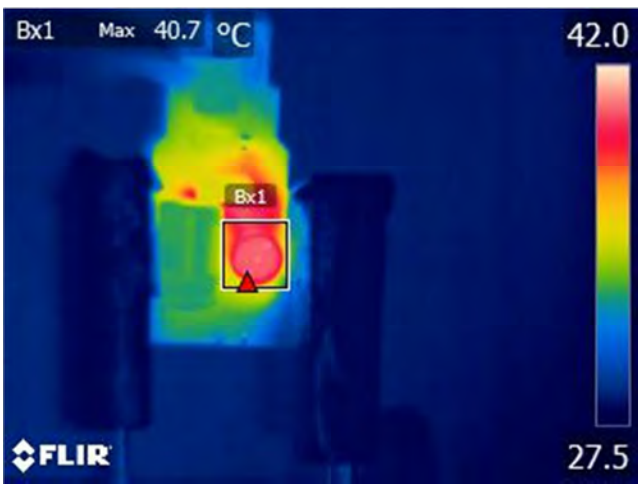

Figure 20 – 115 VAC, Output Short.
Spot 1: Drum Choke (L2): 40.7 ºC.

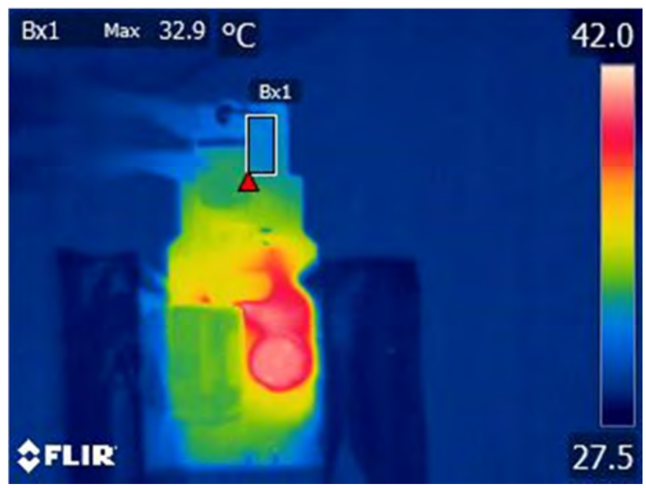

Figure 21 – 115 VAC, Output Short.
Spot 1: Varistor (RV1): 32.9 ºC.

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10.2 *Thermal Performance at 70 ºC Ambient*

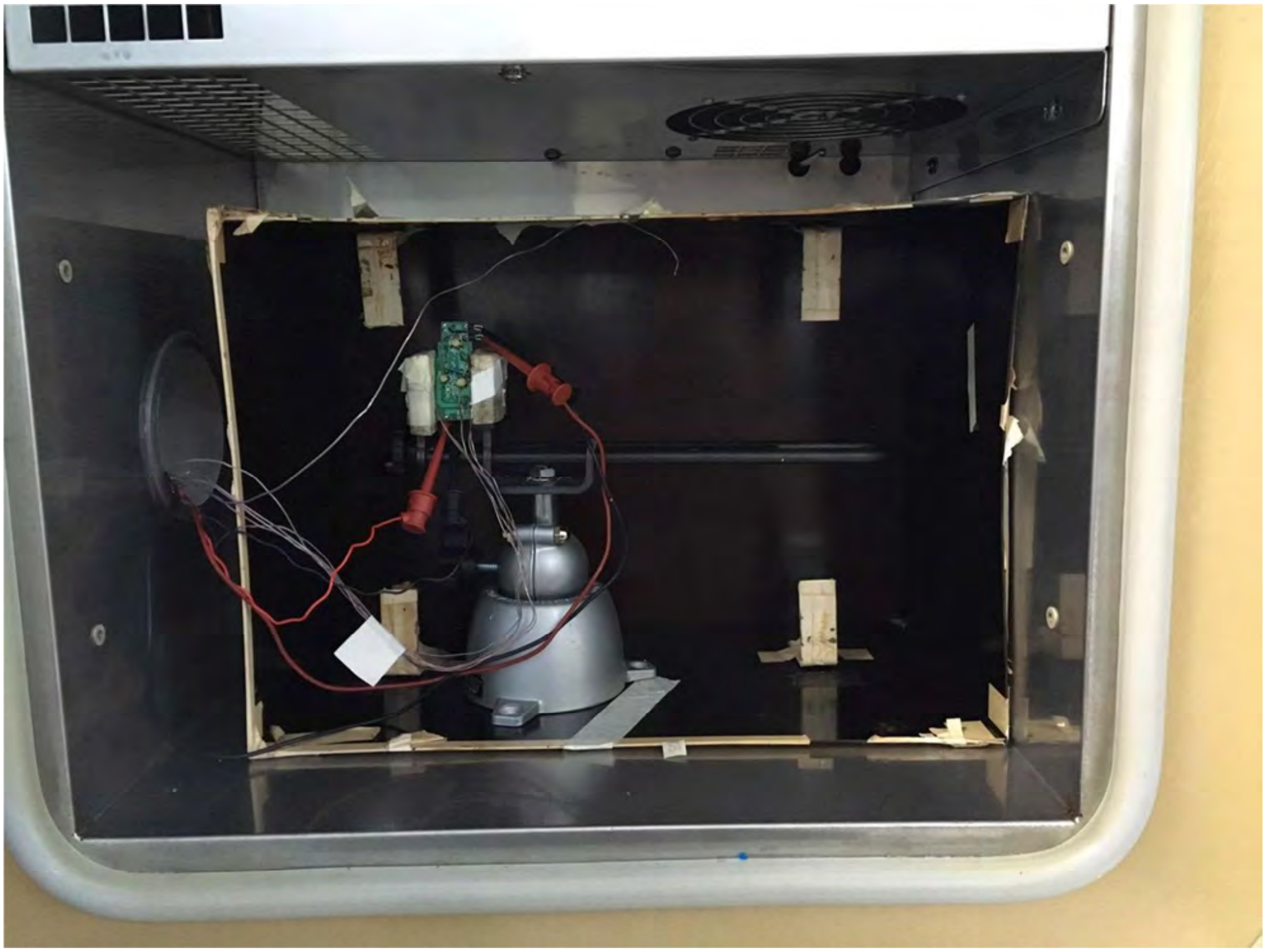

Figure 22 – Test Set-up Picture Thermal at 70 ºC Ambient - Open Frame.

Unit in open frame was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 70 ºC. Temperature was measured using type T thermocouple.

10.2.1 Thermal Performance at 90 VAC, 52 V LED Load

Measurement	Ambient	LYTSwitch-1	D1	L2	BR1	RV1
Maximum (ºC)	71.6	83.6	80.3	83	79.9	75.8
Final (ºC)	71.4	83.5	80.3	83	79.8	75.7

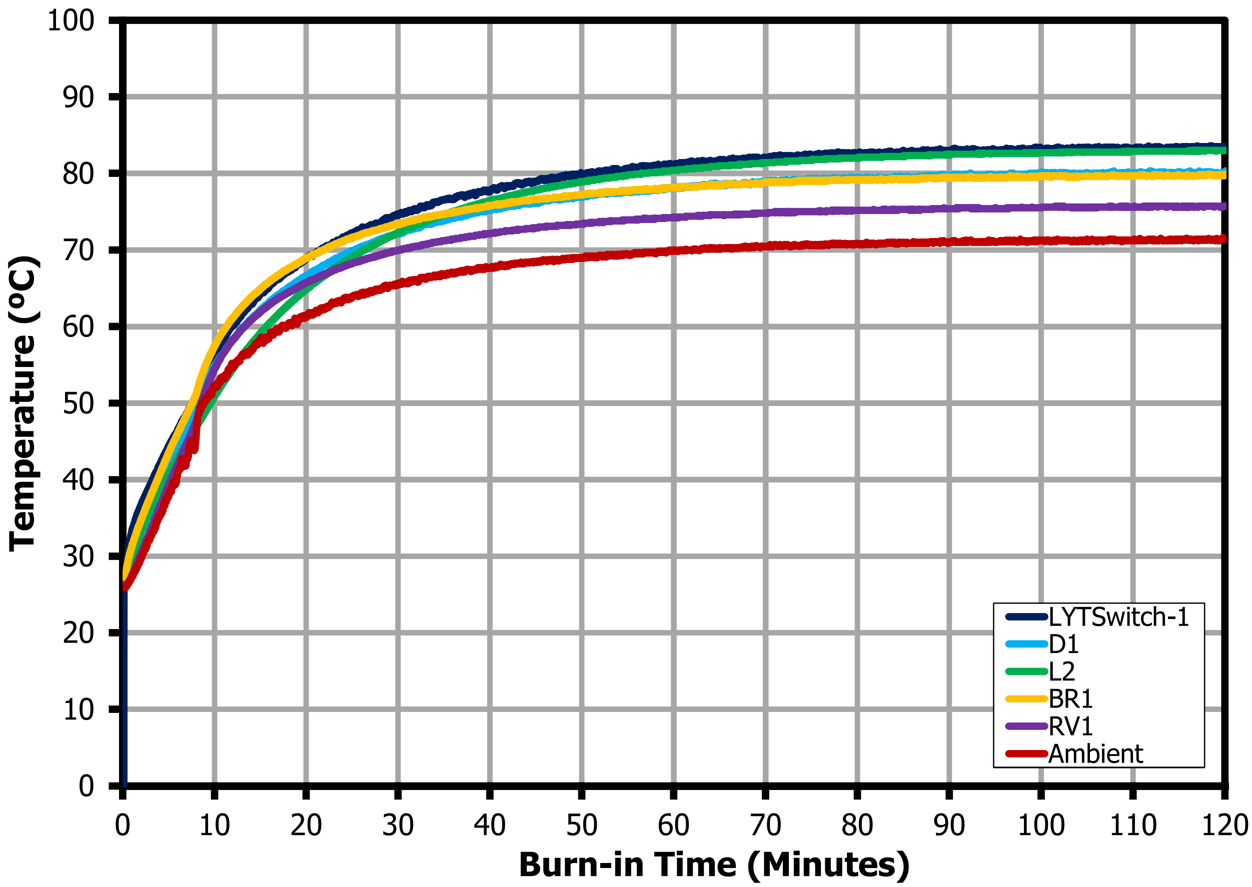

Figure 23 – Component Temperature at 90 VAC, 52 V LED Load, 70 ºC Ambient.

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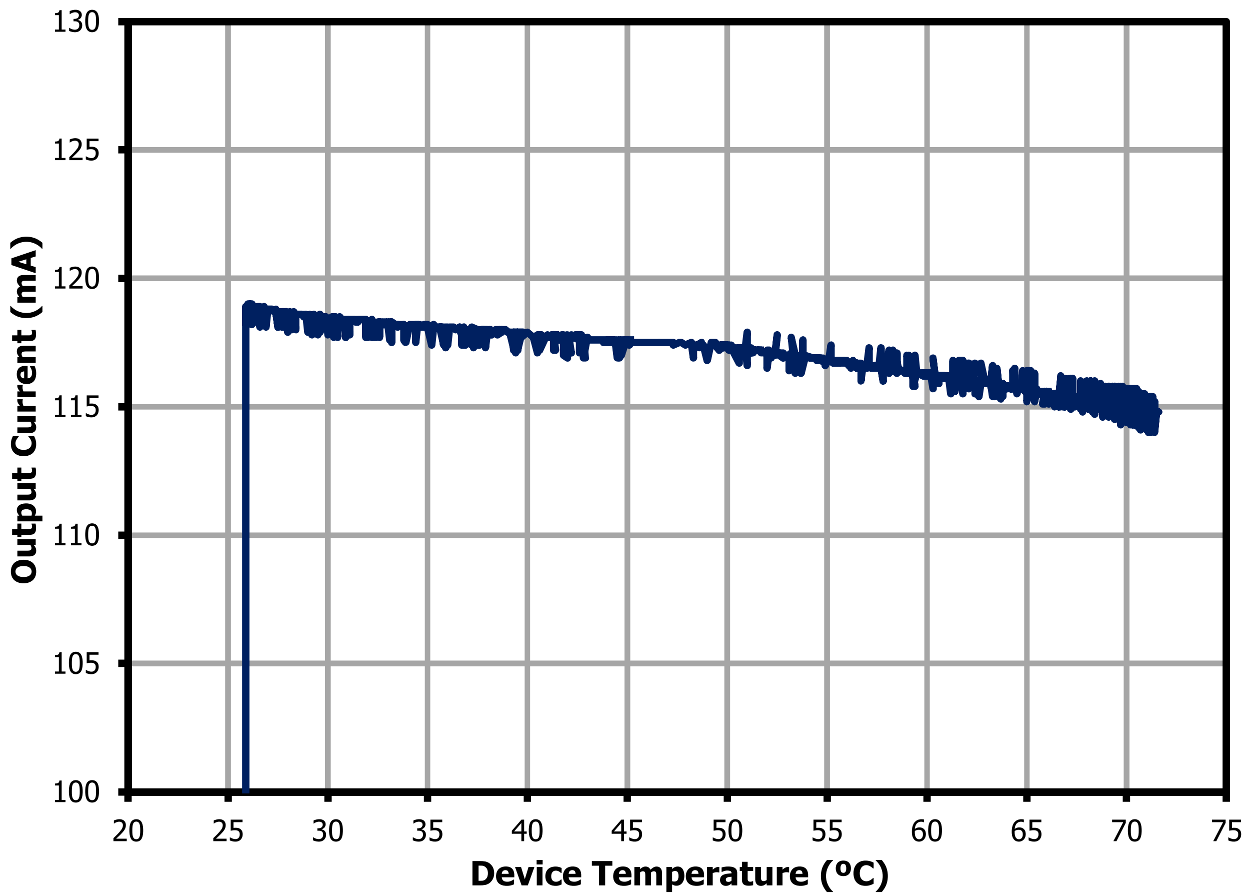

Figure 24 – Output Current vs. Device Temperature at 90 VAC, 52 V LED Load, 70 ºC Ambient.

10.2.2 Thermal Performance at 115 VAC, 52 V LED Load

Measurement	Ambient	LYTSwitch-1	D1	L2	BR1	RV1
Maximum (ºC)	73.9	85.7	83.8	86.6	81.2	75.7
Final (ºC)	73.7	85.7	83.7	86.6	81.1	75.7

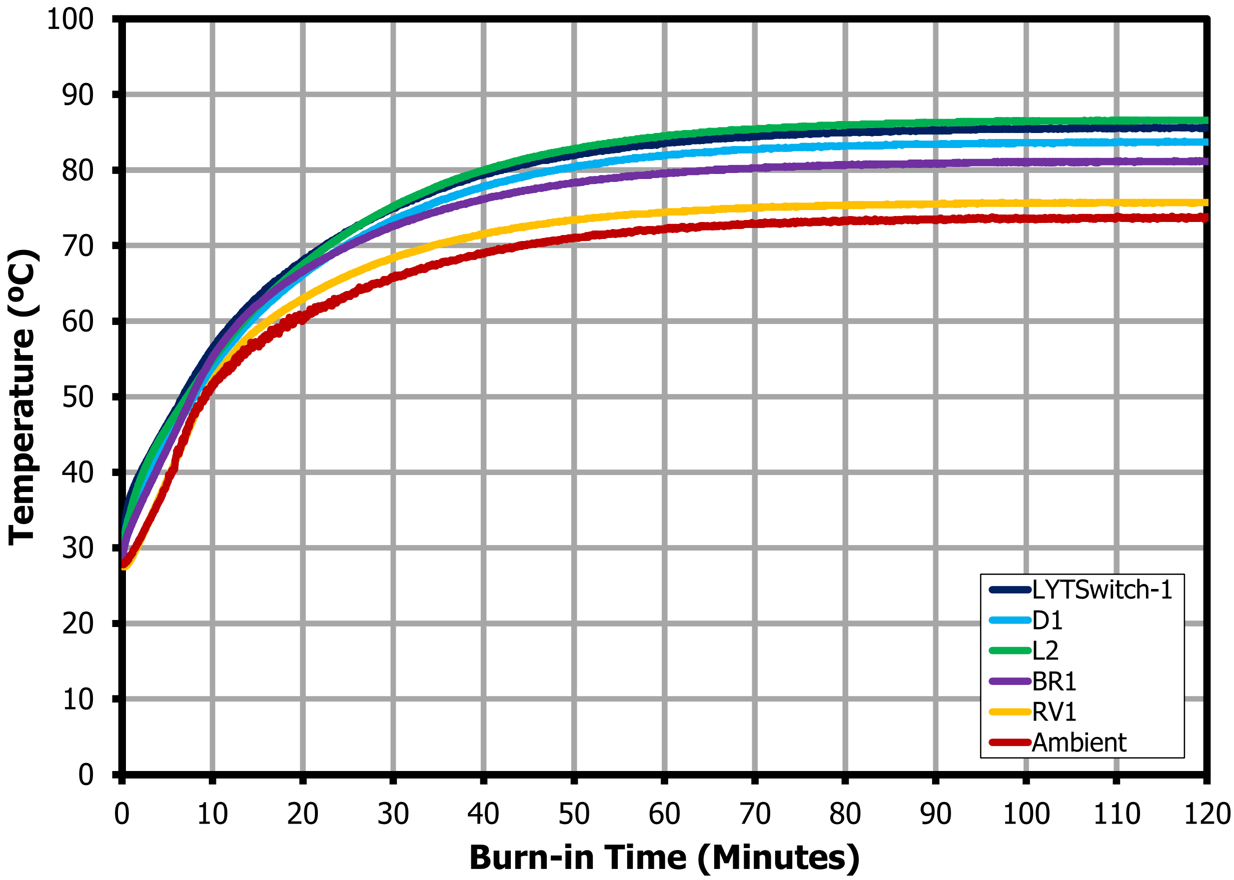

Figure 25 – Component Temperature at 115 VAC, 52 V LED Load, 70 ºC Ambient.

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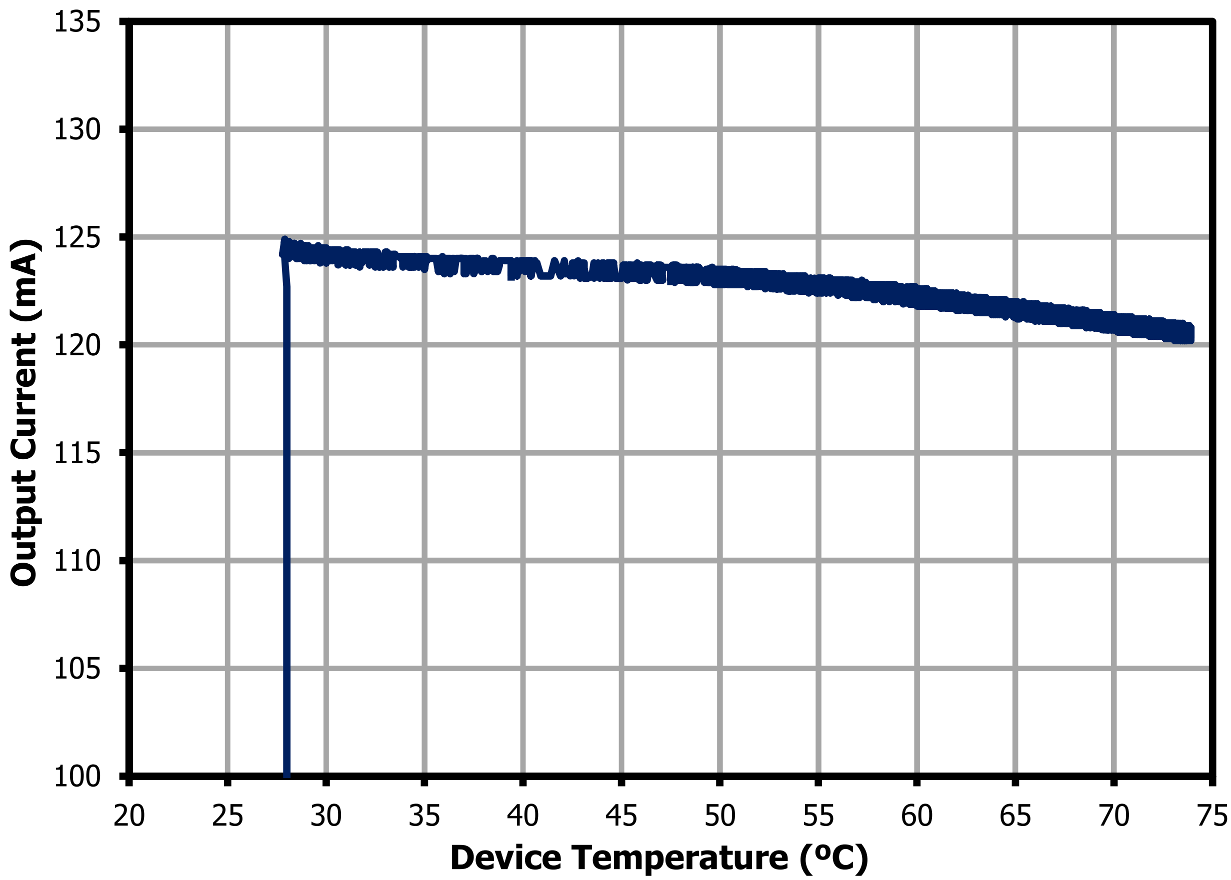

Figure 26 – Output Current vs. Device Temperature at 115 VAC, 52 V LED Load, 70 ºC Ambient.

10.2.3 Thermal Performance at 132 VAC, 52 V LED Load

Measurement	Ambient	LYTSwitch-1	D1	L2	BR1	RV1
Maximum (ºC)	73.3	84.9	82.7	88.2	79.9	76
Final (ºC)	72.9	84.5	82.1	88.1	79.7	76

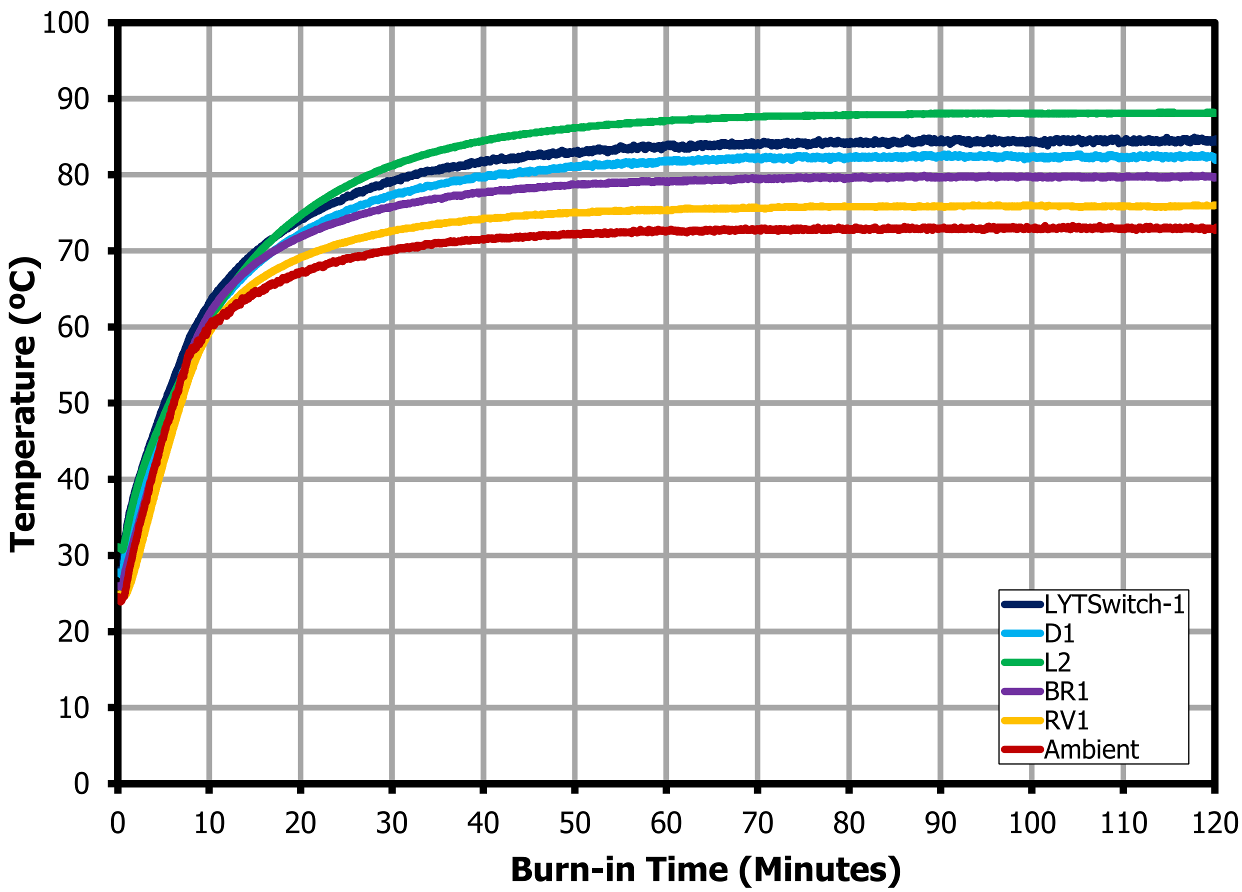

Figure 27 – Component Temperature at 132 VAC, 52 V LED Load, 70 ºC Ambient.

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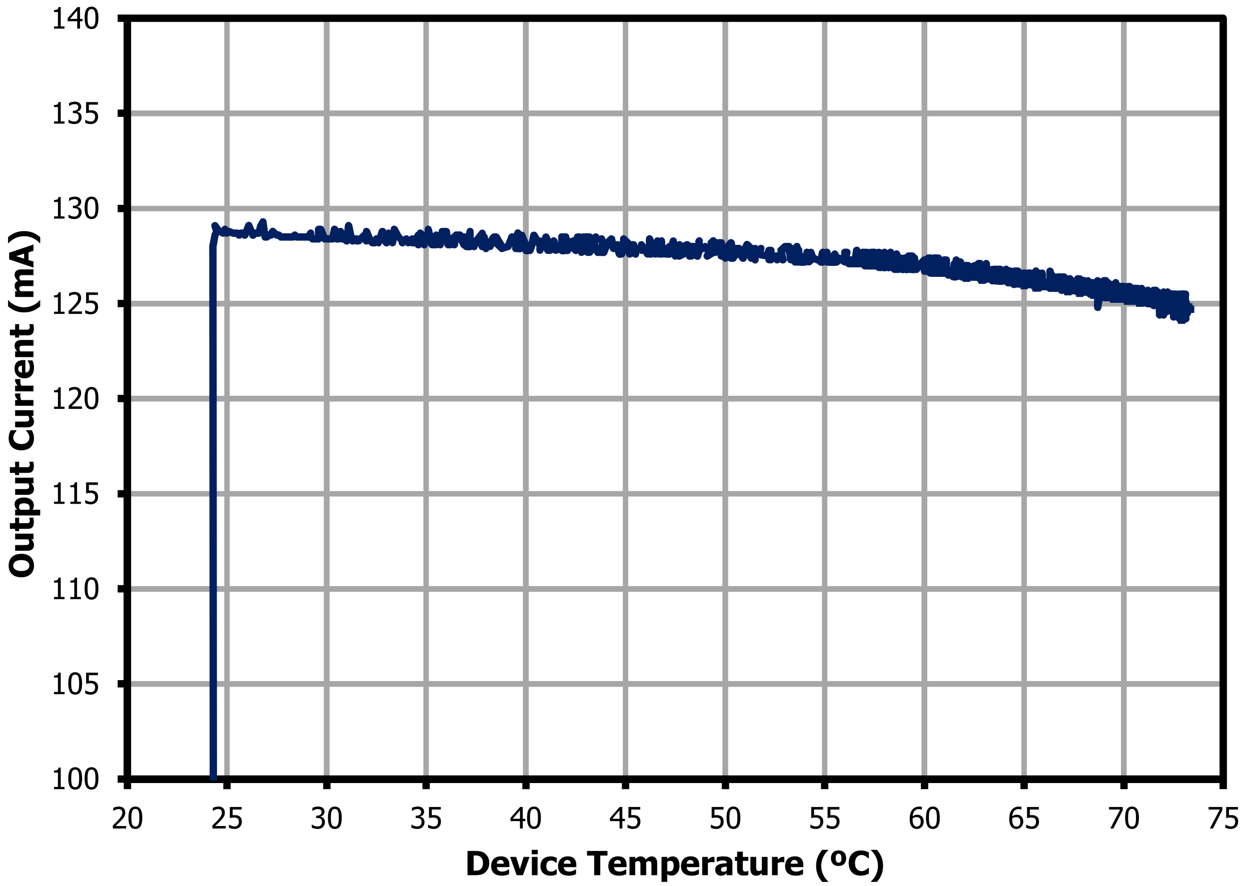

Figure 28 – Output Current vs. Device Temperature at 132 VAC, 52 V LED Load, 70 ºC Ambient.

11 Waveforms

11.1 *Input Voltage and Input Current Waveforms*

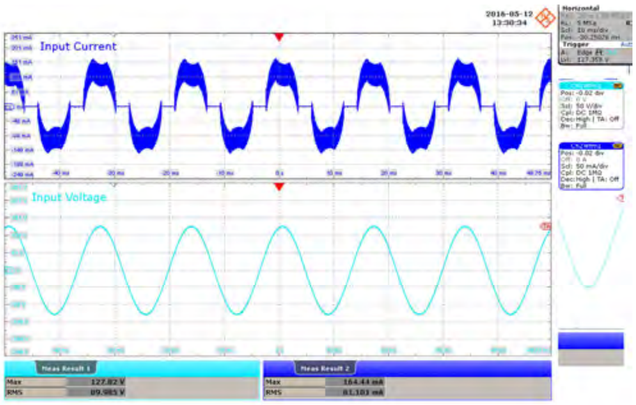

Figure 29 – 90 VAC, 52 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

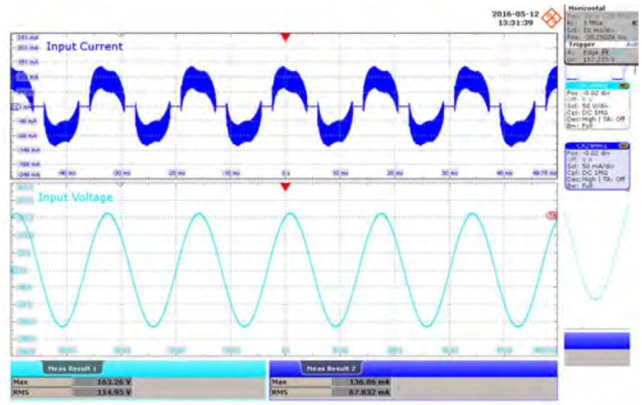

Figure 30 – 115 VAC, 52V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

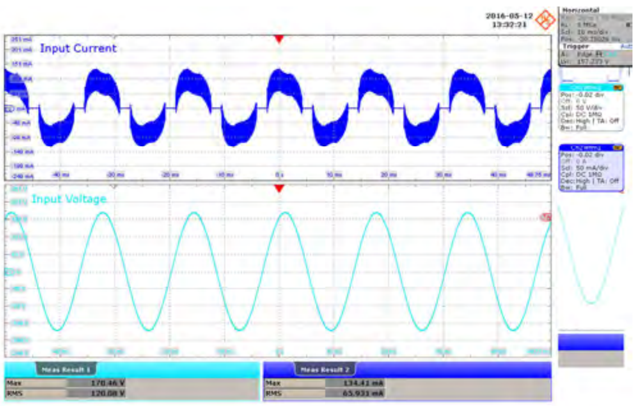

Figure 31 – 120 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

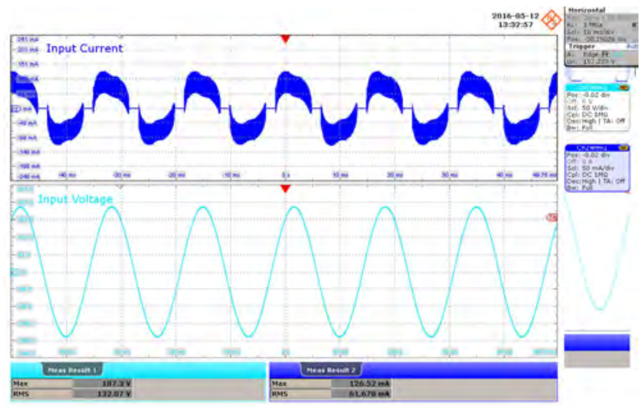

Figure 32 – 132 VAC, 52 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

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11.2 *Start-up Profile*

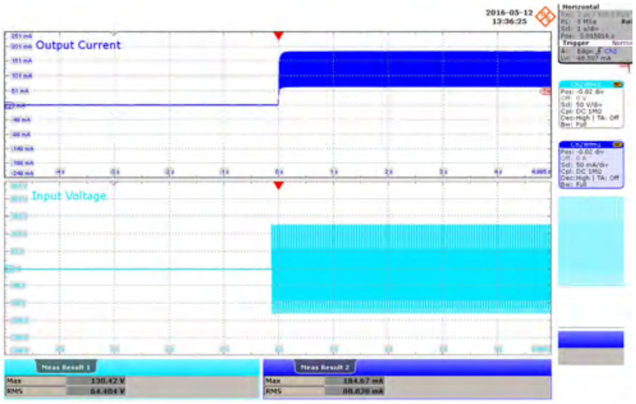

Figure 33 – 90 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

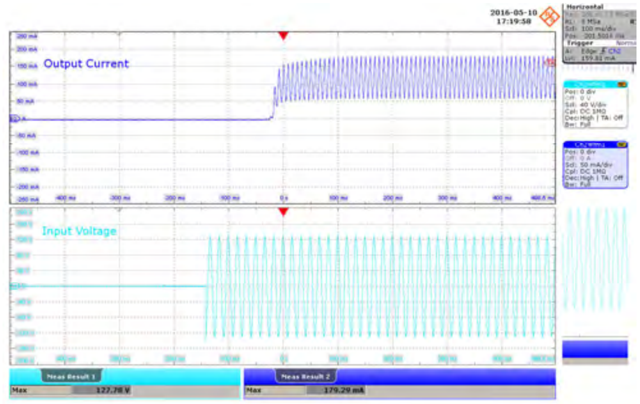

Figure 34 – 90 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

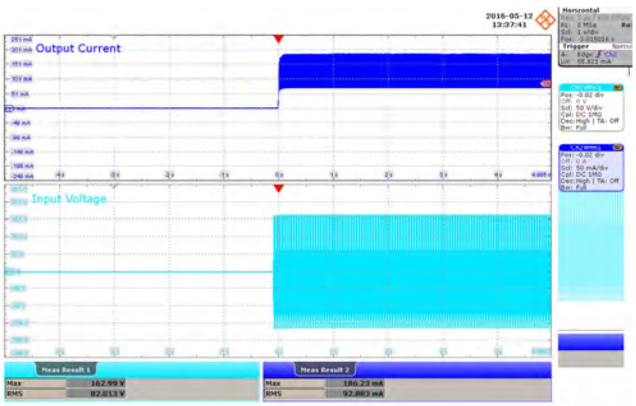

Figure 35 – 115 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

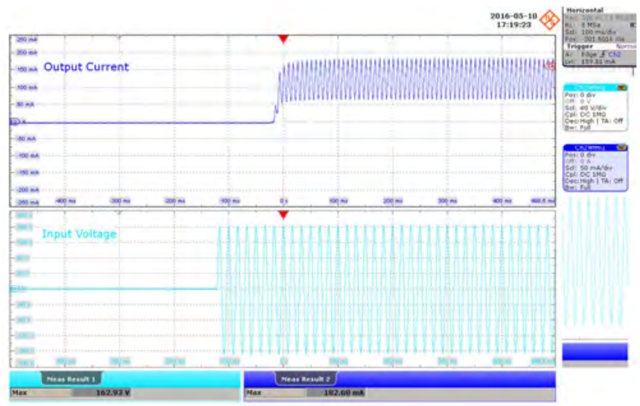

Figure 36 – 115 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

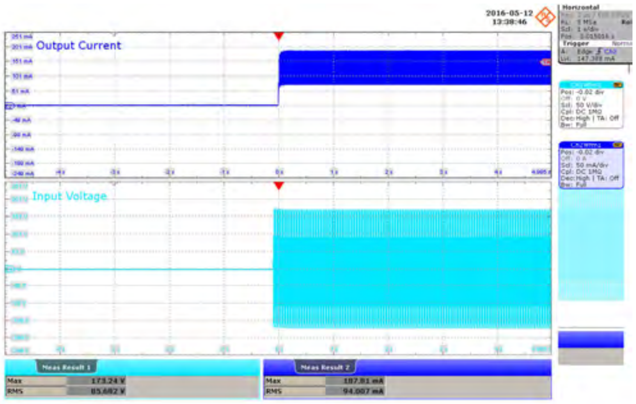

Figure 37 – 120 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

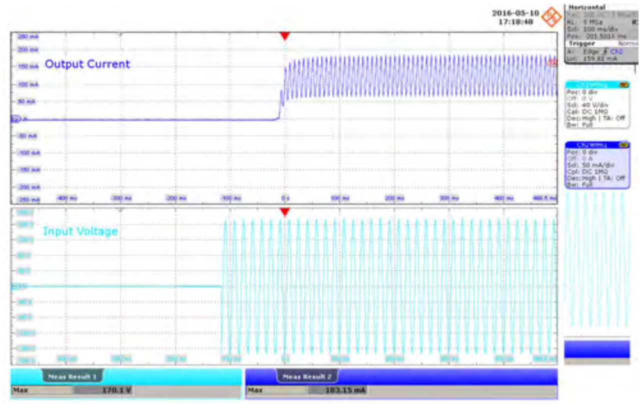

Figure 38 – 120 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div

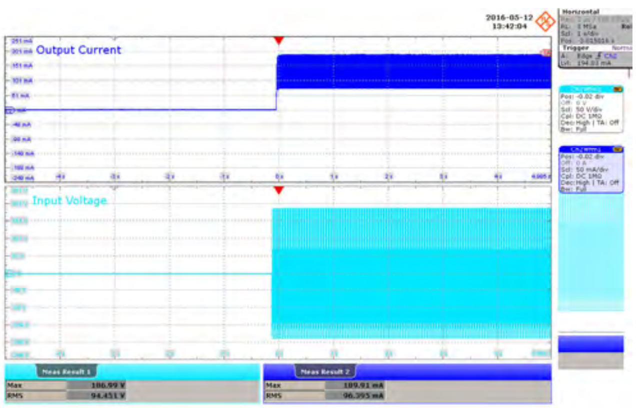

Figure 39 – 132 VAC, 52 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

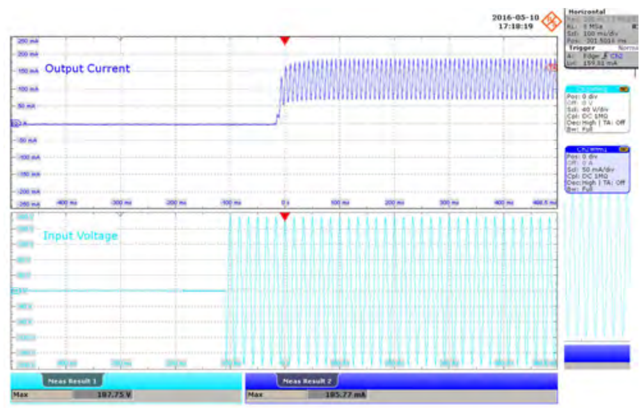

Figure 40 – 132 VAC, 52 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

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11.3 *Output Current Fall*

Figure 41 – 90 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

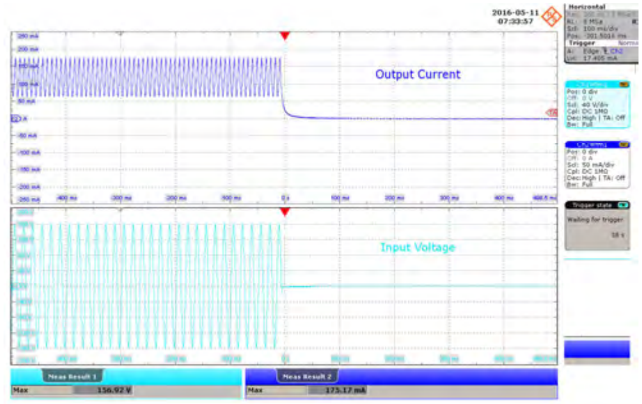

Figure 42 – 115 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

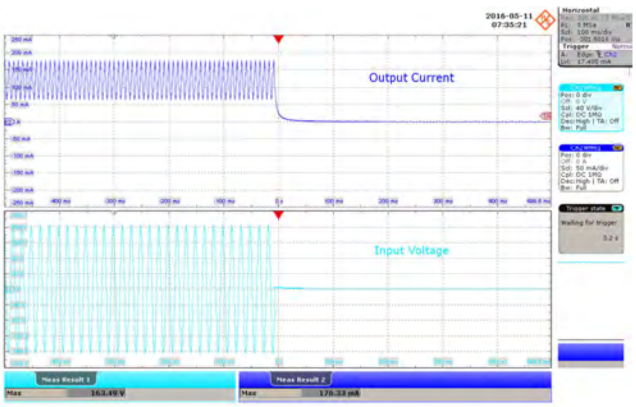

Figure 43 – 120 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

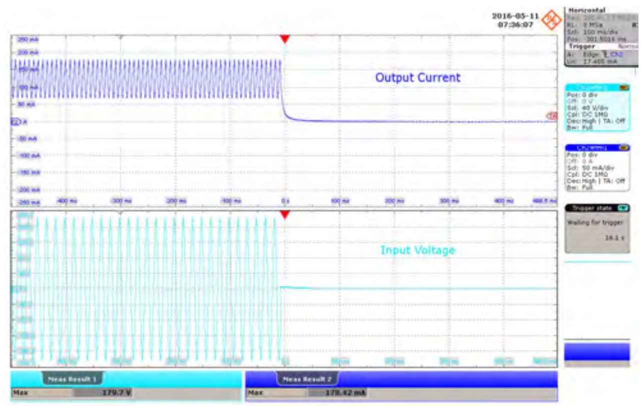

Figure 44 – 132 VAC, 52 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 40 V / div., 100 ms / div.

11.4 *Drain Voltage and Current in Normal Operation*

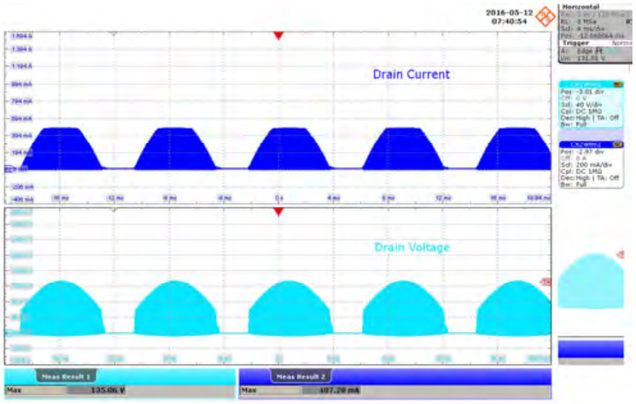

Figure 45 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

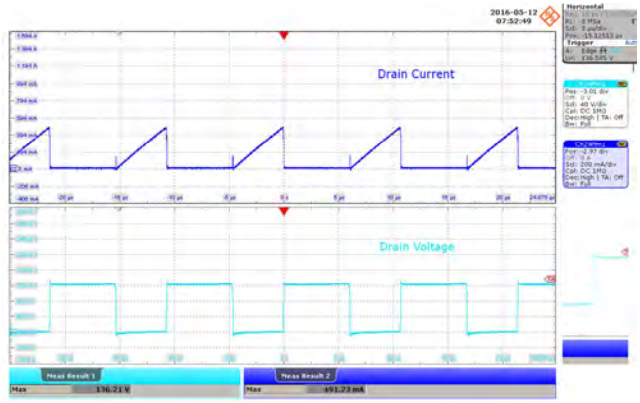

Figure 46 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 µs / div.

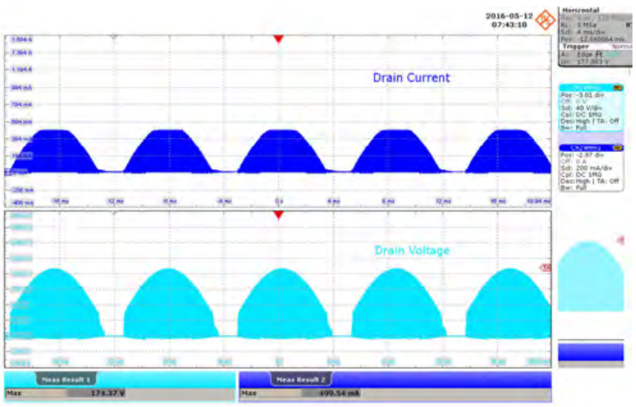

Figure 47 – 115 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

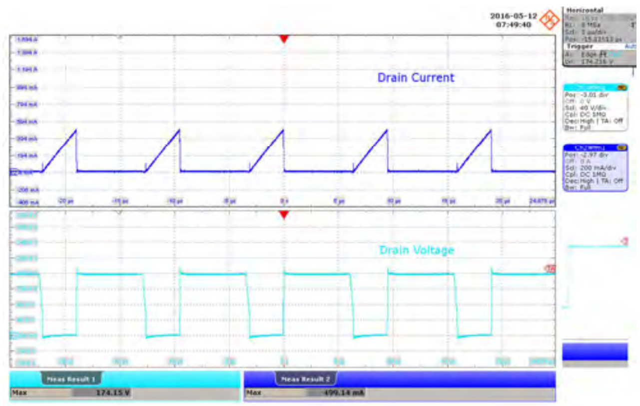

Figure 48 – 115 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 µs / div.

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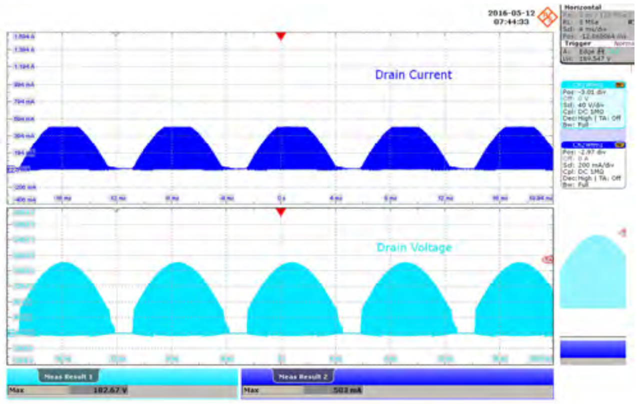

Figure 49 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

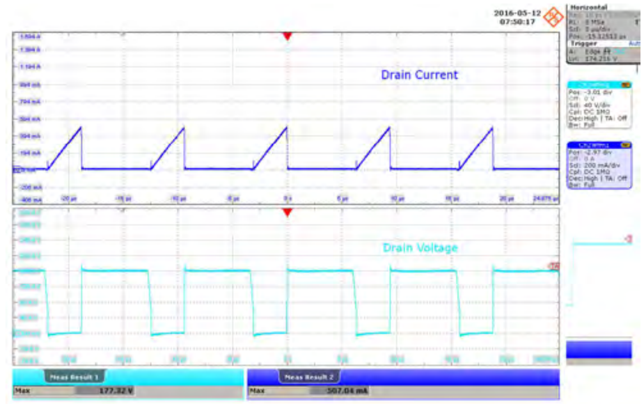

Figure 50 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 µs / div.

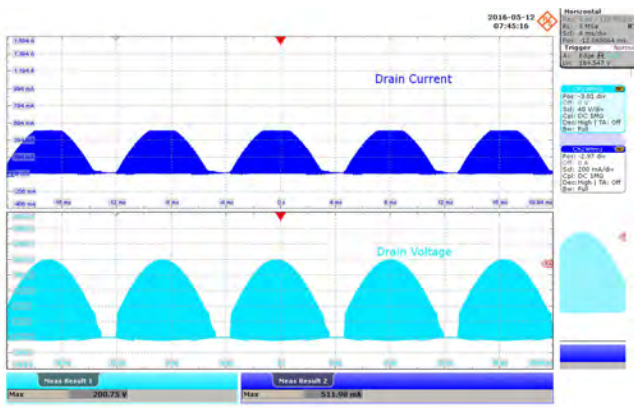

Figure 51 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

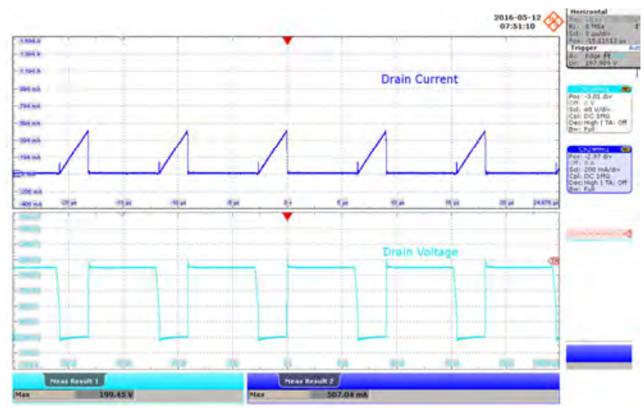

Figure 52 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 µs / div.

11.5 *Drain Voltage and Current Start-up Profile*

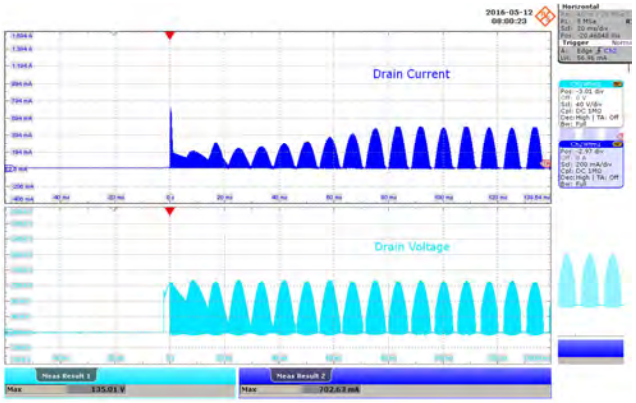

Figure 53 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

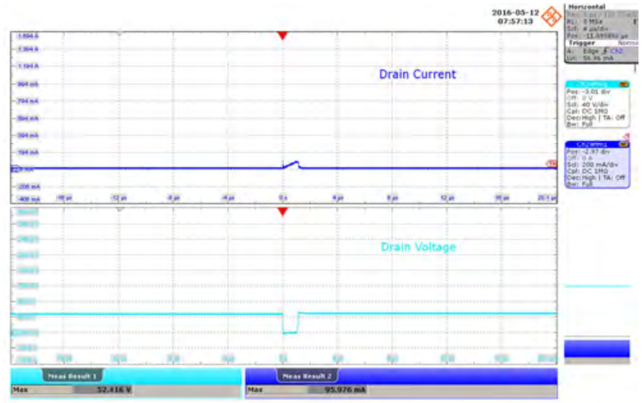

Figure 54 – 90 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 µs / div.

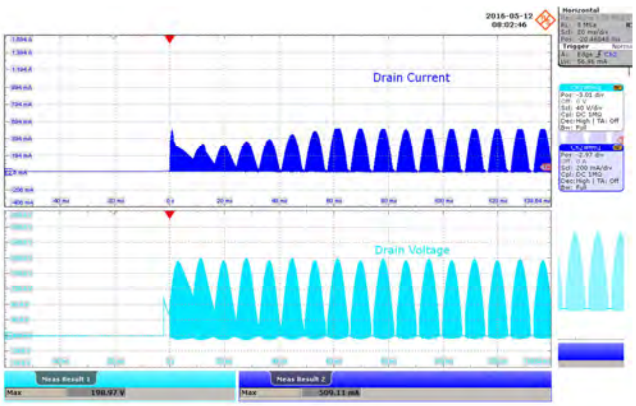

Figure 55 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 20 ms / div.

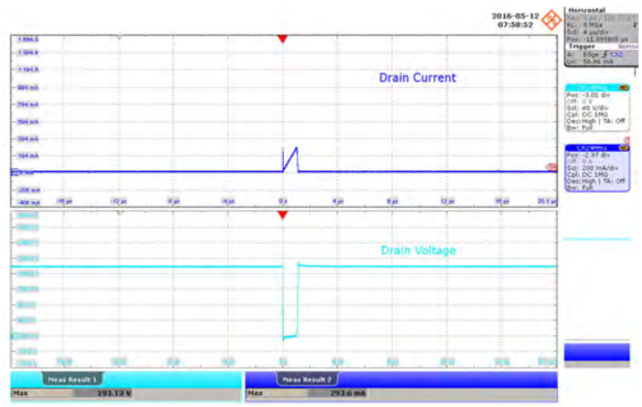

Figure 56 – 132 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 µs / div.

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

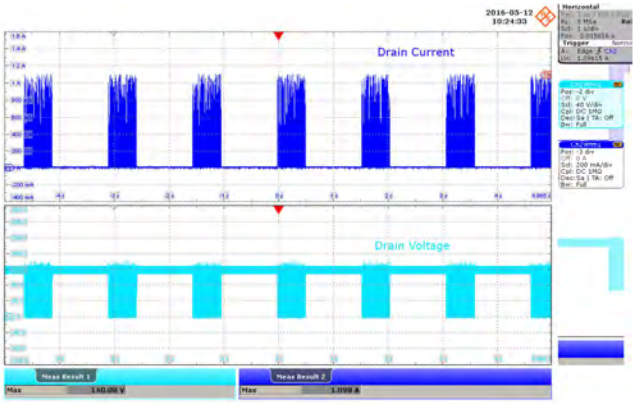

Figure 57 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s / div.

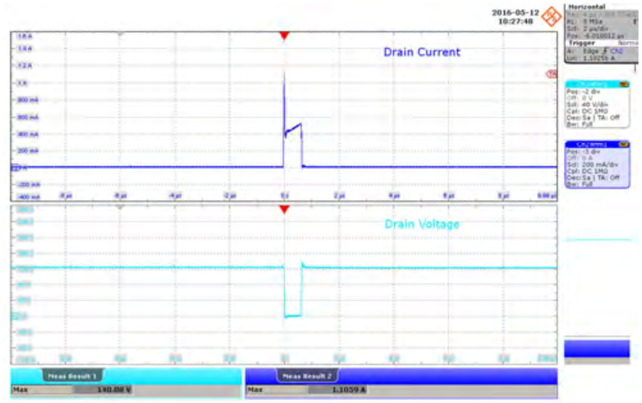

Figure 58 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 2 µs / div.

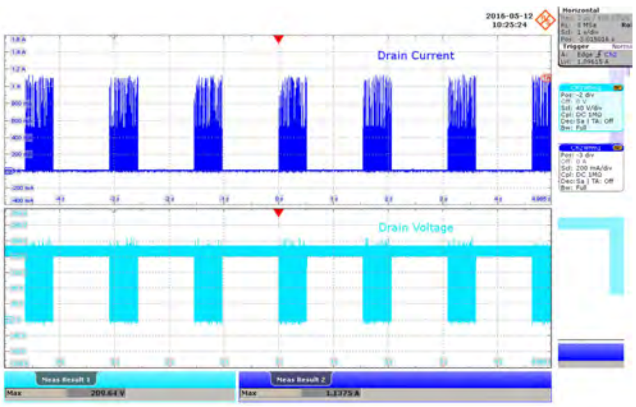

Figure 59 – 132 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s / div.

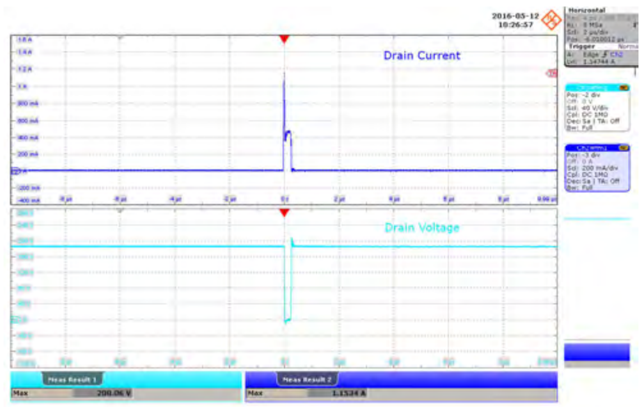

Figure 60 – 132 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 µs / div.

11.7 *Output Diode Voltage and Current in Normal Operation*

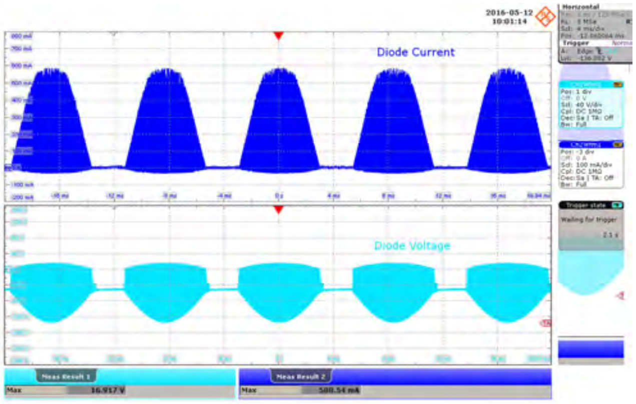

Figure 61 – 90 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

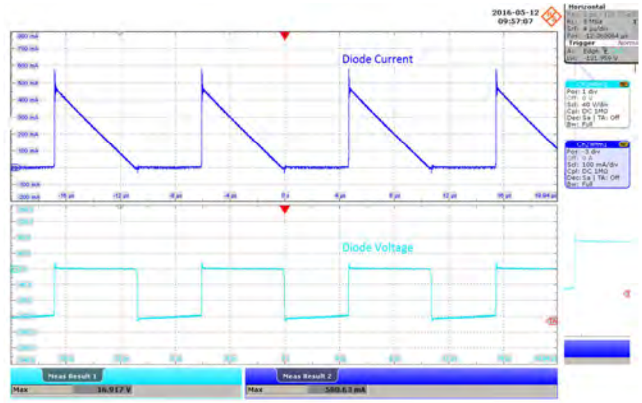

Figure 62 – 90 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

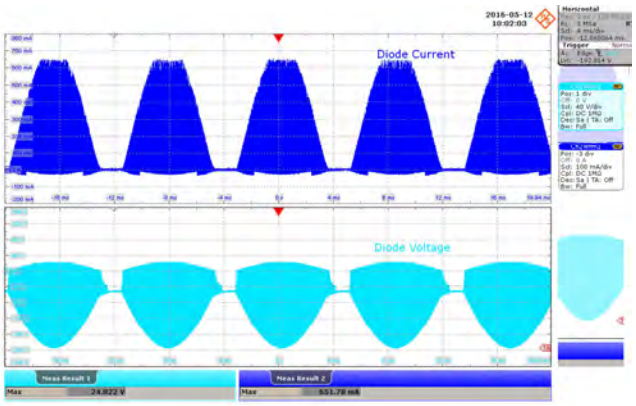

Figure 63 – 132 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

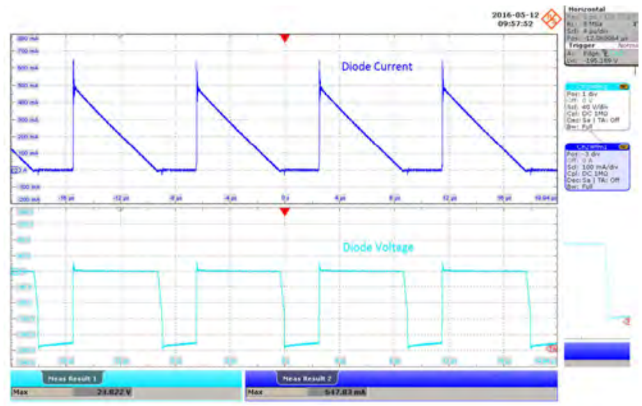

Figure 64 – 132 VAC, 52 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 40 V / div., 4 µs / div.

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

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

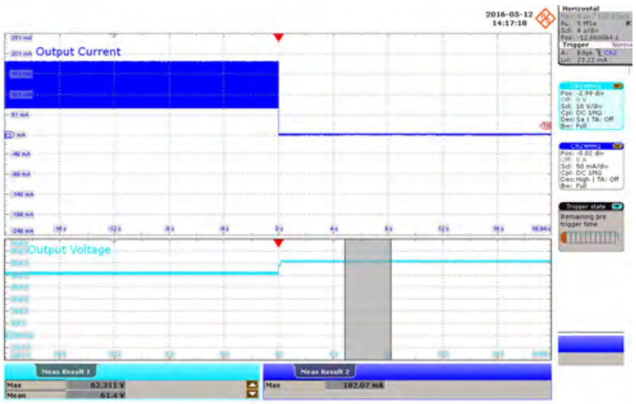

Figure 65 – 100 VAC, 52 V LED Load.
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

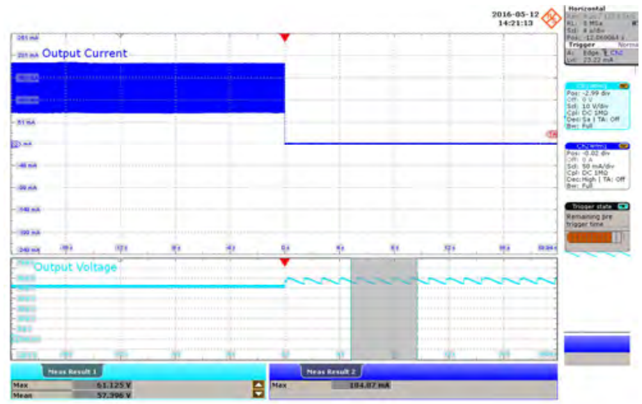

Figure 66 – 120 VAC, 52 V LED Load.
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

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

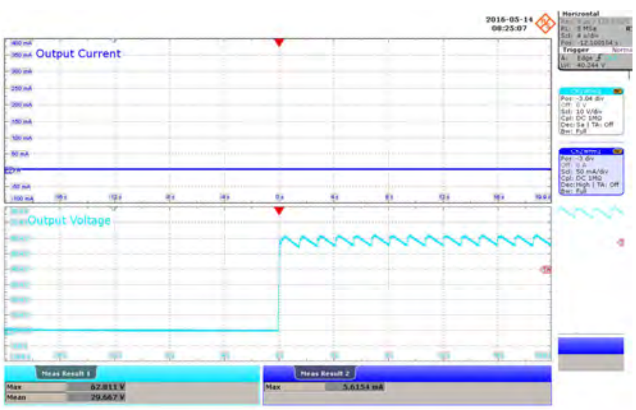

Figure 67 – 100 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

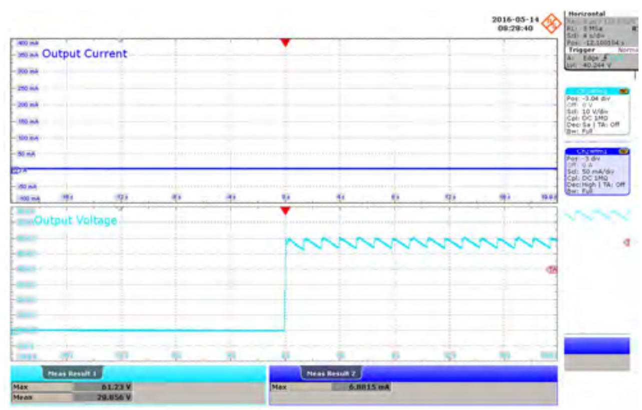

Figure 68 – 120 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

11.10 *Output Ripple Current*

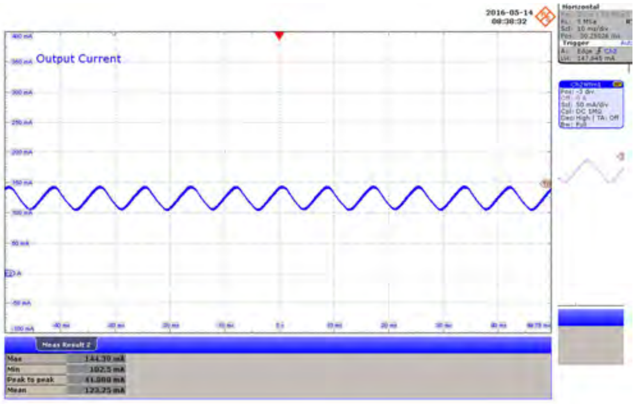

Figure 69 – 90 VAC, 60 Hz, 52 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

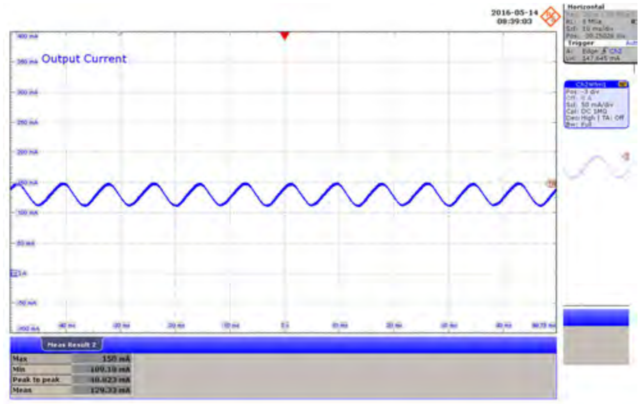

Figure 70 – 115 VAC, 60 Hz, 52 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

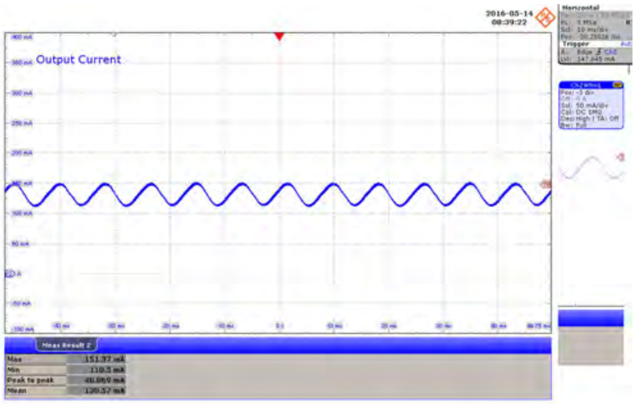

Figure 71 – 120 VAC, 60 Hz, 52 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

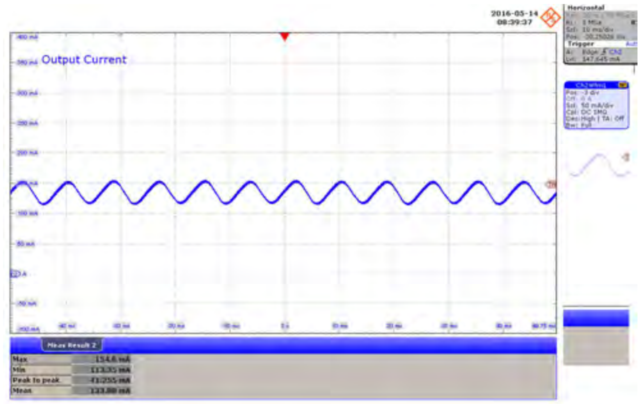

Figure 72 – 132 VAC, 60 Hz, 52 V LED Load.
Upper: I_{OUT}, 50 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN} (mA)	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}+I_{O(MIN)}$)
90	144.39	102.5	123.25	0.34	16.96
115	150	109.18	129.33	0.32	15.75
120	151.37	110.5	130.57	0.31	15.61
132	154.6	113.35	133.88	0.31	15.40

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12 AC Cycling Test

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

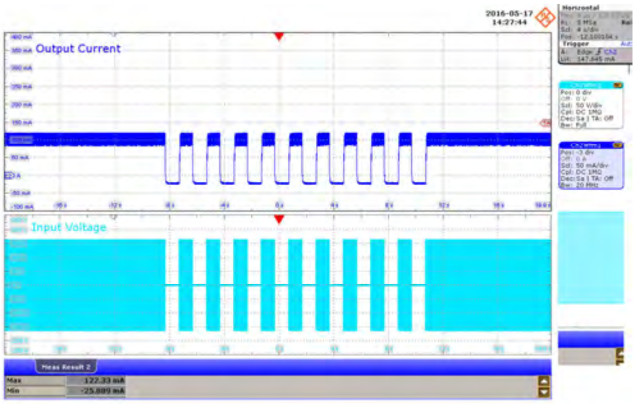

Figure 73 – 115 VAC, 52 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

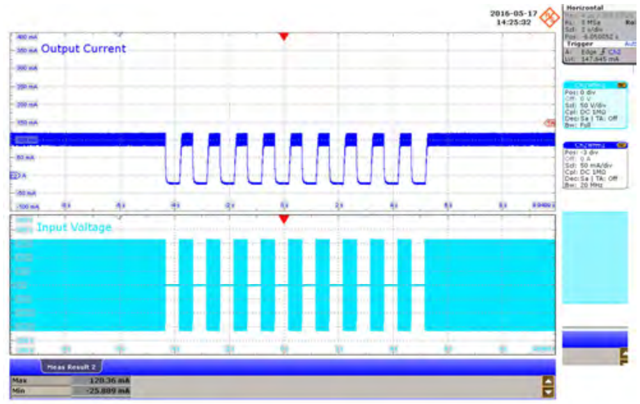

Figure 74 – 115 VAC, 52 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

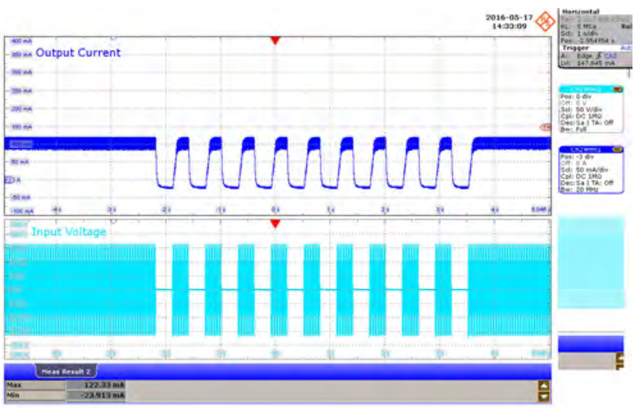

Figure 75 – 115 VAC, 52 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

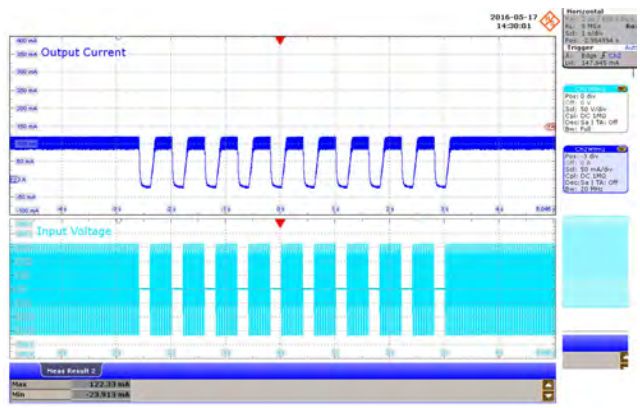

Figure 76 – 115 VAC, 52 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

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.

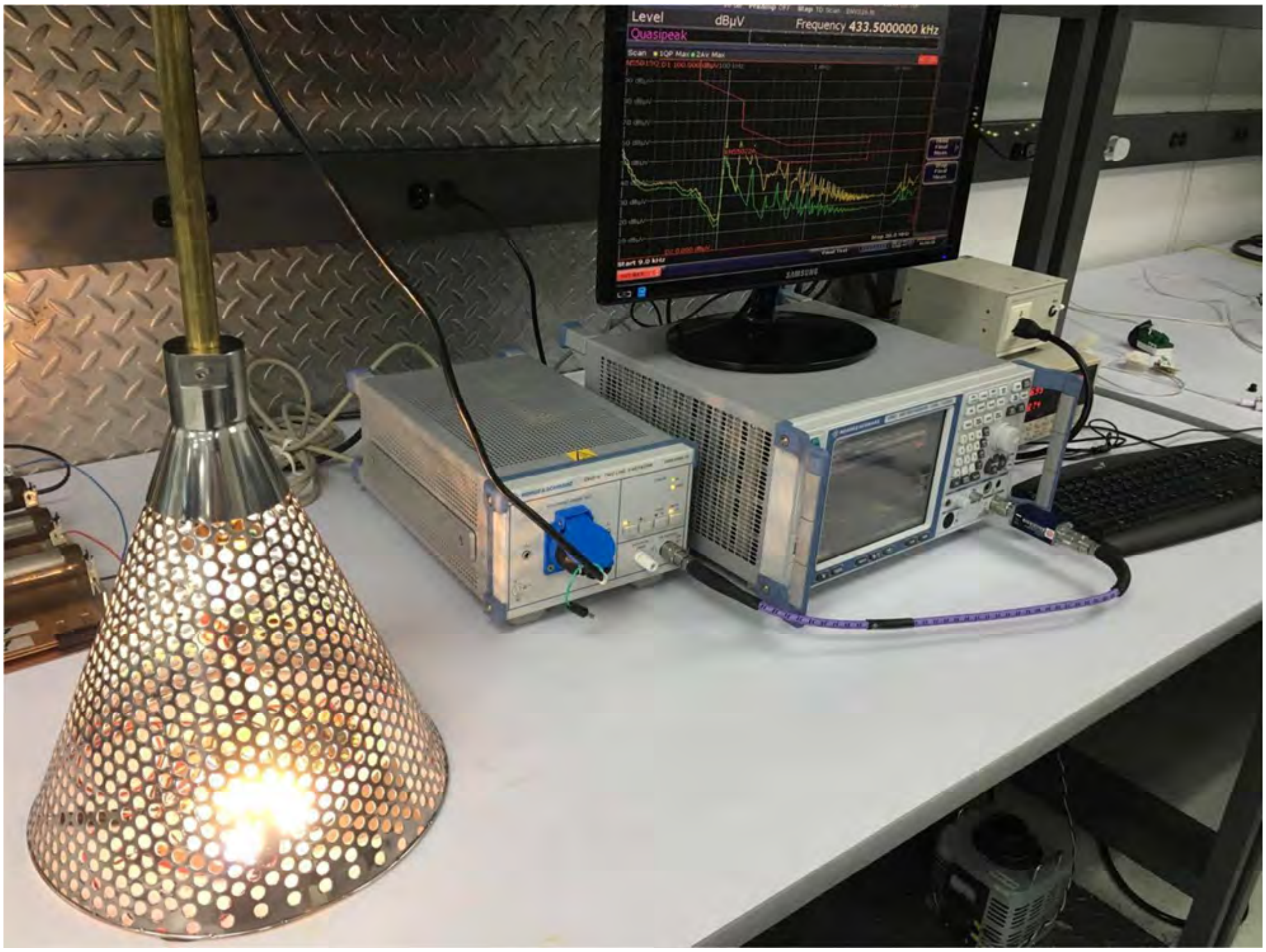

Figure 77 – Conducted EMI Test Set-up.

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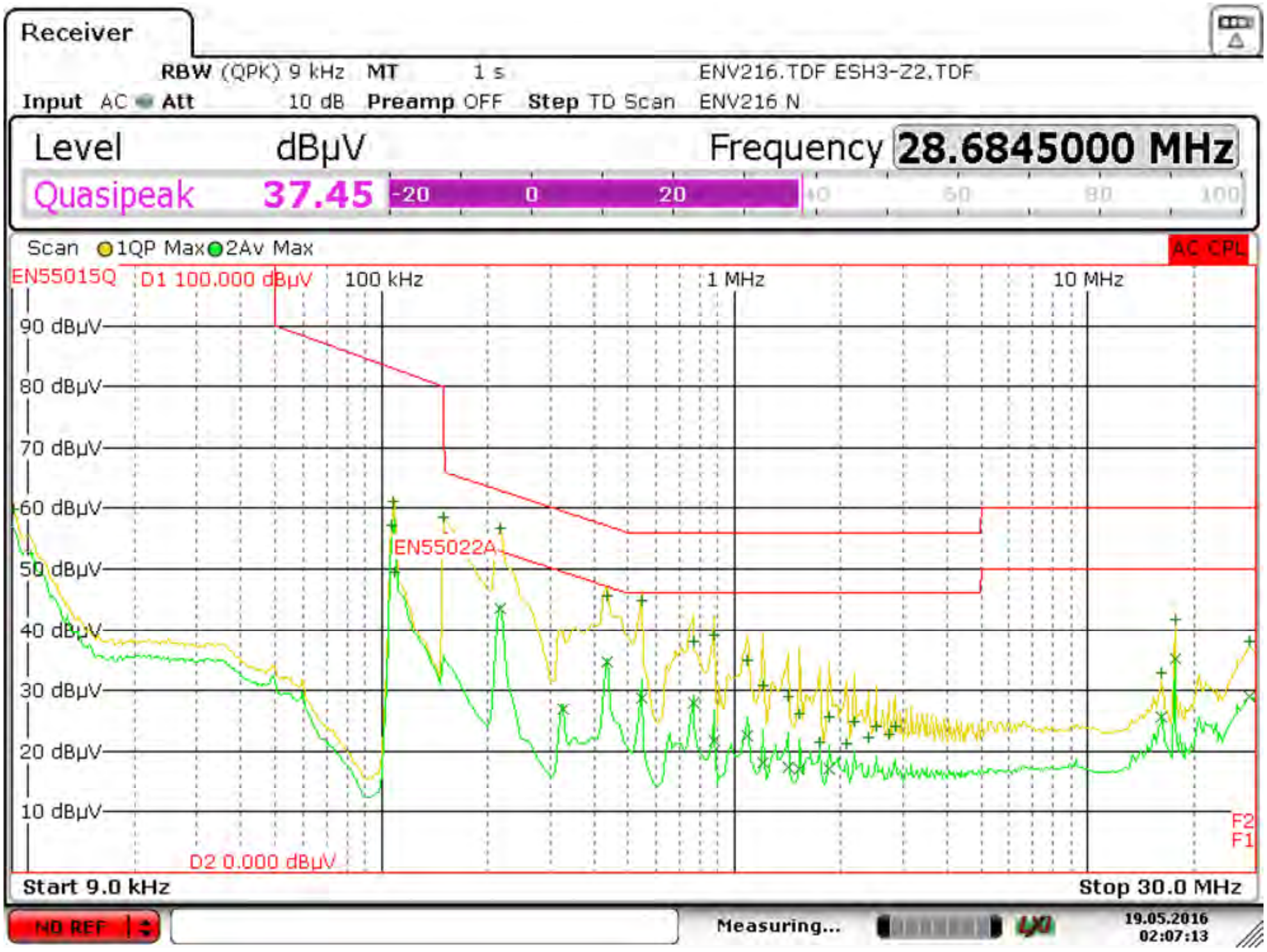
13.2 *EMI Test Result*



Date: 19.MAY.2016 02:07:13

Figure 78 – 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	217.5000 kHz	56.79 N	-6.12 dB
1 Quasi Peak	150.0000 kHz	58.52 N	-7.48 dB
2 Average	217.5000 kHz	43.59 N	-9.32 dB
1 Quasi Peak	546.0000 kHz	44.93 N	-11.07 dB

Figure 79 – 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.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	120	L to N	0	Pass
-1000	120	L to N	0	Pass
+1000	120	L to N	90	Pass
-1000	120	L to N	90	Pass

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

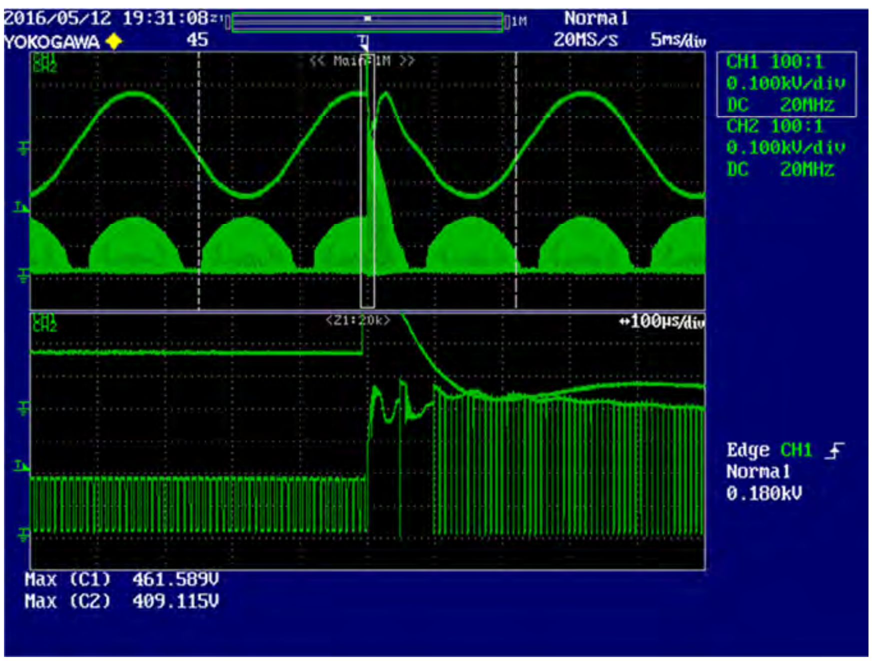


Figure 80 – +1000 kV Differential Surge, 90º Phase Angle.
V_{DRAIN}, 100 V / div., 5 m / div.
Peak V_{DRAIN}: 461.59 V.

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15 Brown-in / Brown-out Test

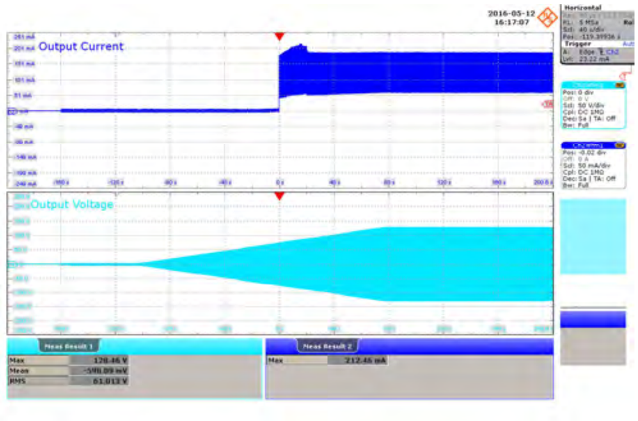

Figure 81 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

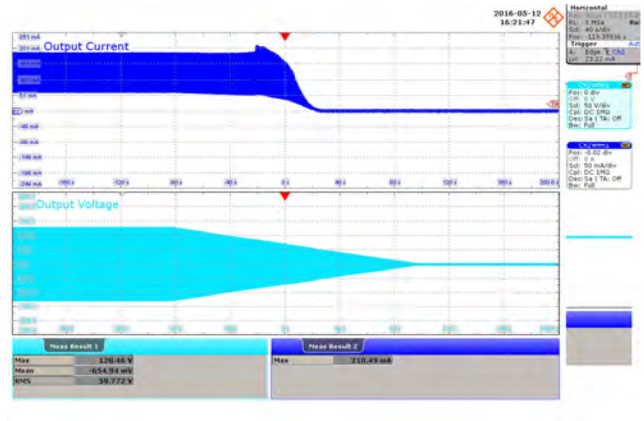

Figure 82 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 50 V / div.
Time Scale: 40 s / div.

16 Revision History

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

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