Design Example Report

Title	*40 W Wide Range Dimmable, High Efficiency (>85%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-7 LYT7504D*
Specification	100 VAC – 300 VAC Input; 52 V_{TYP}, 380 mA_{TYP} Dual Output
Application	Ceiling Lamp
Author	Applications Engineering Department
Document Number	DER-570
Date	November 15, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9 measured at 115 VAC input
- Two-rail outputs in a single board
- Accurate constant current regulation for both outputs, ±5%
- Meets <30% flicker requirement for each output
- Highly energy efficient, >85% at
- Low cost and low component count for compact PCB solution
- 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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PATENT INFORMATION
The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <http://www.powerint.com/ip.htm>.
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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 an LED driver configured as a low-side buck utilizing the LYT7504D from the LYTSwitch-7 family of devices. This is a low component dimmable LED driver designed to power a dual output 52 V LED voltage string at 380 mA output current each, from an input voltage range of 100 VAC to 300 VAC. Dimming performance is optimized at low line input (i.e. 120 VAC), while maintaining accurate regulation for non-dimmable high-line input.

LYTSwitch-7 is a SO-8 package LED driver controller IC family designed for non-isolated buck applications. The LYTSwitch-7 family provides high efficiency, high power factor and accurate LED current regulation. It incorporates a high-voltage 725V power MOSFET and a control engine to switch the power MOSFET in critical conduction mode with variable on-time and variable frequency which also help achieves low EMI and low THD. The controller also integrates protection features such as input and output overvoltage protection, thermal fold-back, over temperature shutdown, output short-circuit and over-current protection. The controller also allows natural dimming with only the addition of a damper resistor and an RC network for damping the input current ringing when the TRIAC turns on.

DER-570 offers a compact size solution for 40 W LED drivers for ceiling light applications. The key design goals were high efficiency, accurate constant current regulation for both outputs and low component count.

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

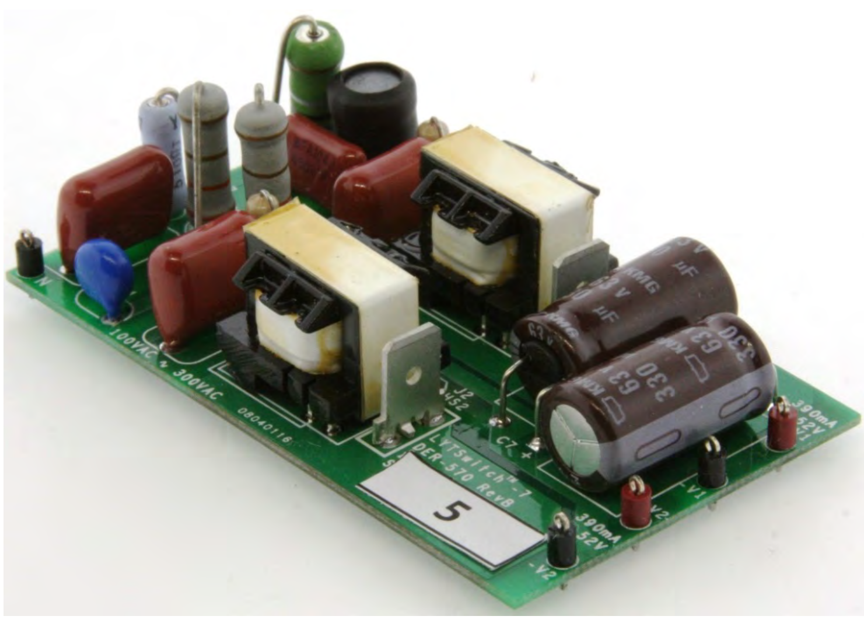

Figure 1 – Populated Circuit Board.

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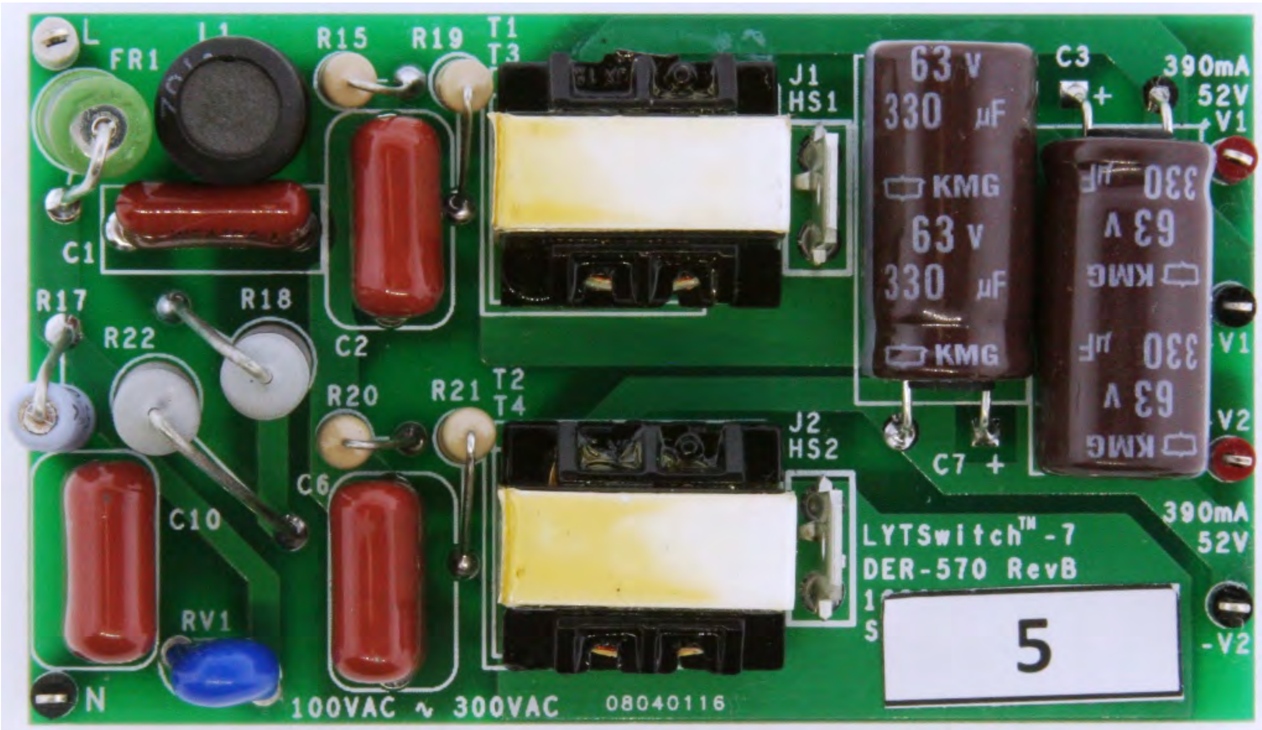

Figure 2 – Populated Circuit Board, Top View.

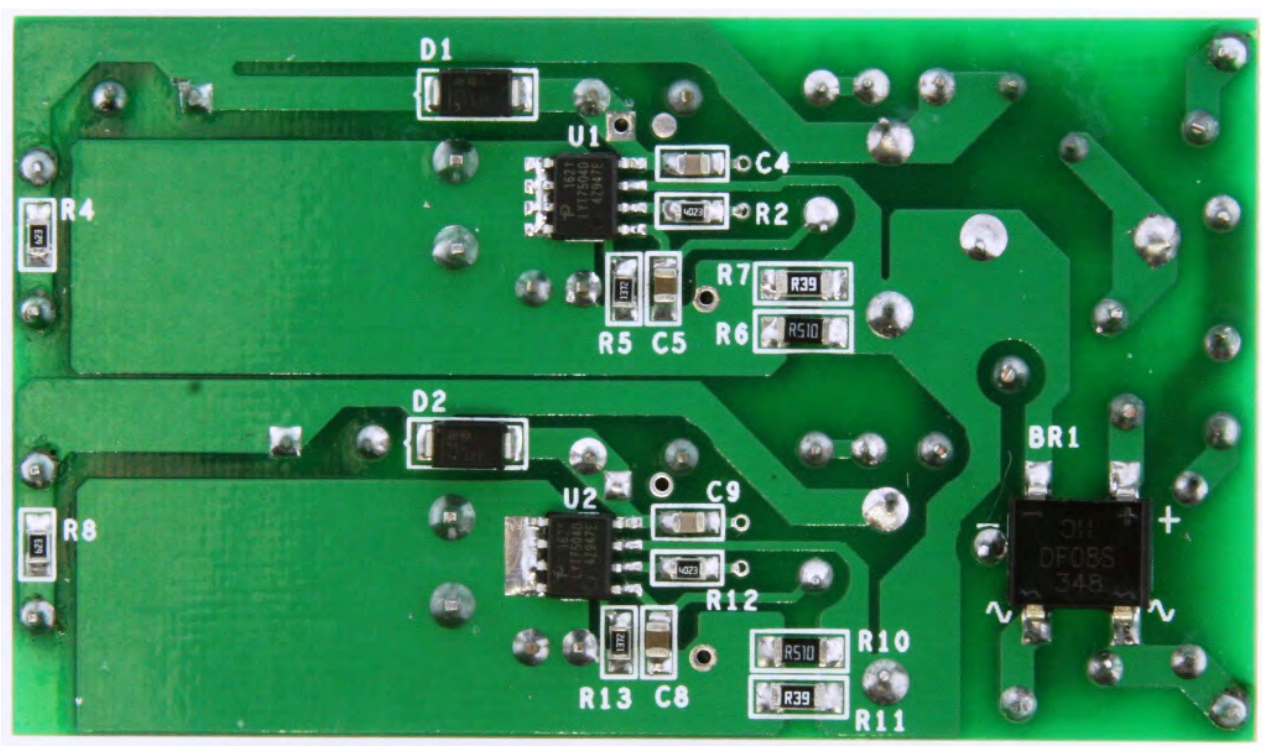

Figure 3 – Populated Circuit Board, Bottom View.

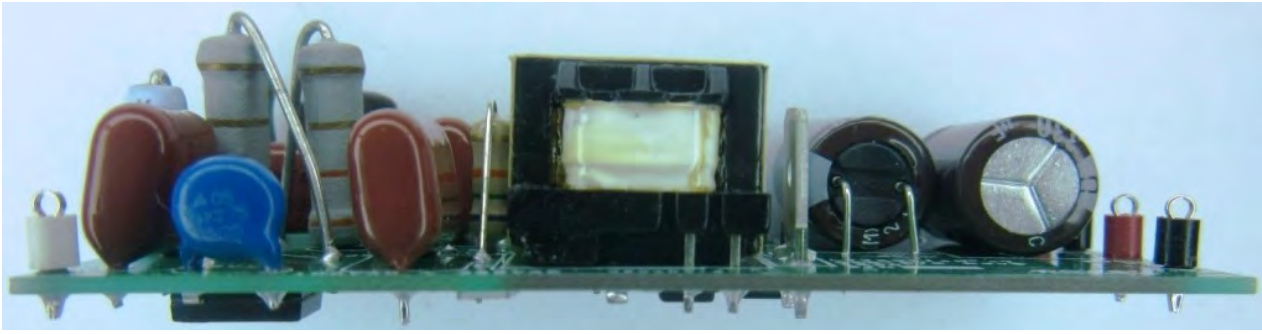

Figure 4 – Populated Circuit Board, Side View.

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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}	100	115	300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage 1	V_{OUT1}		52		V	
Output Current 1	I_{OUT1}		380		mA	
Output Voltage 2	V_{OUT2}		52		V	
Output Current 2	I_{OUT2}		380		mA	
Total Output Power			40		W	
Continuous Output Power	P_{OUT}		40		W	
Efficiency						
Full Load	η		85		%	115 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 115 VAC / 50 Hz.
Ambient Temperature	T_{AMB}			75	ºC	Free Convection, Sea Level.

3 Schematic

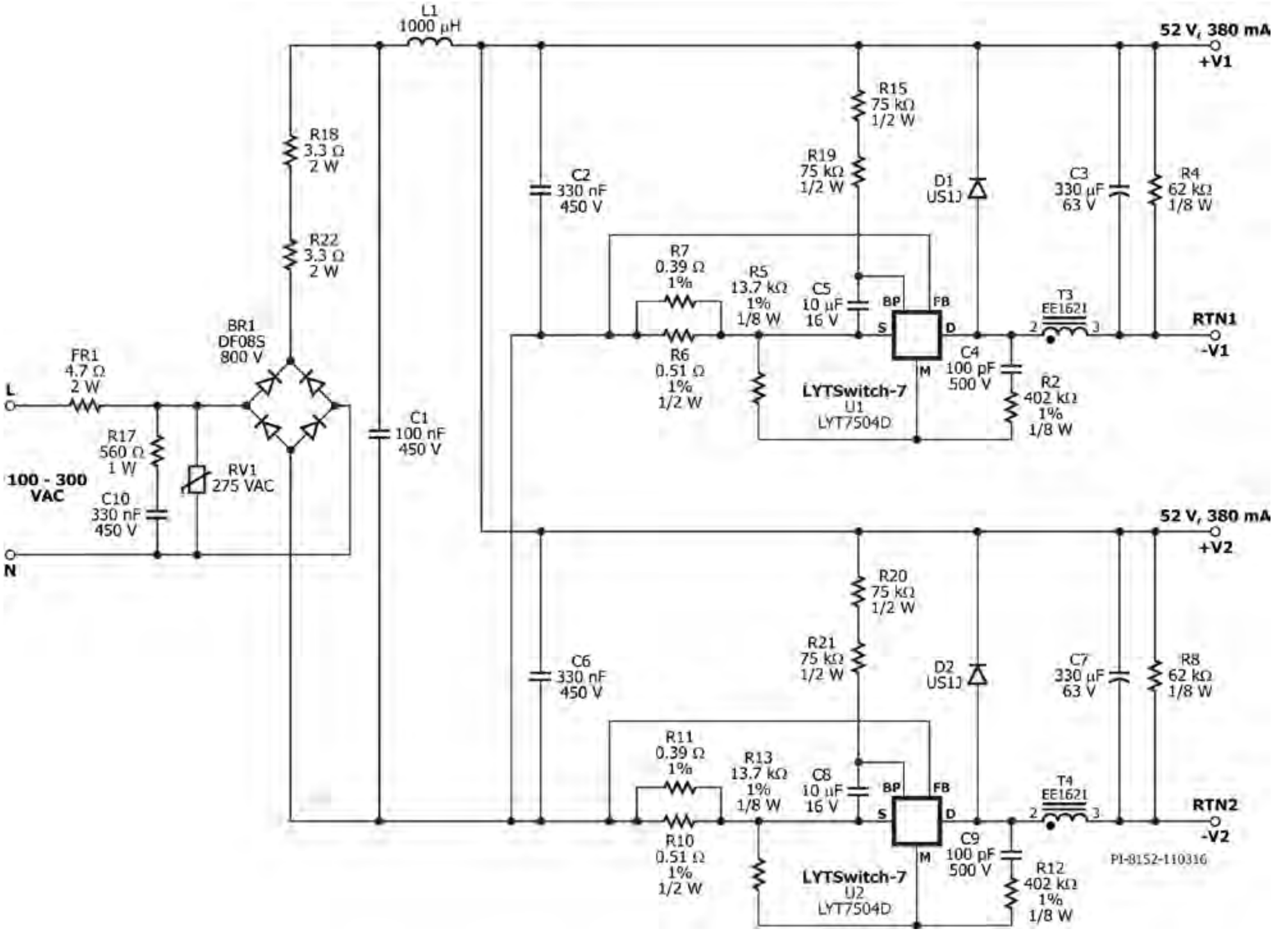

Figure 5 – Schematic.

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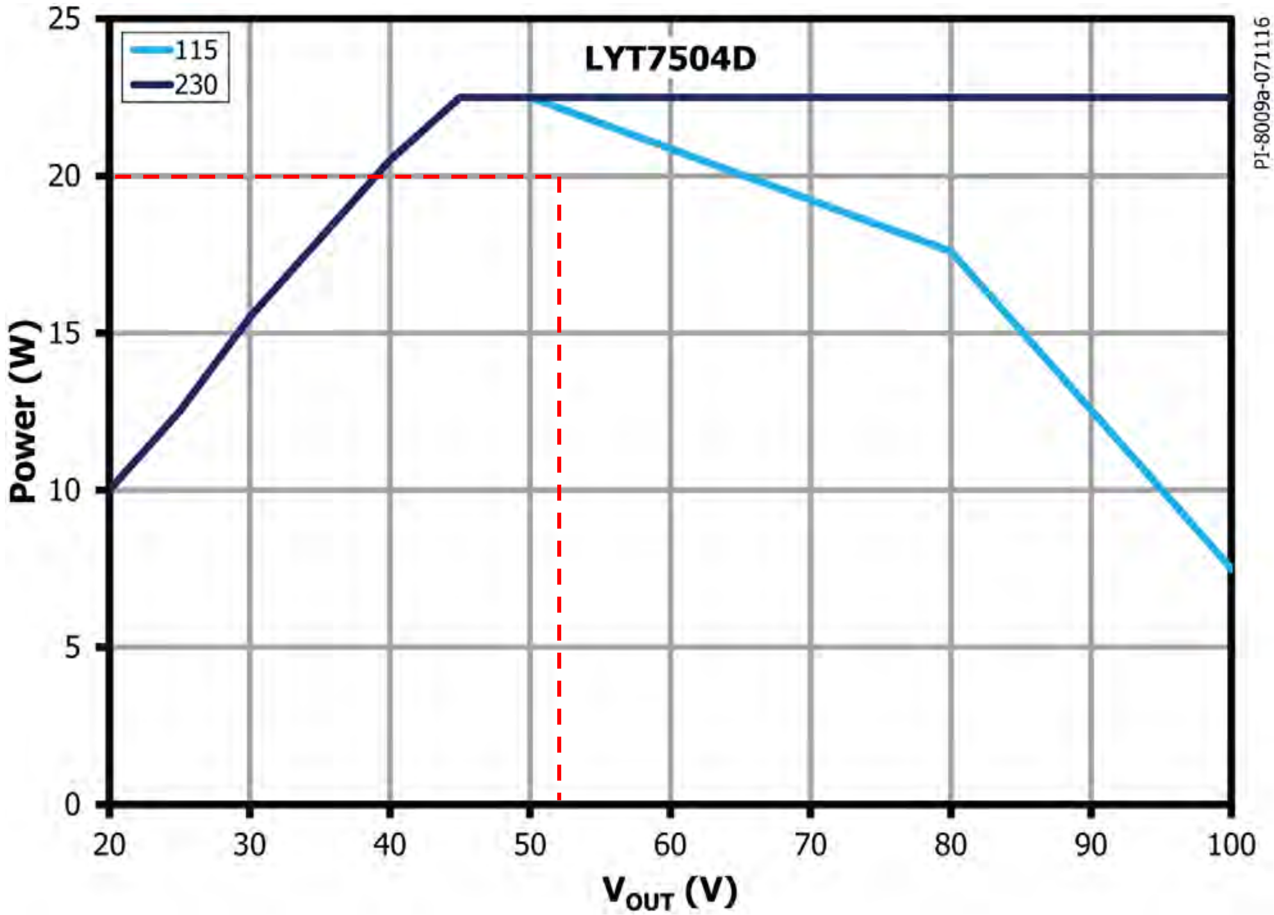
4 Circuit Description

The LYTSwitch-7 device (U1/U2-LYT7504D) incorporates a high-voltage 725 power MOSFET and a control engine to switch the power MOSFET in critical conduction mode with variable on-time and variable frequency in a single SO-8 package. It is configured to drive a 52 V output non-isolated buck LED driver with 380 mA constant current for each output. The LYT7504D device was selected based from the power graph (see LYTSwitch-7 family data sheet). Each output with output power of 20 W and output voltage of 52 V.



4.1 *Input Stage*

The input fuse FR1 provides a multi-purpose function namely safety protection, current limiting against differential surge and acts as a damping element reducing inrush current ringing when TRIAC dimming. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 275 VAC rated part was selected with a maximum clamping voltage specification of 720 V – lower than the device minimum drain breakdown voltage (725 V). The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD.

4.2 *EMI Filter*

Inductor L1, C1 and C2 / C6 form as an EMI π filter which attenuates conducted and common mode EMI currents. If required, a 10 kΩ can be added across L1 to damp the Q-factor of the filter inductor. This will improve the filtering of high frequency EMI without reducing low frequency attenuation.

The addition of the RC damper network R17 and C10 makes the driver compatible with TRIAC (phase-cut) dimmers. The RC damper in the circuit may be place before or after the bridge rectifier. In this design, the RC damper is located before the bridge rectifier to load the TRIAC more. This will increase the conduction angle thus increasing the output current close to 100% regulation at full conduction but with lower dimming range. Putting the RC damper after the bridge will result to higher dimming range.

4.3 *LYTSwitch-7 Control Circuit*

The LED driver circuit is a low side buck configuration operating in critical conduction mode; the controller allows complete transfer of the energy stored in the inductor to the load before starting the next switch cycle. The inductor demagnetization is sensed, detecting when the voltage across the inductor begins to collapse as flywheel diode (D1 / D2) conduction stop.

Capacitors C5 and C8 provide local decoupling for the BYPASS (BP) pin of U1 and U2 respectively and provide power to LYTswitch-7 controller during the power MOSFET on time. The IC has an internal regulator that draws power from the high voltage DRAIN (D) pin and charges the bypass capacitor C5 / C8 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 time), where $V_{IN} < V_{OUT}$ and during dimming at low conduction angles, resistors R15 / R19 and R20 / R21 are employed to keep the bypass charged. The value of capacitor should be large enough to keep the bypass voltage above the $V_{BP(RESET)}$ value of 4.5 V. The suggested minimum value for the bypass capacitor is 10 μF; an X7R type is recommended if using ceramic type capacitor.

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

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resistors (R_{FB}) R6 / R7 and R10 / R11. The voltage drop is compared to an internal 280mV reference voltage ($V_{FB(REF)}$) . The value R_{FB} can be calculated from the equation.

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

Where: k = 3.6 which is the ratio of I_{PK}: I_{OUT}

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

The MULTIFUNCTION (M) pin has several functions. These include input overvoltage, output overvoltage and zero current detection to maintain Critical Conduction Mode of operation.

The AC line (input) overvoltage event is being detected when the internal MOSFET is in the ON-state. During this state, the M pin is internally connected to the SOURCE (S) pin. It can detect then the rectified input line voltage which is in this case is the voltage across the inductor, i.e. (V_{IN} - V_{OUT}). The M pin samples this voltage via C4 / C9 and the current flowing out of the M pin is set by resistors R2 / R12. Thus, the line overvoltage trigger point (V_{LINE_OVP}) is calculated by:

$$V_{LINE\_OVP} = I_{IOV} \times R2 + V_{OUT1}$$

or

$$V_{LINE\_OVP} = I_{IOV} \times R12 + V_{OUT2}$$

R2 or R12 are assumed to be 402 kΩ ±1%.

Once the detected current exceeds the input overvoltage threshold (I_{IOV} = 1 mA typical), the IC will instantaneously inhibit switching and initiate auto-restart to protect the internal power MOSFET of the IC and the LED load from voltage overstress.

The M pin also monitors the output for overvoltage or undervoltage events. When the internal power MOSFET is in off-state, the voltage across the inductor T3 / T4 is equal to the output voltage. This voltage is being sampled via C4 / C5 and output OVP can now be computed from the divider resistors R2 and R12 or R5 and R13. When an output open-load condition occurs, the voltage at the M pin will rise abruptly. When it exceeds the V_{OOV} threshold of 2.4 V (typical), the IC will inhibit switching and initiate an auto-restart to prevent the output voltage from rising further. The overvoltage cut-off is typically set at 120% of the output voltage, which is equivalent to 2 V on the M pin.

$$V_{OUT\_OVP} = V_{OUT} \times 2.4\ V / 2\ V$$

If desired, a higher overvoltage cut-off can be selected by setting a lower M pin voltage target. Resistors R2 and R12 are set to a fixed value of 402 kΩ ±1% allowing resistors R5 and R13 to determine the output overvoltage limit. A short-circuit at the output will reduce output voltage and be detected when the M pin voltage falls below the undervoltage threshold (V_{OUV} = 1 V typical). The IC will inhibit switching and initiate auto-restart limiting the average input power to less than 1 W, preventing any components from overheating during a short-circuit.

Resistor R5 and R13 can be calculated as follows:

$$R5 = 2\ V \times R2 / (V_{OUT\,1} - 2\ V)$$

$$R13 = 2\ V \times R12 / (V_{OUT\,2} - 2\ V)$$

A small capacitor C4 and C9 is needed to couple the high-side referenced analog of the output voltage to the M pin of the IC via resistor divider network R2 and R12 or R5 and R13. Calculation and practical experience shows that, a capacitance value of 100 pF provides a good compromise between AC line rejection and flatness of the output voltage during the off-time of the switch.

Another function of the M pin is for zero current detection (ZCD). Detecting this condition is necessary for operation in critical conduction mode (CrM). Inductor demagnetization is detected when the voltage across the inductor begins to collapse as flywheel diode (D1) conduction ends.

4.4 *Output Stage*

During the power MOSFET switch off-state, free-wheeling diodes D1 / D2 rectify and conduct the voltage across T3 / T4 and the output is filtered by C3 / C7. An ultrafast 1 A, 600 V with 75 ns reverse recovery time (t_{RR}) diode was selected for efficiency and good regulation over line and across temperature. The value of the output capacitors C3 / C7 were selected to give peak-to-peak LED ripple current equal to 30% of the mean value. For designs where lower ripple is required, the output capacitance value can be increased. The ripple is dependent on both output capacitance and the bulk resistance of the LED load; it recommended that the actual load be used when sizing the output capacitor in order to correctly achieve the specified ripple current.

A small output pre-load resistor R4 / R8 discharges the output capacitors when the driver is turned off, giving a quick and smooth decay of the LED light after turn-off. Recommended pre-load power dissipation is ≤0.25 % of the output power.

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5 PCB Layout

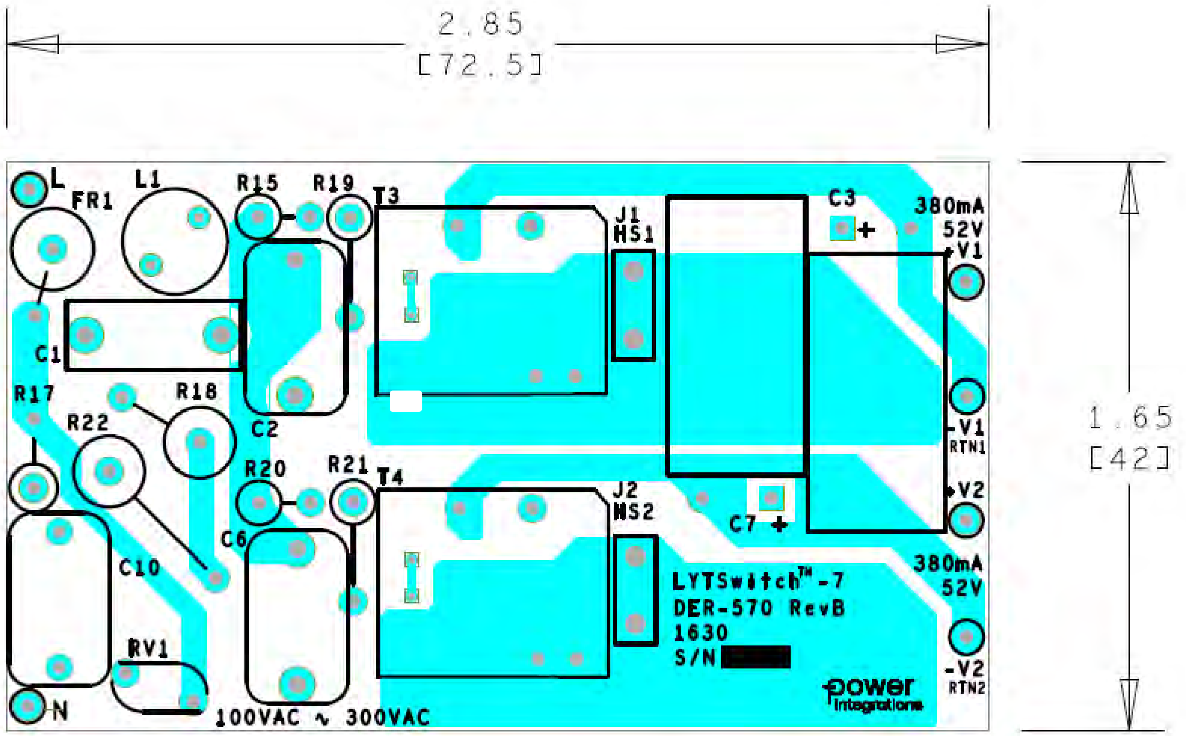

Figure 6 – Top Side.

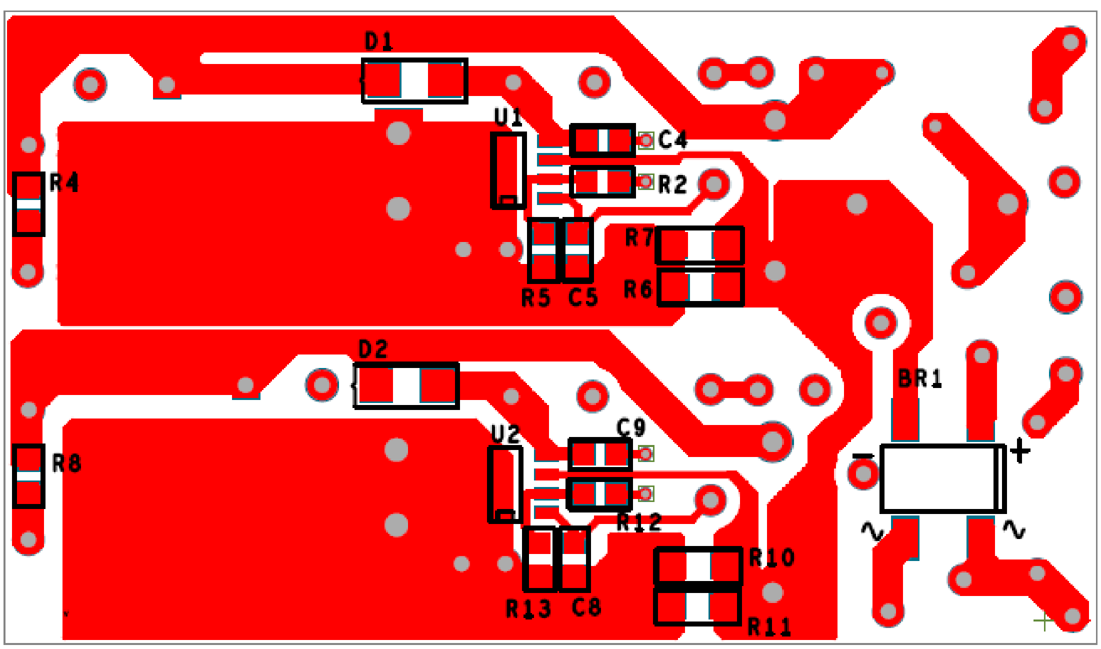

Figure 7 – Bottom Side.

6 Bill of Materials

Item	Ref Des	Qty	Description	Mfg Part Number	Manufacturer
1	BR1	1	800 V, 1 A, Bridge Rectifier, SMD, DFS	DF08S	Diodes, Inc.
2	C1	1	100 nF, 450 V, Polypropylene Film	ECW-F2W104JAQ	Panasonic
3	C2	1	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
4	C3	1	330 μF, 63 V, Electrolytic, (10 x 20)	EKMG630ELL331MJ20S	United Chemi-con
5	C4	1	100 pF, 500 V, Ceramic, NPO, 0805	501R15N101KV4T	Johanson Dielectrics
6	C5	1	10 μF, ±10%, 16V, X7R, Ceramic Capacitor	CL21B106KOQNNNE	Samsung
7	C6	1	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
8	C7	1	330 μF, 63 V, Electrolytic, (10 x 20)	EKMG630ELL331MJ20S	United Chemi-con
9	C8	1	10 μF, ±10%, 16V, X7R, Ceramic Capacitor	CL21B106KOQNNNE	Samsung
10	C9	1	100 pF, 500 V, Ceramic, NPO, 0805	501R15N101KV4T	Johanson Dielectrics
11	C10	1	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
12	D1	1	DIODE Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
13	D2	1	DIODE Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
14	FR1	1	RES, 4.7 Ω, 5%, 2 W, Wirewound, Fusible	FW20A4R70JA	Bourns
15	J1	1	0.250" (6.35 mm), Heat Sink	1287-ST	Keystone
16	J2	1	0.250" (6.35 mm), Heat Sink	1287-ST	Keystone
17	L1	1	1000 μH, 0.3 A	RLB0914-102KL	Bourns
18	R2	1	RES, 402 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4023V	Panasonic
19	R4	1	RES, 62 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ623V	Panasonic
20	R5	1	RES, 13.7 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1372V	Panasonic
21	R6	1	RES, SMD,0.51 Ω ±1% 0.5W	ERJ-8BQFR51V	Panasonic
22	R7	1	RES, 0.39 Ω 1/4W, 1%,Thick Film, 1206	ERJ-8RQFR39V	Panasonic
23	R8	1	RES, 62 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ623V	Panasonic
24	R10	1	RES, SMD, 0.51 Ω ±1% 0.5 W	ERJ-8BQFR51V	Panasonic
25	R11	1	RES, 0.39 Ω1/4W, 1%,Thick Film, 1206	ERJ-8RQFR39V	Panasonic
26	R12	1	RES, 402 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4023V	Panasonic
27	R13	1	RES, 13.7 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1372V	Panasonic
28	R15	1	RES, 75 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-75K	Yageo
29	R17	1	RES, 560 Ω, 5%, 1 W, Metal Oxide	RSF100JB-560R	Yageo
30	R18	1	RES, 3.3 Ω, 5%, 2 W, Metal Oxide	RSF200JB-3R3	Yageo
31	R19	1	RES, 75 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-75K	Yageo
32	R20	1	RES, 75 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-75K	Yageo
33	R21	1	RES, 75 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-75K	Yageo
34	R22	1	RES, 3.3 Ω, 5%, 2 W, Metal Oxide	RSF200JB-3R3	Yageo
35	RV1	1	275 VAC, 8.6 J, 5 mm, RADIAL	S05K275	Epcos
36	T3	1	Bobbin, EE1621, Vertical, 8 pins, 4pri, 4sec	EE-1621	Shen Zhen Xin Yu Jia Tech
37	T4	1	Bobbin, EE1621, Vertical, 8 pins, 4pri, 4sec	EE-1621	Shen Zhen Xin Yu Jia Tech
38	U1	1	LYTSwitch-7, Dimmable, SO-8	LYT7504D	Power Integrations
39	U2	1	LYTSwitch-7, Dimmable, SO-8	LYT7504D	Power Integrations

Miscellaneous

1	L	1	Test Point, BLK, Miniature Thru-Hole Mount	5001	Keystone
2	N	1	Test Point, WHT, Miniature Thru-Hole Mount	5002	Keystone
3	+V1	1	Test Point, RED, Miniature Thru-Hole Mount	5000	Keystone
4	-V1	1	Test Point, BLK, Miniature Thru-Hole Mount	5001	Keystone
5	+V2	1	Test Point, RED, Miniature Thru-Hole Mount	5000	Keystone
6	-V2	1	Test Point, BLK, Miniature Thru-Hole Mount	5001	Keystone

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7 Inductor Specification

7.1 *Electrical Diagram*

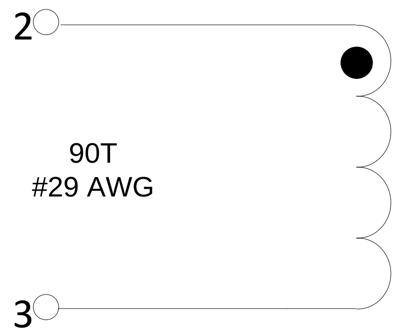

Figure 8 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 2 and pin 3, with all other windings open.	520 µH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE1621.
[2]	Bobbin: EE1621, Vertical, 8 pins.
[3]	Magnet Wire: #29 AWG.
[4]	Polyester Tape: 5.5 mm.
[5]	Transformer Tape: 6.5 mm.

7.4 *Inductor Build Diagram*

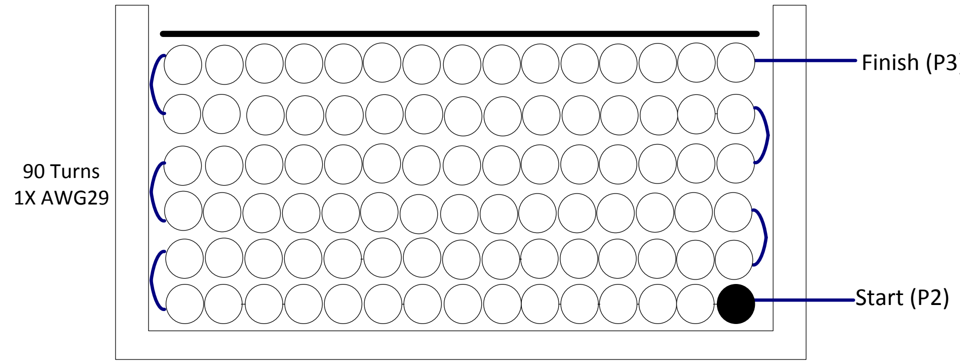

Figure 9 – Transformer Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pins are in the left side. The winding direction is clockwise as shown in the figure.
Winding 1	Use wire item [3], start at pin 2 and wind 90 turns, then finish the winding on pin 3.
Insulation	Add 2 layer of tape, item [4], for insulation.
Terminal Pins	Pull out terminal pins 1, 4, 5 and 6.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 520 μH.
Core Assembly	Assemble the 2 cores on the bobbin with the un-gapped core place on the terminal pin side as shown in the figure. Wrap the 2 cores with polyester tape item [5].
Finish	Dip the transformer assembly in 2:1 thinner and varnish solution.

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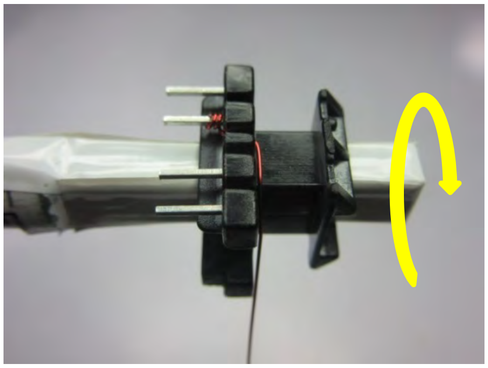
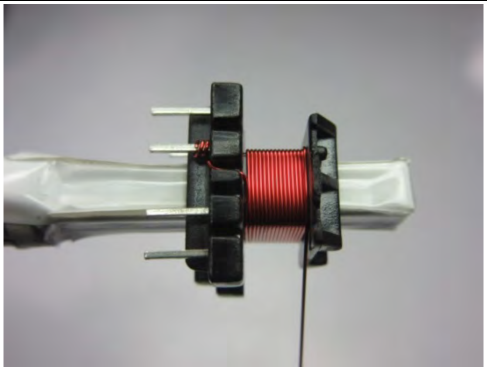
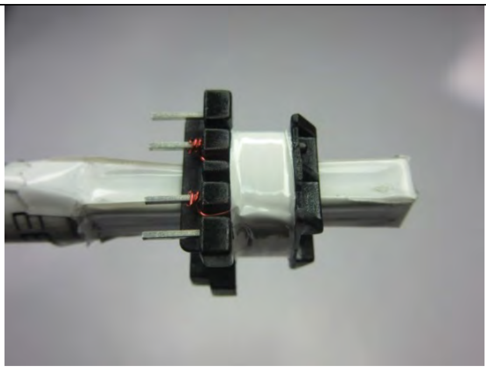
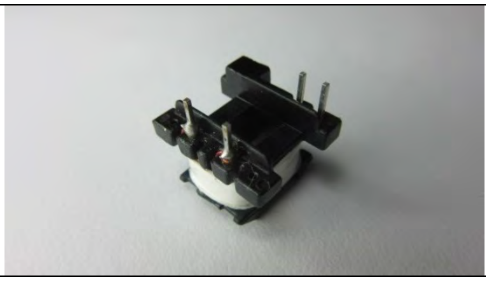
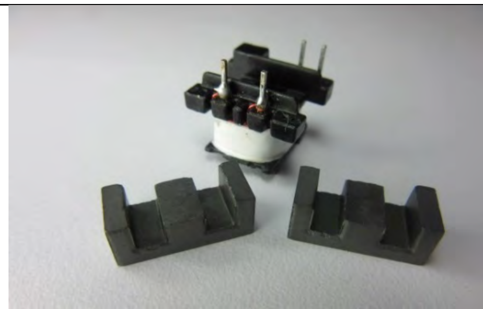
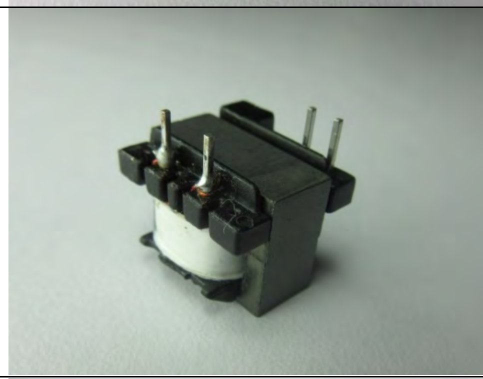
7.6 *Winding Illustrations*

Winding Directions		Bobbin is oriented on winder jig such that terminal pins are in the Left side. The winding direction is clockwise as shown in the figure.
Winding 1		Use wire item [3], start at pin 2 and wind 90 turns, then finish the winding on pin 3.
Insulation		Add 2 layer of tape, item [4], for insulation.
Terminal Pins		Pull out terminal pins 1, 4, 5 and 6.

Core Grinding		Grind the center leg of one core until it meets the nominal inductance of 520 μH.
Core Assembly		Assemble the 2 cores on the bobbin with the un-gapped core place on the terminal pin side as shown in the figure. Wrap the 2 cores with polyester tape item (5). See figure on the right side.
Finish		Dip the transformer assembly in 2:1 thinner and varnish solution.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch7_Buck_062416; Rev.0; Copyright Power Integrations 2016	INPUT	INFO	INFO	OUTPUT	OUTPUT
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMIN	100		100	Volts AC	Minimum AC line voltage
VACTYP	115		115	Volts AC	Typical AC line voltage
VACMAX	300		300	Volts AC	Maximum AC line voltage
fL	60		60	Hz	AC mains frequency
VO	52		52	Volts DC	Output Voltage
IO	380		380	Amperes	Average output current specification
EFFICIENCY	0.85		0.85		Efficiency estimate
PO			19.76	Watts	Continuous output power
VD	0.70		0.70	Volts DC	Output diode forward voltage drop
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	Volts DC	This Spreadsheet supports 725V device only
DEVICE CODE	LYT7504D		LYT7504D		Actual LYTSwitch-7 device
ILIMITMIN			1.61	Amperes	Minimum Current Limit
ILIMITTYP			1.75	Amperes	Typical Current Limit
ILIMITMAX			1.88	Amperes	Maximum Current Limit
TON			6.60	us	On-time during the fixed on-time region at VACTYP
FSW			50	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.89		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	EE1621		EE1621		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			25.00	mm^2	Core effective cross cectional area
LE			35.00	mm	Core effective path length
AL			2600.00	nH/turn^2	Core ungapped effective inductance
AW			15.00	mm^2	Window Area of the bobbin
BW			5.00	mm	Bobbin physical winding width
LAYERS	6		6.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN_ABSOLUTE			331	uH	Absolute minimum design inductance
LP_TYP	520	Warning	520	uH	Typical design inductance
LP_TOLERANCE	5		5	%	Tolerance of the design inductance
LP_MAX			387	uH	Absolue maximum design inductance
TURNS	90		90	Turns	Number of inductor turns
ALG			64.20	nH/turn^2	Inductance per turns squared
BMAX			3907	Gauss	Operating maximum flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.477	mm	Core air gap
BWE			30	mm	Effective bobbin width
OD			0.33	mm	Outer diameter of the wire with insulation
INS			0.06	mm	Wire insulation
DIA			0.28	mm	Outer diameter of the wire without insulation
AWG	29		29		AWG of the bare wire.
CM			128	Cmils	Bare wire circular mils
CMA			240	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			6.1	A/mm^2	Bare wire current density

BOBBIN FILL FACTOR			66.67%		Area of the bobbin occupied by wire
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.37	Amperes	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			1.37	Amperes	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.32	Amperes	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.43	Amperes	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.53	Amperes	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.205	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.205	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Resistor					
RUPPER			402.00	kOhms	Upper resistor on the M-pin divider network (E96 / 1%)
RLOWER	13.7		13.70	kOhms	Lower resistor on the M-pin divider network (E96 /1%)
VO_OVP		Info	72.1	V	VO_OVP is 1.39 * VO.
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			10	uF	BP Capacitor
RBP			146.4	kOhms	Recommended Pull-up Resistor from DC Bus to BP pin
VOLTAGE STRESS PARAMETERS					
VDRAIN			424	Volts DC	Estimated worst case drain voltage
PIVD			424	Volts DC	Output Rectifier Maximum Peak Inverse Voltage

Note: The LYTSwitch-7 family of ICs is optimized for single line operation. Warning and info tags in the inductor spreadsheet are due to universal operation. The design was done to optimize regulation at highline and dimming performance at low line.

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9 Performance Data

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

9.1 *Efficiency*

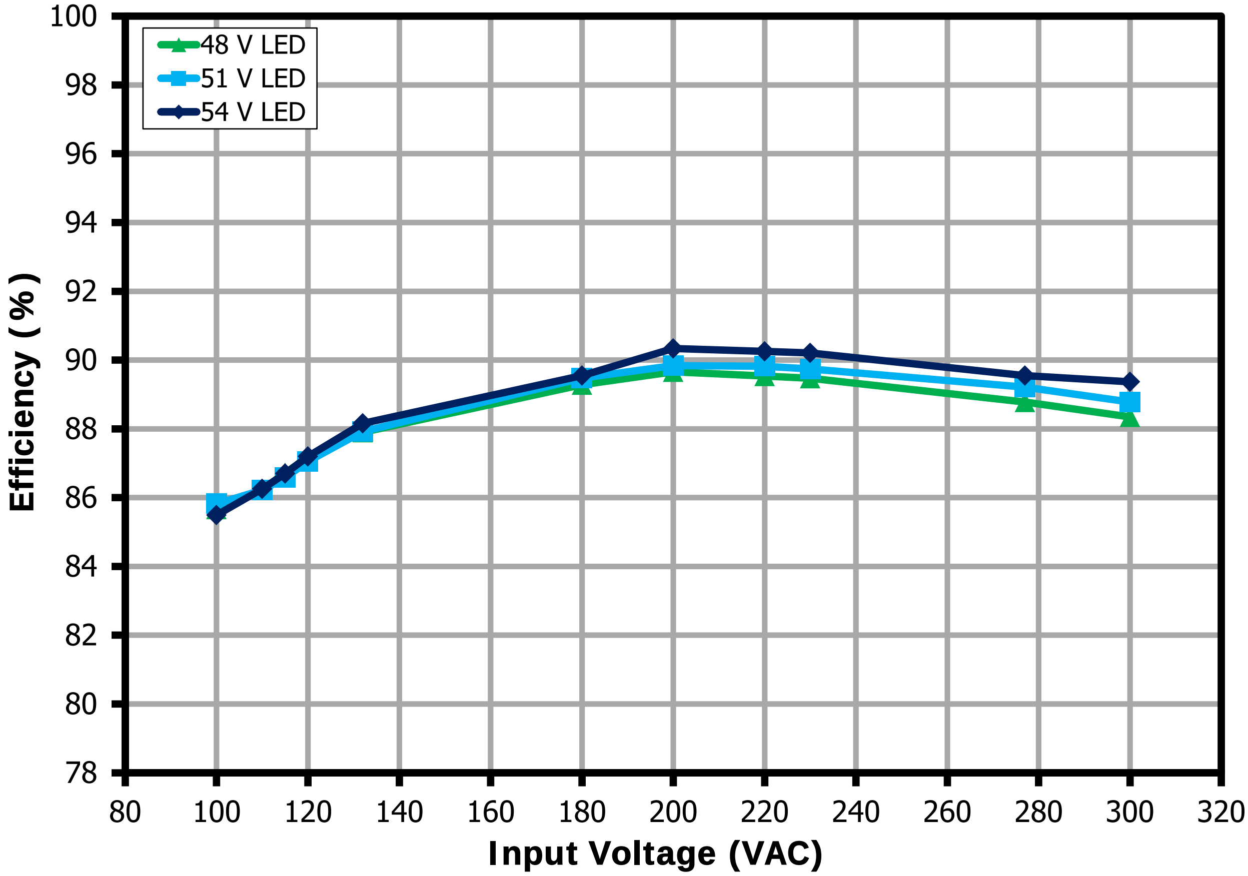

Figure 10 – Efficiency vs. Line and LED Load.

9.2 *Line Regulation*

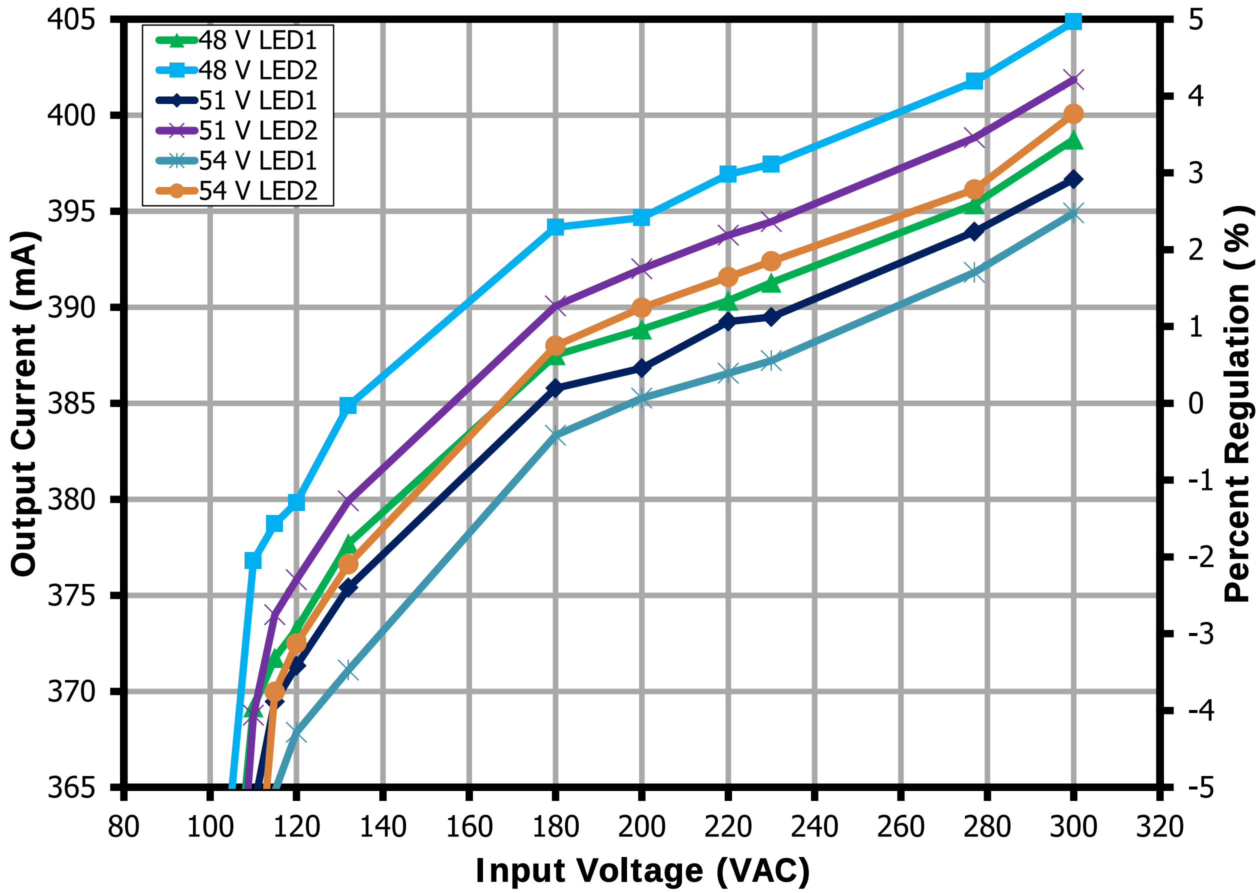

Figure 11 – Regulation vs. Line and LED Load.

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9.3 *Power Factor*

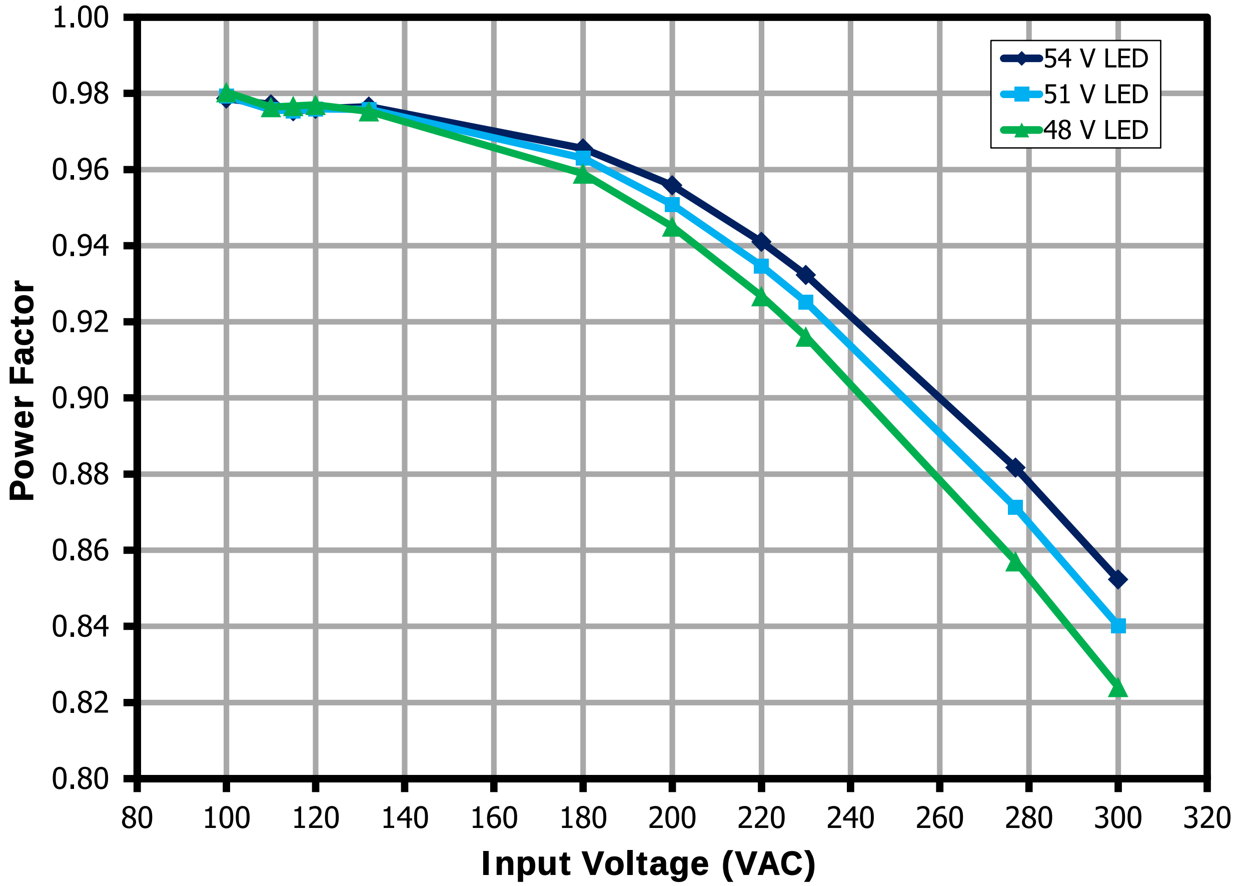

Figure 12 – Power Factor vs. Line and LED Load.

9.4 *%ATHD*

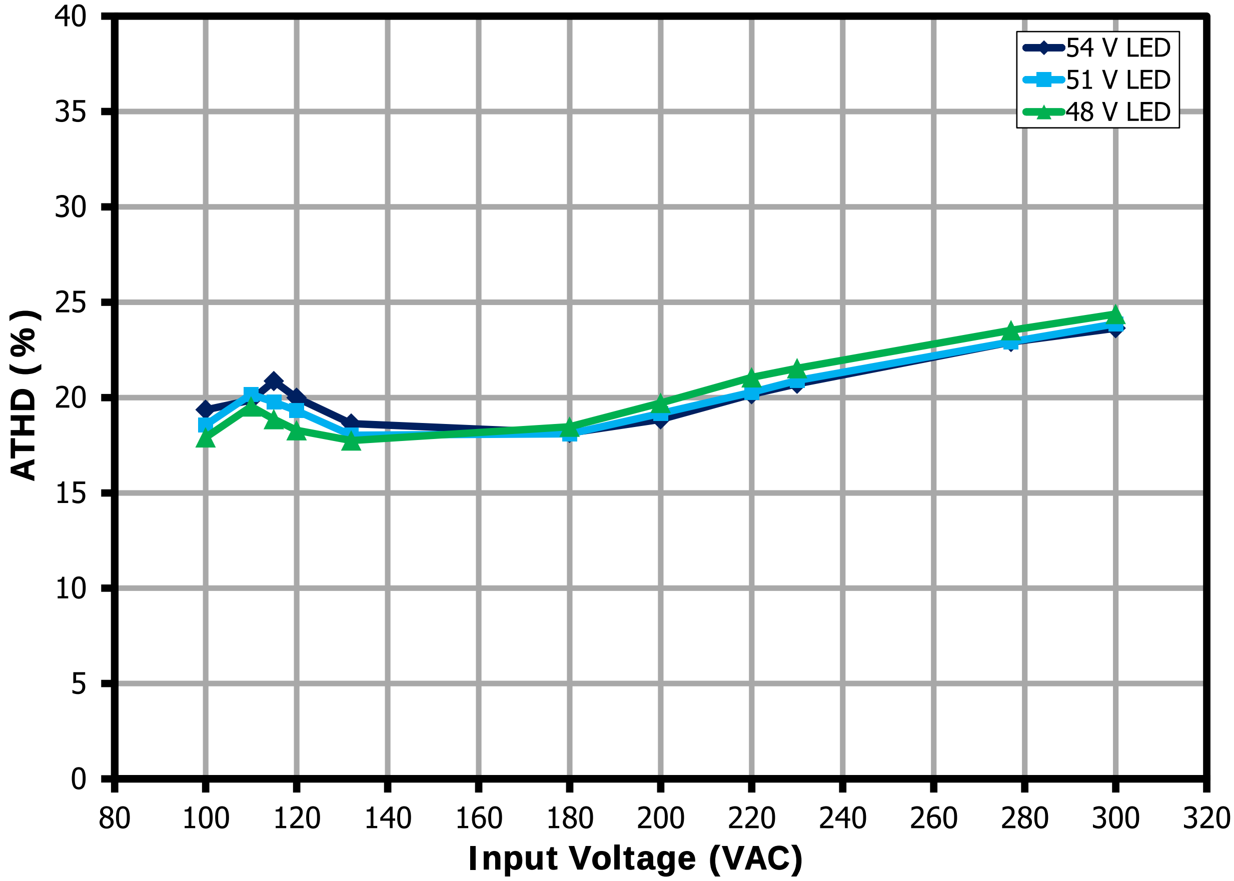

Figure 13 – %ATHD vs. Line and LED Load.

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10 Test Data

10.1 *Test Data, 54 V LED Loads*

Input		Input Measurement					LED Load1 Measurement			LED Load2 Measurement			P_{OUT} Total	Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT1} (V_{DC})	I_{OUT1} (mA_{DC})	P_{OUT1} (W)	V_{OUT2} (V_{DC})	I_{OUT2} (mA_{DC})	P_{OUT2} (W)		
100	60	99.85	402.53	39.28	0.98	19.75	52.28	320.11	16.76	52.41	324.24	17.02	33.79	86.03
110	60	109.87	409.59	43.93	0.98	20.06	53.41	352.04	18.83	53.50	356.81	19.12	37.96	86.40
115	60	114.92	408.88	45.77	0.97	20.97	53.84	364.80	19.67	53.91	369.97	19.97	39.65	86.62
120	60	119.89	393.76	46.01	0.97	20.22	53.93	367.86	19.87	53.96	372.50	20.13	40.00	86.94
132	60	131.88	357.46	45.99	0.98	18.82	54.04	371.11	20.08	54.09	376.61	20.40	40.48	88.02
180	50	179.92	269.92	46.93	0.97	17.77	54.49	383.33	20.93	54.47	388.00	21.17	42.10	89.70
200	50	199.96	245.88	46.99	0.96	18.53	54.55	385.26	21.05	54.52	389.97	21.30	42.35	90.12
220	50	219.91	227.99	47.18	0.94	19.72	54.59	386.56	21.14	54.56	391.57	21.40	42.54	90.15
230	50	229.93	220.67	47.32	0.93	20.15	54.61	387.22	21.18	54.58	392.39	21.45	42.63	90.08
277	50	276.96	197.23	48.24	0.88	22.27	54.78	391.82	21.50	54.70	396.13	21.70	43.20	89.54
300	50	300.00	190.92	48.96	0.85	23.24	54.90	394.90	21.71	54.83	400.07	21.97	43.68	89.21

10.2 *Test Data, 51 V LED Loads*

Input		Input Measurement					LED Load1 Measurement			LED Load2 Measurement			P_{OUT} Total	Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT1} (V_{DC})	I_{OUT1} (mA_{DC})	P_{OUT1} (W)	V_{OUT2} (V_{DC})	I_{OUT2} (mA_{DC})	P_{OUT2} (W)		
100	60	99.85	395.33	38.66	0.98	18.56	49.29	333.73	16.48	49.27	338.21	16.70	33.18	85.82
110	60	109.87	399.20	42.80	0.98	20.17	50.29	363.84	18.33	50.26	368.76	18.57	36.90	86.22
115	60	114.93	386.92	43.38	0.98	19.77	50.45	369.46	18.67	50.41	373.99	18.88	37.56	86.58
120	60	119.90	370.86	43.40	0.98	19.31	50.50	371.32	18.78	50.46	375.81	18.99	37.78	87.05
132	60	131.88	338.39	43.55	0.98	18.03	50.64	375.40	19.04	50.58	379.92	19.25	38.29	87.92
180	50	179.93	255.48	44.27	0.96	18.10	51.00	385.78	19.71	50.91	390.07	19.90	39.61	89.48
200	50	199.97	232.95	44.29	0.95	19.17	51.02	386.83	19.77	50.97	392.00	20.02	39.79	89.84
220	50	219.91	216.94	44.59	0.93	20.27	51.10	389.26	19.93	51.02	393.75	20.12	40.05	89.82
230	50	229.93	210.09	44.69	0.93	20.89	51.11	389.49	19.94	51.04	394.45	20.17	40.11	89.74
277	50	276.96	188.93	45.59	0.87	22.92	51.26	393.93	20.23	51.18	398.83	20.45	40.67	89.21
300	50	300.00	183.43	46.23	0.84	23.86	51.36	396.67	20.41	51.28	401.85	20.64	41.04	88.78

10.3 *Test Data, 48 V LED Loads*

Input		Input Measurement					LED Load1 Measurement			LED Load2 Measurement			P_{OUT} Total	Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT1} (V_{DC})	I_{OUT1} (mA_{DC})	P_{OUT1} (W)	V_{OUT2} (V_{DC})	I_{OUT2} (mA_{DC})	P_{OUT2} (W)		
100	60	99.85	385.74	37.76	0.98	17.90	46.23	345.84	16.02	46.16	352.85	16.32	32.35	85.66
110	60	109.88	378.99	40.66	0.98	19.53	46.94	369.17	17.36	46.87	376.80	17.70	35.06	86.23
115	60	114.93	362.61	40.71	0.98	18.87	46.99	371.74	17.50	46.91	378.72	17.80	35.30	86.72
120	60	119.91	347.09	40.66	0.98	18.29	47.03	373.22	17.58	46.93	379.83	17.86	35.44	87.17
132	60	131.89	318.37	40.95	0.98	17.75	47.16	377.69	17.85	47.08	384.87	18.15	36.00	87.90
180	50	179.93	241.12	41.60	0.96	18.47	47.47	387.51	18.44	47.35	394.17	18.71	37.14	89.28
200	50	199.97	219.84	41.54	0.95	19.72	47.51	388.85	18.51	47.36	394.66	18.73	37.24	89.66
220	50	219.91	205.30	41.84	0.93	21.06	47.55	390.35	18.60	47.42	396.92	18.86	37.46	89.53
230	50	229.93	199.20	41.96	0.92	21.54	47.58	391.28	18.65	47.43	397.45	18.89	37.54	89.47
277	50	276.96	180.49	42.85	0.86	23.53	47.71	395.37	18.90	47.56	401.76	19.14	38.04	88.78
300	50	300.00	175.95	43.50	0.82	24.38	47.82	398.74	19.10	47.65	404.86	19.33	38.43	88.34

11 Dimming Performance Data

Agilent 6812B AC source programmed as a leading-edge dimmer and Yokogawa WT310E for input and output measurements are used for the following tests.

11.1 *Dimming Curve*

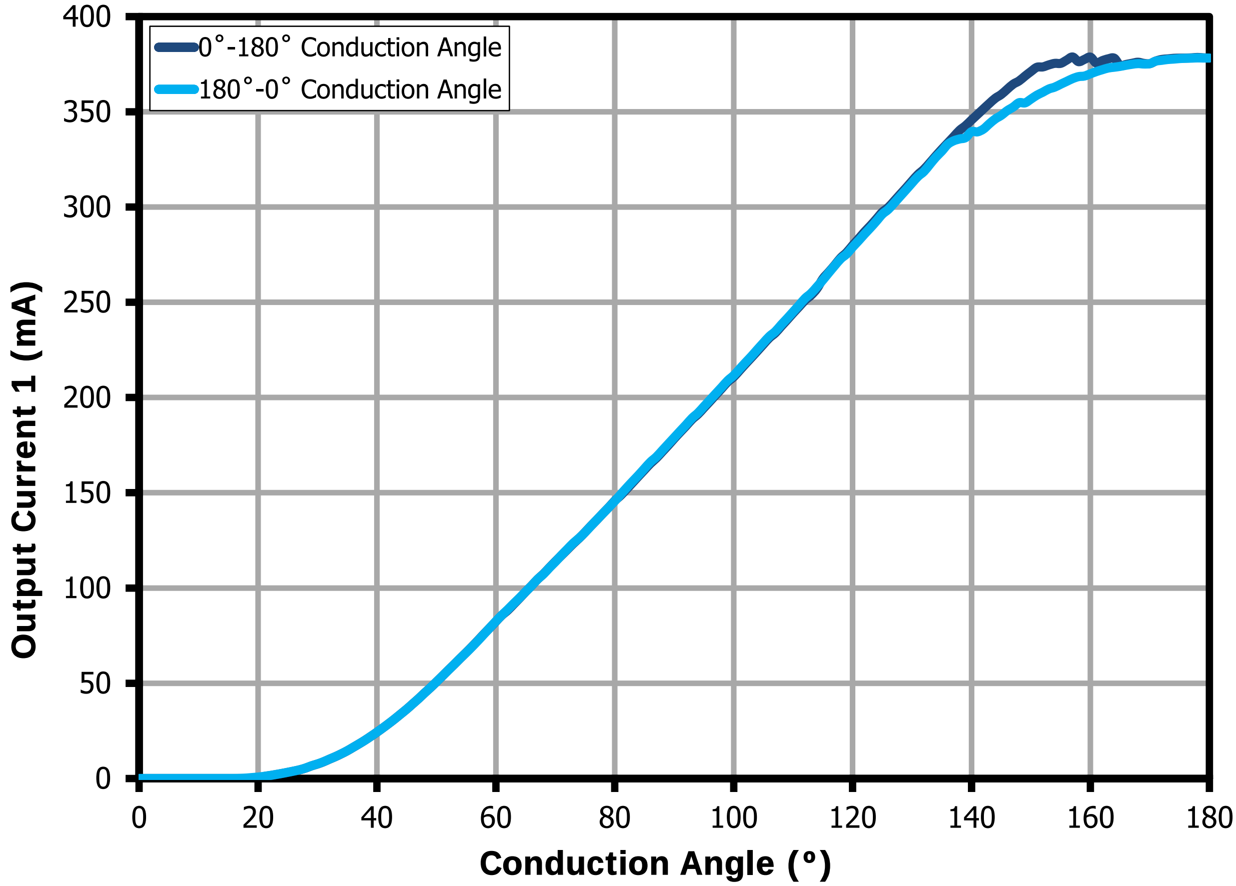

Figure 14 – Dimming Curve, Output Current 1 at 120 VAC, 60 Hz Input.

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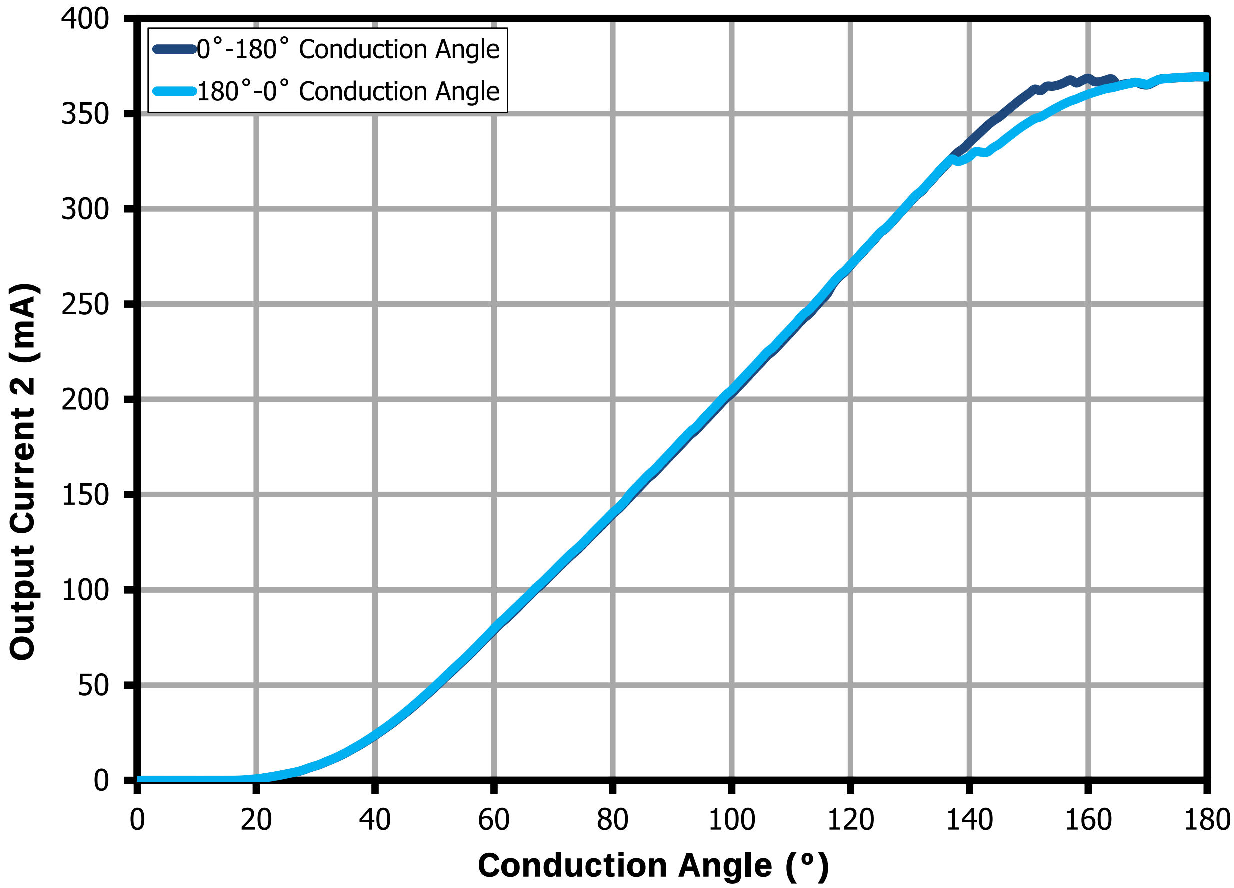

Figure 15 – Dimming Curve, Output Current 2 at 120 VAC, 60 Hz Input.

11.2 *Dimming Efficiency*

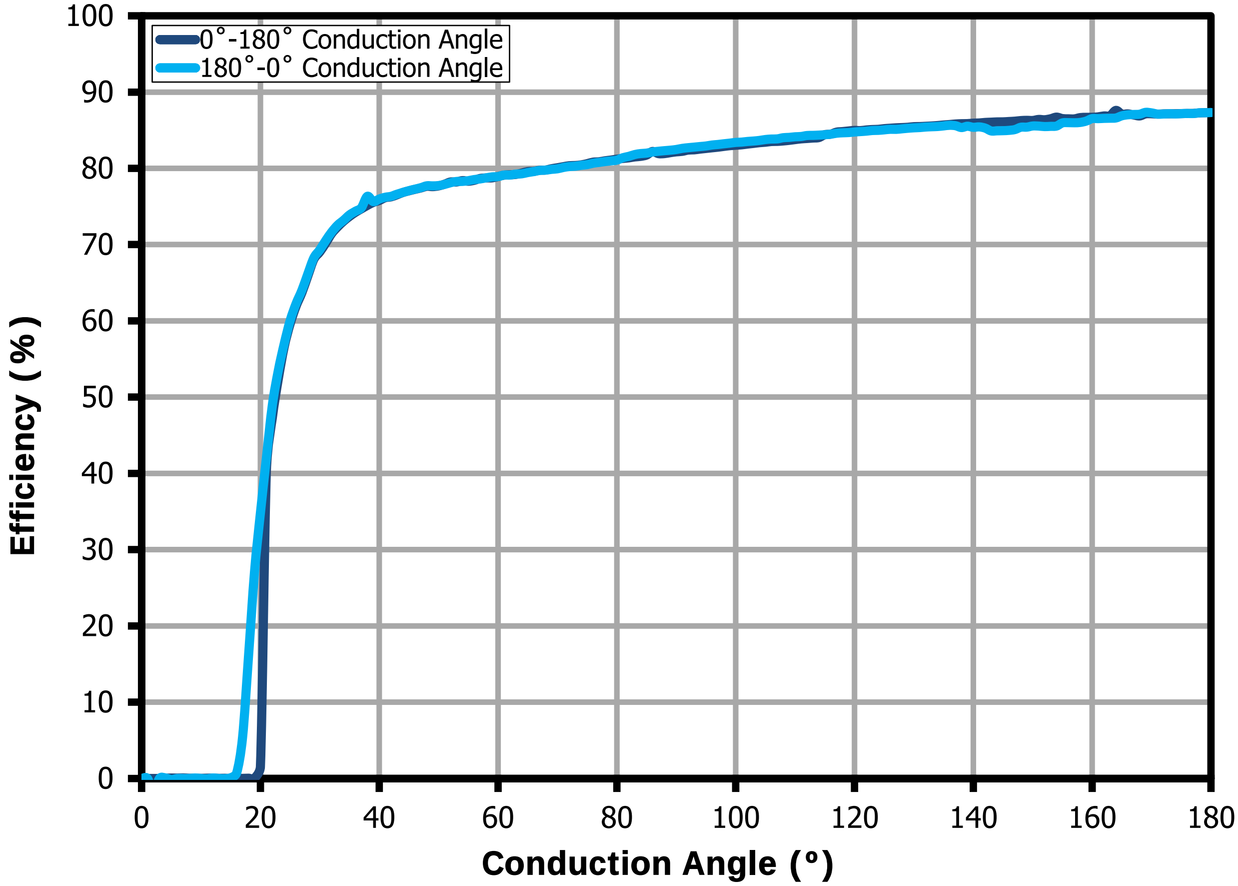

Figure 16 – Dimming Efficiency at 120 VAC, 60 Hz Input.

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11.3 *Driver Power Loss During Dimming*

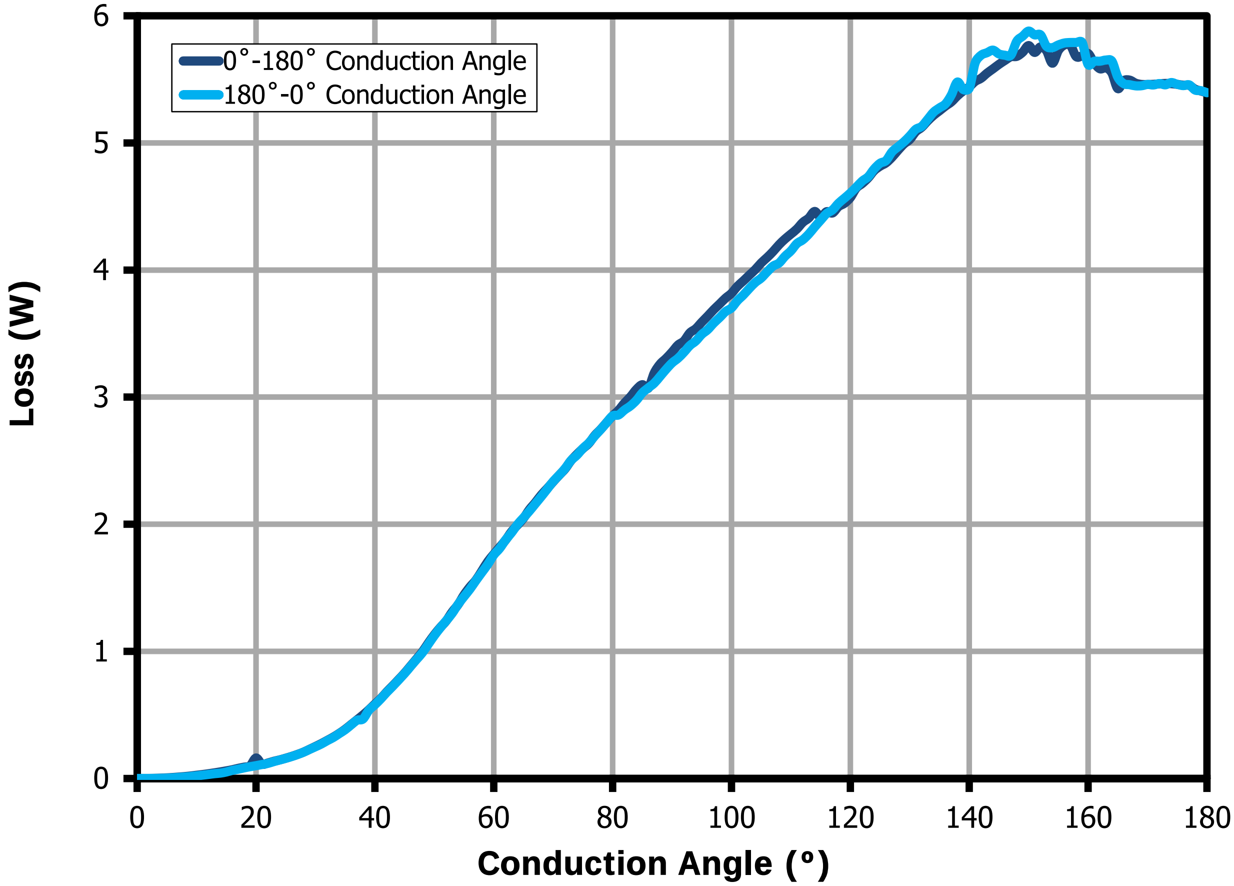

Figure 17 – Dimming Power Loss at 120 VAC, 60 Hz Input.

11.4 *Dimmer Compatibility List*

The following dimmers were tested at 25 ºC ambient temperature with 120 V, 60 Hz line input and 52 V LED loads.

No	Brand	Model	Type	Max 1 (mA)	Min 1 (mA)	Max 2 (mA)	Min 2 (mA)	Remarks
1	LEVITON	1PE04-1LZ	T	271.89	7.724	311.2	25.1	No flicker/shimmer
2	LUTRON	AYCL-153P-WH	L	343.21	63.79	361.1	74.33	No flicker/shimmer
3	LUTRON	SCL-153P-WH	L	343.43	65.89	360.9	74.8	No flicker/shimmer
4	LUTRON	RRD-10ND-WH	L	318.47	4.044	344.04	16.8	No flicker/shimmer
5	LUTRON	RRD-6NA-WH	T	321.29	3.253	347.6	31.6	No flicker/shimmer
6	LUTRON	TGCL-153PH-WH	L	347.64	58.1	360.1	67.8	No flicker/shimmer
7	LEVITON	IPL06	L	333.31	18.47	355.4	34.3	No flicker/shimmer
8	LUTRON	SLV-603P-WH	L	341.57	18.024	359.3	22.42	No flicker/shimmer
9	LUTRON	TGCL-153PH-WH	L	348.18	42.89	359.8	50.53	No flicker/shimmer
10	LUTRON	MRF2-6ND-120-BI	L	321.11	13.183	304.1	14.96	No flicker/shimmer
11	LUTRON	D-600P-WH	L	345.7	10.8	359.1	11.3	No flicker/shimmer
12	LUTRON	AYLV-600P-WH	L	344.44	32.93	359.5	20.8	No flicker/shimmer
13	LUTRON	DVLV-103P-WH	L	334.49	9.7	356.1	11.5	No flicker/shimmer
14	LUTRON	GL-600-WH	L	342.58	54.73	359.8	97.9	No flicker/shimmer
15	LEVITON	R02-06613-PLW	L	347.42	8.9	367.4	10.8	No flicker/shimmer
16	LEVITON	R62-RP106-1LW	L	346.61	35.33	367.6	46	No flicker/shimmer
17	LUTRON	S-1000-WH	L	347.04	13.75	367.5	29.8	No flicker/shimmer
18	LUTRON	S-600PH-WH	L	343.69	13.74	359.8	23.5	No flicker/shimmer
19	LUTRON	S-600PNLH-WH	L	344.62	15.4	359.5	21.7	No flicker/shimmer
20	LUTRON	S-600-WH	L	343.41	30	359.2	76.33	No flicker/shimmer
21	LUTRON	SPSELV-600-WH	L	331.94	38.23	348.3	44.8	No flicker/shimmer
22	LEVITON	601-6631-I	L	370.8	16.8	362.1	24.28	No flicker/shimmer
23	LEVITON	6681	L	375.3	37.4	367.4	39.74	No flicker/shimmer
24	LEGRAND	HLV703PW	L	373	5.52	363.3	6.04	No flicker/shimmer
25	LEVITON	6615	T	349.3	38.46	339.4	39.3	No flicker/shimmer

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12 Thermal Performance Scan – Open Frame Unit

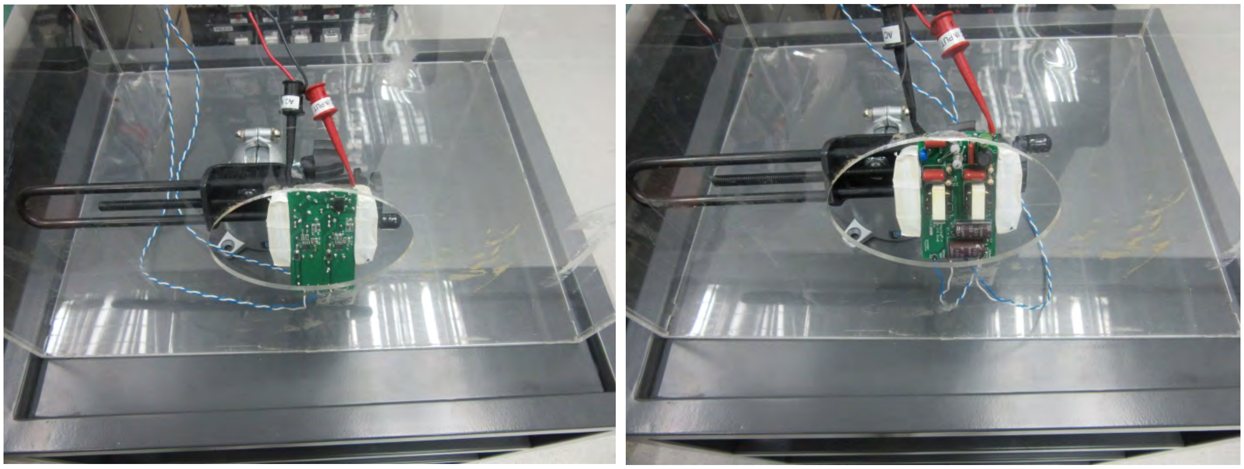

Figure 18 – Test Set-up Picture - Open Frame: Bottom Side (Left), Top Side (Right).

Unit in open frame was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR thermal camera. The ambient temperature is around 30 ºC.

12.1 *Non-Dimming, 120 VAC Input, 52 V LED Loads*

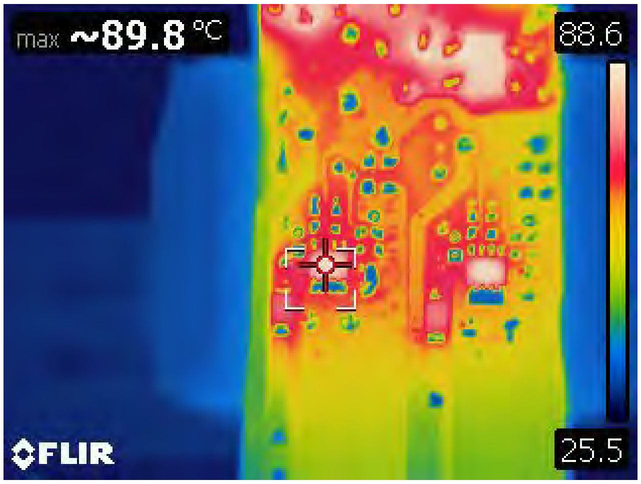

Figure 19 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U1): 89.8 ºC.

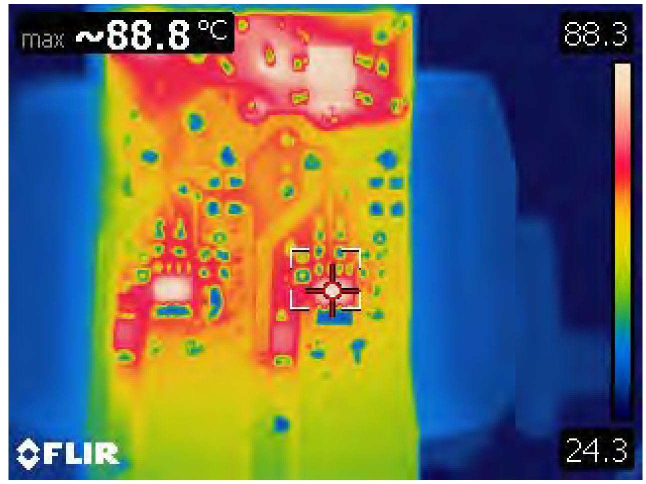

Figure 20 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U2): 88.8 ºC.

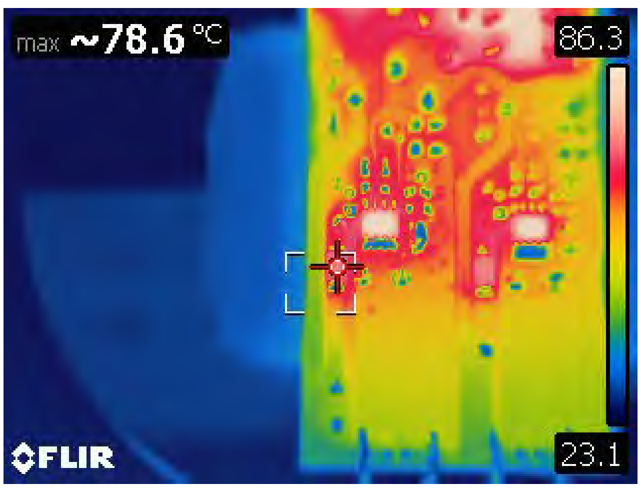

Figure 21 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D1): 78.6 ºC.

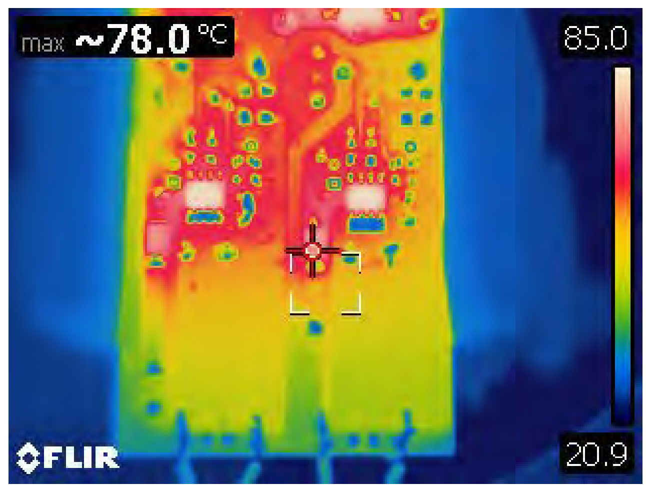

Figure 22 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D2): 78.0 ºC.

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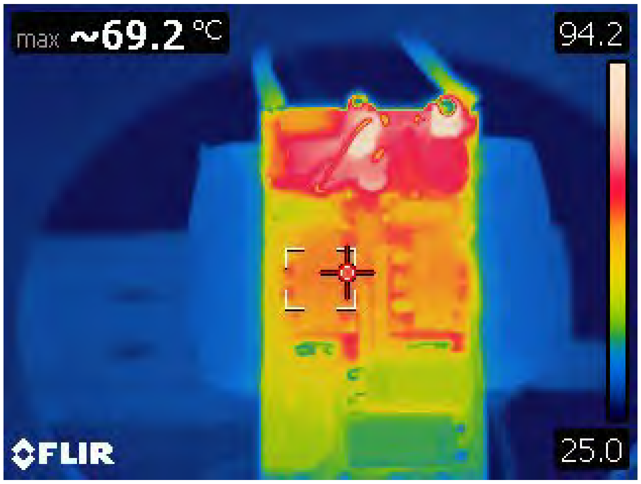

Figure 23 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T3): 69.2 ºC.

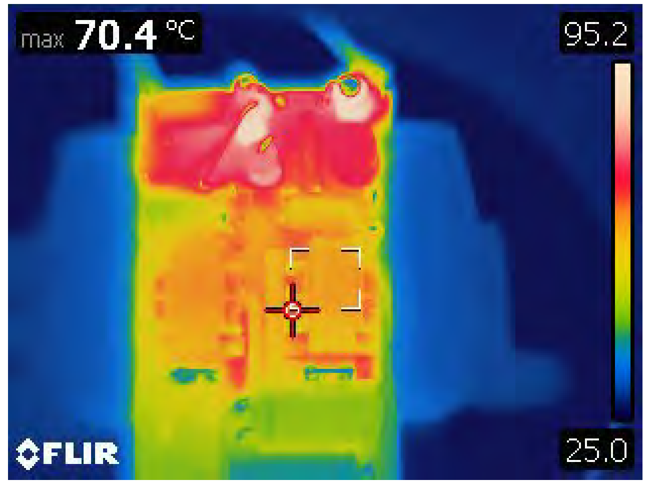

Figure 24 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T4): 70.4 ºC.

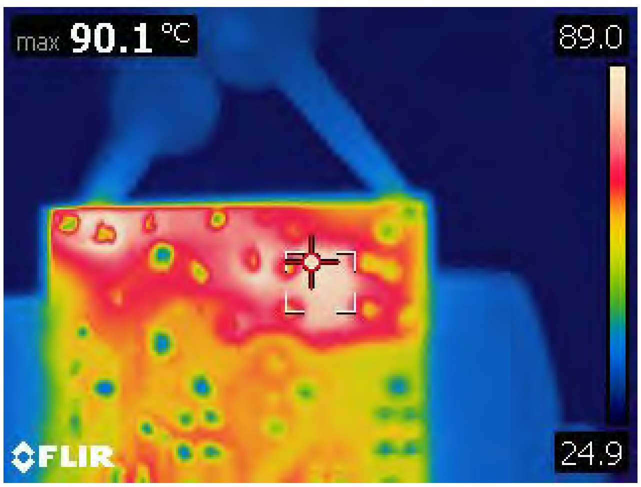

Figure 25 – 120 VAC, 52 V LED Loads.
Spot 1: Bridge Diode (BR1): 90.1 ºC.

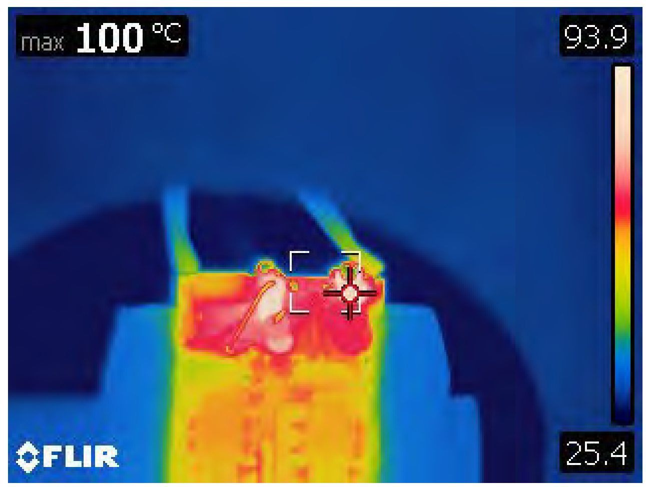

Figure 26 – 120 VAC, 52 V LED Loads.
Spot 1: Fusible Resistor (FR1): 100 ºC.

12.2 *Non-Dimming, 230 VAC Input, 52 V LED Loads*

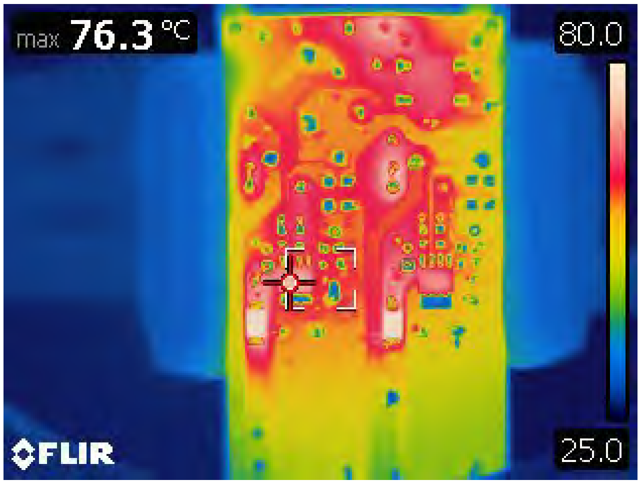

Figure 27 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U1): 76.3 ºC.

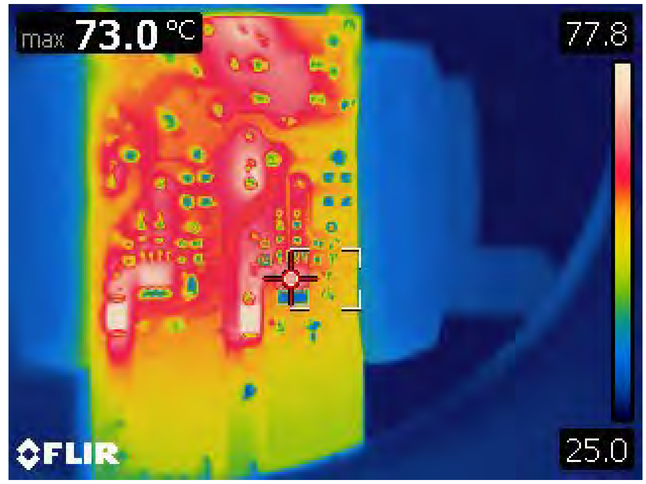

Figure 28 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U2): 73.0 ºC.

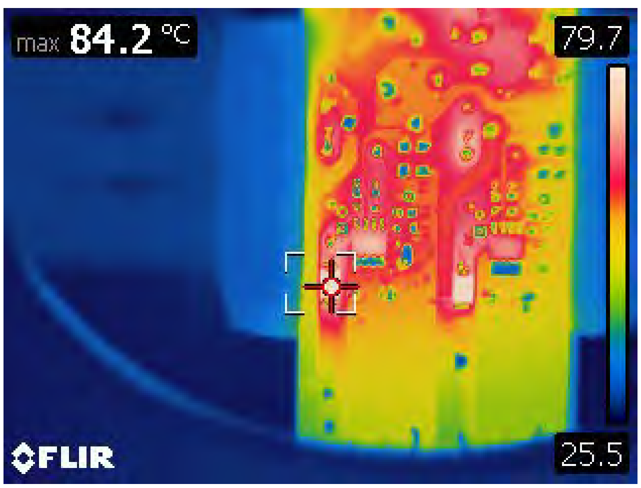

Figure 29 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D1): 84.2 ºC.

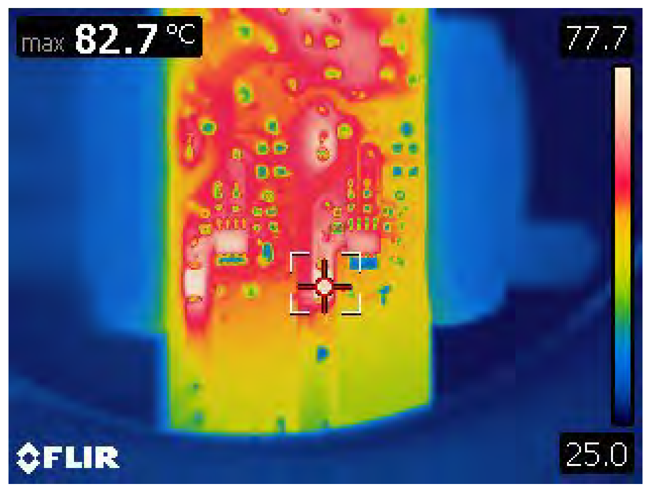

Figure 30 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D2): 82.7 ºC.

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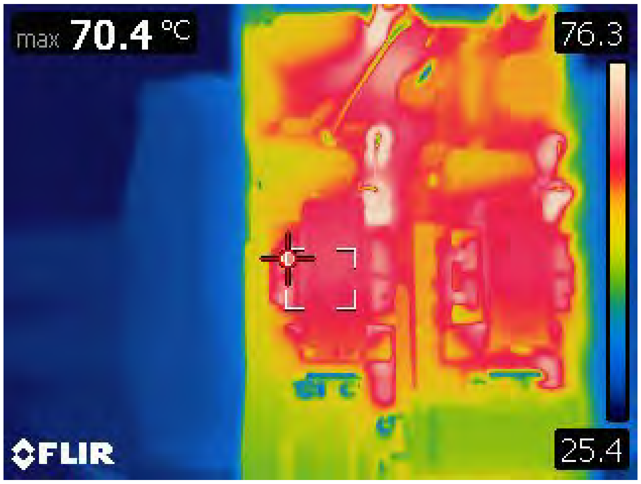

Figure 31 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T3): 70.4ºC.

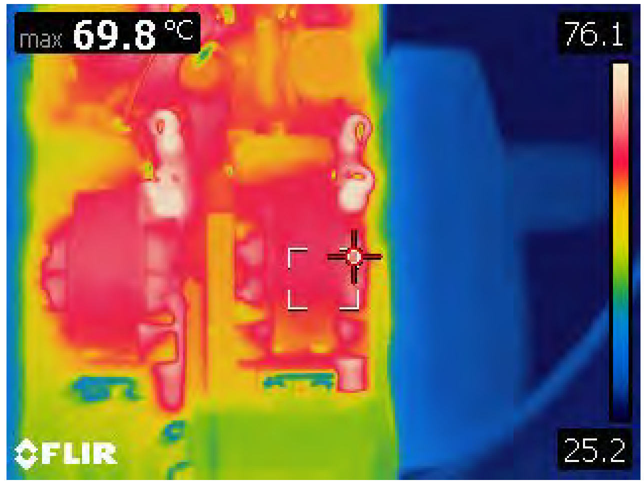

Figure 32 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T4): 69.8 ºC.

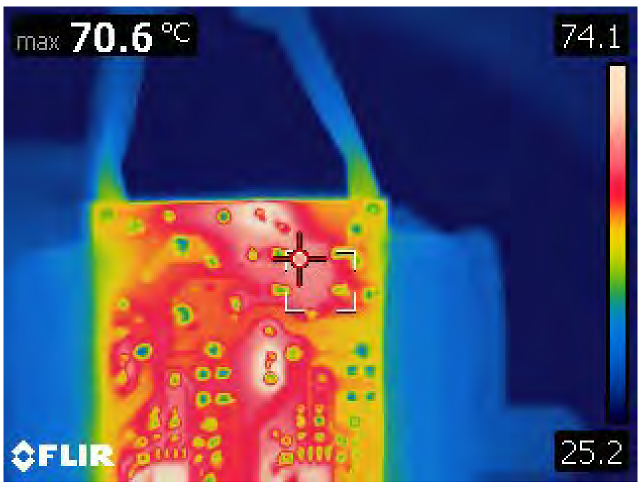

Figure 33 – 120 VAC, 52 V LED Loads.
Spot 1: Bridge Diode (BR1): 70.6 ºC.

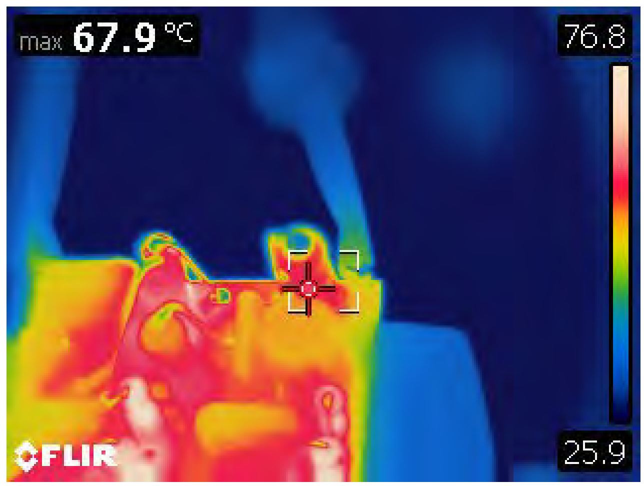

Figure 34 – 120 VAC, 52 V LED Loads.
Spot 1: Fusible Resistor (FR1): 67.9 ºC.

12.3 *Non-Dimming, Output Short-Circuit at 120 VAC Input*

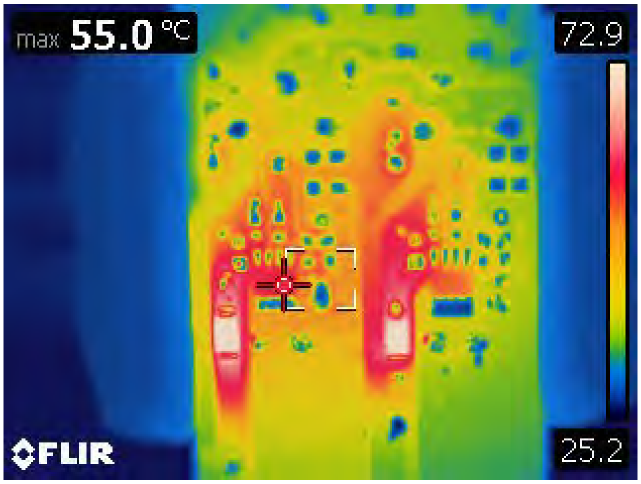

Figure 35 – 120 VAC, Output Short.
Spot 1: LYT7504D (U1): 55.0 ºC.

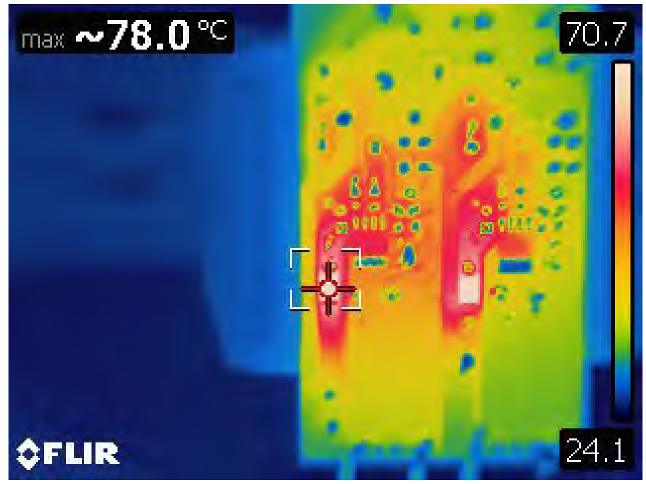

Figure 36 – 120 VAC, Output Short.
Spot 1: Flywheel Diode (D1): 78.0 ºC.

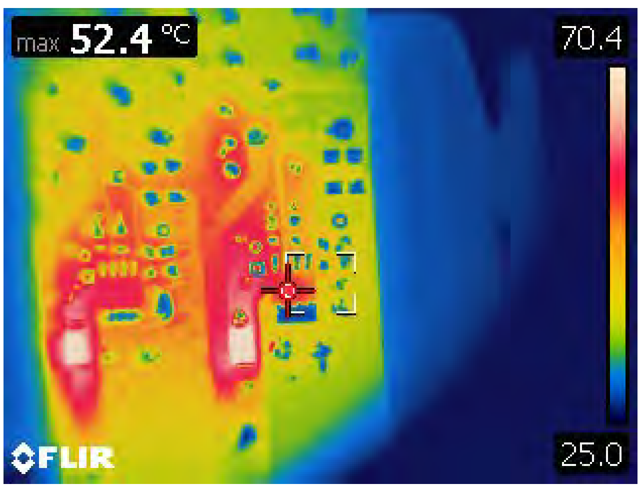

Figure 37 – 120 VAC, Output Short.
Spot 1: LYT7504D (U2): 52.4 ºC.

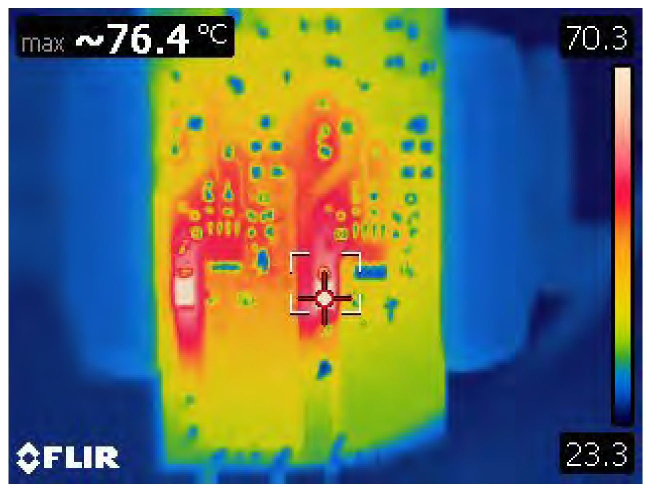

Figure 38 – 120 VAC, Output Short.
Spot 1: Flywheel Diode (D2): 76.4 ºC.

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12.4 *Dimming, 120 VAC Input, 52 V LED Loads, 150° Conduction Angle*

A TRIAC dimmer is used to set the conduction angle at 150° where the maximum dimming loss occurs.

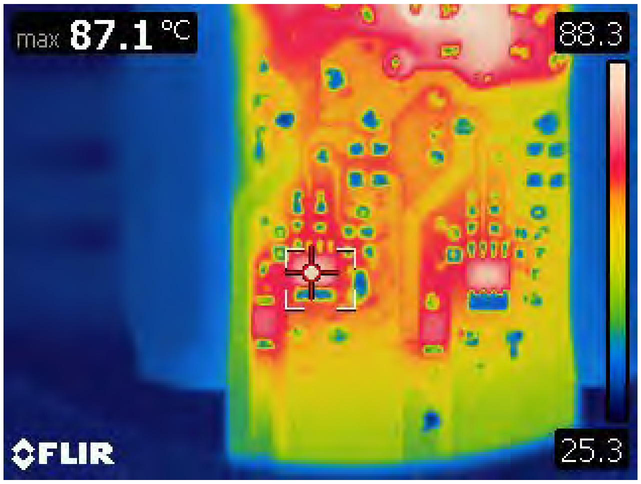

Figure 39 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U1): 87.1 ºC.

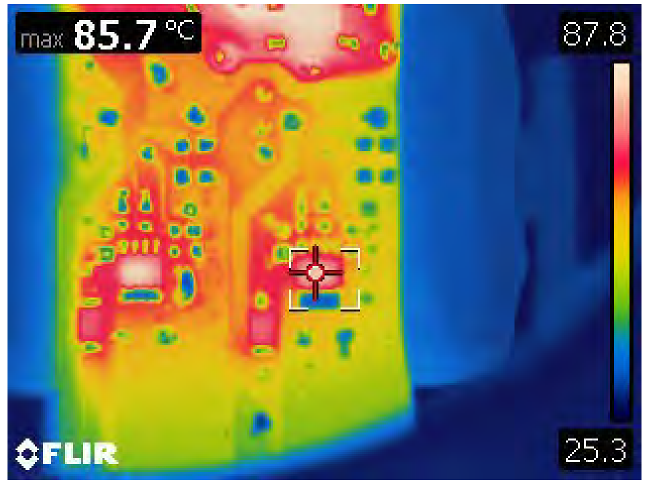

Figure 40 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U2): 85.7 ºC.

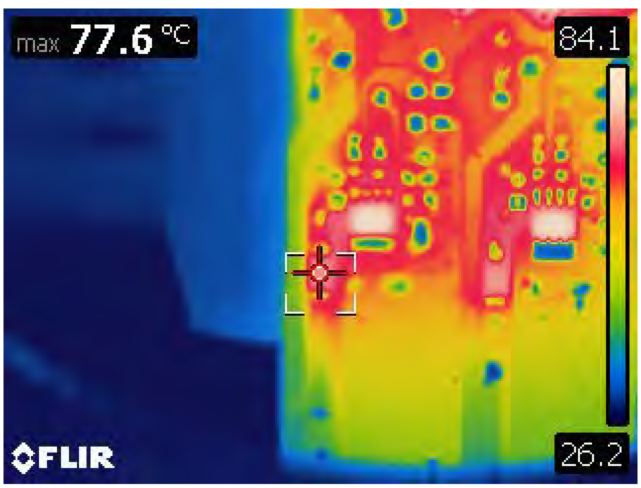

Figure 41 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D1): 77.6 ºC.

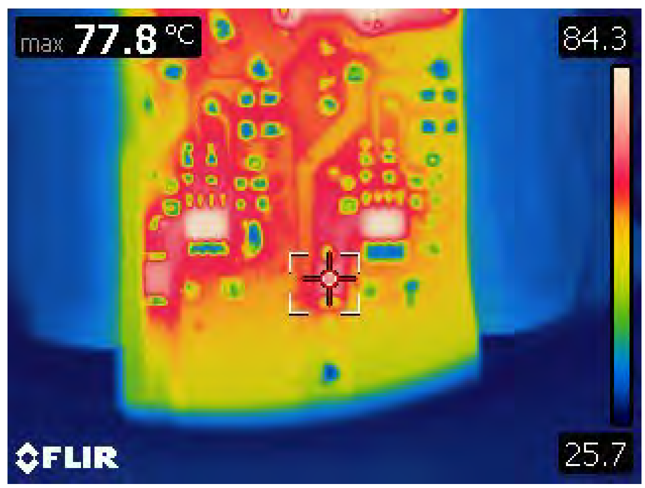

Figure 42 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D2): 77.8 ºC.

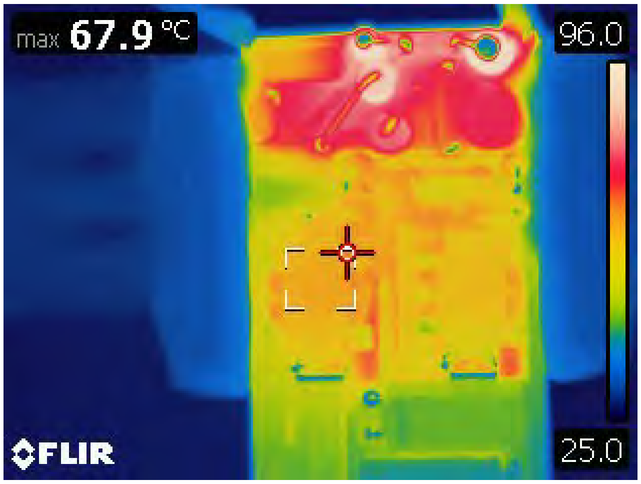

Figure 43 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T3): 67.9 ºC.

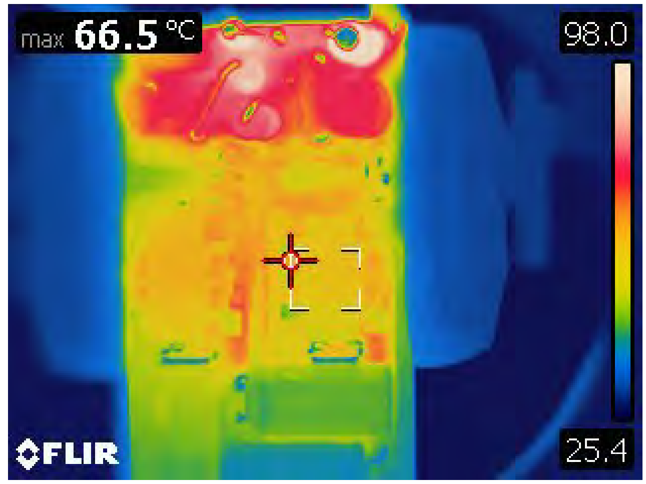

Figure 44 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T4): 66.5 ºC.

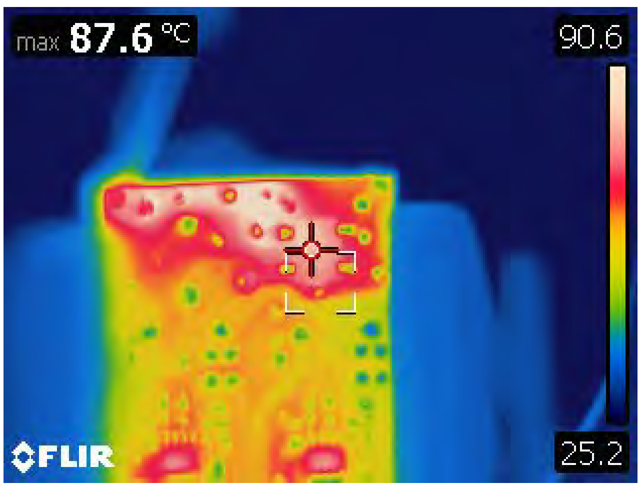

Figure 45 – 120 VAC, 52 V LED Loads.
Spot 1: Bridge Diode (BR1): 87.6 ºC.

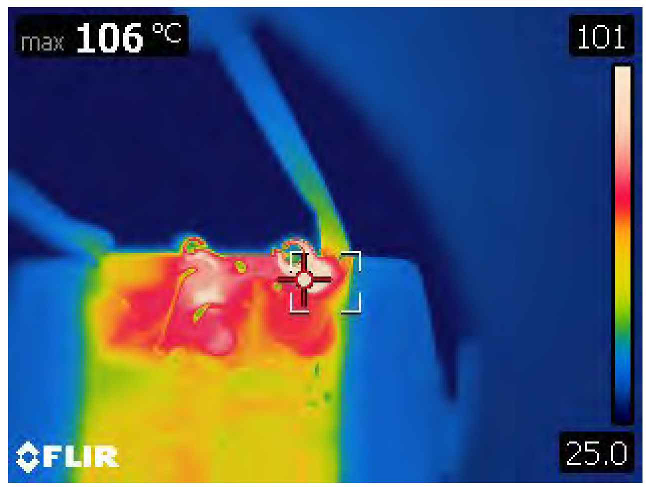

Figure 46 – 120 VAC, 52 V LED Loads.
Spot 1: Fusible Resistor (FR1): 106 ºC.

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12.5 *Dimming, 120 VAC Input, 52 V LED Loads, Maximum Conduction Angle*

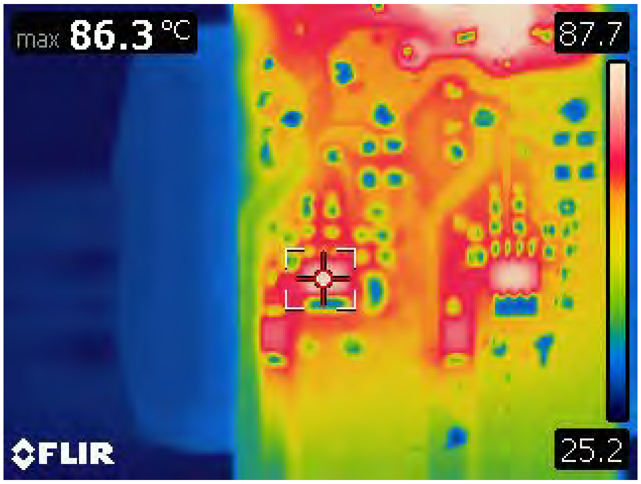

Figure 47 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U1): 86.3 ºC.

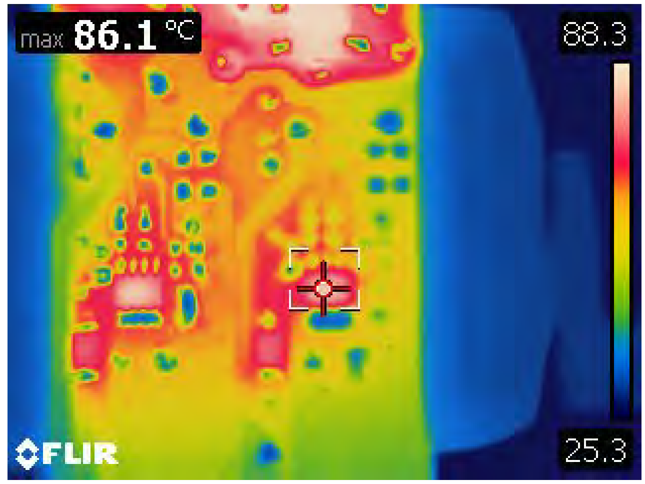

Figure 48 – 120 VAC, 52 V LED Loads.
Spot 1: LYT7504D (U2): 86.1 ºC.

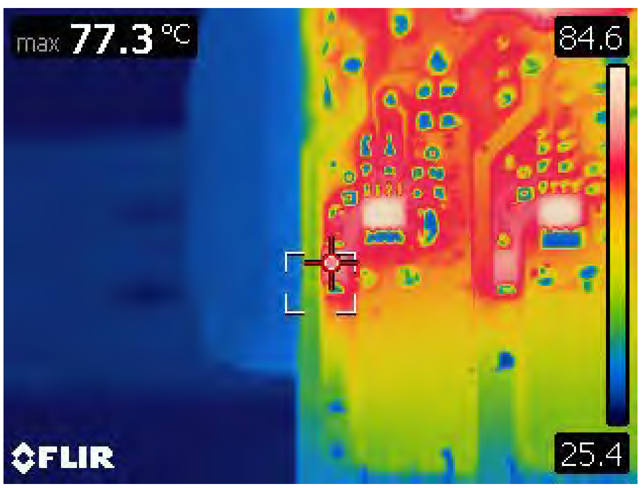

Figure 49 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D1): 77.3 ºC.

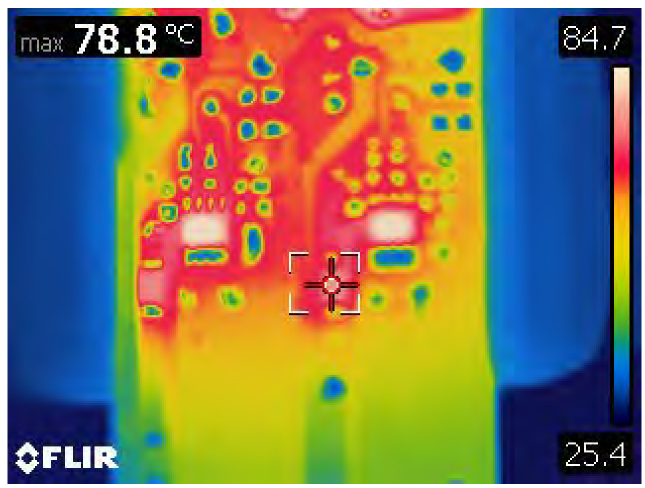

Figure 50 – 120 VAC, 52 V LED Loads.
Spot 1: Flywheel Diode (D2): 78.8 ºC.

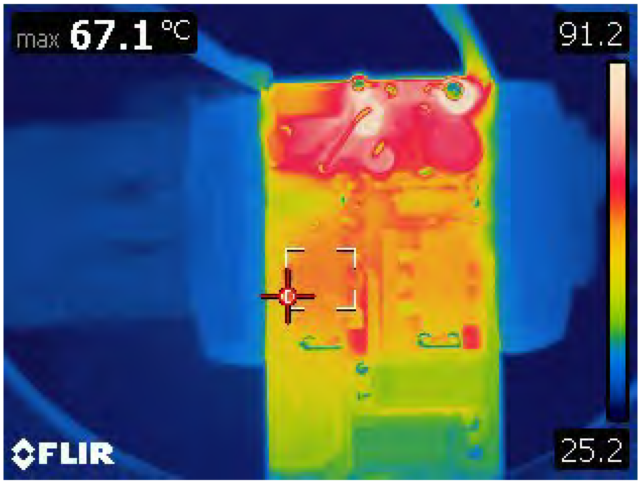

Figure 51 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T3): 67.1 ºC.

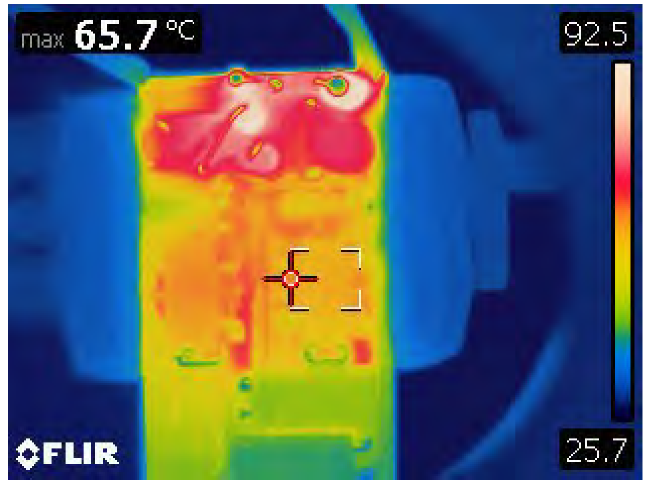

Figure 52 – 120 VAC, 52 V LED Loads.
Spot 1: Buck Inductor (T4): 65.7 ºC.

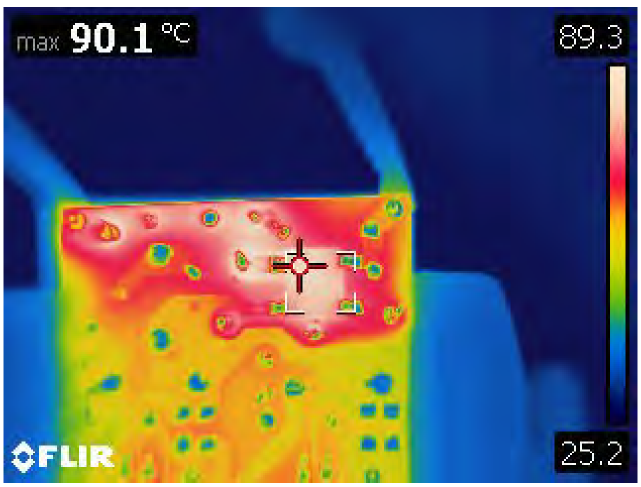

Figure 53 – 120 VAC, 52 V LED Loads.
Spot 1: Bridge Diode (BR1): 90.1 ºC.

Figure 54 – 120 VAC, 52 V LED Loads.
Spot 1: Fusible Resistor (FR1): 103 ºC.

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12.6 *Thermal Performance Inside Chamber – Open Frame Unit*

Figure 55 – Test Set-up Picture Thermal at 60 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 60 ºC at 120 VAC line while 75 ºC at 230 VAC line to test a worst case condition. Temperature was measured using T-type thermocouple. Thermal fold-back was also tested up to 100 °C ambient.

12.6.1 Non-dimming, 120 VAC Input, 52 V LED Loads at 60 °C Ambient

Components	Measurement (°C)	
Part Ref	**Maximum**	**Final**
Ambient	60.5	60.3
U1	129.6	129.2
U2	135.5	134.6
BR1	116.5	116.1
D1	103.6	103.5
D2	108.0	107.6
L1	112.3	112
T3	97.0	96.6
T4	103.6	103.2
FR1 (FUSE)	127.8	127.6
R17 (BLEEDER)	113.6	113.2
R18 (DAMPER1)	137.4	137
R22 (DAMPER2)	132.4	132.2
IOUT1	0.385	0.373
IOUT2	0.379	0.373

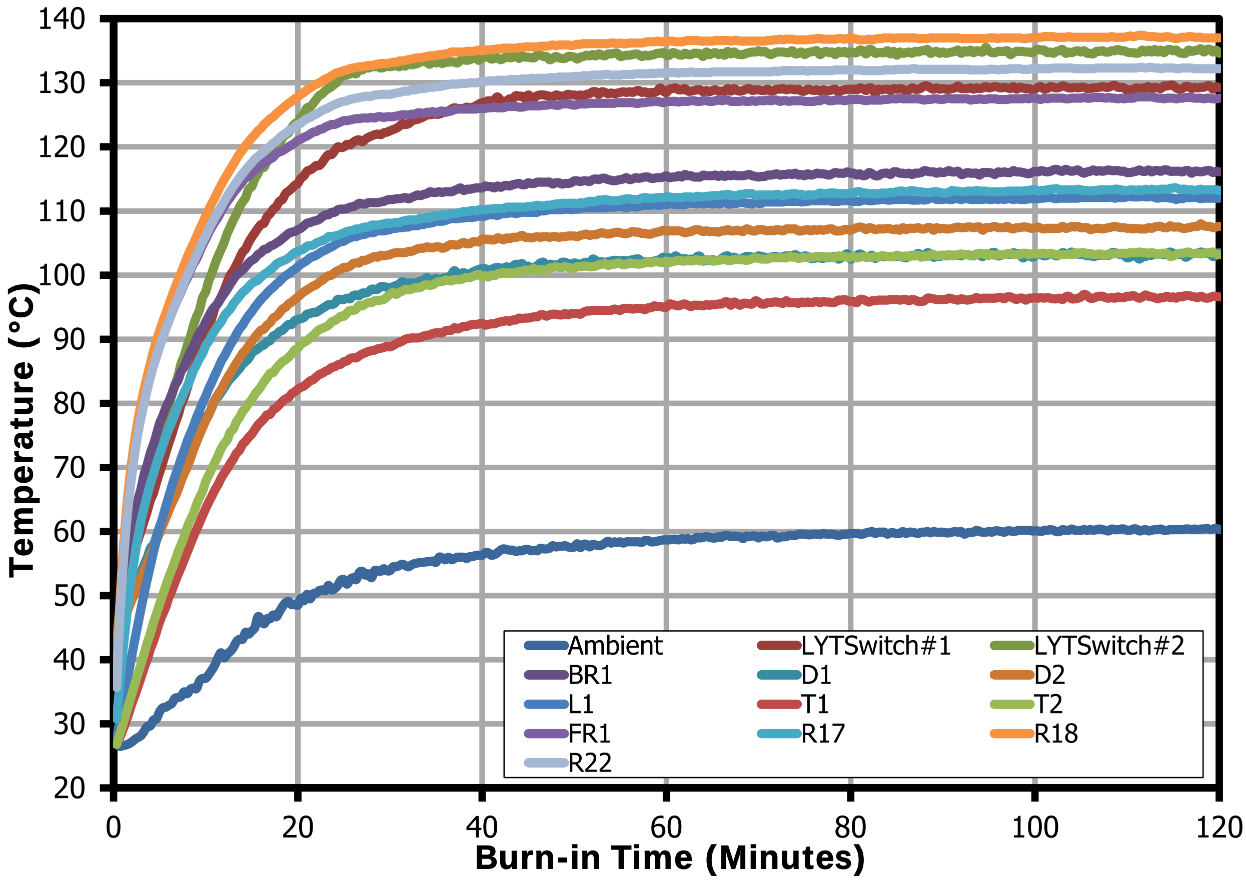

Figure 56 – Component Temperature at 120 VAC, 52 V LED Loads, 60 ºC Ambient.

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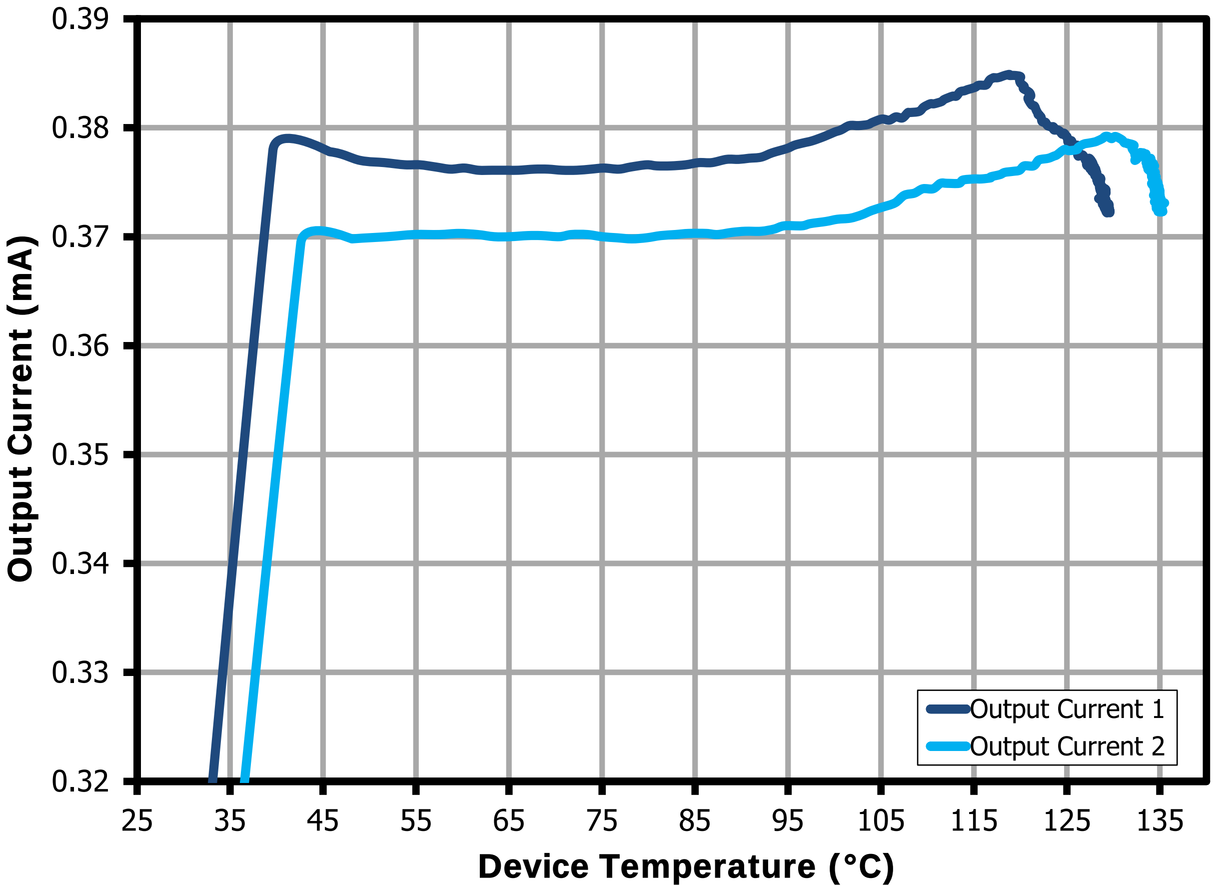

Figure 57 – Output Current vs. Device Temperature (LYT7504D) at 120 VAC, 52 V LED Loads, 60 ºC Ambient.

12.6.2 Non-dimming, 230 VAC Input, 52 V LED Loads at 75 °C Ambient

Components	Measurement (°C)	
Part Ref	Maximum	Final
Ambient	74.3	73.2
U1	125.1	124.7
U2	128.8	128.8
BR1	107.5	106.2
D1	120.6	119.9
D2	126.1	125.8
L1	106.7	106.1
T3	112.3	111.3
T4	116.5	116.3
FR1 (FUSE)	102.0	101.8
R17 (BLEEDER)	109.3	108.5
R18 (DAMPER1)	116.8	116.2
R22 (DAMPER2)	115.4	115.4
IOUT1	0.395	0.392
IOUT2	0.391	0.390

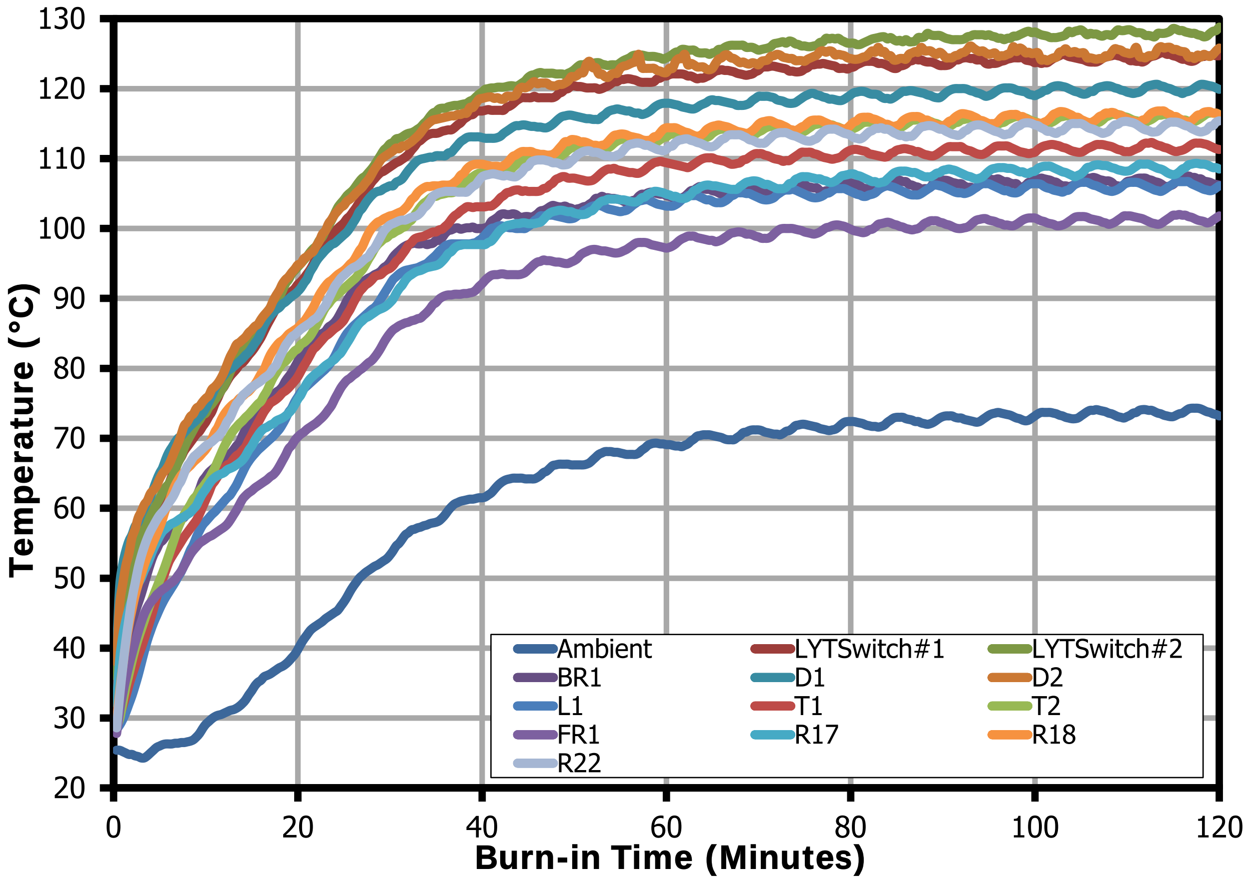

Figure 58 – Component Temperature at 230 VAC, 52 V LED Loads, 75 ºC Ambient.

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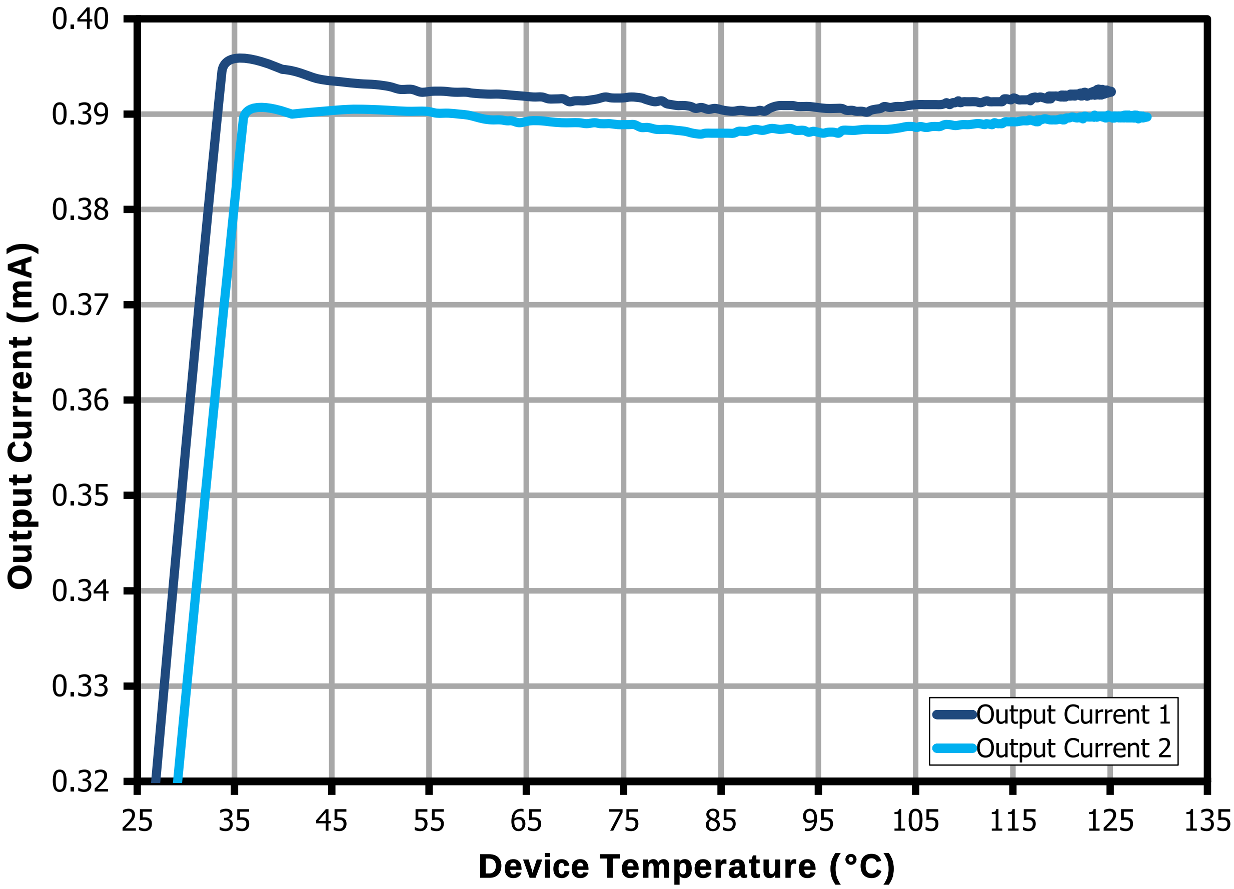

Figure 59 – Output Current vs. Device Temperature (LYT7504D) at 120 VAC, 52 V LED Loads, 75 ºC Ambient.

12.6.3 Non-dimming, 120 VAC Input, 52 V LED Loads at Fold-back (100 ºC Ambient)

Components	Measurement (°C)	
Part Ref	Maximum	Final
Ambient	99.3	99.3
U1	140.5	140.2
U2	144.6	144.5
BR1	131.8	131.8
D1	125.7	125.7
D2	131.1	131.1
L1	130.4	130.4
T3	121.5	121.5
T4	126.1	126
FR1 (FUSE)	136.8	136.8
R17 (BLEEDER)	128.6	128.6
R18 (DAMPER1)	143.8	143.8
R22 (DAMPER2)	142.7	142.7
IOUT1	0.384	0.311
IOUT2	0.379	0.316

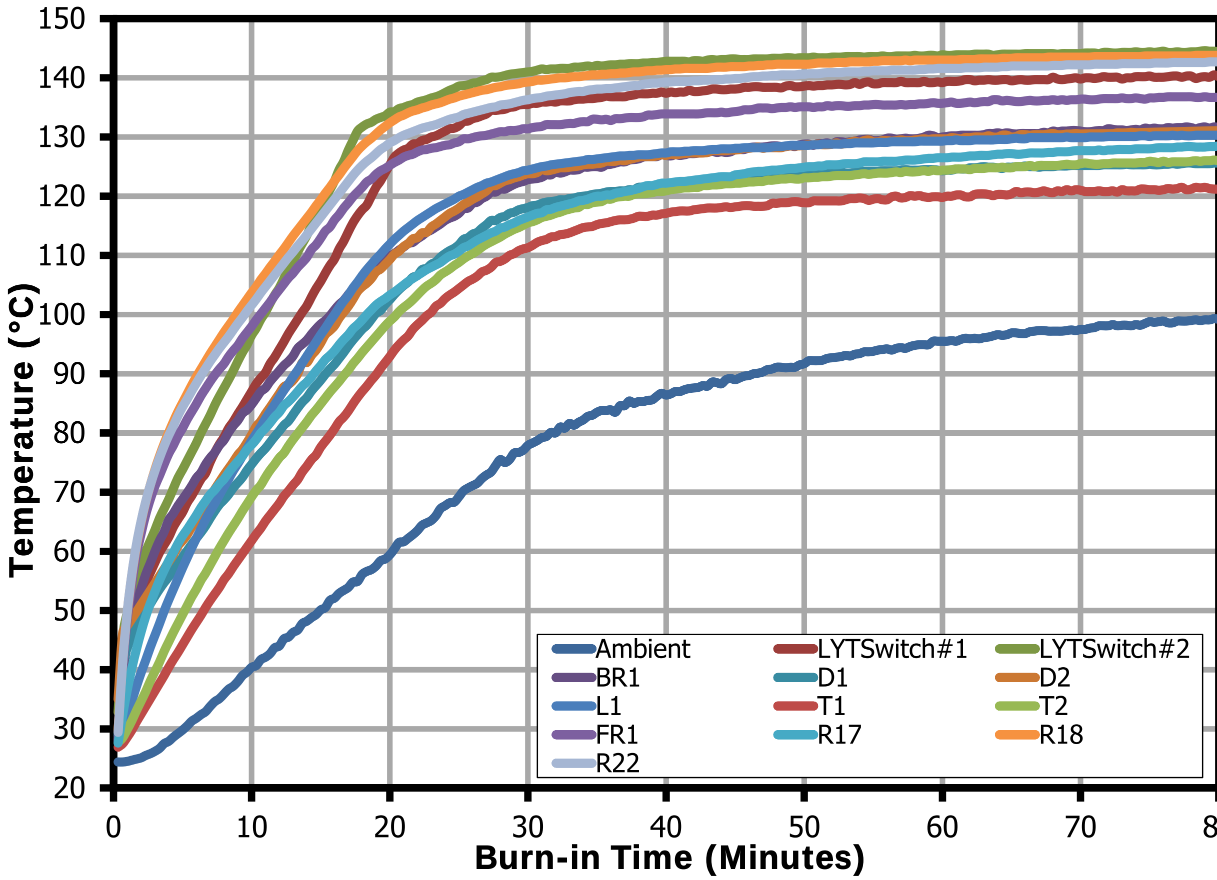

Figure 60 – Component Temperature at 120 VAC, 52 V LED Loads, 100 ºC Ambient.

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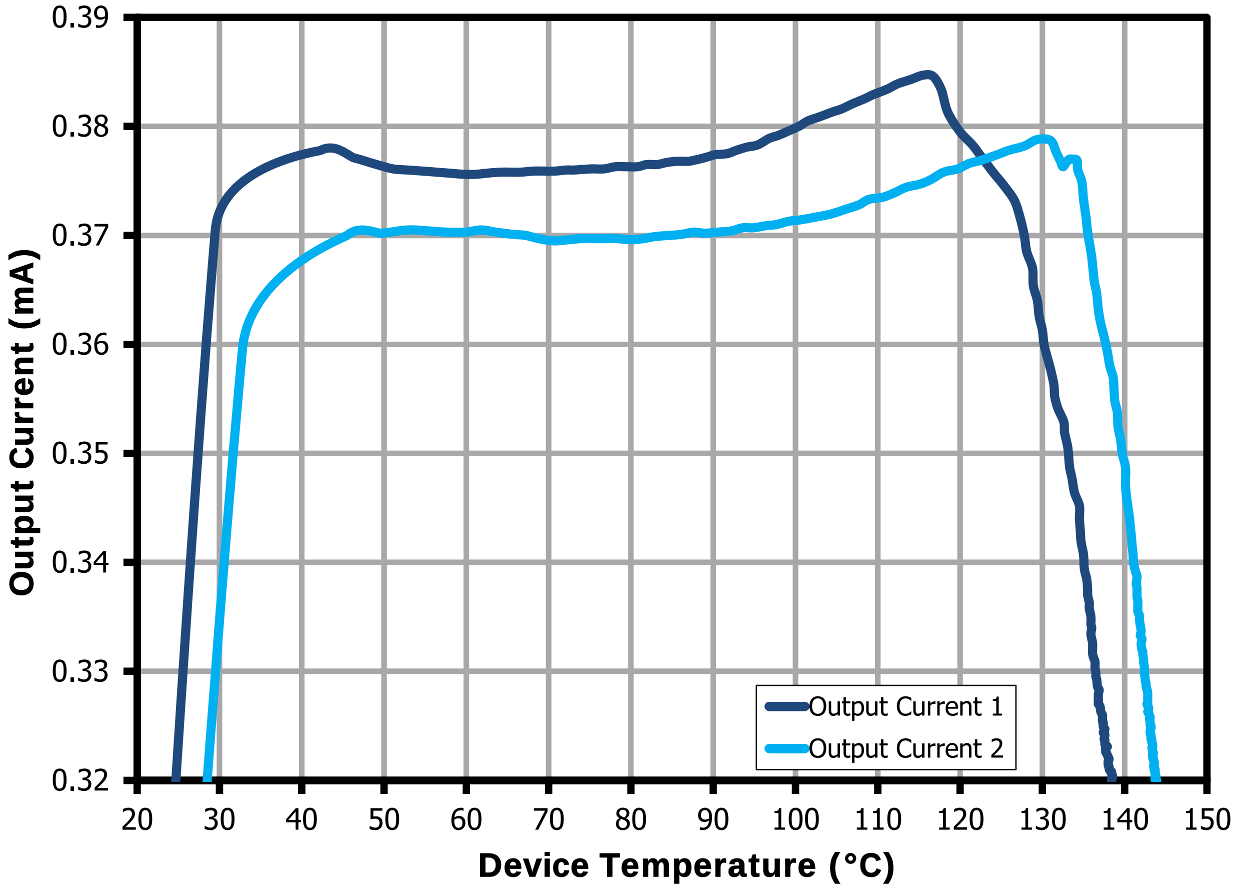

Figure 61 – Output Current vs. Device Temperature (LYT7504D) at 120 VAC, 52 V LED Loads, at Fold-back, 100 ºC Ambient.

Note: During thermal fold-back of both rails, output light continues even at elevated temperatures. Over temperature shutdown is observed as protection to fault conditions.

13 Waveforms

13.1 *Non-dimming, Input Voltage and Input Current Waveforms*

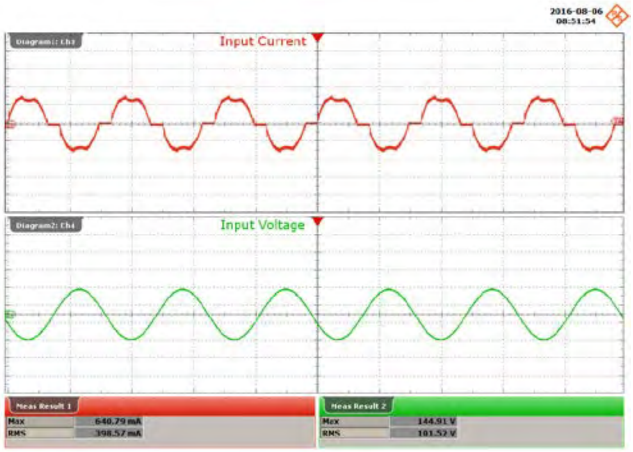

Figure 62 – 100 VAC, 52 V LED Loads.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

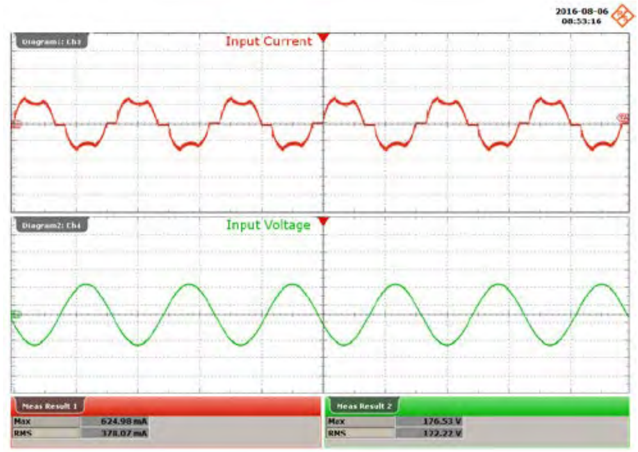

Figure 63 – 120 VAC, 52 V LED Loads.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

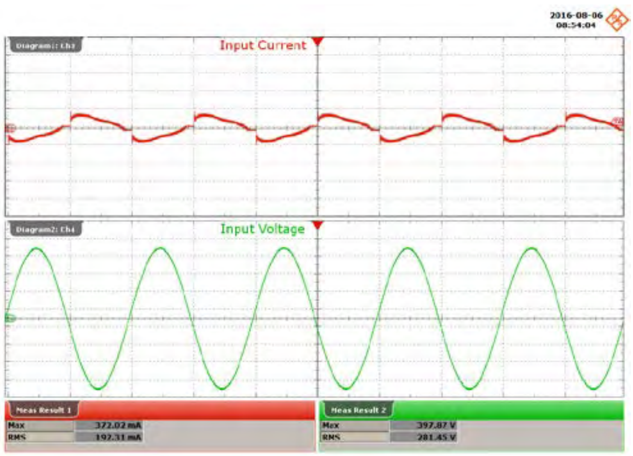

Figure 64 – 277 VAC, 52 V LED Loads.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

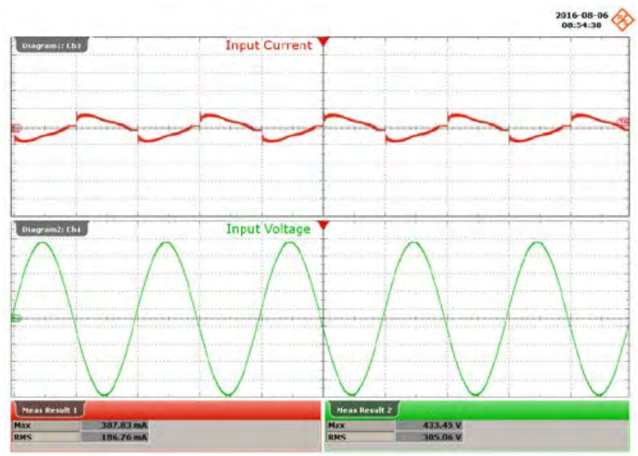

Figure 65 – 300 VAC, 52 V LED Loads.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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13.2 *Dimming, Input Voltage and Input Current Waveforms, Leading-Edge Type*

Dimmer Model: LUTRON LG-603PGH-WH

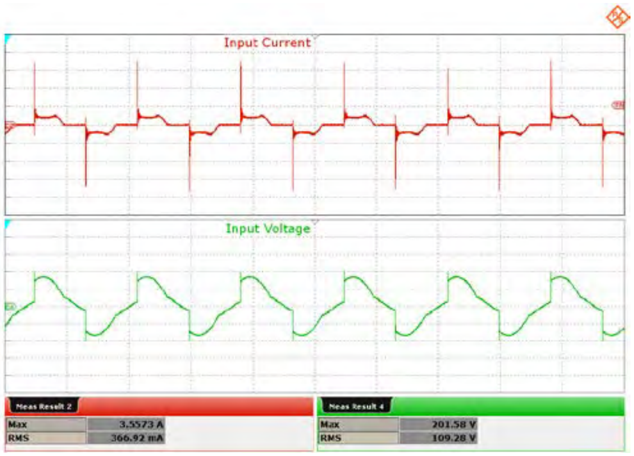

Figure 66 – 120 VAC, 52 V LED Loads.
Maximum (132°) Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

Figure 67 – 120 VAC, 52 V LED Loads.
90° Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

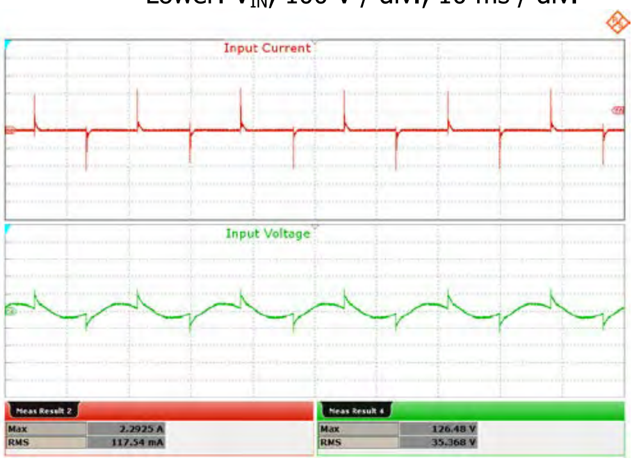

Figure 68 – 120 VAC, 52 V LED Loads.
Minimum (51°) Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

13.3 *Dimming, Input Voltage and Input Current Waveforms, Trailing-Edge Type*

Dimmer Model: LEVITON 1PE04-1LZ

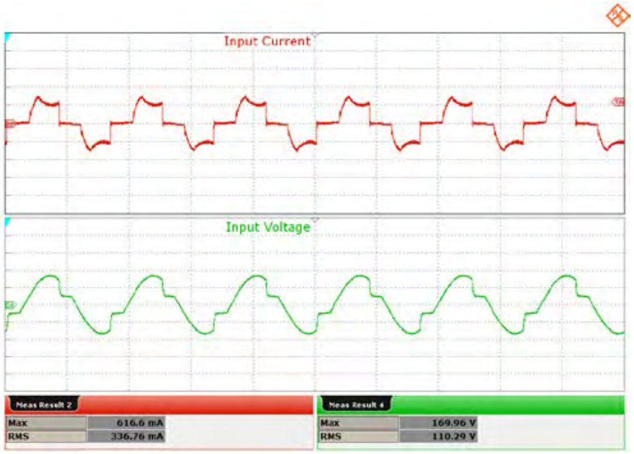

Figure 69 – 120 VAC, 52 V LED Loads.
Maximum (134°) Conduction Angle.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

Figure 70 – 120 VAC, 52 V LED Loads.
90° Conduction Angle.
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

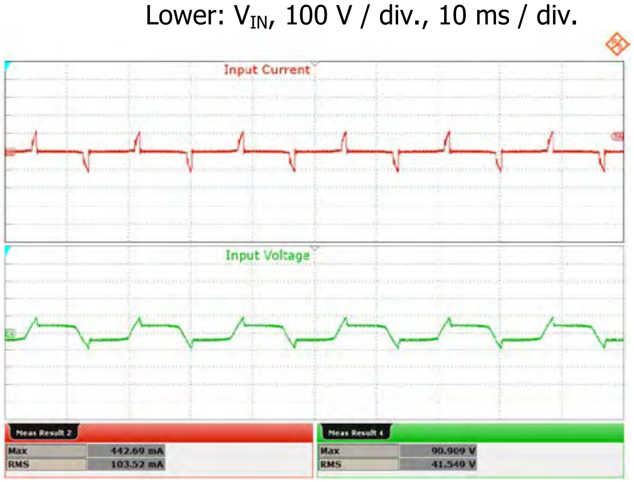

Figure 71 – 120 VAC, 52 V LED Loads.
Minimum (57°) Conduction Angle
Upper: I_{IN}, 400 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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13.4 *Start-up Profile*

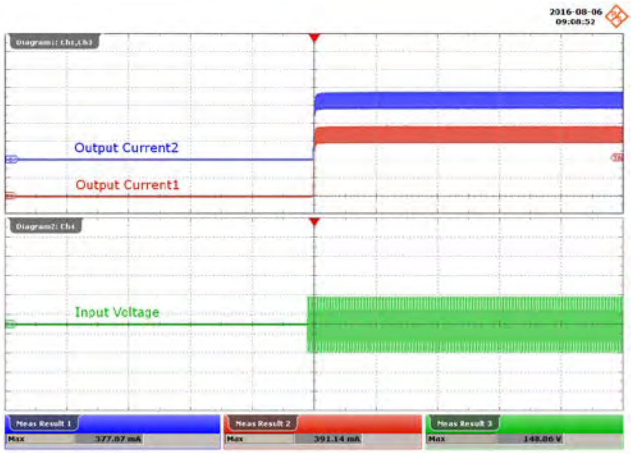

Figure 72 – 100 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

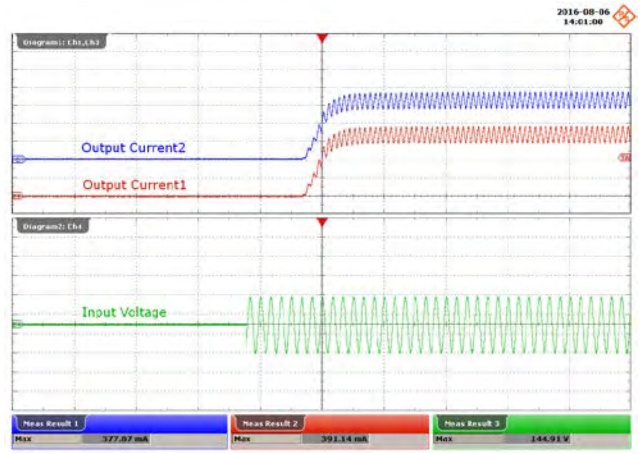

Figure 73 – 100 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

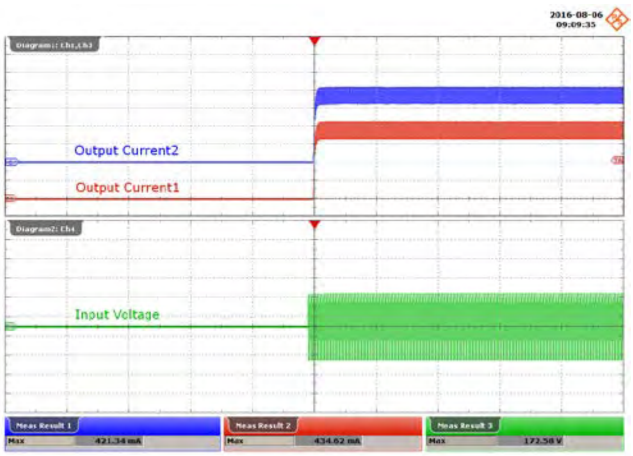

Figure 74 – 120 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

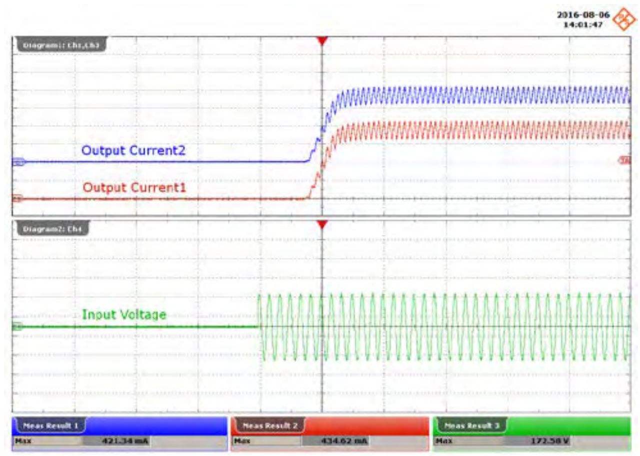

Figure 75 – 120 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

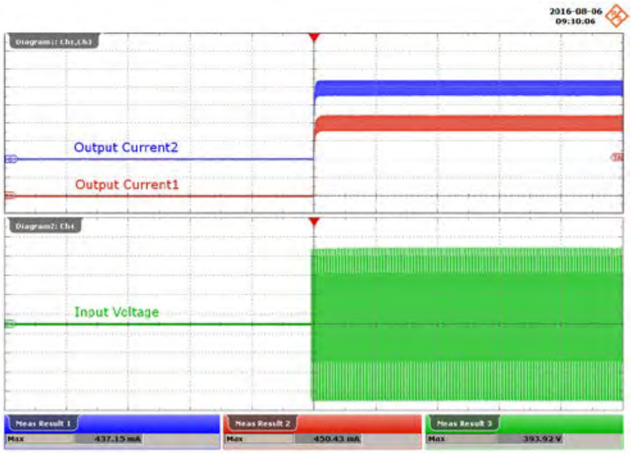

Figure 76 – 277 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

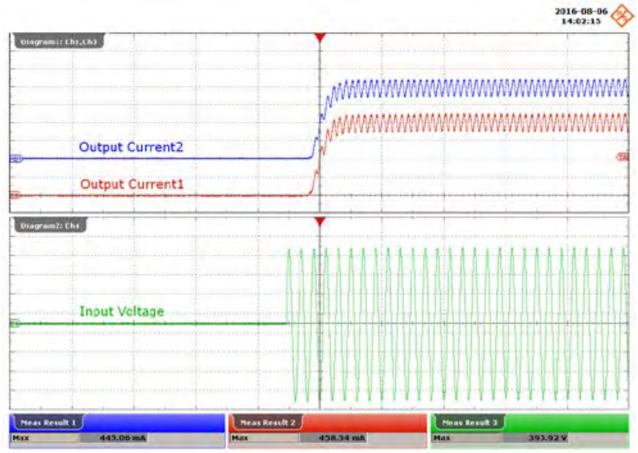

Figure 77 – 277 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div

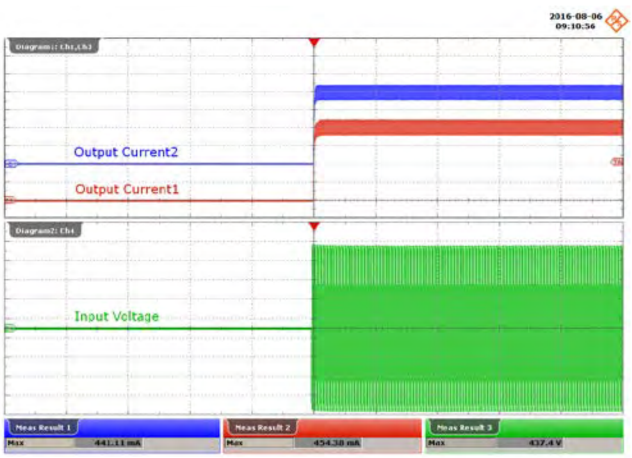

Figure 78 – 300 VAC, 52 V LEDs, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

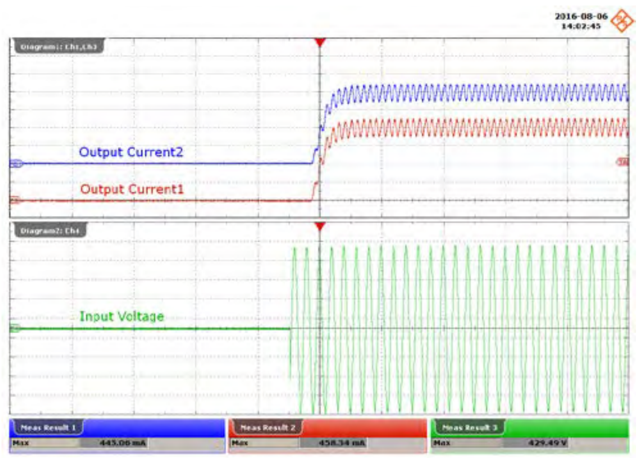

Figure 79 – 300 VAC, 52 V LEDs Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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13.5 *Output Current Fall*

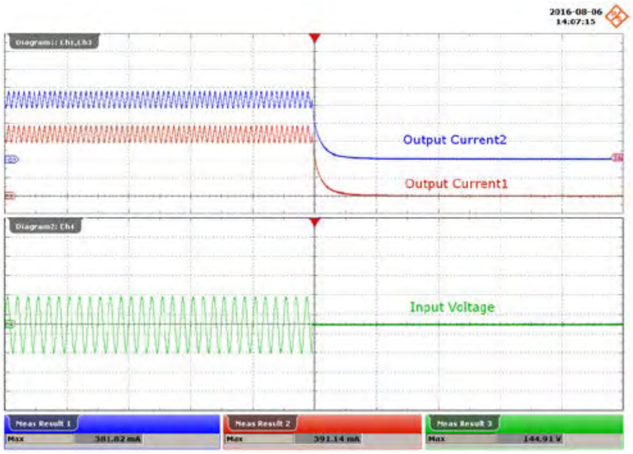

Figure 80 – 100 VAC, 52 V LEDs, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

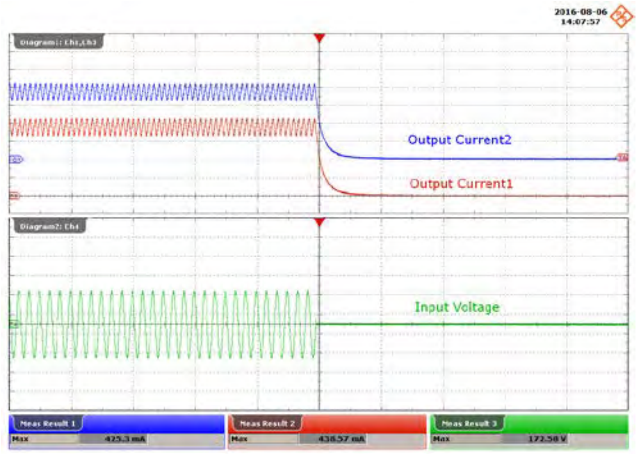

Figure 81 – 120 VAC, 52 V LEDs, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

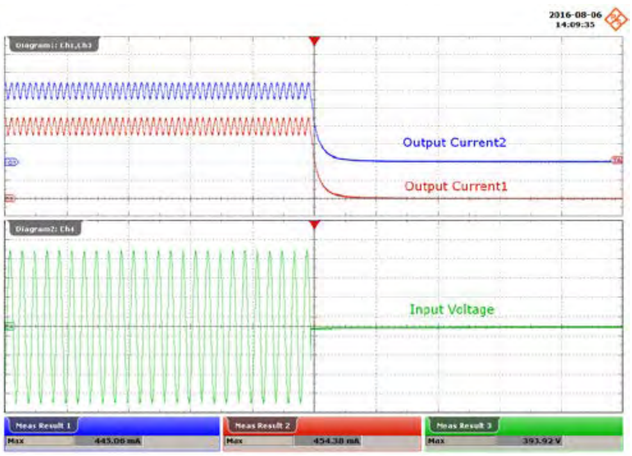

Figure 82 – 277 VAC, 52 V LEDs, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

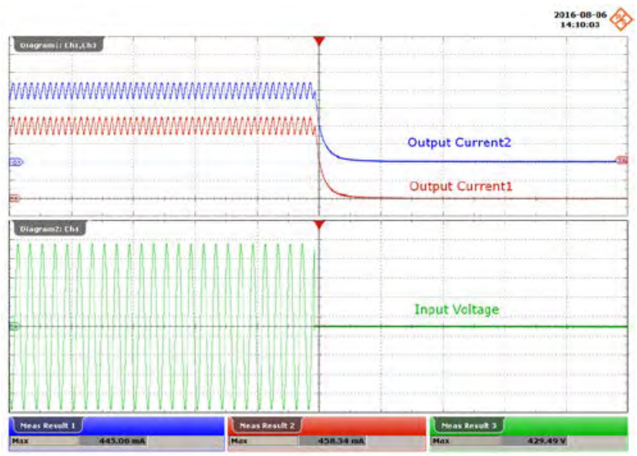

Figure 83 – 300 VAC, 52 V LEDs, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

13.6 *Drain Voltage and Current in Normal Operation*

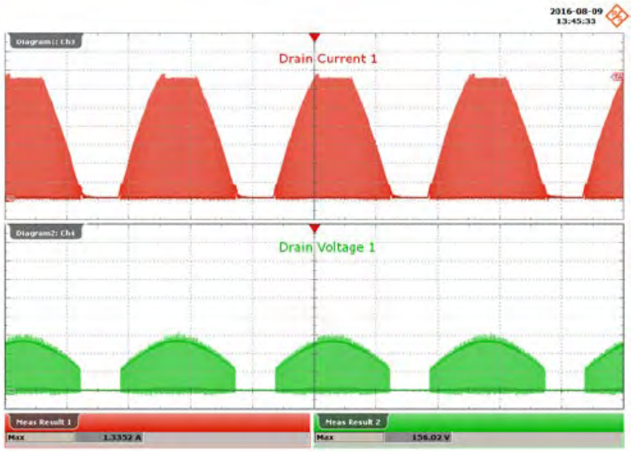

Figure 84 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

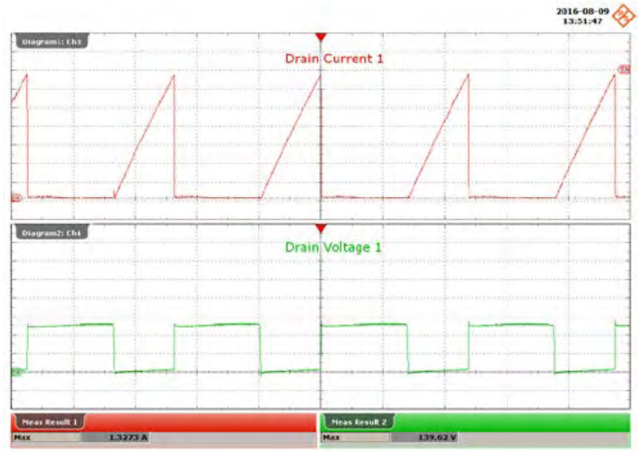

Figure 85 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 µs / div.

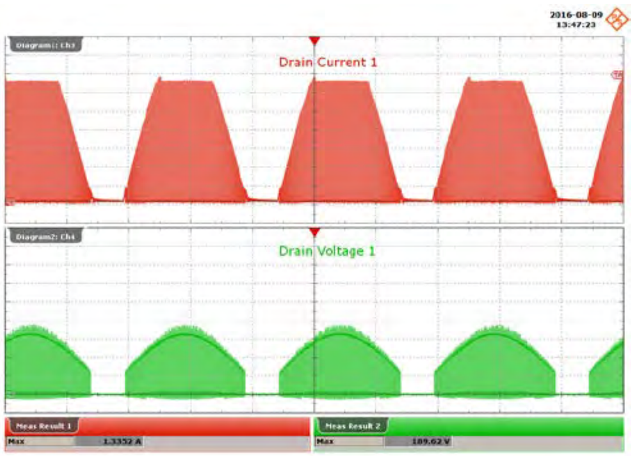

Figure 86 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

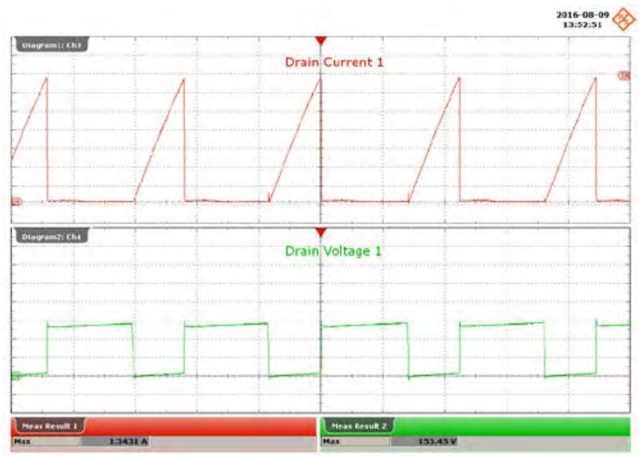

Figure 87 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 µs / div.

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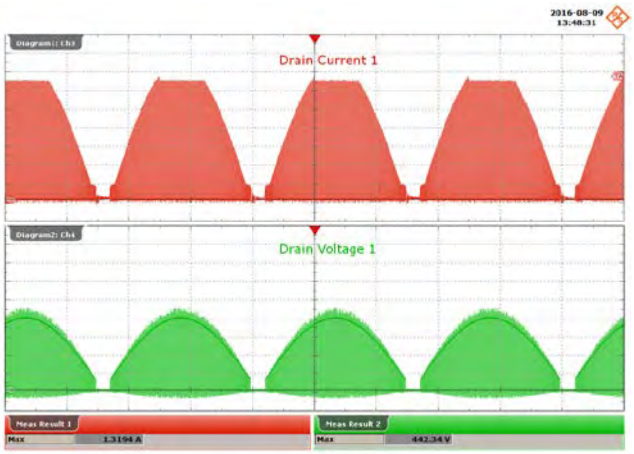

Figure 88 – 277 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

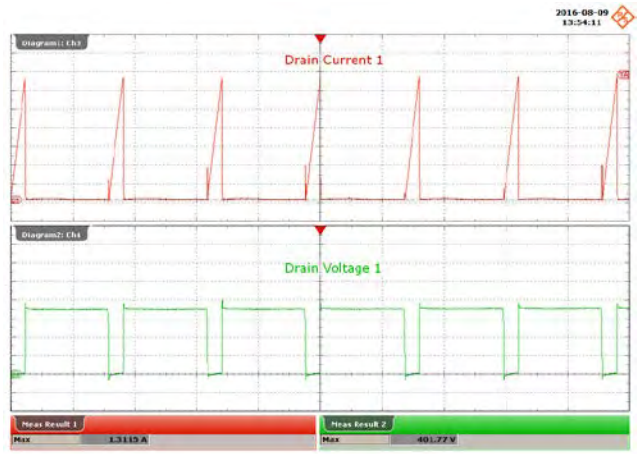

Figure 89 – 277 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

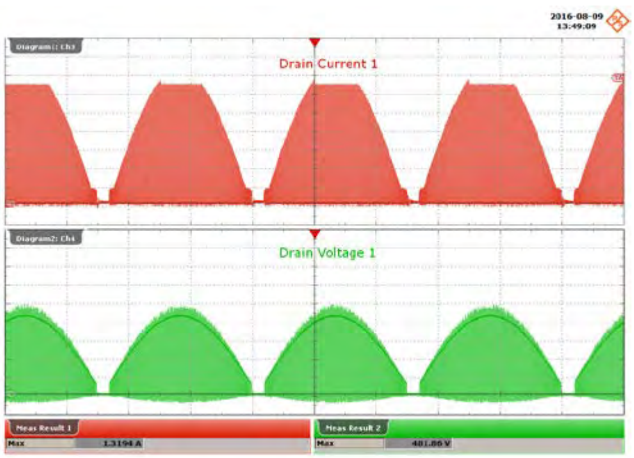

Figure 90 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

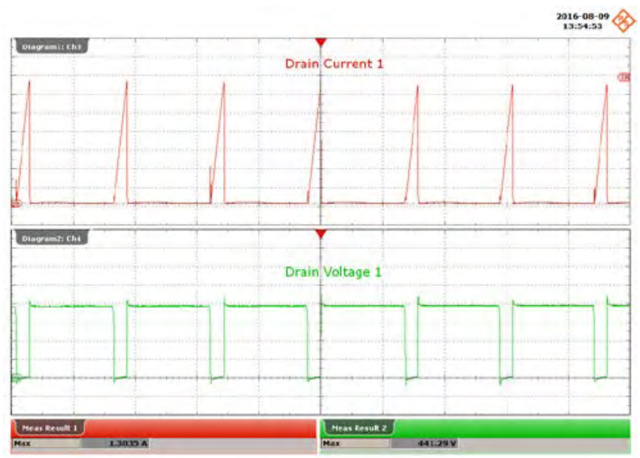

Figure 91 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

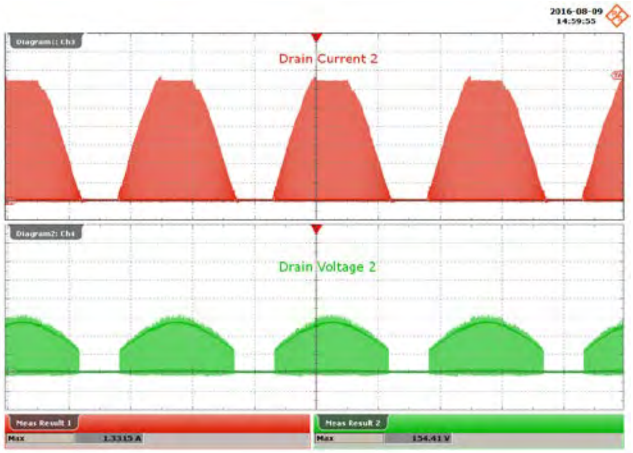

Figure 92 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

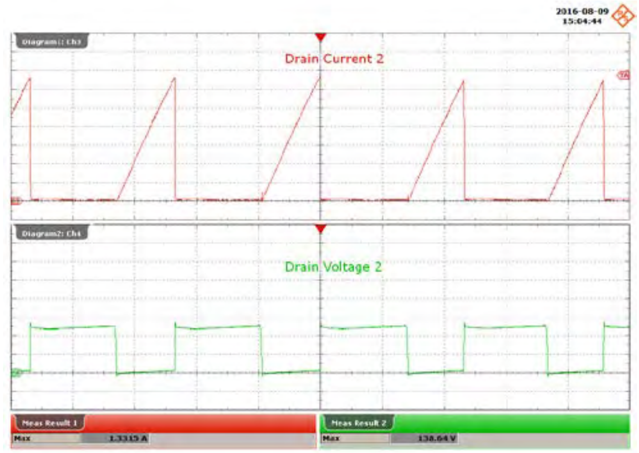

Figure 93 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

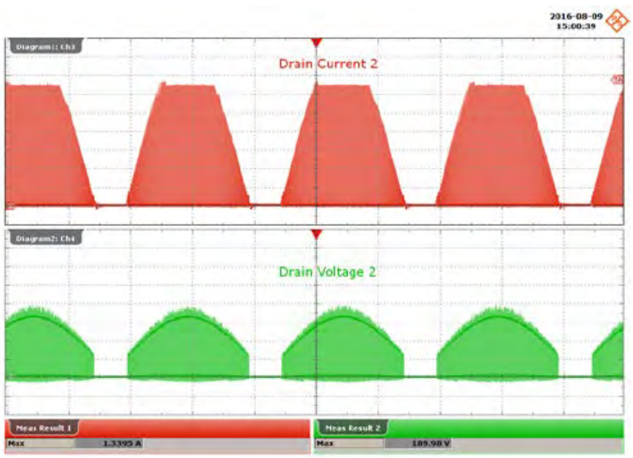

Figure 94 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

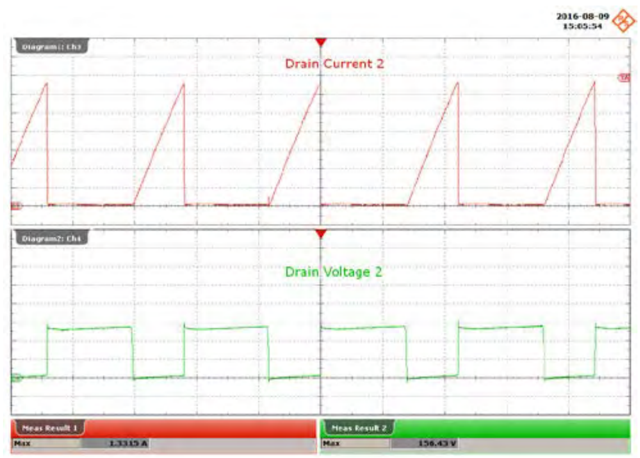

Figure 95 – 120 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

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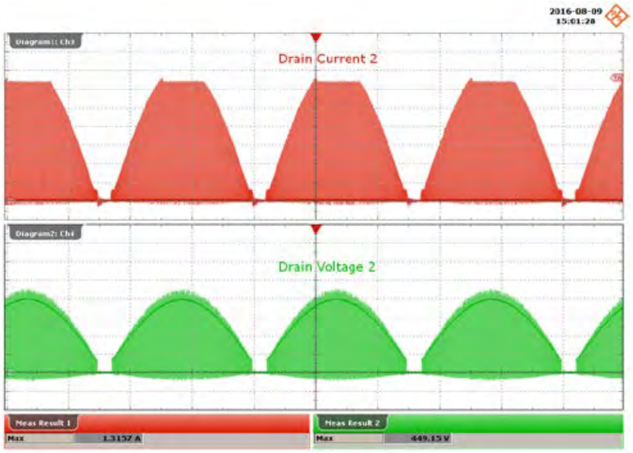

Figure 96 – 277 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

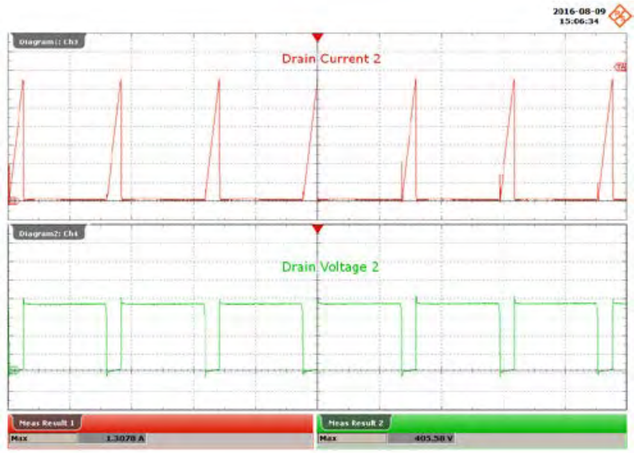

Figure 97 – 277 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

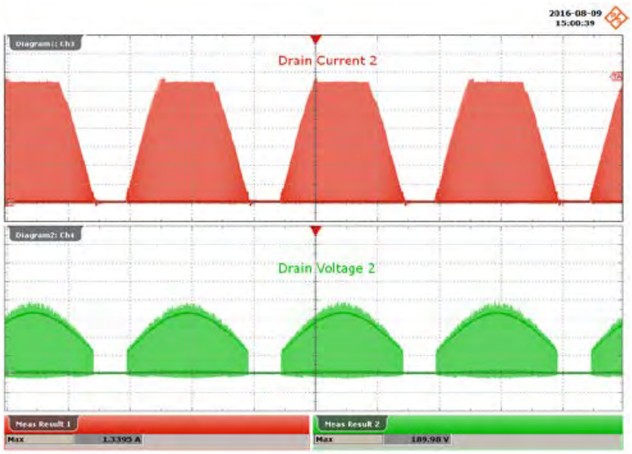

Figure 98 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

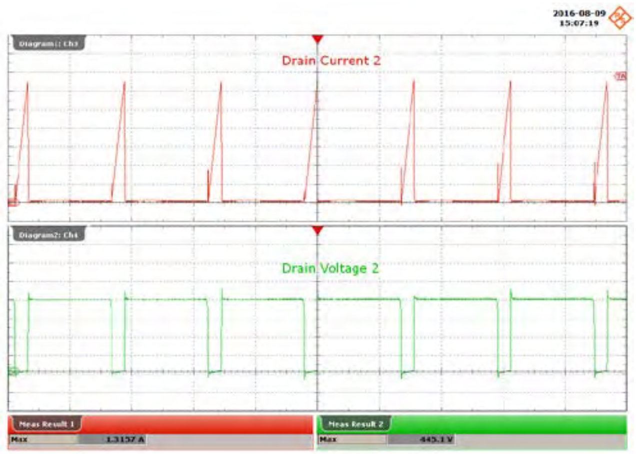

Figure 99 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

13.7 *Drain Voltage and Current Start-up Profile*

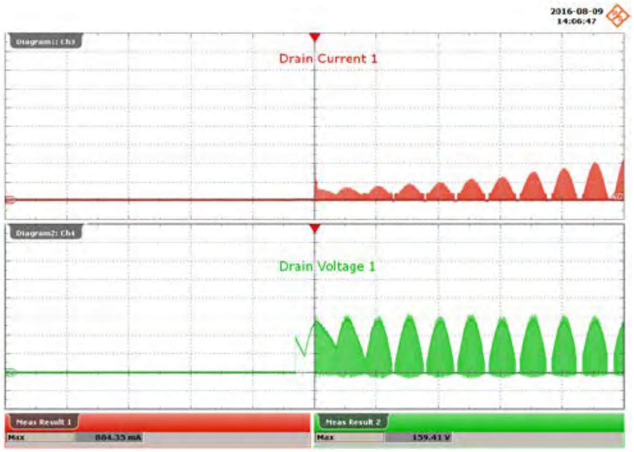

Figure 100 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

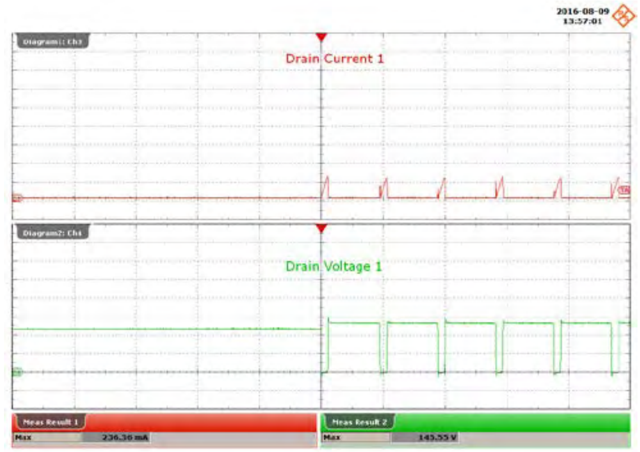

Figure 101 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

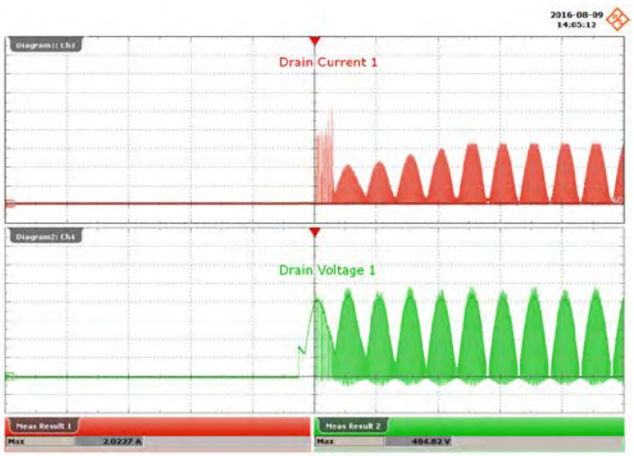

Figure 102 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

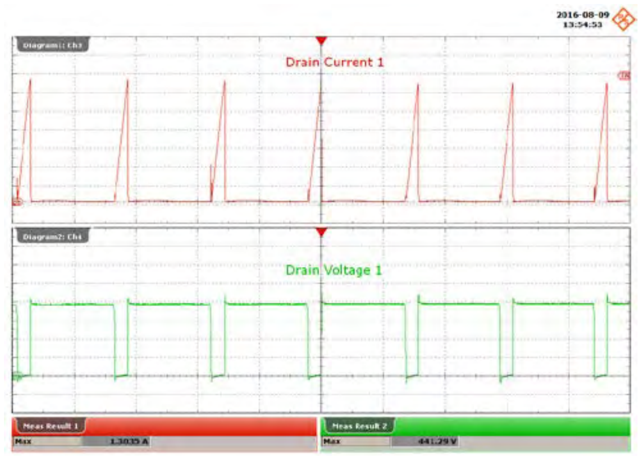

Figure 103 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

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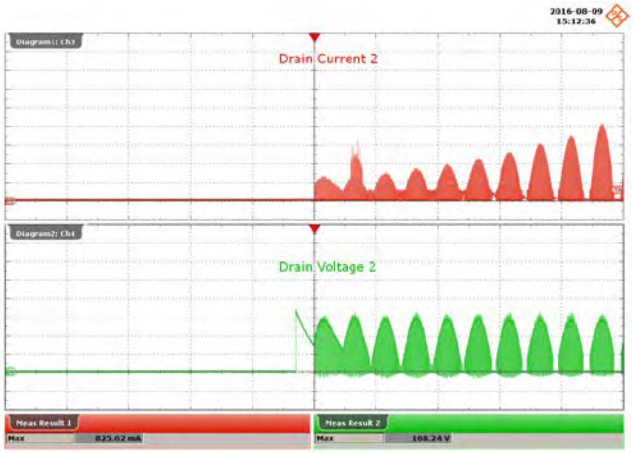

Figure 104 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

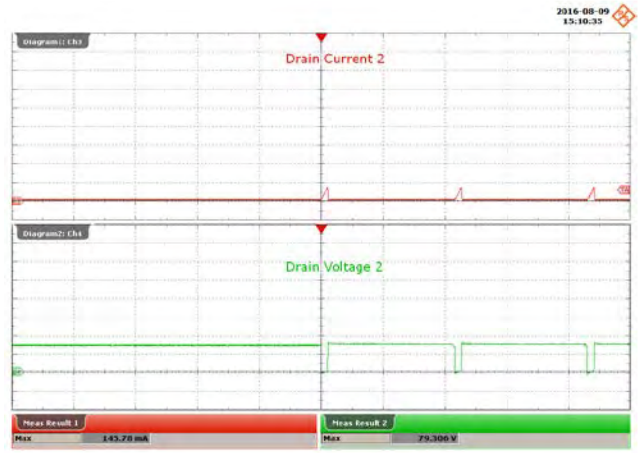

Figure 105 – 100 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

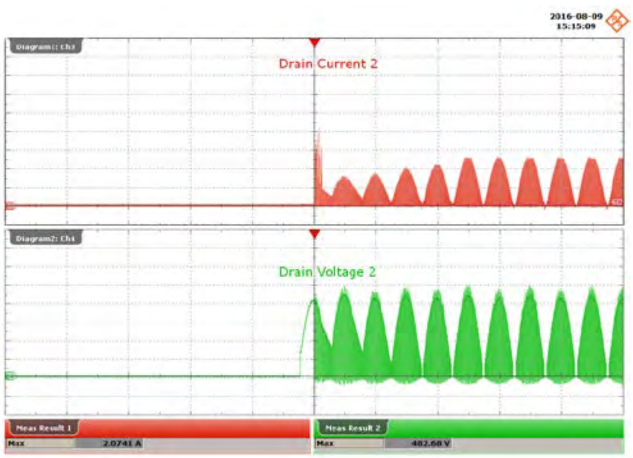

Figure 106 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

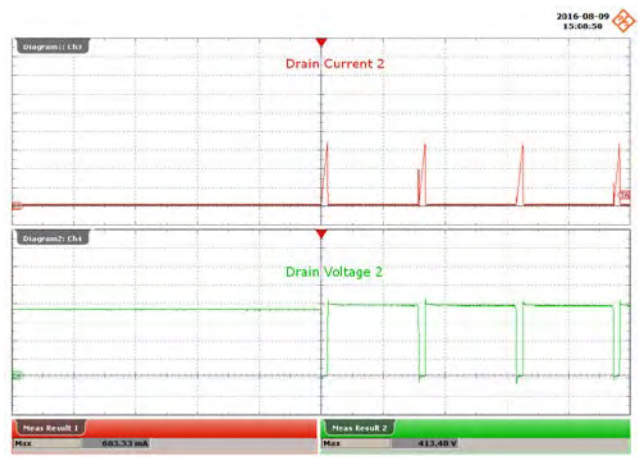

Figure 107 – 300 VAC, 52 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

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

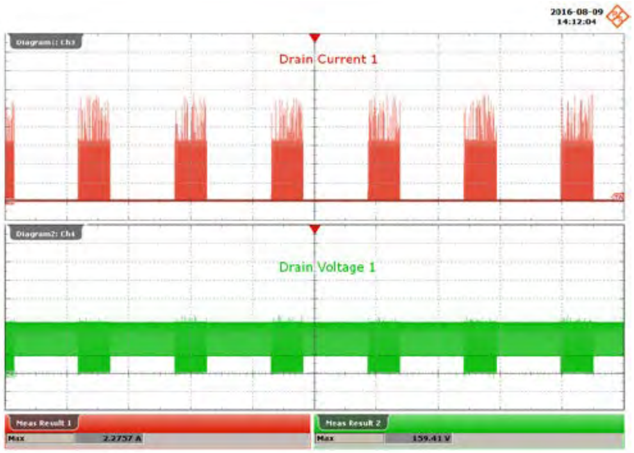

Figure 108 – 100 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

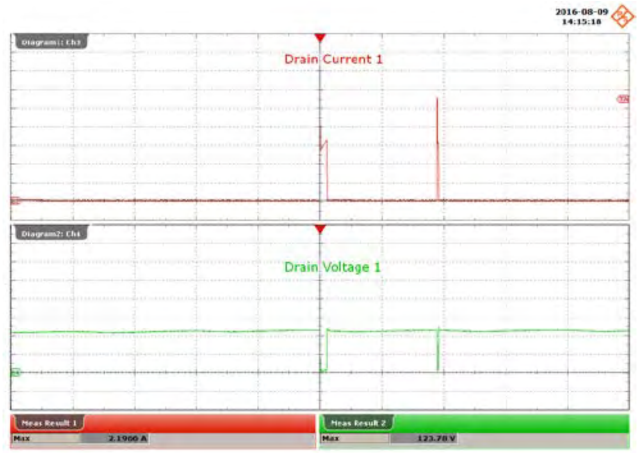

Figure 109 – 100 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 μs / div.

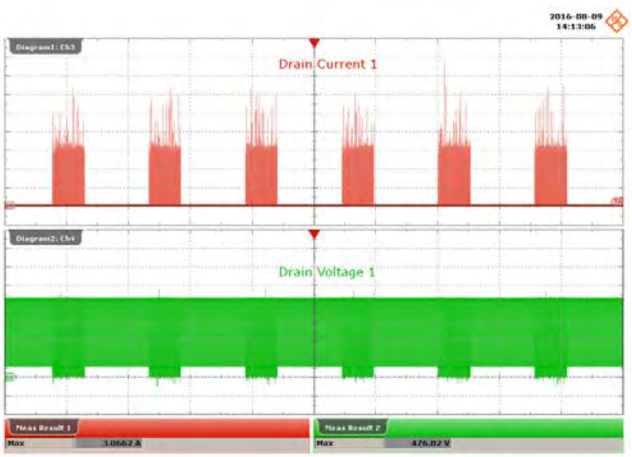

Figure 110 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

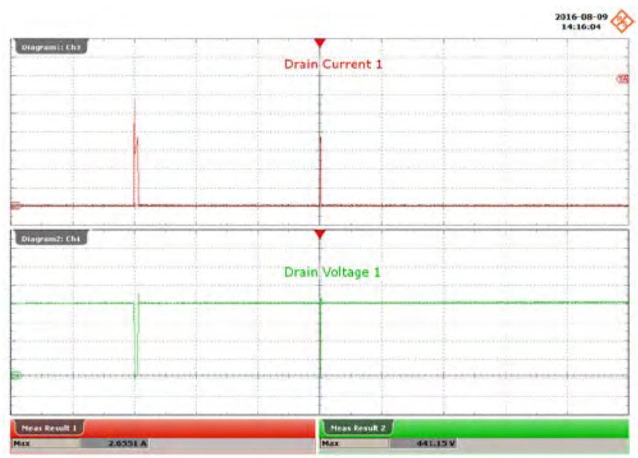

Figure 111 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 μs / div.

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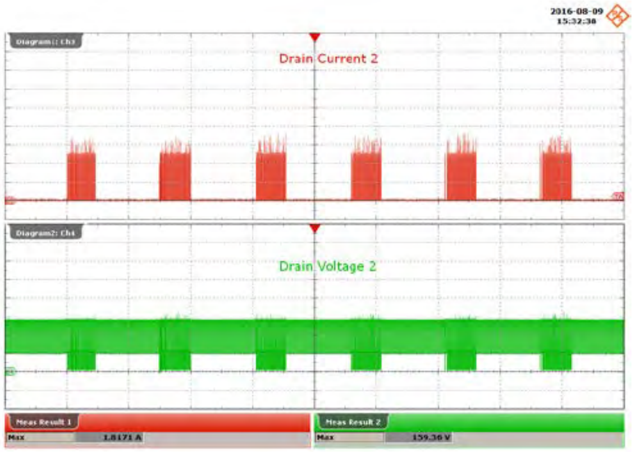

Figure 112 – 100 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

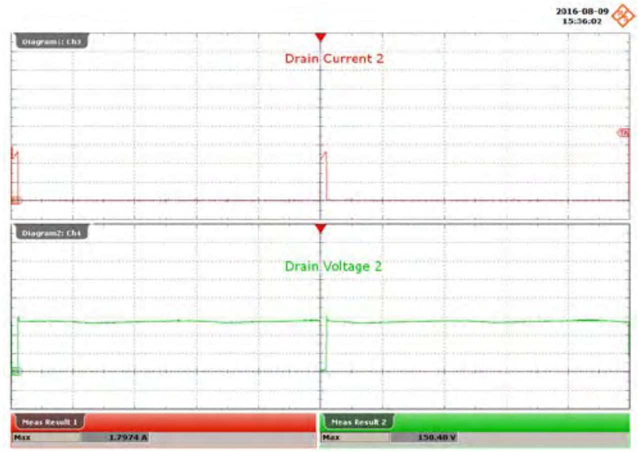

Figure 113 – 100 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 µs / div.

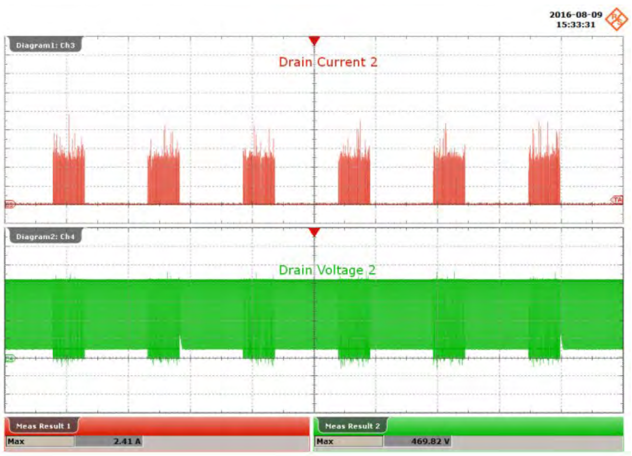

Figure 114 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

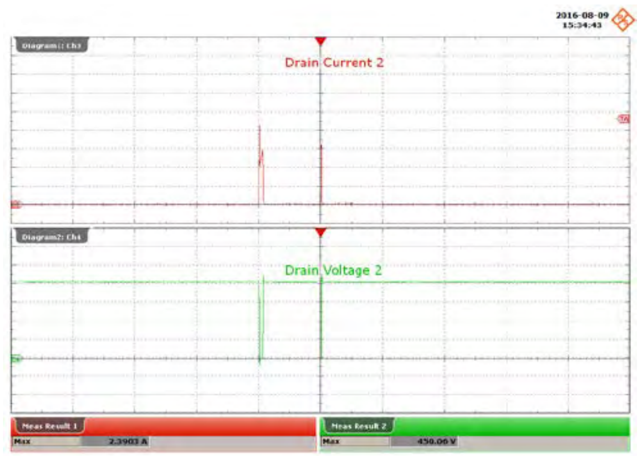

Figure 115 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

V_{IN} (VAC)	Frequency (Hz)	P_{IN} (W)
100	60	2.2
300	50	3.77

13.9 *Output Diode Voltage and Current in Normal Operation*

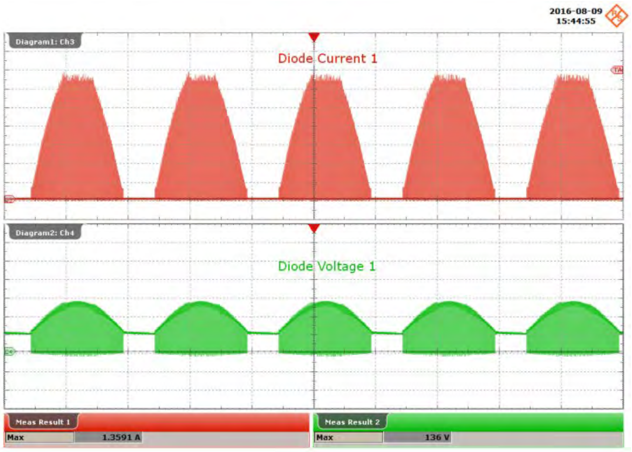

Figure 116 – 100 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 50 V / div., 4 ms / div.

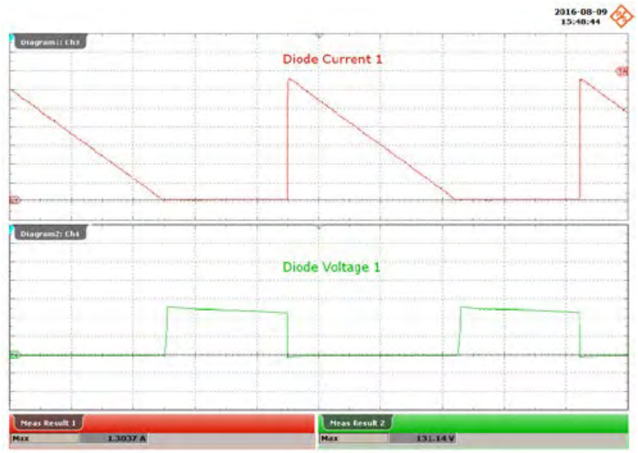

Figure 117 – 100 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 50 V / div., 5 μs / div.

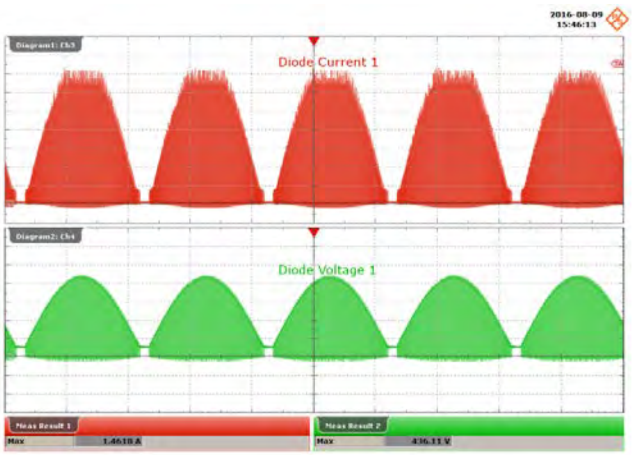

Figure 118 – 300 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

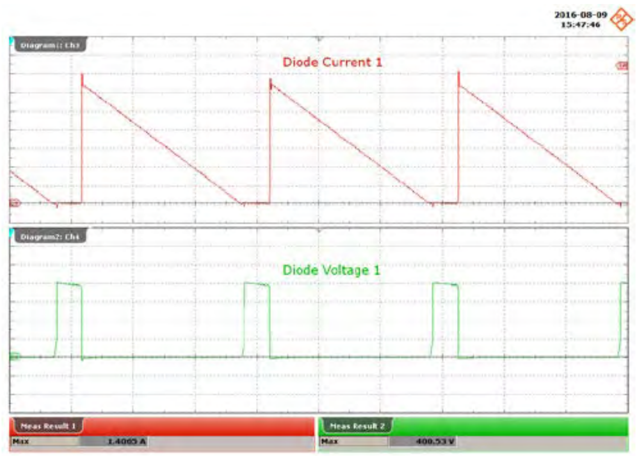

Figure 119 – 300 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 5 μs / div.

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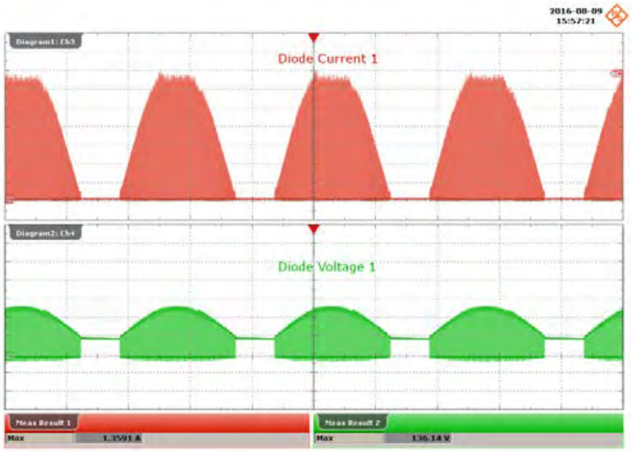

Figure 120 – 100 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 50 V / div., 4 ms / div.

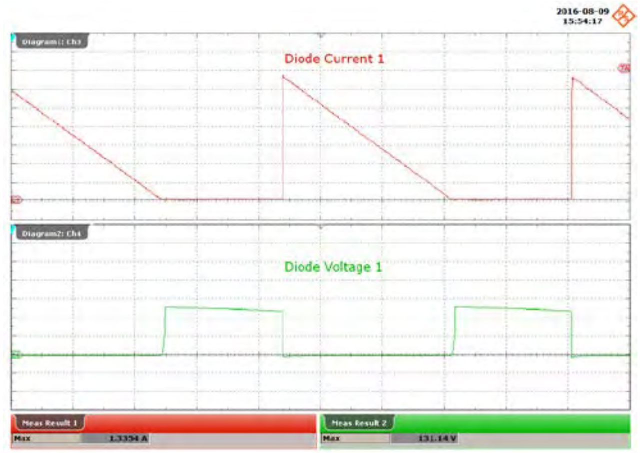

Figure 121 – 100 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 50 V / div., 5 μs / div.

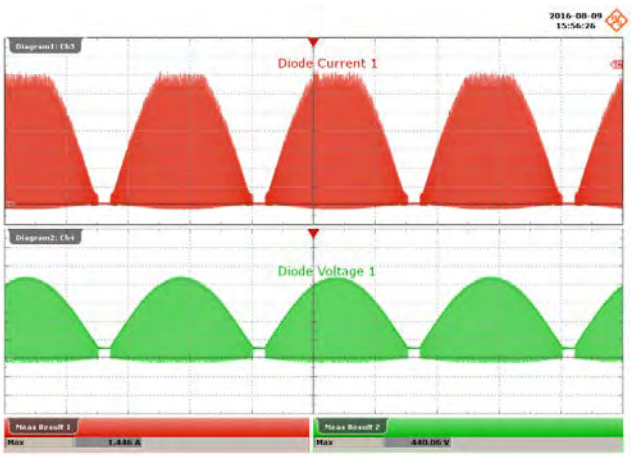

Figure 122 – 300 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

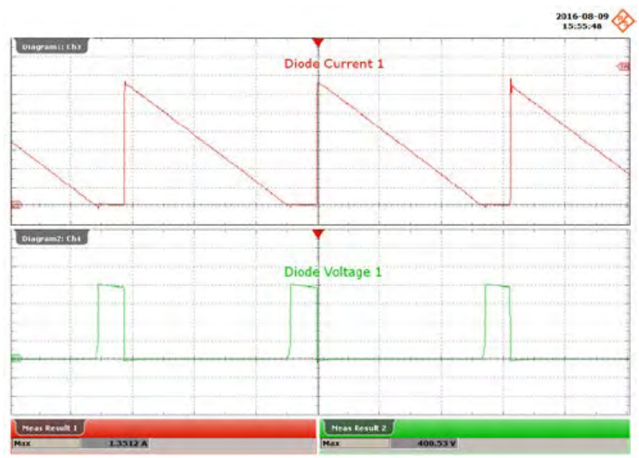

Figure 123 – 300 VAC, 52 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 5 μs / div.

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

Maximum measured no-load output voltage.

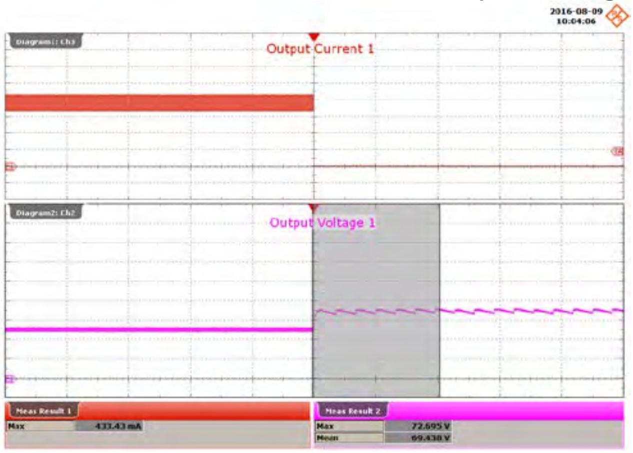

Figure 124 – 120 VAC, 52 V LED Load.
Output 1 Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

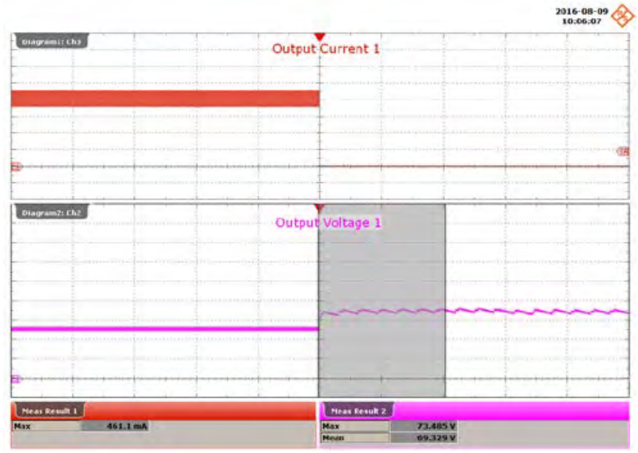

Figure 125 – 277 VAC, 52 V LED Load.
Output 1 Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

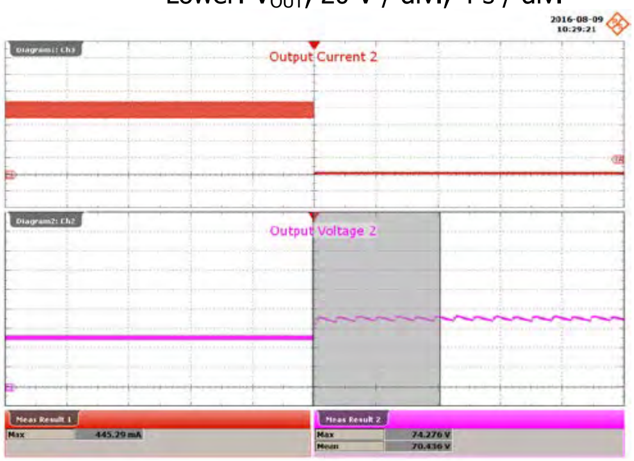

Figure 126 – 120 VAC, 52 V LED Load.
Output 2 Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

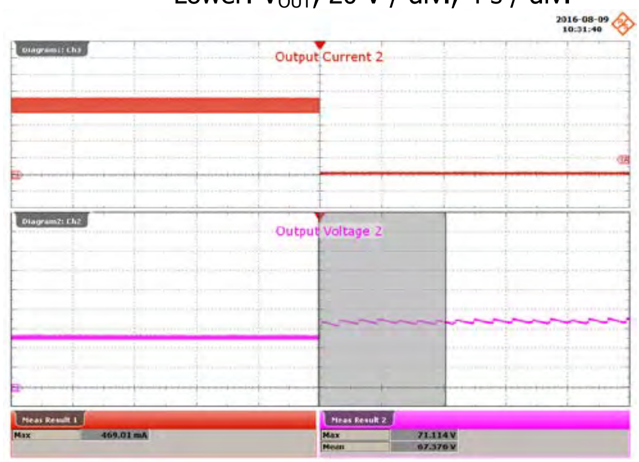

Figure 127 – 277 VAC, 52 V LED Load.
Output 2 Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

Note: The output capacitors can withstand the over voltage level, since based from output capacitor datasheet (ELXZ630ELL151MH20D) the surge voltage for 63 V rated is 79 V. This rating level is still above the maximum voltage measured during open load test.

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

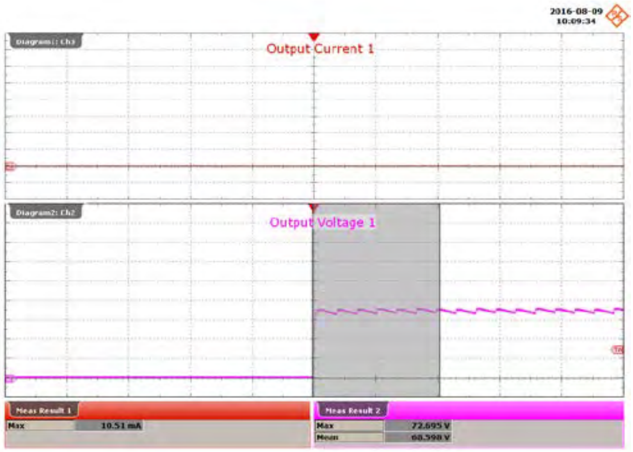

Figure 128 – 120 VAC, 52 V LED Load.
Open Load_1 Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

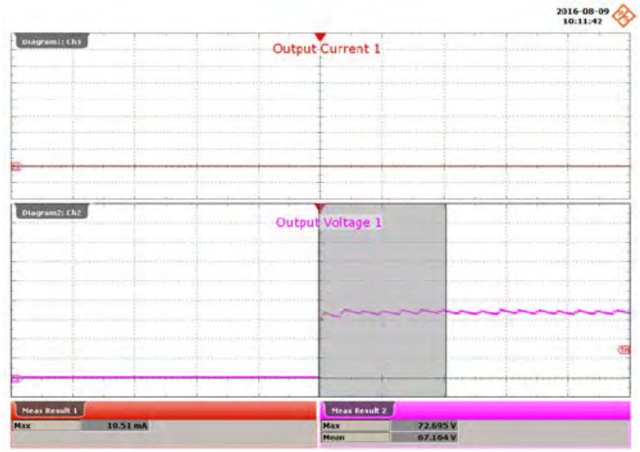

Figure 129 – 277 VAC, 52 V LED Load.
Open Load_2 Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

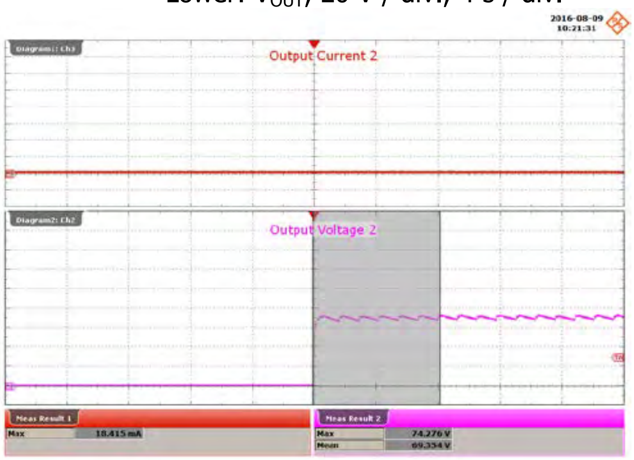

Figure 130 – 100 VAC, 60 V LED Load.
Open Load_2 Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

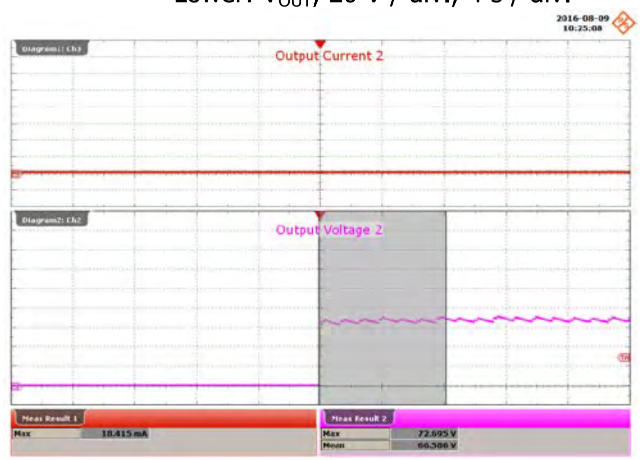

Figure 131 – 100 VAC, 60 V LED Load.
Open Load_2 Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

Note: The output capacitors can withstand the over voltage level, since based from output capacitor datasheet (ELXZ630ELL151MH20D) the surge voltage for 63 V rated is 79 V. This rating level is still above the maximum voltage measured during open load test.

13.12 *Output Ripple Current*

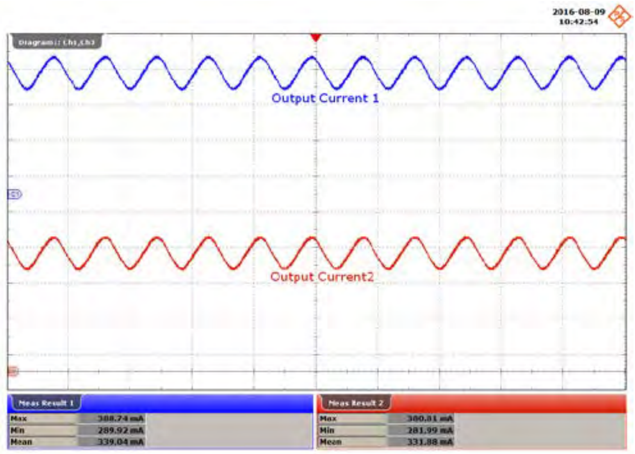

Figure 132 – 100 VAC, 60 Hz, 52 V LED Loads.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

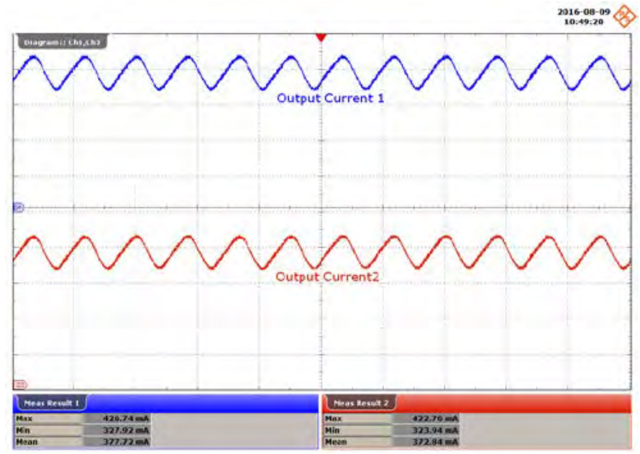

Figure 133 – 120 VAC, 60 Hz, 52 V LEDs Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

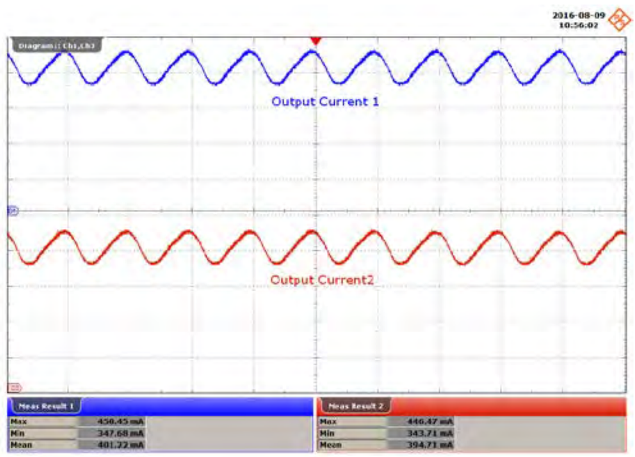

Figure 134 – 277 VAC, 60 Hz, 52 V LEDs Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

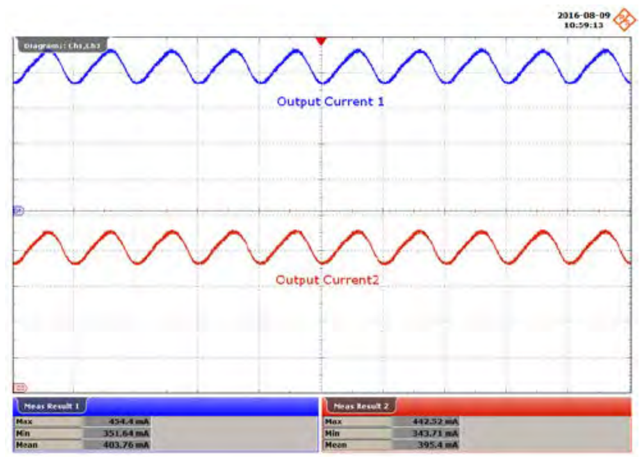

Figure 135 – 300 VAC, 60 Hz, 60 V LEDs Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{O(MAX)1}$ (mA)	$I_{O(MIN)1}$ (mA)	I_{MEAN1}	Ripple Ratio1 (I_{RP-P}/I_{MEAN})	% Flicker1 100 x (I_{RP-P} / $I_{O(MAX)}$+$I_{O(MIN)}$)
100	389	290	339	0.29	14.6
120	427	328	378	0.26	13.1
277	450	348	401	0.25	12.8
300	454	352	404	0.25	12.6
V_{IN} (VAC)	**$I_{O(MAX)2}$ (mA)**	**$I_{O(MIN)2}$ (mA)**	**I_{MEAN2}**	**Ripple Ratio2 (I_{RP-P}/I_{MEAN})**	**% Flicker2 100 x (I_{RP-P} / $I_{O(MAX)}$+$I_{O(MIN)}$)**
100	380	282	332	0.29	14.8
120	423	324	373	0.26	13.2
277	446	344	395	0.26	12.9
300	443	344	395	0.25	12.6

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14 AC Cycling Test

No output current overshoot was observed during on - off cycling at 120 VAC.

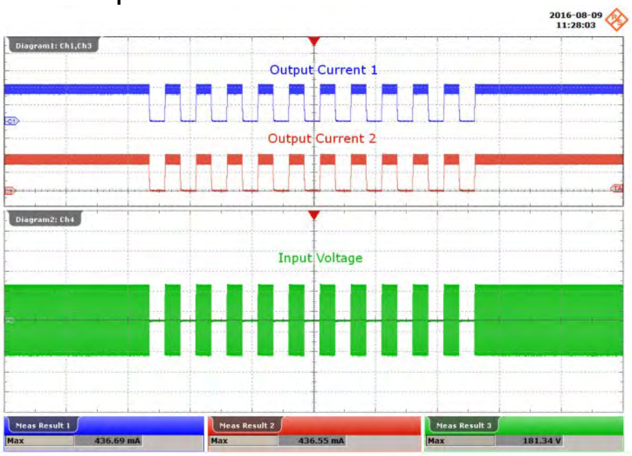

Figure 136 – 120 VAC, 52 V LED Loads.
1 s On – 1 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

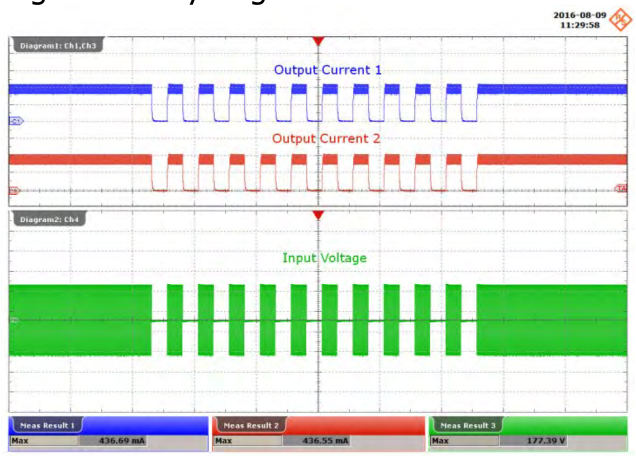

Figure 137 – 120 VAC, 52 V LED Loads.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

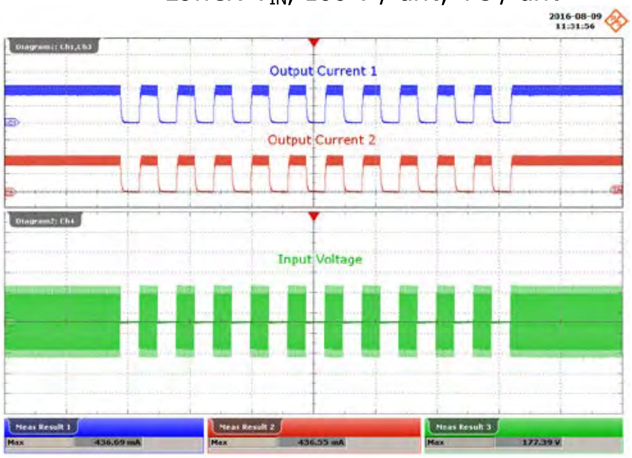

Figure 138 – 120 VAC, 52 V LED Loads.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

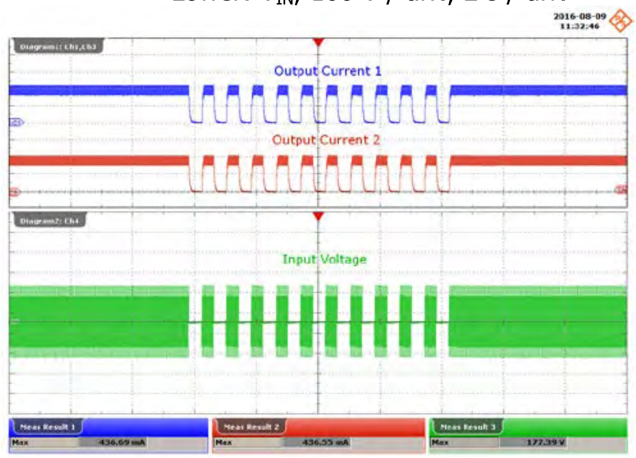

Figure 139 – 120 VAC, 52 V LED Loads.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

Minimal output current overshoot was observed during on - off cycling at 277 VAC.

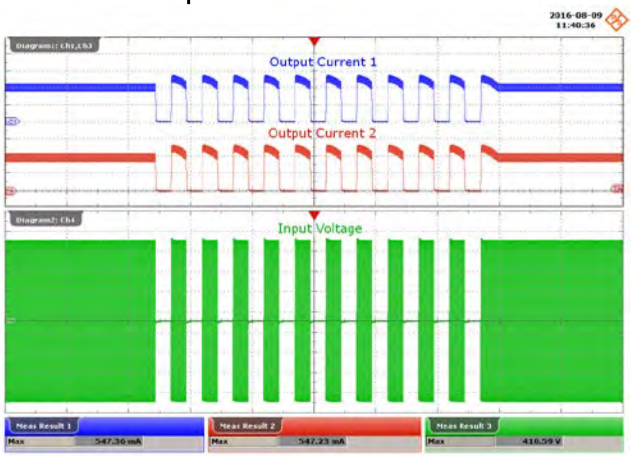

Figure 140 – 277 VAC, 52 V LED Loads.
1 s On – 1 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

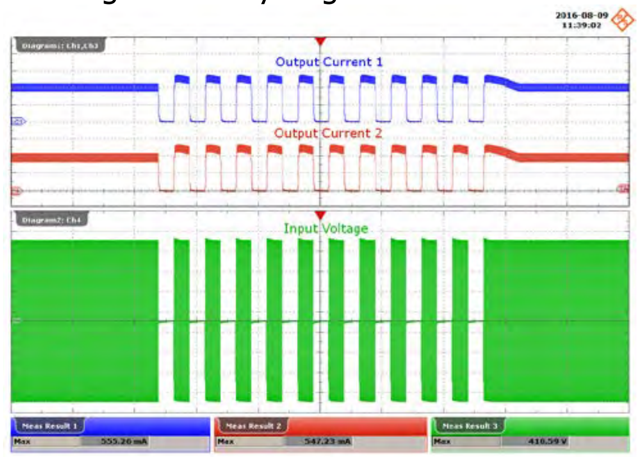

Figure 141 – 277 VAC, 52 V LED Loads.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

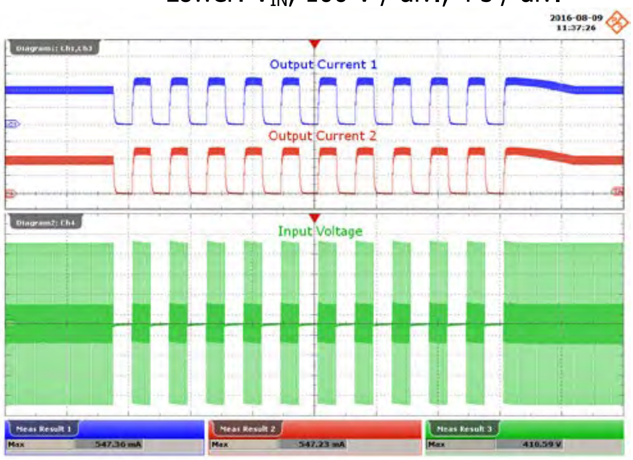

Figure 142 – 277 VAC, 52 V LED Loads.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

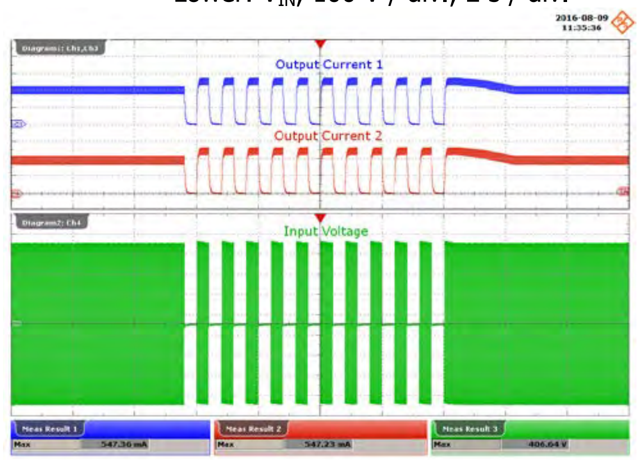

Figure 143 – 277 VAC, 52 V LED Loads.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

Note: No outputs overshoot if the on-off cycling time is more than 2 seconds.

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15 Conducted EMI

15.1 *Test Set-up*

15.1.1 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. Two 52 V LED loads with input voltage set at 115 VAC and 230 VAC.

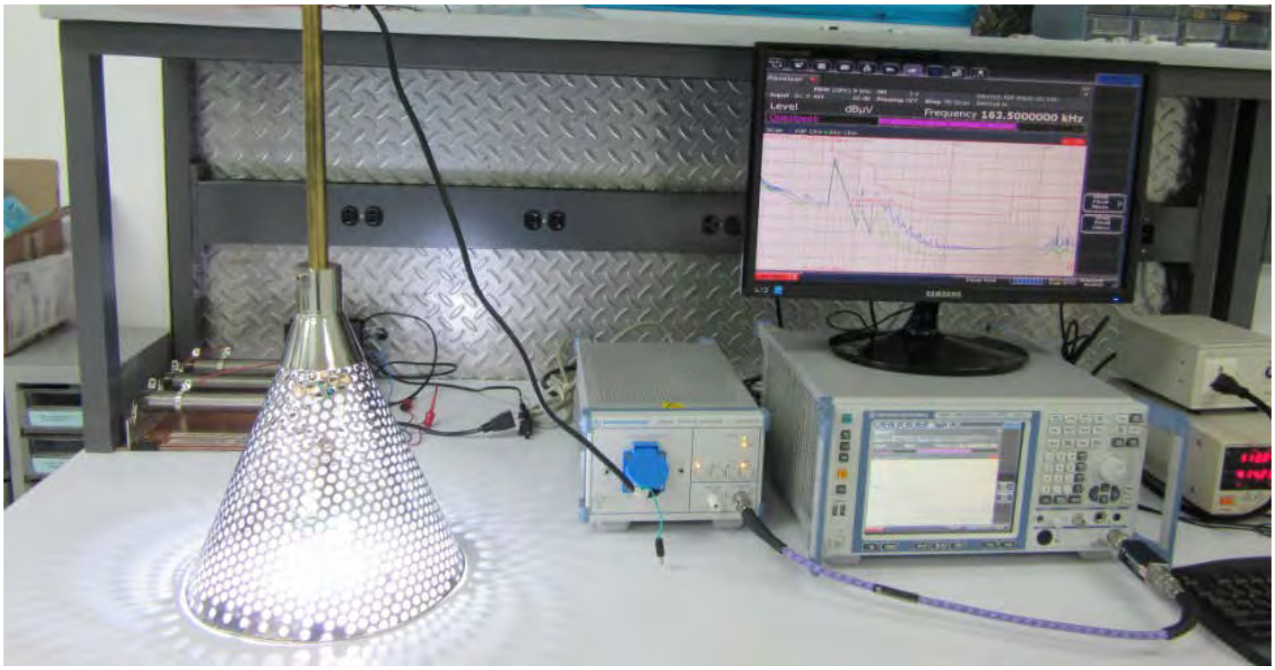

Figure 144 – Conducted EMI Test Set-up.

15.2 *EMI Test Result*

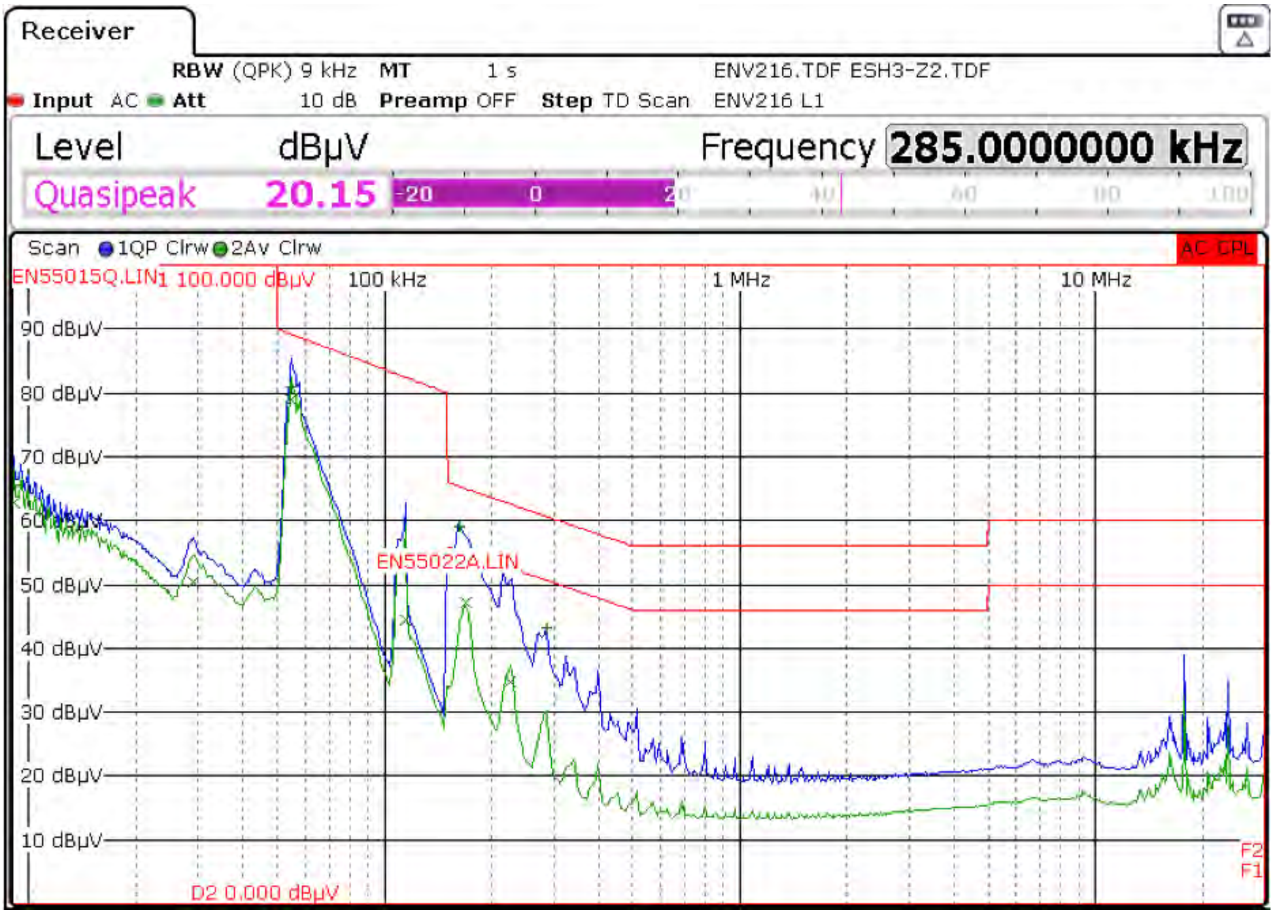

Figure 145 – Conducted EMI QP Scan at 52 V LEDs Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	54.8500 kHz	80.83 L1	-8.33 dB
2 Average	54.8500 kHz	79.02 L1	
1 Quasi Peak	9.0500 kHz	65.59 N	-44.41 dB
2 Average	9.0500 kHz	62.66 L1	
1 Quasi Peak	163.5000 kHz	59.11 L1	-6.17 dB
2 Average	29.0000 kHz	50.45 N	
2 Average	170.2500 kHz	47.13 L1	-7.82 dB
2 Average	114.4000 kHz	44.48 L1	
1 Quasi Peak	285.0000 kHz	43.12 N	-17.55 dB
2 Average	226.5000 kHz	34.80 L1	-17.78 dB

Figure 146 – Conducted EMI Data at 115 VAC, 60 V LED Load.

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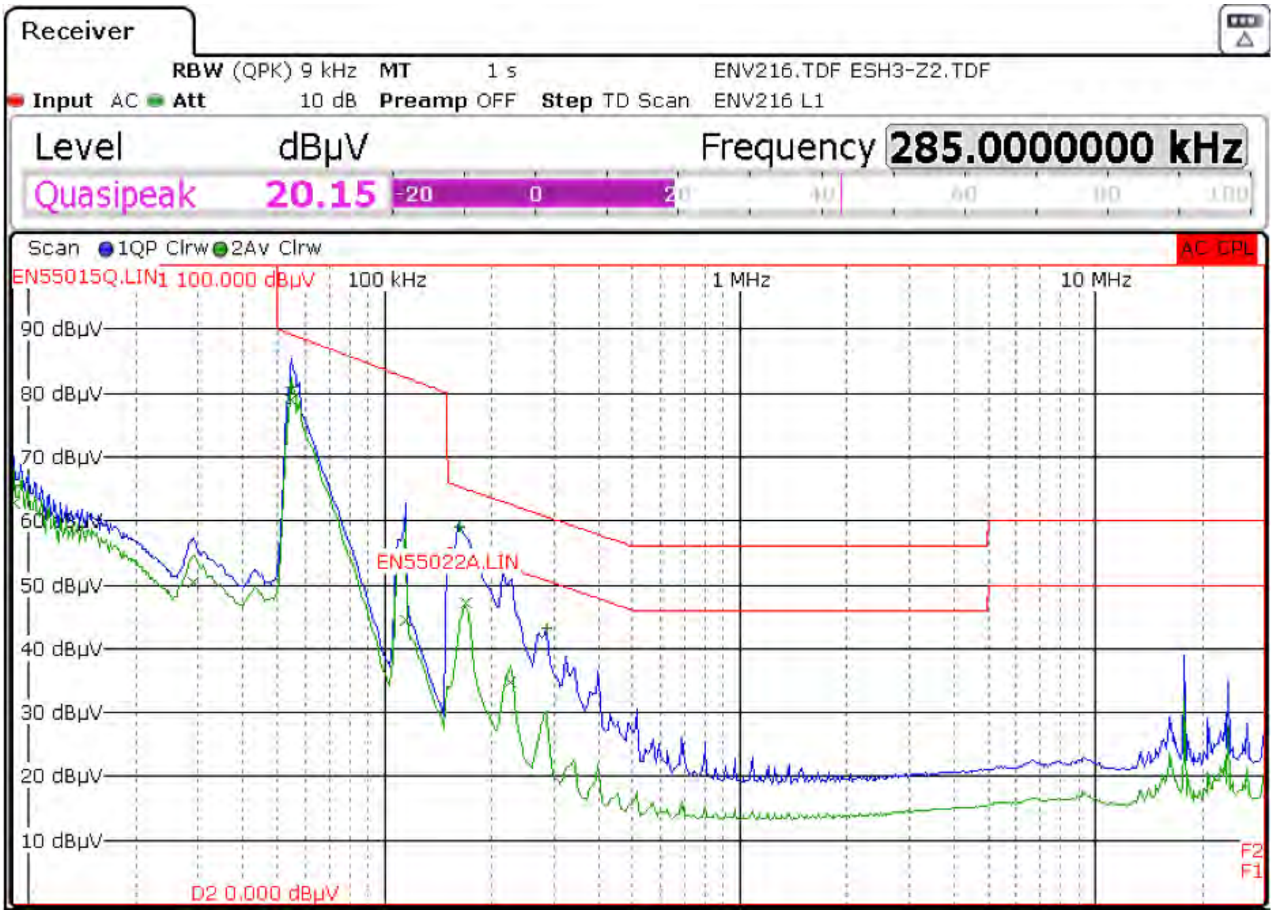

Figure 147 – Conducted EMI QP Scan at 52 V LEDs Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	54.8500 kHz	80.83 L1	-8.33 dB
2 Average	54.8500 kHz	79.02 L1	
1 Quasi Peak	9.0500 kHz	65.59 N	-44.41 dB
2 Average	9.0500 kHz	62.66 L1	
1 Quasi Peak	163.5000 kHz	59.11 L1	-6.17 dB
2 Average	29.0000 kHz	50.45 N	
2 Average	170.2500 kHz	47.13 L1	-7.82 dB
2 Average	114.4000 kHz	44.48 L1	
1 Quasi Peak	285.0000 kHz	43.12 N	-17.55 dB
2 Average	226.5000 kHz	34.80 L1	-17.78 dB

Figure 148 – Conducted EMI Data at 230 VAC, 50 V LED Load.

16 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

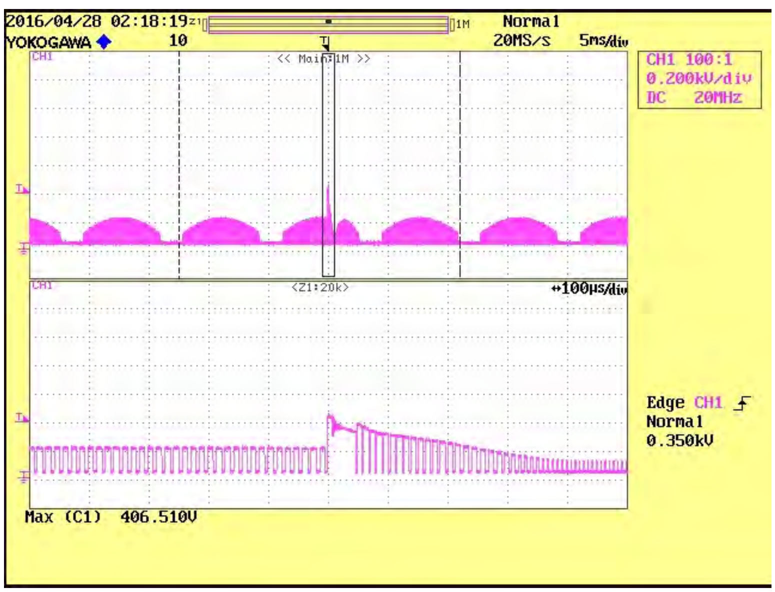

Figure 149 – +1000 kV Differential Surge, 90º Phase Angle.
V_{DRAIN}, 200 V / div., 20 ms / div.
Peak V_{DRAIN}: 406 V.

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17 Brown-in / Brown-out Test

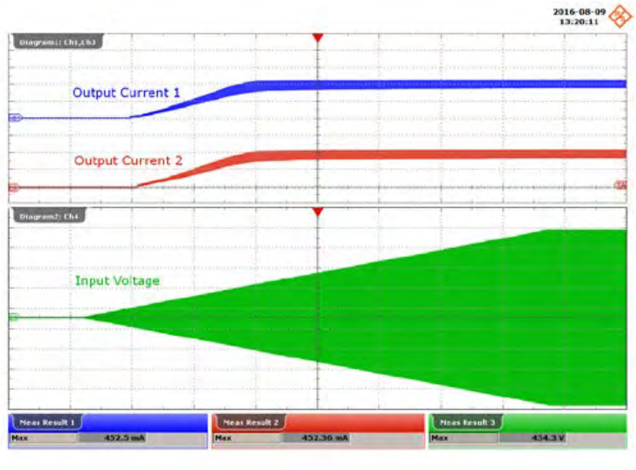

Figure 150 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 100 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

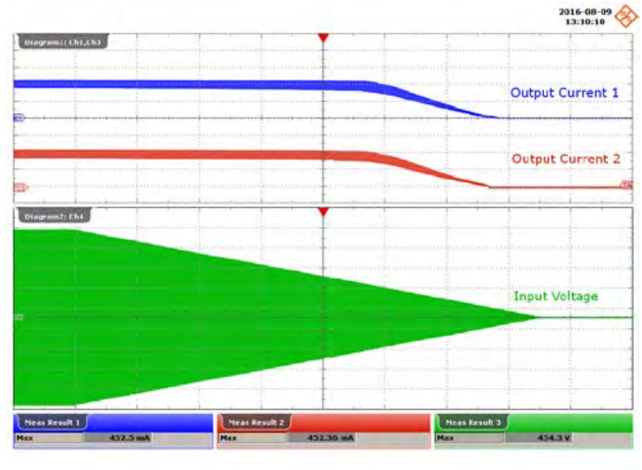

Figure 151 – Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 100 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

18 Revision History

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

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