Design Example Report

Title	***18.4 W Non-Dimmable, High Efficiency (>90%), Power Factor Corrected Non-Isolated Boost LED Driver Using LYTSwitch™-5 LYT5225D***
Specification	195 VAC – 265 VAC Input; 385 V, 48 mA Output
Application	Flood Lamp
Author	Applications Engineering Department
Document Number	DER-543
Date	April 18, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant current regulation, ±5%
- Meets <10% flicker requirement
- Highly energy efficient, >90% at 230 V
- Low cost and low component count for compact PCB solution
- Integrated protection features
    - No-load output 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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5245 Hellyer Avenue, San Jose, CA 95138 USA.
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Table of Contents

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Important Note: Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This engineering report describes a non-dimmable, boost LED driver designed to drive a 385 V LED voltage string at 48 mA from an input voltage range of 195 VAC to 265 VAC. The LED driver utilizes the LYT5225D from the LYTSwitch-5 family of devices.

LYTSwitch-5 is a non-dimmable LED driver IC with single-stage PFC function and accurate LED current control. LYTswitch-5 incorporates a high-voltage power MOSFET and discontinuous mode, variable frequency, variable on-time controller. The controller also provides fast (cycle-by-cycle) current limit, input and output OVP, plus advanced thermal management circuitry.

DER-543 provides a 48 mA accurate output current with a very low ripple (low % flicker) at 385 V LED output. The key design goals were high efficiency, accurate constant current regulation, low components count and low output ripple current.

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

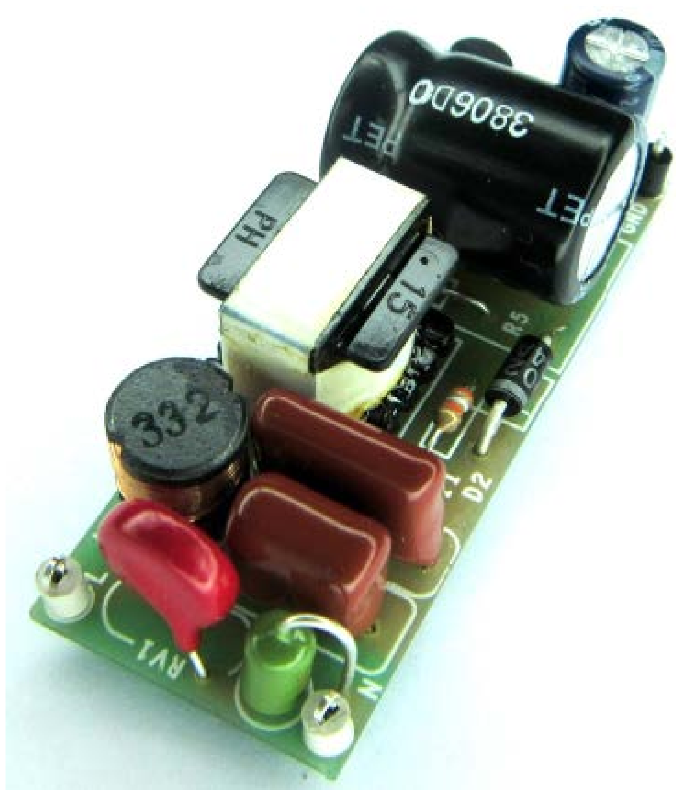

Figure 1 – Populated Circuit Board.

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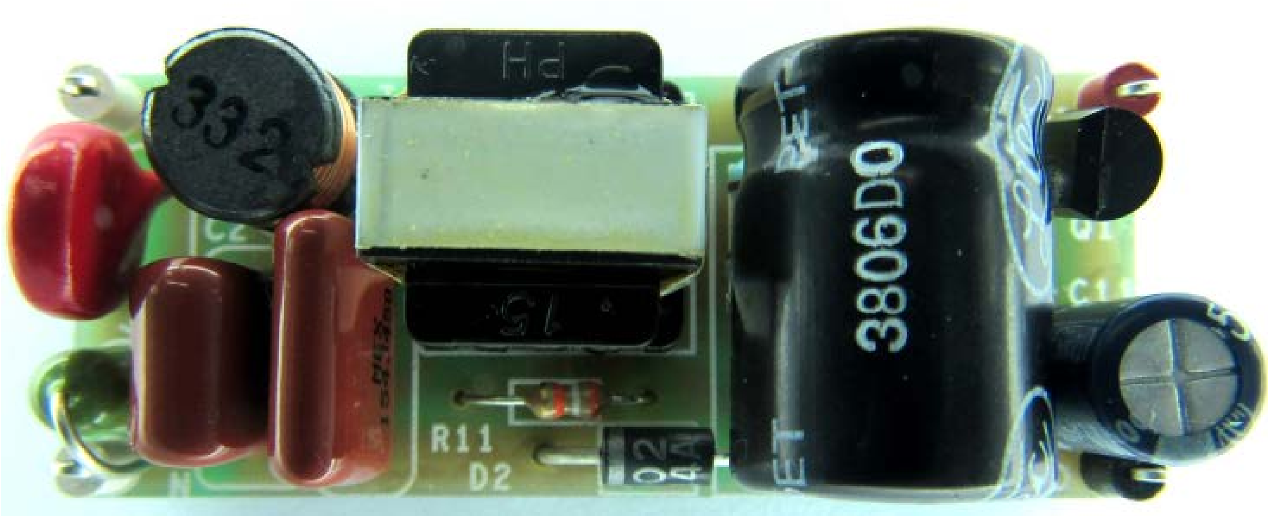

Figure 2 – Populated Circuit Board, Top View.

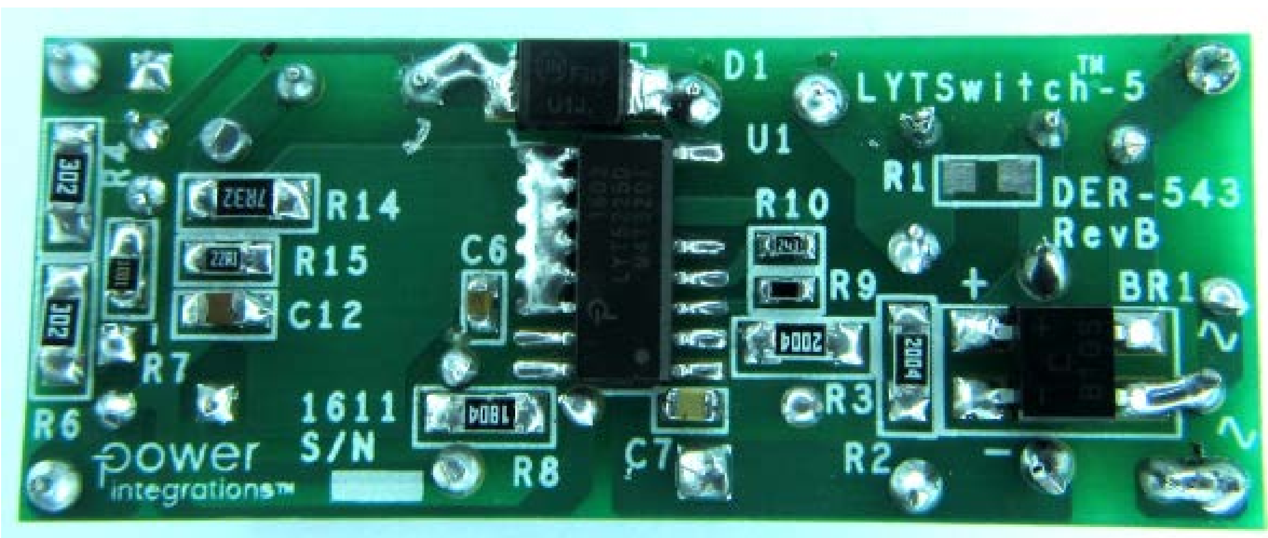

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}		385		V	
Output Current	I_{OUT}		48		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		18.4		W	
Efficiency						
Full Load	η		90		%	230 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 230 VAC / 50 Hz.
Ambient Temperature	T_{AMB}			85	ºC	Free Convection, Sea Level.

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3 Schematic

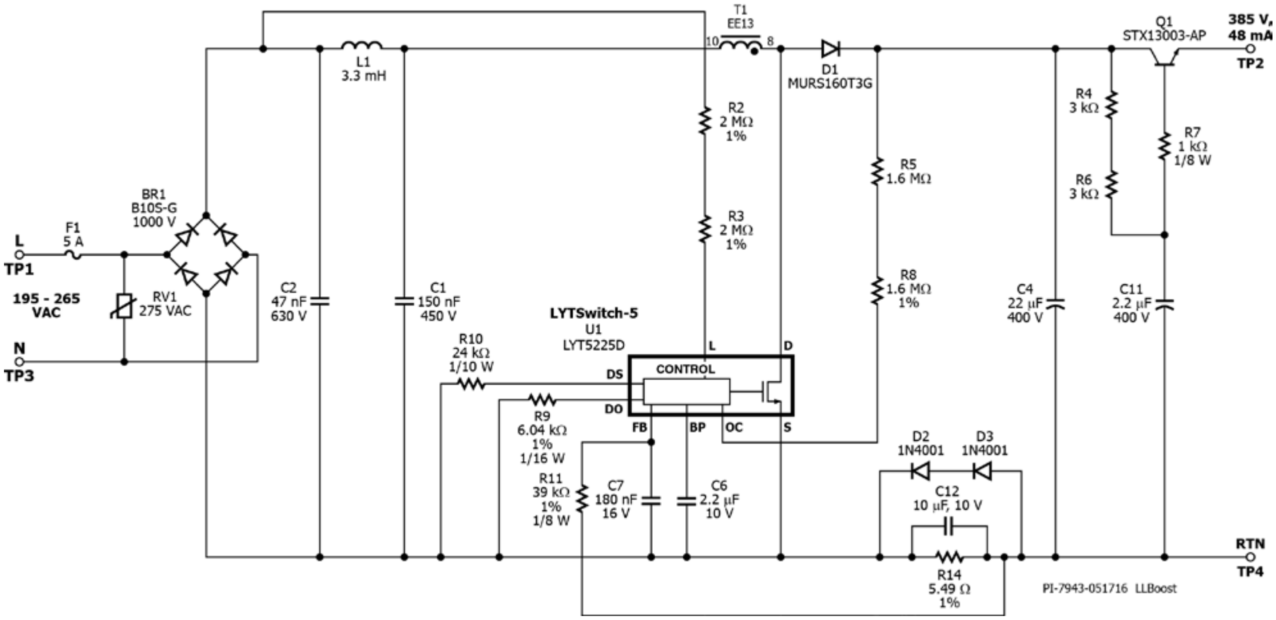

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-5 device (U1-LYT5225D) combines a high-voltage power MOSFET and a power supply controller in a single SO-16 package. For high efficiency solution, a smaller device (LYT5225D) was selected from LYTSwitch-5 output power table instead of larger device. LYT5225D is configured to drive a 385 V output non-isolated boost LED driver with 48 mA constant current output. An active ripple current filter circuit was added to provide lower output ripple current which correlates to a lower % flicker.

4.1 Input Stage

Fuse F1 provides safety protection from component failures. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage (265 VAC).

The AC input is full wave rectified by BR1 to achieve good power factor and low THD.

4.2 EMI Filters

The boost inductor T1 and L1 serve as differential choke. Inductor L1 together with the input filter capacitor C2 and C1 work as an EMI π filter. These EMI filters, together with the LYTSwitch-5 frequency jittering feature ensure compliance with the EN55015 Class B emission limit. Since differential choke L1 and boost inductor T1 are mutually connected in series due to their close proximity, L1 start polarity has great effect on EMI. If L1 is connected incorrectly, the mutual inductance effect would reduce the total series inductance of L1 and T1 and increases EMI. See below correct orientation.

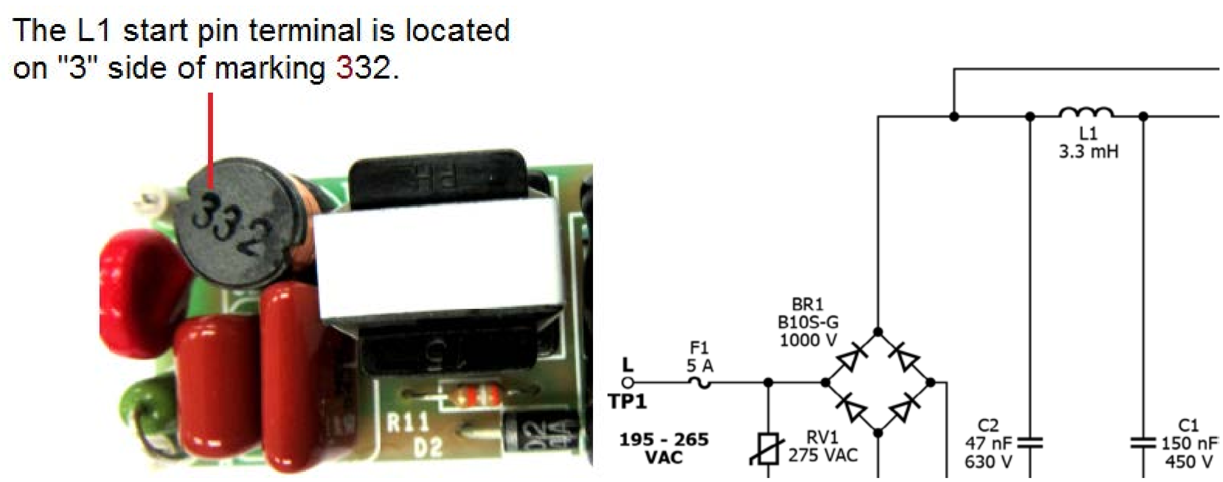

Figure 5 – L1 Marking and Position.

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4.3 LYTSwitch-5 Primary Control Circuit

The LED driver circuit is a boost topology. The primary winding finish terminal (no dot end) of the inductor (T1) is connected to the positive DC bus and the start (dotted end) terminal to the DRAIN (D) pin of the LYTSwitch-5 IC. During the on-time of the power MOSFET, current ramps through the primary winding, storing energy which is then delivered to the output load via output diode D1 during the power MOSFET off-time.

Capacitor C10 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the IC. During start-up, the bypass capacitor C7 is charged to ~5.25 V from IC internal high-voltage current source connected to the D pin.

To provide input line voltage information to U1, the input AC voltage is sensed directly after the bridge rectifier diode through sampling resistors R2 and R3. The device input OVP function is activated when line sense current exceeds the OVP threshold. Output current regulation is achieved through direct output current sensing with respect to DRIVER CURRENT SENSE (DS) pin which is connected to SOURCE (S) pin through R10. With reference to the FEEDBACK (FB) pin threshold of 300 mV and DS, R14 senses the average output LED current directly from the output return rail. The sense resistor is connected before the output capacitor C4 for a faster feedback response enhanced by the output ripple current. Capacitor C10 provides voltage filtering across R14 for a more stable feedback. Resistor R11 and C7 set the desired time constant for optimized transient response. Diode D2 and D3 protects R14 and C12 from start-up transient voltage surge. It also prevents the triggering of the FB OVP function. The IC U1 OUTPUT COMPENSATION (OC) pin senses the output voltage directly through R_{OC} resistors R5 and R8 for the output OVP function at open load. When the OC pin current exceeds the OV threshold, output OVP is activated with the IC latching off. This will prevent the output voltage from rising further. An AC recycle is needed to reset this protection mode once triggered. R_{OC} resistor value should be set so as not to exceed the output capacitor rated surge voltage specification.

4.4 Active Ripple Current Filter (ARF)

Due to tight % flicker requirement on several applications, an active ripple current filter (ARF) is added to reduce the output ripple current. The ARF is almost similar to a linear series pass voltage regulator which comprises of NPN BJT (Q1) and an RC low pass filter (R4, R6 and C11). The low pass filter lowers the Q1 base drive current inducing a voltage drop across Q1 collector emitter. The voltage drop on Q1 CE reduces output ripple voltage, thereby reducing the output ripple current.

5 PCB Layout

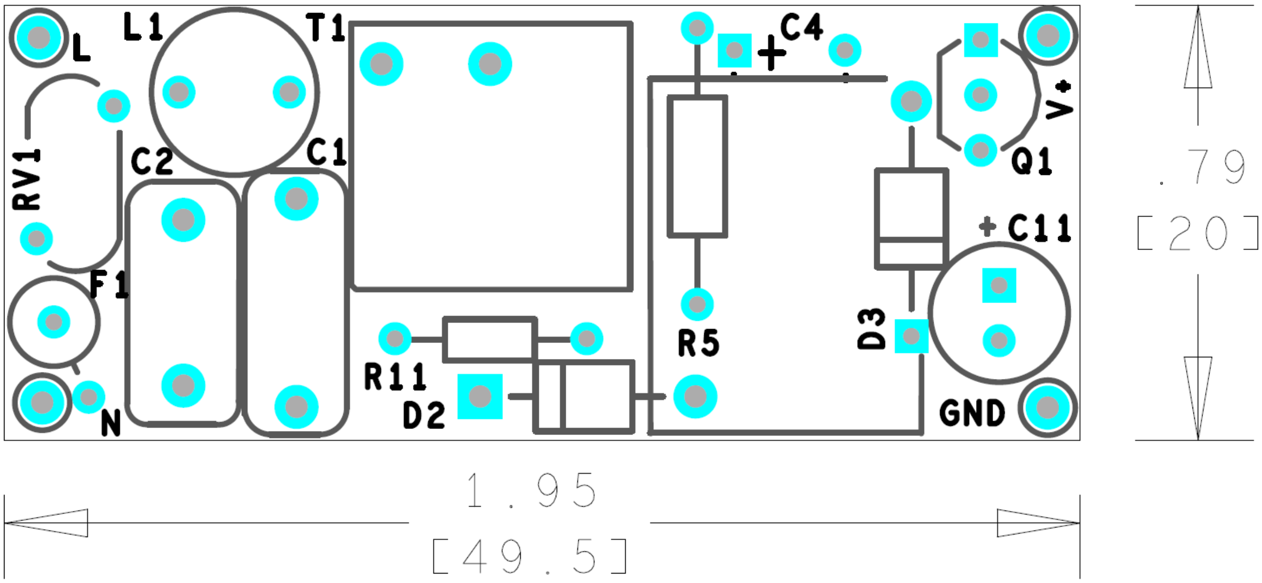

Figure 6 – Top Side.

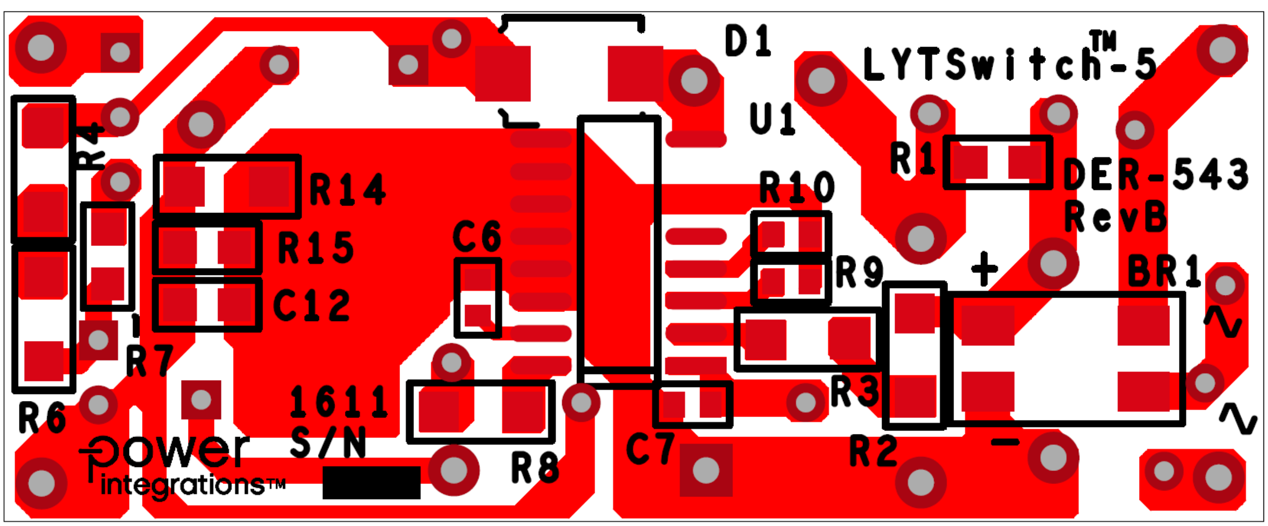

Figure 7 – Bottom Side.

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6 Bill of Materials

Item	QTY	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	150 nF, 450 V, Film	MEXXF3150	Duratech
3	1	C2	47 nF, 630 V, Film	MEXPD24704JJ	Duratech
4	1	C4	22 μF, 400 V, Electrolytic, (12.5 x 16)	TYB2GM220J160	Ltec
5	1	C6	2.2 μF, 10 V, Ceramic, X7R, 0603	GRM188R71A225KE15D	Murata
6	1	C7	180 nF, 16 V, Ceramic, X7R, 0603	GRM188R71C184KA01D	Murata
7	1	C11	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
8	1	C12	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
9	1	D1	600 V, 1 A, Ultrafast Recovery, 35 ns, SMB Case	MURS160T3G	On Semi
10	1	D2	Diode, Gen Purp, 50 V, 1 A, DO204AL	1N4001-E3/54	Vishay
11	1	D3	Diode, Gen Purp, 50 V, 1 A, DO204AL	1N4001-E3/54	Vishay
12	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
13	1	L1	3.3 mH, 0.15 A, Ferrite Core	CTCH895F-332K	CTParts
14	1	Q1	NPN, Power BJT, 400 V, 1 A, TO-92	STX13003-AP	ST Micro
15	1	R2	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
16	1	R3	RES, 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
17	1	R4	RES, 3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ302V	Panasonic
18	1	R5	RES, 1.6 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-1M6	Yageo
19	1	R6	RES, 3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ302V	Panasonic
20	1	R7	RES, 1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
21	1	R8	RES, 1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1604V	Panasonic
22	1	R9	RES, 6.04 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6041V	Panasonic
23	1	R10	RES, 24 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ243V	Panasonic
24	1	R11	RES, 39 kΩ, 5%, 1/8 W, Carbon Film	CF18JT39K0	Stackpole
25	1	R14	RES, 5.49 Ω, 1%, ¼ W, 1206, SMD	RC1206FR-075R49L	Yageo
26	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
27	1	T1	Bobbin, EE13, Vertical, 10 pins	P-1302-2	Pin Shine
28	1	U1	LYTSwitch-5, SO-16B	LYT5225D	Power Integrations

7 Inductor Specification

7.1 Electrical Diagram

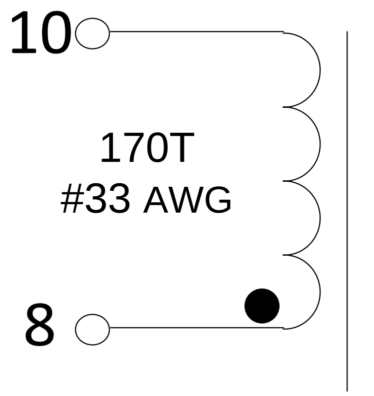

Figure 8 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 8 and pin 10, with all other windings open.	780 μH
Tolerance	Tolerance of Primary Inductance.	±7%

7.3 Material List

Item	Description
[1]	Core: EE13.
[2]	Bobbin: EE13, Vertical, 10 pins, Part no. 25-01023-00.
[3]	Magnet Wire: #33 AWG.
[4]	Polyester tape: 7.9 mm.
[5]	Transformer tape: 5.5 mm.

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7.4 Inductor Build Diagram

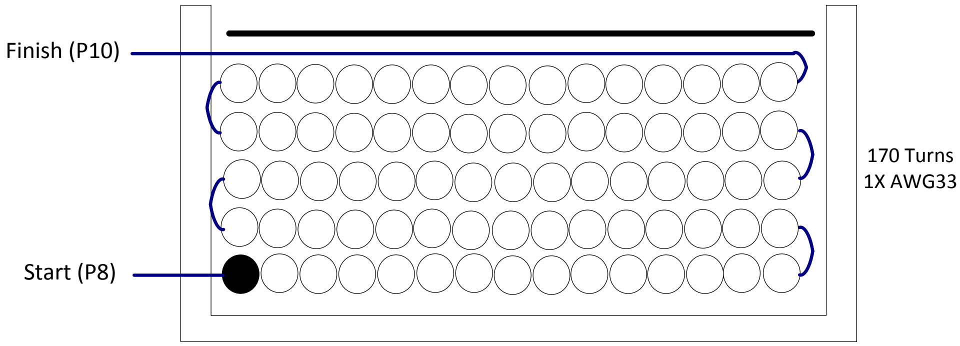


Figure 9 – Transformer Build Diagram.

7.5 Inductor Construction

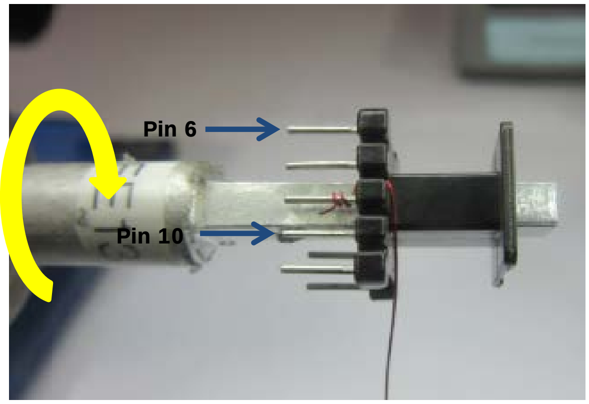
Winding Directions	Bobbin is oriented on winder jig such that terminal pin 6-10 is in the left side. The winding direction is clockwise as shown in the figure.
Winding 1	Use wire item [3], start at pin 8 and wind 170 turns in 5 layers, then finish the winding on pin 10.
Insulation	Add 1 layer of tape, item [4], for insulation.
Terminal Pins	Pull out terminal pins 1-7 and pin 9. Solder pin 8 and pin 10.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 780 μH.
Core Assembly	Assemble the 2 cores on the bobbin with the ungapped core place on the terminal pin side as shown in the figure. Wrap the 2 cores with polyester tape item (5).
Bobbin Tape	Add 1 layer tape, Item (4), around the bobbin together with the core.
Finish	Dip the transformer assembly in 2:1 thinner and varnish solution.

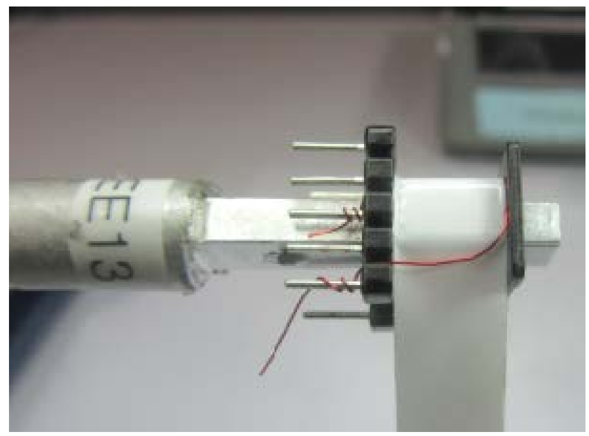
7.6 Transformer Winding Illustrations

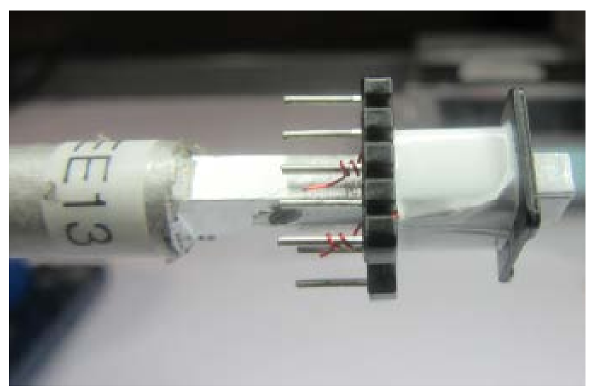
<table>
<tr><td>Winding Directions

Bobbin is oriented on winder jig such that terminal pin 6-10 is in the left side. The winding direction is clockwise as shown in the figure.

Winding 1

Use wire item [3], start at pin 8 and wind 170 turns in 5 layers, then finish the winding on pin 10.</td><td>

</td></tr>
<tr><td>Insulation

Add 1 layer of tape, item [4], for insulation.</td><td></td></tr>
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Terminal Pins

Pull out terminal pins 1-7 and pin 9.

Core Grinding

Grind the center leg of one core until it meets the nominal inductance of 780 μH.

Core Assembly

Assemble the 2 cores on the bobbin with the ungapped 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.

Bobbin Tape

Add 1 layer tape, Item (4), around the bobbin together with the core.

Finish

Dip the transformer assembly in 2:1 thinner and varnish solution.

8 Performance Data

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

8.1 Efficiency

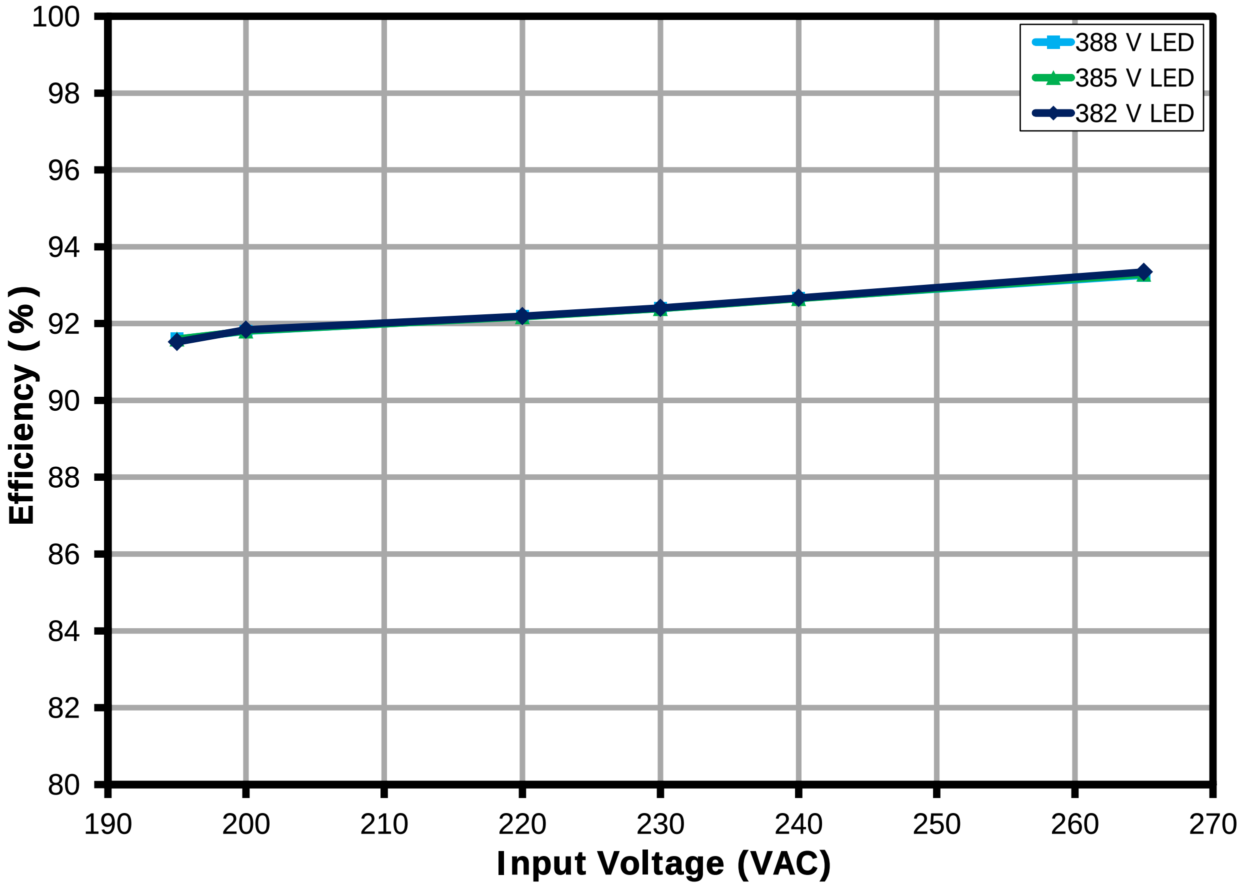

Figure 10 – Efficiency vs. Line and LED Load.

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8.2 Line Regulation

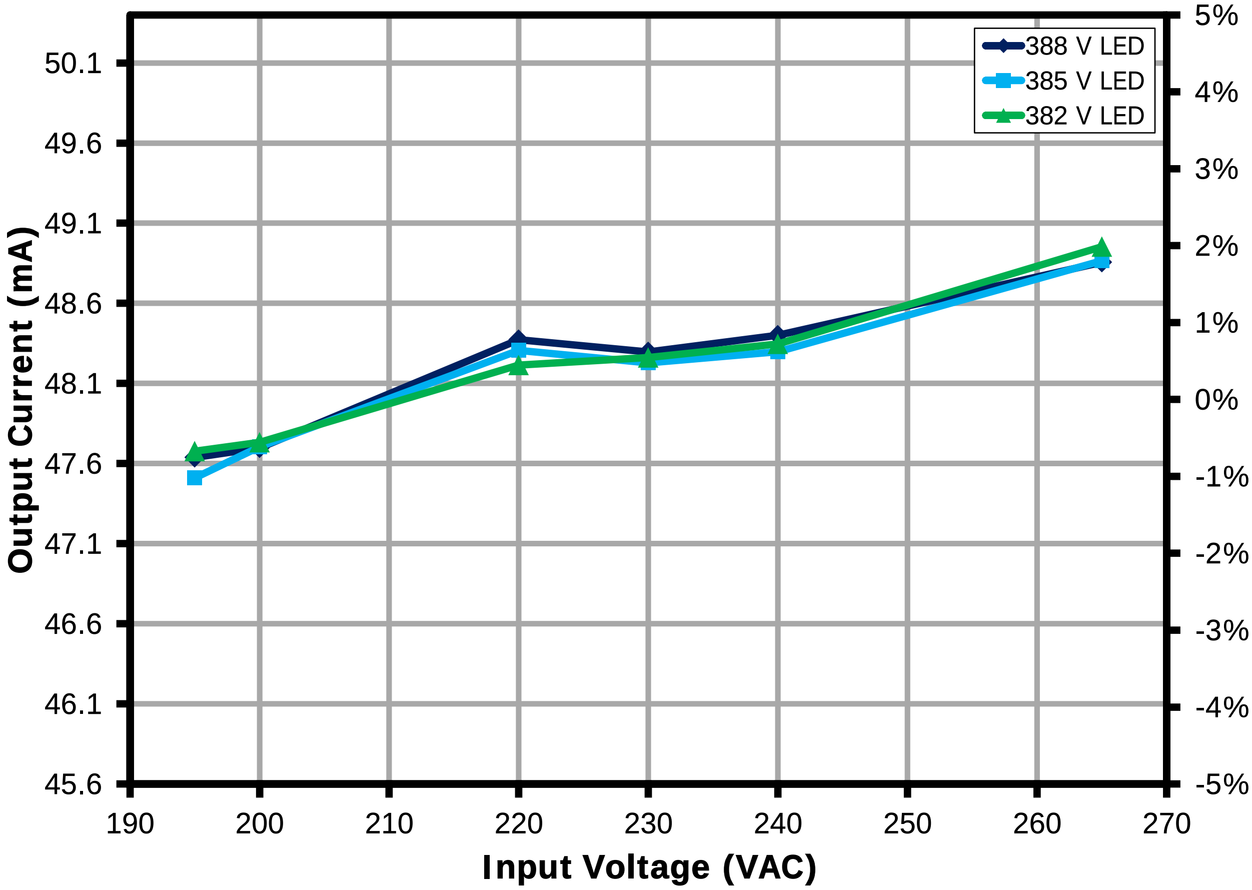

Figure 11 – Regulation vs. Line and LED Load.

8.3 Power Factor

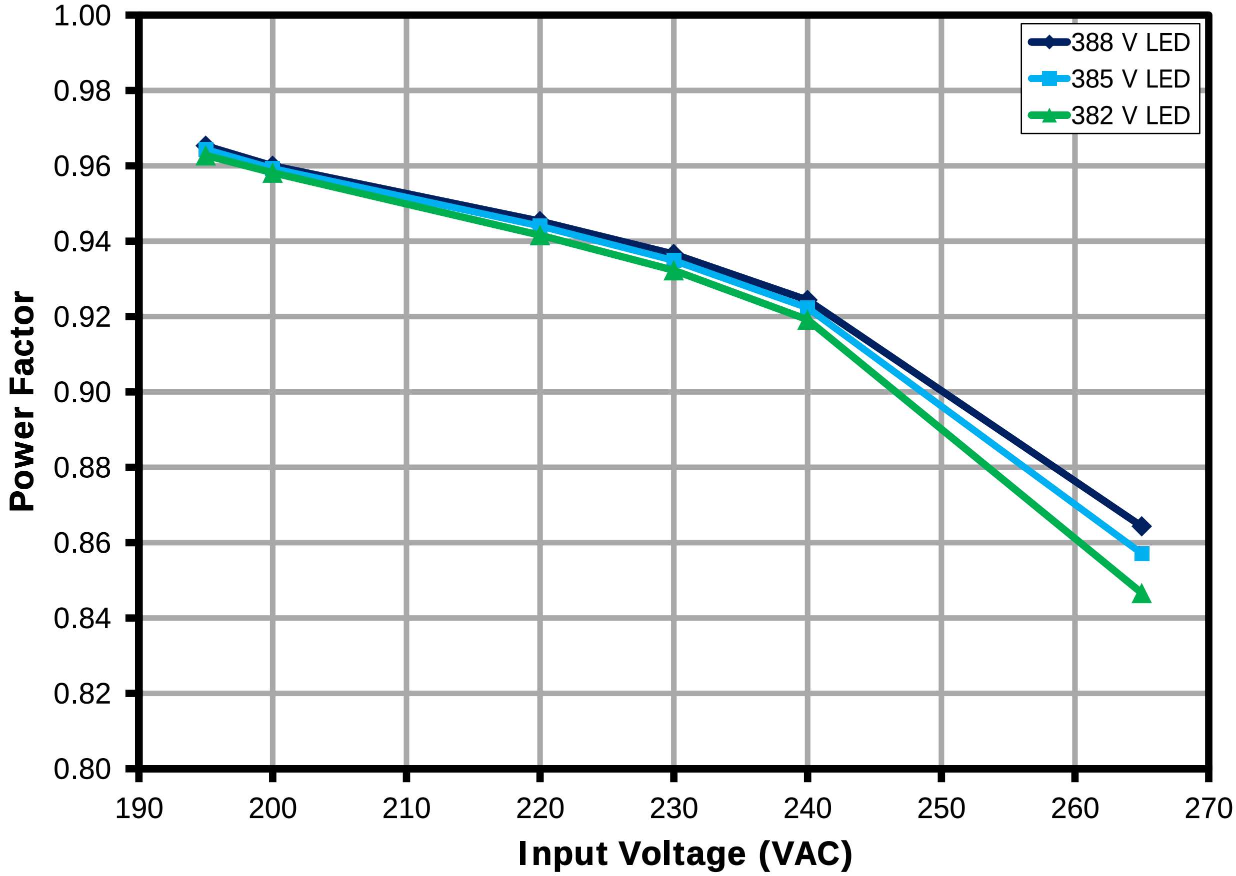

Figure 12 – Power Factor vs. Line and LED Load.

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8.4 %ATHD

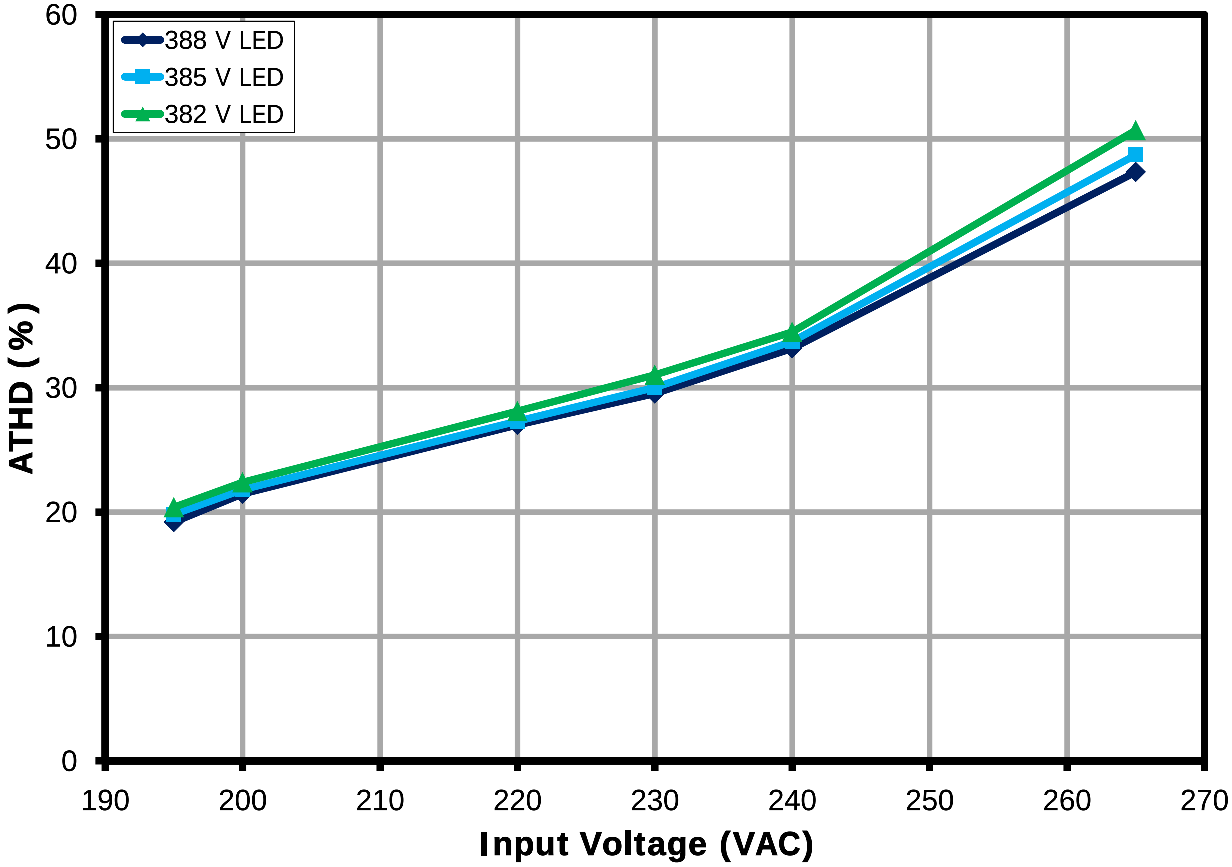

Figure 13 – %ATHD vs. Line and LED Load.

8.5 Individual Harmonics Content

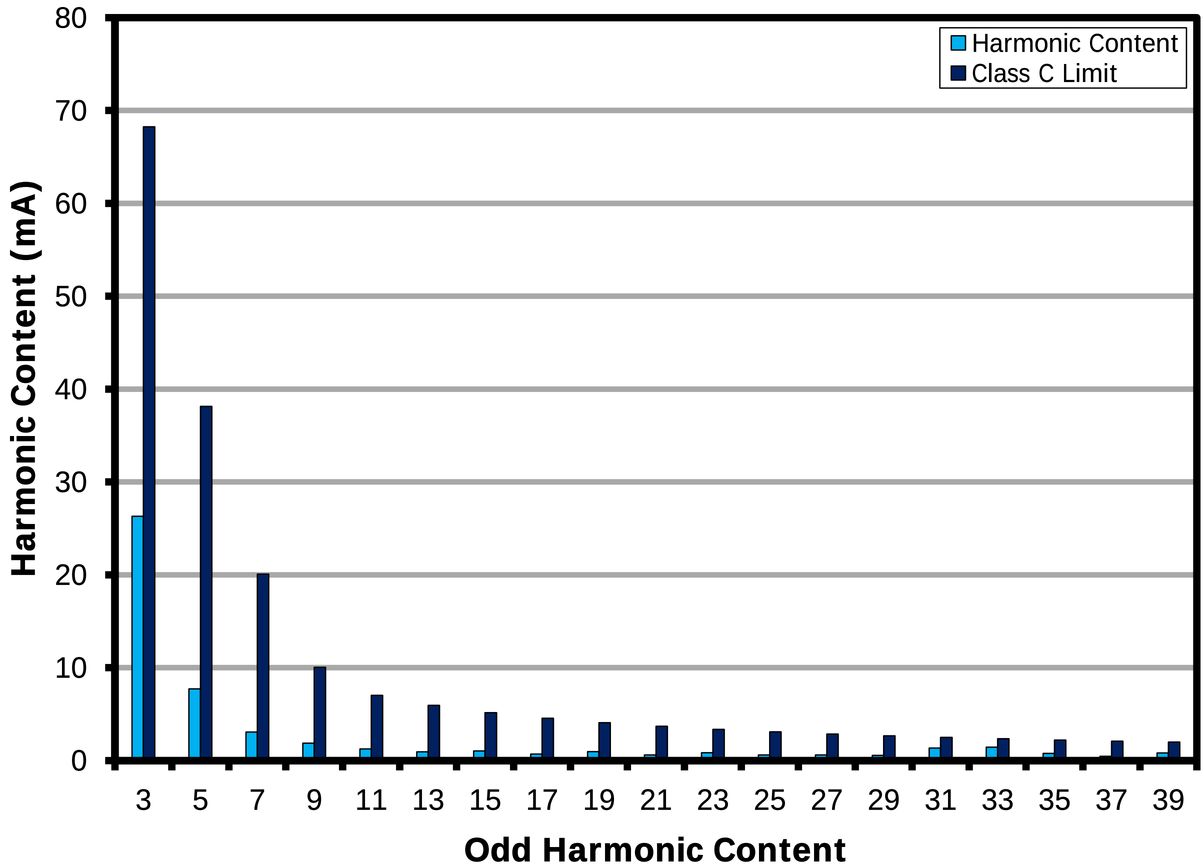

Figure 14 – 385 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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9 Test Data

9.1 Test Data, 387 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
195	50	194.91	107.27	20.18	0.965	19.20	388.06	47.64	18.49	91.60
200	50	199.88	105.00	20.15	0.960	21.46	387.79	47.70	18.50	91.80
220	50	219.92	97.92	20.36	0.945	27.01	387.91	48.37	18.77	92.18
230	50	229.94	94.10	20.27	0.937	29.54	387.66	48.30	18.72	92.39
240	50	239.96	91.26	20.24	0.924	33.16	387.53	48.40	18.76	92.65
265	50	264.98	88.66	20.31	0.864	47.34	387.60	48.86	18.94	93.26

9.2 Test Data, 385 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
195	50	194.91	106.55	20.03	0.964	19.82	386.16	47.51	18.35	91.60
200	50	199.88	104.53	20.04	0.959	21.81	385.72	47.70	18.40	91.80
220	50	219.92	97.36	20.21	0.944	27.32	385.64	48.31	18.63	92.18
230	50	229.94	93.54	20.11	0.935	30.01	385.25	48.23	18.58	92.39
240	50	239.96	90.68	20.07	0.922	33.72	384.98	48.30	18.59	92.65
265	50	264.98	88.82	20.17	0.857	48.71	384.99	48.87	18.81	93.29

9.3 Test Data, 382 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
195	50	194.88	105.96	19.88	0.963	20.39	382.14	47.68	18.22	91.52
200	50	199.85	103.64	19.85	0.958	22.40	381.84	47.73	18.23	91.84
220	50	219.89	96.46	19.97	0.942	28.12	381.87	48.22	18.41	92.19
230	50	229.91	92.97	19.93	0.932	31.04	381.70	48.26	18.42	92.41
240	50	239.93	90.25	19.91	0.919	34.48	381.58	48.35	18.45	92.67
265	50	264.95	89.29	20.03	0.847	50.70	381.73	48.96	18.69	93.35

9.4 Test Data, Harmonic Content at 230 VAC with 385 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50	97.01	20.075	30.14
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	88.38			
2	0.14	0.16%		
3	26.31	29.77%	68.26	Pass
5	7.72	8.74%	38.14	Pass
7	3.07	3.47%	20.08	Pass
9	1.87	2.12%	10.04	Pass
11	1.25	1.41%	7.03	Pass
13	0.93	1.05%	5.95	Pass
15	1.04	1.18%	5.15	Pass
17	0.70	0.79%	4.55	Pass
19	0.97	1.10%	4.07	Pass
21	0.60	0.68%	3.68	Pass
23	0.85	0.96%	3.36	Pass
25	0.61	0.69%	3.09	Pass
27	0.61	0.69%	2.86	Pass
29	0.54	0.61%	2.67	Pass
31	1.35	1.53%	2.49	Pass
33	1.43	1.62%	2.34	Pass
35	0.76	0.86%	2.21	Pass
37	0.45	0.51%	2.09	Pass
39	0.81	0.92%	1.98	Pass

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10 Thermal Performance

10.1 Thermal Performance Scan – Open Frame Unit

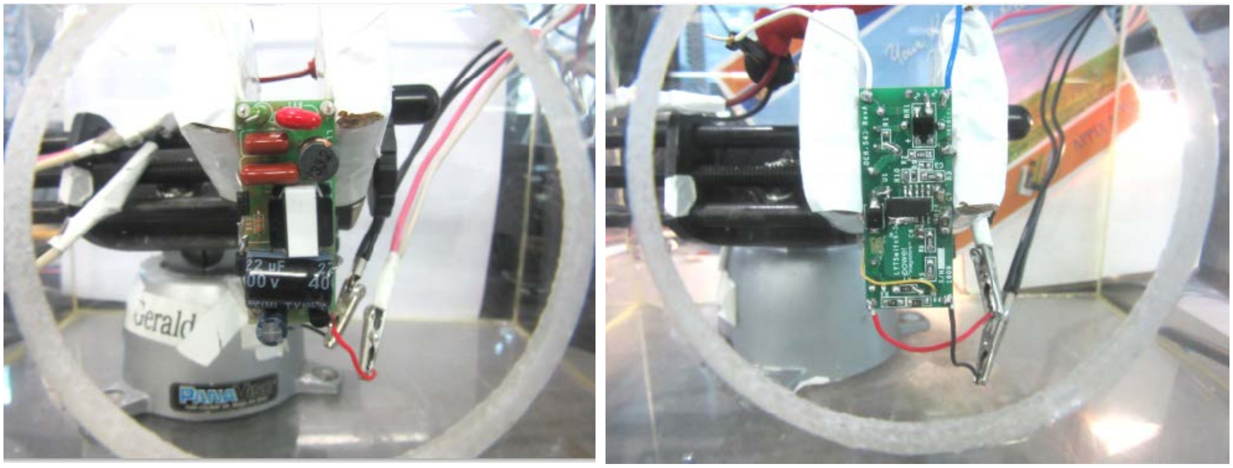

Figure 15 – Test Set-up Picture - Open Frame.

Unit in open frame was placed inside the acrylic enclosure to prevent airflow that might affect the thermal measurements. Temperature was measured using FLIR thermal camera.

10.1.1 Thermal Scan

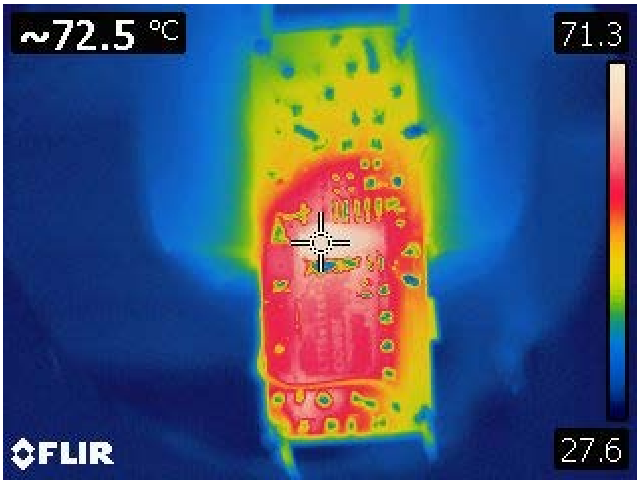

Figure 16 – 230 VAC, 385 V LED Load.
Spot 1: LYT5225D (U1): 72.5 ºC.

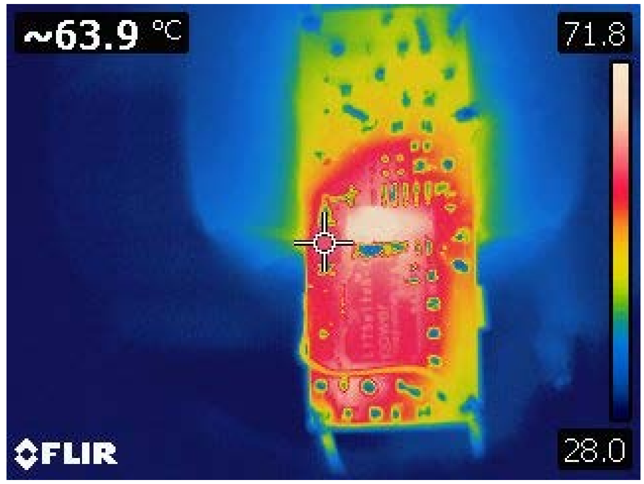

Figure 17 – 230 VAC, 385 V LED Load.
Spot 1: Output Diode (D1): 63.9 ºC.

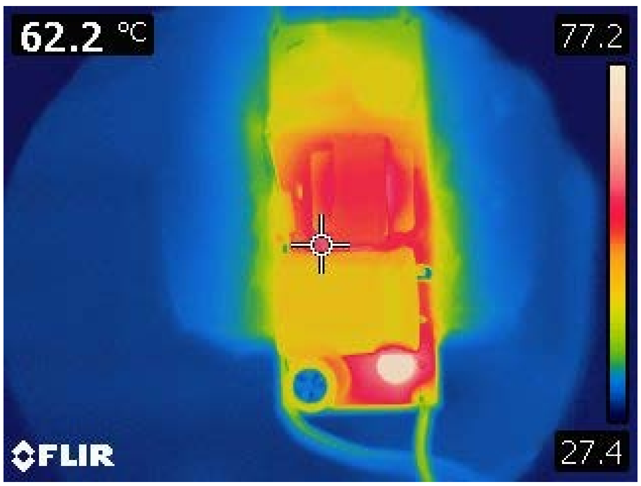

Figure 18 – 230 VAC, 385 V LED Load.
Spot 1: Inductor (T1): 62.2 ºC.

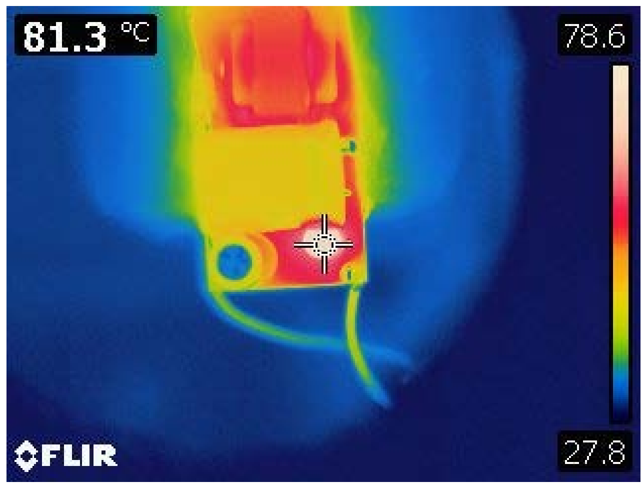

Figure 19 – 230 VAC, 385 V LED Load.
Spot 1: ACF (Q1): 81.3 ºC.

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10.2 Thermal Performance at 85 °C Ambient

Figure 20 – Test Set-up Picture Thermal at 85^{0}C Ambient- Open Frame

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

10.2.1 Thermal Performance at 195 VAC with a 385 V LED Load

Measurement	Ambient	LYTSwitch-5	Q1	D1	T1
Maximum (°C)	86.1	122.3	121.8	114.7	116.9
Final (°C)	86.0	122.1	121.7	114.1	116.7

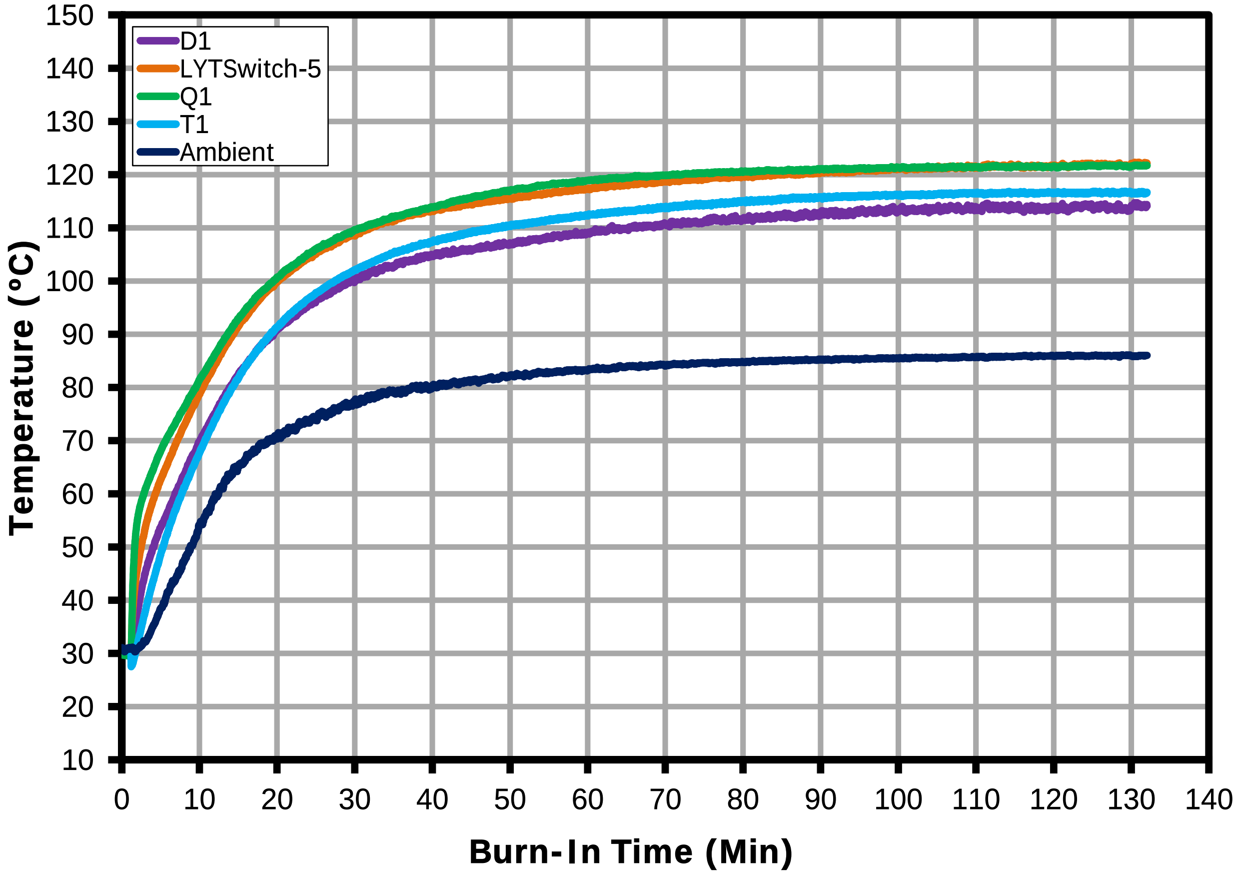

Figure 21 – Component Temperature at 195 VAC, 385 V LED Load, 85 ºC Ambient.

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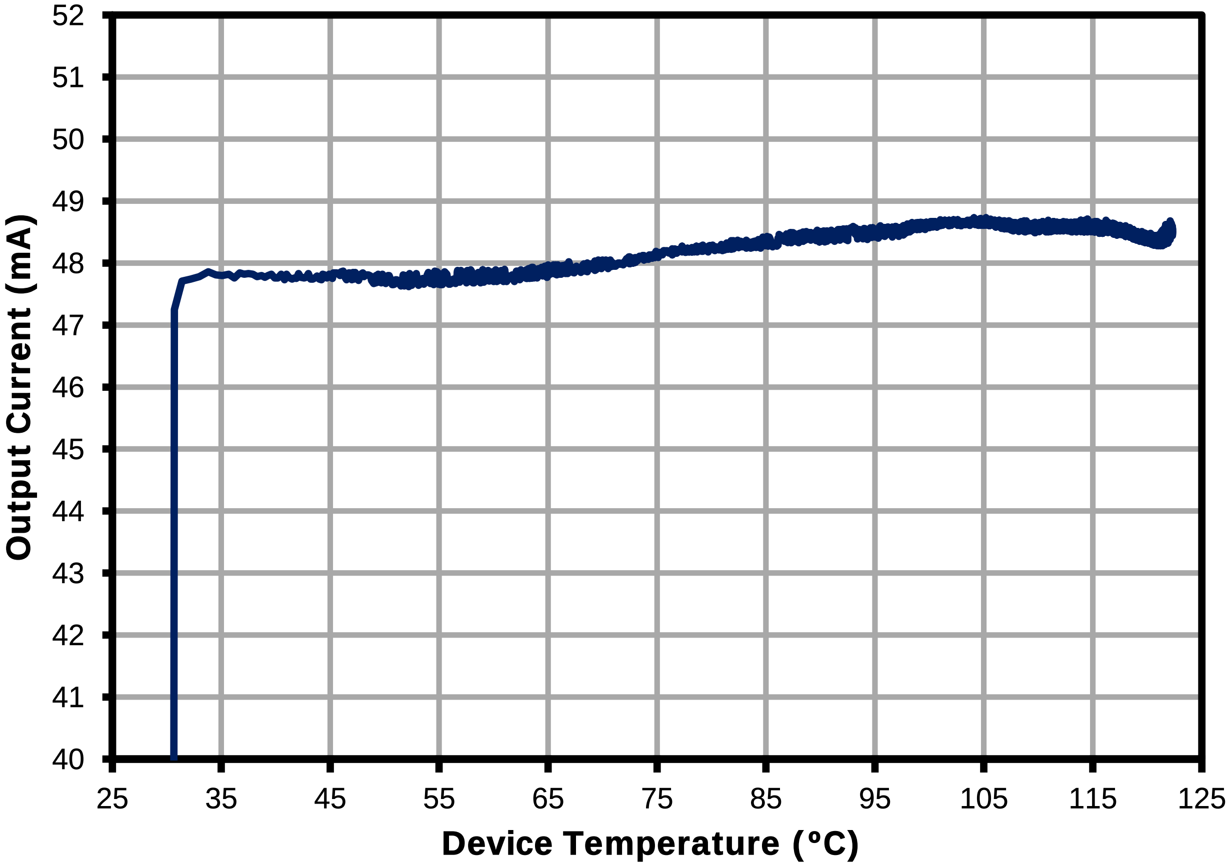

Figure 22 – Output Current vs. Device Temperature at 195 VAC, 385 V LED Load, 85 ºC Ambient.

10.2.2 Thermal Performance at 230 VAC with a 385 V LED Load

Measurement	Ambient	LYTSwitch-5	Q1	D1	T1
Maximum (°C)	85.7	117.0	120.9	111.4	111.0
Final (°C)	85.6	116.7	120.7	110.6	110.7

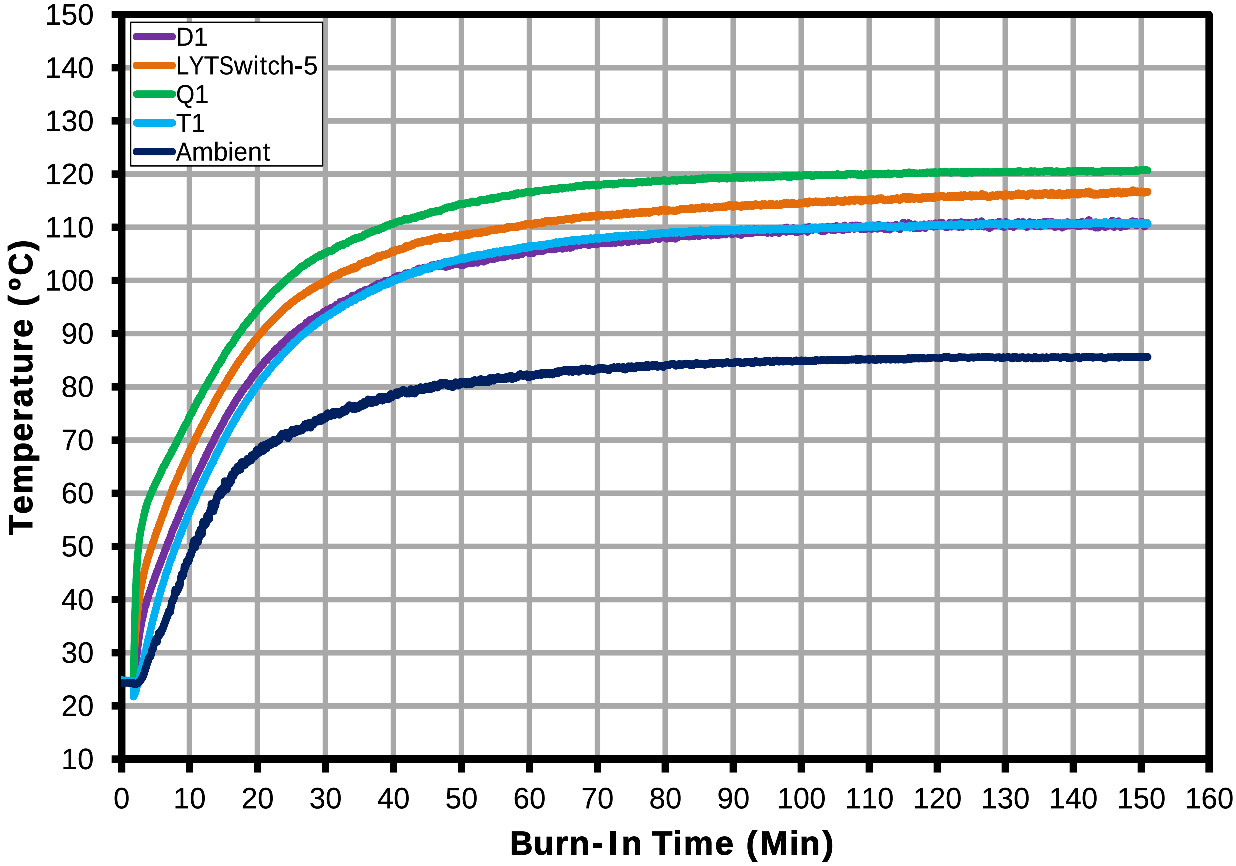

Figure 23 – Component Temperature at 230 VAC, 385 V LED Load, 85 ºC Ambient.

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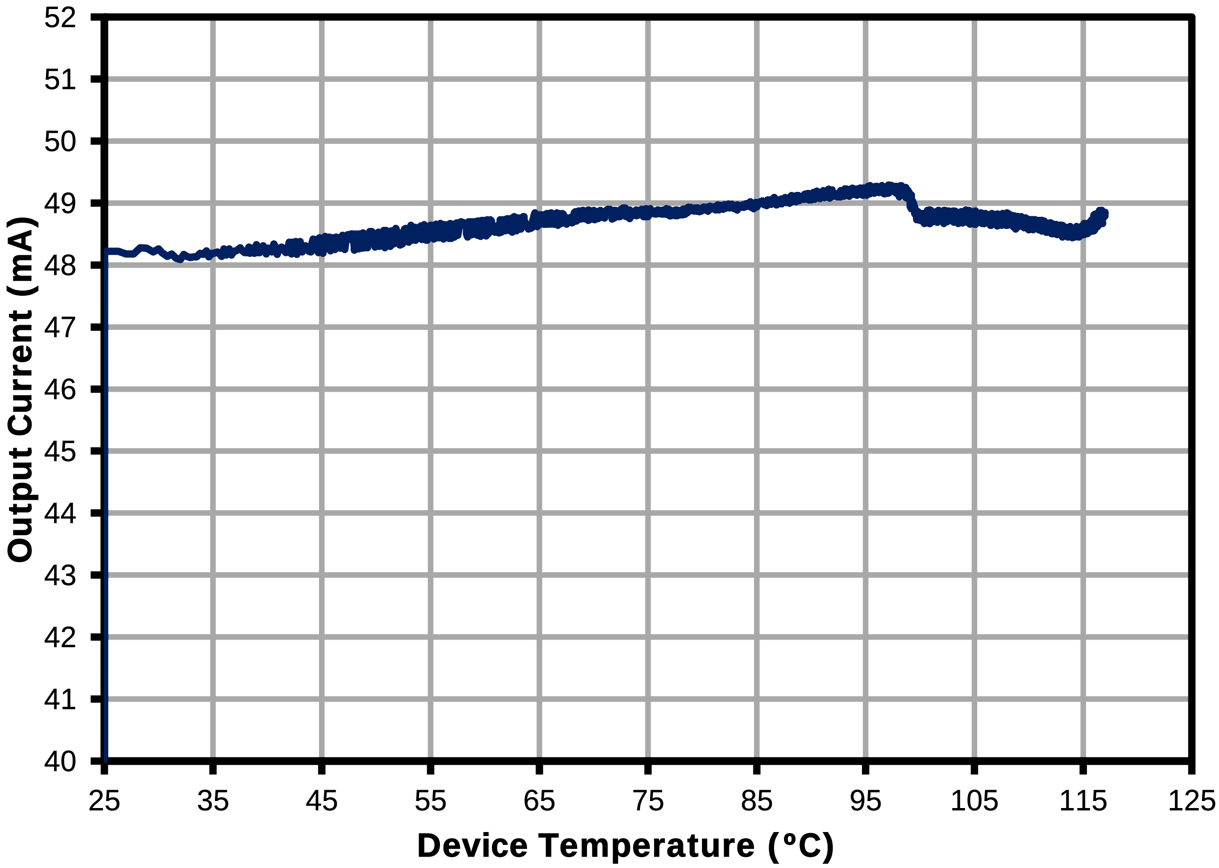

Figure 24 – Output Current vs. Device Temperature at 230 VAC, 385 V LED Load, 85 ºC Ambient.

10.2.3 Thermal Performance at 265 VAC with a 385 V LED Load

Measurement	Ambient	LYTSwitch-5	Q1	D1	T1
Maximum (°C)	86.0	112.1	120.5	106.7	104.6
Final (°C)	85.8	111.8	120.4	106.2	104.6

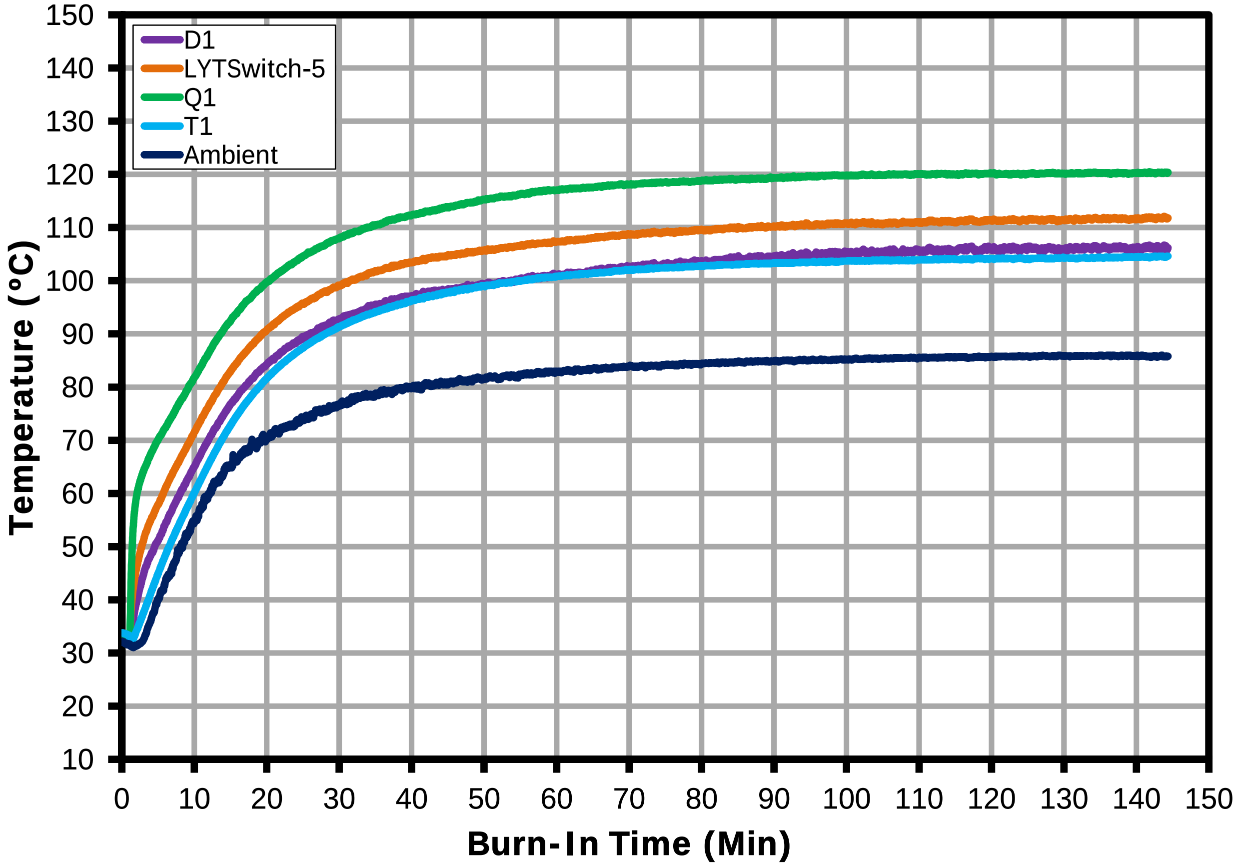

Figure 25 – Component Temperature at 265 VAC, 385 V LED Load, 85 ºC Ambient.

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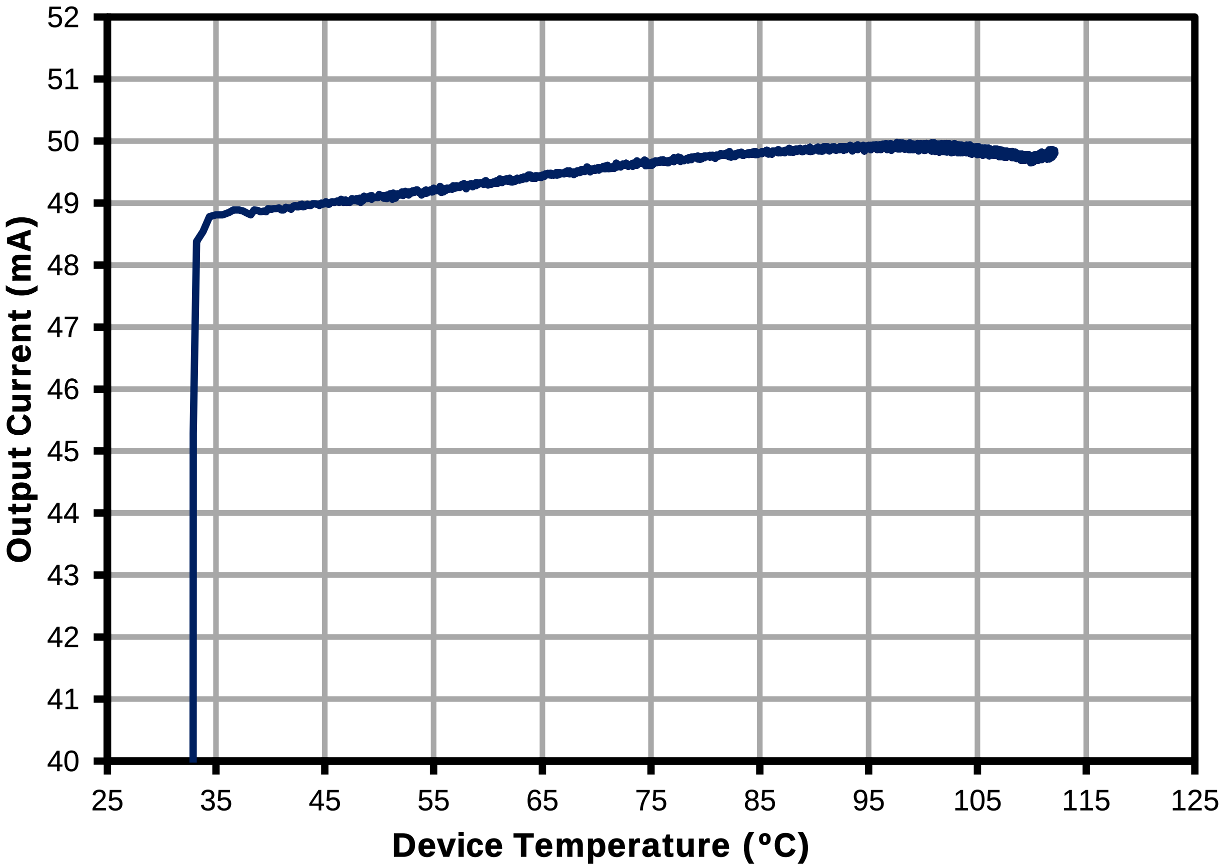

Figure 26 – Output Current vs. Device Temperature at 265 VAC, 385 V LED Load, 85 ºC Ambient.

11 Waveforms

11.1 Input Voltage and Input Current Waveforms

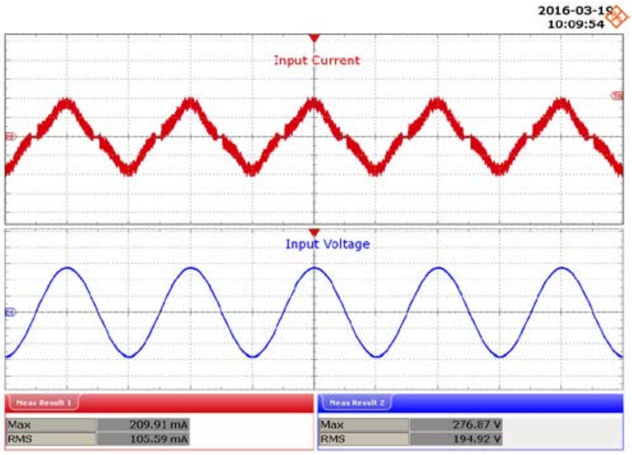

Figure 27 – 195 VAC, 385 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

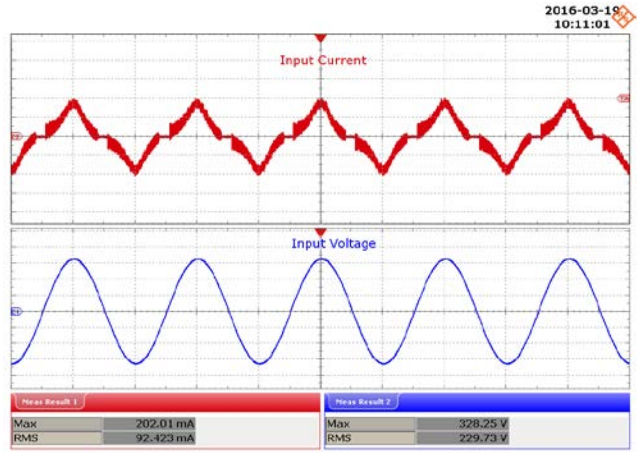

Figure 28 – 230 VAC, 385 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

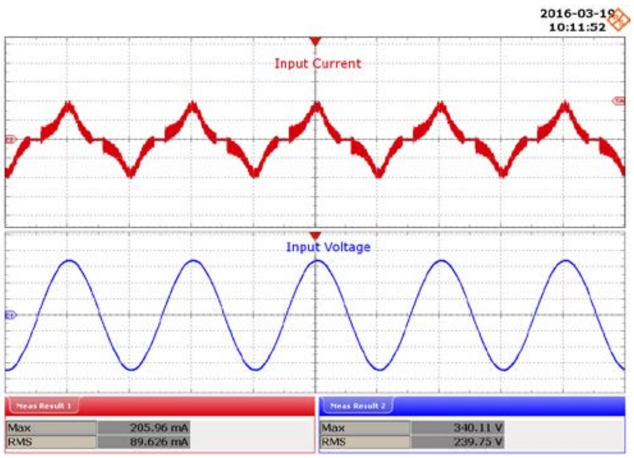

Figure 29 – 240 VAC, 385 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

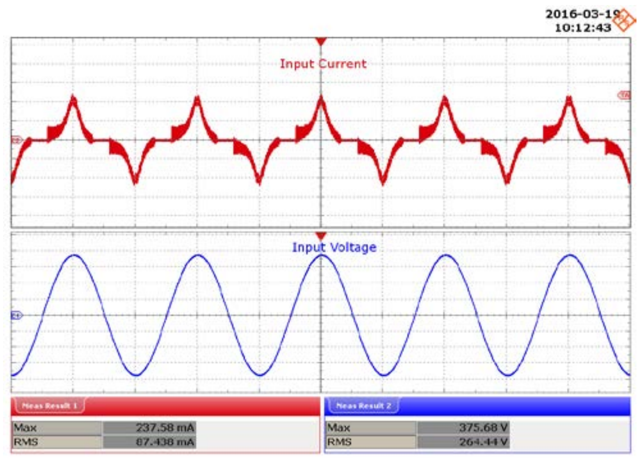

Figure 30 – 265 VAC, 385 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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11.2 Start-up Profile

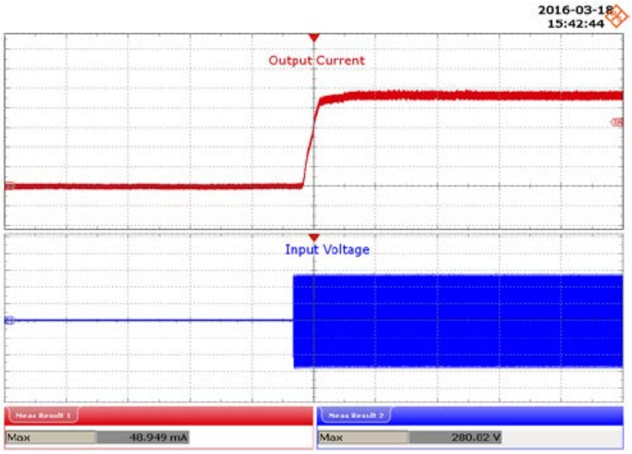

Figure 31 – 195 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Start-up Time: 440 ms.

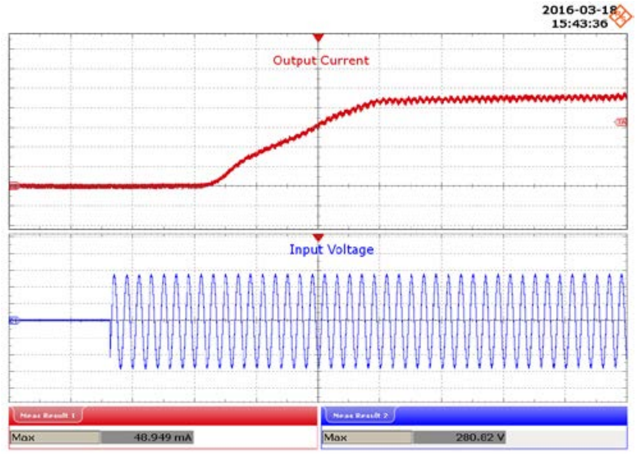

Figure 32 – 195 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Start-up Time: 440 ms.

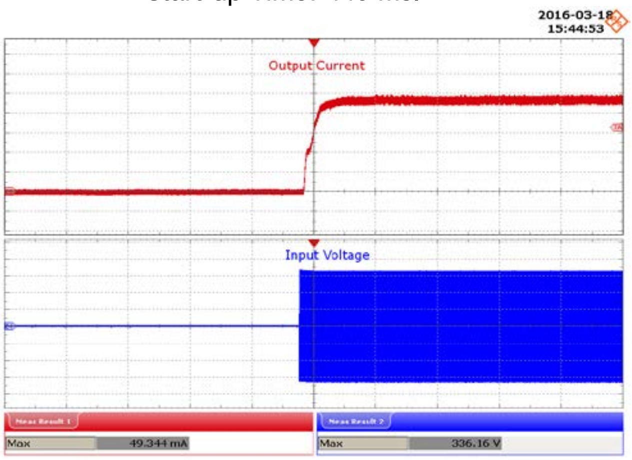

Figure 33 – 230 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Start-up Time: 310 ms.

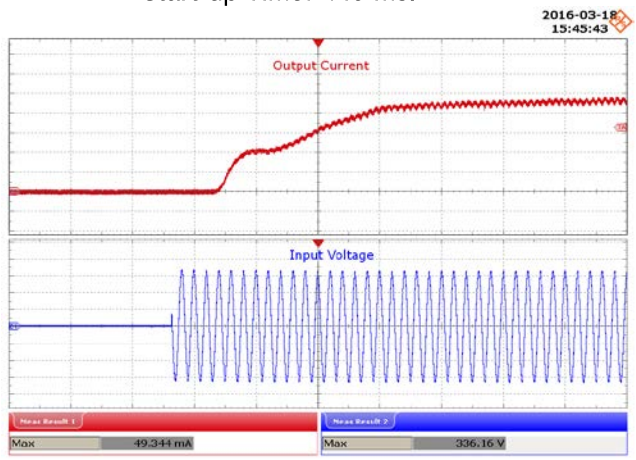

Figure 34 – 230 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Start-up Time: 310 ms.

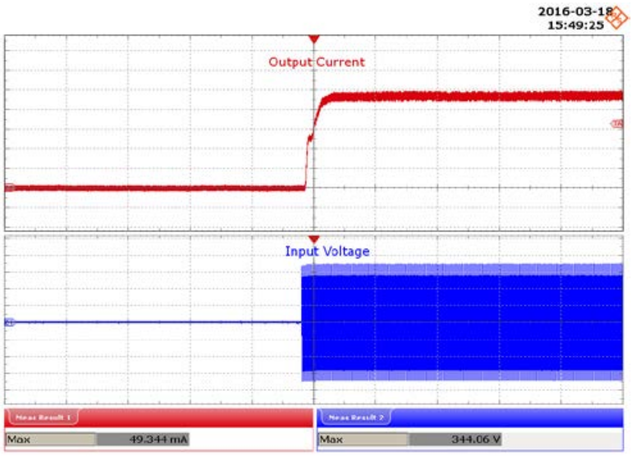

Figure 35 – 240 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Start-up Time: 300 ms.

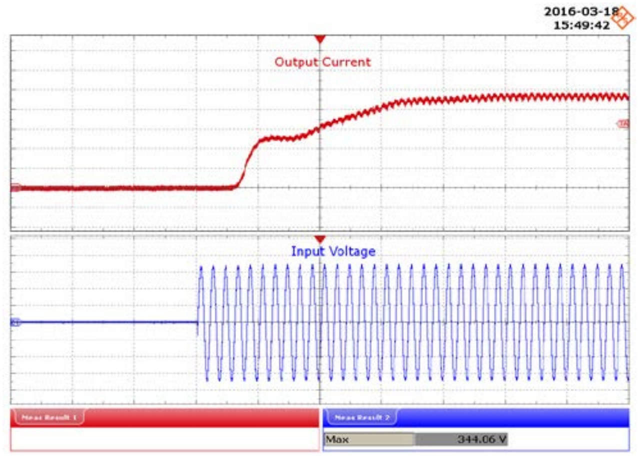

Figure 36 – 240 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Start-up Time: 300 ms.

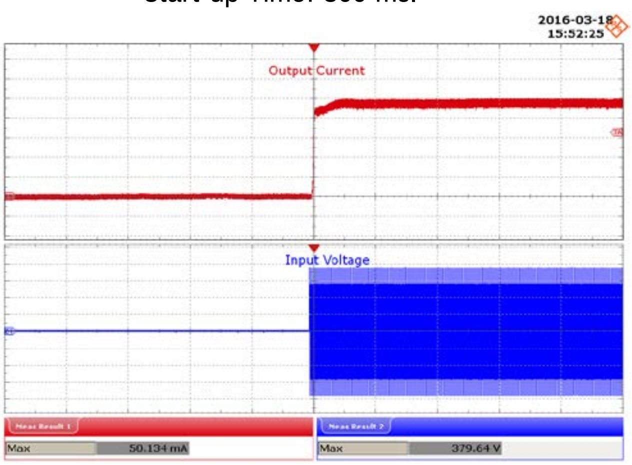

Figure 37 – 265 VAC, 385 V LED, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.
Start-up Time: 250 ms.

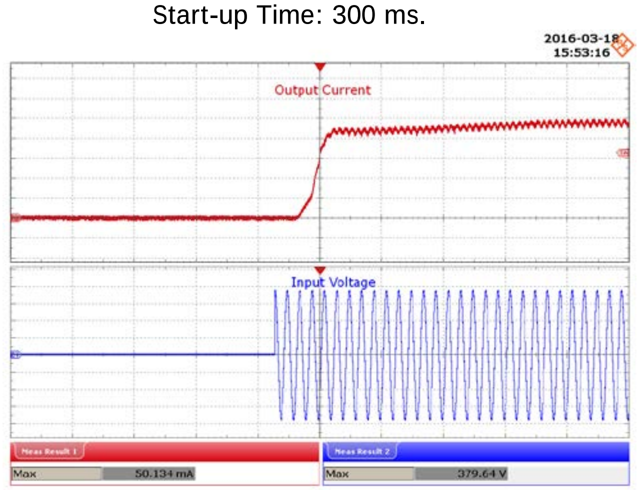

Figure 38 – 265 VAC, 385 V LED Load, Output Rise.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Start-up Time: 250 ms.

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11.3 Output Current Fall

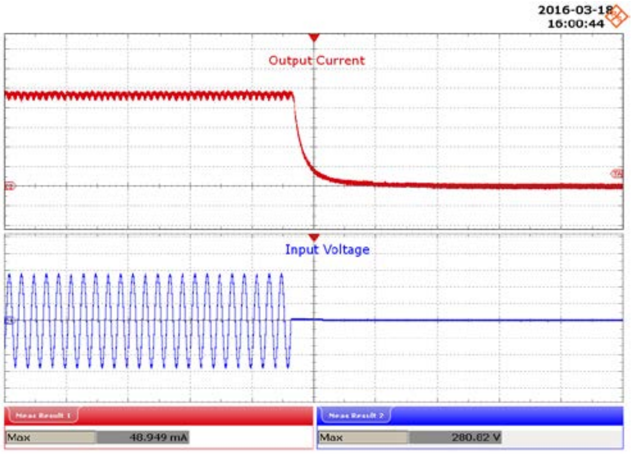

Figure 39 – 195 VAC, 385 V LED, Output Fall.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

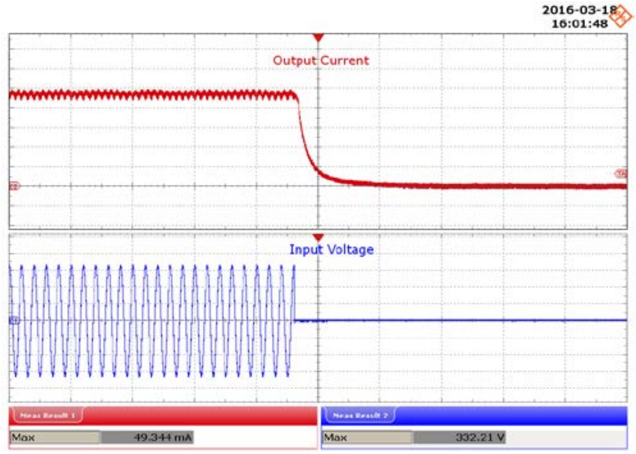

Figure 40 – 230 VAC, 385 V LED, Output Fall.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

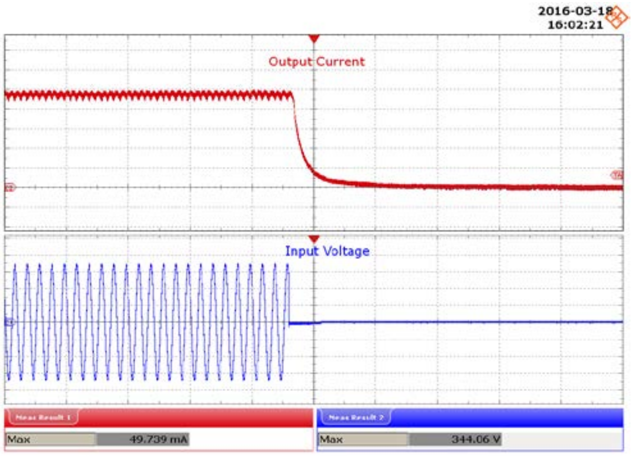

Figure 41 – 240 VAC, 385 V LED, Output Fall.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

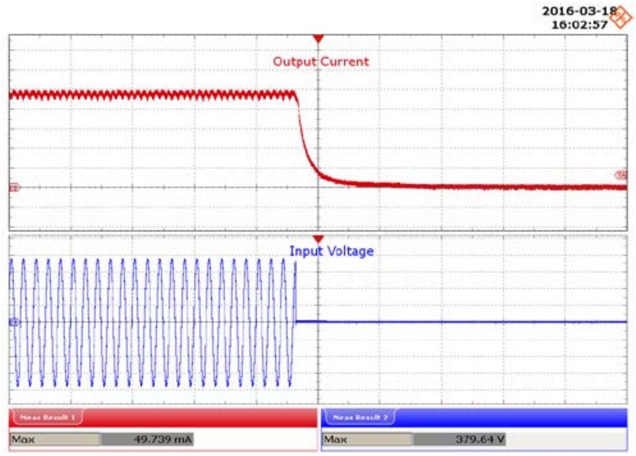

Figure 42 – 265 VAC, 385 V LED, Output Fall.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

11.4 Drain Voltage and Current in Normal Operation

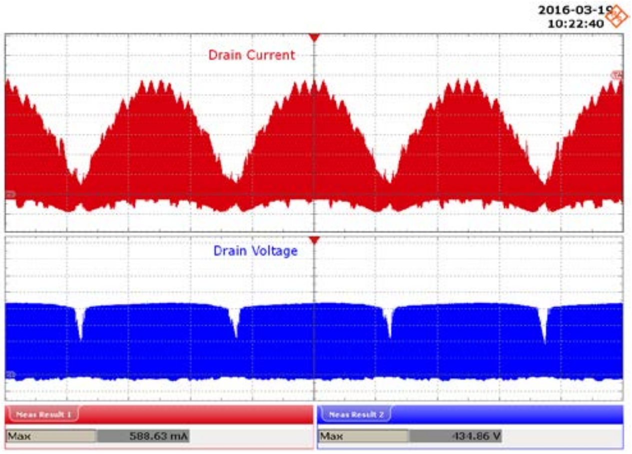

Figure 43 – 195 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

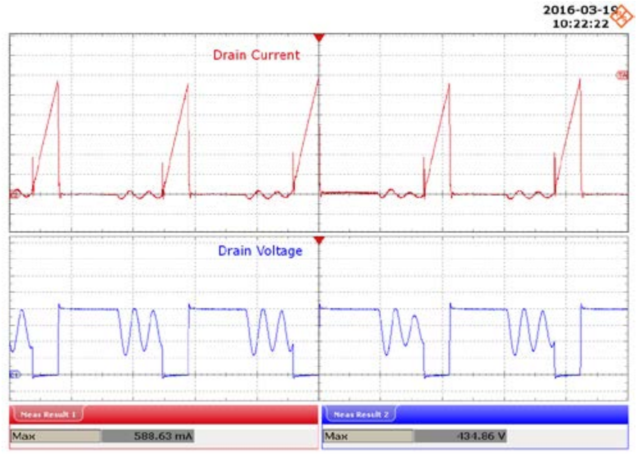

Figure 44 – 195 VAC, 385V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

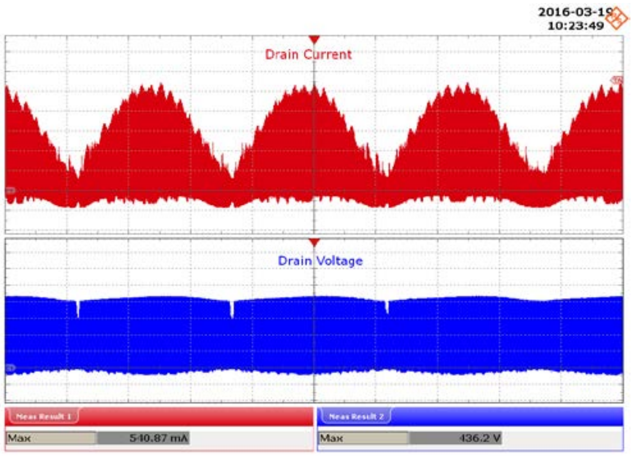

Figure 45 – 230 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

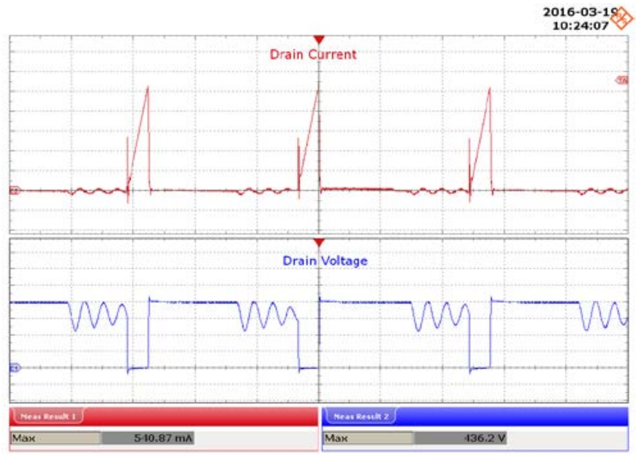

Figure 46 – 230 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

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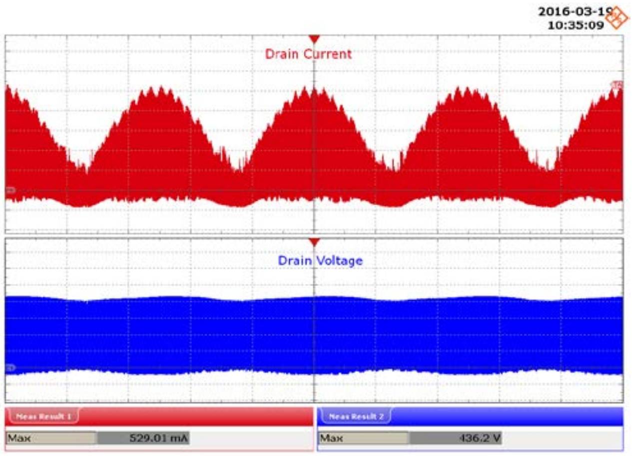

Figure 47 – 240 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

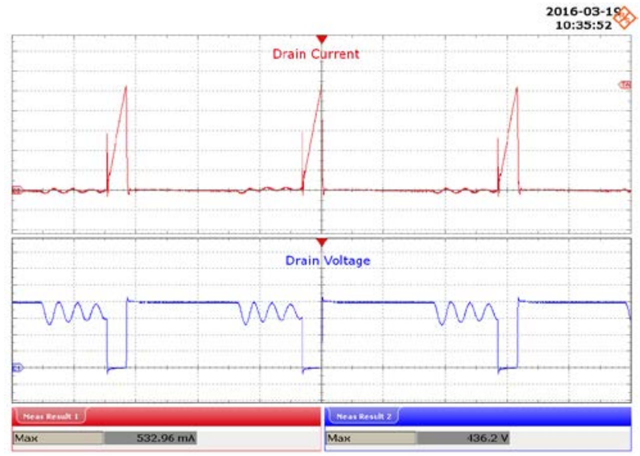

Figure 48 – 240 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

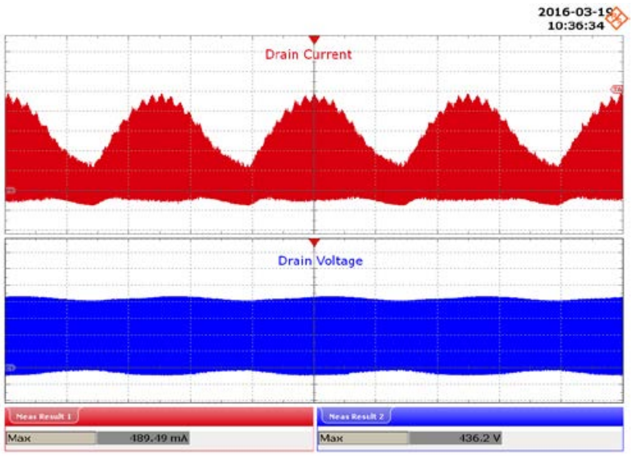

Figure 49 – 265 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

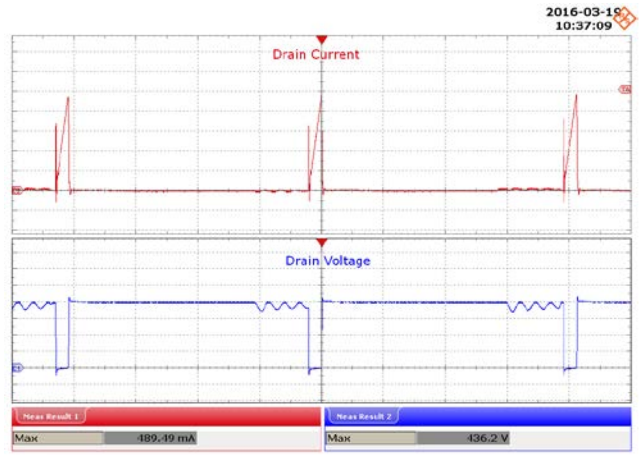

Figure 50 – 265 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

11.5 Drain Voltage and Current Start-up Profile

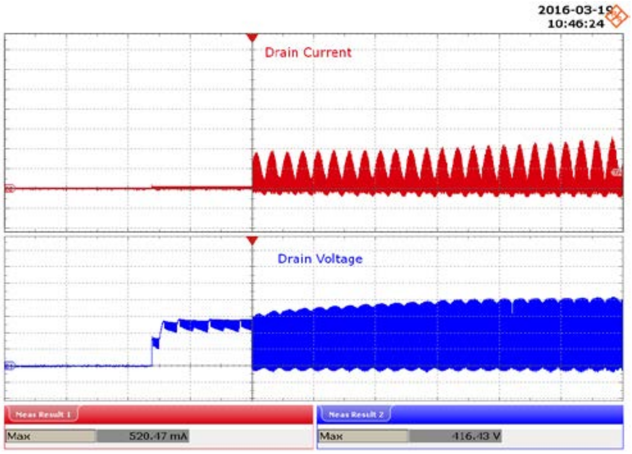

Figure 51 – 195 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 10 V / div., 40 ms /div.

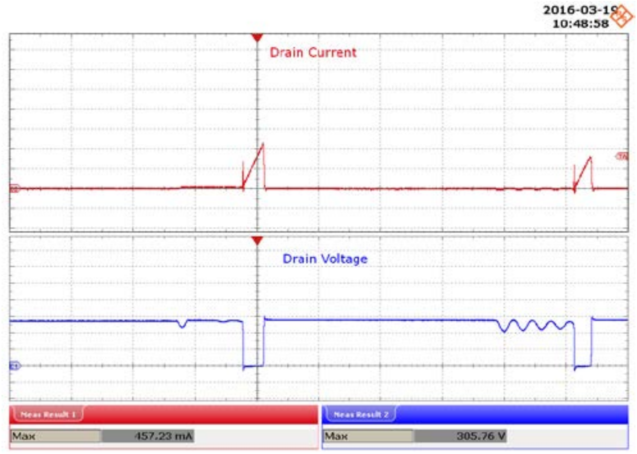

Figure 52 – 195 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs /div.

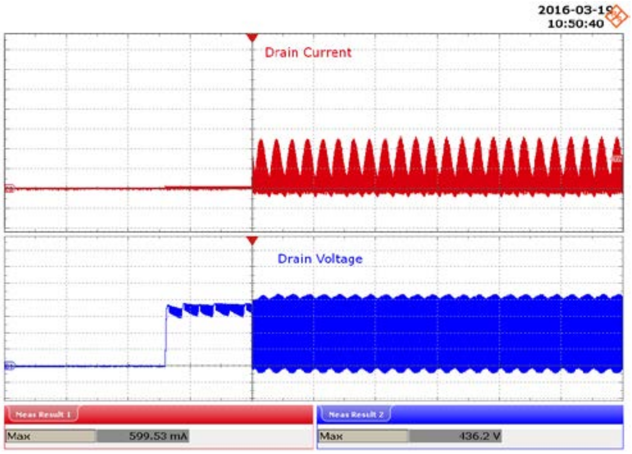

Figure 53 – 265 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 10 V / div., 40 ms /div.

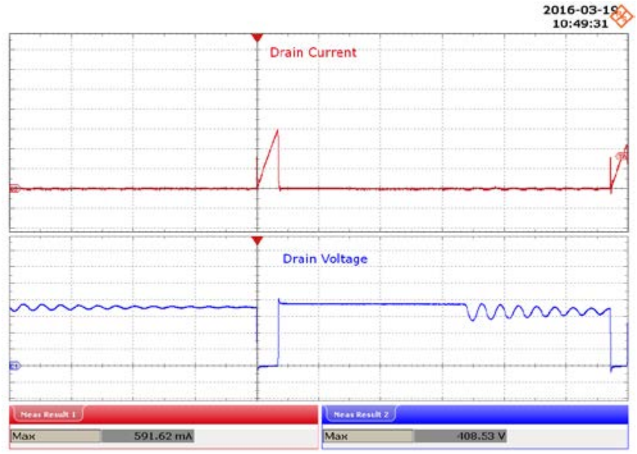

Figure 54 – 265 VAC, 385 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs /div.

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11.6 Output Diode Voltage and Current in Normal Operation

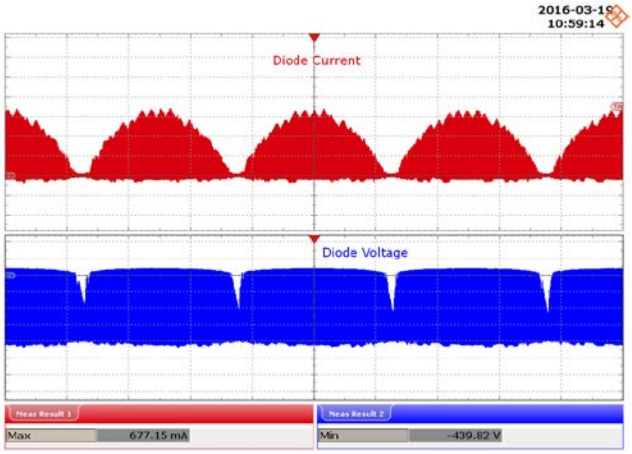

Figure 55 – 195 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

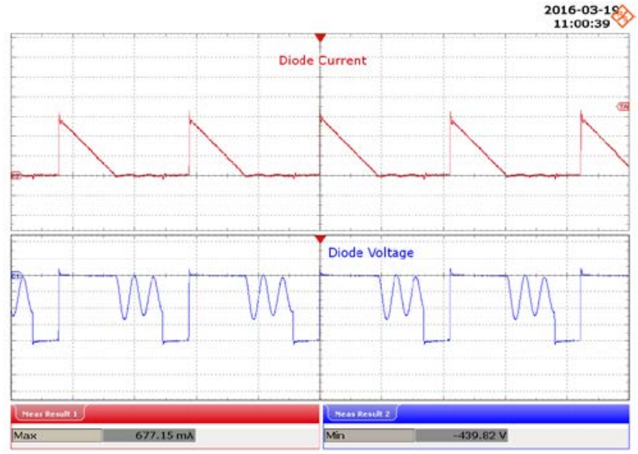

Figure 56 – 195 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 µs / div.

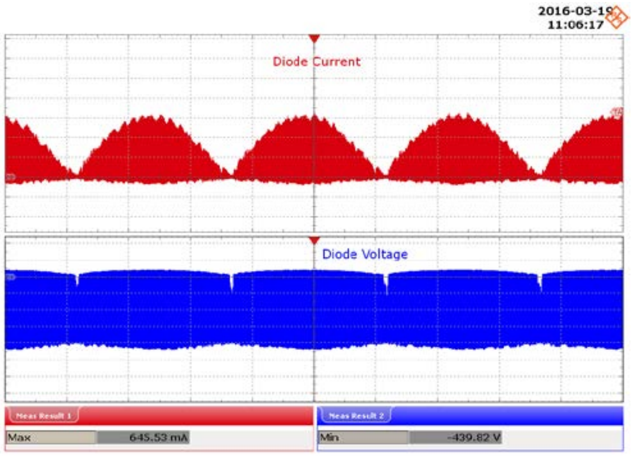

Figure 57 – 230 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

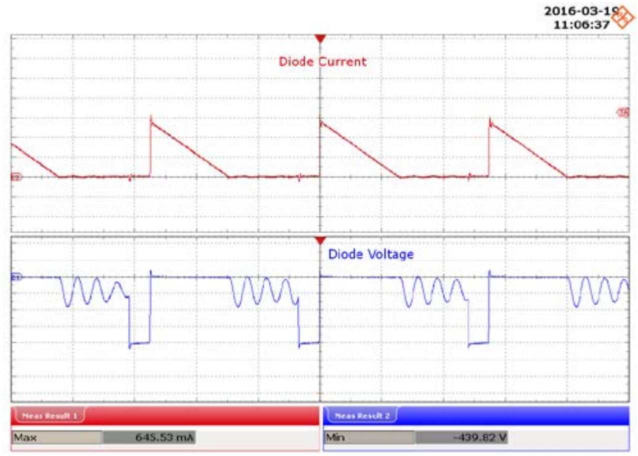

Figure 58 – 230 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 µs / div.

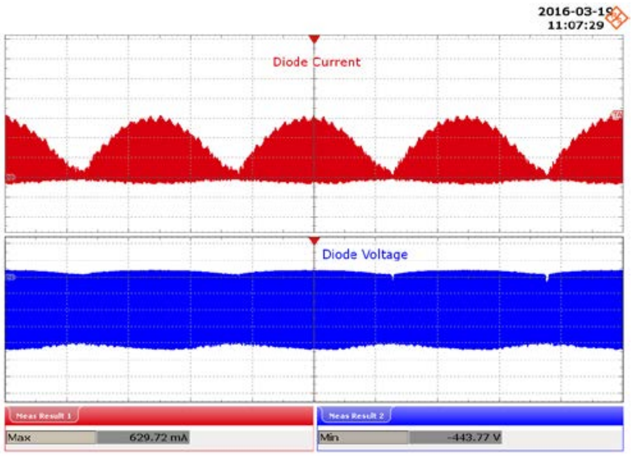

Figure 59 – 240 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

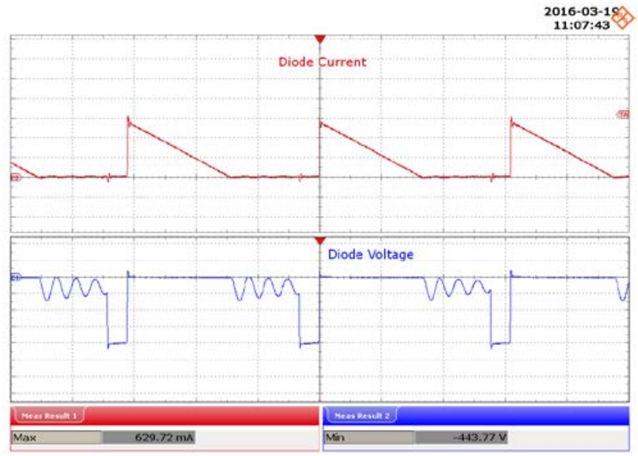

Figure 60 – 240 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 μs / div.

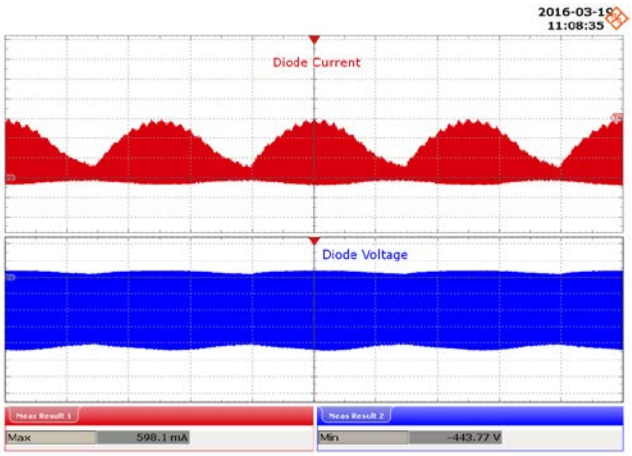

Figure 61 – 265 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

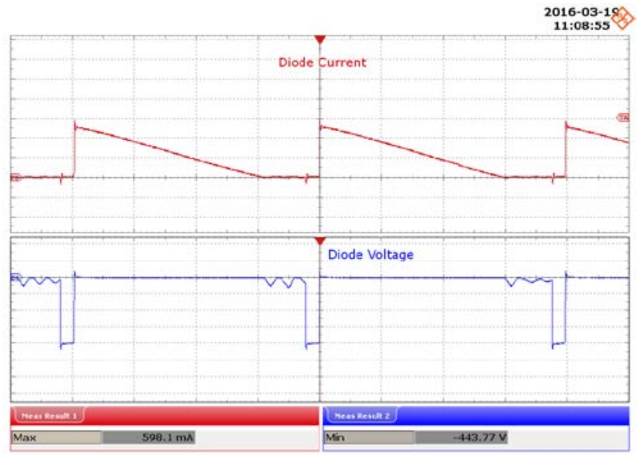

Figure 62 – 265 VAC, 385 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 100 V / div., 5 μs / div.

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11.7 Output Voltage and Current – Open Output LED Load

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

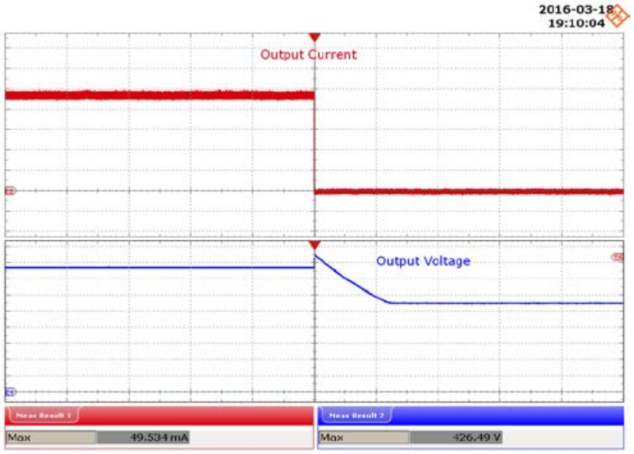

Figure 63 – 195 VAC, 385 V LED Load.
Running Open Load.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{OUT}, 50 V / div., 10 s / div.
V_{OUTMAX}: 426.5 V.

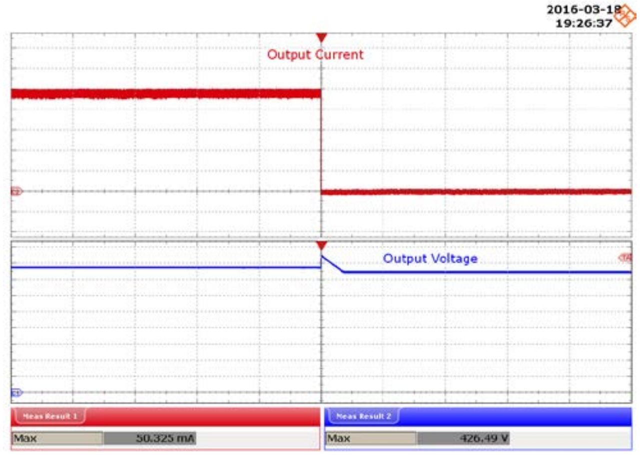

Figure 64 – 265 VAC, 385 V LED Load.
Running Open Load.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{OUT}, 50 V / div., 10 s / div.
V_{OUTMAX}: 426.5 V.

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

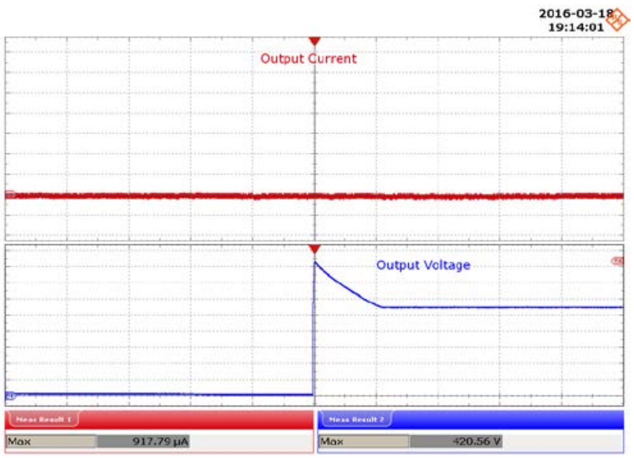

Figure 65 – 195 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{OUT}, 50 V / div., 10 s / div.
V_{OUTMAX}: 420.56 V.

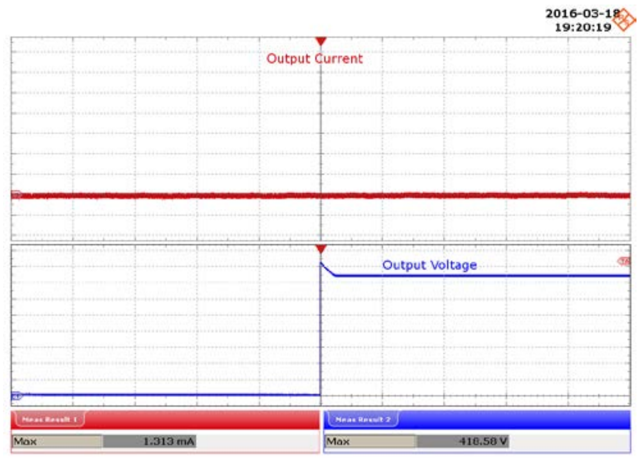

Figure 66 – 265 VAC, Open Load.
Open Load Start-up.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{OUT}, 50 V / div., 10 s / div.
V_{OUTMAX}: 418.58 V.

11.9 Output Ripple Current

Figure 67 – 195 VAC, 50 Hz, 385 V LED Load.
Upper: I_{OUT}, 10 mA / div., 20 ms / div.

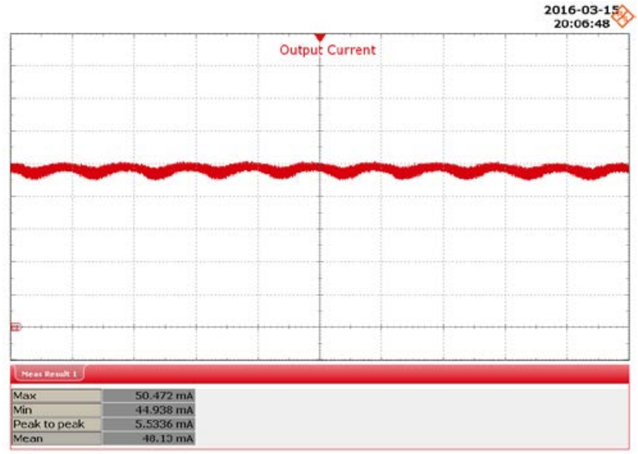

Figure 68 – 230 VAC, 50 Hz, 385 V LED Load.
Upper: I_{OUT}, 10 mA / div., 10 ms / div.

Figure 69 – 240 VAC, 50 Hz, 385 V LED Load.
Upper: I_{OUT}, 10 mA / div., 20 ms / div.

Figure 70 – 265 VAC, 50 Hz, 385 V LED Load.
Upper: I_{OUT}, 10 mA / div., 20 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN}	Ripple Ratio ($I_{RP\text{-}P}$ / I_{MEAN})	% Flicker 100 x ($I_{RP\text{-}P}$ / $I_{O(MAX)} + I_{O(MIN)}$)
195	50.47	44.54	47.85	0.12	6.24
230	50.47	44.99	48.13	0.11	5.74
240	51.26	45.33	48.65	0.12	6.14
265	51.66	45.33	48.84	0.13	6.53

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11.10 Output Current Overshoot at Ramp Up Input (230 V – 240 V)

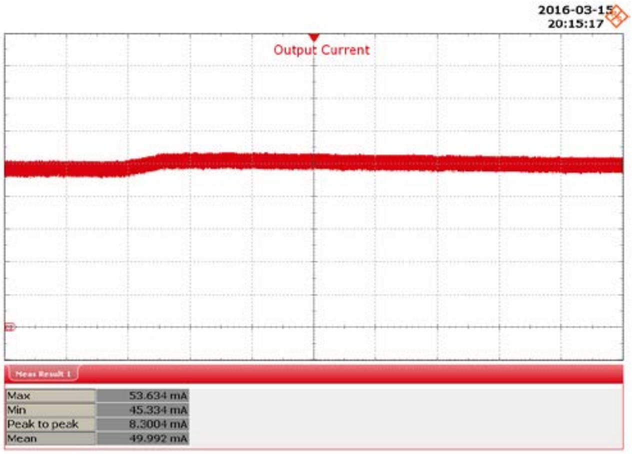

Figure 71 – 230 VAC - 240 V, 50 Hz, Ramp Up.
Ramp Up Rate: 1 V / sec.
Upper: I_{OUT}, 10 mA / div., 5 s / div.
Nominal I_{OUT}: 48.2 mA.
Overshoot: 50.6 mA.

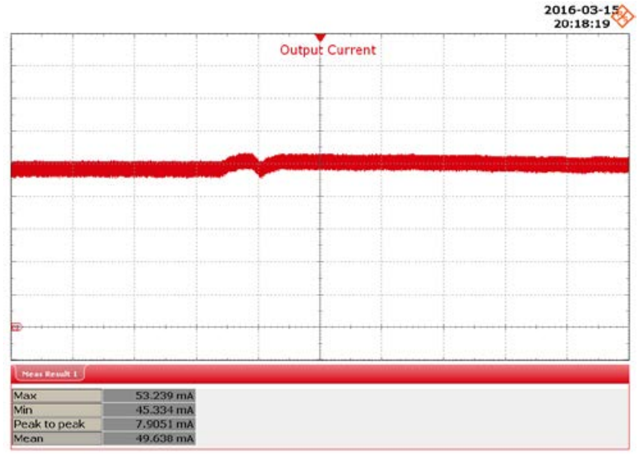

Figure 72 – 230 VAC - 240 V, 50 Hz, Ramp Up.
Ramp Up Rate: 2 V / sec.
Upper: I_{OUT}, 10 mA / div., 5 s / div.
Nominal I_{OUT}: 48.2 mA.
Overshoot: 50.6 mA.

11.11 Output Current Undershoot at Ramp Down (230 V – 220 V)

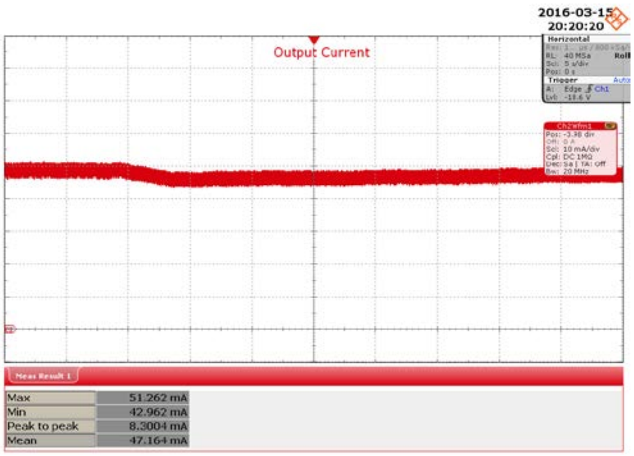

Figure 73 – 230 VAC - 220 V, 50 Hz, Ramp Down.
Ramp Down Rate: 1 V / sec.
Upper: I_{OUT}, 10 mA / div., 5 s / div.
Nominal I_{OUT}: 48.2 mA.
Undershoot: 45.5 mA.

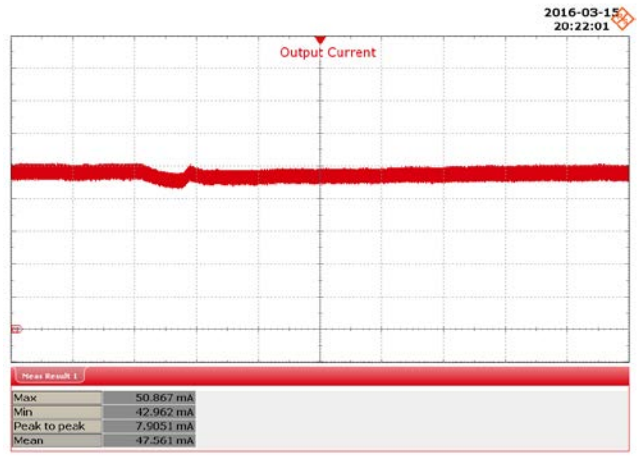

Figure 74 – 230 VAC - 220 V, 50 Hz, Ramp Down.
Ramp Down Rate: 2 V / sec.
Upper: I_{OUT}, 10 mA / div., 5 s / div.
Nominal I_{OUT}: 48.2 mA.
Undershoot: 45.5 mA.

12 AC Cycling Test

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

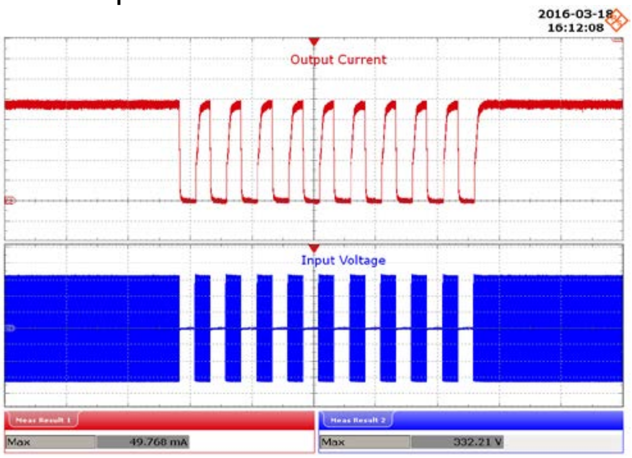

Figure 75 – 230 VAC, 385 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

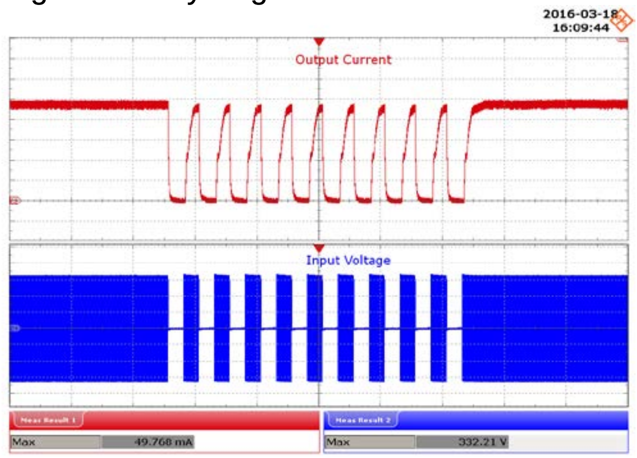

Figure 76 – 230 VAC, 385 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

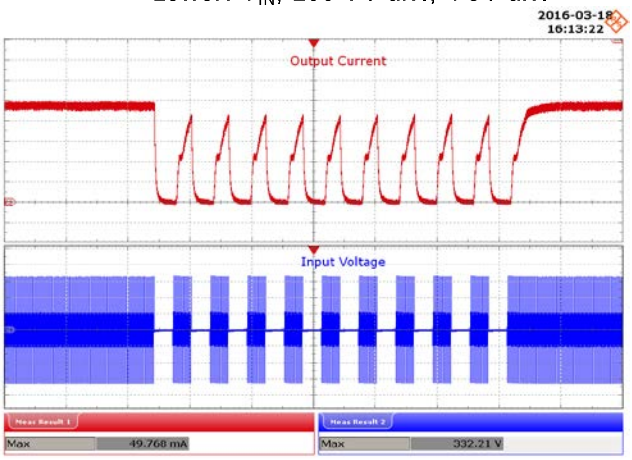

Figure 77 – 230 VAC, 385 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

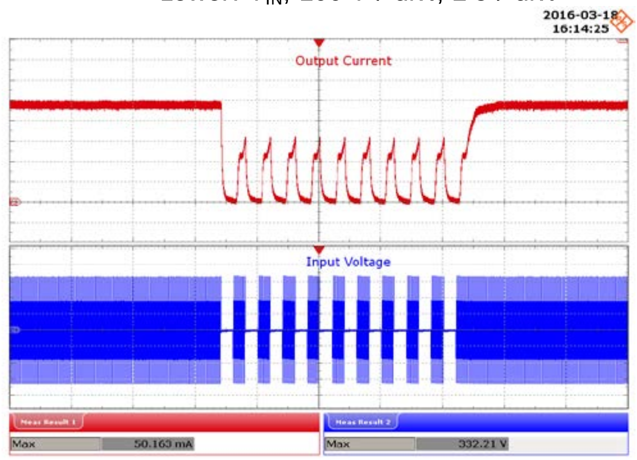

Figure 78 – 230 VAC, 385 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

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

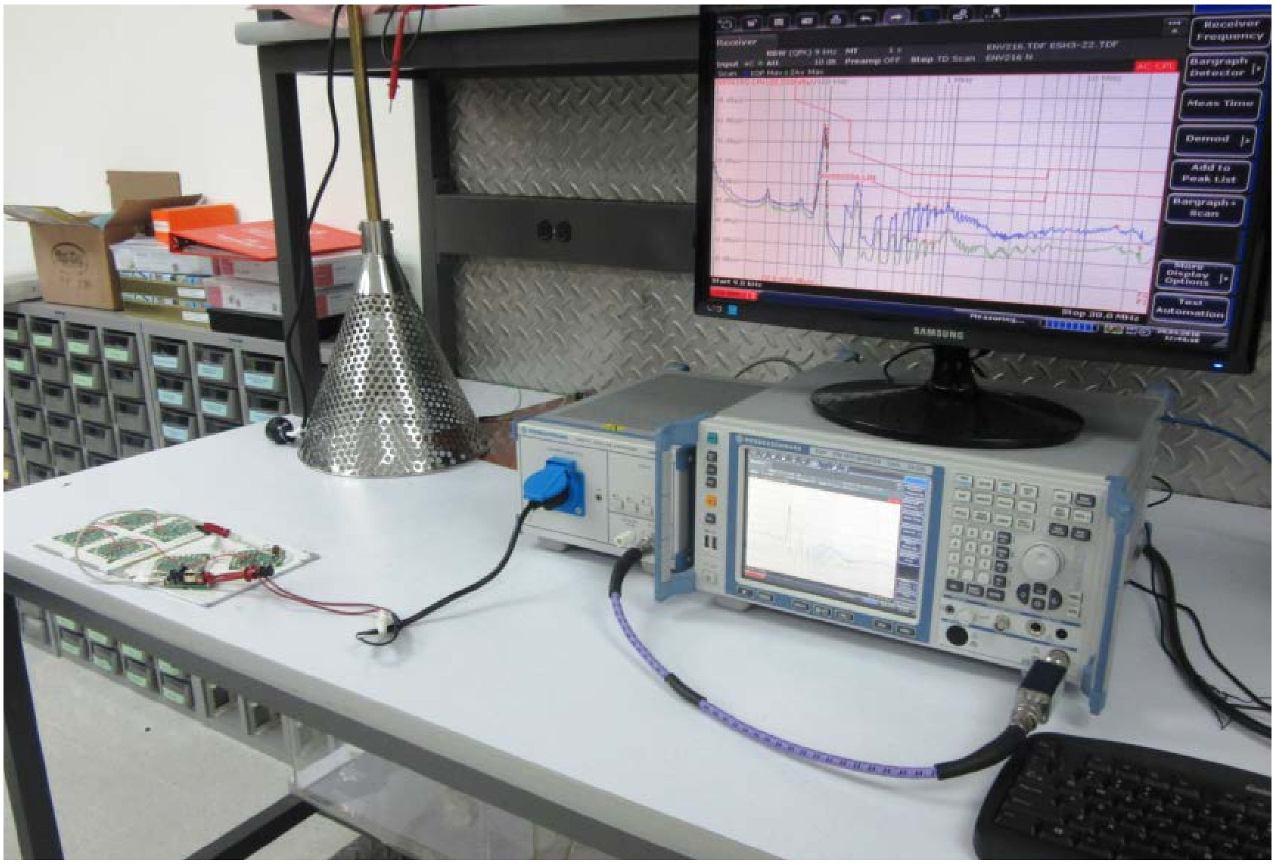

Figure 79 – Conducted EMI Test Set-up.

13.2 EMI Test Result

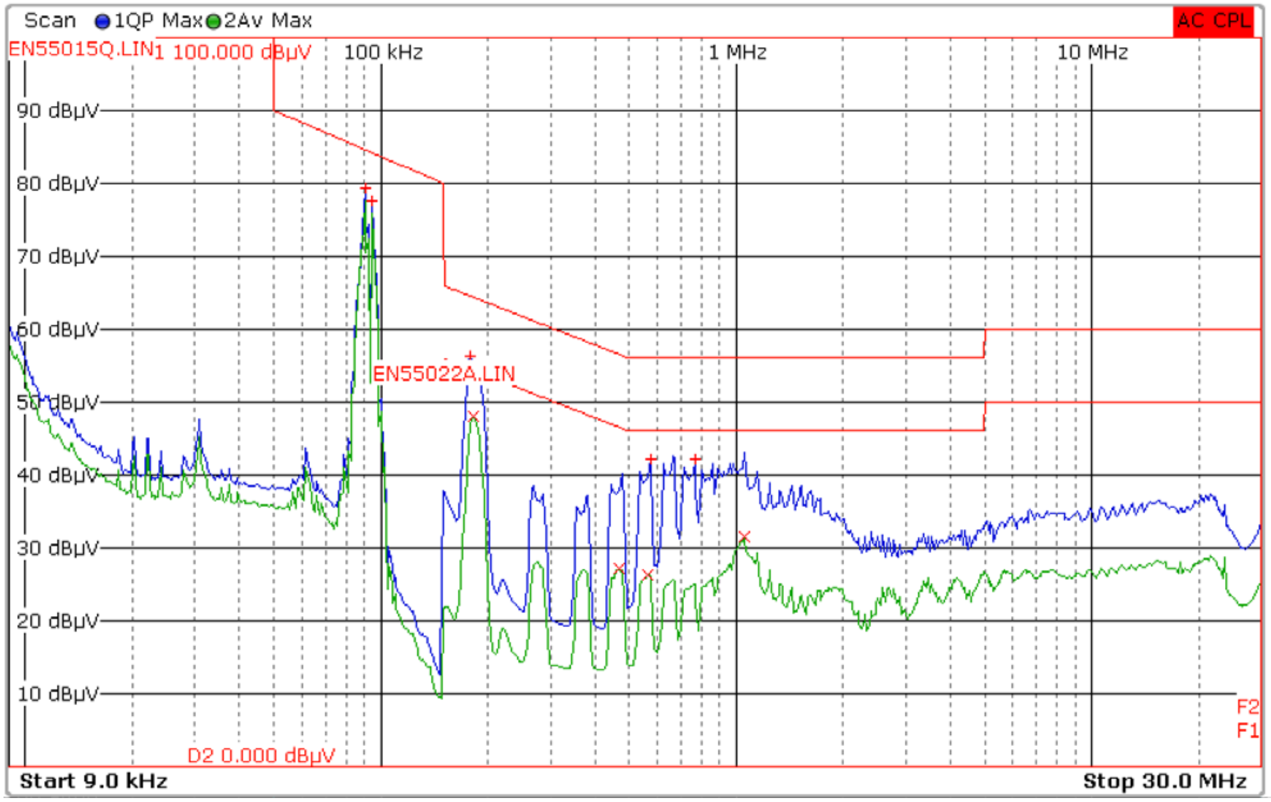

Figure 80 – Conducted EMI QP Scan at 385 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	90.5000 kHz	79.35 L1	-5.25 dB
2 Average	181.5000 kHz	47.98 N	-6.44 dB
1 Quasi Peak	94.3000 kHz	77.66 N	-6.56 dB
1 Quasi Peak	179.2500 kHz	56.39 L1	-8.13 dB
1 Quasi Peak	573.0000 kHz	42.20 N	-13.80 dB
1 Quasi Peak	764.2500 kHz	42.13 N	-13.87 dB
2 Average	1.0523 MHz	31.42 N	-14.58 dB
2 Average	467.2500 kHz	27.27 L1	-19.29 dB
2 Average	564.0000 kHz	26.20 L1	-19.80 dB

Figure 81 – Conducted EMI Data at 385 V LED Load.

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

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

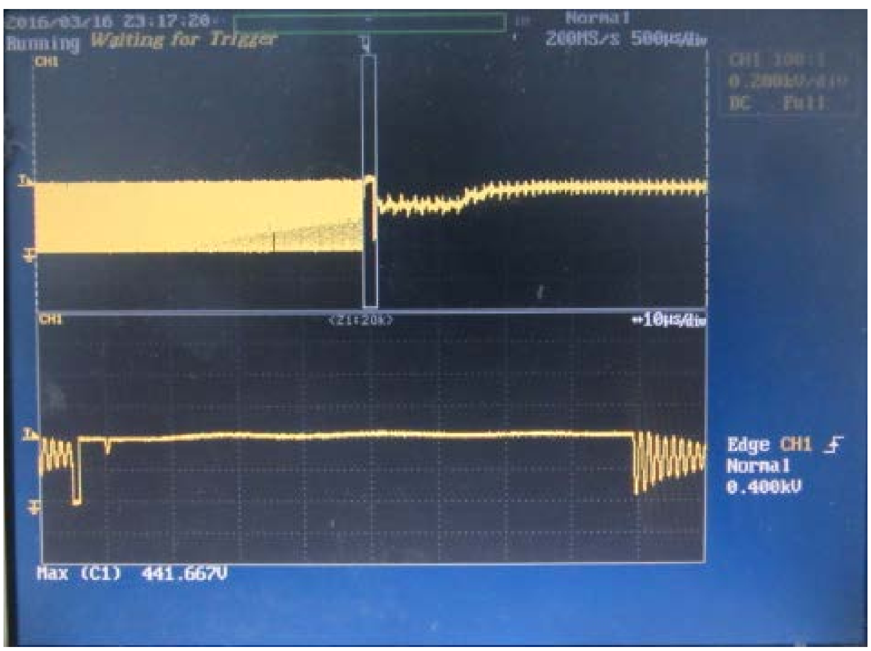

Figure 82 – +1000 kV Differential Surge, 90º Phase Angle.
Lower: V_{DRAIN}, 200 V / div., 500 µs / div.
Peak V_{DRAIN}: 442 V.

15 Brown-in / Brown-out Test

The device auto restart function will be enabled during low DC bus voltage due to it charges the output capacitor when device is still at off state. The OC pin detects output undervoltage.

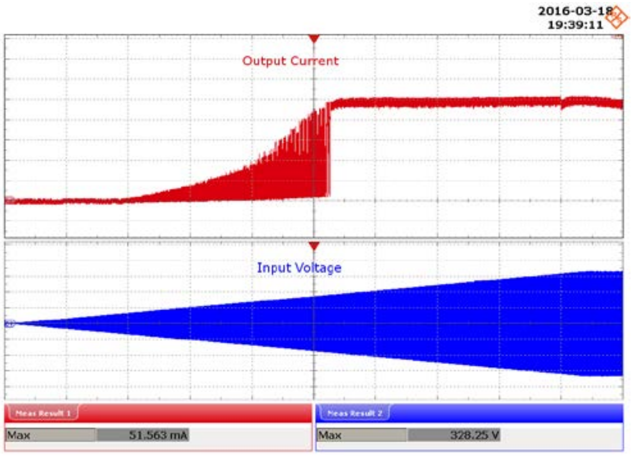

Figure 83 – Brown-in Test at 0.5 V / s.
Ch1: I_{OUT}, 10 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

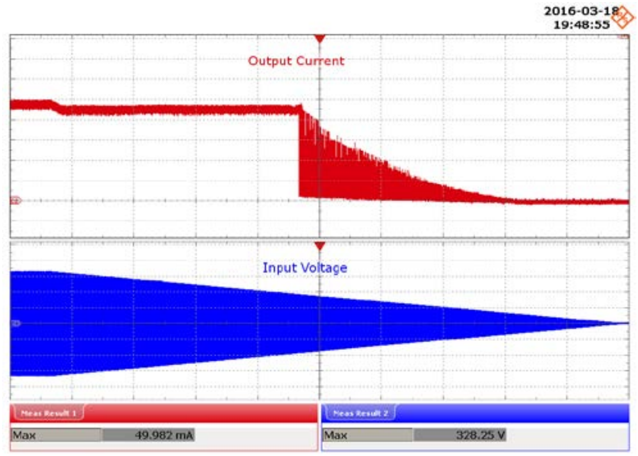

Figure 84 – Brown-out Test at 0.5 V / s.
Ch1: I_{OUT}, 10 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

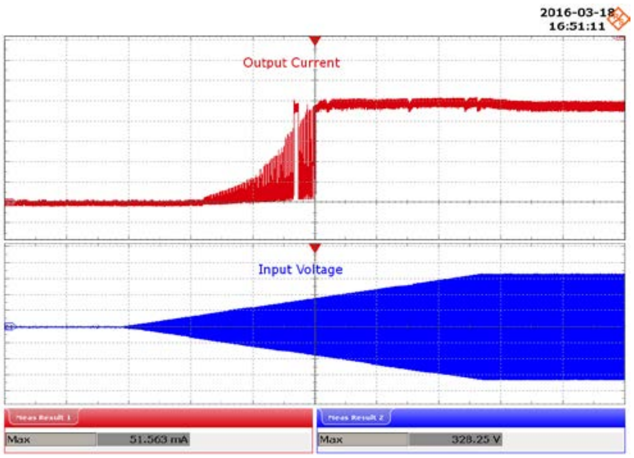

Figure 85 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 10 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

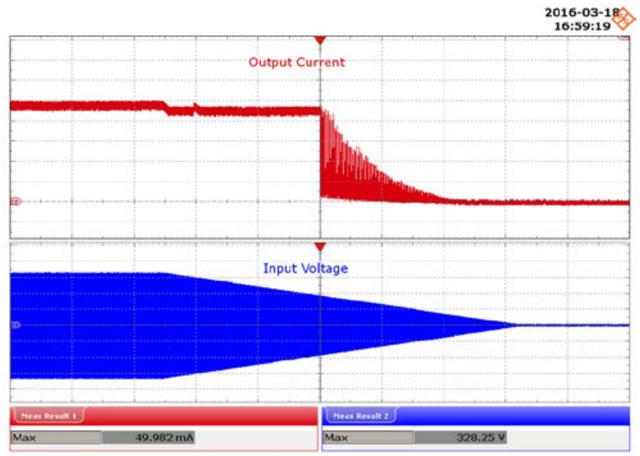

Figure 86 – Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 10 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

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16 Revision History

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

For the latest updates, visit our website: www.power.com

Patent Information

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@power.com

GERMANY
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@power.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
e-mail: chinasales@power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@power.com

UK
Cambridge Semiconductor,
a Power Integrations company
Westbrook Centre, Block 5,
2nd Floor
Milton Road
Cambridge CB4 1YG
Phone: +44 (0) 1223-446483
e-mail: eurosales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
Fax: +86-755-8672-8690
e-mail: chinasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI)
Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@power.com