Design Example Report

Title	***7 W Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1403D with Active Ripple Filter (ARF)***
Specification	190 VAC – 265 VAC; 39 V_{TYP}, 180 mA_{TYP} Output
Application	PAR30 LED Light Bulb
Author	Applications Engineering Department
Document Number	DER-634
Date	July 12, 2017
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9 at 230 VAC
- Accurate constant current regulation, ±5%
- Meets <7% flicker requirement
- Highly energy efficient, >85% at 230 VAC, 42V LED Load
- Low cost and low component count for compact PCB solution
- Integrated protection features
  - No-load / open-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
- Meets 500 V differential surge
- Meets EN55015 conducted EMI

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

1 Introduction

This engineering report describes a low cost, low-side buck LED driver designed to drive a 39 V LED voltage string at 180 mA output current from an input voltage range of 190 VAC to 265 VAC. The LED driver utilizes the LYT1403D from the LYTSwitch-1 family of devices. The key design goals were high efficiency, accurate constant current regulation, very low flicker requirement, and low component count.

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

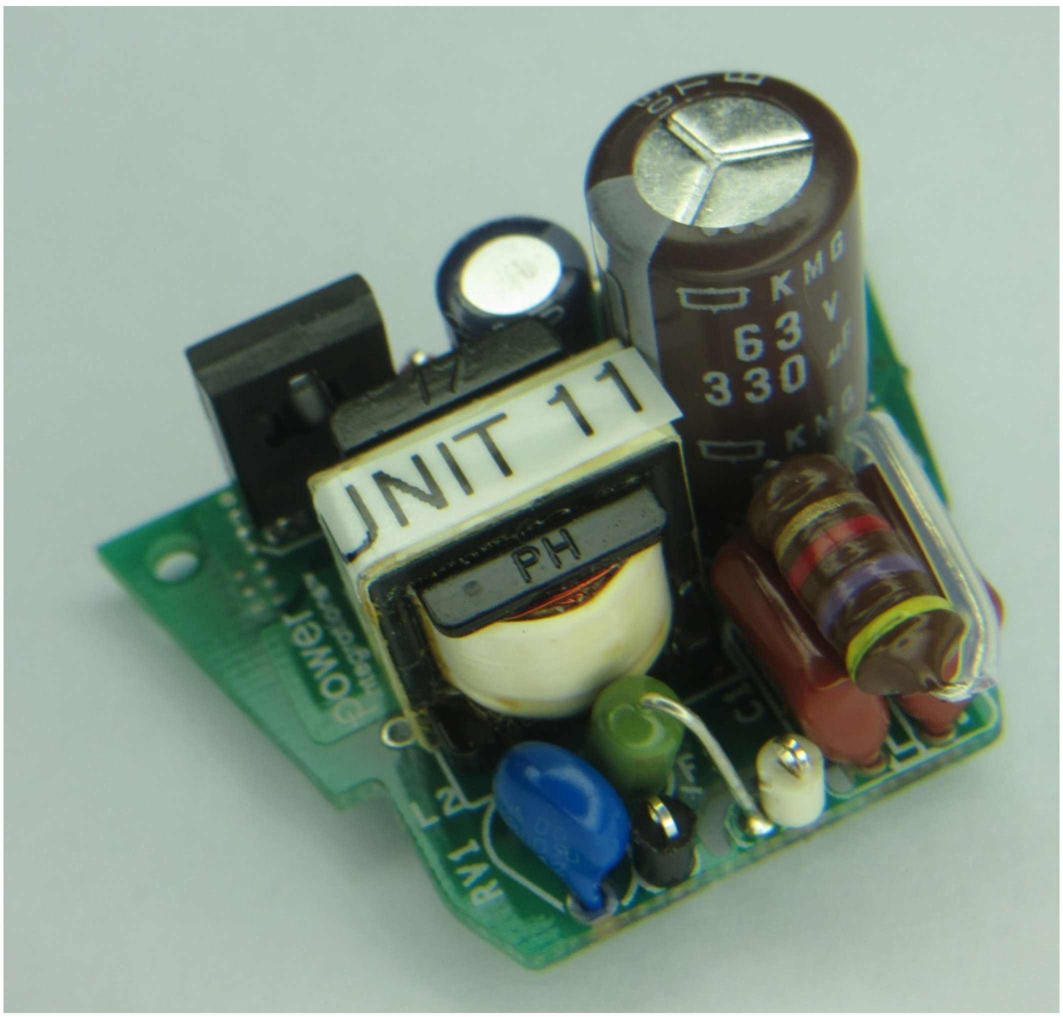

Figure 1 – Populated Circuit Board.

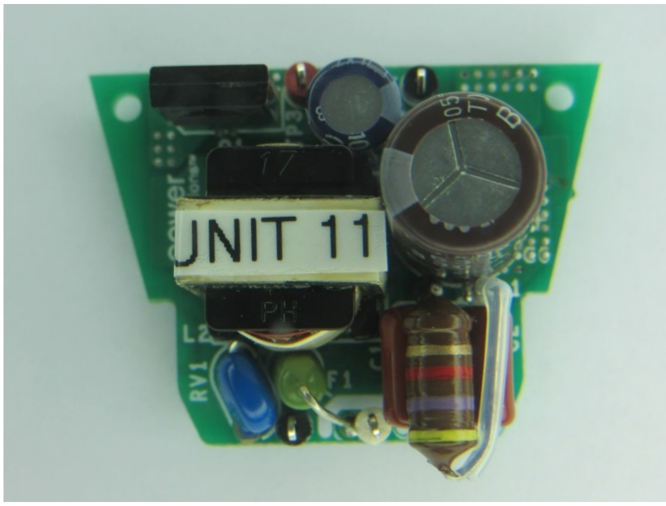

Figure 2 – Populated Circuit Board, Top View.

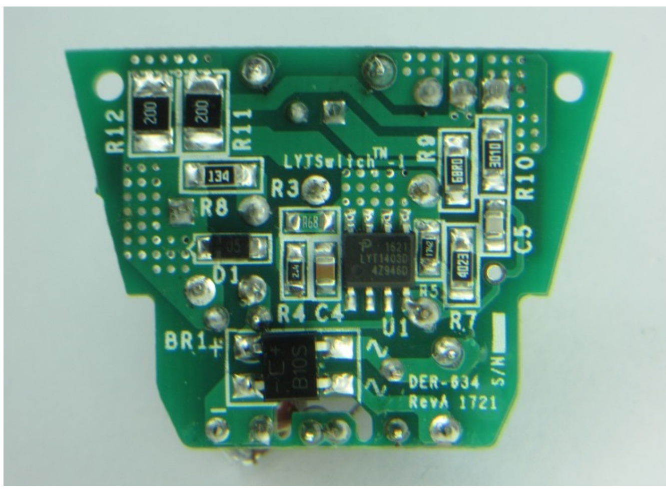

Figure 3 – Populated Circuit Board, Bottom View.

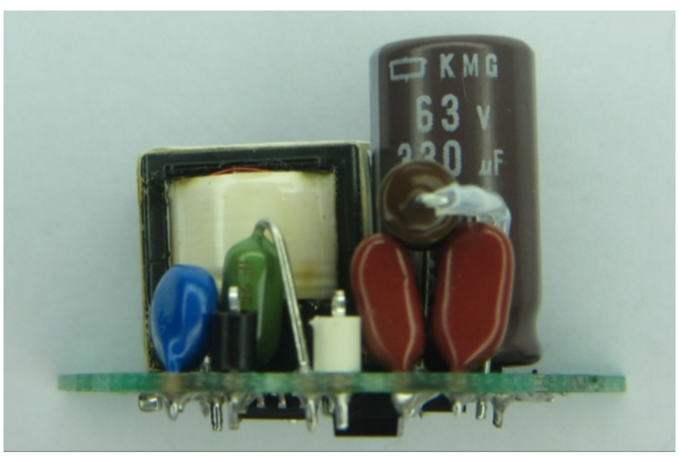

Figure 4 – Populated Circuit Board, Front View.

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}	190	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		39		V	
Output Current	I_{OUT}		180		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		7		W	
Efficiency						
Full Load	η		85		%	230 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)			0.5		kV	
Power Factor			0.90			Measured at 230 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			75	ºC	Free Convection, Sea Level.

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3 Schematic

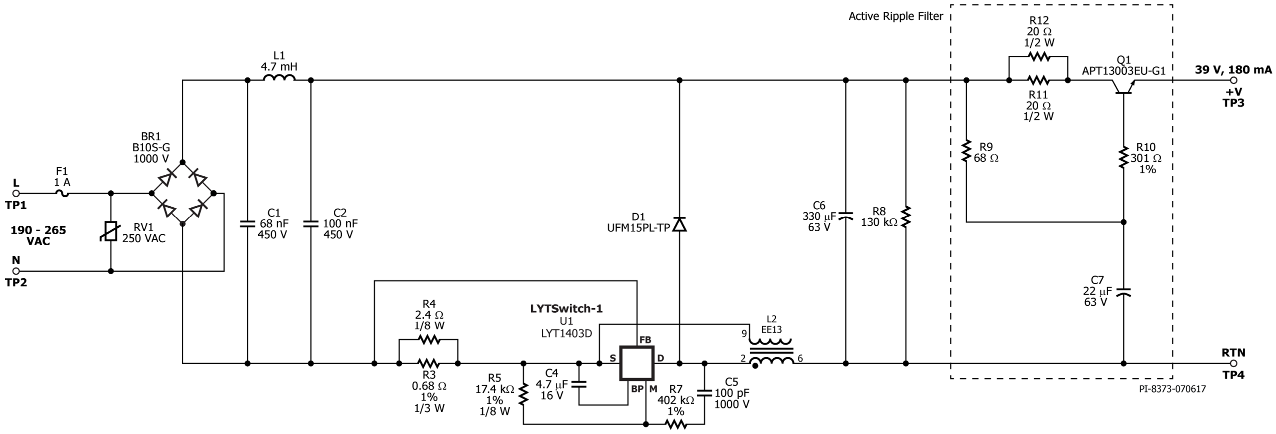

Figure 5 – Schematic.

4 Circuit Description

LYT1403D from the LYTSwitch-1 family of devices combines a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. The LYT1403D was configured to drive a 39 V low-side buck LED driver with an output current of 180 mA.

4.1 *Input Stage*

The input fuse F1 (1 A rated) provides safety protection. Varistor RV1 (250 V rated) acts as a voltage clamp which limits the voltage spikes on the input during line transient surge events. The full wave bridge rectifier BR1 rectifies the input AC to a pulsating DC, provides good power factor and low total harmonic distortion.

4.2 *EMI Filter*

A pi filter is composed of a differential choke inductor L1 and input filter capacitors C1 and C2. The EMI filter, together with the LYTSwitch-1's variable frequency / variable on-time and critical conduction mode control engine ensures compliance with the EN55015 Class B emission limit. The values were chosen to achieve a balance between power factor and efficiency.

4.3 *LYTSwitch-1 Control Circuit*

The LED driver circuit is a low-side buck topology. During switch on-time of the power MOSFET, current ramps through inductor L2 storing energy in it. Energy stored in the inductor is delivered to the output load via the freewheeling diode D1 during power MOSFET switch off-time.

The output capacitor C6 is used as a filter to minimize the output current ripple. The value of the output capacitor is chosen to ensure that the LED current is within a certain flicker value. The flicker requirement is also set by the active ripple filter to meet the specification (see Section 4.4). To avoid long ghosting effect of light output after power off, resistor R8 preload discharges the output capacitor voltage below the LED voltage.

Capacitor C4 provides local decoupling for the BYPASS (BP) pin of U1, and provides power to the IC during the switch on-time. The IC internal regulator draws power from high voltage DRAIN (D) pin to charge the bypass capacitor C4 during the power switch off time. The typical BP pin voltage is ~5.25 V. The value of capacitor should be large enough to keep the BP pin voltage above reset value $V_{BP\ (RESET)}$ ~4.6 V, when controller is switching at maximum frequency or max T_{on} conditions.

Constant output current regulation is achieved through inductor force peak current limit with a device constant ratio between the peak current period and the dead zone period. The FEEDBACK (FB) pin directly senses the source or inductor current when the power MOSFET is on using external current sense resistors R3 and R4. This is to set a constant

inductor peak current I_{PK} by comparing the sensed voltage with the reference current limit threshold (V_{FBth} ≥ 0.28 V, I_{PK}=0.28 V / R_{SENSE}).
The MULTIFUNCTION (M) pin detects AC line overvoltage. During on-state of the power MOSFET, the M pin is internally connected to SOURCE (S) pin and detects the rectified input voltage and current flowing out of M pin set by R7.

The line overvoltage trigger point (VLINE_OVP) is calculated by;

$$V_{LINE\_OVP} = I_{IOV} \times R_7 + V_{OUT}$$

Resistor R7 is set at 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 as protection to internal power MOSFET and the LED load from voltage overstress.

When the power MOSFET is at off-state, the M pin also provides zero current detection (ZCD), and output OVP detection through sampling resistors R5 and R7. The ZCD is to guarantee critical conduction mode operation which means that the MOSFET must be turned on immediately once inductor has been demagnetized. The inductor demagnetization is sensed when the voltage across the inductor begins to collapse towards zero as flywheel diode (D1) conduction expires. The ZCD threshold is when M pin voltage is V_M <0.25 V (negative edge triggered).

The addition of a small capacitor C5 is needed to couple the high-voltage referenced signal of the output voltage into the M pin of the IC through the resistor divider network R5 and R7.

The OVP detection is also achieved through R5 and R7. The OVP threshold is typically set at 120% of steady-state value (2.0 V). Resistor R7 is set to a fixed value of 402 kΩ ±1% to minimize power loss during MOSFET on duration. The value of R_5 is calculated below.

$$R_5 = 2\text{ V} \times R_7 / (V_{OUT} - 2\text{ V})$$

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

4.4 *Active Ripple Filter (ARF)*

Resistor R9 and capacitor C7 filter the output ripple. The corner frequency of network R9/C7 is set below the line frequency to reduce the 100 Hz line frequency ripple present at the output. Resistor R10 limits the base current flowing into the transistor during output short circuit condition.

Eliminating large ripple does not come without penalty. Transistor Q1 dissipates heat as it blocks the AC line ripple from the input. The heat dissipation is determined by the amount of ripple that is going to be rejected. To minimize the heat dissipated by Q1, resistors R11 and R12 also dissipate at least 50% of this ripple blocked by Q1.

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5 PCB Layout

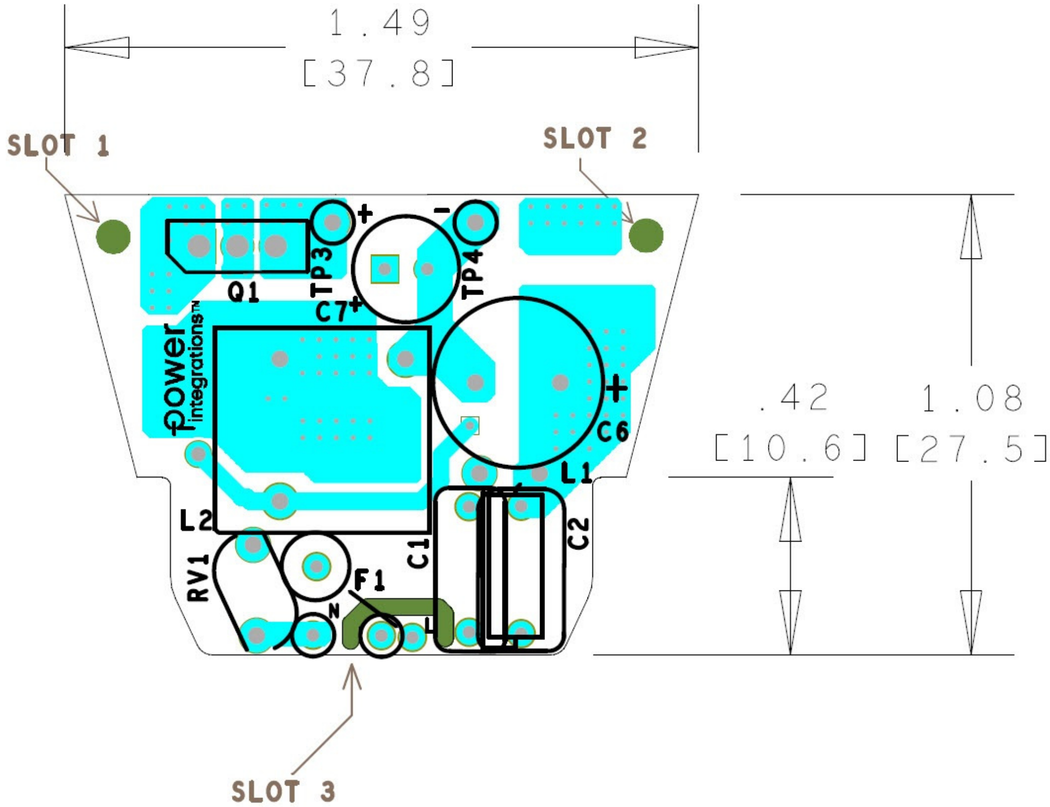

Figure 6 – Top Side.

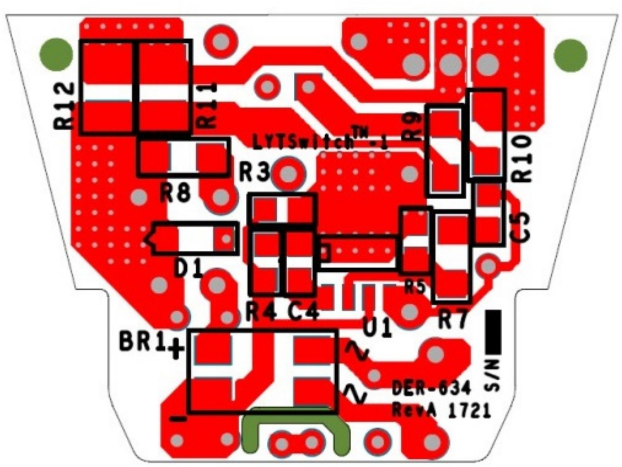

Figure 7 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	68 nF, 450 VDC, 5%, Film	MEXXD26804JJ	Duratech
3	1	C2	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
4	1	C4	4.7 μF, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KA73L	Murata
5	1	C5	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
6	1	C6	330 μF, 63 V, Electrolytic, (10 x 20)	EKMG630ELL331MJ20S	United Chemi-con
7	1	C7	22 μF, 63, Electrolytic, Low ESR, 1000 mΩ, (6.3 x 11.5)	ELXZ630ELL220MFB5D	Nippon Chemi-Con
8	1	D1	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	Micro Commercial
9	1	F1	FUSE PICO FAST 1 A 250 V AXIAL	0263001.MXL	Littlefuse
10	1	L1	4.7 mH, 90 mA, 20 Ω, RF Inductor	B82144A2475J	Epcos
11	1	L2	Bobbin, EE13, Vertical, 10 pins	P-1302-2	Pin Shine
12	1	Q1	NPN, 450V, 1.3 A, TO126	APT13003EU-G1DI-ND	Diodes, Inc.
13	1	R3	RES, 0.68 Ω 1/3 W, 1%,Thick Film, 0805	RL1220S-R68-F	Susumu
14	1	R4	RES, 2.4 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ2R4V	Panasonic
15	1	R5	RES, 17.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1742V	Panasonic
16	1	R7	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
17	1	R8	RES, 130 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ134V	Panasonic
18	1	R9	RES, 68 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ680V	Panasonic
19	1	R10	RES, 301 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3010V	Panasonic
20	2	R11 R12	RES, 20 Ω, ±5%, 0.5 W, ½ W, 1210 (3225 Metric), Automotive AEC-Q200, Thick Film	CRCW121020R0JNEA	Vishay
21	1	RV1	390 VAC, 8.2 J, 5 mm, RADIAL	S05K250	Epcos
22	1	U1	LYTSwitch-1, Wide Range, 8 W, 25 V – 50 V, SO-8	LYT1403	Power Integrations

Miscellaneous

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	TP1	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
2	1	TP2 TP4	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
3	2	TP3	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
4	1	INSULATION1	Tubing & Sleeving – Non Shrink, #20 AWG TUBING PTFE	TFT20 – NT	Parker/Texloc (Atlantic Tubing)

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7 Inductor Specification

7.1 *Electrical Diagram*

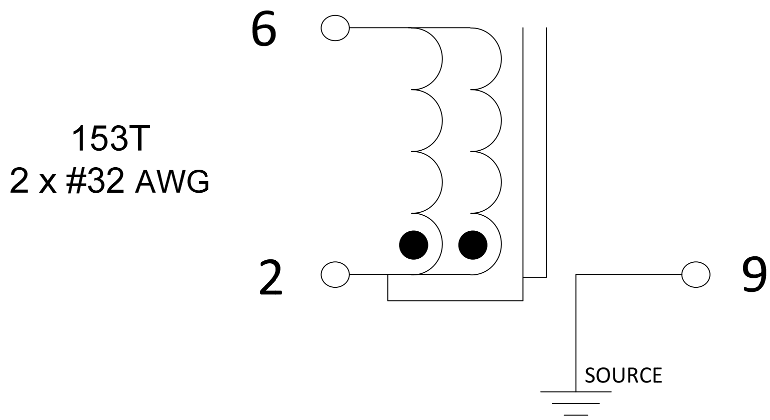

Figure 8 – Inductor Electrical Diagram.

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 6.	1350 μH
Tolerance	Tolerance of primary inductance.	±10%

7.3 *Material List*

Item	Description
[1]	Core: EE13.
[2]	Bobbin: EE13, Vertical, 10 pins.
[3]	Magnet Wire: #32 AWG.
[4]	Transformer Tape: 7.9 mm.
[5]	Transformer Tape: 5.5 mm.

7.4 *Inductor Build Diagram*

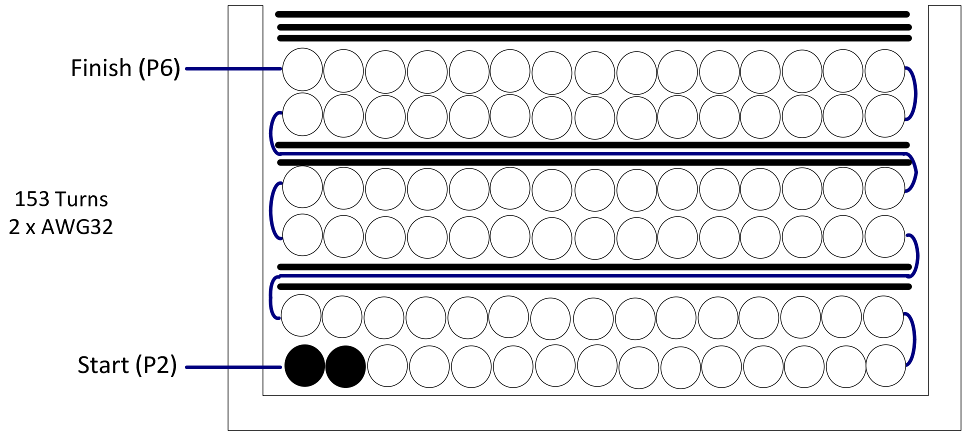

Figure 9 – Inductor Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 1-5 is on the left side. The winding direction is counterclockwise.
Winding 1	Use 2 parallel wires of Item [3], bifilar coil, start at pin 2 and wind 2 layers across the bobbin width.
Insulation	Add 1 layer of tape, Item [4], for insulation.
Z-Winding 1	Continue with Z-winding by placing the wire flatly to the other side of bobbin.
Insulation	Add 1 layer of tape, Item [4], for insulation.
Winding 2	Repeat the 2-layer winding and Z-winding, with insulation, until 153 turns. On the last layer spread winding evenly across the bobbin width. Terminate the winding on pin 6.
Insulation	Add 2 layers of tape, Item [4], for insulation.
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 1350 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 3 layers of tape, Item [5].
Pins	Pull out terminals 1, 3, 4, 5, 7, 8, and 10. Pin 9 is tied to the SOURCE pin.
Finish	Dip the transformer in varnish.

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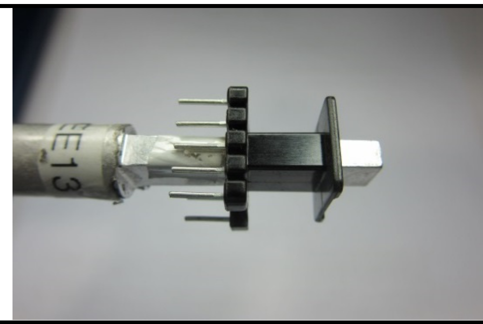
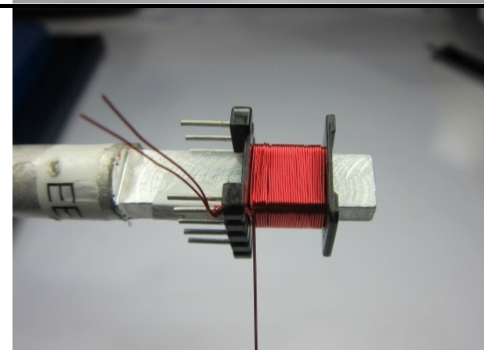
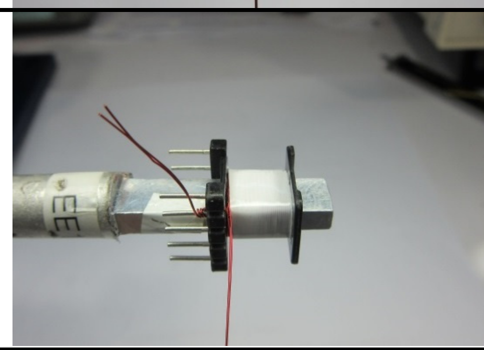
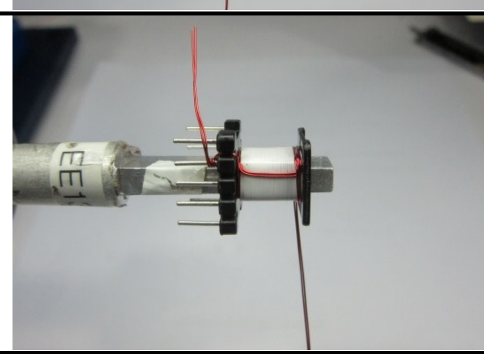
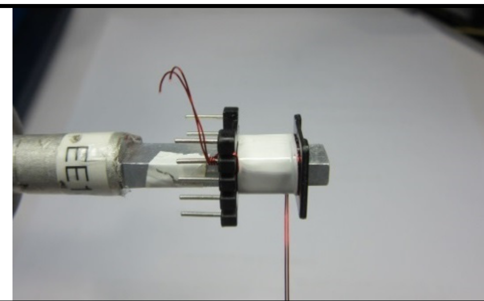
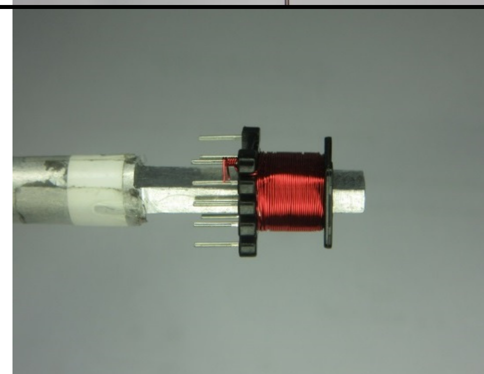
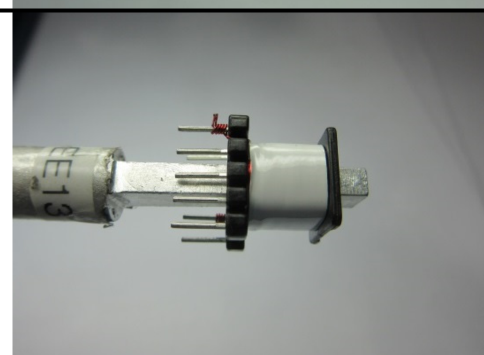
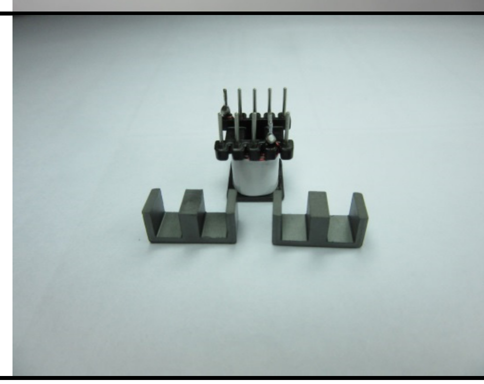
7.6 *Winding Illustrations*

Winding Directions	Bobbin, Item [2], is oriented on winder jig such that terminal pin 1-5 is on the left side. The winding direction is counterclockwise.	
Winding 1	Use 2 parallel wires of Item [3], bifilar coil, start at pin 2 and wind 2 layers across the bobbin width.	
Insulation	Add 1 layer of tape, Item [4], for insulation.	
Z-Winding 1	Continue with Z-winding by placing the wire flatly to the other side of bobbin.	

Insulation	Add 1 layer of tape, Item [4], for insulation.	
Winding 2	Repeat the 2-layer winding and Z-winding, with insulation, until 153 turns. On the last layer spread winding evenly across the bobbin width. Terminate the winding on pin 6.	
Insulation	Add 2 layers of tape, Item [4], for insulation.	
Core Grinding	Grind the center leg of one core, Item [1], until it meets the nominal inductance of 1350 μH.	

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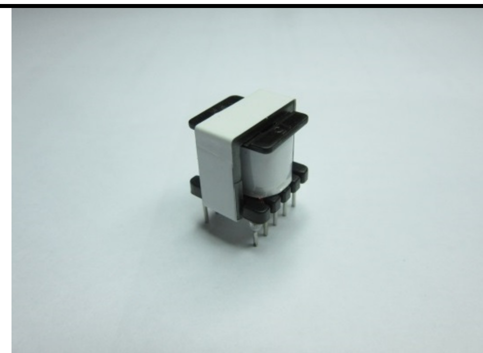
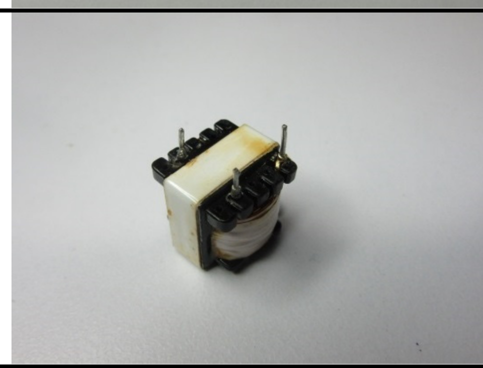
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 3 layers of tape, Item [5].	
Pins	Pull out terminals 1, 3, 4, 5, 7, 8, and 10. Pin 9 is tied to the SOUCRE pin.	
Finish	Dip the transformer in varnish.	

8 Inductor Design Spreadsheet

ACDC_LYTSwitch1_ Buck_020317; Rev.1.1; Copyright Power Integrations 2017	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-1 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			High Line		AC line voltage range
VACMIN	**190**		190	V	Minimum AC line voltage
VACTYP	**230**		230	V	Typical AC line voltage
VACMAX	**265**		265	V	Maximum AC line voltage
FL			50	Hz	AC mains frequency
VO	**39**		39	V	Output Voltage
IO	**180**		180	mA	Average output current specification
EFFICIENCY			0.90		Efficiency estimate
PO			7.02	W	Continuous output power
VD			0.70	V	Output diode forward voltage drop
OPTIMIZATION PARAMETER	**BOM**		BOM		BOM selects IC with lowest peak current. THD selects IC for lowest THD.
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	V	This Spreadsheet supports 725V device only
DEVICE	**Auto**		LYT1403D		Actual LYTSwitch-1 device
ILIMITMIN			1.06	A	Minimum Current Limit
ILIMITTYP			1.15	A	Typical Current Limit
ILIMITMAX			1.24	A	Maximum Current Limit
TON			3	us	On-time during the fixed on-time region at VACTYP
FSW			47	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.71		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	**EE13**		EE13		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			17.10	mm^2	Core effective cross cectional area
LE			30.20	mm	Core effective path length
AL			1130.00	nH/turn^2	Core ungapped effective inductance
AW			21.28	mm^2	Window Area of the bobbin
BW			7.40	mm	Bobbin physical winding width
LAYERS			6.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN			610	uH	Absolute minimum design inductance
LP_TYP	**1350**		1350	uH	Typical design inductance
LP_TOLERANCE			10	%	Tolerance of the design inductance
LP_MAX			8810	uH	Absolue maximum design inductance
TURNS	**153**		153	Turns	Number of inductor turns
ALG			57.67	nH/turn^2	Inductance per turns squared
BMAX			3678	Gauss	Actual saturation flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.354	mm	Core air gap
BWE			44.4	mm	Effective bobbin width
OD			0.29	mm	Outer diameter of the wire with insulation
INS			0.05	mm	Wire insulation
DIA			0.24	mm	Outer diameter of the wire without insulation
AWG			31		AWG of the bare wire.
CM			81	Cmils	Bare wire circular mils
CMA			345	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			3.5	A/mm^2	Bare wire current density

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BOBBIN FILL FACTOR			60.56%		Area of the bobbin occupied by wire
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.18	A	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.54	A	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.09	A	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.22	A	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.23	A	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.519	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.523	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Components					
BUCK_CONFIG	**Low Side Buck**				Buck Topology Switch Configuration
RUPPER			402	kOhms	Upper resistor on the M-pin divider network (E96 / 1%)
RLOWER	**17.4**		17.8	kOhms	Lower resistor on the M-pin divider network (E96 /1%)
VO_OVP		Info1	55.9	V	!!Info1. The VO_OVP is 1.44 * VO.
Line_OVP			441	V	Line overvoltage threshold
CC			100	pF	Coupling Capacitor for Low Side Buck Configuration
RPRELOAD			39	kOhms	Minimum Output Preload Resistor
CBP			4.7	uF	BP Capacitor
VOLTAGE STRESS PARAMETERS					
VDRAIN			375	V	Estimated worst case drain voltage
PIVD			375	V	Output Rectifier Maximum Peak Inverse Voltage

Note: The output overvoltage is monitored at output short-circuit test. The rating of the output capacitor is selected to withstand this voltage during short-circuit.

9 Performance Data

All measurements were performed at room temperature using 36 V, 39 V, and 42 V LED load. 1 minute soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

9.1 *Efficiency*

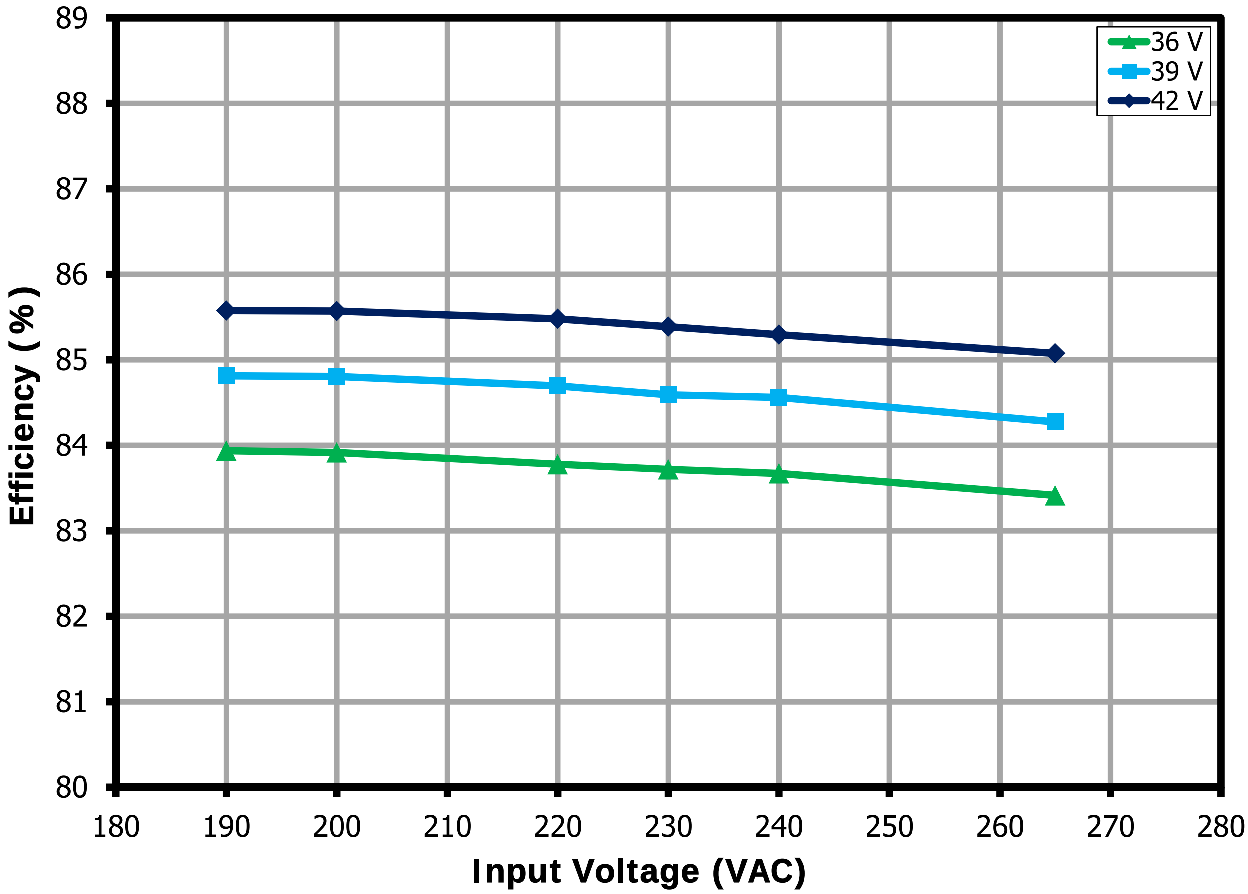

Figure 10 – Efficiency vs. Line.

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9.2 *Load Regulation*

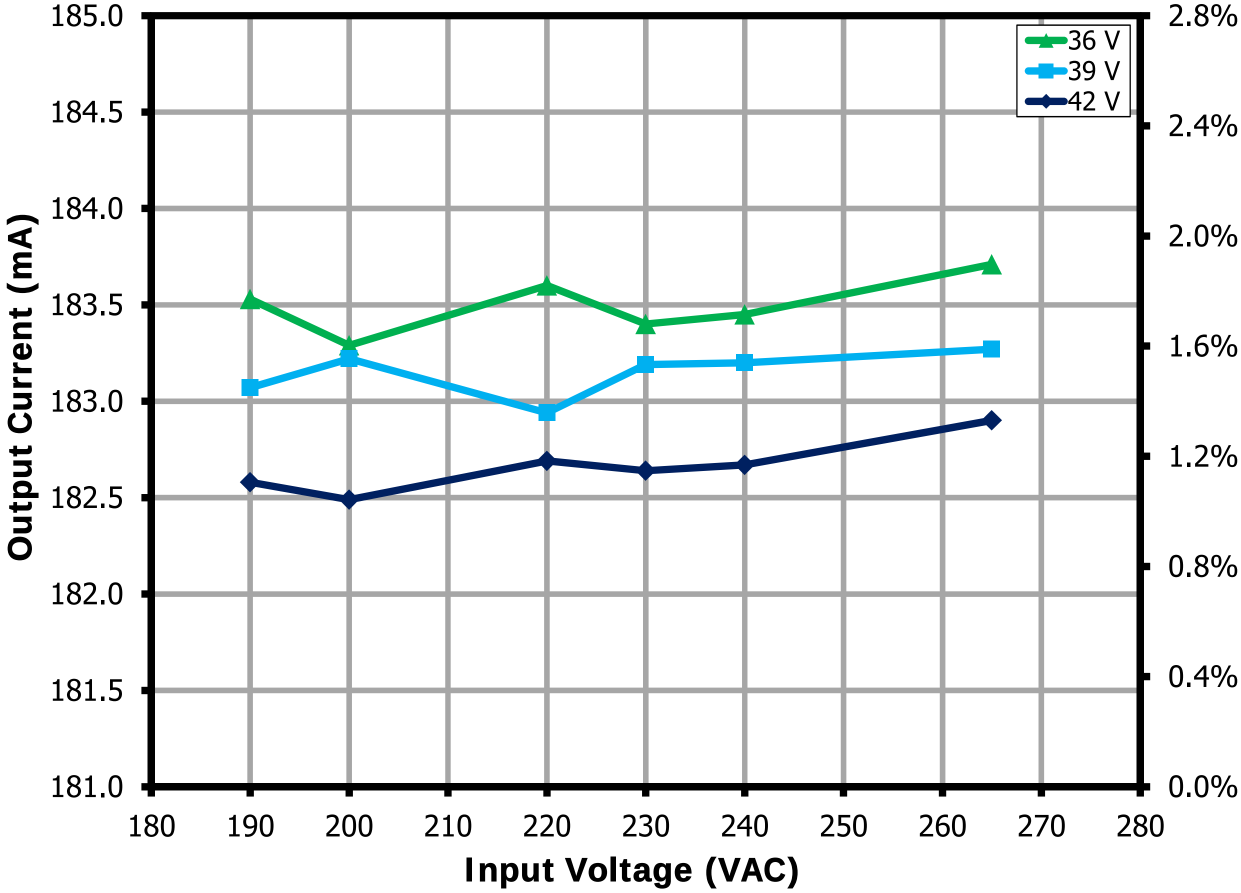

Figure 11 – Load Regulation vs. Line.

9.3 *Power Factor*

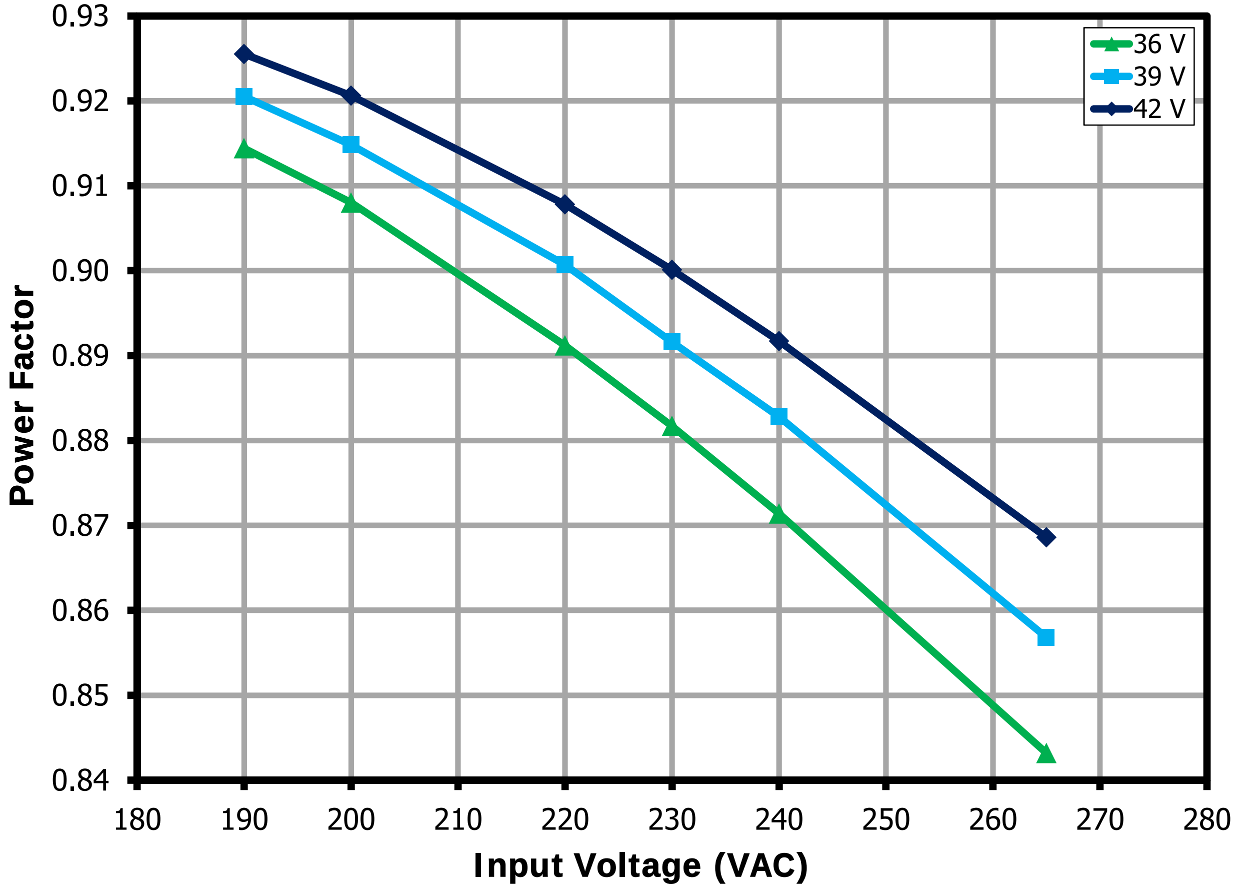

Figure 12 – Power Factor vs. Line.

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9.4 *%ATHD*

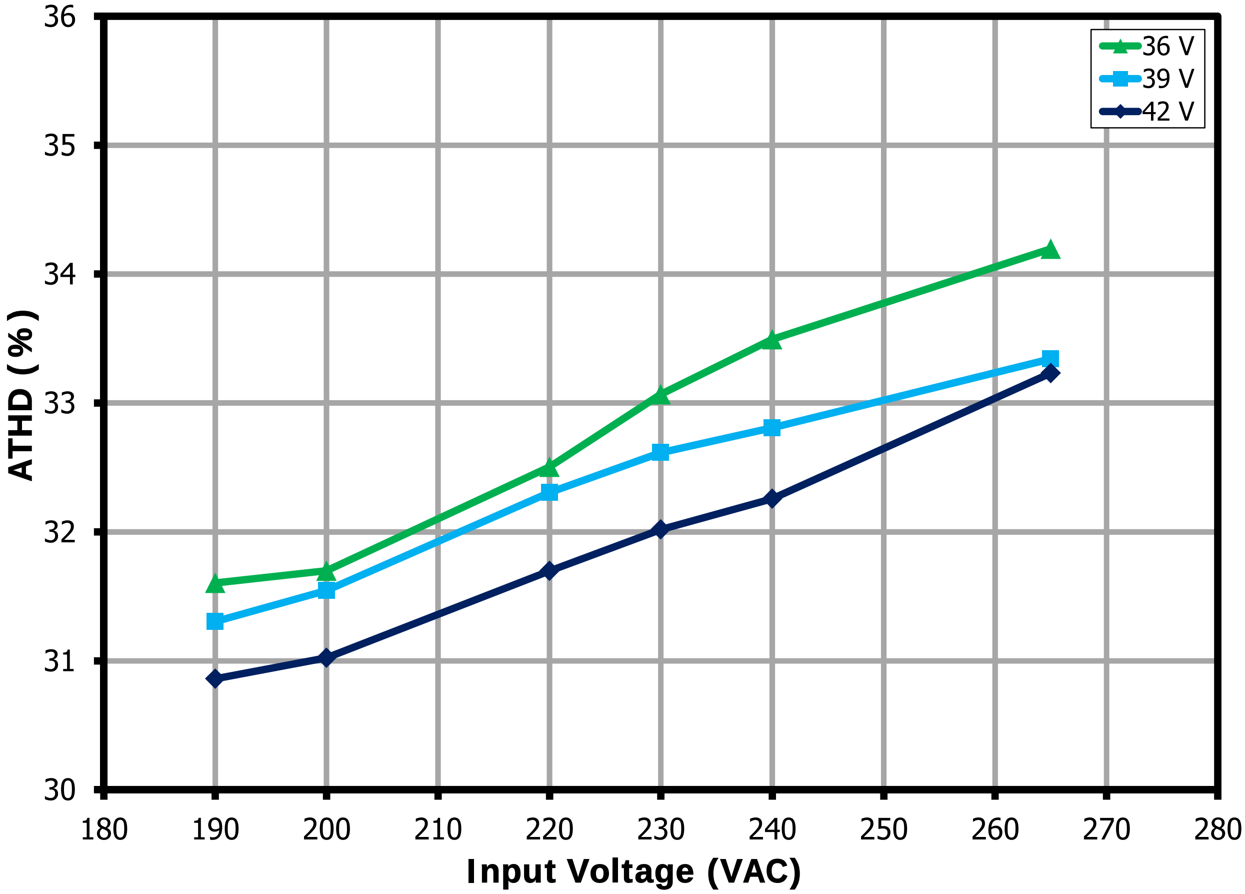

Figure 13 – %ATHD vs. Line.

9.5 *Individual Harmonics Content*

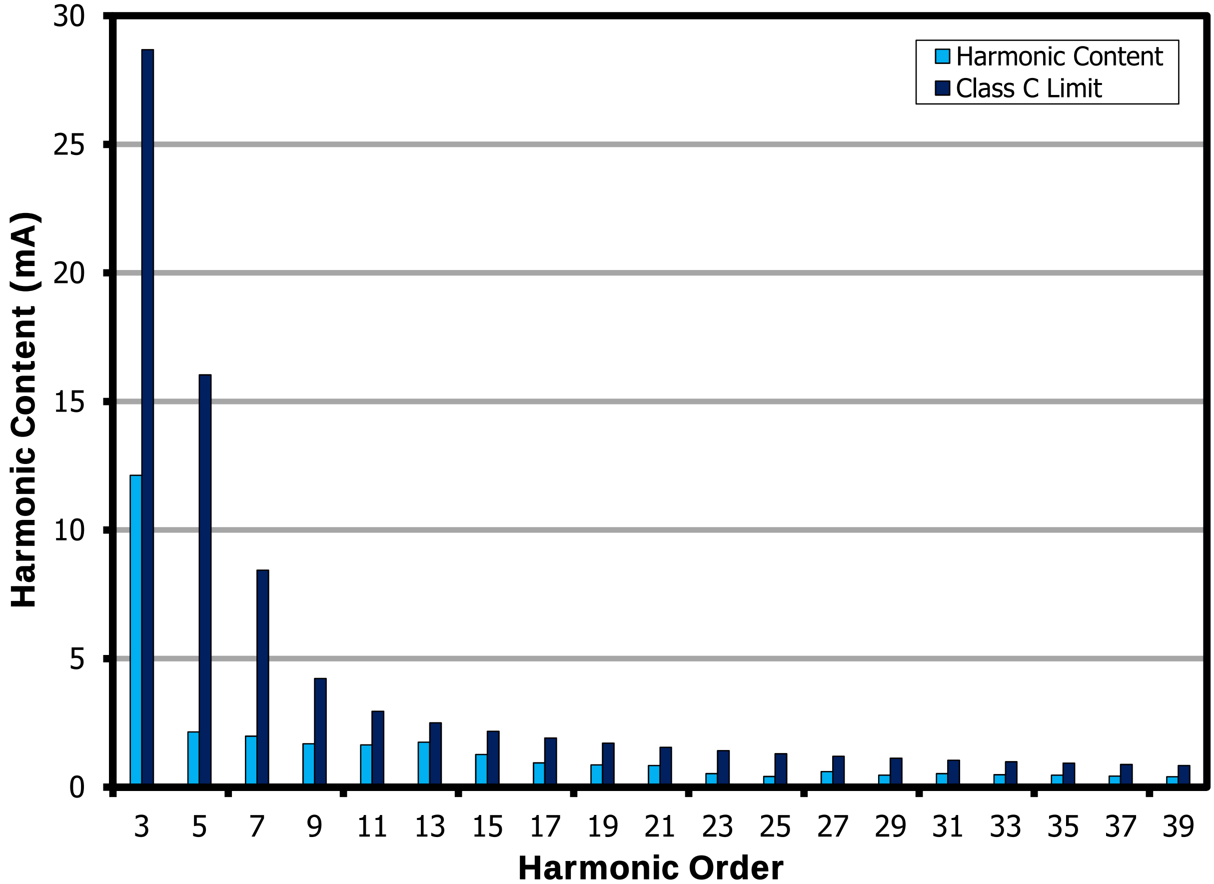

Figure 14 – 39 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10 Test Data

10.1 *Test Data, 36 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)	
190	50	189.98	45.01	7.82	0.91	31.61	35.75	183.53	6.56	83.94
200	50	199.99	43.06	7.82	0.91	31.70	35.79	183.29	6.56	83.92
220	50	220.03	40.00	7.84	0.89	32.51	35.79	183.60	6.57	83.78
230	50	230.05	38.65	7.84	0.88	33.07	35.77	183.40	6.56	83.72
240	50	239.99	37.50	7.84	0.87	33.49	35.77	183.45	6.56	83.67

10.2 *Test Data, 39 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)	
190	50	189.97	48.08	8.41	0.92	31.31	38.94	183.07	7.13	84.81
200	50	199.99	46.04	8.42	0.91	31.55	38.98	183.22	7.14	84.80
220	50	220.03	42.47	8.42	0.90	32.31	38.95	182.94	7.13	84.70
230	50	230.05	41.13	8.44	0.89	32.62	38.95	183.19	7.14	84.59
240	50	239.99	39.83	8.44	0.88	32.81	38.95	183.20	7.14	84.56

10.3 *Test Data, 42 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)	
190	50	189.98	50.95	8.96	0.93	30.86	41.98	182.58	7.67	85.58
200	50	199.99	48.67	8.96	0.92	31.02	42.02	182.49	7.67	85.57
220	50	220.03	44.96	8.98	0.91	31.70	42.01	182.69	7.68	85.48
230	50	230.05	43.40	8.99	0.90	32.02	42.01	182.64	7.67	85.39
240	50	239.99	42.04	9.00	0.89	32.26	42.00	182.67	7.67	85.30

10.4 *Test Data, Harmonic Content at 230 VAC with 39 V LED Load*

V	Freq	I (mA_{RMS})	P	PF	%THD
230	50.00	41.13	8.4370	0.8916	32.615
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	37.96				
2	0.06	0.16%		2.00%	
3	12.13	31.96%	28.6858	26.75%	Pass
5	2.15	5.66%	16.0303	10.00%	Pass
7	1.98	5.21%	8.4370	7.00%	Pass
9	1.68	4.43%	4.2185	5.00%	Pass
11	1.64	4.32%	2.9530	3.00%	Pass
13	1.74	4.59%	2.4987	3.00%	Pass
15	1.27	3.33%	2.1655	3.00%	Pass
17	0.94	2.48%	1.9107	3.00%	Pass
19	0.86	2.27%	1.7096	3.00%	Pass
21	0.83	2.19%	1.5468	3.00%	Pass
23	0.53	1.39%	1.4123	3.00%	Pass
25	0.41	1.09%	1.2993	3.00%	Pass
27	0.60	1.59%	1.2031	3.00%	Pass
29	0.46	1.22%	1.1201	3.00%	Pass
31	0.52	1.37%	1.0478	3.00%	Pass
33	0.48	1.27%	0.9843	3.00%	Pass
35	0.46	1.22%	0.9281	3.00%	Pass
37	0.43	1.13%	0.8779	3.00%	Pass
39	0.40	1.06%	0.8329	3.00%	Pass

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11 Thermal Performance – Inside Bulb Case

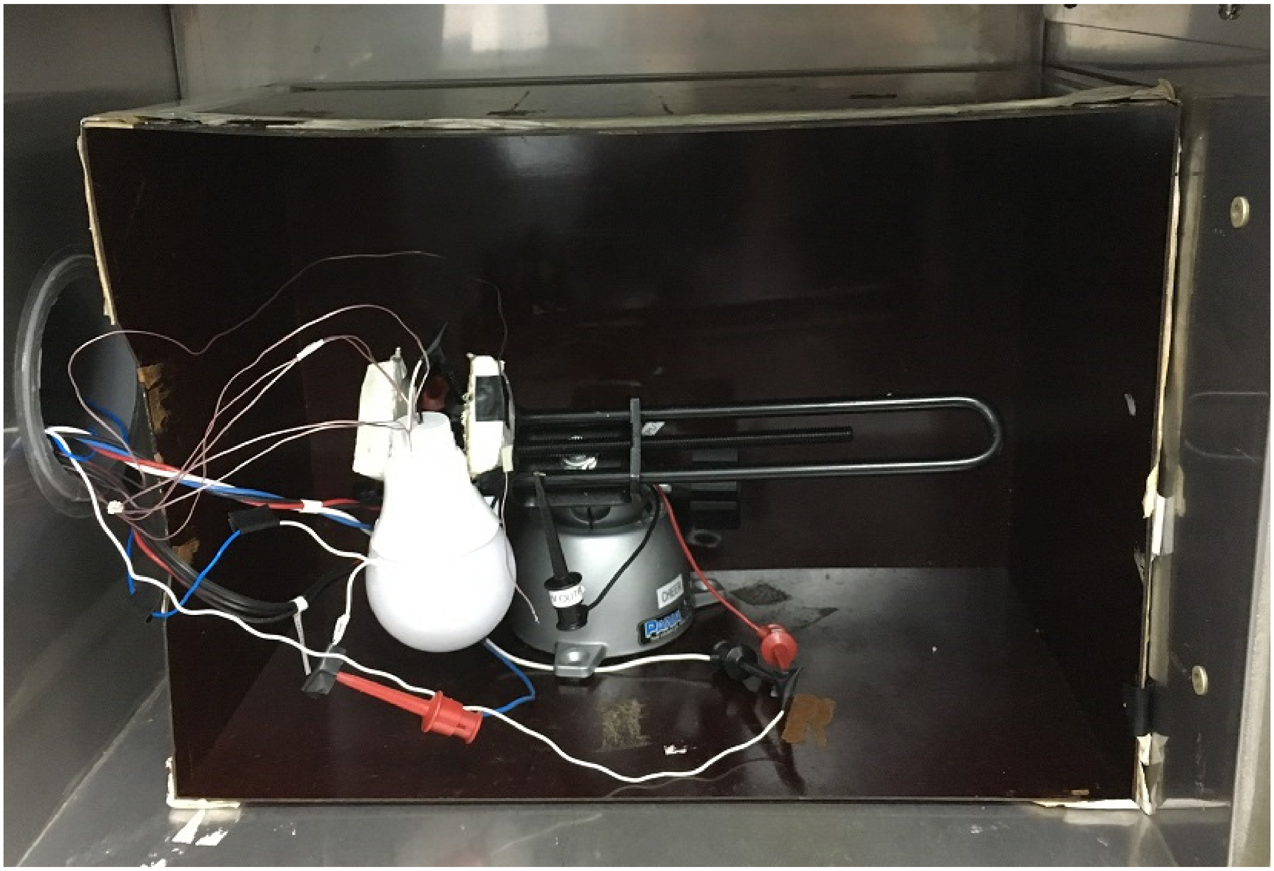

Figure 15 – Thermal Test setup inside the Chamber.

The bulb was placed inside the enclosure to prevent airflow that might affect the thermal measurements. Ambient temperature inside enclosure is 25 ºC and 40 ºC at 230 VAC with almost 1 hour soak time. Temperature was measured using T-type thermocouple.

11.1 *Thermal Performance at 230 VAC with a 42 V LED Load, 25 ºC Ambient*

Reference	Max (°C)	Final (°C)
Ambient (Inside Enclosure)	37.3	37.0
U1	121.9	121.9
R11	129.2	126.9
Q1	134.3	134.1
L2	124.9	123.4
Internal (Inside Bulb Case)	104.9	104.1
I_{OUT} (mA)	185.3	182.8

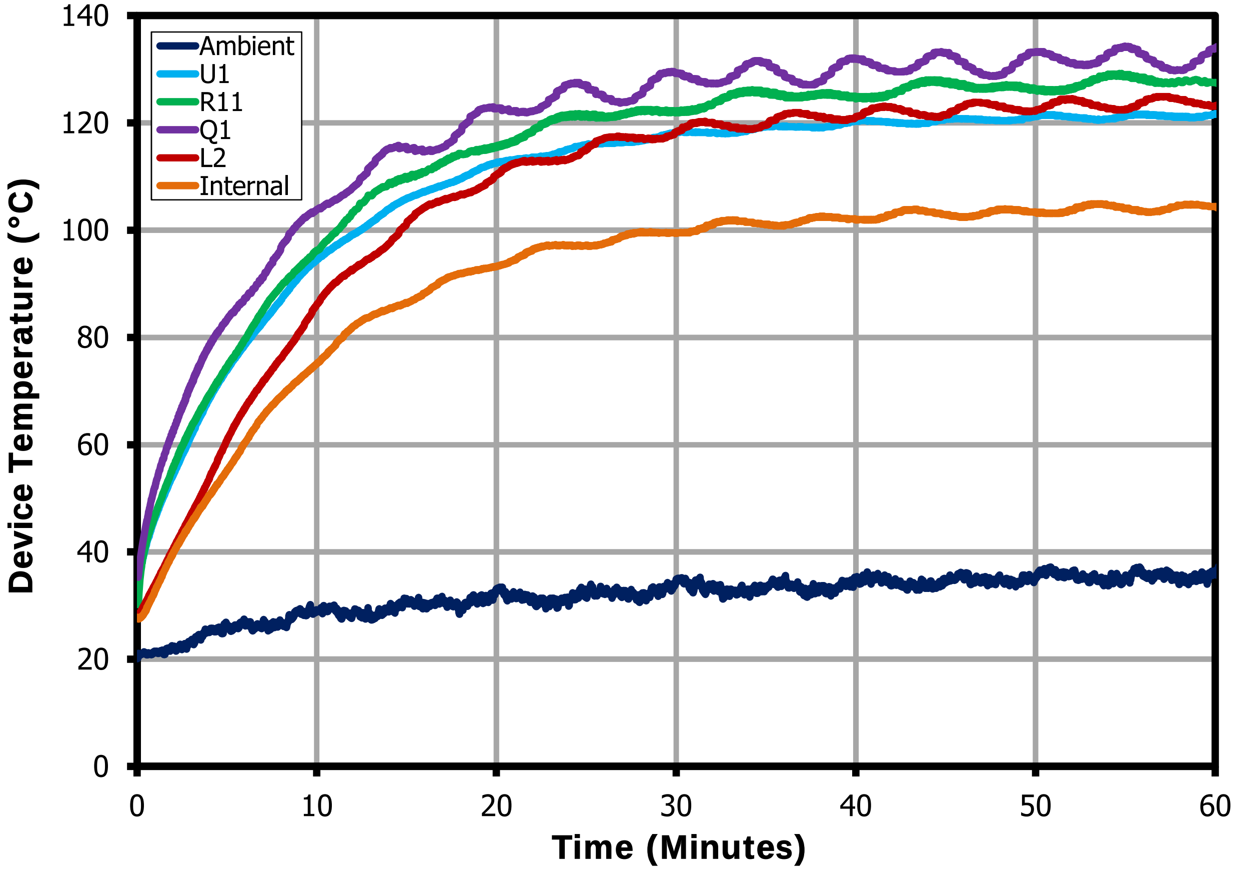

Figure 16 – Component Temperature at 230 VAC, 42 V LED Load, 25 ºC Ambient.

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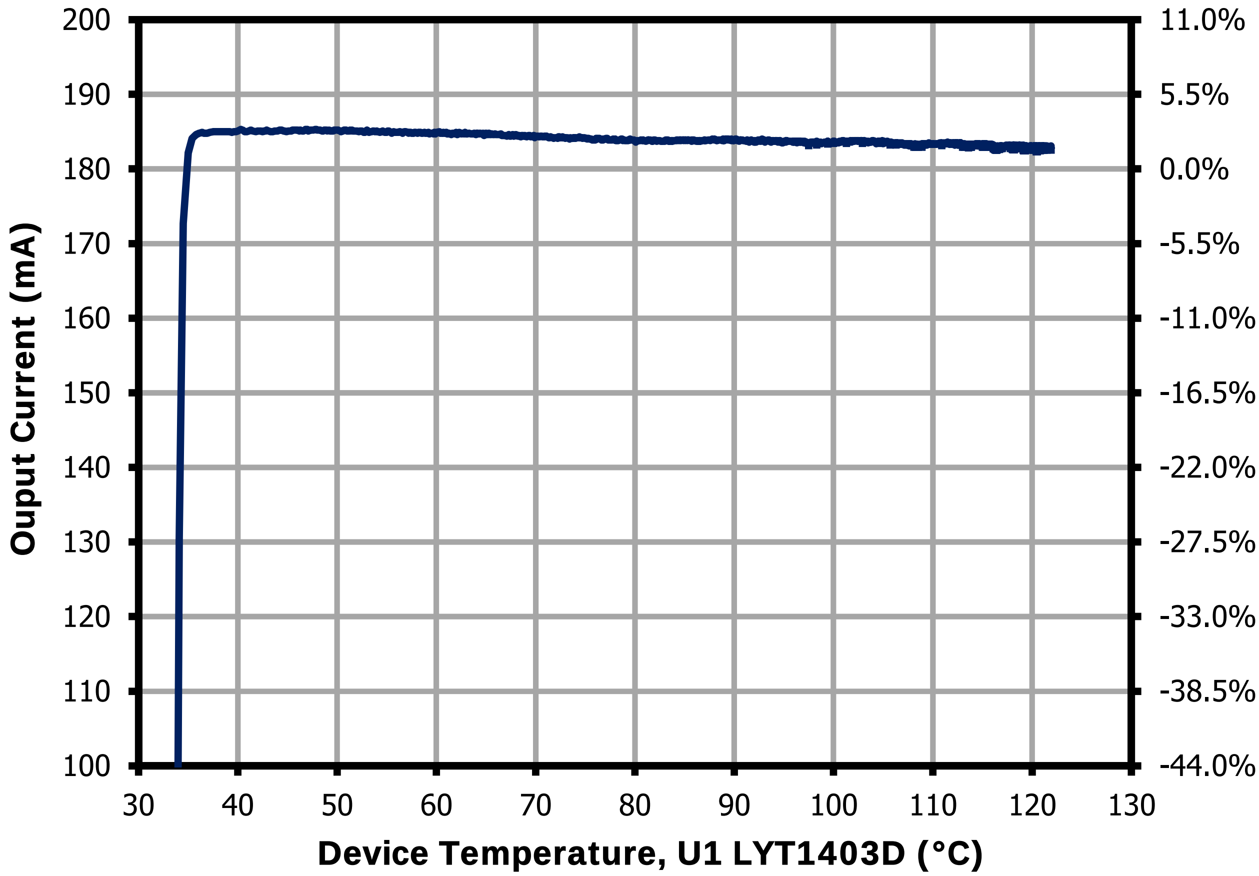

Figure 17 – Output Current vs Device Temperature (LYT1403D), 230 VAC, 25 ºC Ambient.

11.2 *Thermal Performance at 230 VAC with a 42 V LED Load, 40 ºC Ambient*

Reference	Max (°C)	Final (°C)
Ambient (Inside Enclosure)	51.6	50.2
U1	129.7	129.4
R11	142.9	140.5
Q1	147.4	144.7
L2	138.7	138.4
Internal (Inside Bulb Case)	117.0	116.5
I_{OUT} (mA)	185.8	181.5

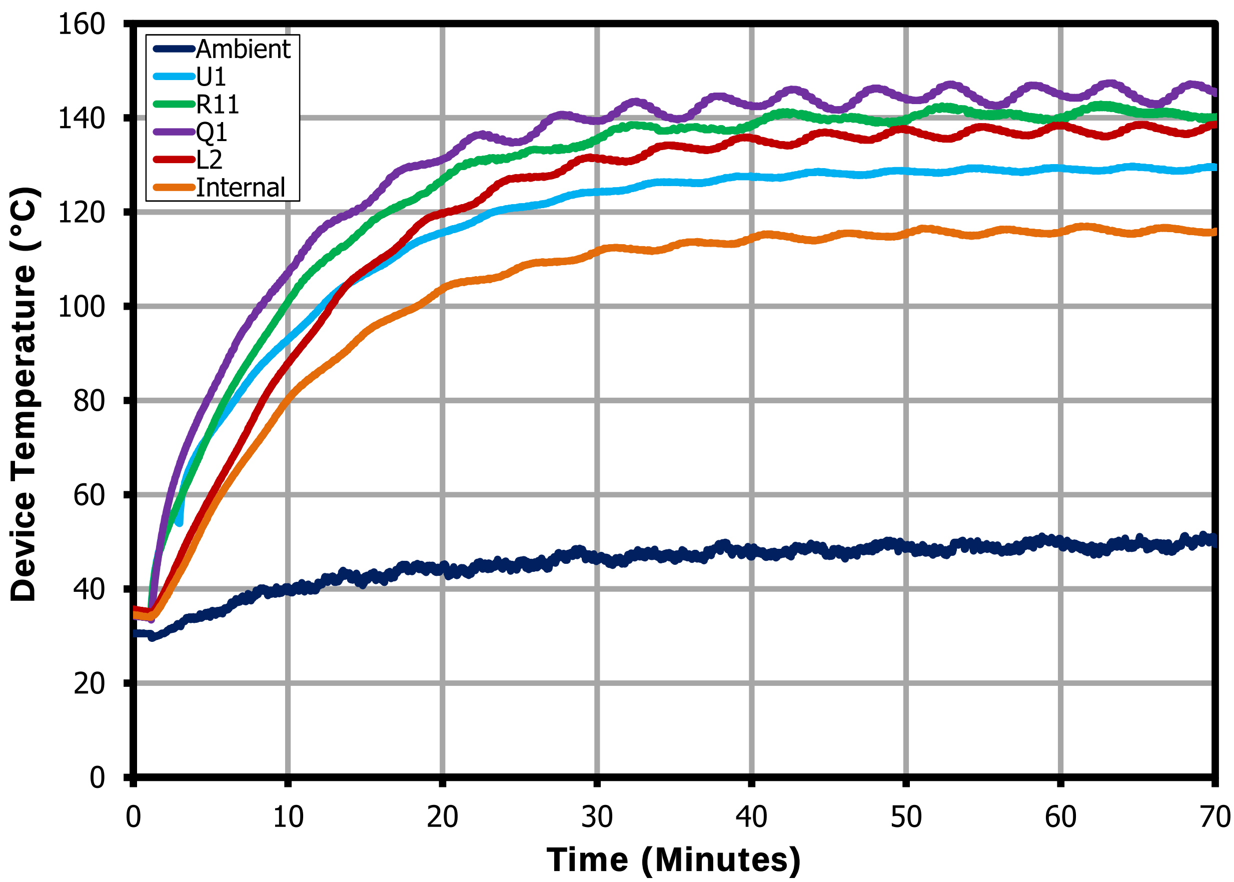

Figure 18 – Component Temperature at 230 VAC, 42 V LED Load, 40 ºC Ambient.

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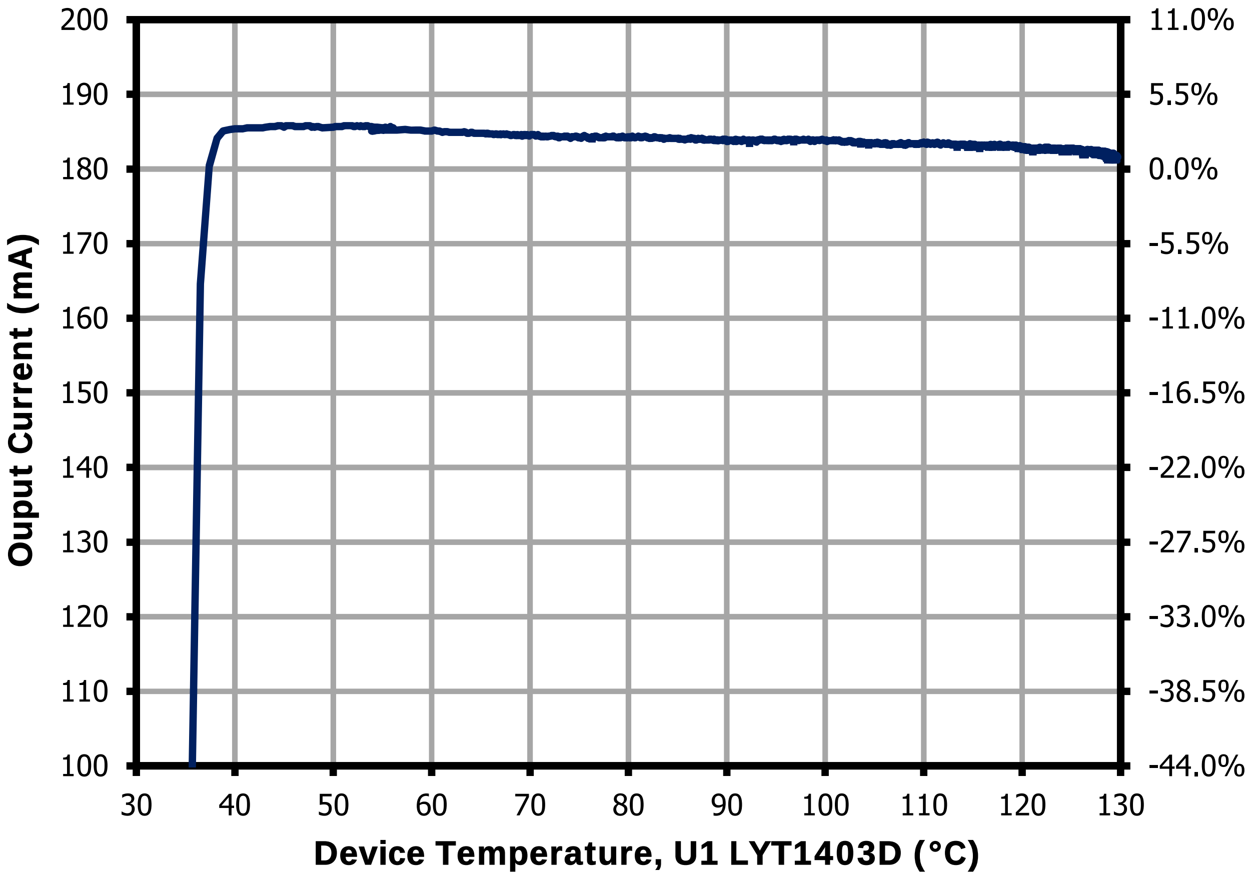

Figure 19 – Output Current vs Device Temperature (LYT1403D), 230VAC, 40 ºC Ambient.

12 Waveforms

12.1 *Input Voltage and Input Current Waveforms*

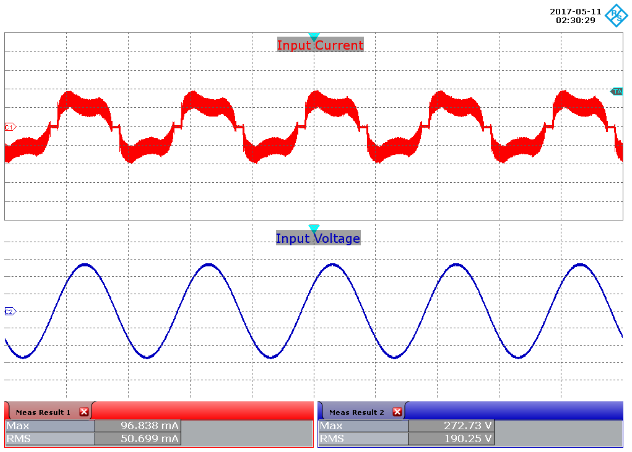

Figure 20 – 190 VAC, 42 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

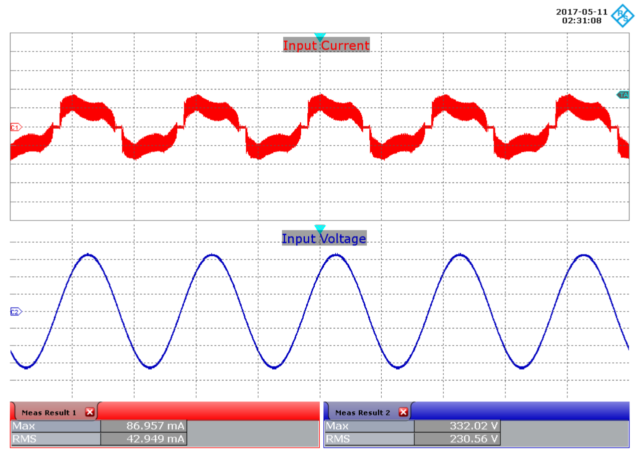

Figure 21 – 230 VAC, 42 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

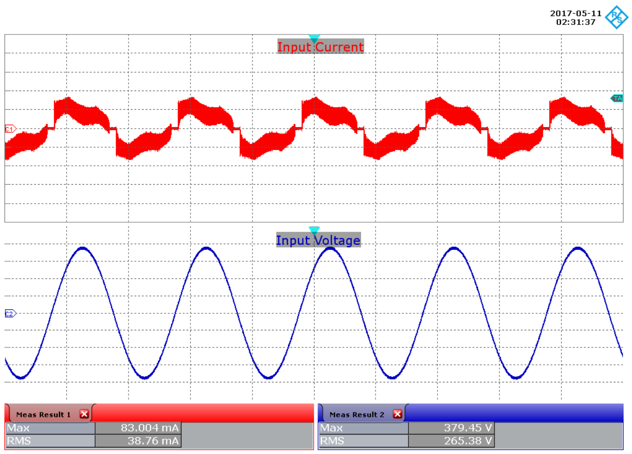

Figure 22 – 265 VAC, 42 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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12.2 *Start-up Profile*

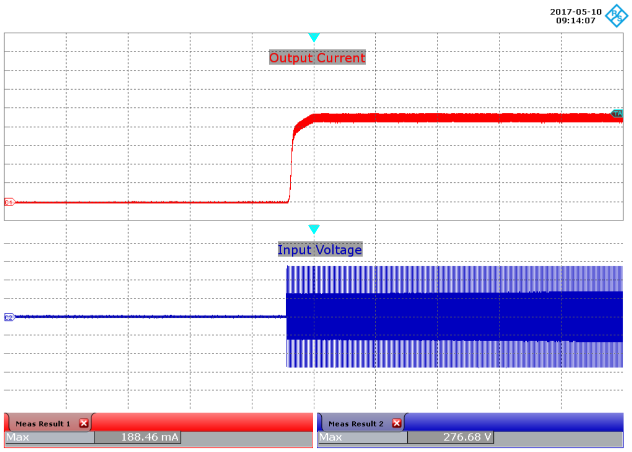

Figure 23 – 190 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

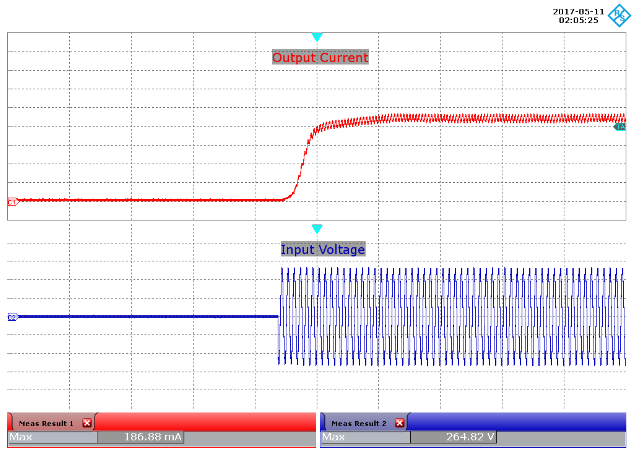

Figure 24 – 190 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

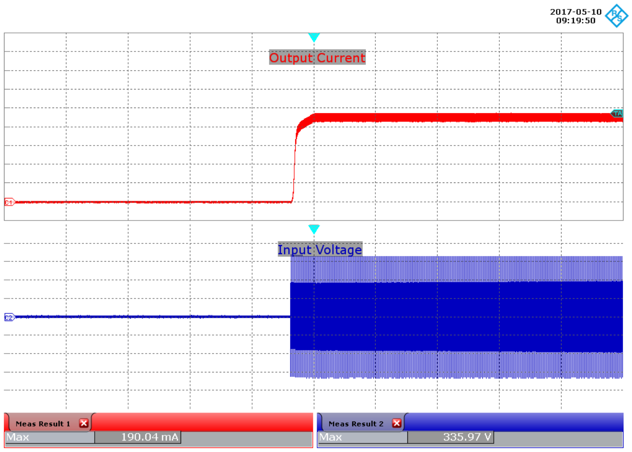

Figure 25 – 230 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

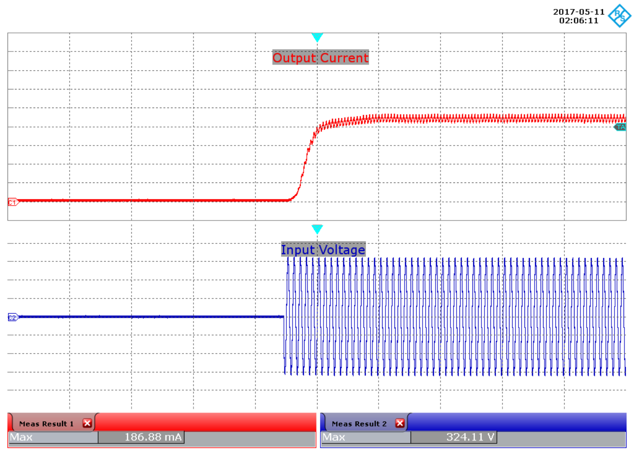

Figure 26 – 230 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

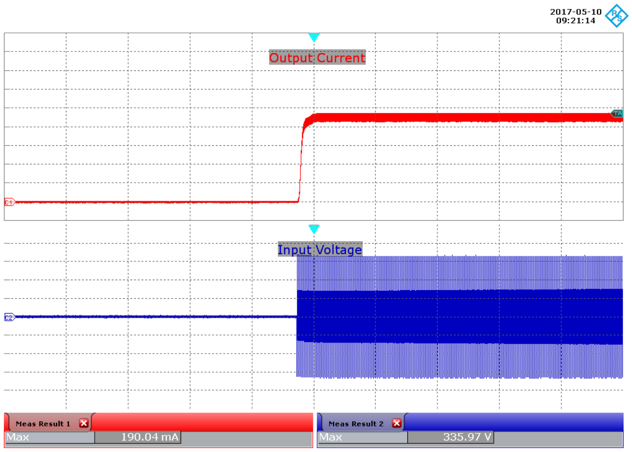

Figure 27 – 265 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

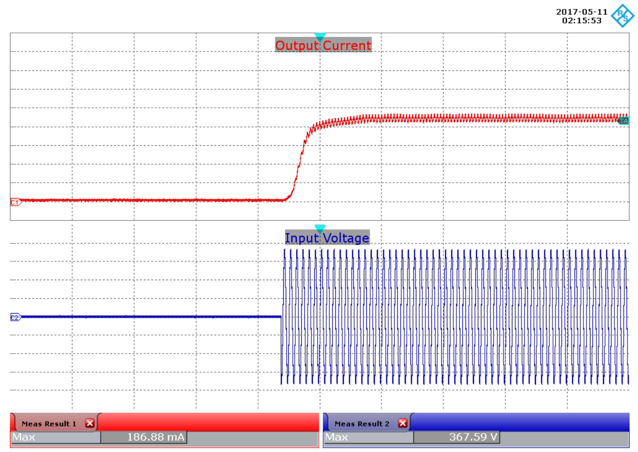

Figure 28 – 265 VAC, 42 V LED, Output Rise.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

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12.3 *Output Current Fall*

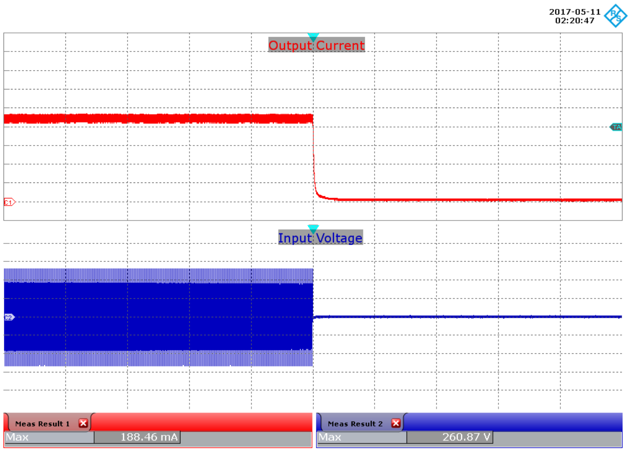

Figure 29 – 190 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

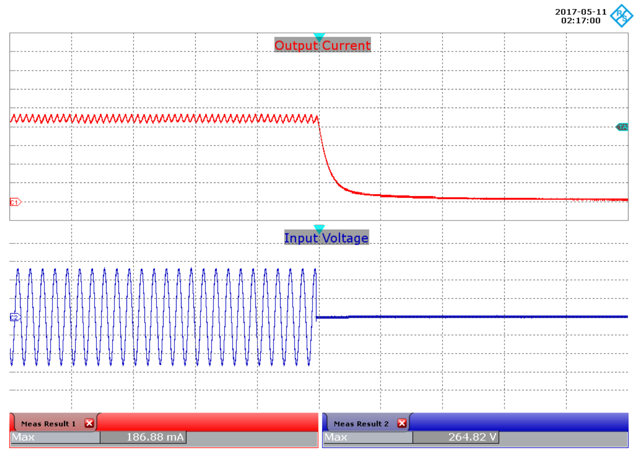

Figure 30 – 190 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

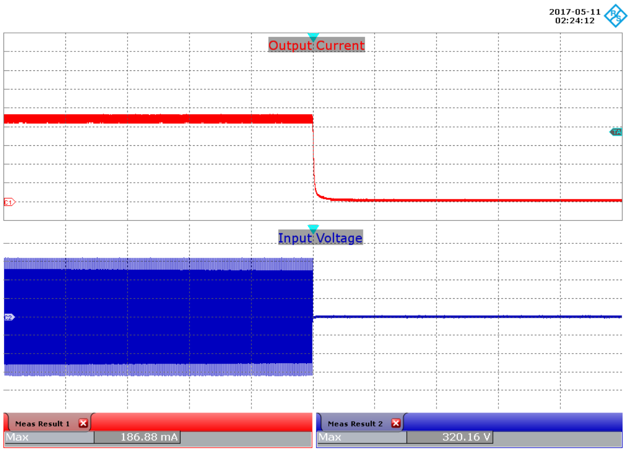

Figure 31 – 230 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

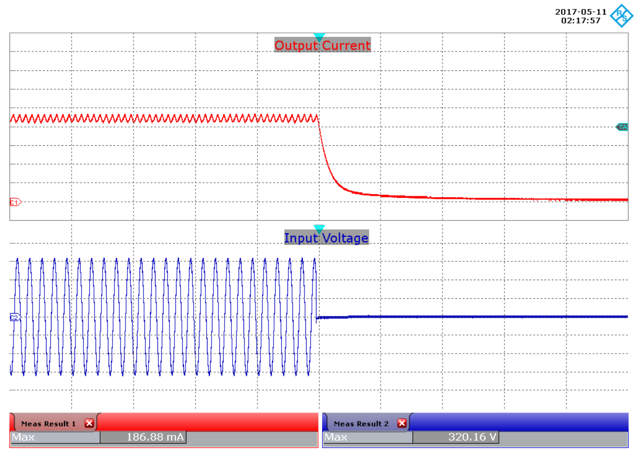

Figure 32 – 230 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

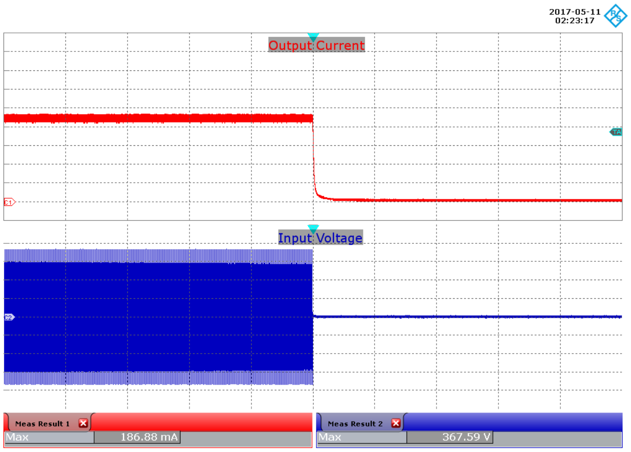

Figure 33 – 265 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

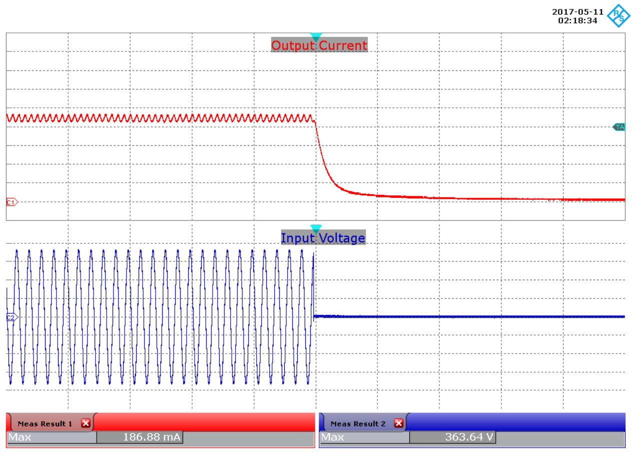

Figure 34 – 265 VAC, 42 V LED, Output Fall.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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12.4 *Drain Voltage and Current in Normal Operation*

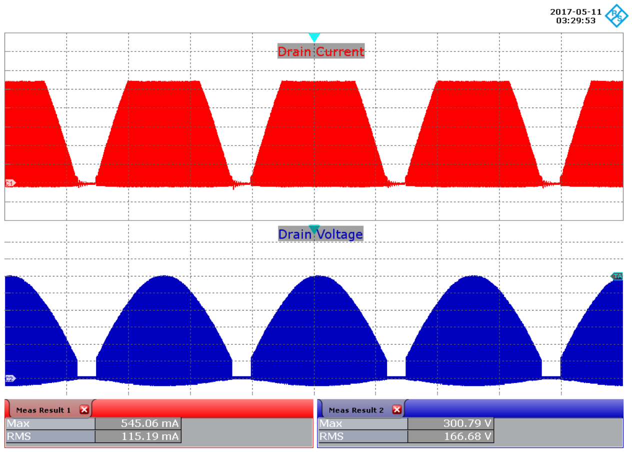

Figure 35 – 190 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

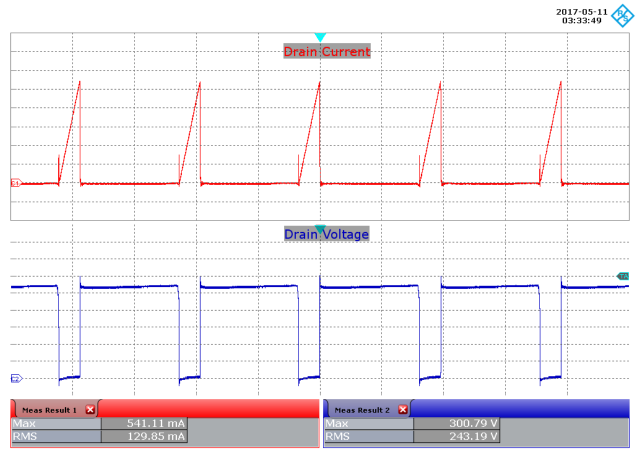

Figure 36 – 190 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

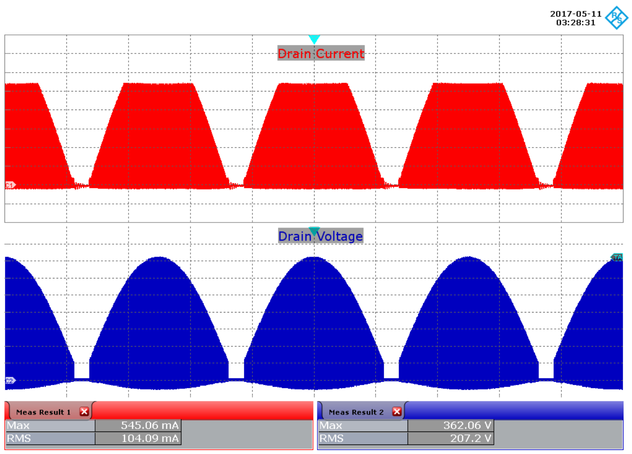

Figure 37 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

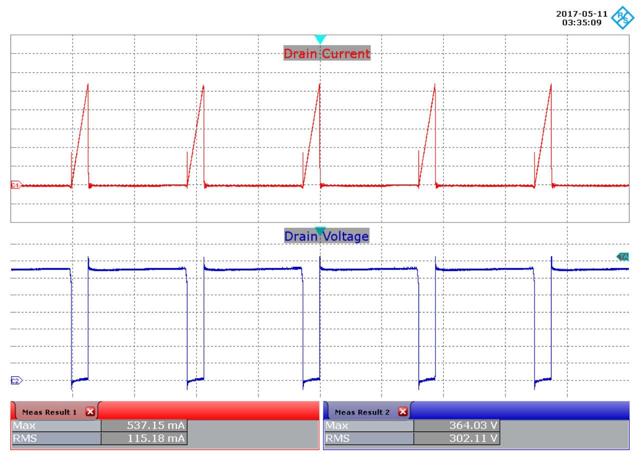

Figure 38 – 230 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

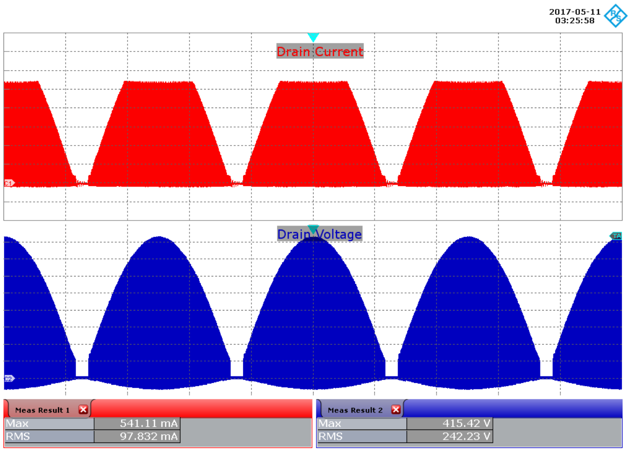

Figure 39 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 ms / div.

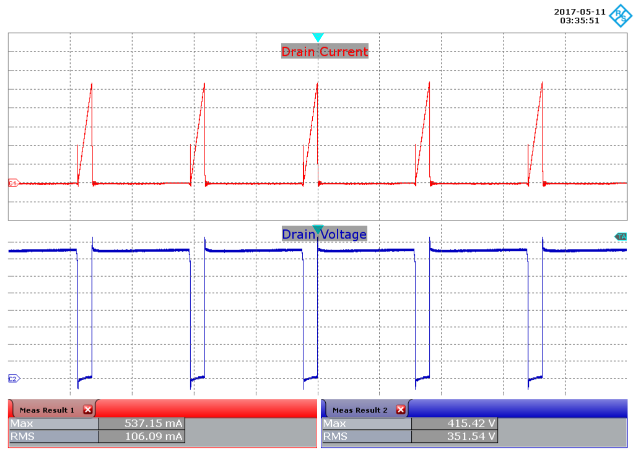

Figure 40 – 1265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 10 μs / div.

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12.5 *Drain Voltage and Current Start-up Profile*

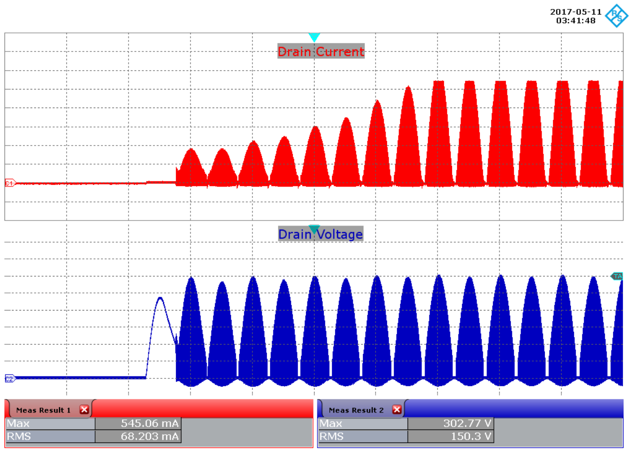

Figure 41 – 190 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

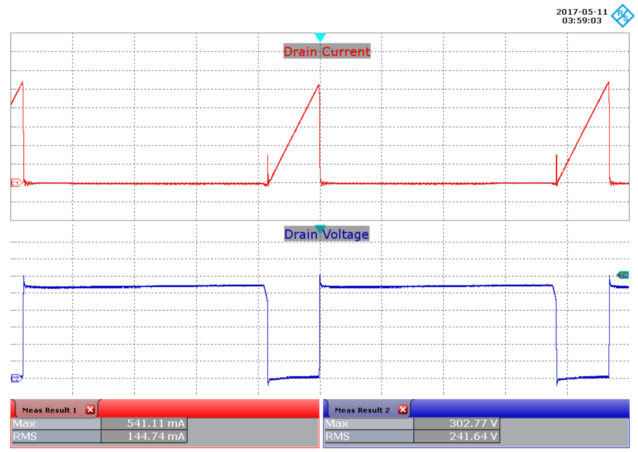

Figure 42 – 190 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 μs / div.

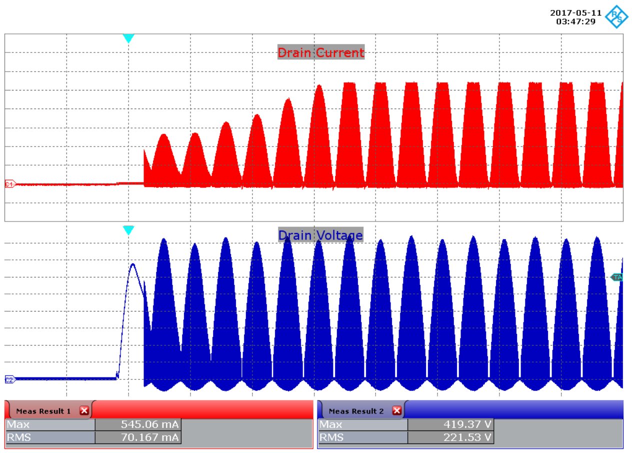

Figure 43 – 265 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 20 ms / div.

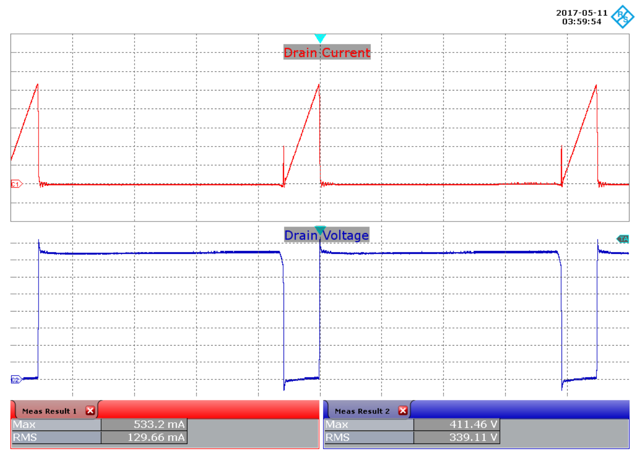

Figure 44 – 132 VAC, 54 V LED Load.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 50 V / div., 4 μs / div.

12.6 *Drain Voltage and Current at Output Short-Circuit*

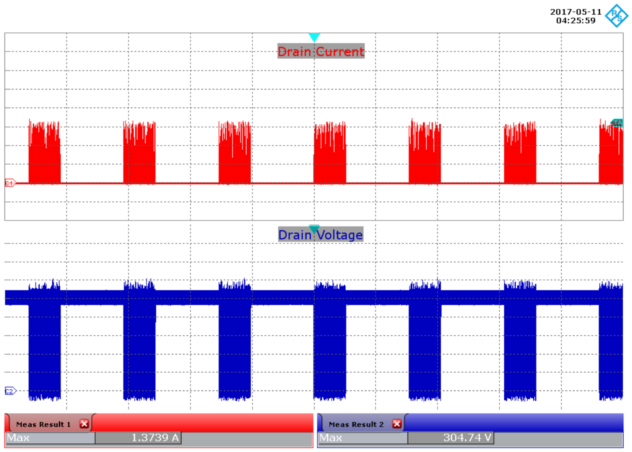

Figure 45 – 190 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

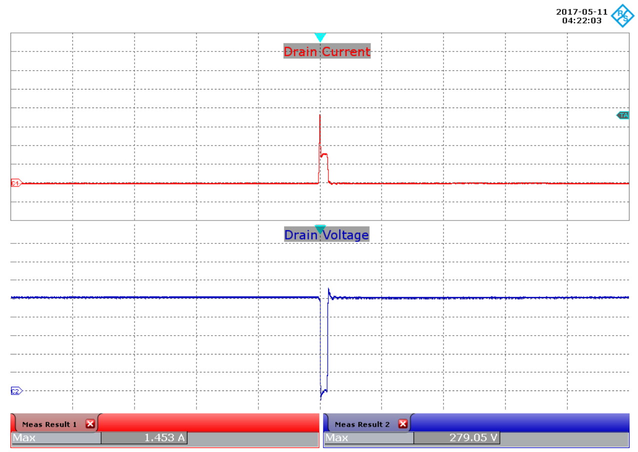

Figure 46 – 190 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 2 μs / div.

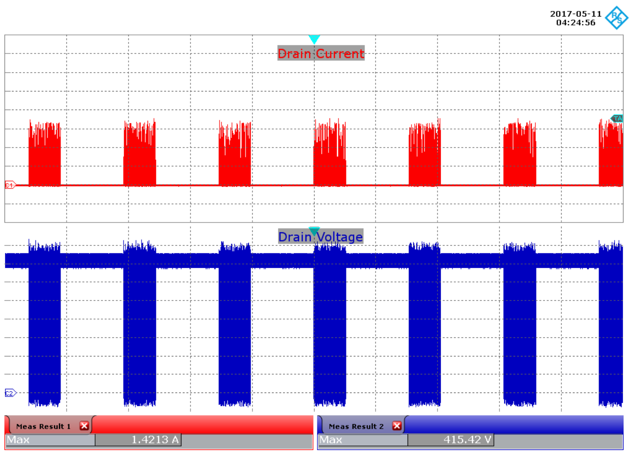

Figure 47 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

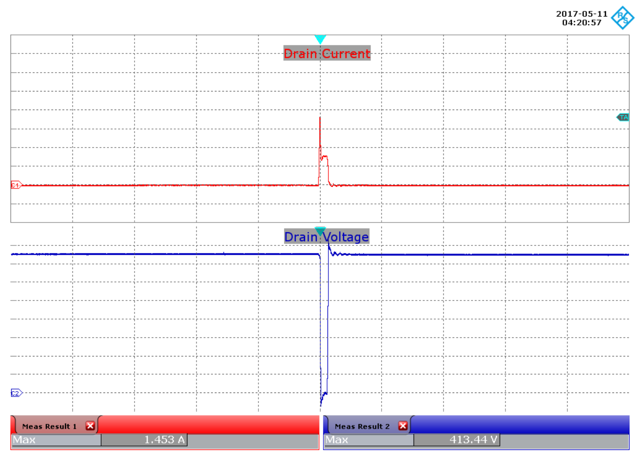

Figure 48 – 265 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 2 μs / div.

12.6.1 Input Power at Output Short-Circuit

Input		Input Measurement		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)
190	50	189.98	5.76	0.343
220	50	220.02	5.17	0.371
230	50	230.04	5.04	0.380
265	50	265.00	4.68	0.395

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12.7 *Output Diode Voltage and Current in Normal Operation*

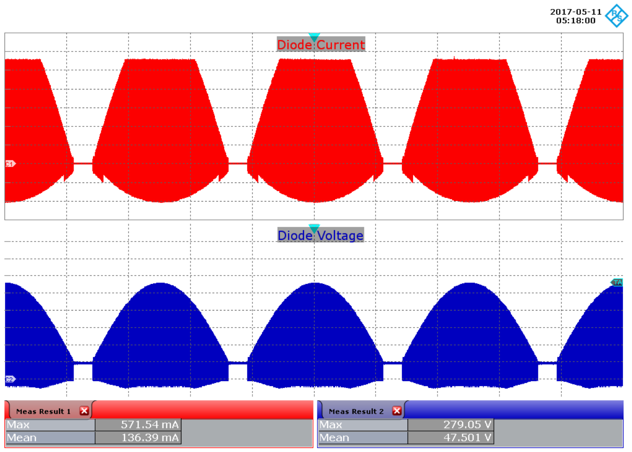

Figure 49 – 190 VAC, 42 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 4 ms / div.

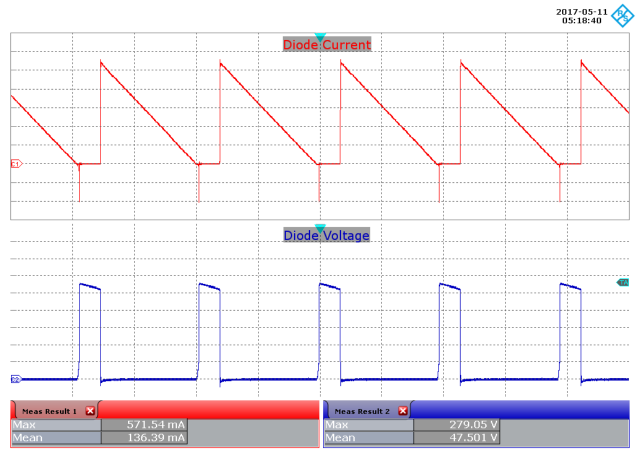

Figure 50 – 190 VAC, 42 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 10 μs / div.

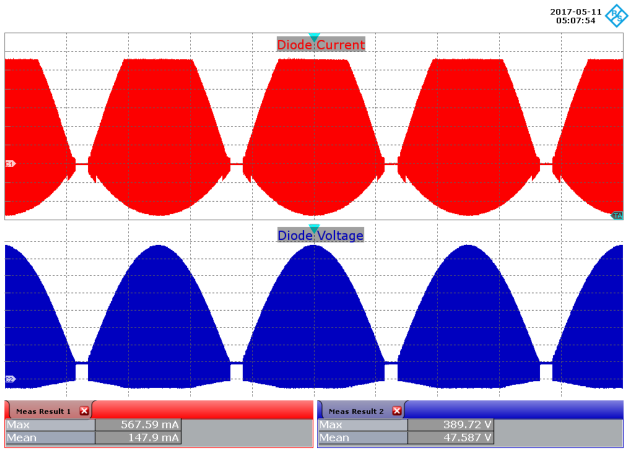

Figure 51 – 265 VAC, 42 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 4 ms / div.

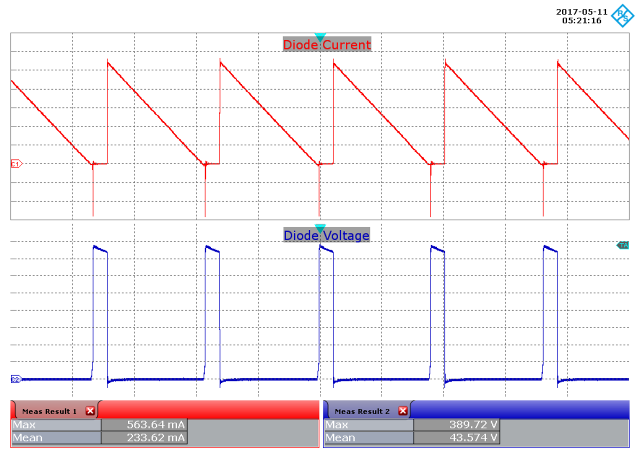

Figure 52 – 265 VAC, 42 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 50 V / div., 4 μs / div.

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

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

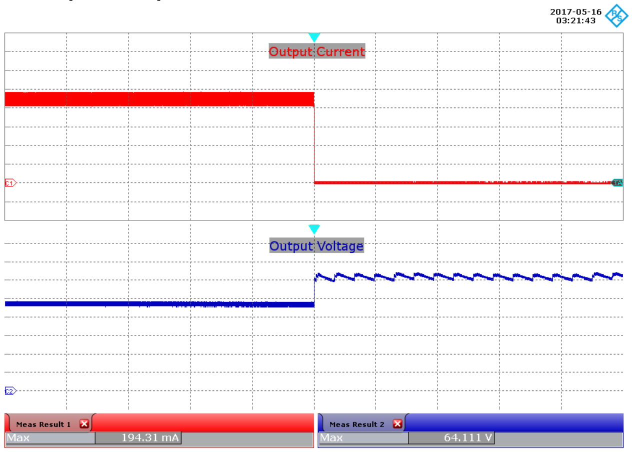

Figure 53 – 190 VAC, 42 V LED Load,
Running Open Load.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

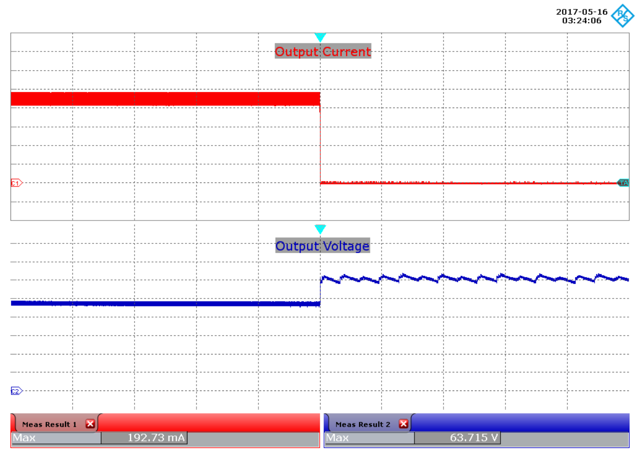

Figure 54 – 265 VAC, 42 V LED Load,
Running Open Load.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

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

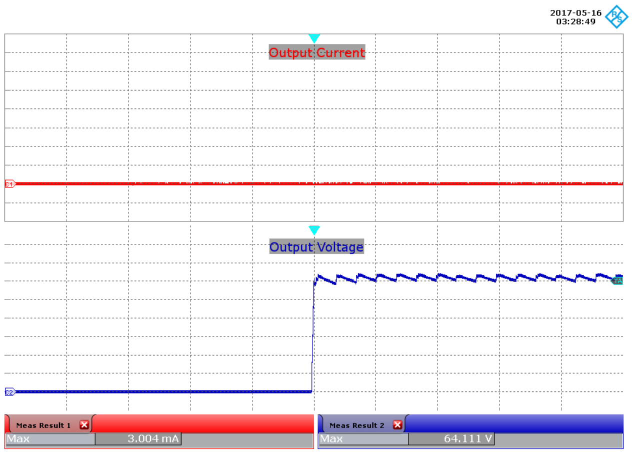

Figure 55 – 190 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

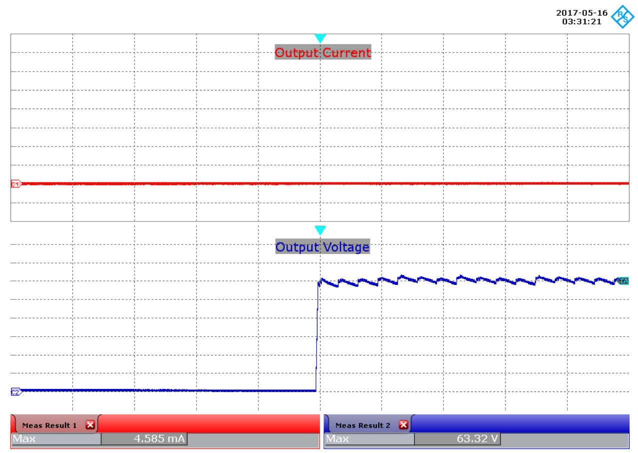

Figure 56 – 265 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{OUT}, 10 V / div., 4 s / div.

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12.10 *Output Ripple Current (with Active Ripple Filter)*

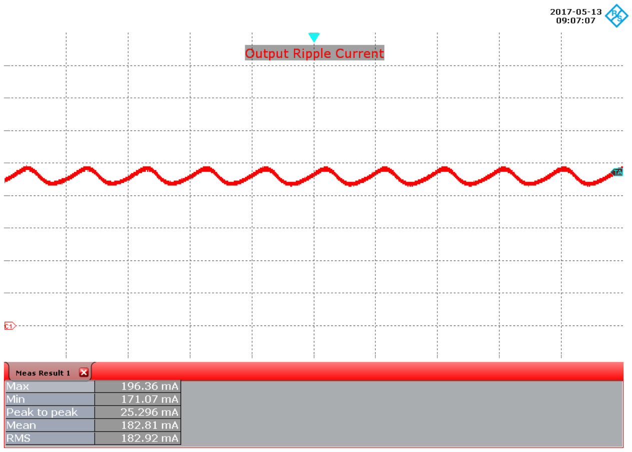

Figure 57 – 190 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

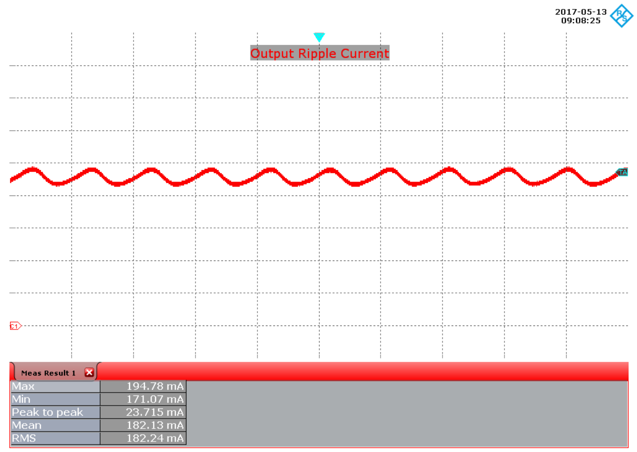

Figure 58 – 220 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

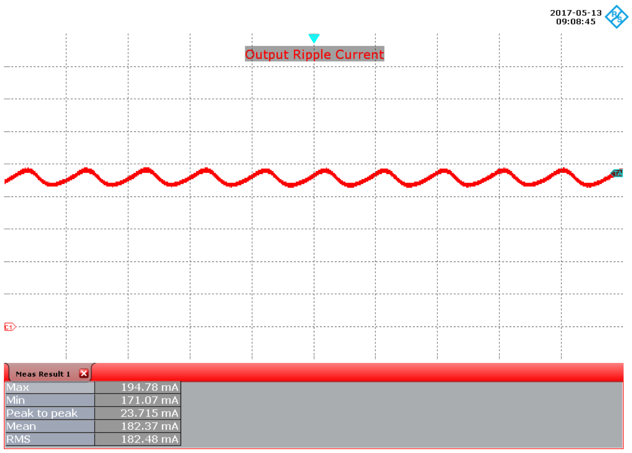

Figure 59 – 230 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 40 mA / div., 10 ms / div.

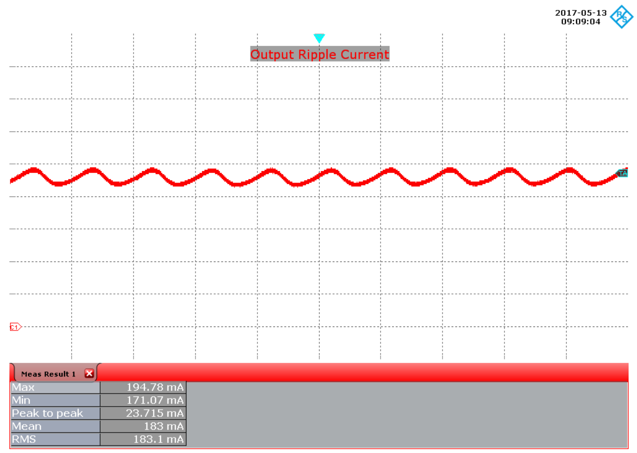

Figure 60 – 265 VAC, 50 Hz, 42 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN}	% Flicker 100 x (I_{RP-P} / $I_{OUT(MAX)}$ + $I_{OUT(MIN)}$)
190	193.36	171.07	182.81	6.10
220	194.78	171.07	182.13	6.51
230	194.78	171.07	182.37	6.50
265	194.78	171.07	183	6.48

13 AC Cycling Test

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

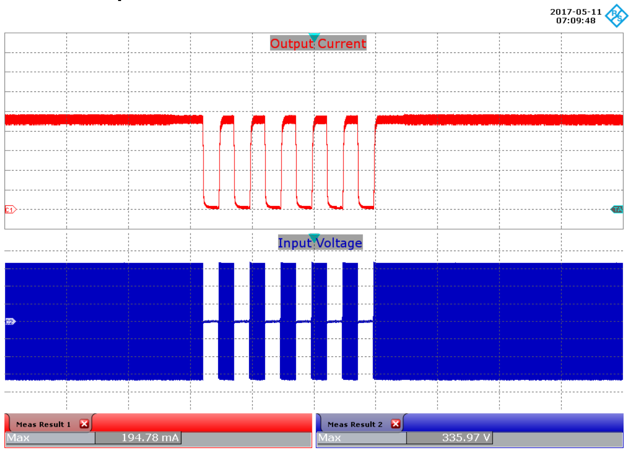

Figure 61 – 230 VAC, 42 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

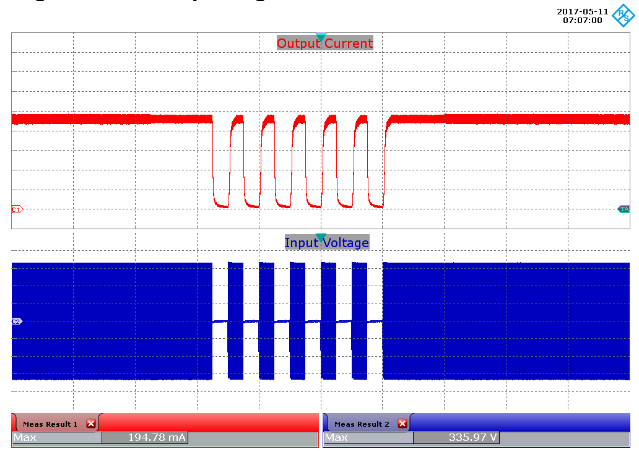

Figure 62 – 230 VAC, 42 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

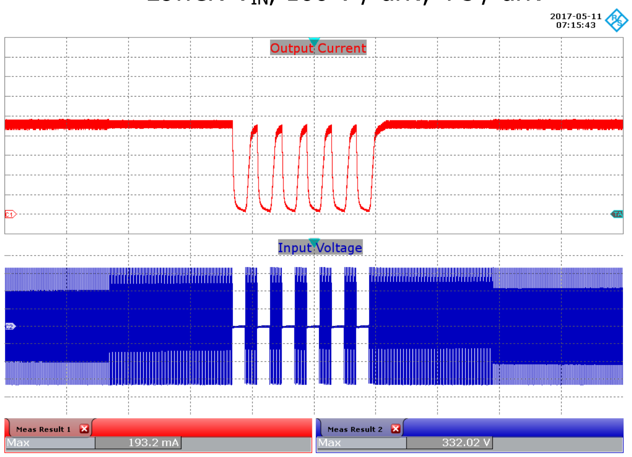

Figure 63 – 230 VAC, 42 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

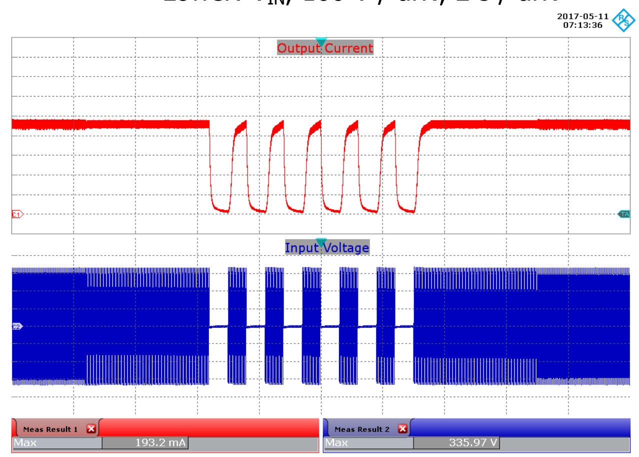

Figure 64 – 230 VAC, 42 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 100 V / div., 1 s / div.

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14 Conducted EMI

14.1 *Test Set-up*

14.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. 42 V LED load with input voltage set at 230 VAC.

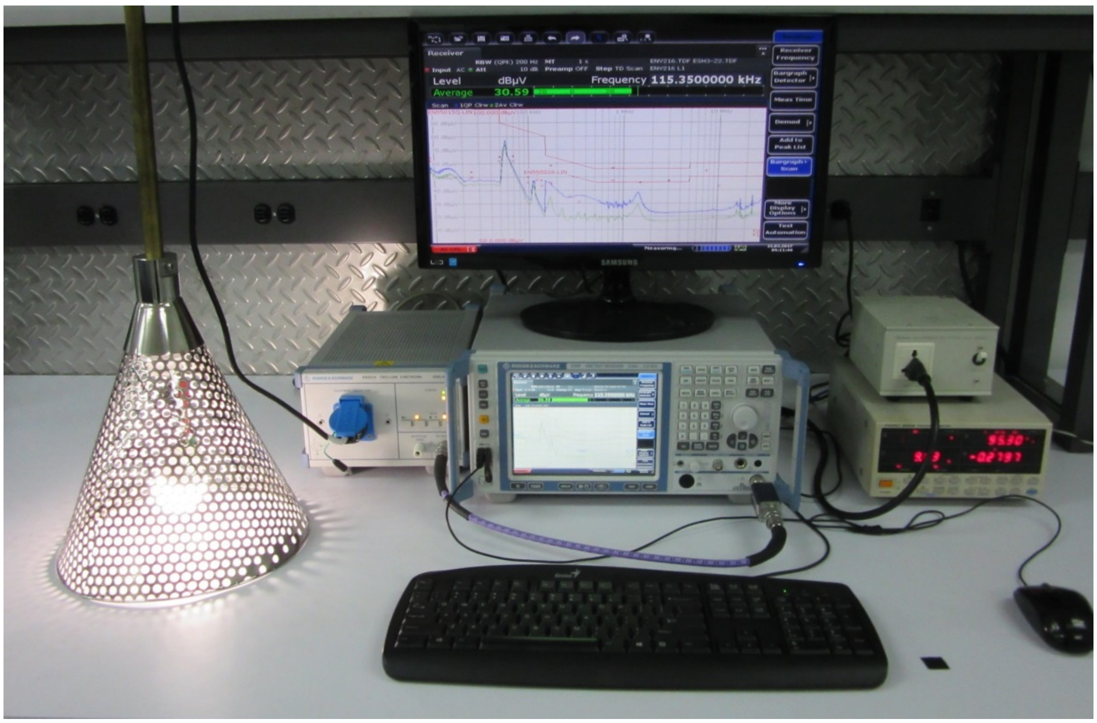
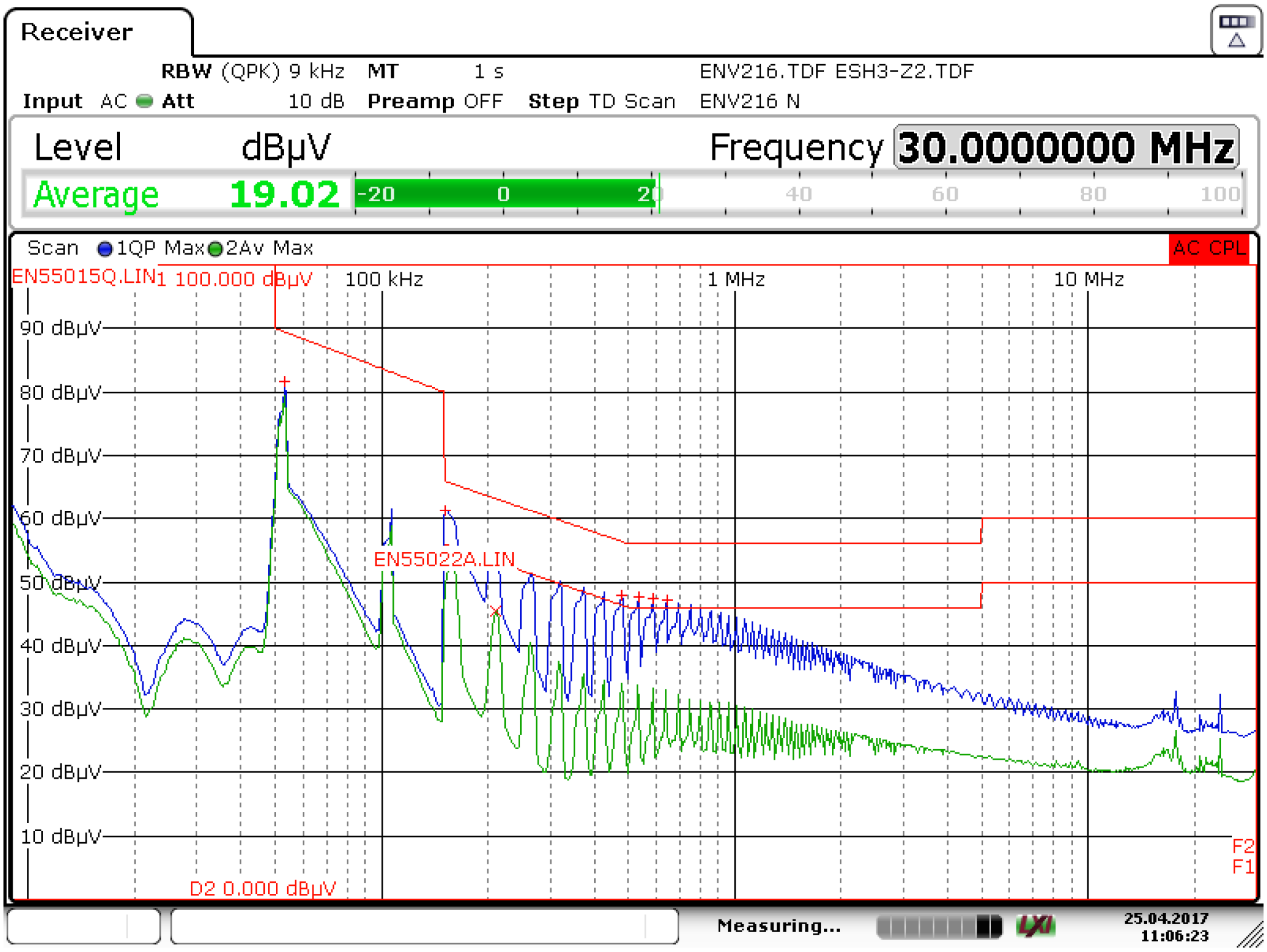


Figure 65 – Conducted EMI Test Set-up.

14.2 *EMI Test Result*



Date: 25.APR.2017 11:06:23

Figure 66 – Conducted EMI QP Scan at 42 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

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Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	159.0000 kHz	53.58 N	-1.94 dB
1 Quasi Peak	152.2500 kHz	61.27 N	-4.61 dB
1 Quasi Peak	53.3000 kHz	81.75 N	-7.67 dB
2 Average	210.7500 kHz	45.43 N	-7.75 dB
1 Quasi Peak	534.7500 kHz	47.72 N	-8.28 dB
1 Quasi Peak	480.7500 kHz	47.93 N	-8.40 dB
1 Quasi Peak	588.7500 kHz	47.51 N	-8.49 dB
1 Quasi Peak	642.7500 kHz	47.15 N	-8.85 dB

Insert Frequency Delete Frequency Sort by Frequency

Symbols OFF ON Peak List Export Decim Sep . ,

Figure 67 – Conducted EMI Data at 230 VAC, 42 V LED Load.

15 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±500 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)
+500 V	230	L to N	0	Pass
-500 V	230	L to N	0	Pass
+500 V	230	L to N	90	Pass
-500 V	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

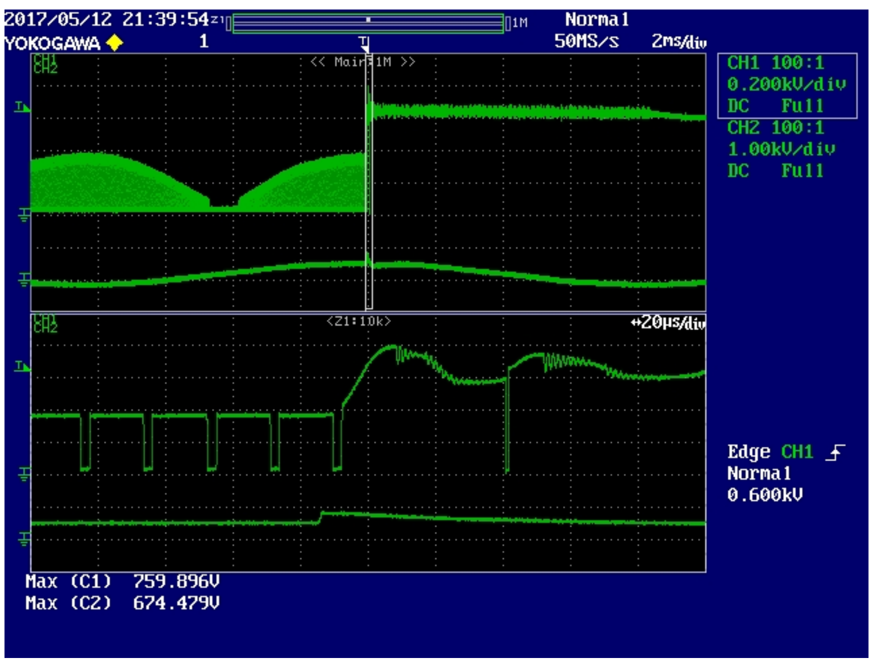

Figure 68 – +500 V Differential Surge at Worst Case Input (230 VAC), 90º Phase Angle.
V_{DRAIN}, 200 V / div., 2 ms / div.
Peak V_{DRAIN}: 759.90 V

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16 Brown-in / Brown-out Test

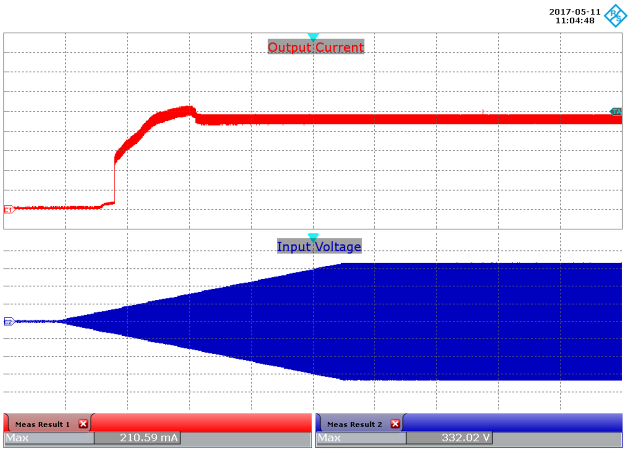

Figure 69 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 40 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

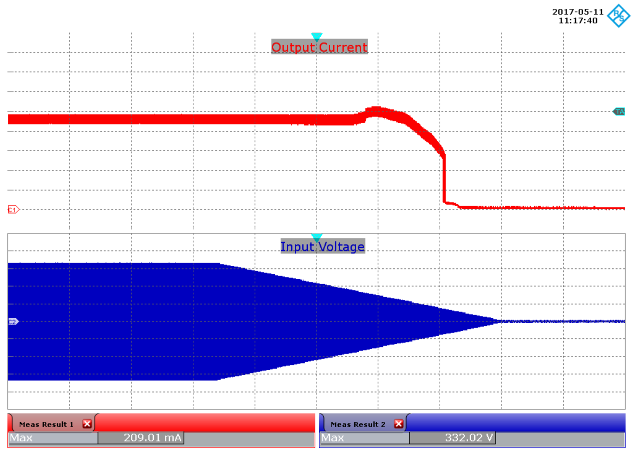

Figure 70 – Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 40 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
12-Jul-17	CA	1.0	Initial release	Apps & Mktg

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