Title	***Reference Design Report for 8 W Non-Dimmable, High Efficiency (>90%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1603D***
Specification	90 VAC – 300 VAC Input; 60 V_{TYP}, 135 mA_{TYP} Output
Application	A19 Bulb
Author	Applications Engineering Department
Document Number	RDR-464
Date	October 28, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9 at 115 VAC / 230 VAC
- Accurate constant current regulation, ±5%
- Meets <30% flicker requirement
- Highly energy efficient, >90% at 115 VAC / 230 VAC
- 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
  - Over temperature protection
  - No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 500 V differential surge
- Meets EN55015 conducted EMI

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PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <http://www.powerint.com/ip.htm>.

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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 low cost, non-isolated non-dimmable buck LED driver designed to drive a 60 V LED voltage string at 135 mA output current from an input voltage range of 90 VAC to 300 VAC. The LED driver utilizes the LYT1603D from the LYTSwitch-1 family of devices. The key design goals were high efficiency, accurate constant current regulation, high power factor low THD and low components count.

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

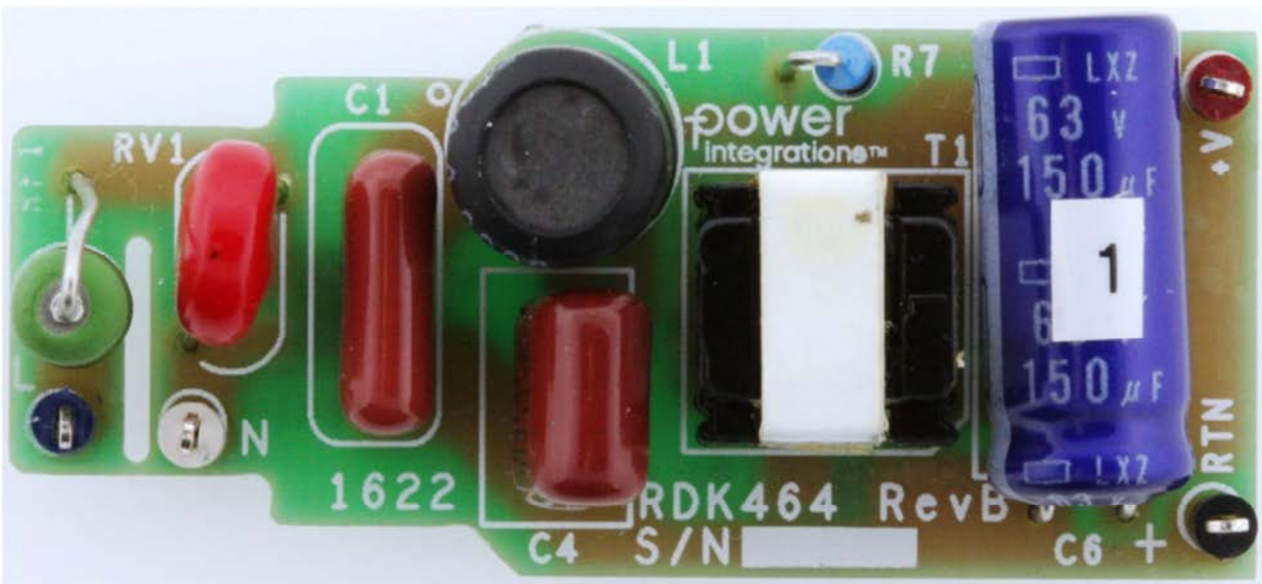

Figure 1 – Populated Circuit Board, Top View.

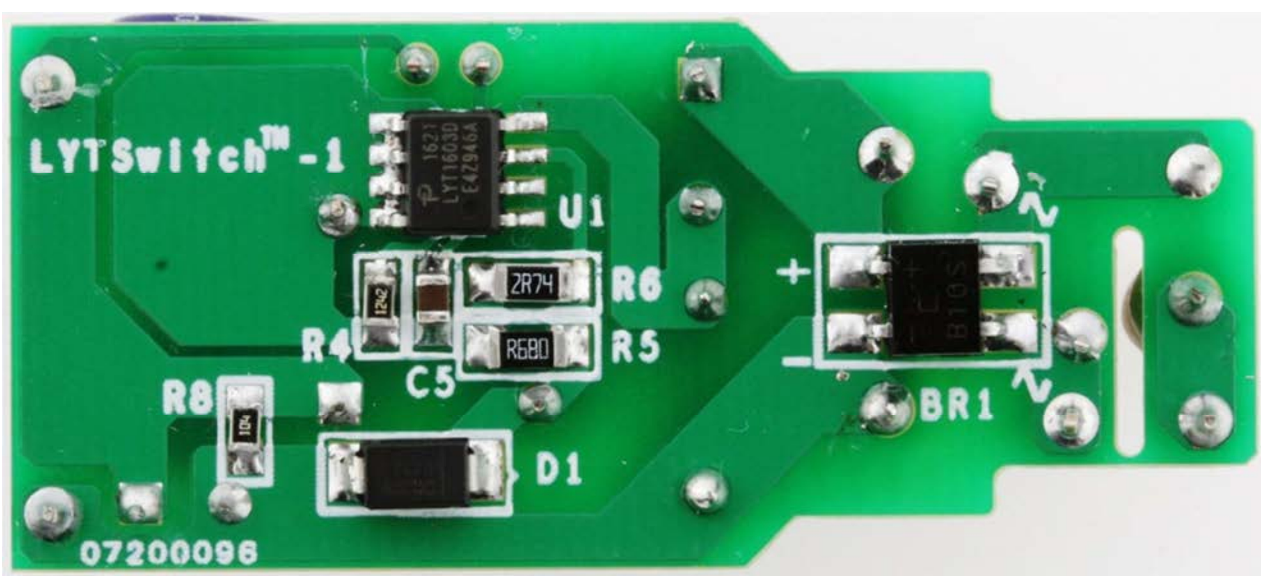

Figure 2 – Populated Circuit Board, Bottom View.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115/230	300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}		60		V	
Output Current	I_{OUT}		135		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		8		W	
Efficiency						
Full Load	η		90		%	115 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)			500		V	
Power Factor			0.9			Measured at 115 / 230 VAC, 50 / 60 Hz.
Ambient Temperature	T_{AMB}			75	ºC	Free Convection, Sea Level.

3 Schematic

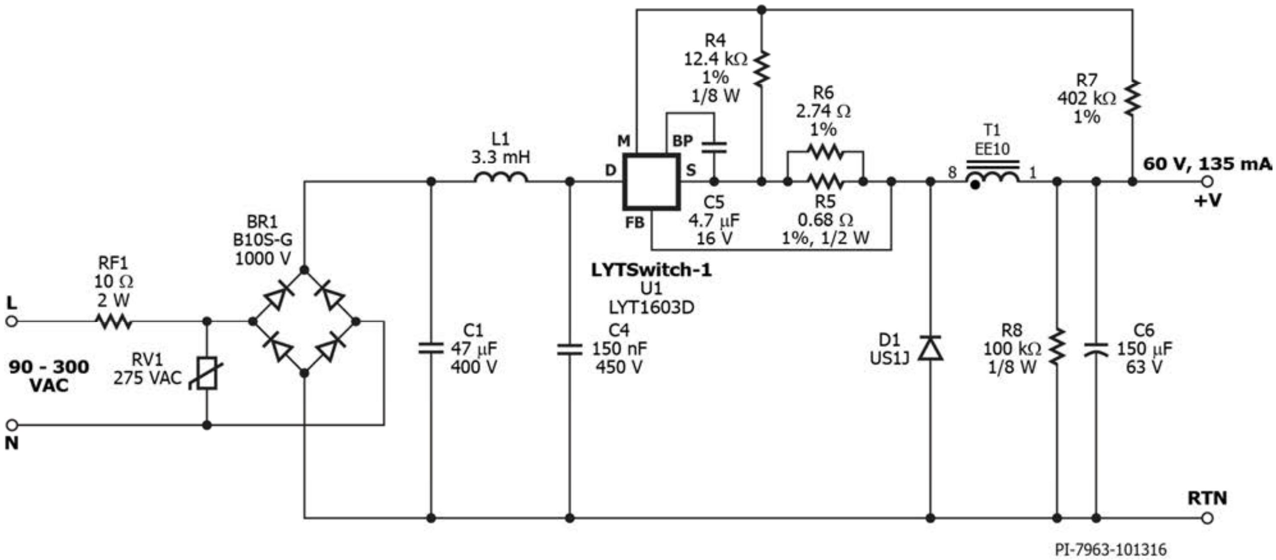

Figure 3 – Schematic.

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4 Circuit Description

The LYTSwitch-1 device (U1-LYT1603D) combines a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. The LYT1603D device is configured to drive a 60 V output buck LED driver with 135 mA constant current output. The LYT1603D device was selected based on the power table based on maximum output power (8 W for low line). The LYT1603D IC was also chosen to achieve low THD and high PF while maintaining good regulation.

4.1 *Input Stage*

The input fusible resistor RF1 serves as a safety protection from input component failures. Varistor RV1 (275 V rated) acts as a voltage clamp which limits the voltage spikes on the primary during line transient surge events. The full wave bridge rectifier BR1 provides good power factor and low total harmonic distortion.

4.2 *EMI Filter*

After the rectified AC input voltage an EMI π filter circuit is cascaded. The circuit is composed of a differential choke inductor L1 and input filter capacitors C1 and C4. The EMI filter, together with the LYTSwitch-1 variable frequency / variable on-time and critical conduction mode control engine ensures compliance with the EN55015 Class B emission limit.

4.3 *LYTSwitch-1 Control Circuit*

The LED driver circuit topology is a low side buck where both the power MOSFET of U1 and the inductor T1 are connected to the positive rail. During on-time, the Source current flows through inductor T1 to the load, storing energy in the form of magnetic field which is then delivered to the output load via flywheel diode D1 during the power MOSFET off-time.

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

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1. This capacitor also acts as energy storage to provide power to the IC during the switch on-time. The IC internal regulator draws power from high-voltage SOURCE (S) pin and charges the bypass capacitor C5 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 $T_{ON(MAX)}$ conditions.

A constant ratio of 0.75 between the constant peak current period and the buck dead zone period is maintained to achieve constant current regulation. The FEEDBACK (FB) pin directly senses the Source or inductor current during the power MOSFET on-time using external current sense resistors R5 and R6. This feedback voltage is used by the

LYTSwitch-1 IC to set the constant inductor peak current (I_{PK}) by comparing the sensed voltage to the reference current limit threshold ($V_{FBth} \geq 0.28V$, $I_{PK} = 0.28\ V / R_{SENSE}$). Output LED current is computed as $I_{LED} = I_{PK} / 4.666$ for LYT1603D device.

During the power MOSFET on-time, the MULTIFUNCTION (M) pin provides line OVP detection. The M pin is shorted internally to S pin to detect line OVP by sampling the voltage across the inductor (V_{IN}-V_{OUT}) and the current flowing out of the M pin. This current is defined by resistor R4 ($I_M = (V_{IN}-V_{OUT})/R4$). The M pin line OVP current threshold is $I_{MOVL} = 1\ mA_{\ TYP}$.

During the power MOSFET off-state, the M pin provides zero current detection and output OVP detection through sampling resistors R4 and R7. The ZCD is to guarantee critical conduction mode operation which means that the power MOSFET must be turned on immediately as soon as the inductor has been demagnetized. The inductor demagnetization is sensed when the voltage across the inductor begins to collapse towards zero as flywheel diode D1 conduction expires. The ZCD threshold is when M pin voltage is V_M <0.25 V (negative edge triggered). The OVP detection is achieved through R4 and R7 voltage divider network. The OVP threshold is set at 120% of steady state value (2.0 V). Resistor R7 is set to fixed value of 402 kΩ ±1% to minimize power loss during power MOSFET on-duration and ease of OVL detection for all output voltage designs.

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

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5 PCB Layout

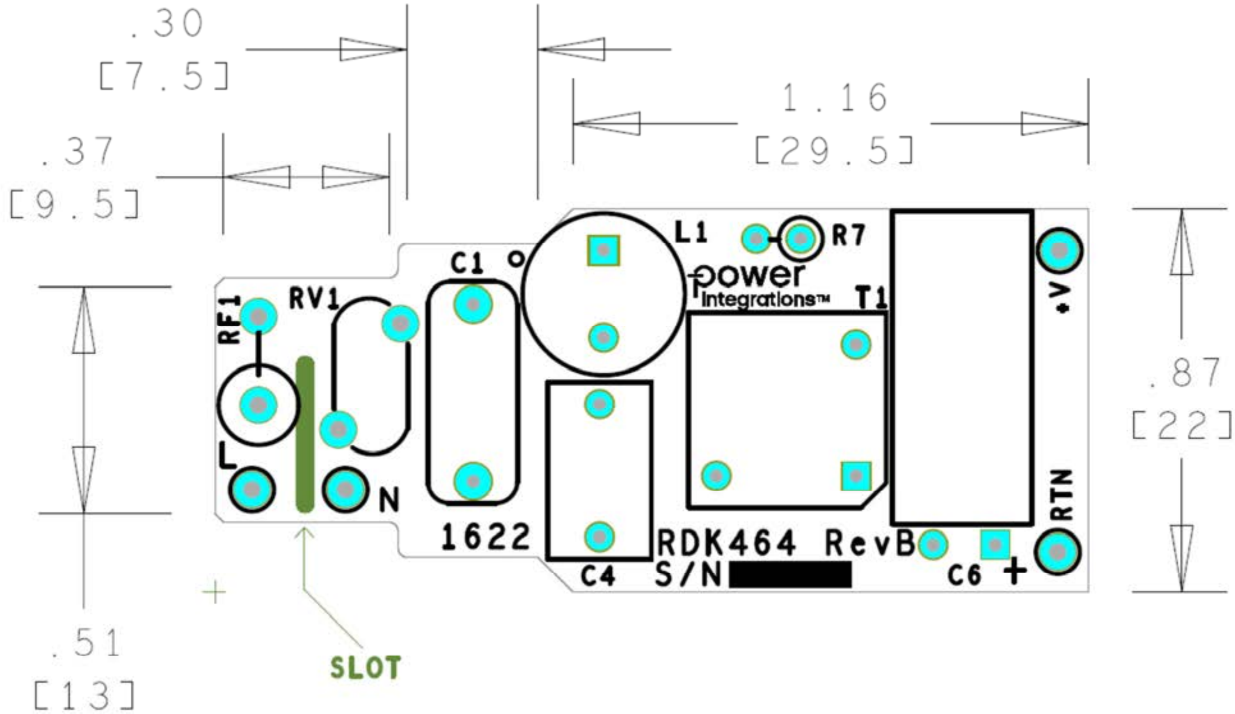

Figure 4 – Top Side.

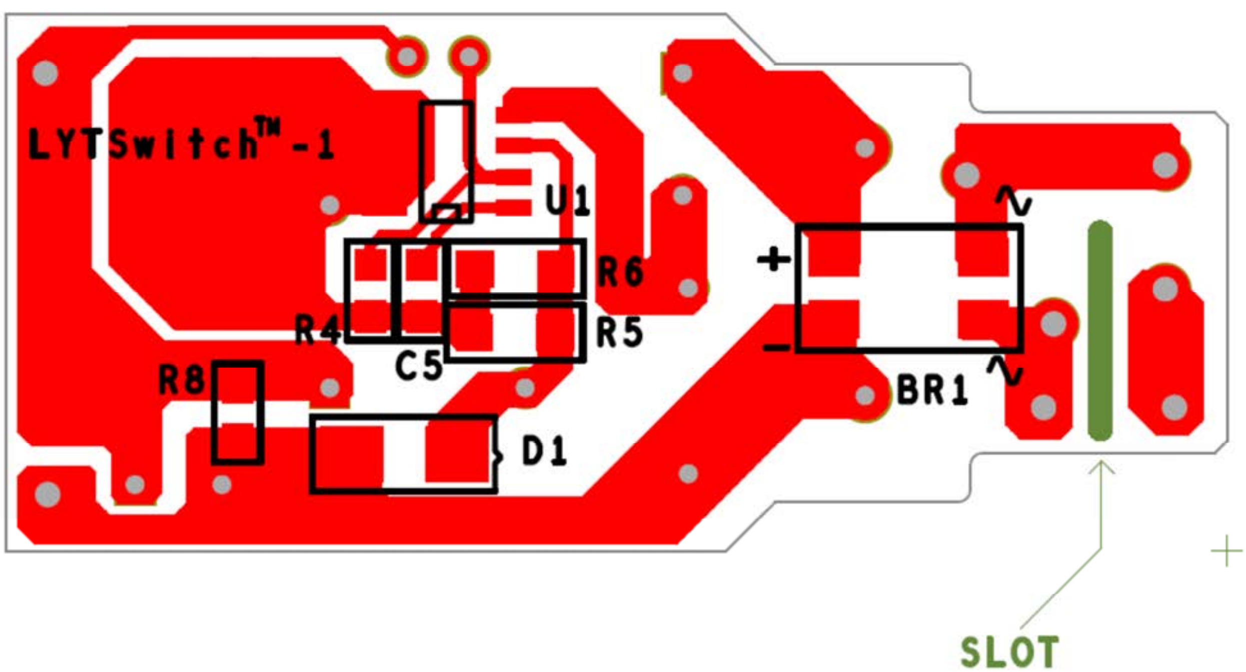

Figure 5 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	+V	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
2	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
3	1	C1	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
4	1	C4	150 nF, 450 V, 10%, Polypropylene Metalized	C222S154K30	Faratronic
5	1	C5	4.7 μF, 16 V, Ceramic, X7R, 0805	GRM21BR71C475KA73L	Murata
6	1	C6	150 μF, 63 V, Electrolytic, Low ESR, 210 mΩ, (8 x 20)	ELXZ630ELL151MH20D	Nippon Chemi-Con
7	1	D1	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
8	1	L	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
9	1	L1	3.3 mH, 0.150 A, 20%	RL-5480-3-3300	Renco
10	1	N	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
11	1	R4	RES, 12.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1242V	Panasonic
12	1	R5	RES, SMD, 0.68 Ω, 1%, ½ W, 1206, ±200ppm/°C, -55°C ~ 125°C	RL1206FR-7W0R68L	Yageo
13	1	R6	RES, SMD, 2.74 Ω, 1%, ¼ W, 1206, ±100ppm/°C, -55°C ~ 155°C	CRCW12062R74FKEA	Vishay
14	1	R7	RES, 402 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-402K	Yageo
15	1	R8	RES, 100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
16	1	RF1	RES, 10 Ω, 5%, 2 W, Wire wound, Fusible	FW20A10R0JA	Bourns
17	1	RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
18	1	RV1	275 VAC, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
19	1	T1	Bobbin, EE10, Vertical, 8 pins (10.2 mm W x 10.4 mm L x 9.7 mm H)	EE-1016	Yulongxin
20	1	U1	LYTSwitch-1, Wide Range, 8W, 45 V – 65 V, SO-8	LYT1603D	Power Integrations

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7 Inductor Specification

7.1 *Electrical Diagram*

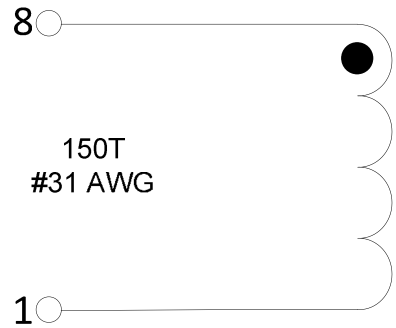

Figure 6 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 8.	1000 µH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE10.
[2]	Bobbin: EE10, Vertical, 8 pins, Part No: 25-01068-00.
[3]	Magnet Wire: #31 AWG.
[4]	Transformer Tape: 6.5 mm.
[5]	Transformer Tape: 4.0 mm.

7.4 *Inductor Build Diagram*

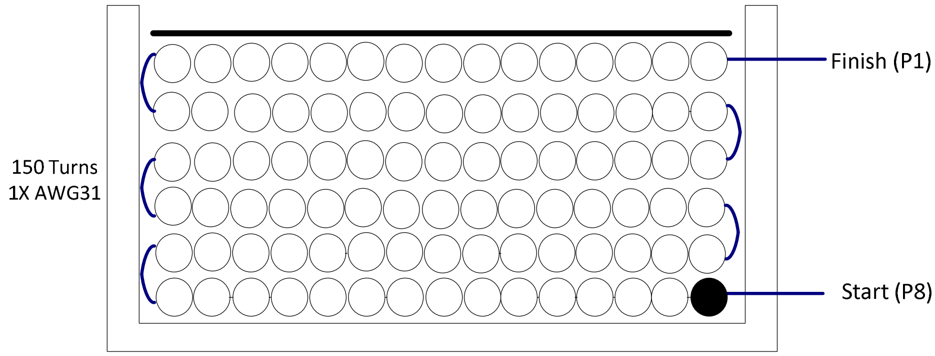

Figure 7 – Transformer Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-4 is on the left side. The winding direction is clockwise.
Winding 1	Use wire item [3], start at pin 8 and wind 150 turns in 6 layers, then finish the winding on pin 1.
Insulation	Add 1 layer of tape, item [4], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 1000 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 2 layer of tape, item [5].
Pins	Pull out terminal pin no. 2, 3, 5, 6 and 7.
Finish	Dip the transformer assembly in varnish.

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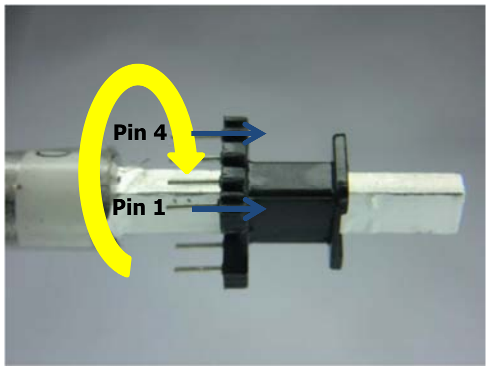
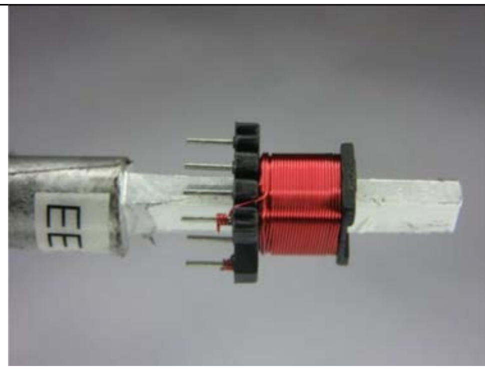
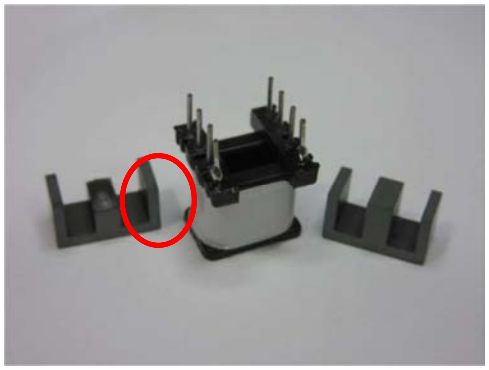
7.6 *Winding Illustrations*

Winding Directions		Bobbin is oriented on winder jig such that terminal pin 1-4 is on the left side. The winding direction is clockwise.
Winding 1		Use wire item [3], start at pin 8 and wind 150 turns in 6 layers, then finish the winding on pin 1.
Insulation		Add 1 layer of tape, item [4], for insulation.
Terminal Pins		Pull out terminal pin no. 2, 3, 5, 6 and 7.

Core Grinding		Grind the center leg of one core until it meets the nominal inductance of 1000 μH.
Core Assembly **Finish**		Assemble the 2 cores on the bobbin and wrap with 2 layer of tape, item (5). Dip the transformer assembly in varnish.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch1_Buck_051116; Rev.1.0; Copyright Power Integrations 2016	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LYTSwitch-1 Buck Design Spreadsheet**
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMIN	90		90	V	Minimum AC line voltage
VACTYP			115	V	Typical AC line voltage
VACMAX	300		300	V	Maximum AC line voltage
FL			50	Hz	AC mains frequency
VO			60	V	Output Voltage
IO	135		135	mA	Average output current specification
EFFICIENCY			0.90		Efficiency estimate
PO			8.10	W	Continuous output power
VD			0.70	V	Output diode forward voltage drop
OPTIMIZATION PARAMETER	THD		THD		BOM selects IC with lowest peak current. THD selects IC for lowest THD.
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	V	This Spreadsheet supports 725V device only
DEVICE	LYT1603D		LYT1603D		Actual LYTSwitch-1 device
ILIMITMIN			1.06	A	Minimum Current Limit
ILIMITTYP			1.15	A	Typical Current Limit
ILIMITMAX			1.24	A	Maximum Current Limit
TON			4	us	On-time during the fixed on-time region at VACTYP
FSW			78	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.90		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	EE10		EE10		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			12.10	mm^2	Core effective cross cectional area
LE			26.10	mm	Core effective path length
AL			850.00	nH/turn^2	Core ungapped effective inductance
AW			11.88	mm^2	Window Area of the bobbin
BW			6.60	mm	Bobbin physical winding width
LAYERS			6.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN			735	uH	Absolute minimum design inductance
LP_TYP	1000		1000	uH	Typical design inductance
LP_TOLERANCE	5		5	%	Tolerance of the design inductance
LP_MAX			4286	uH	Absolue maximum design inductance
TURNS	150		150	Turns	Number of inductor turns
ALG			44.44	nH/turn^2	Inductance per turns squared
BMAX			3374	Gauss	Actual saturation flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.324	mm	Core air gap

BWE			39.60	mm	Effective bobbin width
OD			0.26	mm	Outer diameter of the wire with insulation
INS			0.05	mm	Wire insulation
DIA			0.21	mm	Outer diameter of the wire without insulation
AWG			32		AWG of the bare wire.
CM			64	Cmils	Bare wire circular mils
CMA			361	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			3.2	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR			88.00%		Area of the bobbin occupied by wire
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.12	A	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.49	A	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.11	A	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.14	A	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.18	A	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.576	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.576	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Components					
BUCK_CONFIG	High Side Buck				Buck Topology Switch Configuration
RUPPER			402.00	kOhms	Upper resistor on the M-pin divider network (E96 / 1%)
RLOWER			13.70	kOhms	Lower resistor on the M-pin divider network (E96 /1%)
VO_OVP			72.1	V	VO overvoltage threshold
Line_OVP			462	V	Line overvoltage threshold
CC			NA	pF	Coupling Capacitor for Low Side Buck Configuration
RPRELOAD			60	kOhms	Minimum Output Preload Resistor
CBP			4.7	uF	BP Capacitor
VOLTAGE STRESS PARAMETERS					
VDRAIN			424	V	Estimated worst case drain voltage
PIVD			424	V	Output Rectifier Maximum Peak Inverse Voltage

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9 Performance Data

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

9.1 *Efficiency*

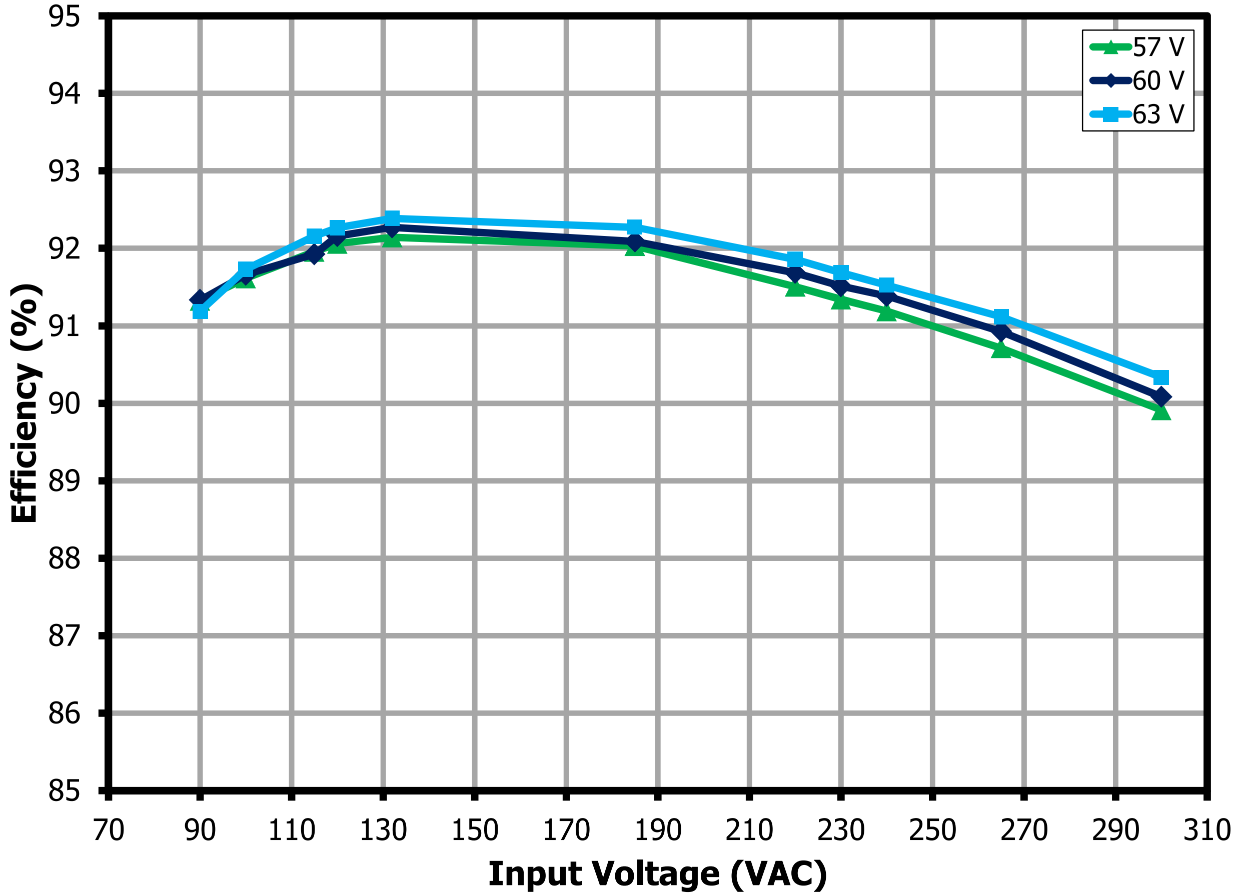

Figure 8 – Efficiency vs. Line and LED Load.

9.2 *Line Regulation*

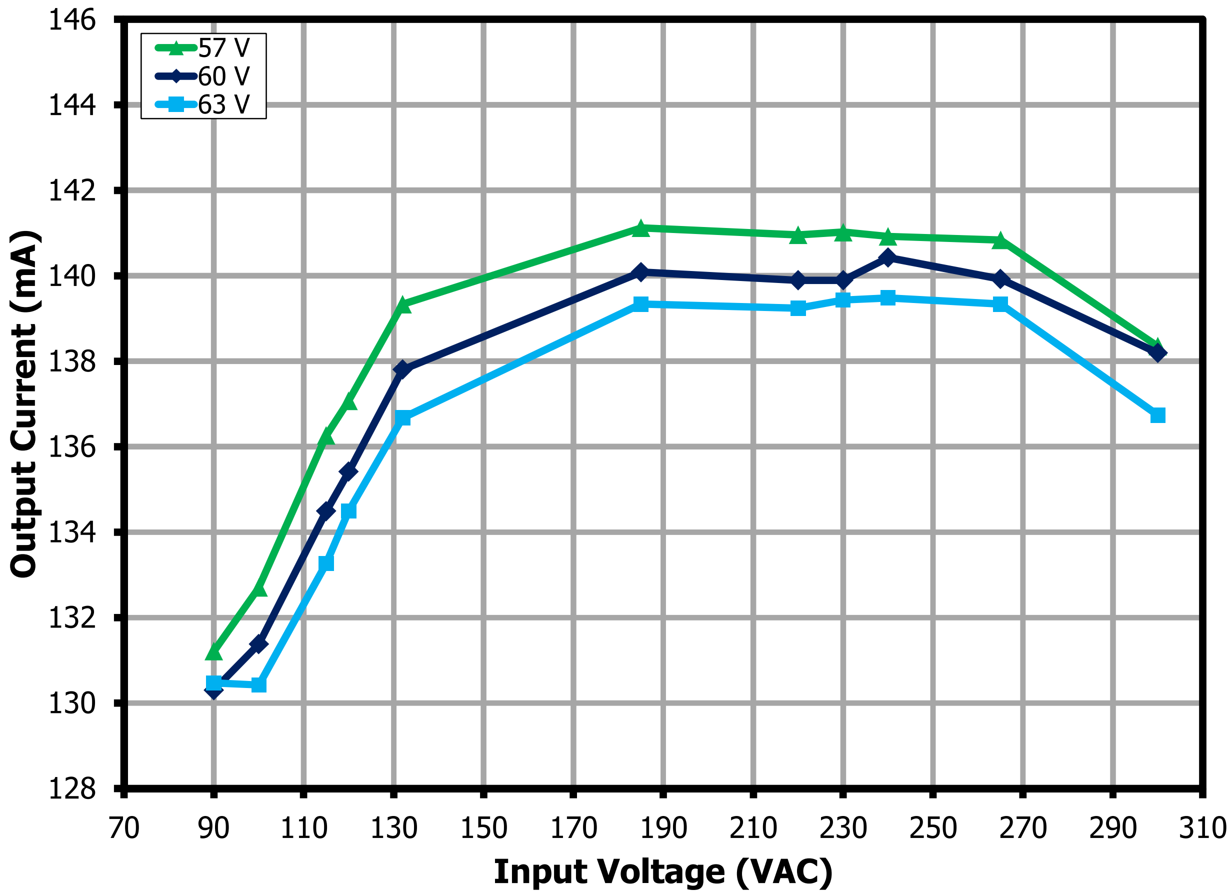

Figure 9 – Regulation vs. Line and LED Load.

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9.3 *Power Factor*

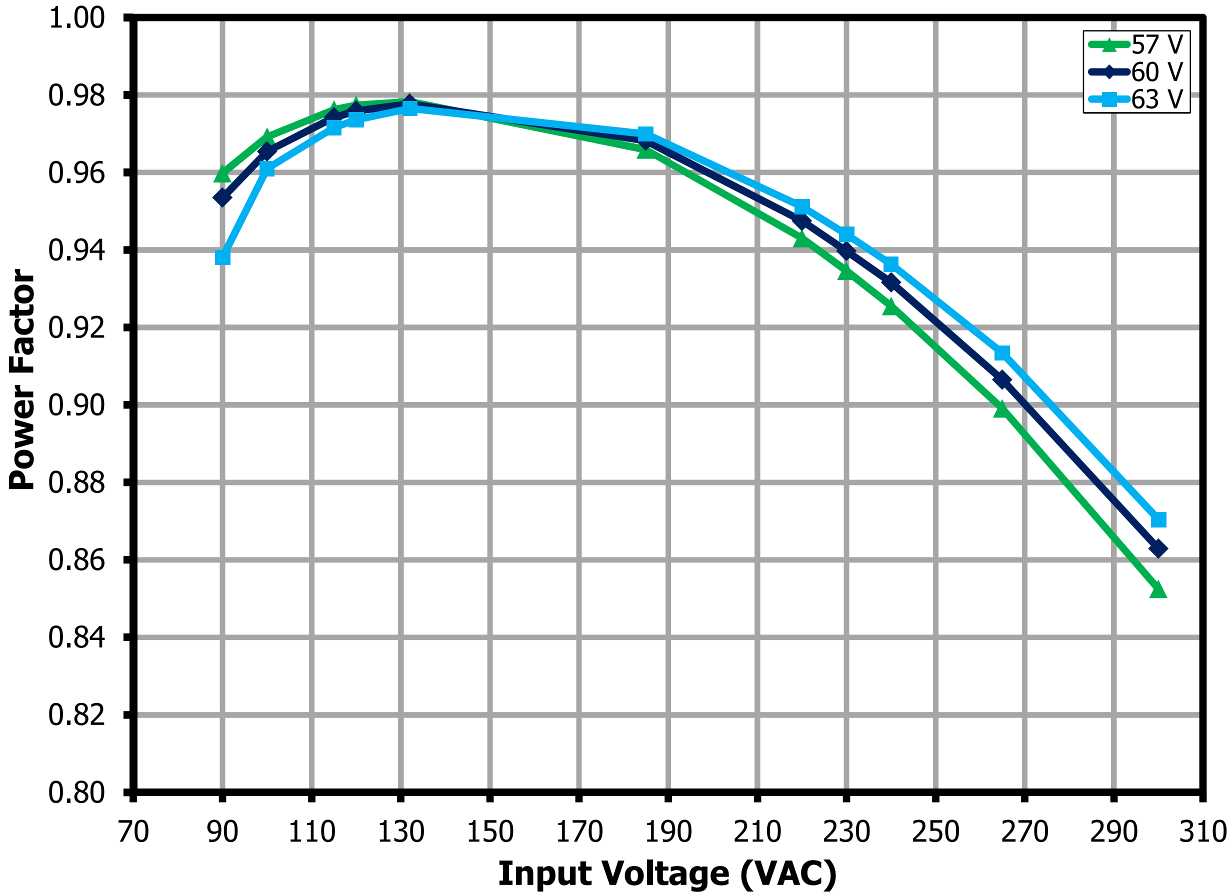

Figure 10 – Power Factor vs. Line and LED Load.

9.4 *%ATHD*

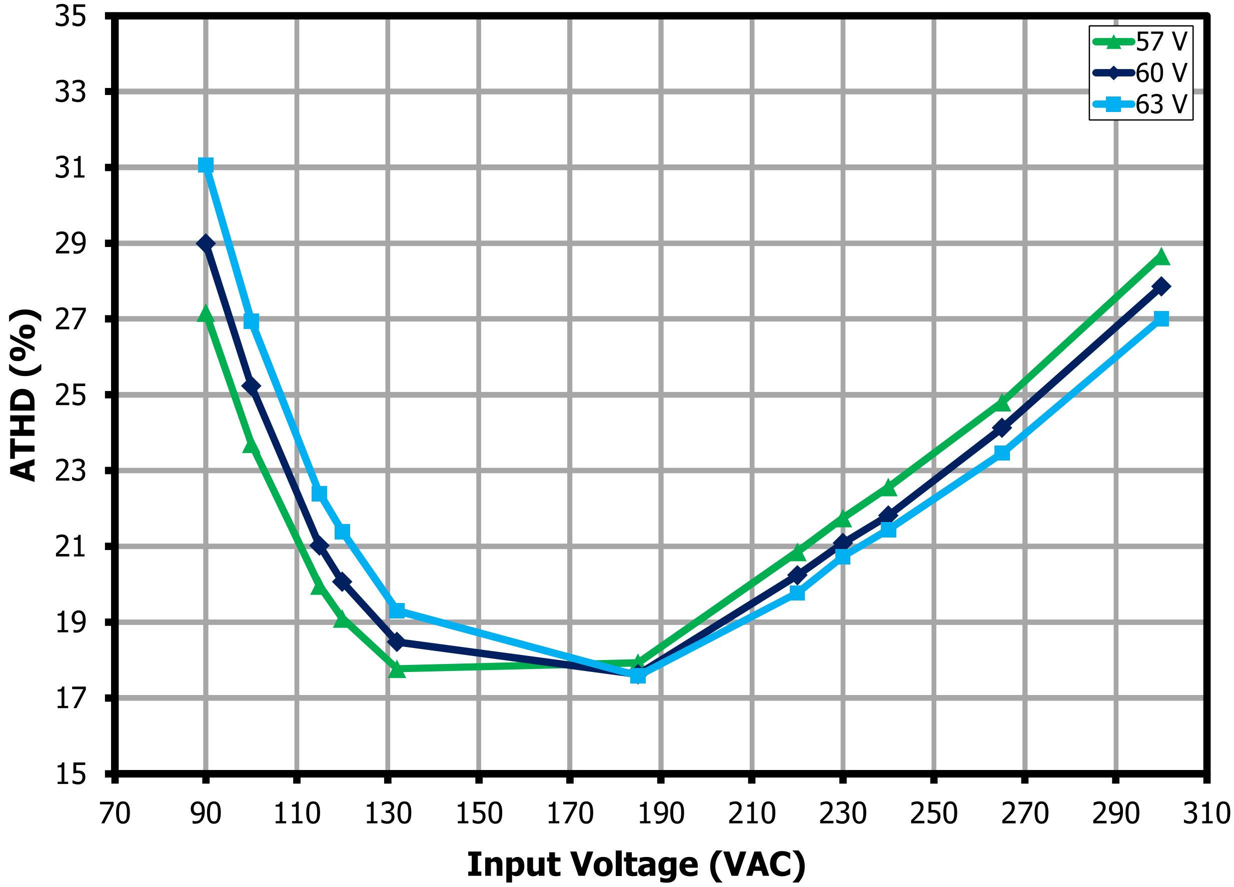

Figure 11 – %ATHD vs. Line and LED Load.

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9.5 *Individual Harmonics Content*

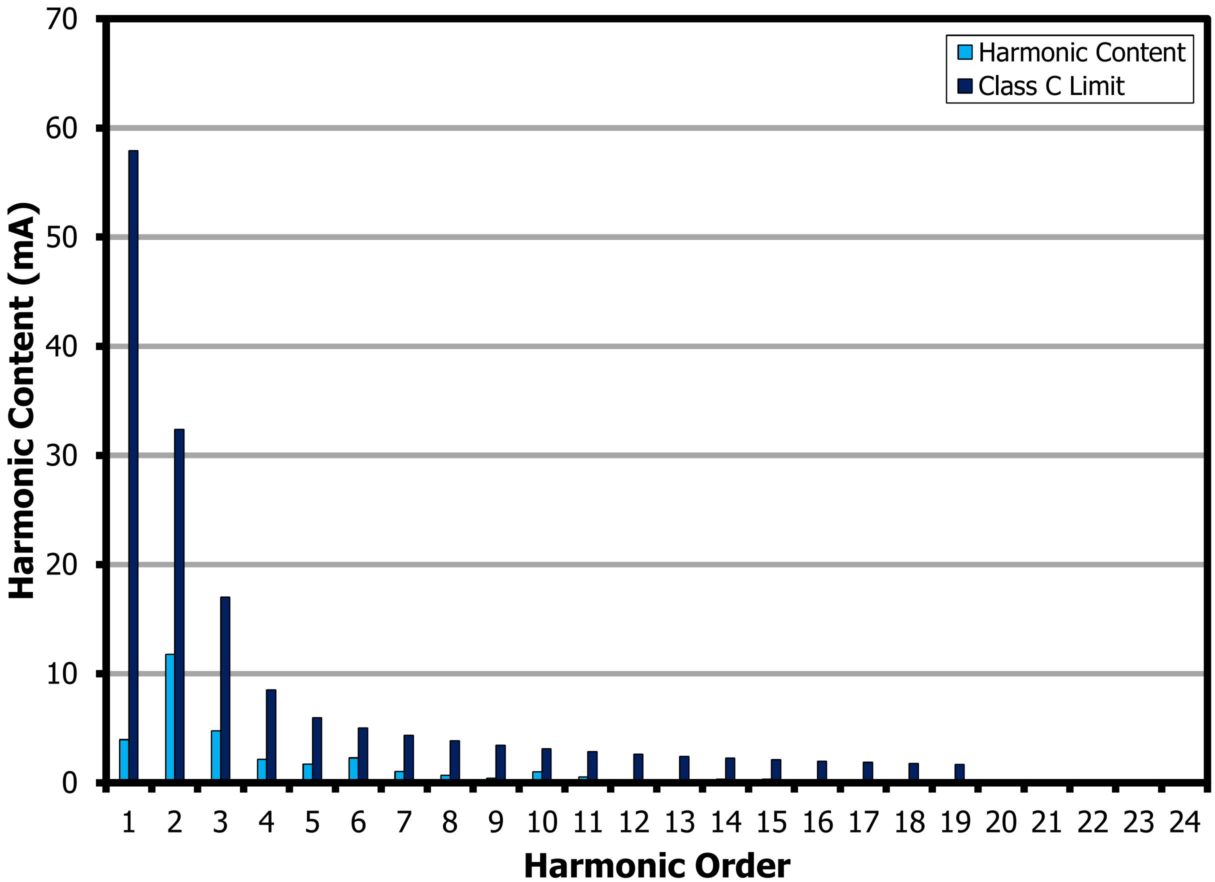

Figure 12 – 60 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

10 Test Data

10.1 *Test Data, 57 V LED Load*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.98	95.85	8.28	0.960	27.17	57.50	131.21	7.56	91.33
100	60	99.97	85.92	8.32	0.969	23.7	57.36	132.70	7.63	91.61
110	60	114.95	75.92	8.52	0.976	19.96	57.39	136.26	7.83	91.96
115	60	119.95	72.95	8.55	0.977	19.10	57.35	137.07	7.87	92.06
120	60	132.00	67.31	8.69	0.978	17.77	57.38	139.33	8.01	92.14
132	60	89.98	95.85	8.28	0.960	27.17	57.50	131.21	7.56	91.33
185	50	184.99	49.37	8.82	0.966	17.93	57.41	141.12	8.12	92.03
220	50	220.00	42.68	8.85	0.943	20.85	57.37	140.96	8.10	91.51
230	50	230.01	41.26	8.87	0.935	21.75	57.35	141.02	8.10	91.34
240	50	240.03	39.95	8.87	0.926	22.56	57.32	140.92	8.09	91.19
265	50	265.04	37.40	8.91	0.899	24.80	57.31	140.84	8.09	90.71
300	50	300.06	34.45	8.81	0.853	28.66	57.18	138.35	7.92	89.91

10.2 *Test Data, 60 V LED Load*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.95	100.22	8.60	0.954	28.99	60.14	130.30	7.85	91.33
100	60	99.96	89.47	8.63	0.965	25.24	60.13	131.38	7.91	91.66
115	60	114.94	78.83	8.83	0.974	21.02	60.23	134.49	8.11	91.92
120	60	119.93	75.73	8.86	0.976	20.06	60.23	135.41	8.17	92.16
132	60	132.01	69.89	9.02	0.978	18.47	60.31	137.80	8.32	92.27
185	50	184.99	51.37	9.20	0.968	17.62	60.38	140.08	8.47	92.09
220	50	219.99	44.24	9.22	0.948	20.24	60.34	139.89	8.46	91.68
230	50	230.01	42.72	9.24	0.940	21.08	60.32	139.89	8.45	91.51
240	50	240.03	41.52	9.28	0.932	21.81	60.32	140.42	8.48	91.38
265	50	265.04	38.67	9.29	0.907	24.13	60.29	139.92	8.45	90.93
300	50	300.06	35.71	9.25	0.863	27.86	60.19	138.19	8.33	90.08

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10.3 *Test Data, 63 V LED Load*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.98	107.38	9.06	0.938	31.06	63.23	130.47	8.27	91.18
100	60	99.99	93.49	8.98	0.961	26.94	63.09	130.42	8.24	91.73
115	60	114.98	81.84	9.14	0.972	22.39	63.14	133.26	8.43	92.16
120	60	119.95	78.94	9.22	0.974	21.38	63.14	134.49	8.51	92.27
132	60	132.00	72.65	9.36	0.977	19.30	63.21	136.67	8.65	92.39
185	50	184.99	53.37	9.58	0.970	17.58	63.31	139.34	8.84	92.27
220	50	219.98	45.91	9.61	0.951	19.77	63.27	139.24	8.82	91.86
230	50	230.01	44.36	9.63	0.944	20.73	63.25	139.43	8.83	91.68
240	50	240.02	42.95	9.65	0.936	21.44	63.24	139.48	8.83	91.52
265	50	265.04	39.99	9.68	0.913	23.46	63.22	139.34	8.82	91.12
300	50	300.06	36.60	9.56	0.870	27.01	63.08	136.74	8.64	90.34

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10.4 *Test Data, Harmonic Content at 115 VAC with 60 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
115	60.00	78.83	8.8270	0.9742
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	73.96			
2	0.09	0.12%		
3	5.23	7.07%	60.0236	Pass
5	12.87	17.40%	33.5426	Pass
7	4.46	6.03%	17.6540	Pass
9	1.47	1.99%	8.8270	Pass
11	2.12	2.87%	6.1789	Pass
13	2.48	3.35%	5.2283	Pass
15	0.77	1.04%	4.5312	Pass
17	0.37	0.50%	3.9981	Pass
19	0.78	1.05%	3.5773	Pass
21	1.10	1.49%	3.2366	Pass
23	0.27	0.37%	2.9551	Pass
25	0.10	0.14%	2.7187	Pass
27	0.27	0.37%	2.5173	Pass
29	0.47	0.64%	2.3437	Pass
31	0.28	0.38%	2.1925	Pass
33	0.03	0.04%	2.0596	Pass
35	0.28	0.38%	1.9419	Pass
37	0.20	0.27%	1.8370	Pass
39	0.26	0.35%	1.7428	Pass

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10.5 *Test Data, Harmonic Content at 230 VAC with 60 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	%THD
230	50.00	41.52	9.2840	0.9316
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**Remarks**
1	40.24			
2	0.09	0.22%		
3	6.56	16.30%	31.5656	Pass
5	3.32	8.25%	17.6396	Pass
7	3.07	7.63%	9.2840	Pass
9	2.82	7.01%	4.6420	Pass
11	1.89	4.70%	3.2494	Pass
13	1.48	3.68%	2.7495	Pass
15	0.98	2.44%	2.3829	Pass
17	0.53	1.32%	2.1026	Pass
19	0.65	1.62%	1.8812	Pass
21	0.62	1.54%	1.7021	Pass
23	0.55	1.37%	1.5541	Pass
25	0.51	1.27%	1.4297	Pass
27	0.39	0.97%	1.3238	Pass
29	0.21	0.52%	1.2325	Pass
31	0.15	0.37%	1.1530	Pass
33	0.20	0.50%	1.0831	Pass
35	0.32	0.80%	1.0212	Pass
37	0.38	0.94%	0.9660	Pass
39	0.33	0.82%	0.9165	Pass

11 Thermal Performance

11.1 Thermal Performance Scan – Open Frame Unit

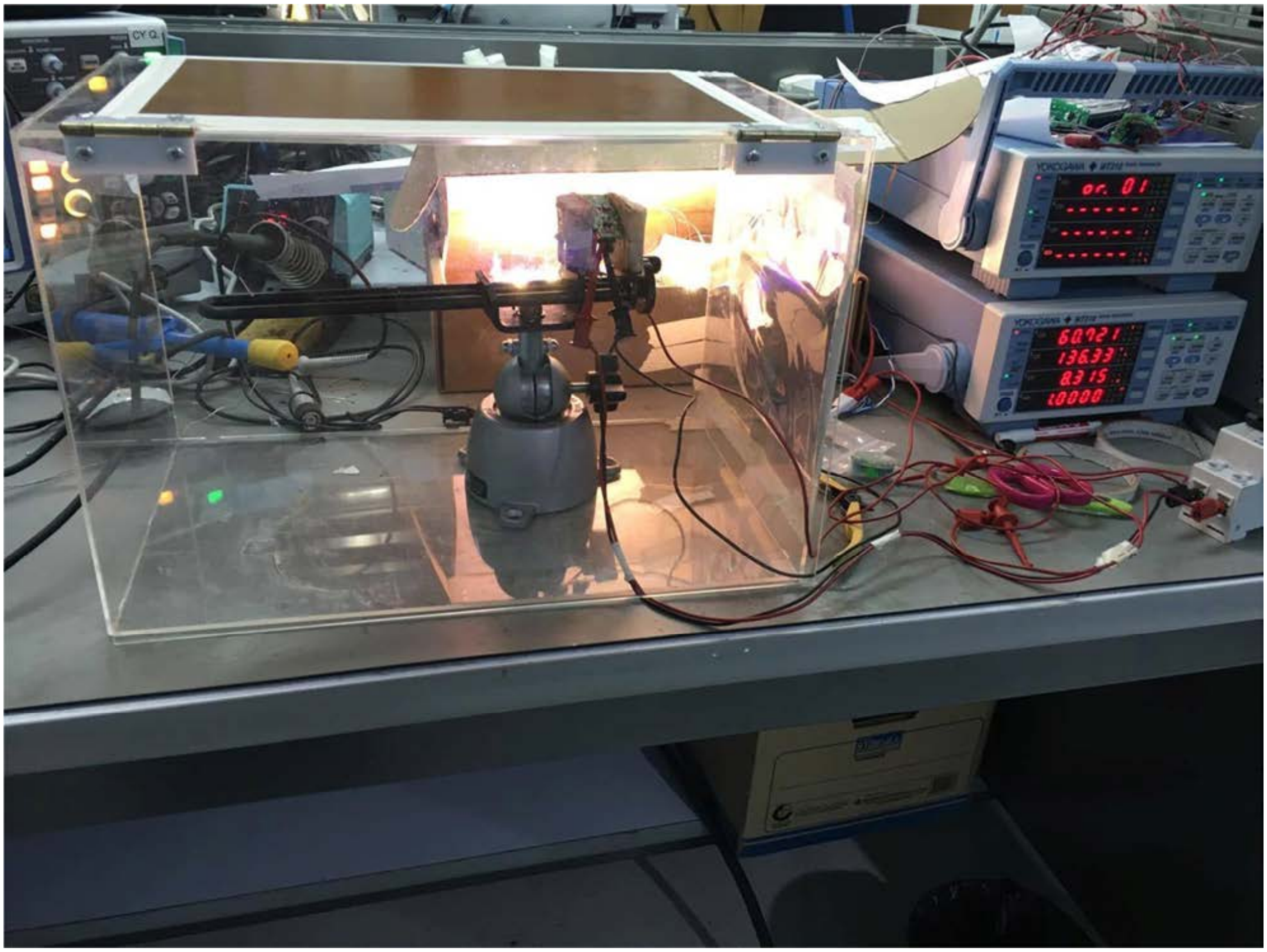

Figure 13 – Test Set-up Picture - Open Frame.

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

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11.1.1 Thermal Scan at Normal Operation 115 V, 60 LED Load

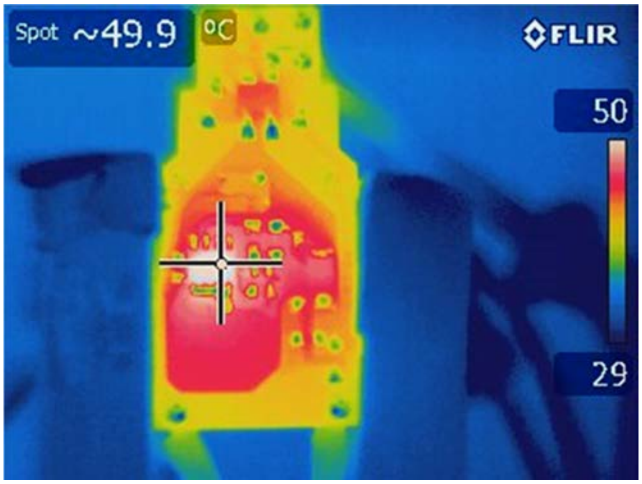

Figure 14 – 115 VAC, 60 V LED Load.
Spot 1: LYT1603D (U1): 49.9 ºC.

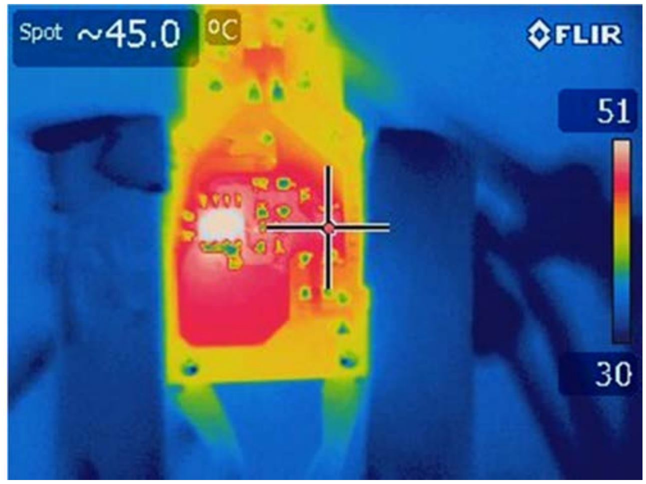

Figure 15 – 115 VAC, 60 V LED LOA Load.
Spot 1: Flywheel Diode (D1): 45 ºC.

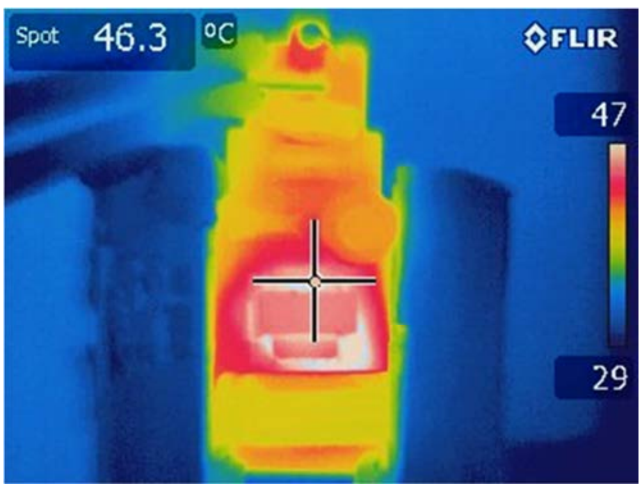

Figure 16 – 115 VAC, 60 V LED Load.
Spot 1: Inductor (T1): 46.3 ºC.

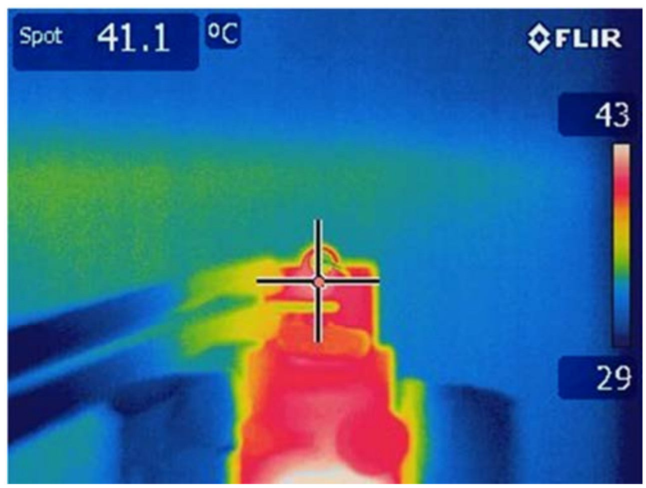

Figure 17 – 115 VAC, 60 V LED Load.
Spot 1: Fusible Resistor (RF1): 41.1 ºC.

11.1.2 Thermal Scan During Output Short-Circuit at 115 VAC Input

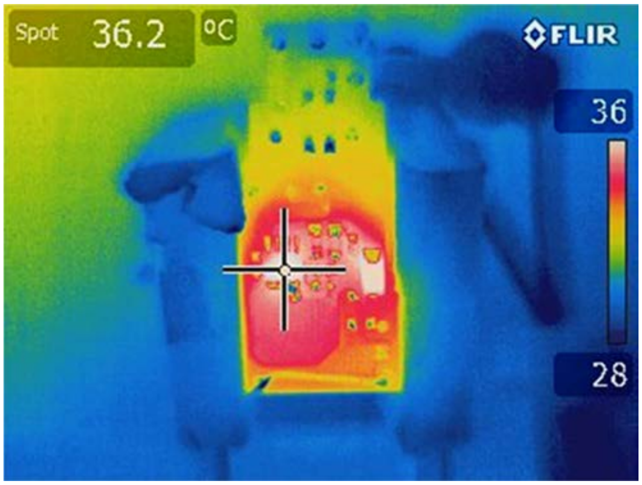

Figure 18 – 115 VAC, Output Shorted.
Spot 1: LYT1603D (U1):36.2 ºC.

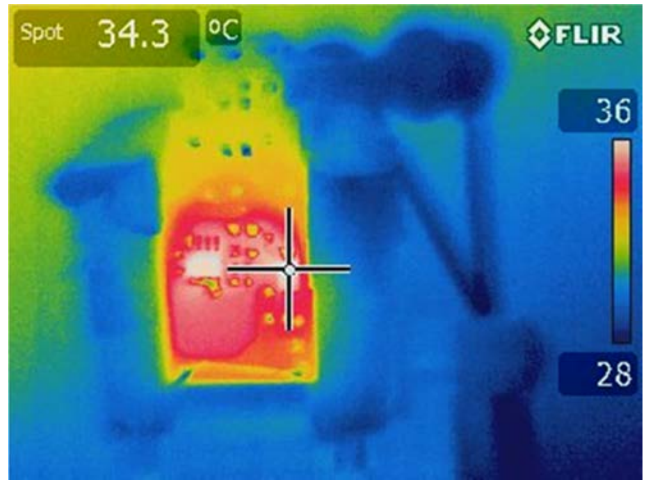

Figure 19 – 115 VAC, Output Shorted.
Spot 1: Flywheel Diode (D1): 34.3 ºC.

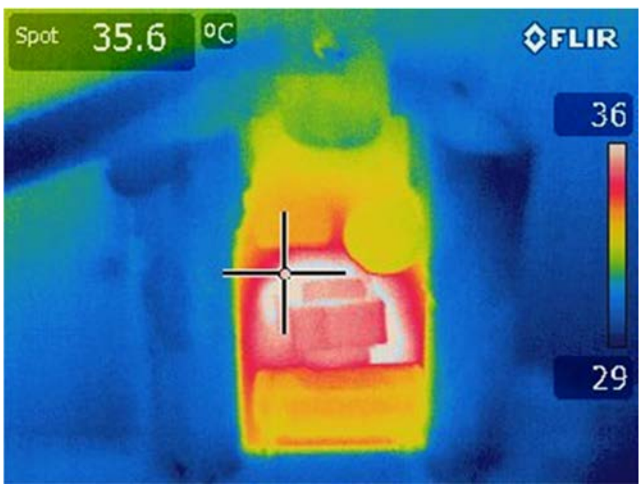

Figure 20 – 115 VAC, Output Shorted.
Spot 1: Inductor (T1): 35.6 ºC.

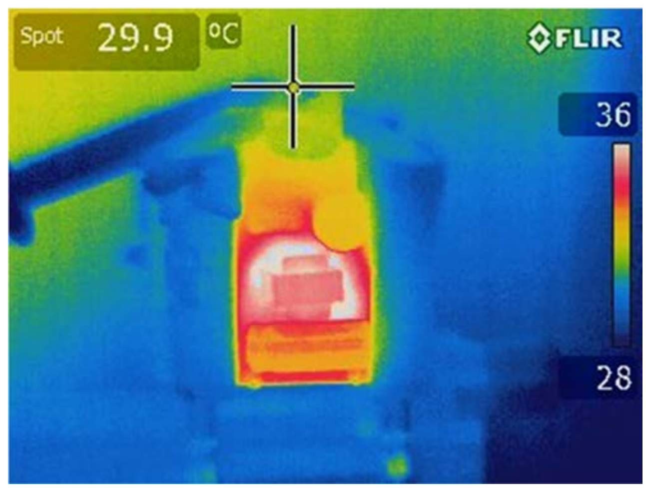

Figure 21 – 115 VAC, 60V Output Shorted.
Spot 1: Fusible Resistor (RF1): 29.9 ºC.

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11.2 *Thermal Performance at 75 ºC Ambient*

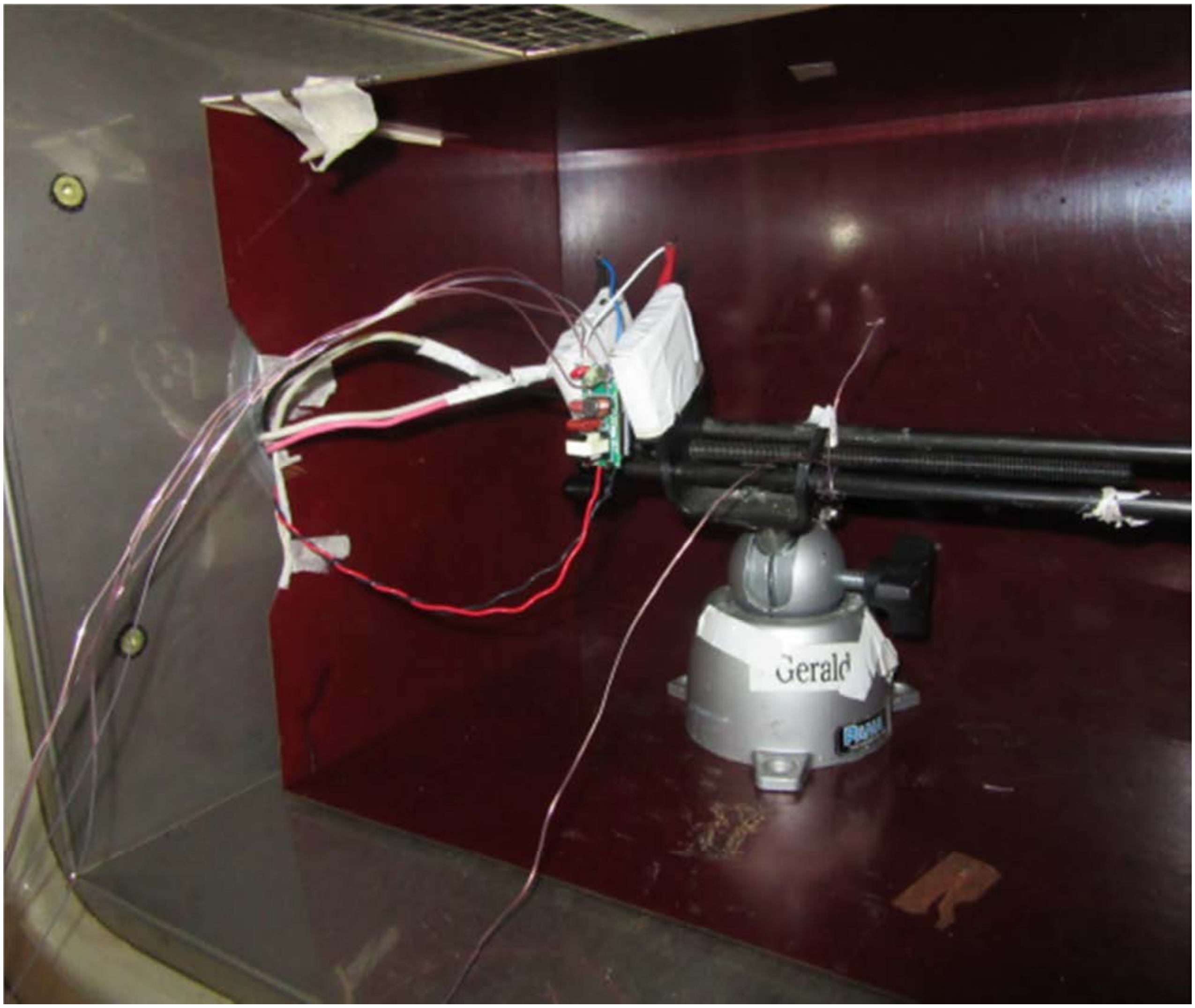

Figure 22 – Test Set-up Picture Thermal at 75 ºC Ambient- Open Frame

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

11.2.1 Thermal Performance at 90 VAC with a 60 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	C6
Maximum (ºC)	74.9	86.9	81.6	79.7	81.3	75.1
Final (ºC)	74.8	86.8	81.5	79.5	81.3	75

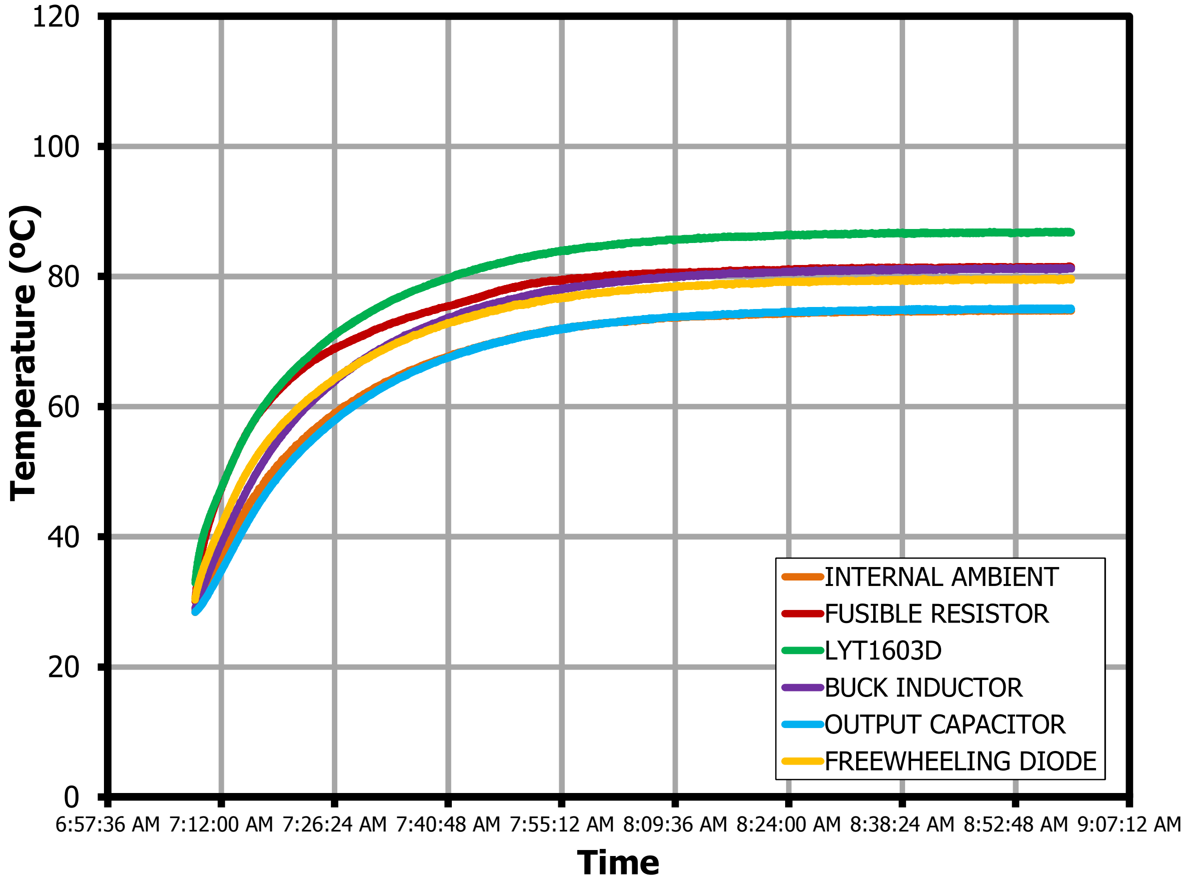

Figure 23 – Component Temperature / Output Current at 90 VAC, 60 V LED Load, 75 ºC Ambient.

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11.2.2 Thermal Performance at 115 VAC with a 60 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	C6
Maximum (ºC)	74	86.8	77	81.1	81.5	75.1
Final (ºC)	73.8	86.6	76.8	81	81.3	75.1

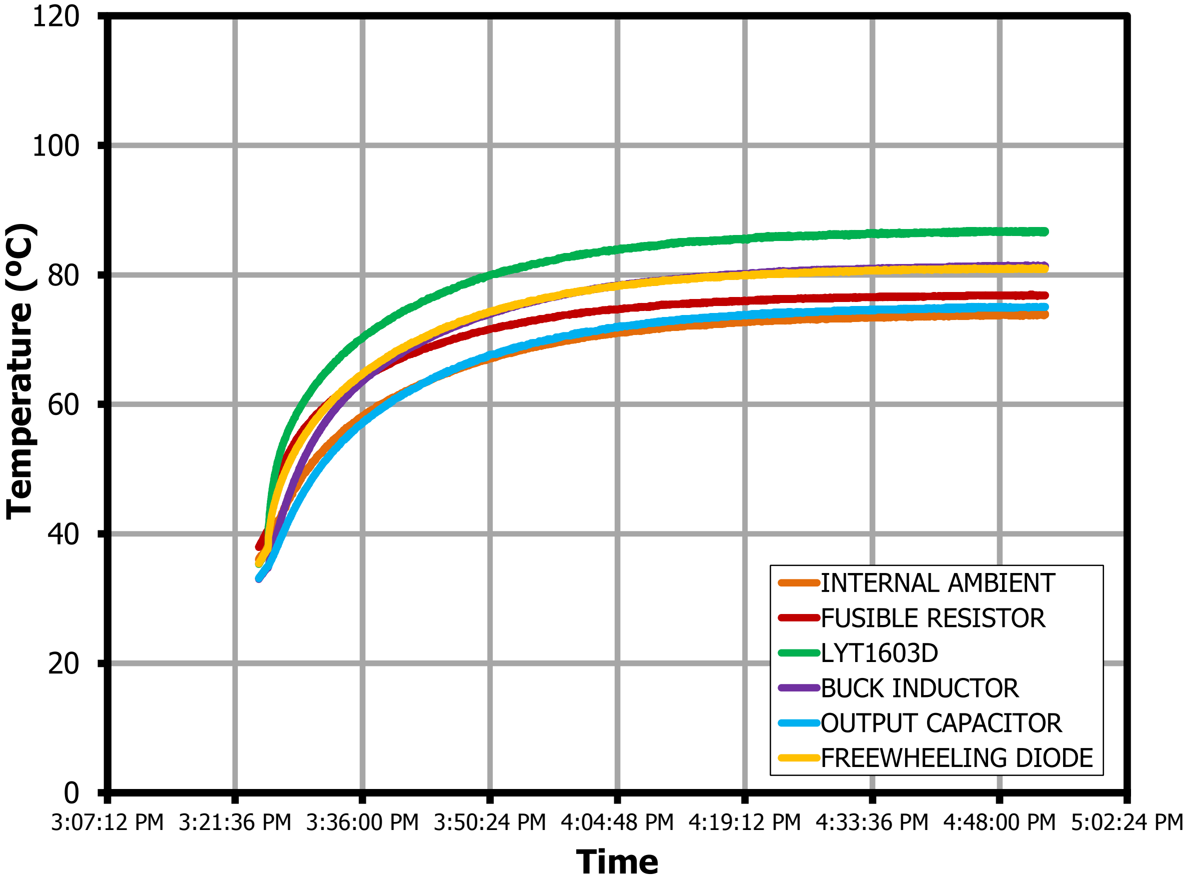

Figure 24 – Component Temperature / Output Current at 115 VAC, 60 V LED Load, 75 ºC Ambient.

11.2.3 Thermal Performance at 230 VAC with a 60 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	C6
Maximum (ºC)	76.1	95.1	74.6	88.3	87.7	79
Final (ºC)	75.6	93.9	73	86.3	87.6	77.7

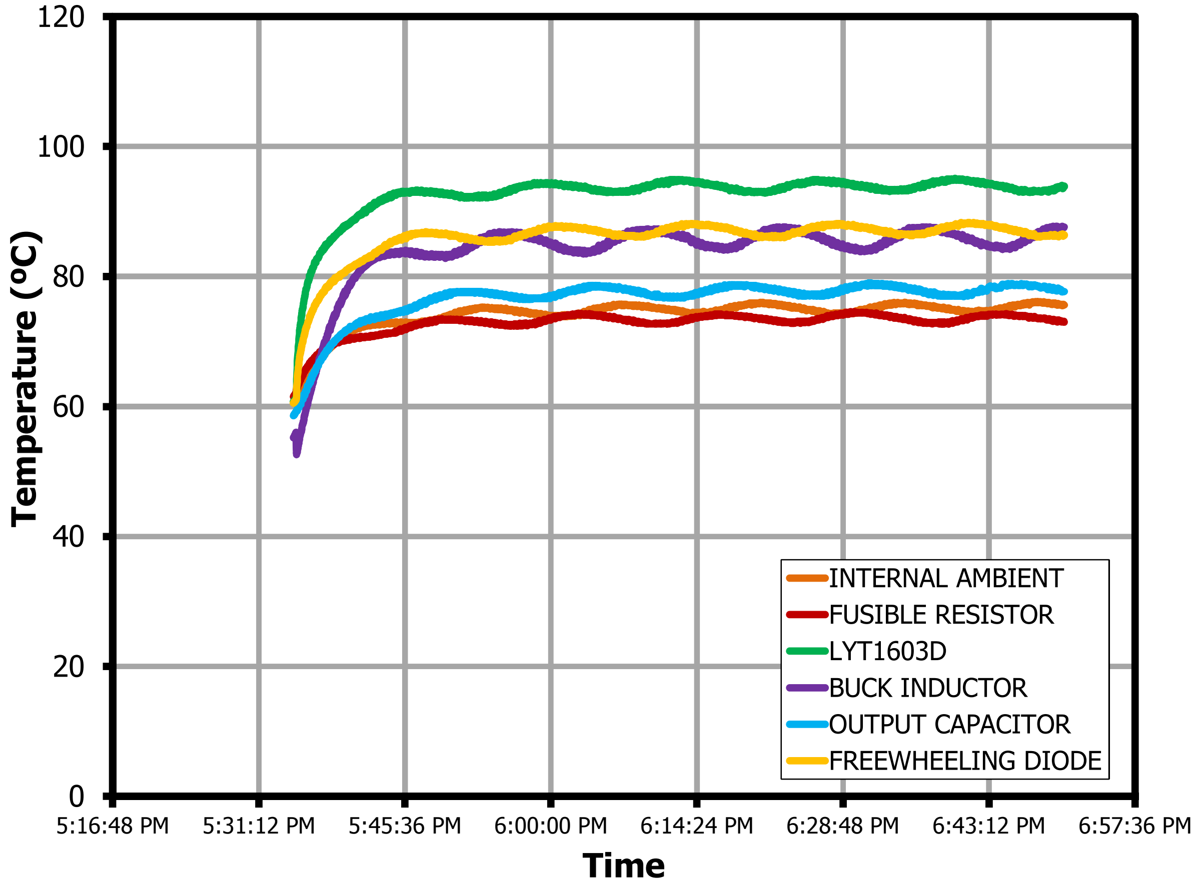

Figure 25 – Component Temperature at 230 VAC, 60 V LED Load, 75 ºC Ambient.

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11.2.4 Thermal Performance at 265 VAC with a 60 V LED Load

Measurement	Ambient	LYTSwitch-1	RF1	D1	T1	C6
Maximum (ºC)	76.7	98.7	79.8	90.3	91.3	80.2
Final (ºC)	75.5	98.2	72.8	89.6	90.5	78.1

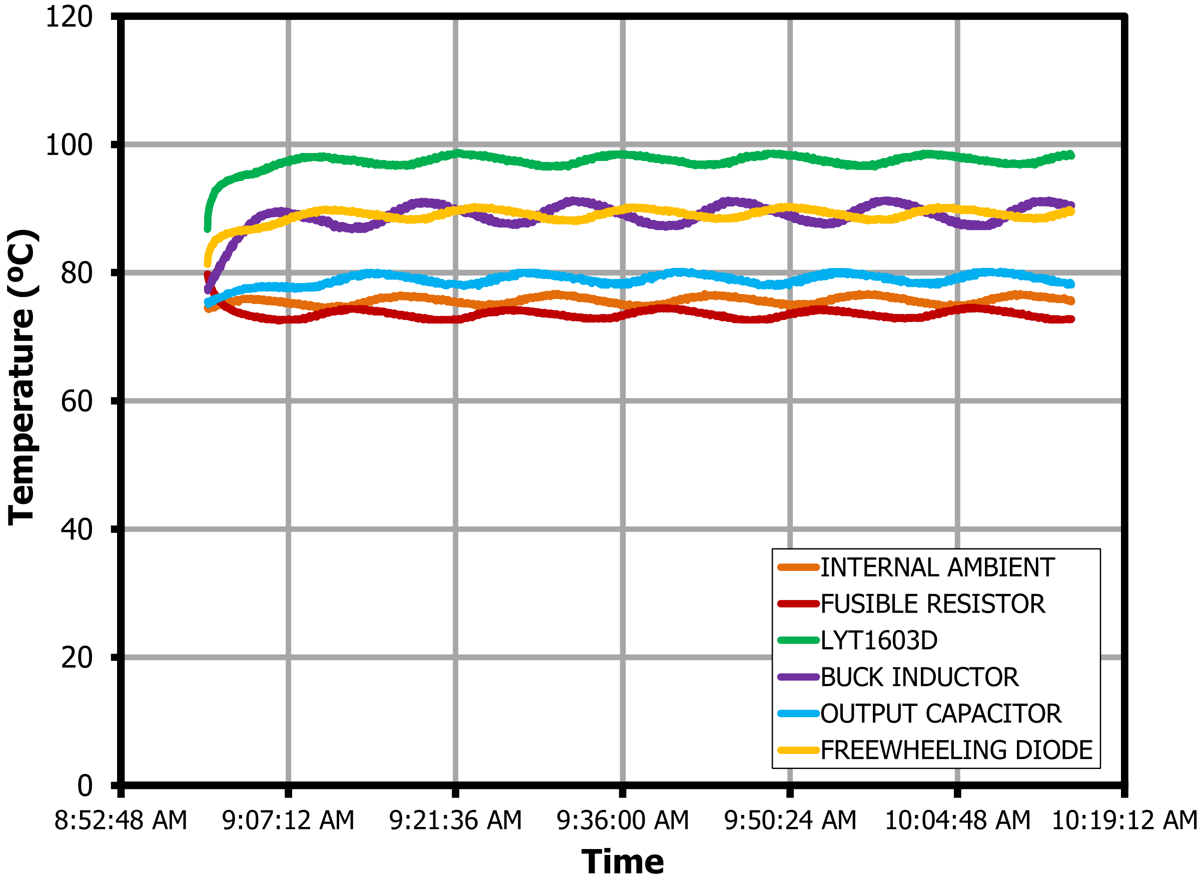

Figure 26 – Component Temperature at 265 VAC, 60 V LED Load, 75 ºC Ambient.

12 Waveforms

12.1 *Input Voltage and Input Current Waveforms*

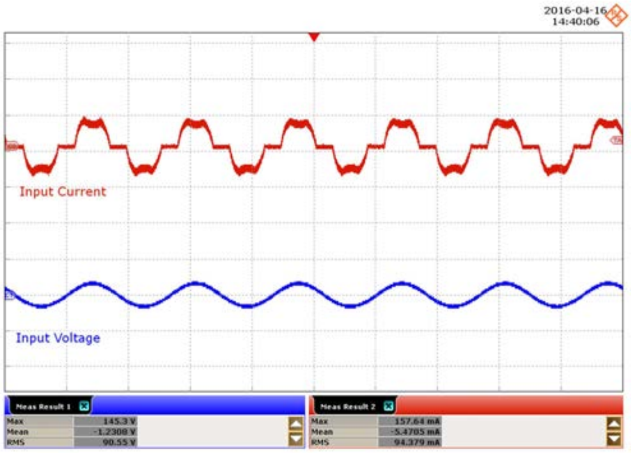

Figure 27 – 90 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

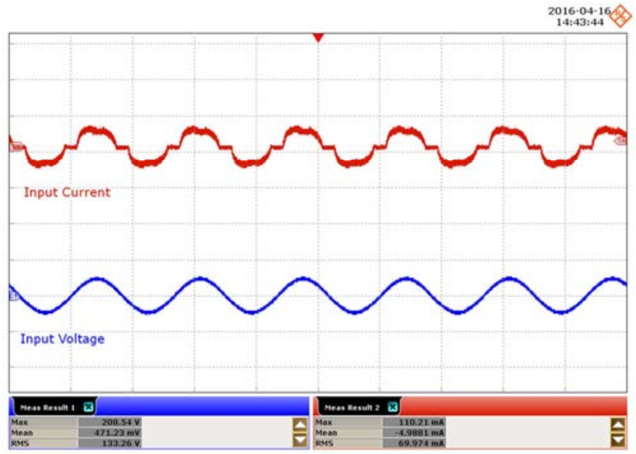

Figure 28 – 115 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

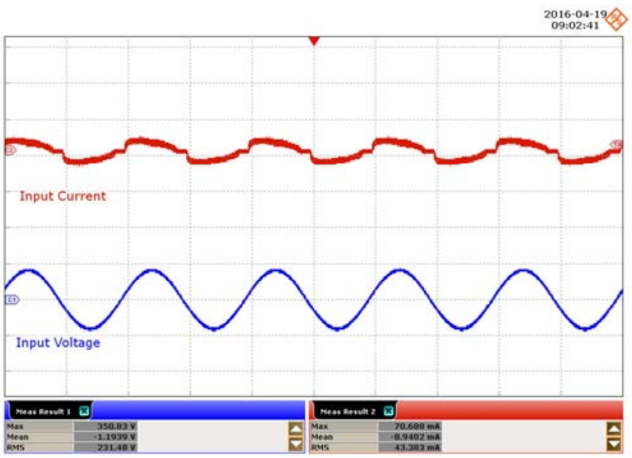

Figure 29 – 230 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

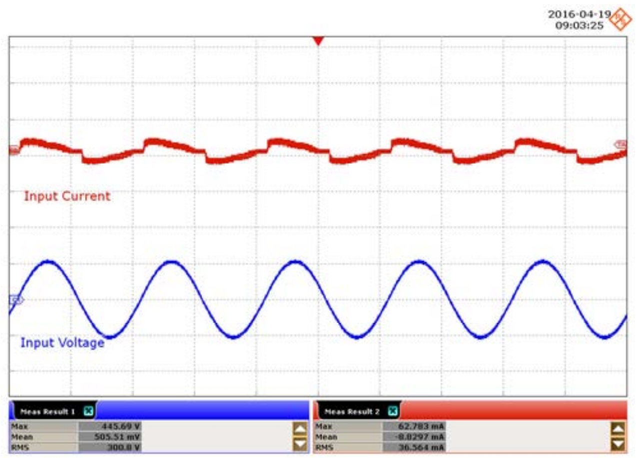

Figure 30 – 300 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

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12.2 *Start-up Profile*

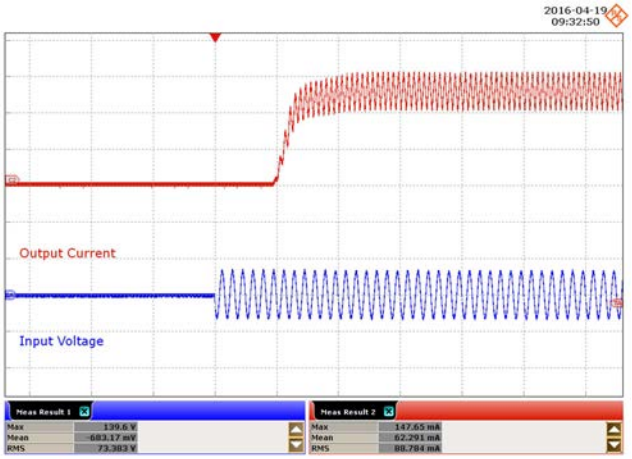

Figure 31 – 90 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

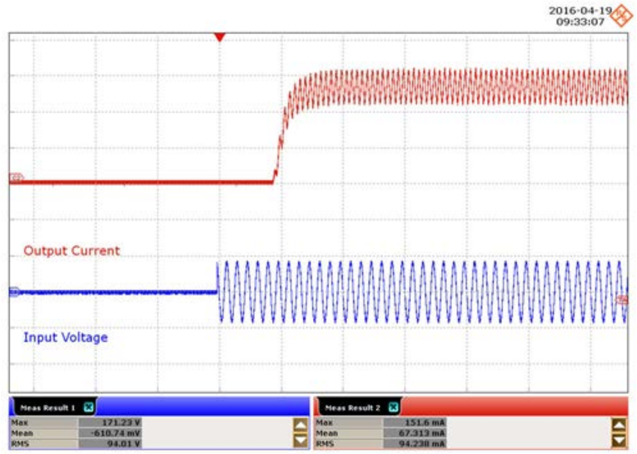

Figure 32 – 115 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

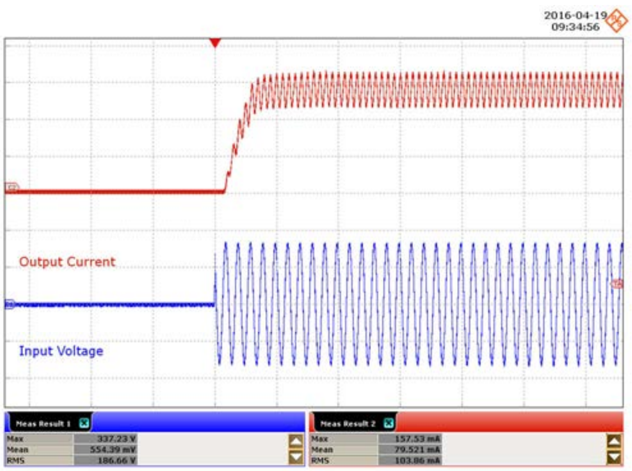

Figure 33 – 230 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

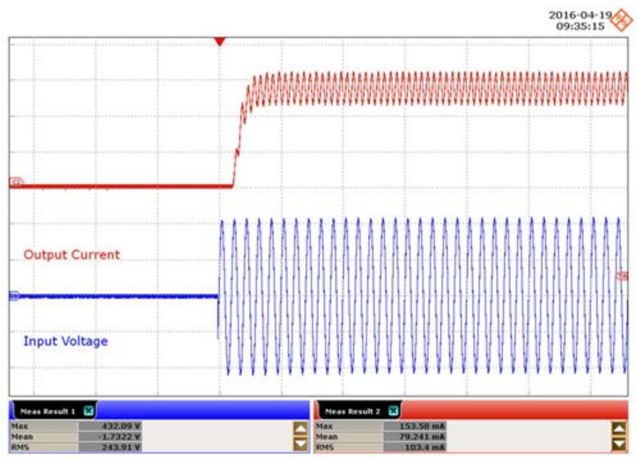

Figure 34 – 300 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

12.3 *Output Current Fall*

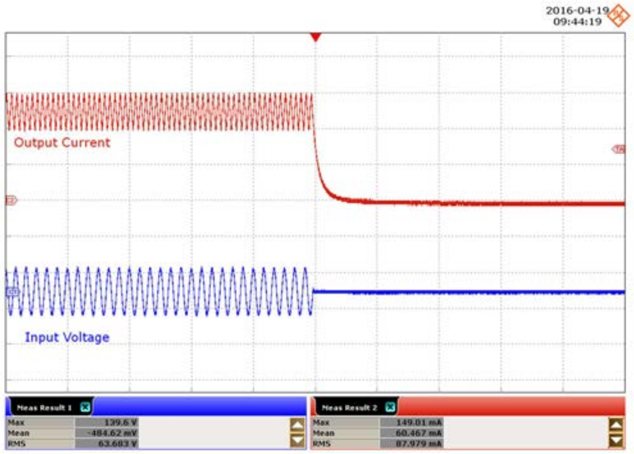

Figure 35 – 90 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

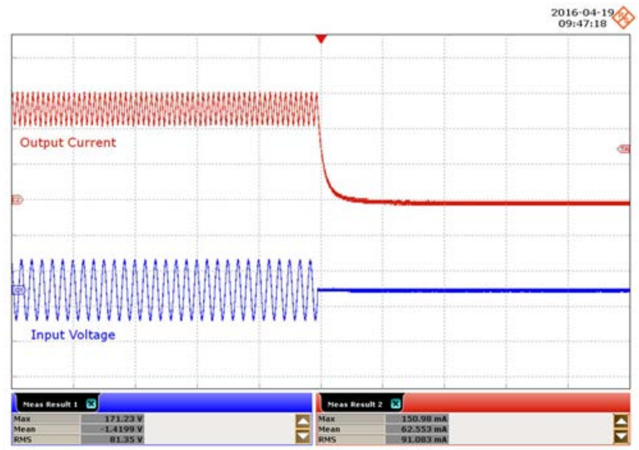

Figure 36 – 115 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

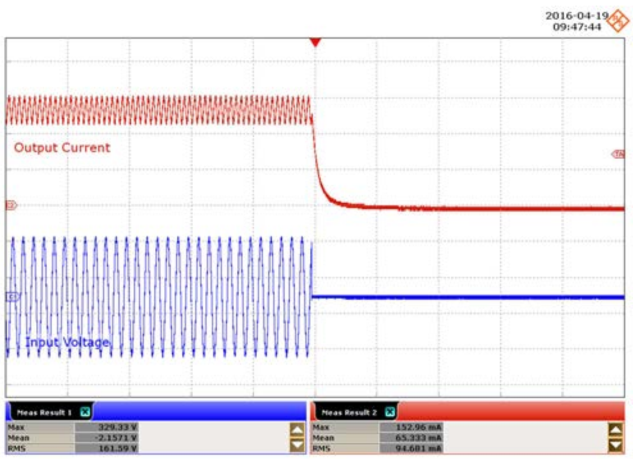

Figure 37 – 230 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

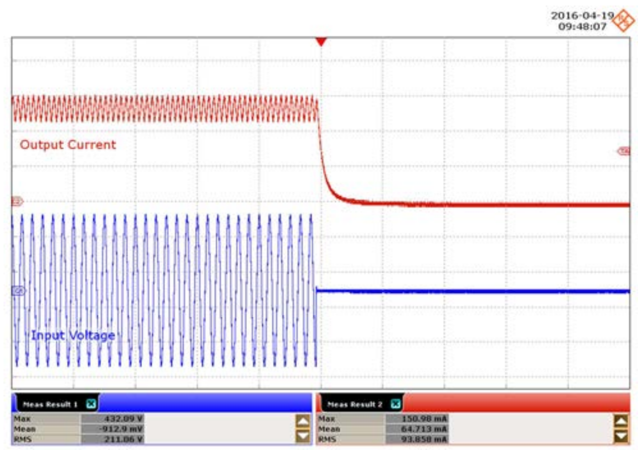

Figure 38 – 300 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

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12.4 *Drain Voltage and Current in Normal Operation*

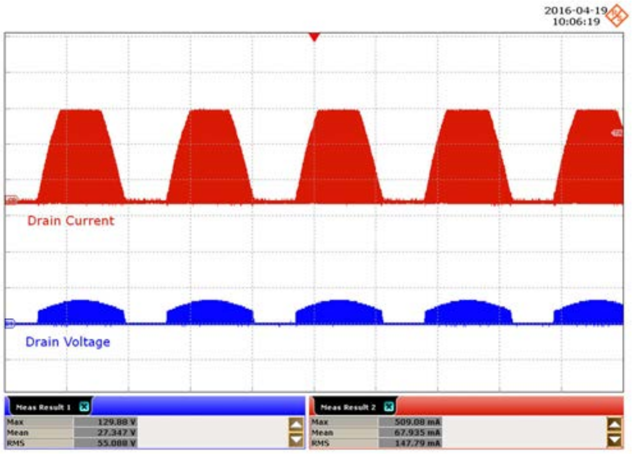

Figure 39 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 4 ms / div.

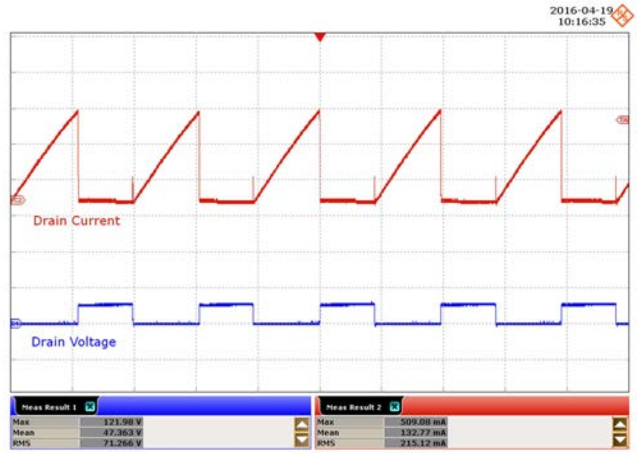

Figure 40 – 90 VAC, 60V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 10 us / div.

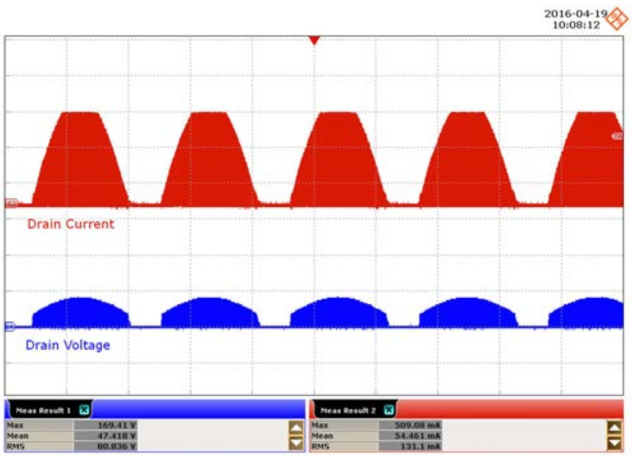

Figure 41 – 115 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 4 ms / div.

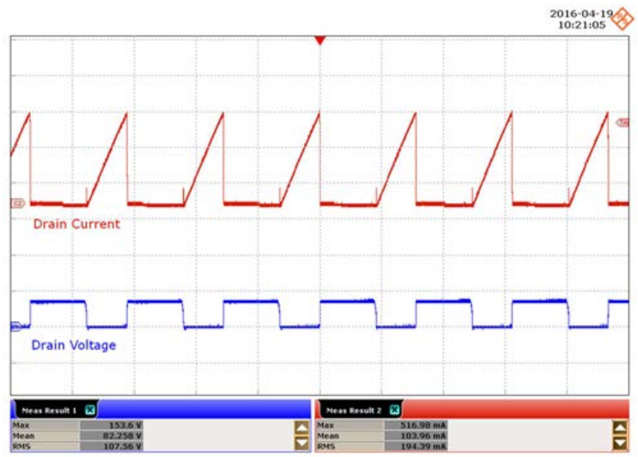

Figure 42 – 115 VAC, 60V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 10 us / div.

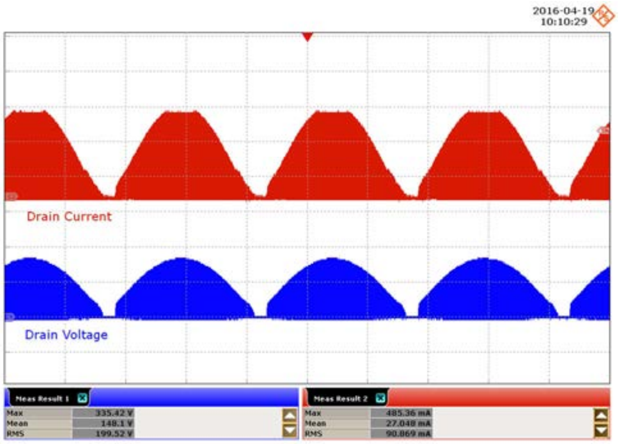

Figure 43 – 230 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 4 ms / div.

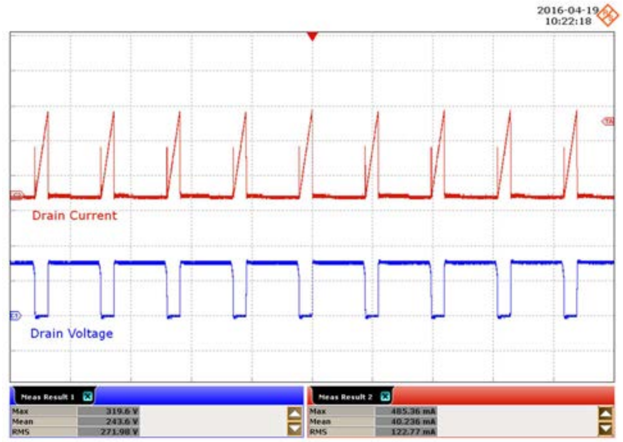

Figure 44 – 230 VAC, 60V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 10 us / div.

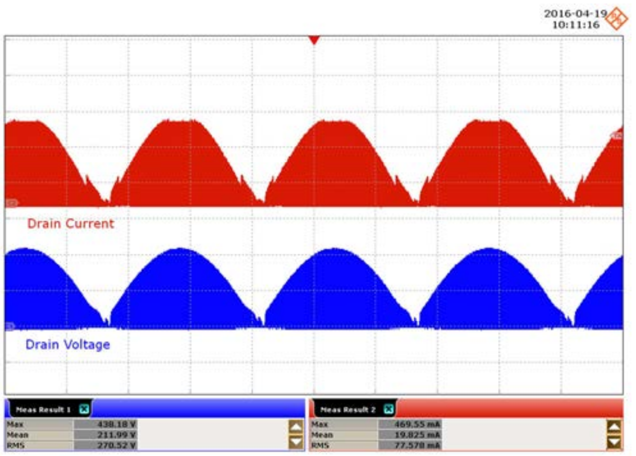

Figure 45 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 4 ms / div.

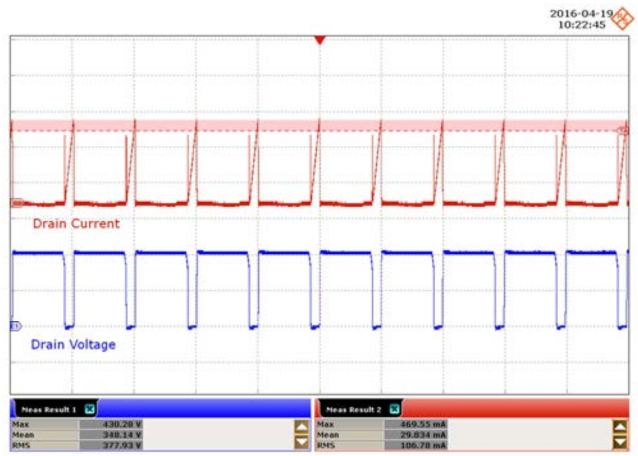

Figure 46 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 10 us / div.

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12.5 *Drain Voltage and Current Start-up Profile*

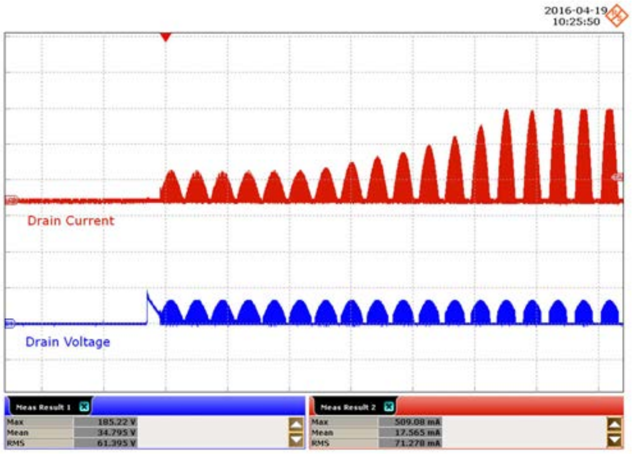

Figure 47 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms /div.

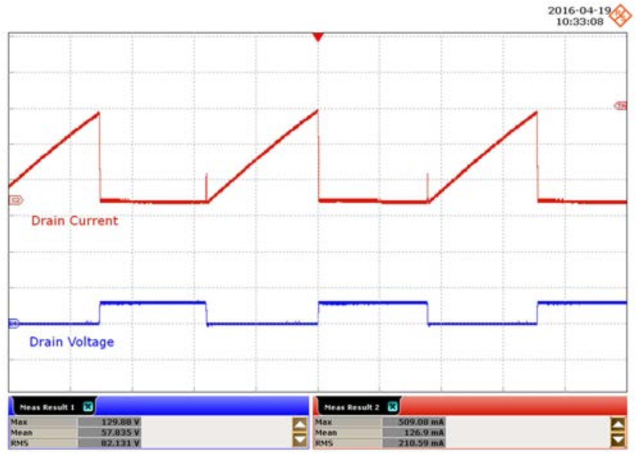

Figure 48 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 5 us /div.

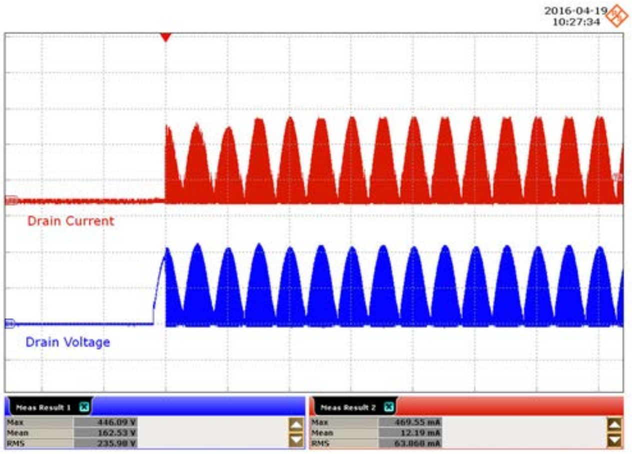

Figure 49 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 20 ms /div.

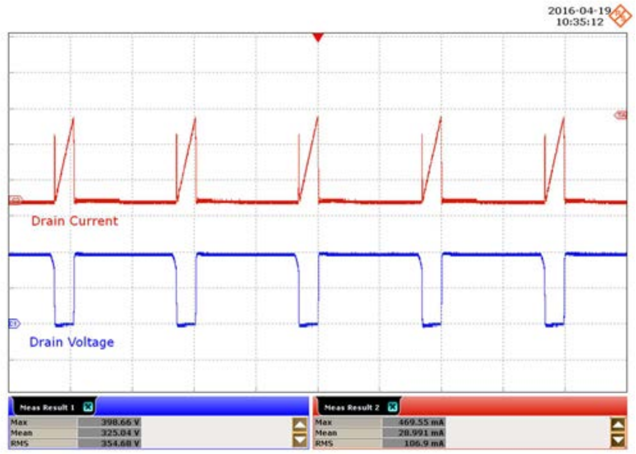

Figure 50 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 200 V / div., 5 us /div.

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

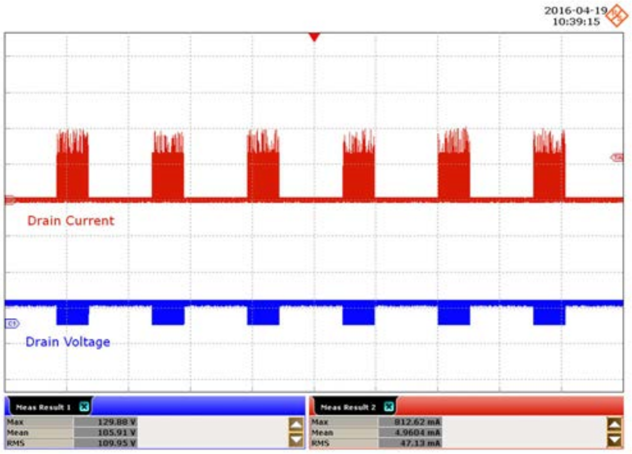

Figure 51 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 200 V / div., 1 s /div.

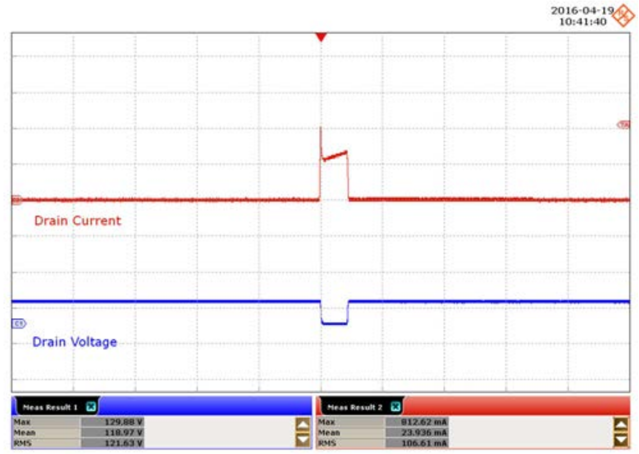

Figure 52 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 200 V / div., 2 us /div.

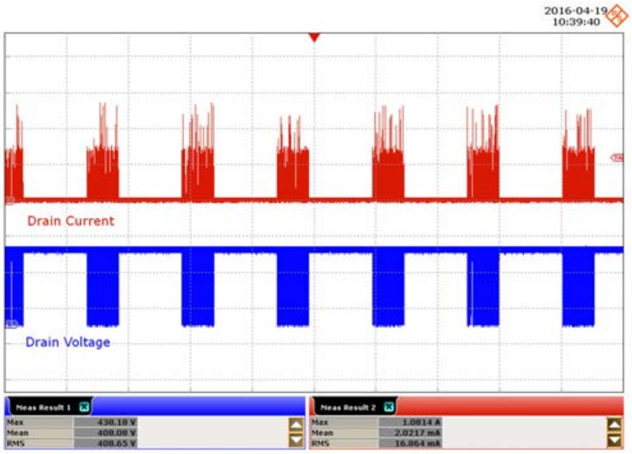

Figure 53 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 200 V / div., 1 s /div.

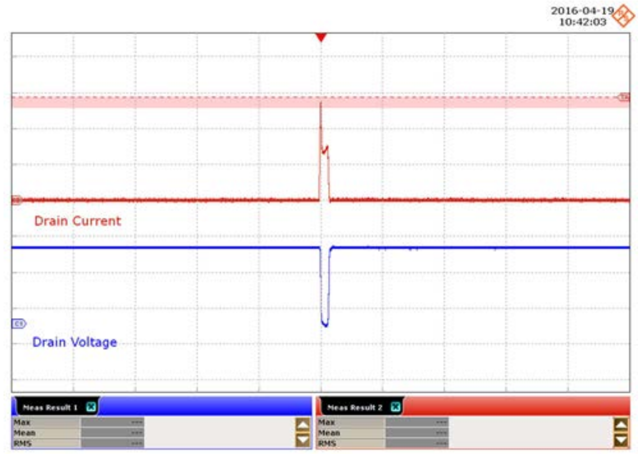

Figure 54 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 200 V / div. 2 us /div.

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12.7 *Output Diode Voltage and Current in Normal Operation*

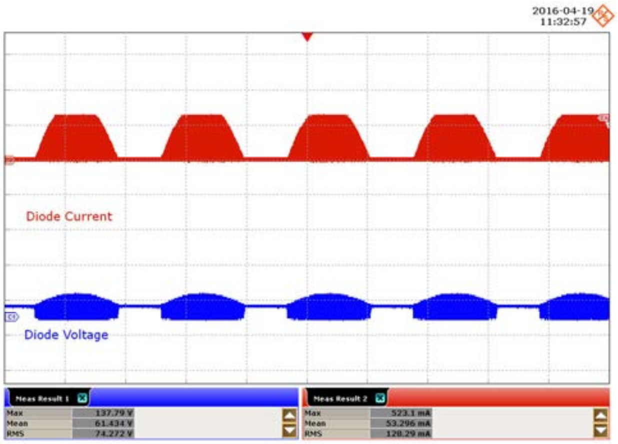

Figure 55 – 90 VAC, 60 V LED Load.
Upper: I_{D1}, 400 mA / div.
Lower: V_{D1}, 200 V / div., 4 ms / div.

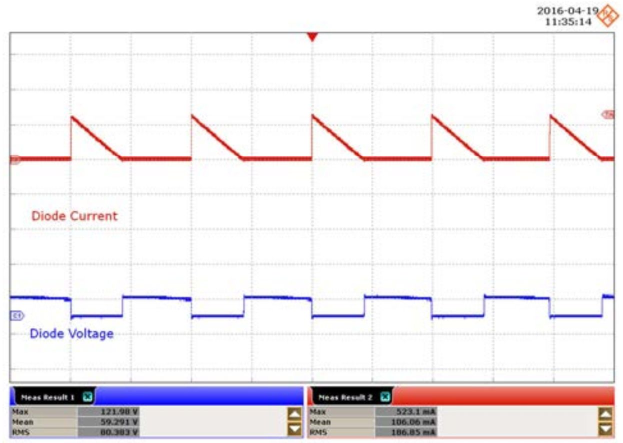

Figure 56 – 90 VAC, 60 V LED Load.
Upper: I_{D1}, 400 mA / div.
Lower: V_{D1}, 200 V / div., 4 us / div.

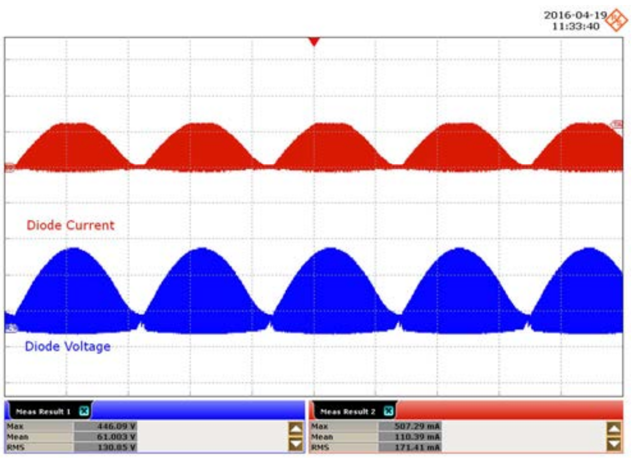

Figure 57 – 300 VAC, 60 V LED Load.
Upper: I_{D1}, 400 mA / div.
Lower: V_{D1}, 200 V / div., 4 ms / div.

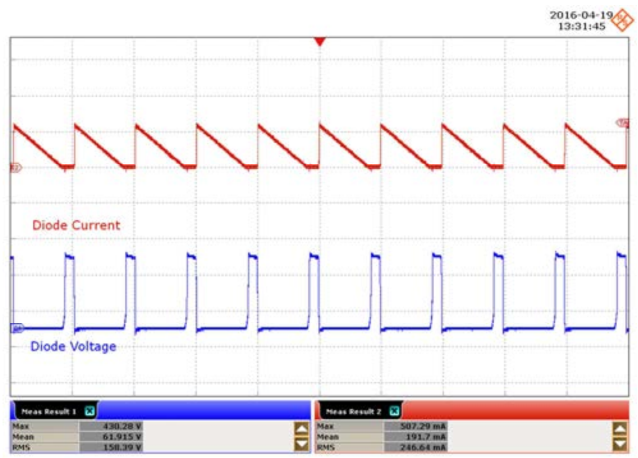

Figure 58 – 300 VAC, 60 V LED Load.
Upper: I_{D1}, 400 mA / div.
Lower: V_{D1}, 200 V / div., 4 us / div.

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.

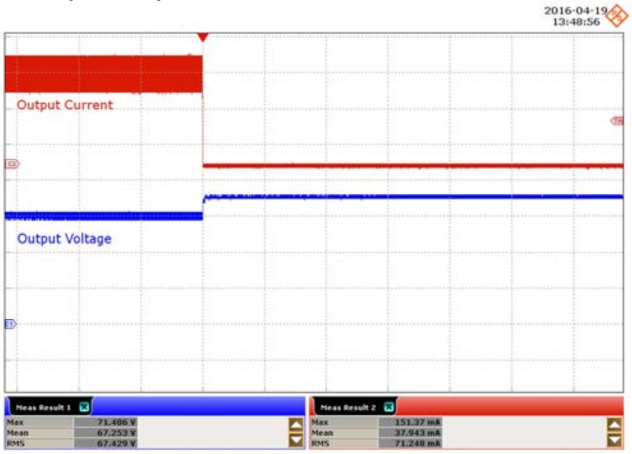

Figure 59 – 90 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

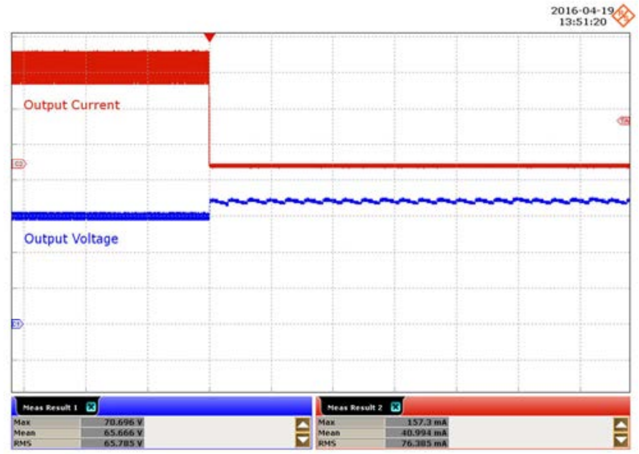

Figure 60 – 300 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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

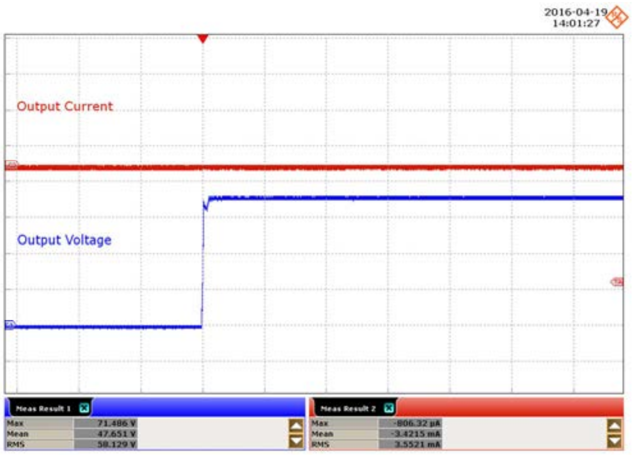

Figure 61 – 90 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

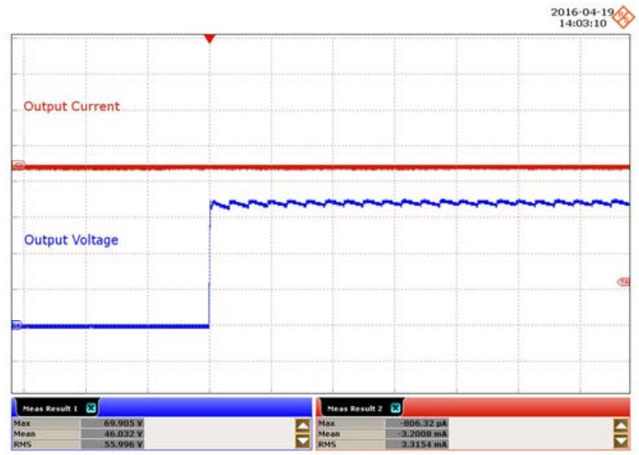

Figure 62 – 300 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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12.10 *Output Ripple Current*

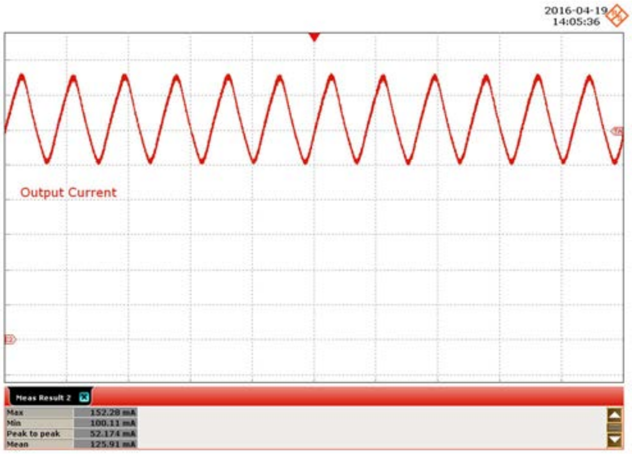

Figure 63 – 90 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

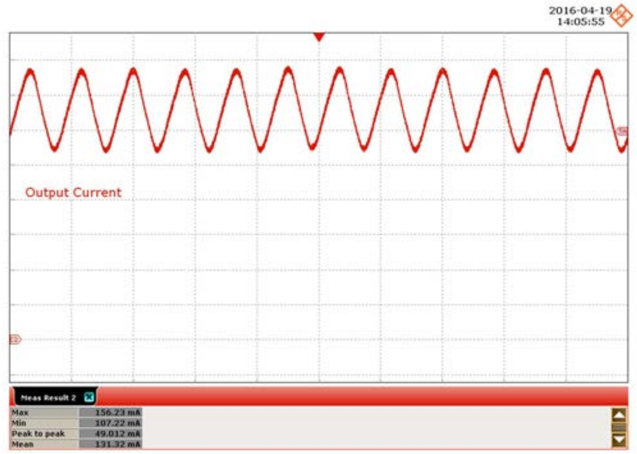

Figure 64 – 115 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

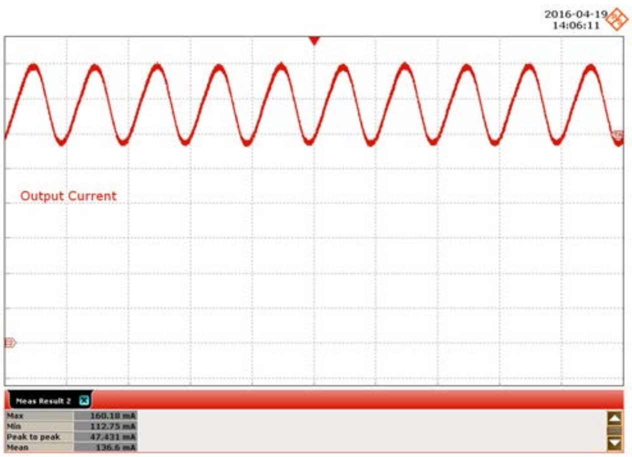

Figure 65 – 230 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

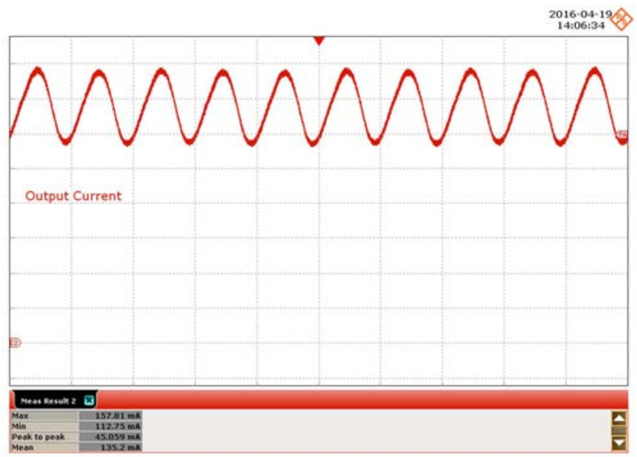

Figure 66 – 300 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

V_{IN} (VAC)	$I_{OUT(MAX)}$ (mA)	$I_{OUT(MIN)}$ (mA)	I_{MEAN}	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{OUT\ (MAX)}+I_{OUT\ (MIN)}$)
90	152.28	100.11	125.91	0.41	20.7
115	156.23	107.23	131.32	0.37	18.6
120	160.18	112.75	136.6	0.35	17.4
132	157.81	112.75	135.2	0.33	16.7

13 AC Cycling Test

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

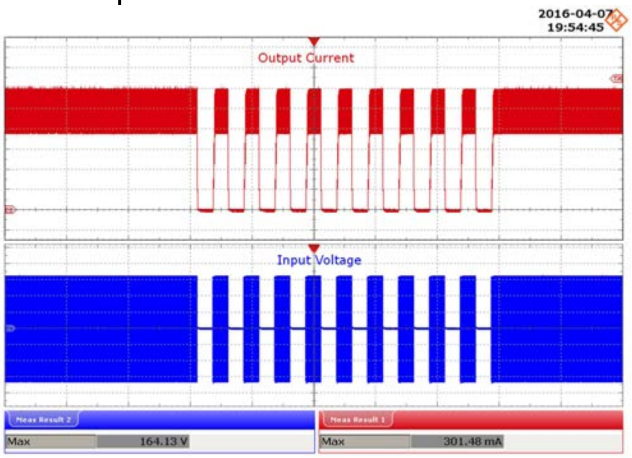

Figure 67 – 115 VAC, 67 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

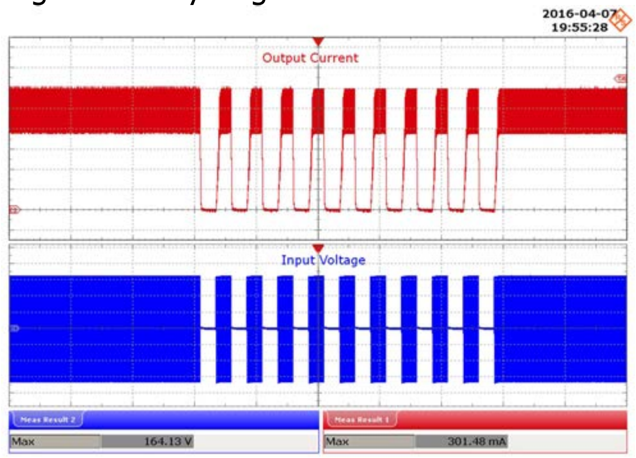

Figure 68 – 115 VAC, 67 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

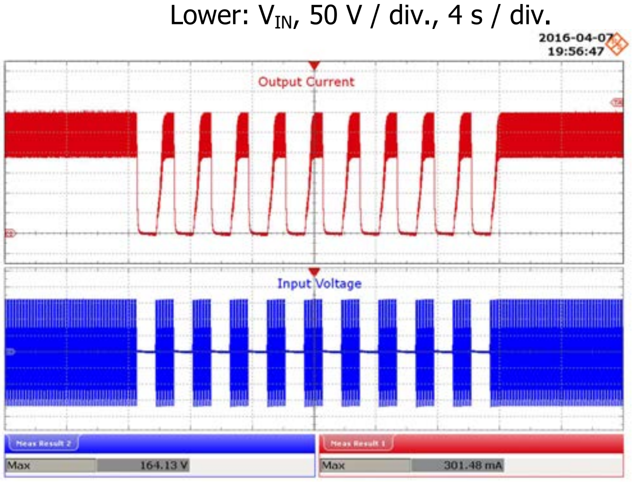

Figure 69 – 115 VAC, 67 V LED Load.
300 ms On – 300 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

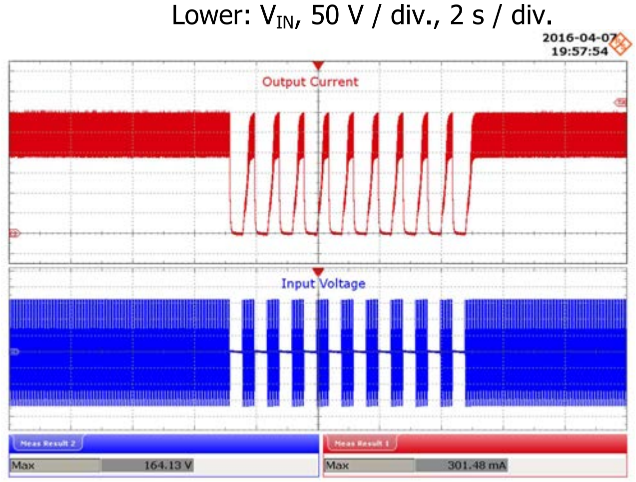

Figure 70 – 115 VAC, 67 V LED Load.
200 ms On – 200 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 1 s / div.

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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. 60 V LED load with input voltage set at 115/230 VAC.

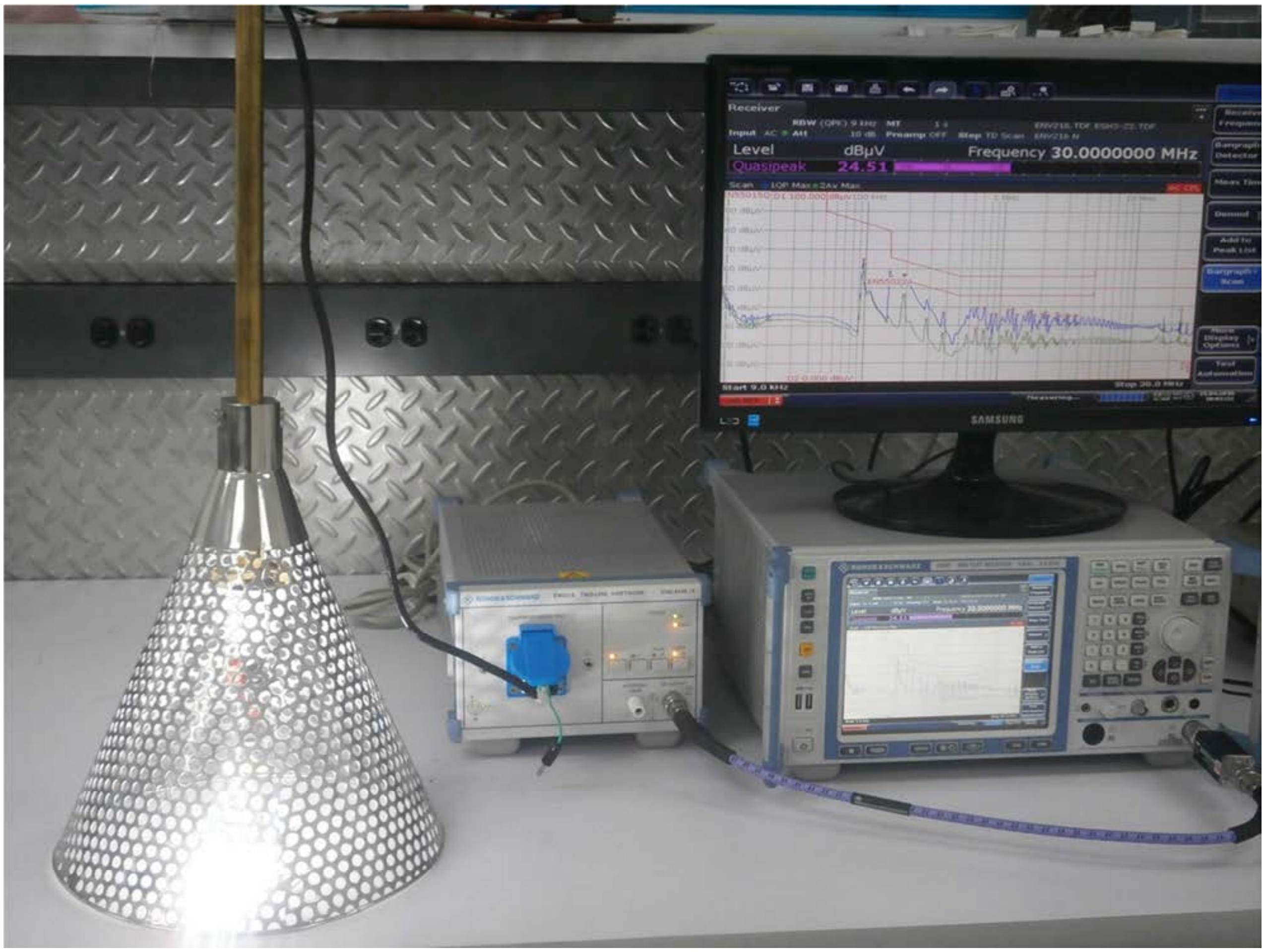

Figure 71 – Conducted EMI Test Set-up.

14.2 *EMI Test Result*

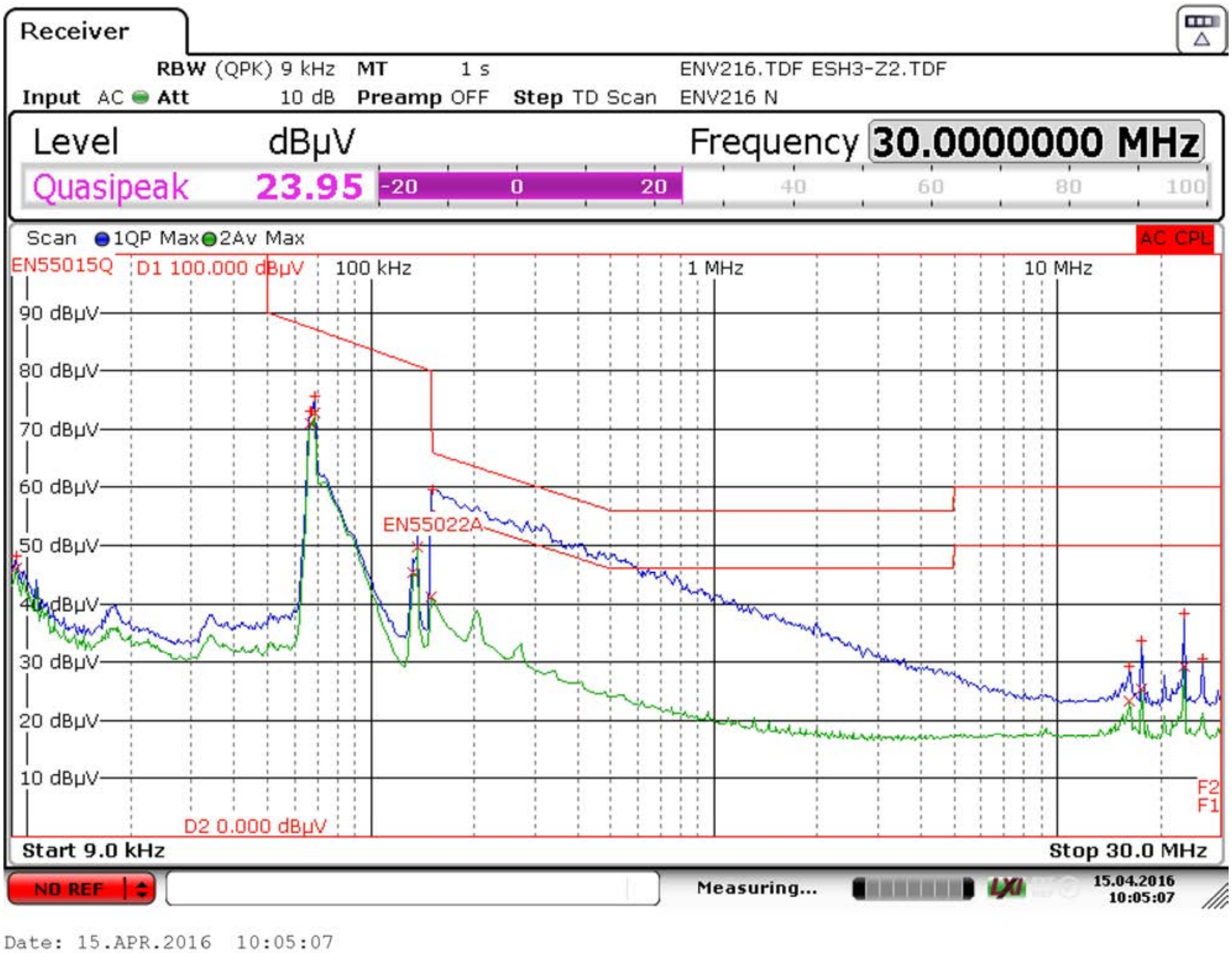

Figure 72 – Conducted EMI QP Scan at 60 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

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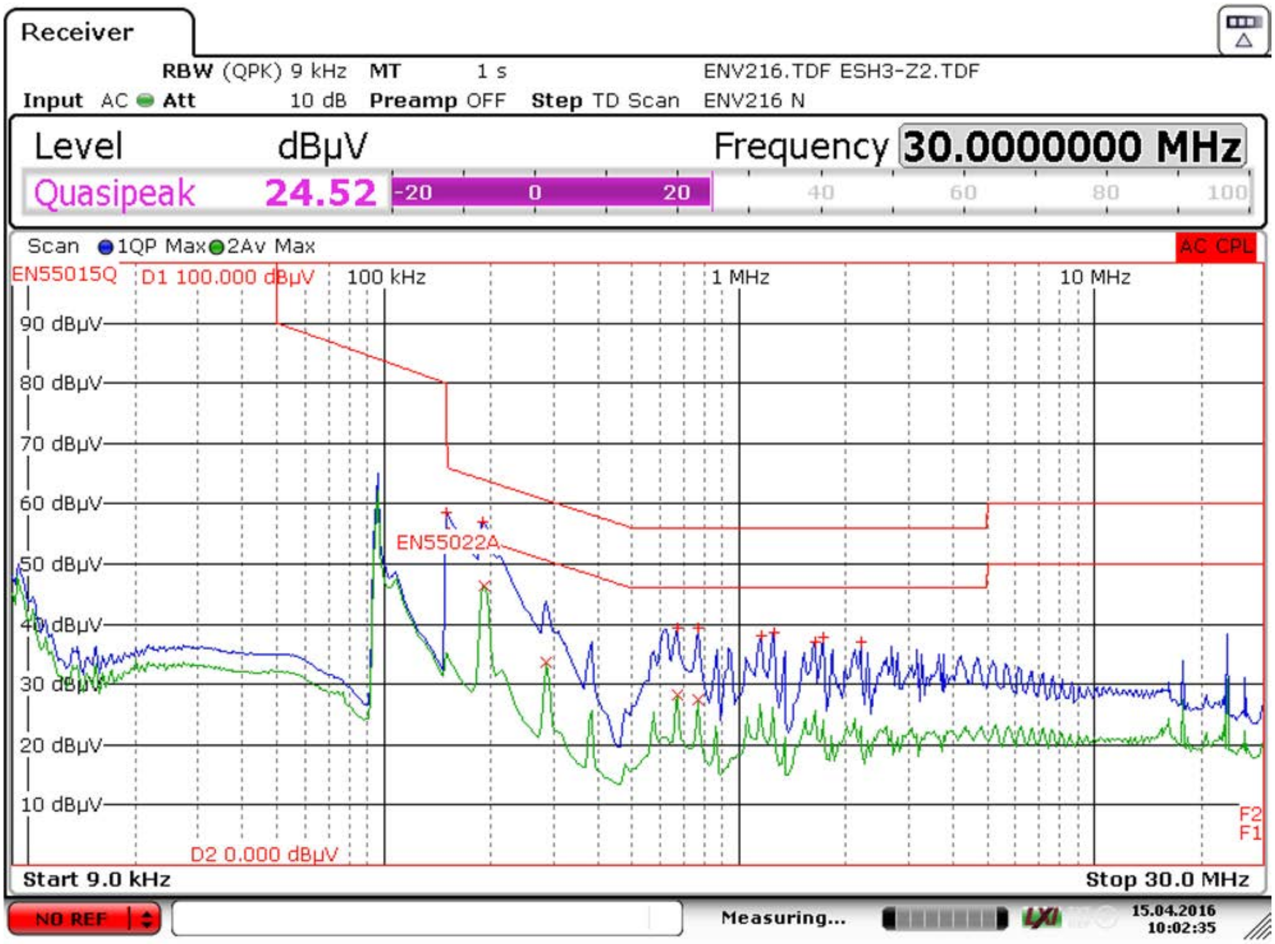
Trace1: EN55015Q   Trace2: EN55022A

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	152.2500 kHz	59.51 N	-6.37 dB
2 Average	150.0000 kHz	41.10 N	-14.90 dB
2 Average	23.5298 MHz	29.27 N	-20.73 dB
1 Quasi Peak	23.5275 MHz	38.29 N	-21.71 dB
2 Average	17.6460 MHz	25.36 N	-24.64 dB
1 Quasi Peak	17.6460 MHz	33.68 N	-26.32 dB
2 Average	16.2285 MHz	23.29 L1	-26.71 dB
1 Quasi Peak	26.4683 MHz	30.66 N	-29.34 dB
1 Quasi Peak	16.2285 MHz	29.18 N	-30.82 dB

Figure 73 – Conducted EMI Data at 115 VAC, 60 V LED Load.



Date: 15.APR.2016 10:02:35

Figure 74 – Conducted EMI QP Scan at 60 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

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Trace1: EN55015Q Trace2: EN55022A

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	190.5000 kHz	57.07 L1	-6.94 dB
2 Average	192.7500 kHz	46.49 N	-7.43 dB
1 Quasi Peak	150.0000 kHz	58.55 N	-7.45 dB
1 Quasi Peak	768.7500 kHz	39.42 L1	-16.58 dB
1 Quasi Peak	672.0000 kHz	39.33 L1	-16.67 dB
2 Average	287.2500 kHz	33.67 L1	-16.93 dB
1 Quasi Peak	1.2503 MHz	38.68 L1	-17.32 dB
1 Quasi Peak	1.1535 MHz	38.18 L1	-17.82 dB
2 Average	672.0000 kHz	28.17 L1	-17.83 dB
1 Quasi Peak	1.7318 MHz	37.89 L1	-18.11 dB
2 Average	766.5000 kHz	27.48 L1	-18.52 dB
1 Quasi Peak	1.6350 MHz	37.09 L1	-18.91 dB
1 Quasi Peak	2.2133 MHz	37.09 L1	-18.91 dB

Figure 75 – Conducted EMI Data at 230 VAC, 60 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	115/230	L to N	0	Pass
-500	115/230	L to N	0	Pass
+500	115/230	L to N	90	Pass
-500	115/230	L to N	90	Pass

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	115/230	L to N	0	Pass
-2500	115/230	L to N	0	Pass
+2500	115/230	L to N	90	Pass
-2500	115/230	L to N	90	Pass

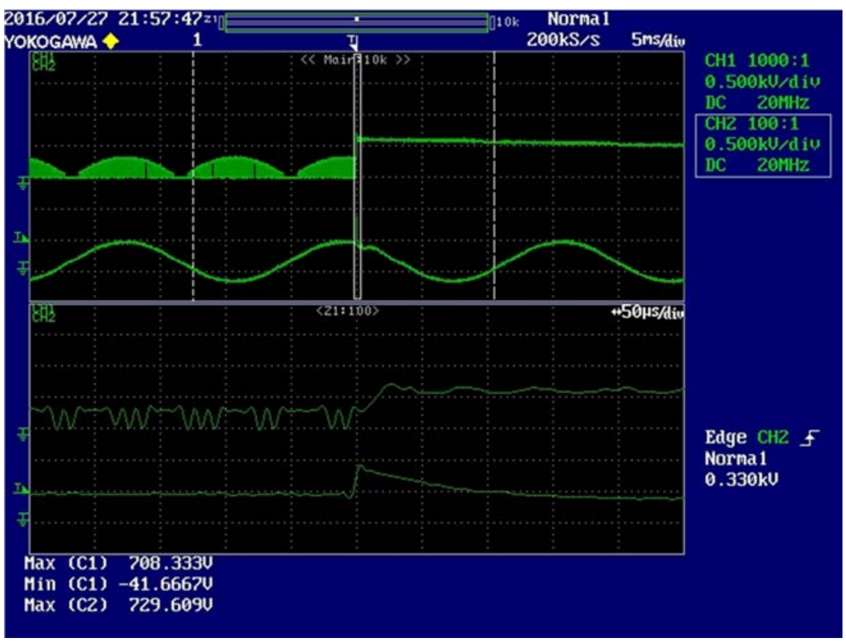

Figure 76 – +500 V Differential Surge @ Worst Case Input (230 VAC), 90º Phase Angle.
V_{DRAIN}, 500 V / div., 5ms / div.
Peak V_{DRAIN}: 708.33 V.

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16 Brown-in / Brown-out Test

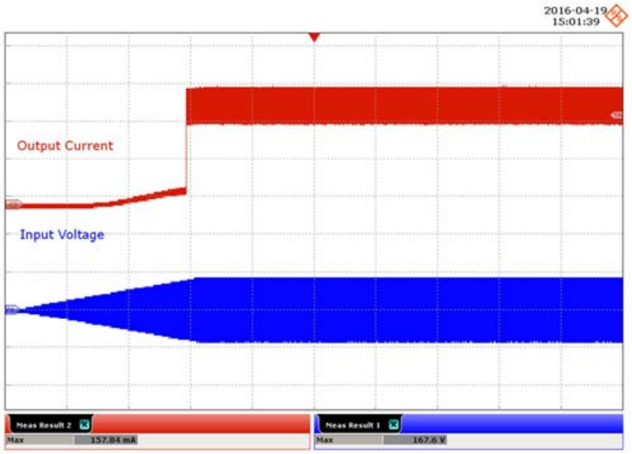

Figure 77 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 200 V / div.
Time Scale: 40 s / div.

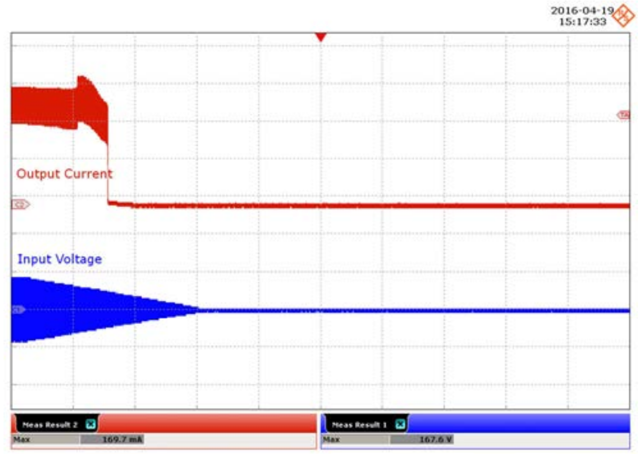

Figure 78 – Brown-out Test at 1 V / s
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 200 V / div.
Time Scale: 40 s / div.

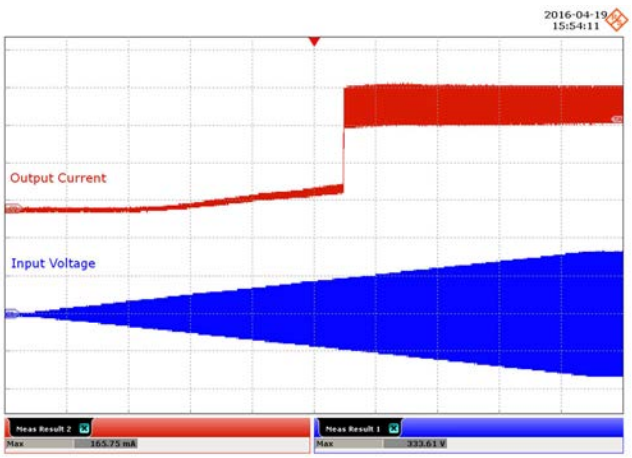

Figure 79 – Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 200 V / div.
Time Scale: 50 s / div.

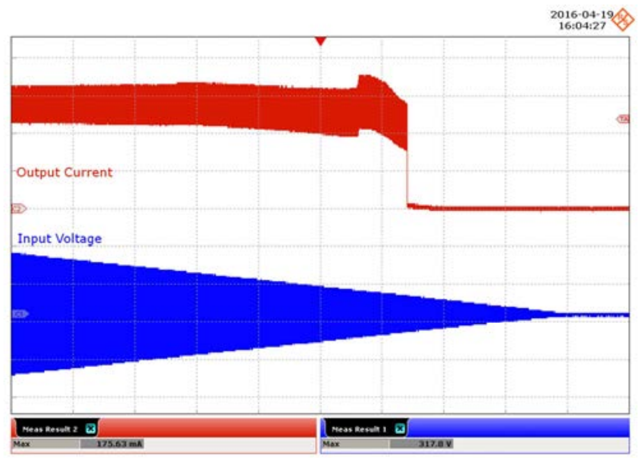

Figure 80 – Brown-out Test at 1 V / s
Ch1: I_{OUT}, 50 mA / div.
Ch2: V_{IN}, 200 V / div.
Time Scale: 50 s / div.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
28-Oct-16	AM/MA	1.0	Initial release	Apps & Mktg

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