Design Example Report

Title	***7.5 W TRIAC Dimmable, High Efficiency, Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch^{TM}-7 LYT7503D***
Specification	90 VAC – 300 VAC Input; 60 V_{TYP}, 125 mA_{TYP} Output
Application	A19 Bulb (Universal Input, Low Line Dimmable)
Author	Applications Engineering Department
Document Number	DER-561
Date	October 13, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9 at 115 VAC, PF >0.85 at 230 VAC
- Accurate constant current regulation, ±5% at 185 VAC to 300 VAC
- Excellent dimming performance at low line input (90 VAC – 132 VAC)
- Meets <30% flicker requirement
- Highly energy efficient, >85%
- 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, 1 kV differential surge
- Meets EN55015 conducted EMI

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

1 Introduction

This engineering report describes a low cost, non-isolated dimmable buck LED driver designed to drive a 60 V LED voltage string at 125 mA output current from an input voltage range of 90 VAC to 300 VAC. The LED driver utilizes the LYT7503D from the LYTSwitch-7 family of devices. The key design goals were high efficiency, accurate constant current regulation at highline, excellent dimming performance at low line and low component count.

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

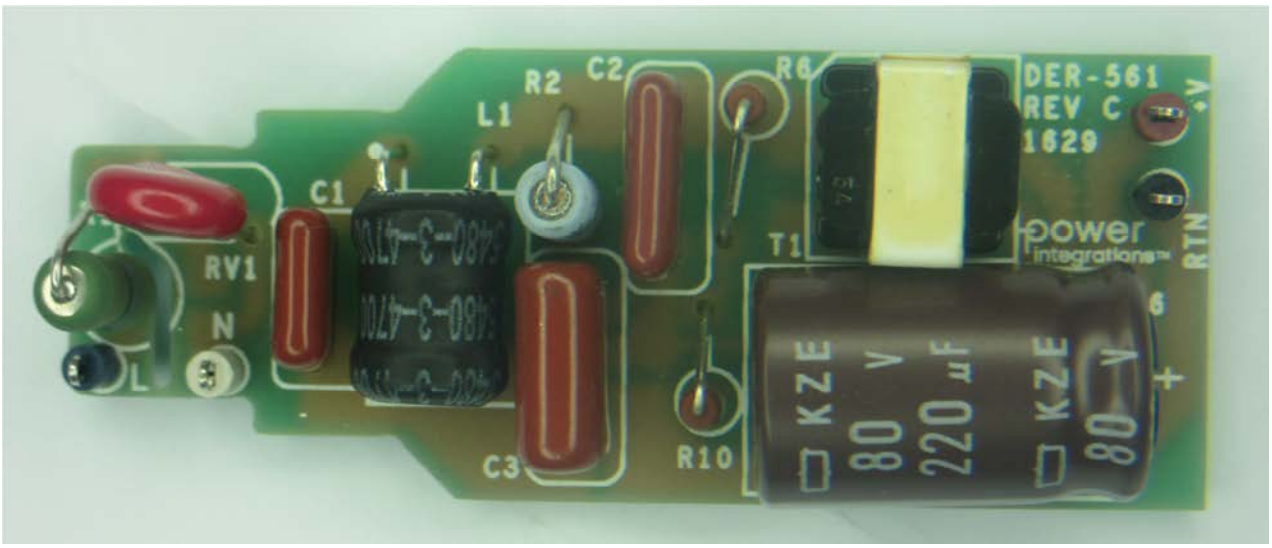

Figure 1 – Populated Circuit Board, Top View.

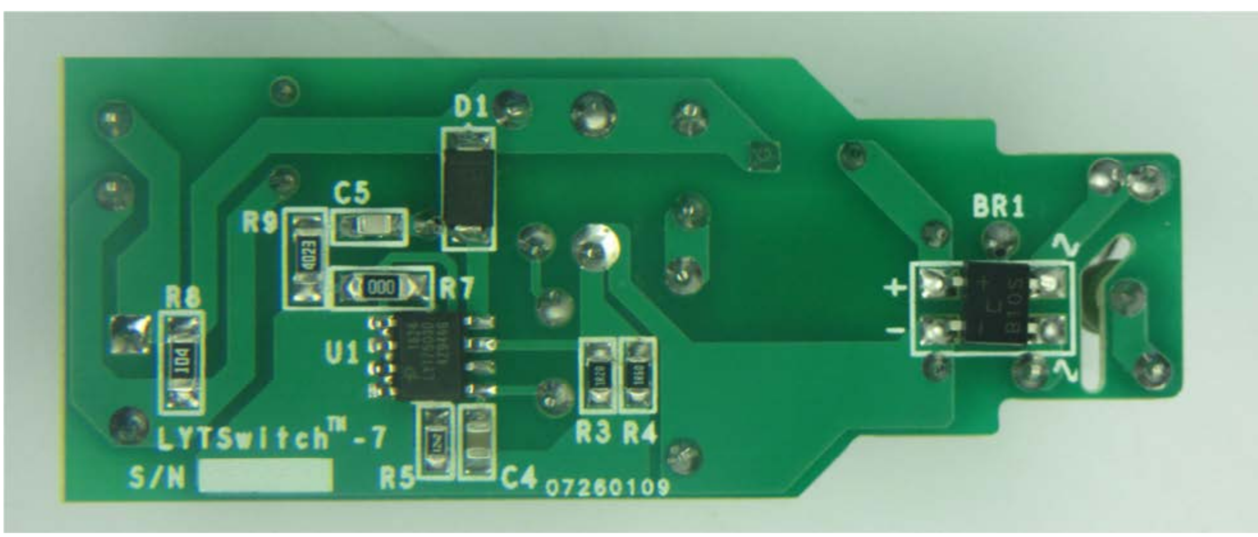

Figure 2– Populated Circuit Board, Bottom View.

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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}		60/50		Hz	
Output						
Output Voltage	V_{OUT}		60		V	
Output Current	I_{OUT}		125		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		7.5		W	
Efficiency						
Full Load	η		85		%	115 V / 60 Hz; 230 V / 50 Hz at 25 ºC.
Environmental						
Conducted EMI			CISPR 15B / EN55015B			
Safety			Isolated			
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1000		V	
Power Factor			0.9/0.85			Measured at 115 / 230 VAC, 60 / 50 Hz.
Ambient Temperature	T_{AMB}			75	ºC	Free Convection, Sea Level.

3 Schematic

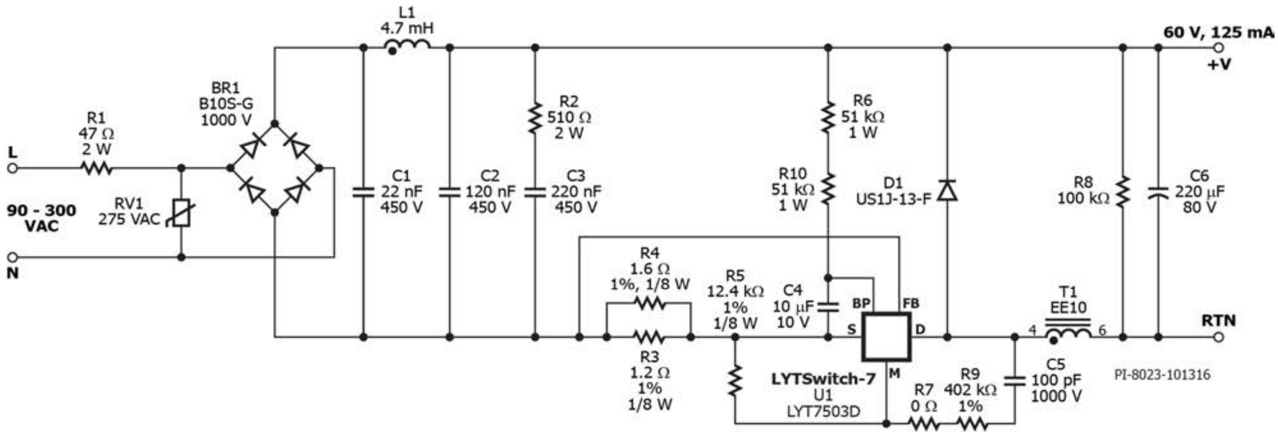

Figure 3 – Schematic.

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4 Circuit Description

LYT7503D from the LYTSwitch-7 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 LYT7503D was configured to drive a 60 V buck LED driver with an output current of 125 mA.

4.1 *Input Stage*

The input fusible resistor R1 serves as a safety protection from component failures. Its value is chosen such that it could serve as a damper to reduce ringing at the input which could cause dimmer incompatibility. Varistor RV1 (275 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-7's variable frequency / variable on-time and critical conduction mode control engine ensures compliance with the EN55015 Class B emission limit. Its values were chosen to achieve a balance between dimmer compatibility, power factor and efficiency.

4.3 *LYTSwitch-7 Control Circuit*

The LED driver circuit topology is a low side buck. During switch on-time, current flows through inductor T1 to the load. Energy is stored in the inductor during switch on-time. During off-time the energy stored in the inductor is transferred to the load through flywheel diode D1.

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 percent flicker requirements. A pre-load resistor with a value of 100 kΩ is used to provide good dimming compatibility while maintaining efficiency within specification.

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 and also during deep dimming. Resistor R6 and R10 are pull up resistors to ensure that there is enough current going into the BP pin during deep dimming.

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 MOSFET is on using external current sense resistors R3 and R4. This is to set a constant inductor peak current I_{PK} by comparing the sensed voltage with the reference current limit threshold ($V_{FBth} \geq 0.28$ V, I_{PK}=0.28 V / R_{SENSE}).

During the MOSFET off-time, the voltage across the output inductor is equal to the output voltage. This voltage is capacitively coupled to C5 and is used by the MULTIFUNCTION (M) pin for a number of functions. When the MOSFET is at off-state, the M pin provides zero current detection (ZCD) and output OVP detection through sampling resistors R5 and R9. 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 OVP detection is achieved through R5, R9 and C5. The OVP threshold is typically set at 120% of steady-state value (2.0 V). Resistor R9 is set to a fixed value of 402 kΩ ±1% to minimize power loss during MOSFET on duration.

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

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5 PCB Layout

Note: R7 is an optional component. A 0 Ω jumper resistor is used in this design for this location.

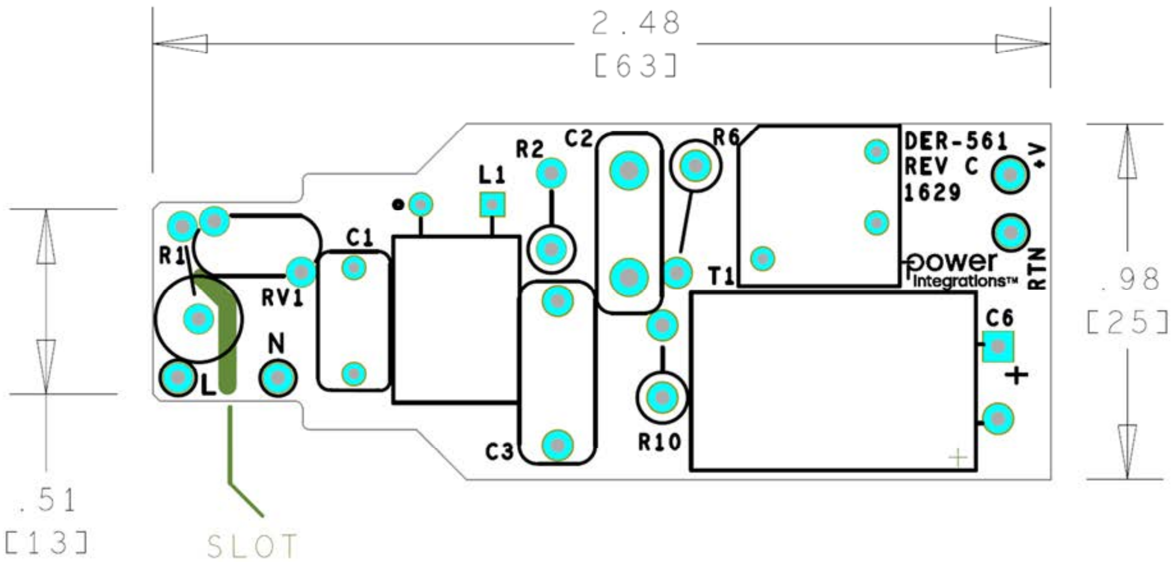

Figure 4 – Top Side.

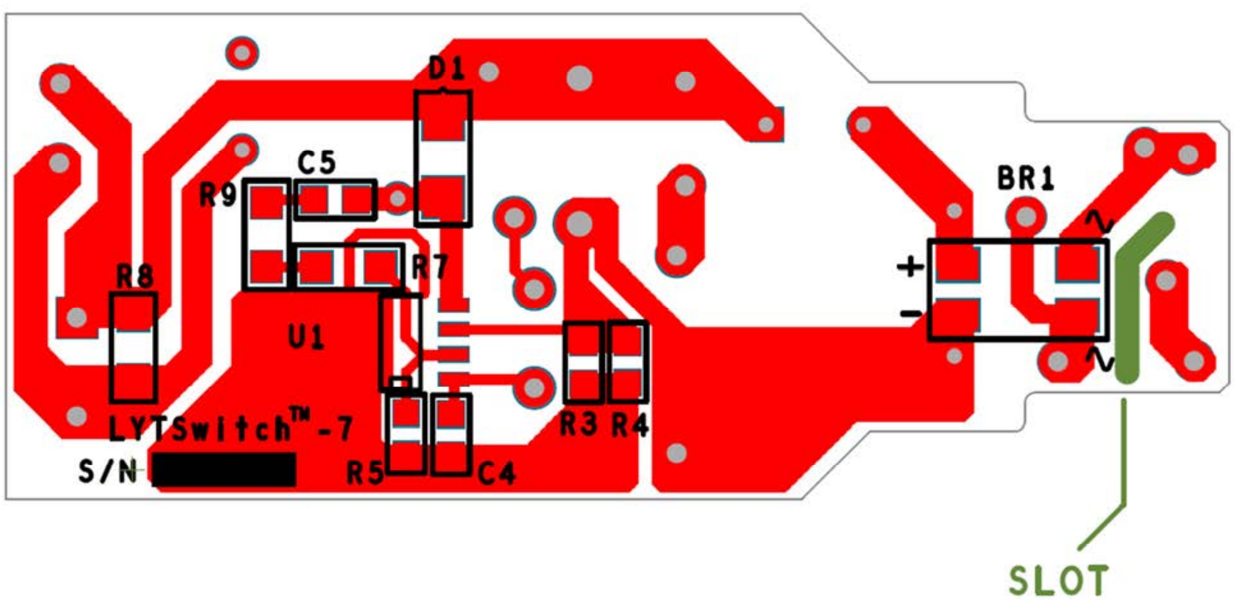

Figure 5 – Bottom Side.

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	22 nF, 450VDC, 5%, Film	MEXXD2220	Duratech
4	1	C2	CAP, FILM, 0.12 uF, 5%, 450VDC, RADIAL	ECW-FD2W124J4	Panasonic
5	1	C3	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
6	1	C4	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK Corp
7	1	C5	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
8	1	C6	220 μF, 80 V, 20%, Electrolytic, General Purpose, 62 mΩ, (12.5 mmD x 20 mmH), LS 0.197" (5.00 mm)	EKZE800ELL221MK20S	United Chemi-Con
9	1	D1	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
10	1	L	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
11	1	L1	4.7 mH, 0.150 A, 20%	RL-5480-3-4700	Renco
12	1	N	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
13	1	R1	RES, 47 Ω, 5%, 2 W, Wire wound, Fusible	FW20A47R0JA	Bourns
14	1	R2	RES, 510 Ω, 5%, 2 W, Metal Oxide Film	ERG-2SJ511	Panasonic
15	1	R3	RES, SMD, 1.2 Ω, 1%, 1/8W, 0805	CRCW08051R20FKEA	Vishay-Dale
16	1	R4	RES, SMD, 1.6 Ω, 1%, 1/8W, 0805	CRCW08051R60FKEA	Vishay-Dale
17	1	R5	RES, 12.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1242V	Panasonic
18	1	R6	RES, 51 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-51K	Yageo
19	1	R7	RES, 0 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
20	1	R8	RES, 100 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ104V	Panasonic
21	1	R9	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
22	1	R10	RES, 51 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-51K	Yageo
23	1	RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
24	1	RV1	275 VAC, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
25	1	T1	Bobbin, EE10, Vertical, 8 pins (10.2 mm W x 10.4 mm L x 9.7 mm H)	EE-1016	Yulongxin
26	1	U1	LYTSwitch-7, Dimmable, SO-8	LYT7503D	Power Integrations

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7 Inductor Specification

7.1 *Electrical Diagram*

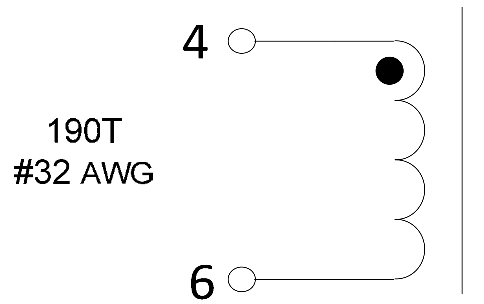

Figure 6 – Inductor Electrical Diagram.

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.	1500 μH
Tolerance	Tolerance of primary inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE10.
[2]	Bobbin: EE10, Vertical, 8 pins.
[3]	Magnet Wire: #32 AWG.
[4]	Transformer Tape: 6.5 mm.
[5]	Transformer Tape: 4.0 mm.

7.4 *Inductor Build Diagram*

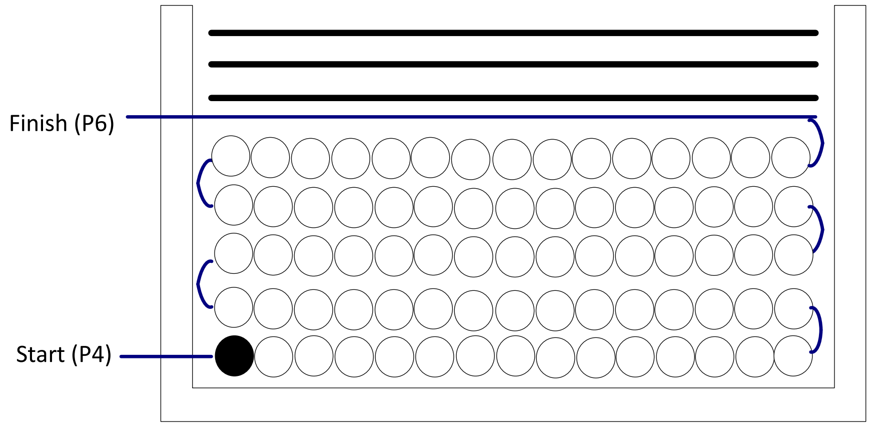

Figure 7 – Transformer Build Diagram.

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 counterclockwise.
Winding 1	Use wire item [3], start at pin 4 and wind 190 turns. On the last layer spread winding evenly across the bobbin width. Terminate the winding on pin 6.
Insulation	Add 3 layers of tape, item [4], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 1500 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 3 layers of tape, item (5).
Pins	Pull out terminal pin no. 1, 2, 3, 5 and 7.
Finish	Dip the transformer assembly in varnish.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch7_ Buck_062416; Rev.0; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-7 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMIN	**90**		90	V	Minimum AC line voltage
VACTYP	**230**		230	V	Typical AC line voltage
VACMAX	**300**		300	V	Maximum AC line voltage
FL			50	Hz	AC mains frequency
VO	**60**	Info1	60	V	!!Info1. VO is higher than recommended output voltage. Verify CC regulation.
IO	**125**		125	mA	Average output current specification
EFFICIENCY			0.90		Efficiency estimate
PO			7.50	W	Continuous output power
VD			0.70	V	Output diode forward voltage drop
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE			725	V	This Spreadsheet supports 725V device only
DEVICE	**Auto**		LYT7503D		Actual LYTSwitch-7 device
ILIMITMIN			1.06	A	Minimum Current Limit
ILIMITTYP			1.15	A	Typical Current Limit
ILIMITMAX			1.24	A	Maximum Current Limit
TON			2.24	us	On-time during the fixed on-time region at VACTYP
FSW			72	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.77		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	**7.0**		7.0		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN			991	uH	Absolute minimum design inductance
LP_TYP	**1500**	Warning	1500	uH	!!!Warning. LP is out of range. Decrease LP.
LP_TOLERANCE			5	%	Tolerance of the design inductance
LP_MAX			811	uH	Absolue maximum design inductance
TURNS	**190**		190	Turns	Number of inductor turns
ALG			41.55	nH/turn^2	Inductance per turns squared
BMAX			3699	Gauss	Actual saturation flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.348	mm	Core air gap
BWE			46.20	mm	Effective bobbin width
OD			0.24	mm	Outer diameter of the wire with insulation
INS			0.05	mm	Wire insulation
DIA			0.20	mm	Outer diameter of the wire without insulation
AWG			33		AWG of the bare wire.
CM			51	Cmils	Bare wire circular mils
CMA			299	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			3.7	A/mm^2	Bare wire current density

BOBBIN FILL FACTOR			94.56%		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			0.45	A	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.08	A	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.15	A	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.17	A	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB_T			0.622	Ohms	Theoretical calculation of the feedback pin sense resistor
RFB			0.619	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Components					
RUPPER			402.00	kOhms	Upper resistor on the M-pin divider network (E96 / 1%)
RLOWER			13.00	kOhms	Lower resistor on the M-pin divider network (E96 /1%)
VO_OVP			75.9	V	VO overvoltage threshold
Line_OVP			462	V	Line overvoltage threshold
CC			100	pF	Coupling Capacitor for Low Side Buck Configuration
RPRELOAD			60	kOhms	Minimum Output Preload Resistor
CBP			10	uF	BP Capacitor
RBP			172	kOhms	Recommended Pull-up Resistor from DC Bus to BP pin
VOLTAGE STRESS PARAMETERS					
VDRAIN			424	V	Estimated worst case drain voltage
PIVD			424	V	Output Rectifier Maximum Peak Inverse Voltage

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

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9 Performance Data

All measurements were performed at room temperature using LED load 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*

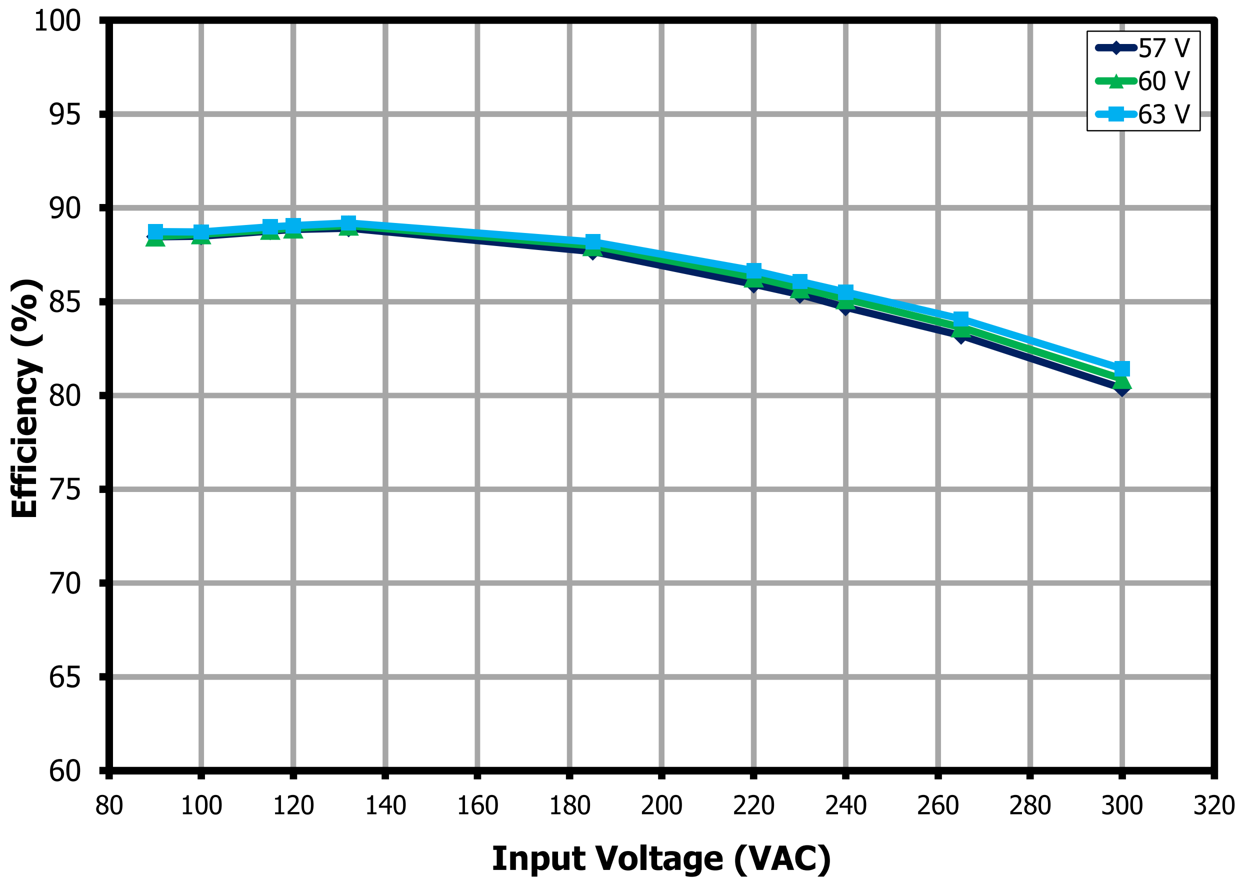

Figure 8 – Efficiency vs. Line and LED Load.

9.2 *Line Regulation*

9.2.1 Low Line Input

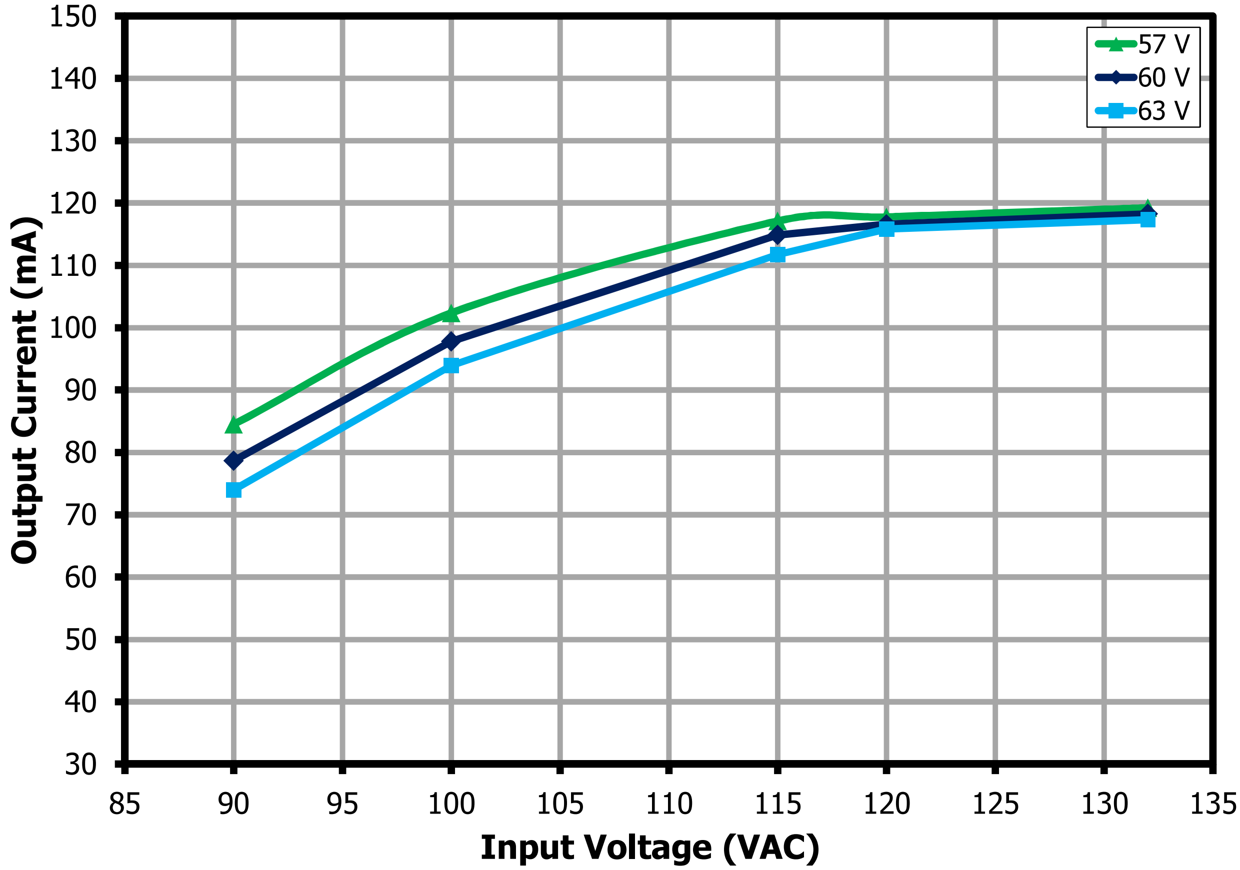

Figure 9 – Regulation vs. Line and LED Load (Low Line).

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9.2.2 High Line Input

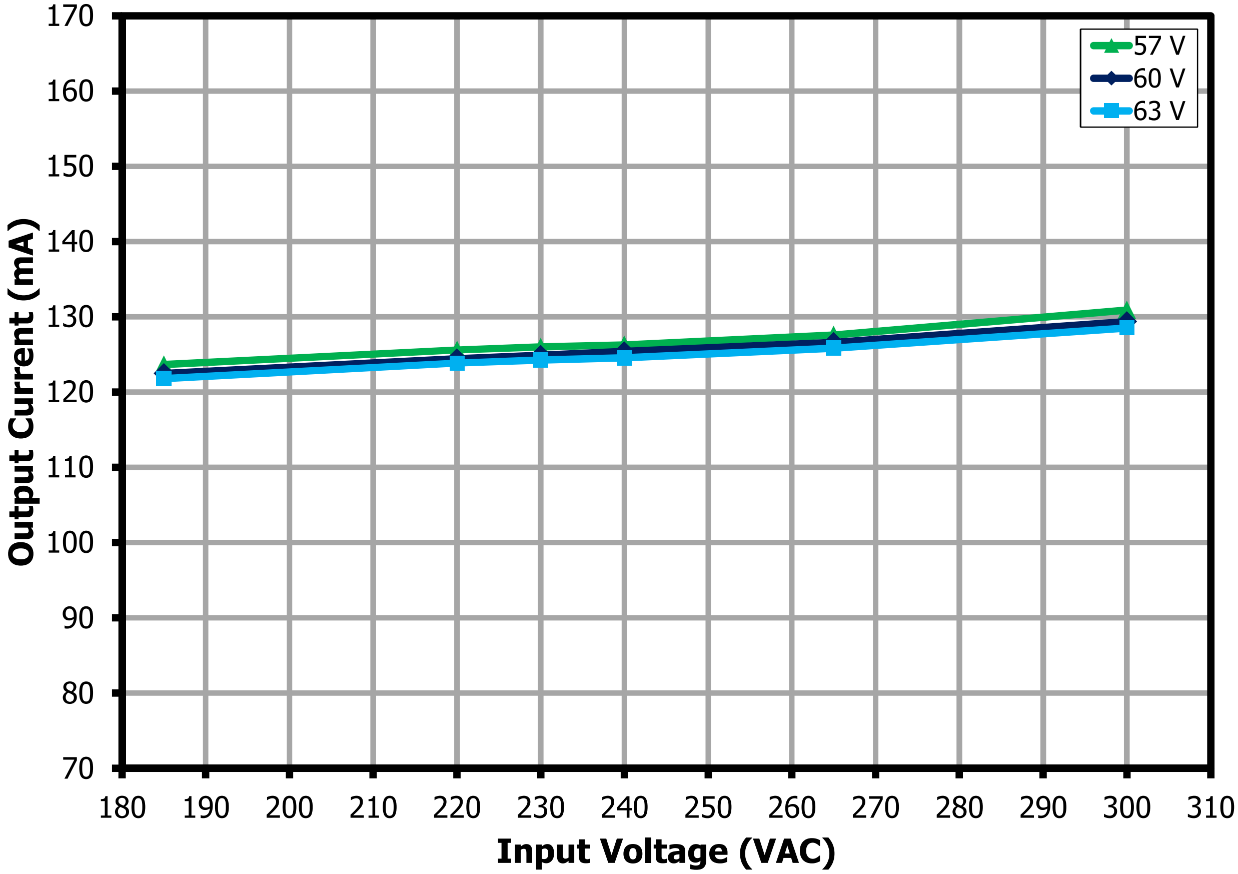

Figure 10 – Regulation vs. Line and LED Load (High Line).

9.3 *Power Factor*

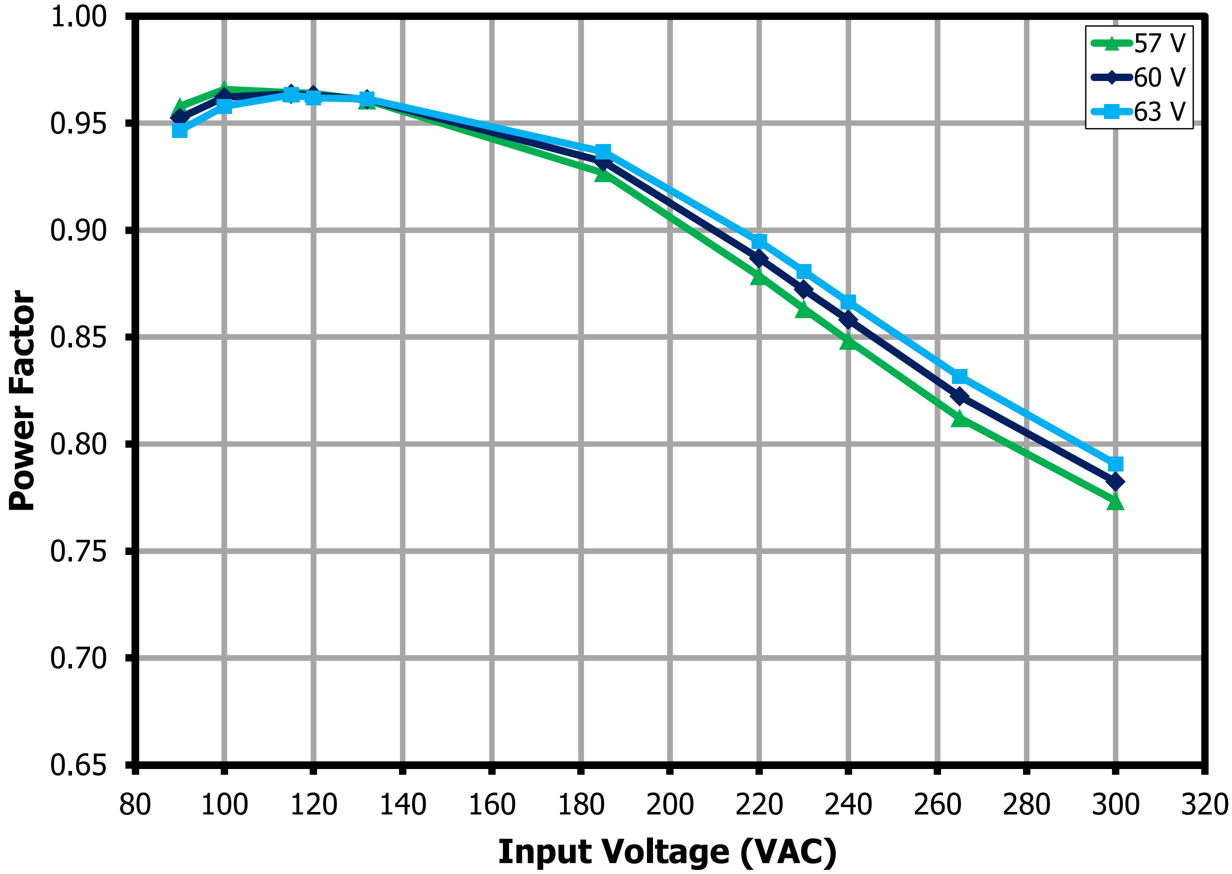

Figure 11 – Power Factor vs. Line and LED Load.

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9.4 *%ATHD*

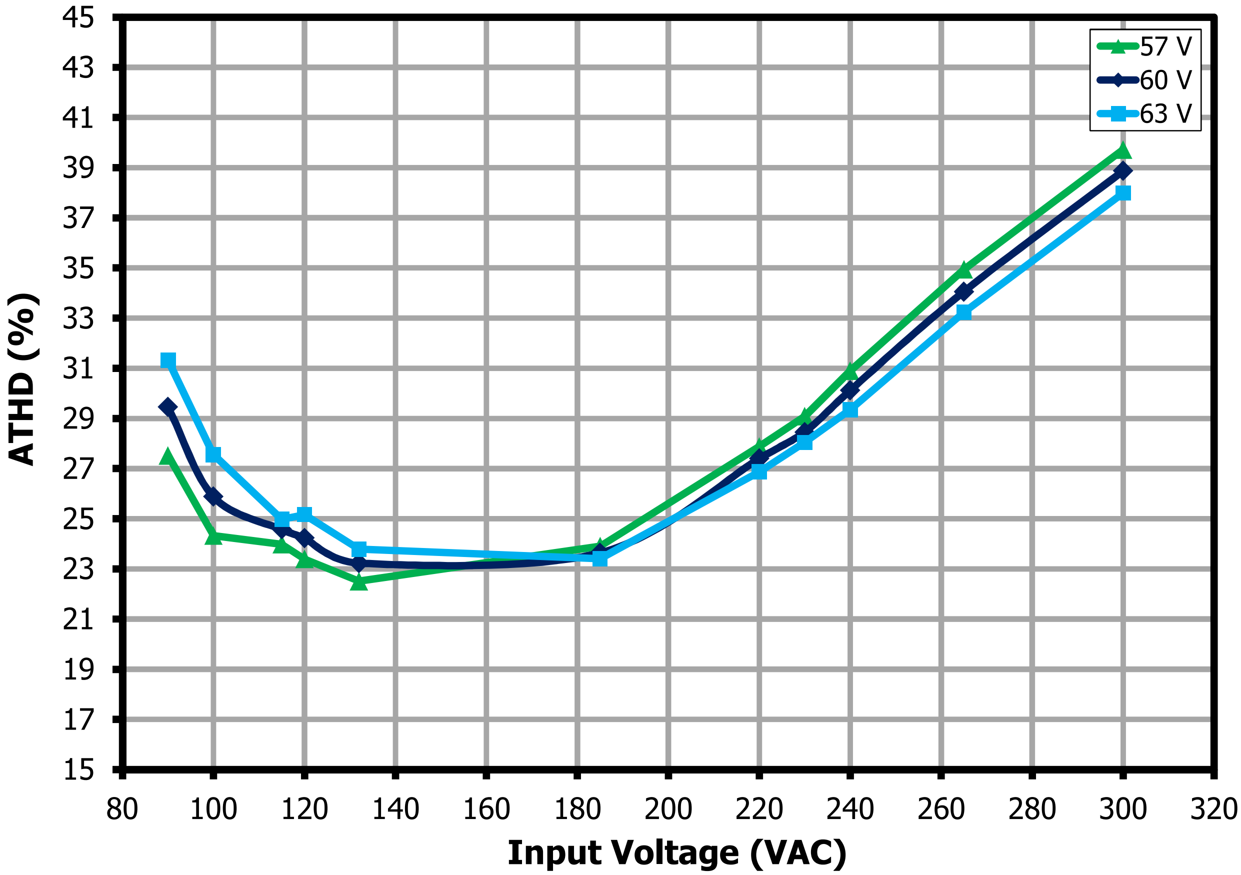

Figure 12 – %ATHD vs. Line and LED Load.

9.5 *Individual Harmonics Content*

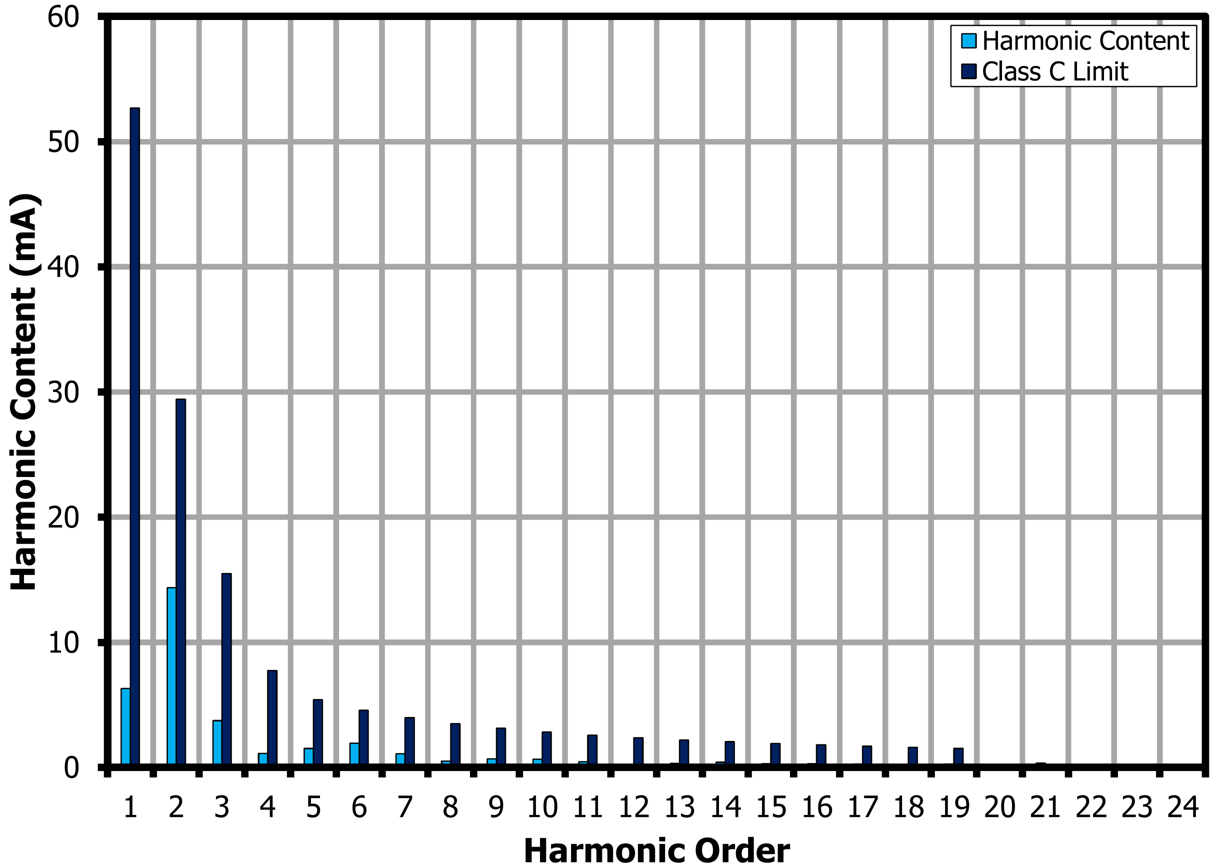

Figure 13 – 60 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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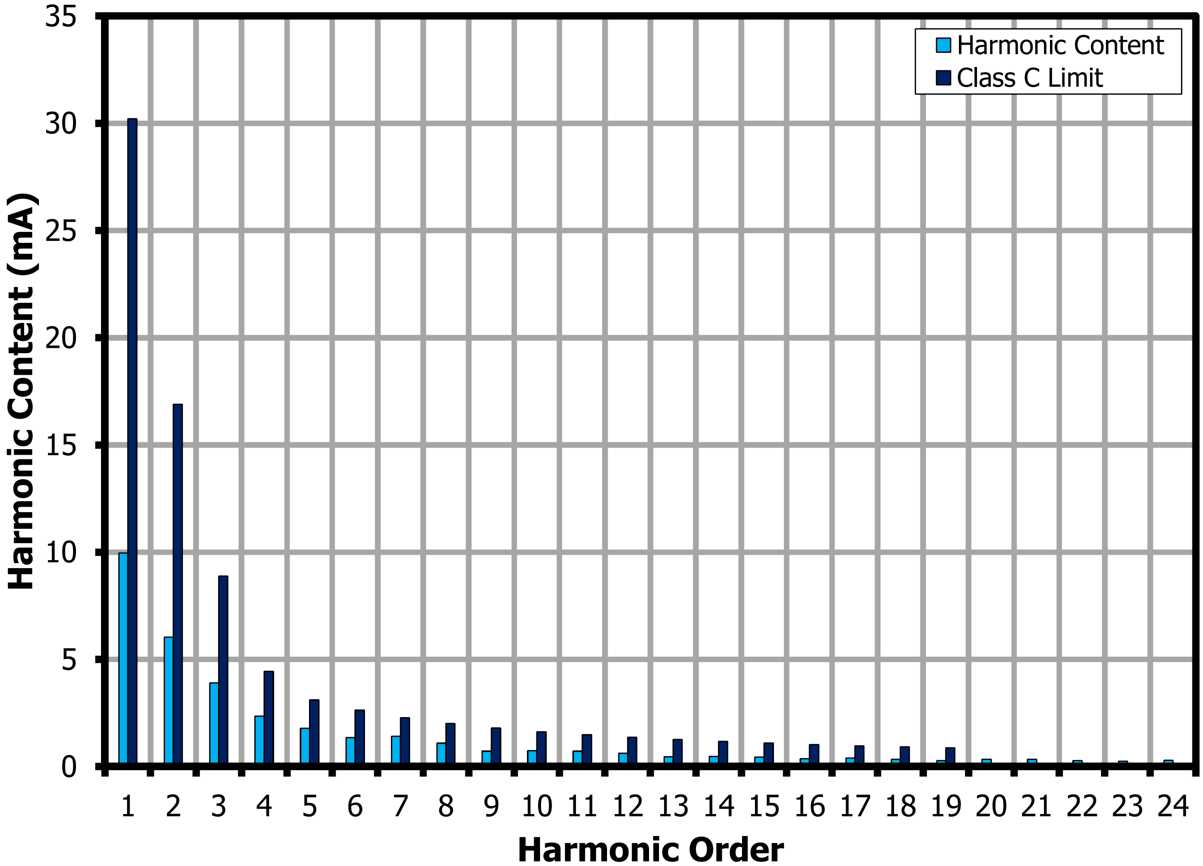

Figure 14 – 60 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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	89.95	61.48	5.30	0.958	27.53	55.40	84.51	4.69	88.46
100	60	99.96	67.52	6.52	0.966	24.33	56.30	102.37	5.77	88.50
115	60	114.94	67.91	7.53	0.964	23.98	56.99	117.12	6.68	88.76
120	60	119.90	65.42	7.56	0.964	23.40	57.00	117.78	6.72	88.85
132	60	131.97	60.40	7.66	0.961	22.51	57.06	119.24	6.81	88.91
185	50	184.95	47.15	8.08	0.927	23.90	57.25	123.63	7.08	87.67
220	50	219.96	43.40	8.39	0.879	27.88	57.33	125.59	7.21	85.92
230	50	229.98	42.64	8.47	0.863	29.09	57.34	125.96	7.23	85.37
240	50	240.00	42.01	8.55	0.848	30.89	57.35	126.26	7.25	84.70
265	50	265.01	40.92	8.81	0.812	34.94	57.40	127.58	7.33	83.19
300	50	300.03	40.39	9.37	0.774	39.71	57.54	130.87	7.53	80.38

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	89.94	60.27	5.16	0.952	29.46	58.02	78.68	4.57	88.48
100	60	99.96	67.82	6.52	0.962	25.88	59.05	97.78	5.78	88.58
115	60	114.93	69.97	7.75	0.964	24.58	59.88	114.88	6.88	88.83
120	60	119.91	68.11	7.87	0.963	24.23	59.95	116.60	6.99	88.92
132	60	131.97	62.87	7.97	0.961	23.23	60.02	118.25	7.10	89.05
185	50	184.95	48.65	8.39	0.932	23.64	60.21	122.45	7.38	87.98
220	50	219.96	44.61	8.70	0.887	27.40	60.29	124.44	7.51	86.30
230	50	229.97	43.82	8.79	0.872	28.45	60.30	124.90	7.54	85.72
240	50	239.99	43.17	8.89	0.858	30.12	60.31	125.39	7.57	85.14
265	50	265.01	41.95	9.14	0.822	34.057	60.36	126.58	7.65	83.63
300	50	300.03	41.23	9.68	0.782	38.869	60.49	129.35	7.83	80.88

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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	89.95	59.40	5.06	0.947	31.32	60.63	73.99	4.49	88.73
100	60	99.96	68.34	6.54	0.958	27.55	61.77	93.92	5.81	88.72
115	60	114.94	71.15	7.88	0.963	24.98	62.69	111.73	7.01	88.98
120	60	119.90	70.97	8.18	0.962	25.16	62.89	115.83	7.29	89.06
132	60	131.97	65.32	8.29	0.961	23.79	62.95	117.33	7.39	89.18
185	50	184.95	50.38	8.73	0.937	23.41	63.16	121.78	7.70	88.19
220	50	219.96	45.95	9.05	0.895	26.87	63.25	123.83	7.84	86.65
230	50	229.98	45.11	9.14	0.881	28.04	63.26	124.25	7.86	86.08
240	50	239.99	44.34	9.22	0.867	29.35	63.26	124.54	7.88	85.50
265	50	265.01	43.03	9.48	0.832	33.23	63.32	125.83	7.97	84.08
300	50	300.02	42.23	10.02	0.791	37.99	63.44	128.51	8.16	81.43

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

V	Freq	I (mA_{RMS})	P	%THD
115	60.00	69.97	7.7490	24.575
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Remarks**
1	66.03			
2	0.04	0.06%		
3	6.33	9.59%	52.6932	Pass
5	14.37	21.76%	29.4462	Pass
7	3.75	5.68%	15.4980	Pass
9	1.14	1.73%	7.7490	Pass
11	1.52	2.30%	5.4243	Pass
13	1.95	2.95%	4.5898	Pass
15	1.11	1.68%	3.9778	Pass
17	0.51	0.77%	3.5098	Pass
19	0.69	1.04%	3.1404	Pass
21	0.67	1.01%	2.8413	Pass
23	0.47	0.71%	2.5942	Pass
25	0.18	0.27%	2.3867	Pass
27	0.34	0.51%	2.2099	Pass
29	0.43	0.65%	2.0575	Pass
31	0.32	0.48%	1.9248	Pass
33	0.30	0.45%	1.8081	Pass
35	0.28	0.42%	1.7048	Pass
37	0.20	0.30%	1.6126	Pass
39	0.29	0.44%	1.5299	Pass

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

V	Freq	I (mA_{RMS})	P	%THD
230	50	43.17	8.8890	30.12
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Remarks**
1	41.10			
2	0.02	0.05%		
3	9.96	24.23%	30.2226	Pass
5	6.05	14.72%	16.8891	Pass
7	3.91	9.51%	8.8890	Pass
9	2.35	5.72%	4.4445	Pass
11	1.79	4.36%	3.1112	Pass
13	1.36	3.31%	2.6325	Pass
15	1.42	3.45%	2.2815	Pass
17	1.10	2.68%	2.0131	Pass
19	0.72	1.75%	1.8012	Pass
21	0.75	1.82%	1.6297	Pass
23	0.73	1.78%	1.4879	Pass
25	0.62	1.51%	1.3689	Pass
27	0.47	1.14%	1.2675	Pass
29	0.48	1.17%	1.1801	Pass
31	0.44	1.07%	1.1040	Pass
33	0.37	0.90%	1.0371	Pass
35	0.40	0.97%	0.9778	Pass
37	0.34	0.83%	0.9249	Pass
39	0.29	0.71%	0.8775	Pass

11 Dimming Performance

11.1 *Dimming Curve*

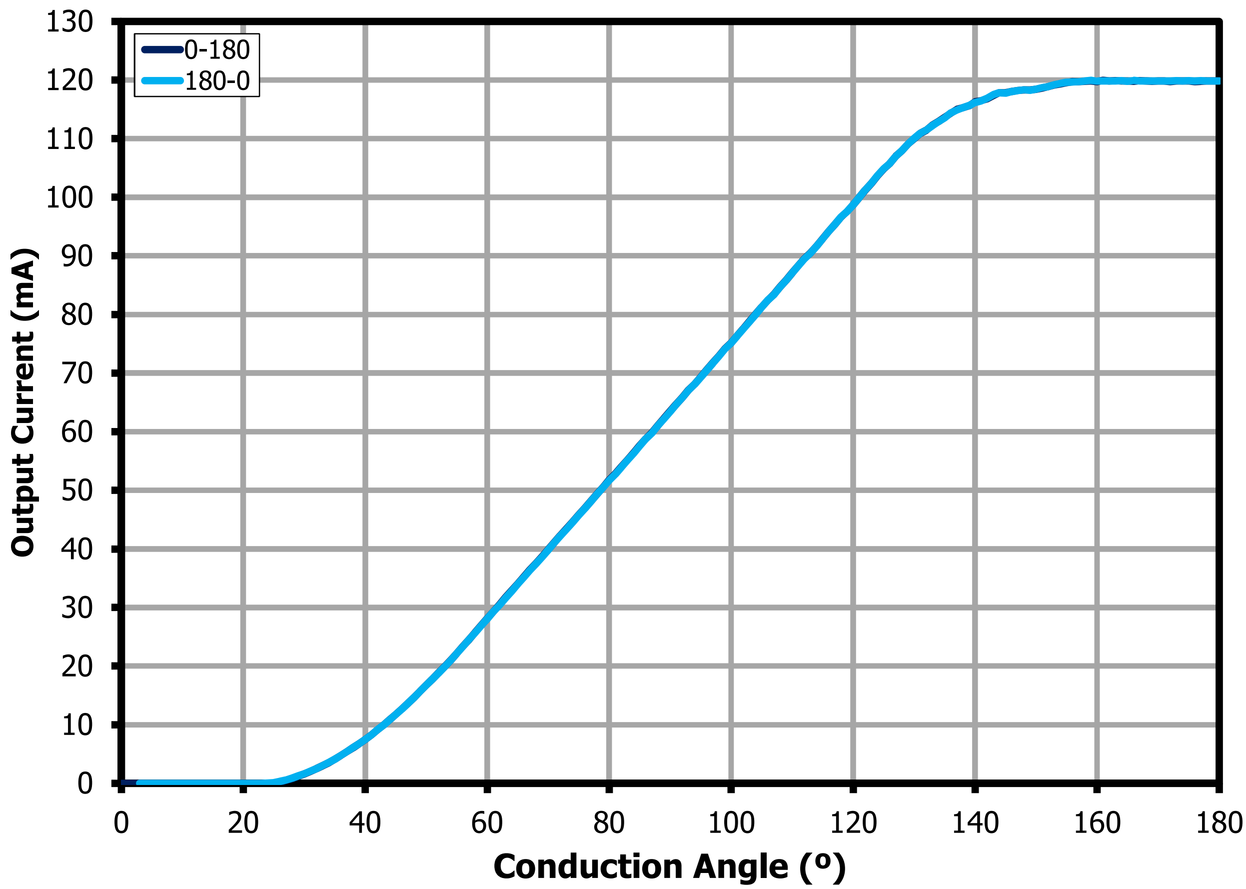

Figure 15 – Dimming Curve at 115 VAC, 60 Hz Input.

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11.2 *Dimming Efficiency*

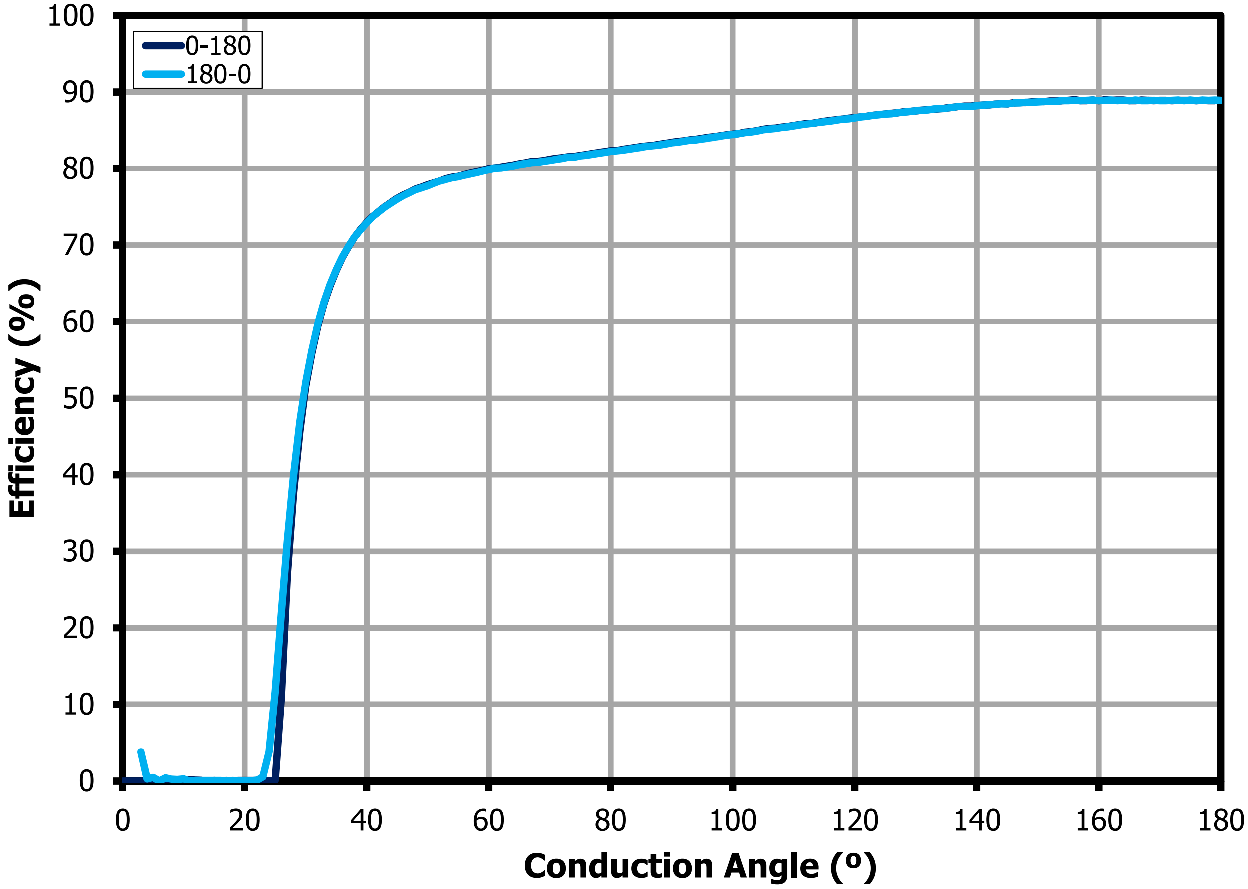

Figure 16 – Dimming Efficiency at 115 VAC, 60 Hz Input.

11.3 *Dimming System Loss*

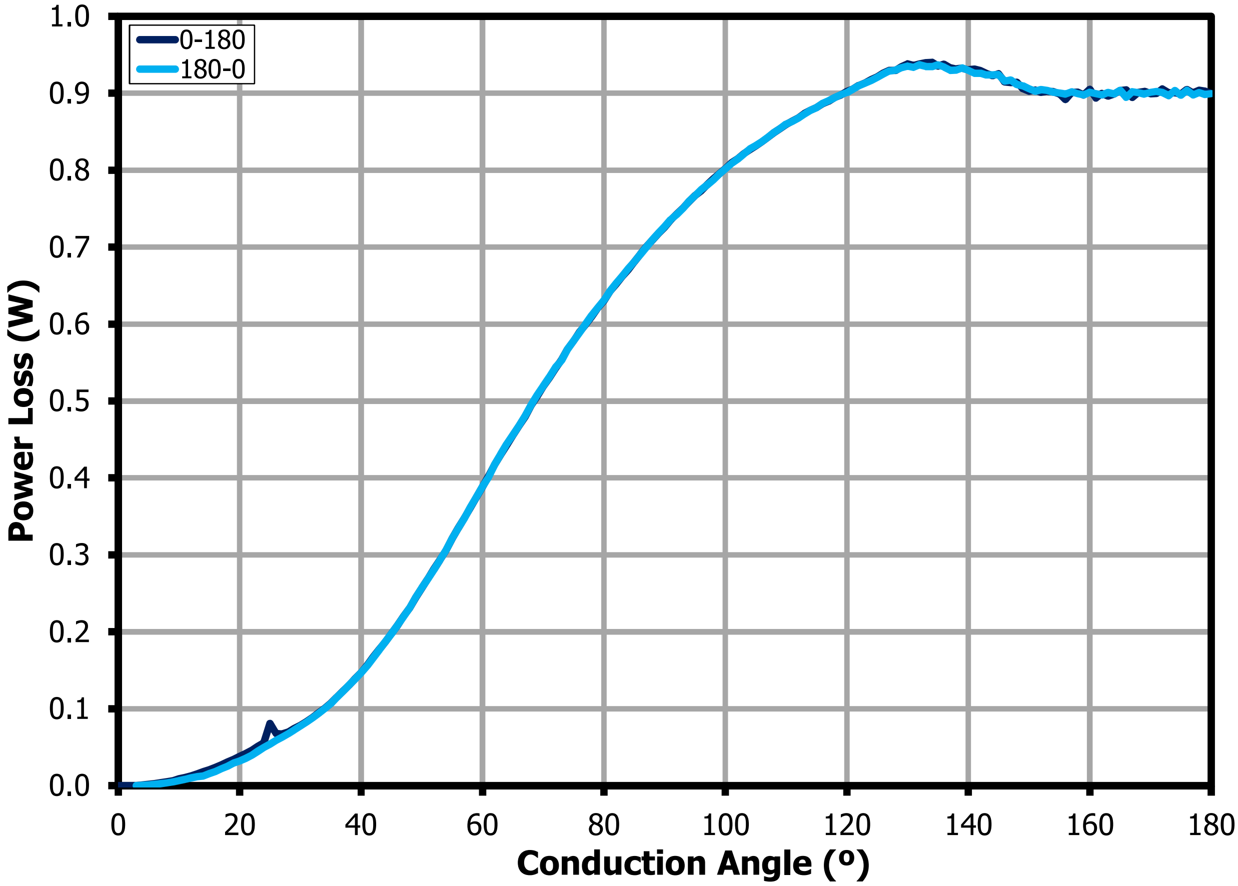

Figure 17 – Dimming Power Loss at 115 VAC, 60 Hz Input.

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11.4 *Dimming Scoresheet*

No	Brand	Model	Type	Max (mA)	Min (mA)	Remarks
1	LUTRON	AY-10PNL-WH	L	112.2	10.6	No Flicker
2	LUTRON	AY-603PG-WH	L	59.5	3.8	No Flicker
3	LUTRON	AYLV-600P-WH	L	94.2	3.8	No Flicker
4	LUTRON	AYLV-603P-WH	L	91.3	3.6	No Flicker
5	LUTRON	GLV-600-IV	L	104	3.7	No Flicker
6	LUTRON	LG-600PH-WH	L	91.1	3.7	No Flicker
7	LUTRON	DV-600P-WH	L	90.7	3.5	No Flicker
8	LUTRON	DV-603P-WH	L	90	7.3	No Flicker
9	LUTRON	DVLV-103P-WH	L	89.4	5	No Flicker
10	LUTRON	DVLV-10P-WH	L	88.2	5	No Flicker
11	LUTRON	DVPDC-203P-WH	L	102.4	5	No Flicker
12	LUTRON	DVWCL-153PH-WH	L	90.5	0.12	No Flicker
13	LUTRON	GL-600-WH	L	86.4	0.92	No Flicker
14	LUTRON	LG-603PGH-WH	L	64.9	3.8	No Flicker
15	LUTRON	CTCL-153P-WH	L	90.5	0.27	No Flicker
16	LEVITON	R02-06613-PLW	L	113	4.5	No Flicker
17	LUTRON	S-103P-WH	L	90.4	4.8	No Flicker
18	LUTRON	S-10P-WH	L	89.6	3.4	No Flicker
19	LUTRON	S-600-WH	L	85.4	0.02	No Flicker
20	LUTRON	LGCL-153PLH-WH	L	91.2	0.66	No Flicker
21	LUTRON	TGCL-153PH-WH	L	91.4	0.45	No Flicker
22	LUTRON	CTCL-153PDH-WH	L	91	0.2	No Flicker
23	COOPER	DAL06P-C2	L	112.9	8.5	No Flicker
24	COOPER	SAL06P	L	113	7.2	No Flicker
25	LEVITON	IPL06	L	94.2	4.4	No Flicker
26	LEVITON	6674	L	95.1	4.2	No Flicker
27	LEGRAND	HCL453PTCCCV6	L	89.7	18.4	No Flicker
28	LEGRAND	H1103PTCCCV6	L	97.3	3.2	No Flicker
29	LUTRON	AYCL-153P-WH	L	91	0.6	No Flicker
30	LUTRON	N-600-WH	L	104	2.4	No Flicker
31	LUTRON	NT-603P-WH	L	106	2.6	No Flicker
32	LUTRON	DV-10P-WH	L	98.8	4.5	No Flicker
33	LUTRON	DVF-103P-WH	L	114	33	No Flicker
34	LEVITON	1PL06-10Z	L	94.5	4.2	No Flicker
35	LEVITON	6672	L	103	9.3	No Flicker
36	COOPER	SLC03P-W-K-L	L	96.6	43	No Flicker
37	LUTRON	SLV600P-WH	L	94.6	3.8	No Flicker
38	LEVITON	TGLV-600PR	L	94.2	3.8	No Flicker
39	LEVITON	1P106	L	95.7	4.2	No Flicker
40	LEVITON	6683	L	119.7	0.03	No Flicker
41	LEVITON	1P106-1LZ	L	112	8.3	No Flicker
42	LEVITON	6681	L	119	0.17	No Flicker
43	LUTRON	AY-600PNL-WH	L	95.5	3.8	No Flicker
44	LUTRON	S-600P-WH	L	93.4	2.81	No Flicker
45	LUTRON	NT-600-WH	L	104.9	2.3	No Flicker
46	LEVITON	6674	L	95.1	4.2	No Flicker
47	LEGRAND	HLV703PW	L	96	3.3	No Flicker
48	LEVITON	6641	L	89.5	19.5	No Flicker
49	LEVITON	6602	L	119.5	0.06	No Flicker
50	LEVITON	TBL03	L	107.7	9.8	No Flicker
51	LUTRON	CTCL-153P-WH	L	90.8	0.19	No Flicker

12 Thermal Performance

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

Measurement	Ambient	LYTSwitch-7	T1	R1	C6	L1	D1
Final (ºC)	73.3	80.9	78.8	85.5	76.9	78.4	79.6

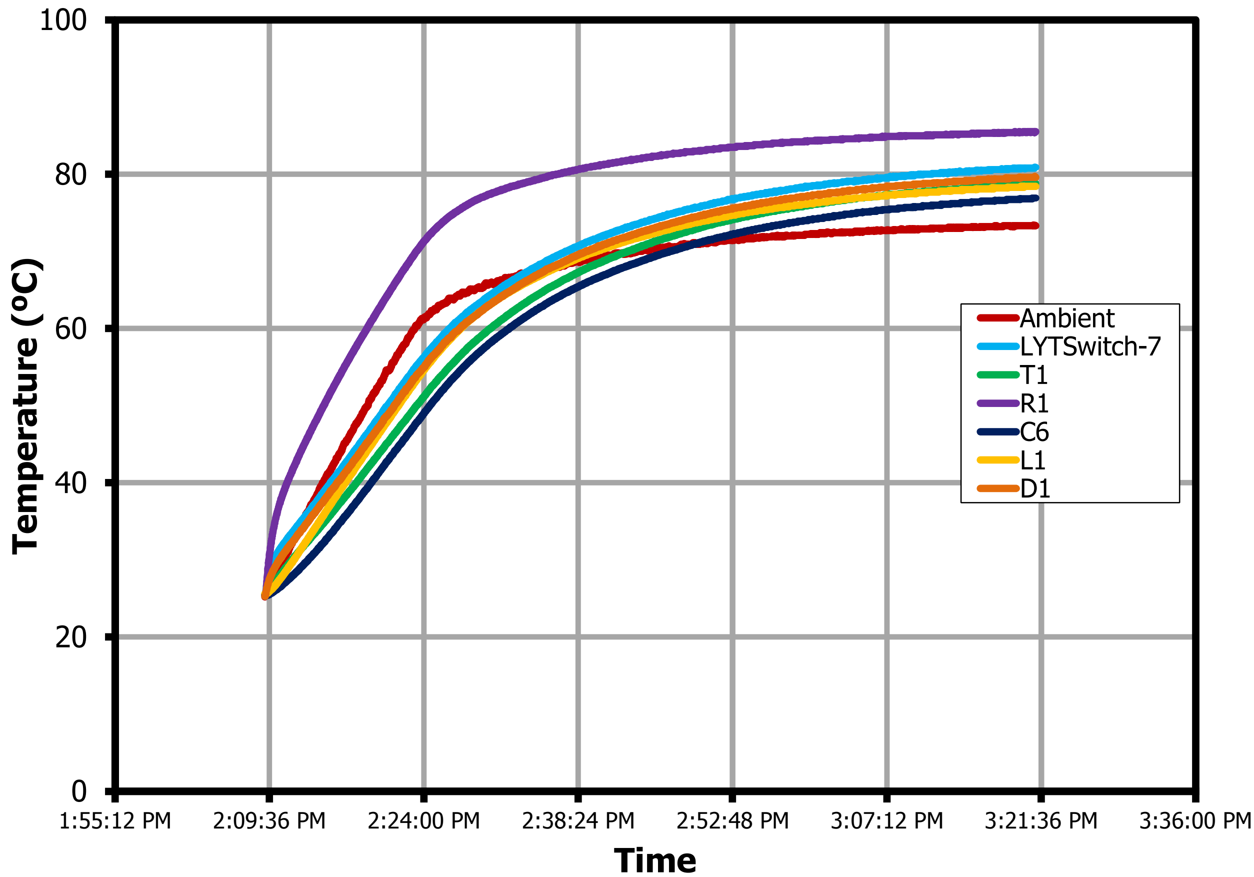

Figure 18 – Component Temperature at 90 VAC, 60 V LED Load, 75 ºC Ambient.

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

Measurement	Ambient	LYTSwitch-7	T1	R1	C6	L1	D1
Final (ºC)	74.1	87.8	85.9	92.8	81.2	83	86.1

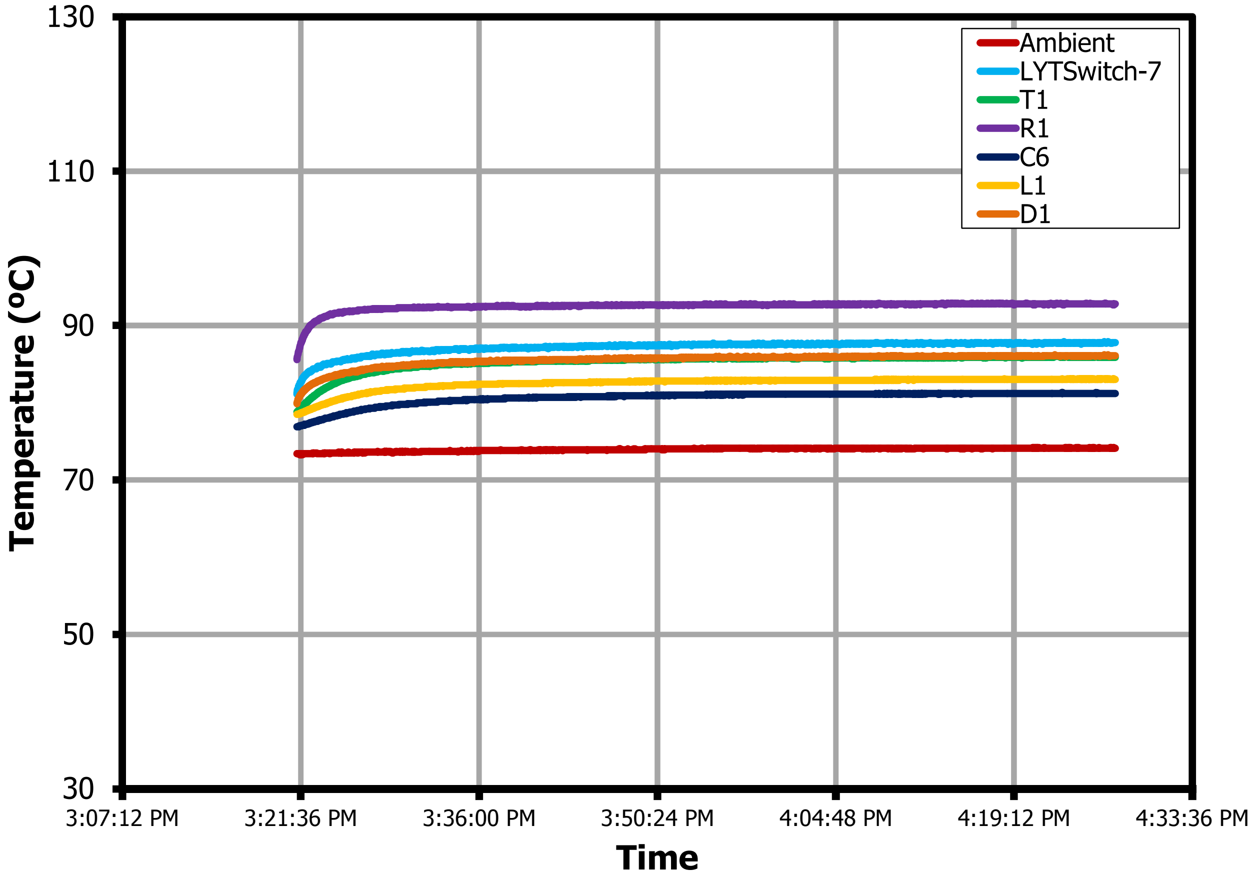

Figure 19 – Component Temperature at 115 VAC, 60 V LED Load, 75 ºC Ambient.

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

Measurement	Ambient	LYTSwitch-7	T1	R1	C6	L1	D1
Final (ºC)	74.8	97.4	92.4	81.7	86.7	83.6	97.5

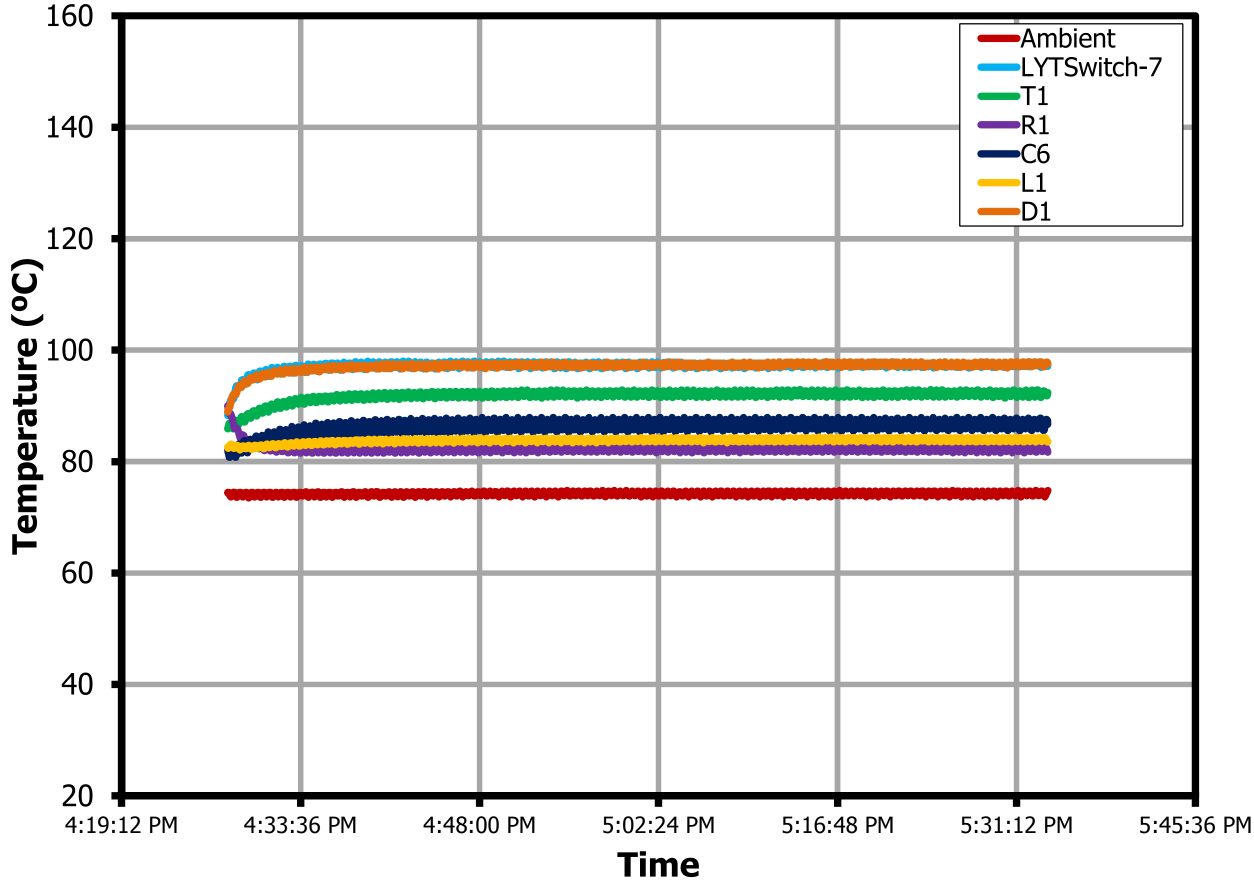

Figure 20 – Component Temperature at 230 VAC, 60 V LED Load, 75 ºC Ambient.

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12.1.4 Thermal Performance at 300 VAC with a 60 V LED Load

Measurement	Ambient	LYTSwitch-7	T1	R1	C6	L1	D1
Final (ºC)	74	108.8	98.3	82.2	91.3	87.9	108

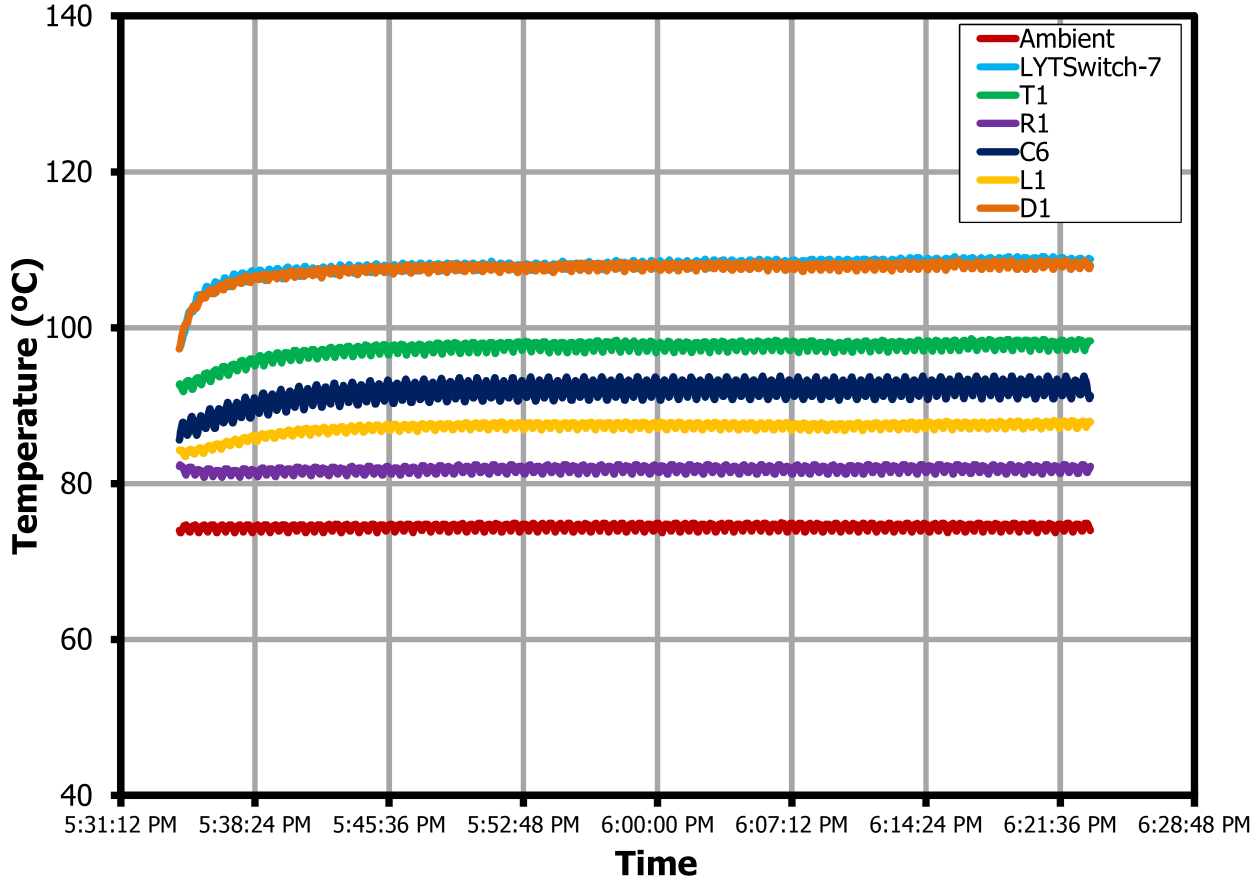

Figure 21 – Component Temperature at 300 VAC, 60 V LED Load, 75 ºC Ambient.

13 Waveforms

13.1 *Input Voltage and Input Current Waveforms*

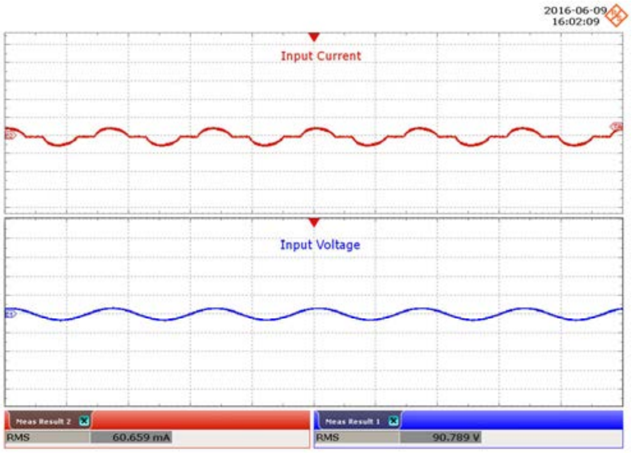

Figure 22 – 90 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

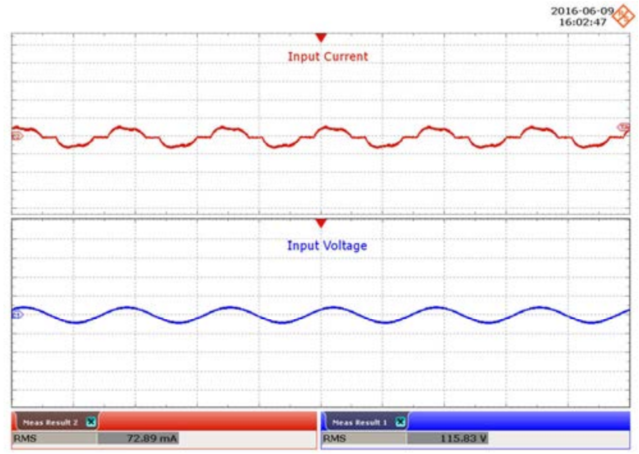

Figure 23 – 115 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

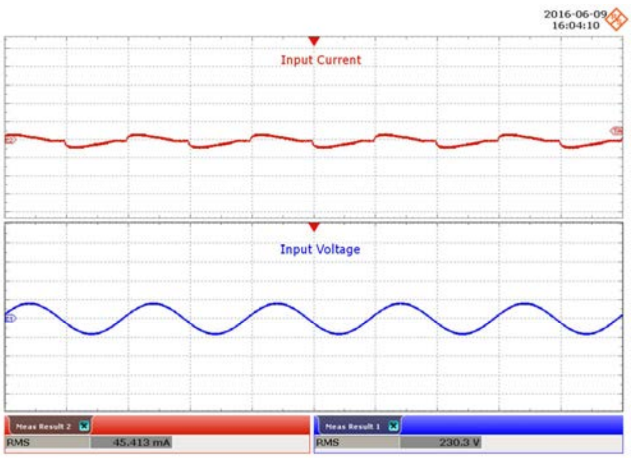

Figure 24 – 230 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

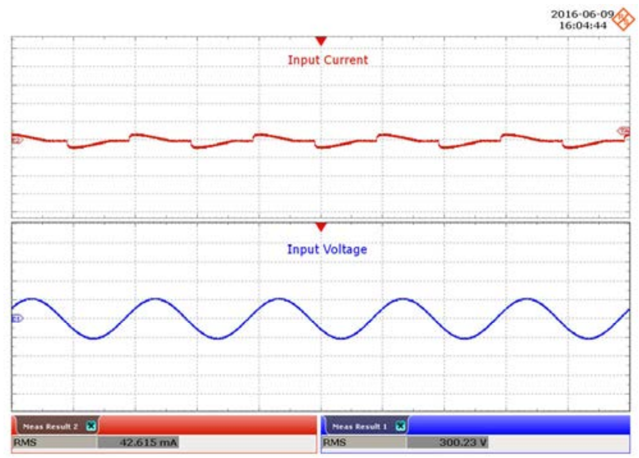

Figure 25 – 300 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 400 V / div., 10 ms / div.

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13.2 *Start-up Profile*

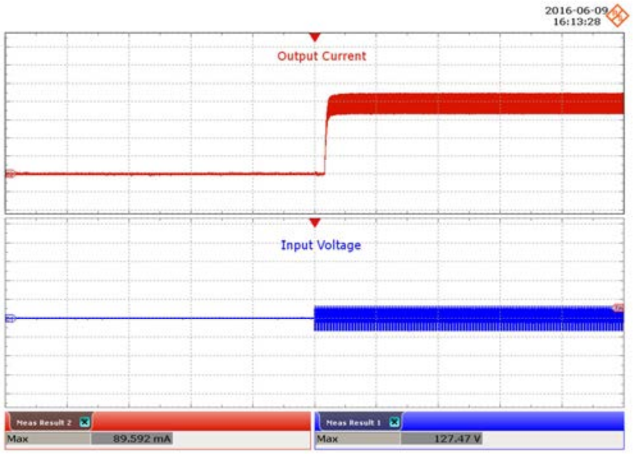

Figure 26 – 90 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 1 s / div.

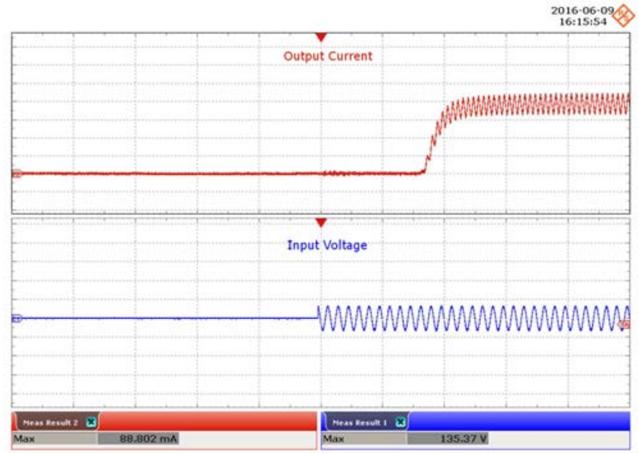

Figure 27 – 90 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

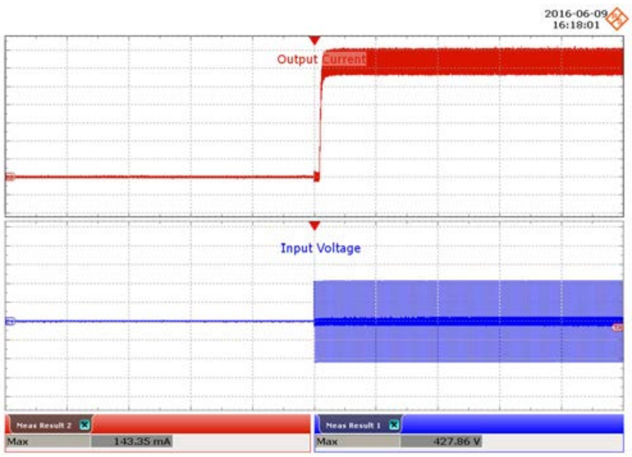

Figure 28 – 300 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 1 s / div.

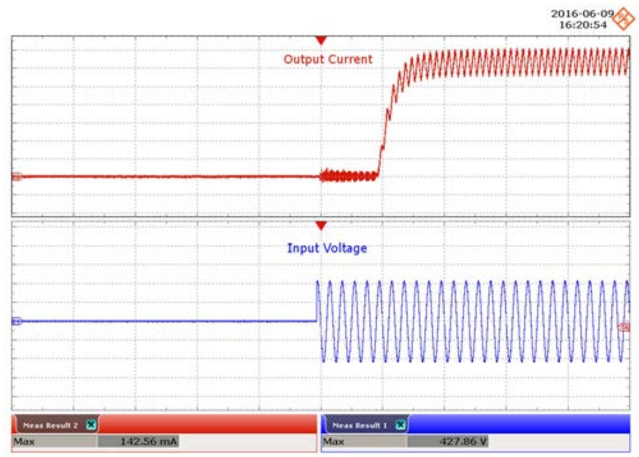

Figure 29 – 300 VAC, 60 V LED, Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

13.3 *Output Current Fall*

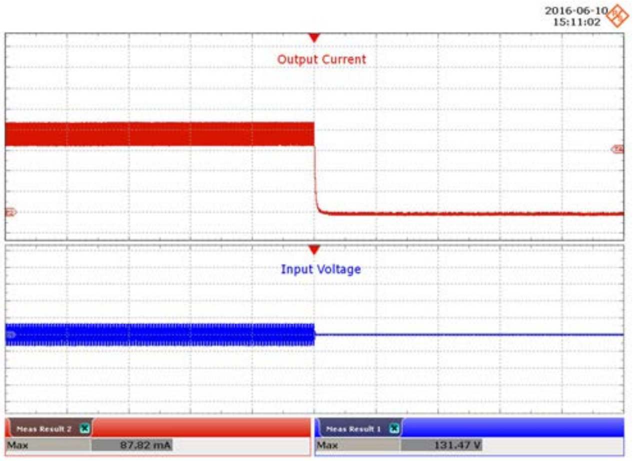

Figure 30 – 90 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 1 s / div.

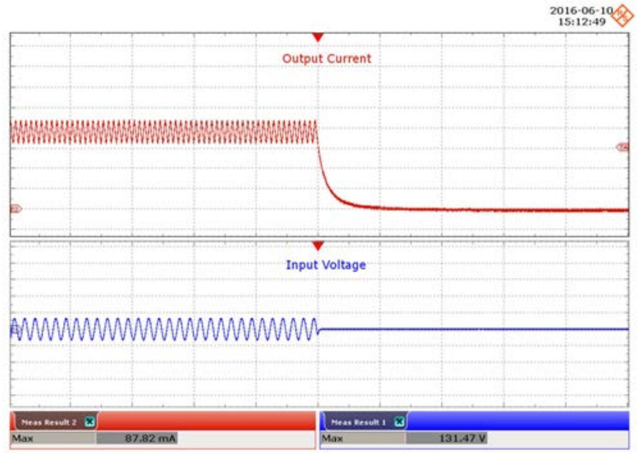

Figure 31 – 90 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

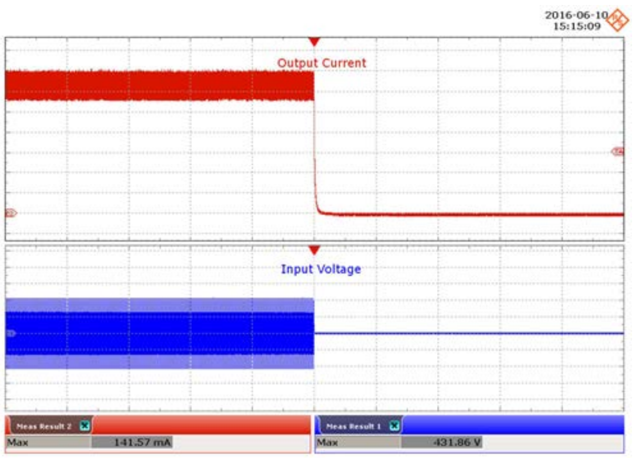

Figure 32 – 300 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 1 s / div.

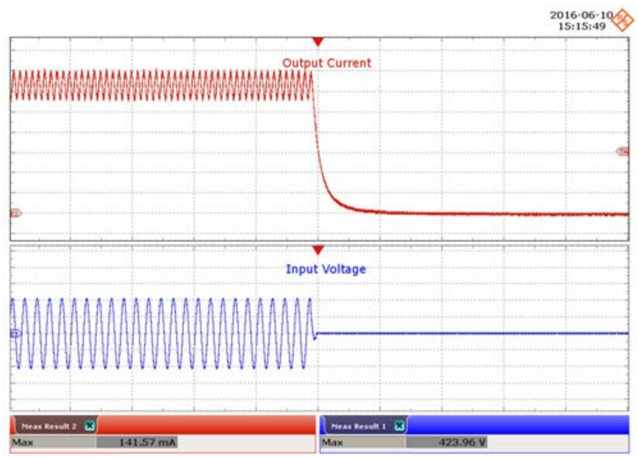

Figure 33 – 300 VAC, 60 V LED, Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 100 ms / div.

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13.4 *Drain Voltage and Current in Normal Operation*

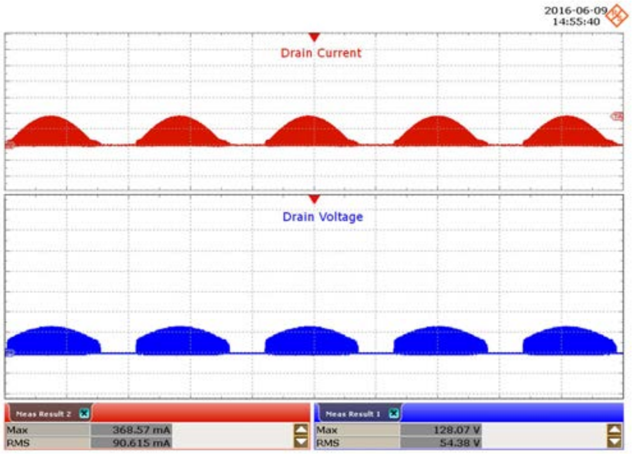

Figure 34 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 35 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

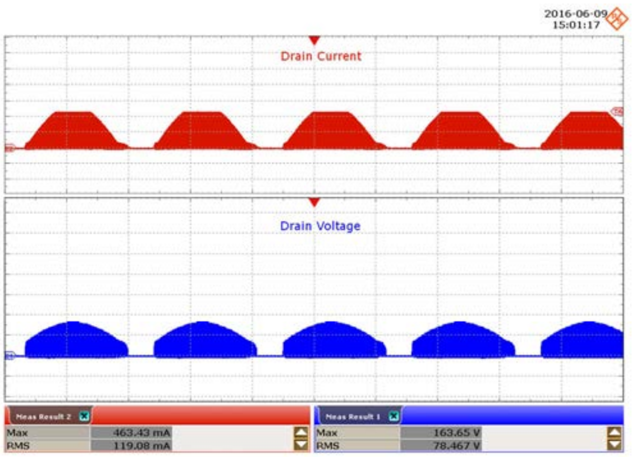

Figure 36 – 115 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

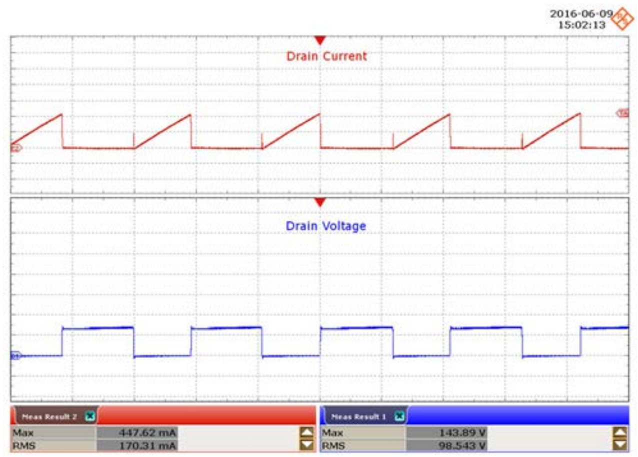

Figure 37 – 115 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

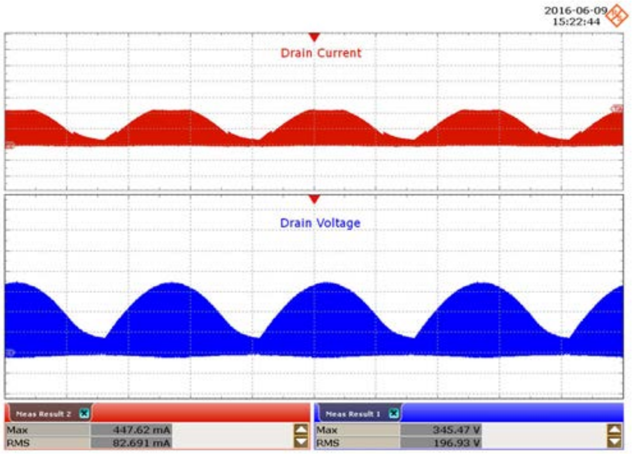

Figure 38 – 230 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 39 – 230 VAC, 60V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

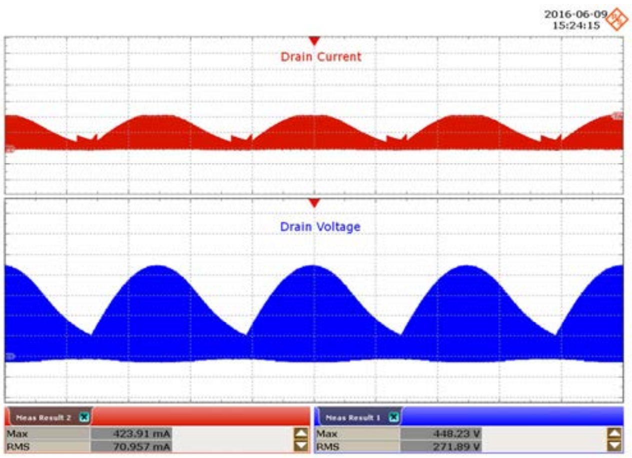

Figure 40 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.

Figure 41 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

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13.5 *Drain Voltage and Current Start-up Profile*

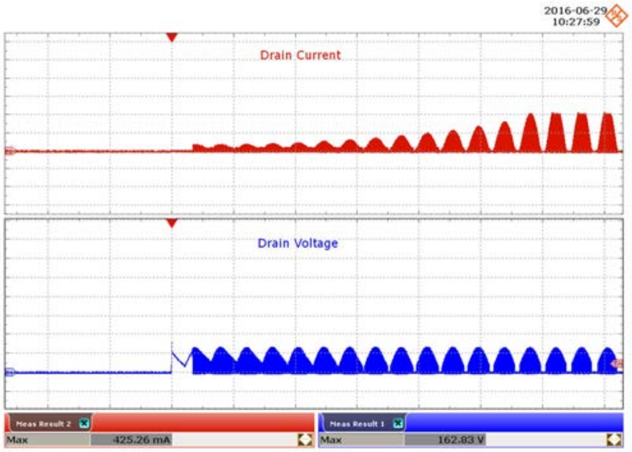

Figure 42 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

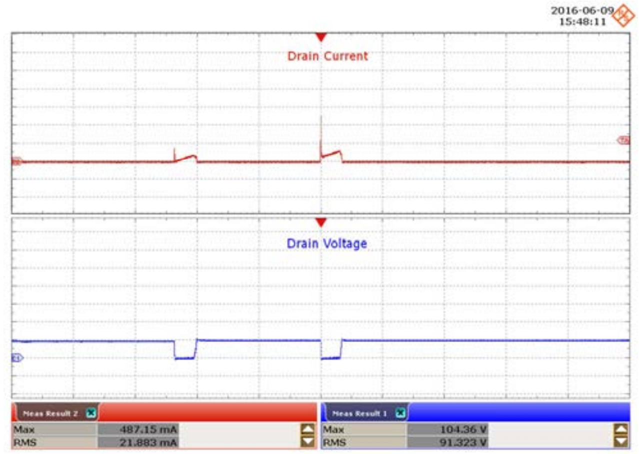

Figure 43 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

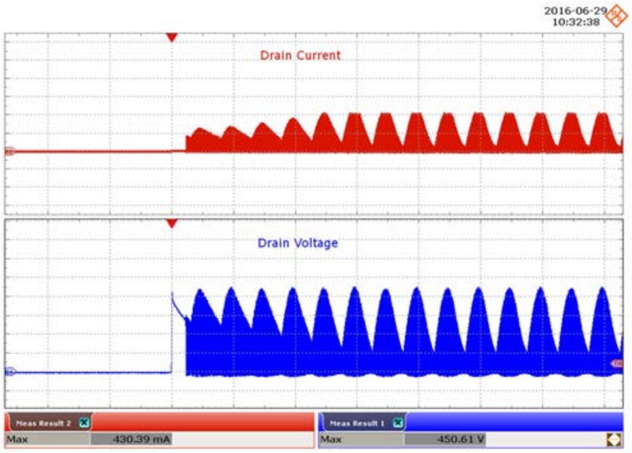

Figure 44 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

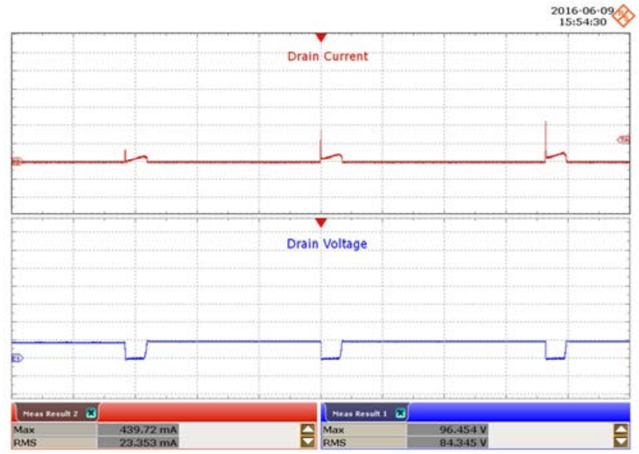

Figure 45 – 300 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 µs / div.

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

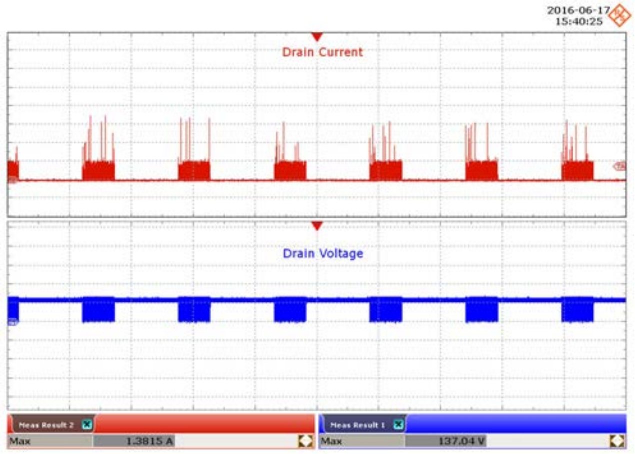

Figure 46 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

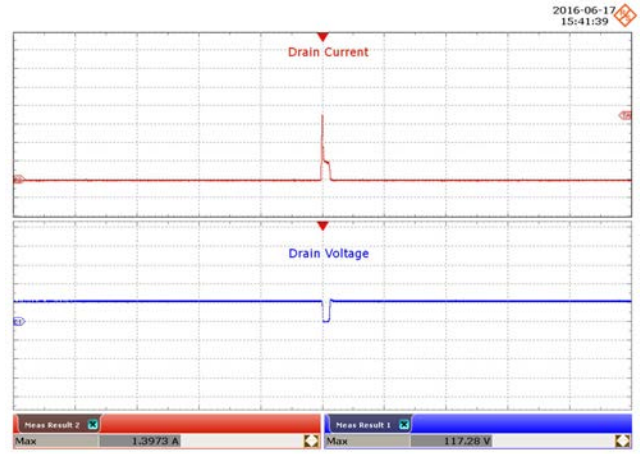

Figure 47 – 90 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.

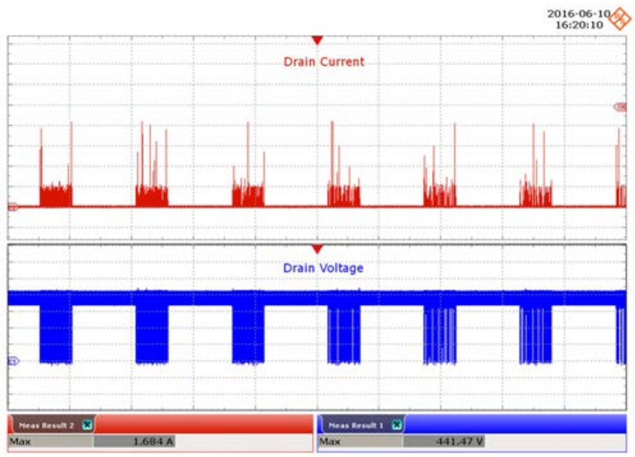

Figure 48 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms / div.

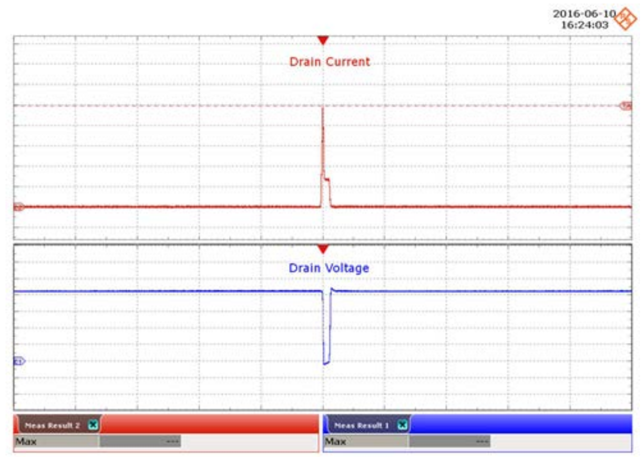

Figure 49 – 300 VAC, Output Short-Circuit.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.

Input Power During Short-Circuit		
VAC (V_{RMS})	**Freq (Hz)**	**P (W)**
90	60	0.251
115	60	0.278
230	50	0.952
300	50	1.695

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13.7 *Output Diode Voltage and Current in Normal Operation*

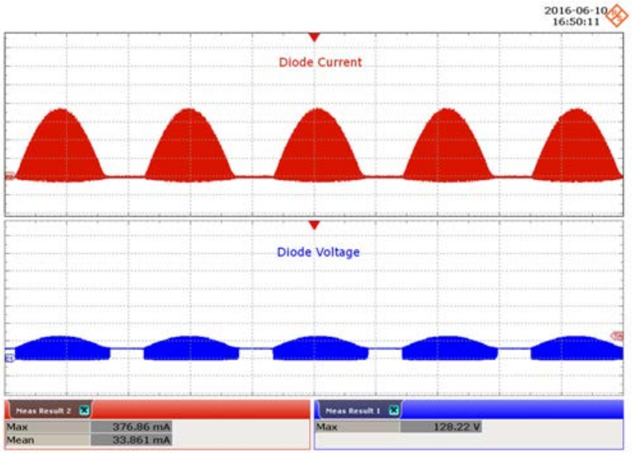

Figure 50 – 90 VAC, 60 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 100 V / div., 4 ms / div.

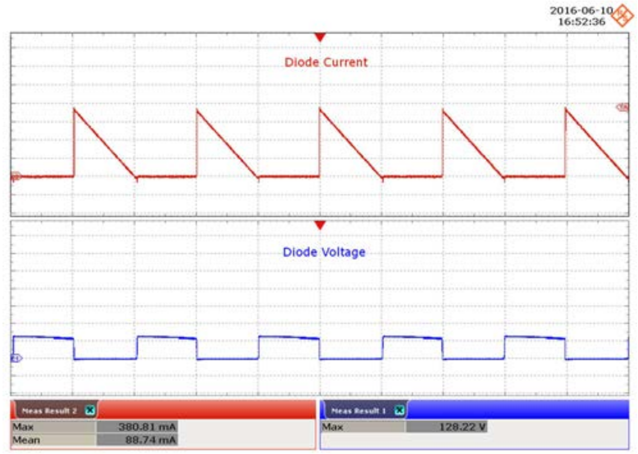

Figure 51 – 90 VAC, 60 V LED Load.
Upper: I_{D1}, 100 mA / div.
Lower: V_{D1}, 100 V / div., 10 μs / div.

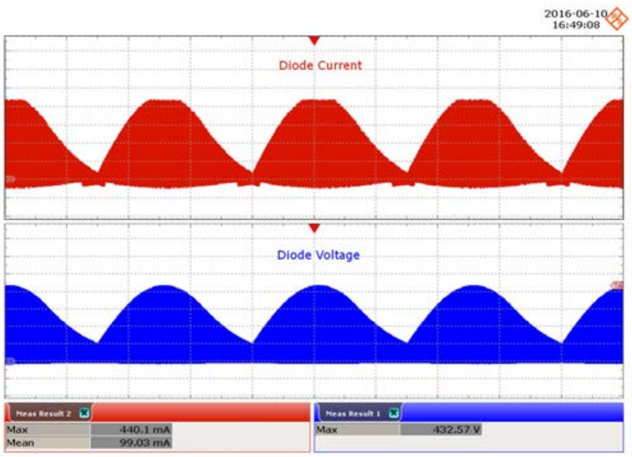

Figure 52 – 300 VAC, 60 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 ms / div.

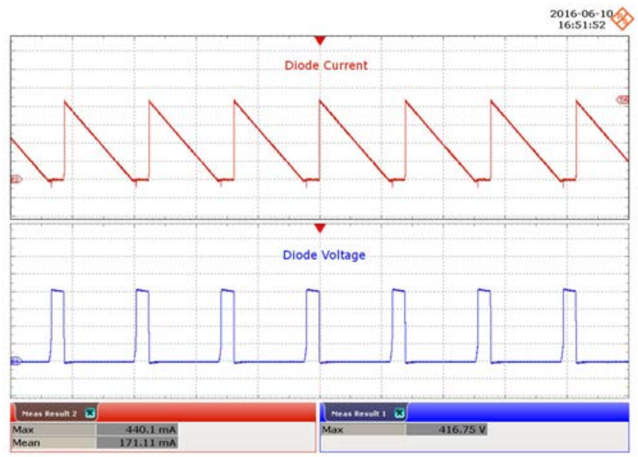

Figure 53 – 300 VAC, 60 V LED Load.
Upper: I_{D1}, 200 mA / div.
Lower: V_{D1}, 40 V / div., 4 μs / div.

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

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

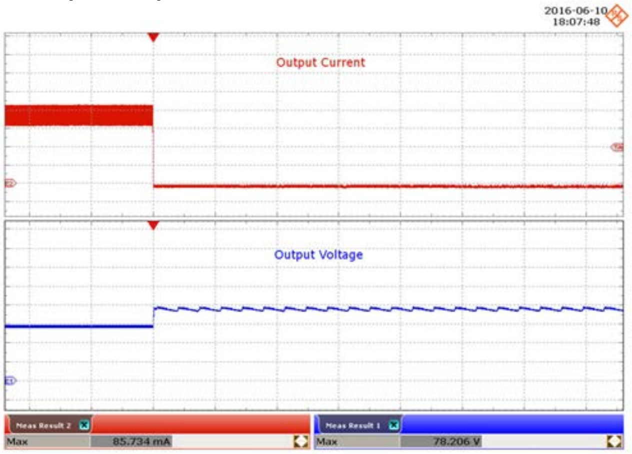

Figure 54 – 90 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

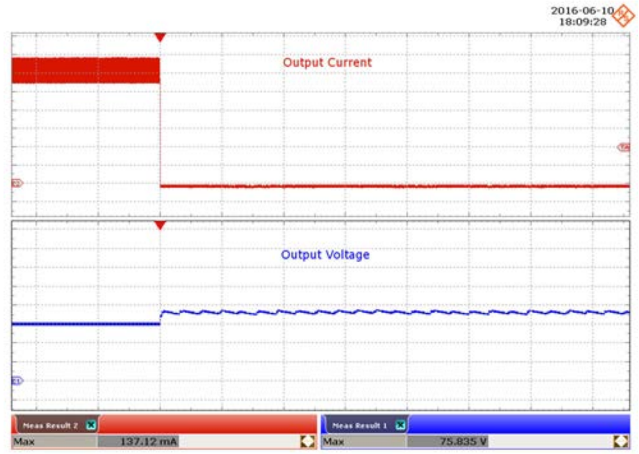

Figure 55 – 300 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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

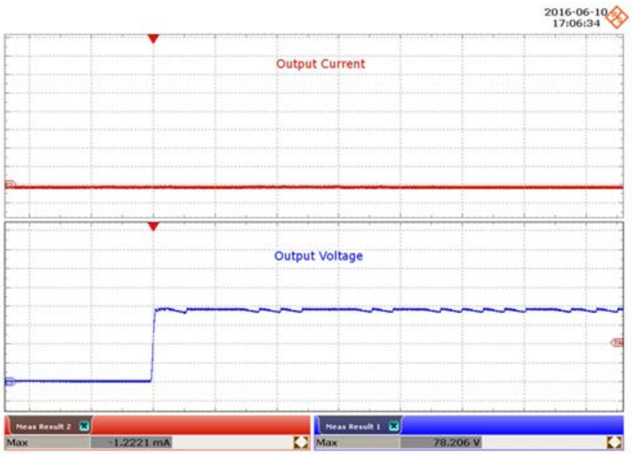

Figure 56 – 90 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

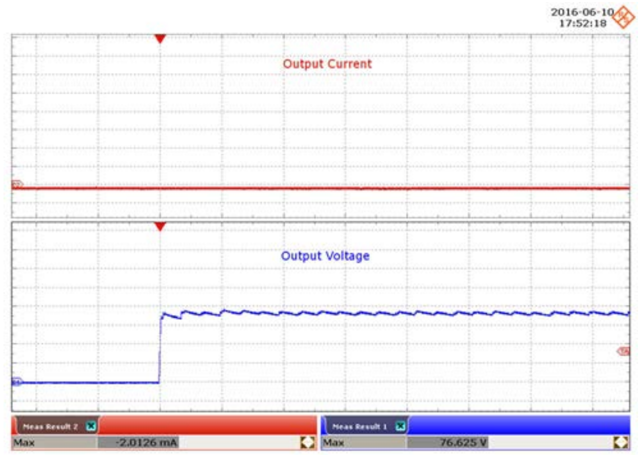

Figure 57 – 300 VAC, Open Load,
Open Load Start-up.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V / div., 4 s / div.

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13.10 *Output Ripple Current*

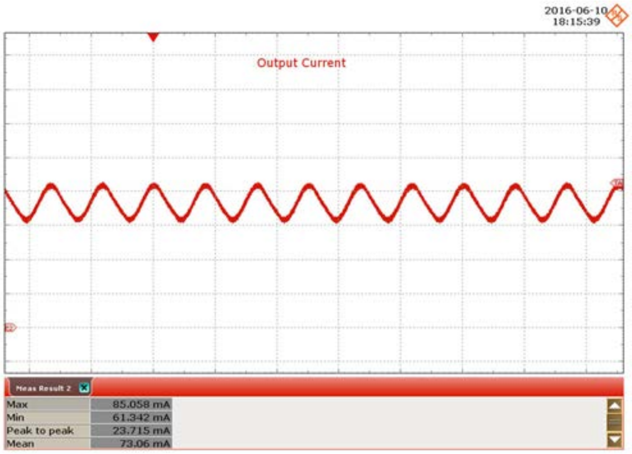

Figure 58 – 90 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

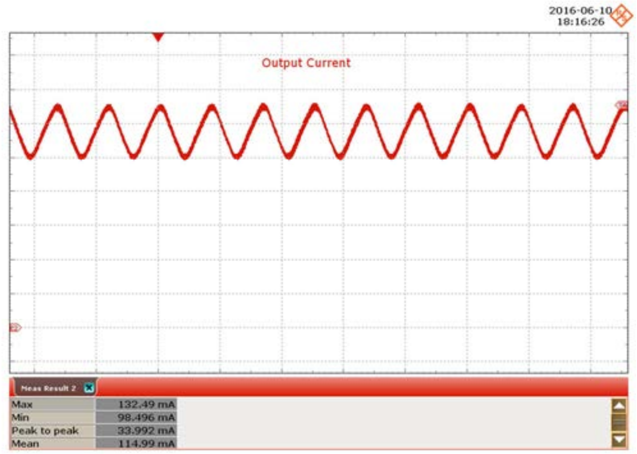

Figure 59 – 115 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

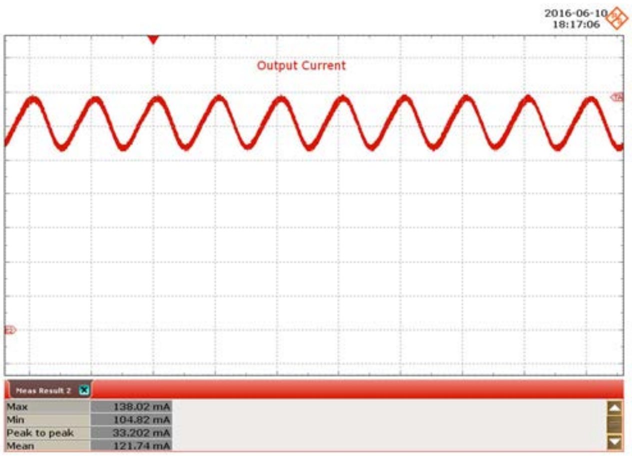

Figure 60 – 230 VAC, 50 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

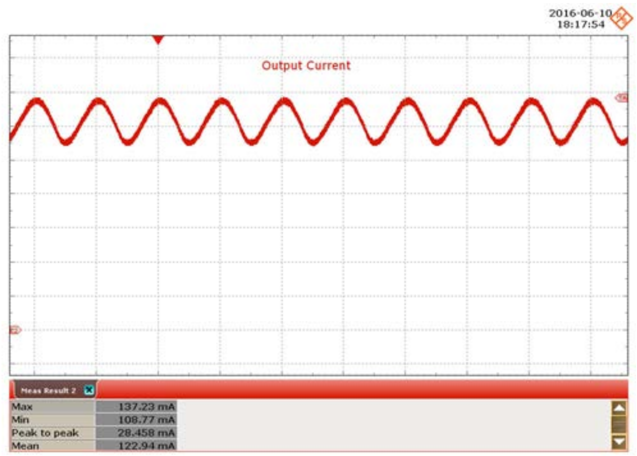

Figure 61 – 300 VAC, 50 Hz, 60 V LED Load.
Upper: I_{OUT}, 20 mA / div., 10 ms / div.

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	85.058	61.342	73.06	0.324	16.2%
115	132.49	98.496	114.99	0.296	14.7%
230	138.02	104.82	121.74	0.273	13.7%
300	137.23	108.77	122.94	0.231	12.6%

14 Dimming Waveforms

14.1 *Lutron N-600-WH*

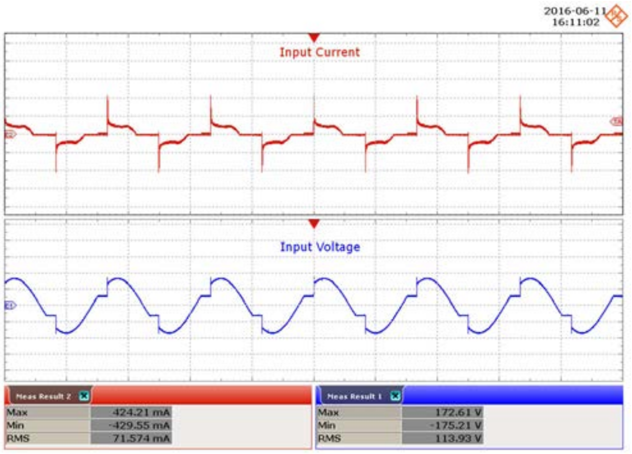

Figure 62 – 120 VAC, 60 Hz, 60 V LED Load.
180° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

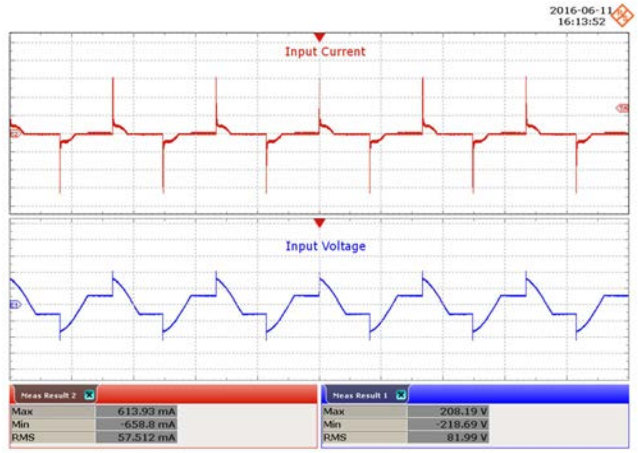

Figure 63 – 120 VAC, 60 Hz, 60 V LED Load.
90° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

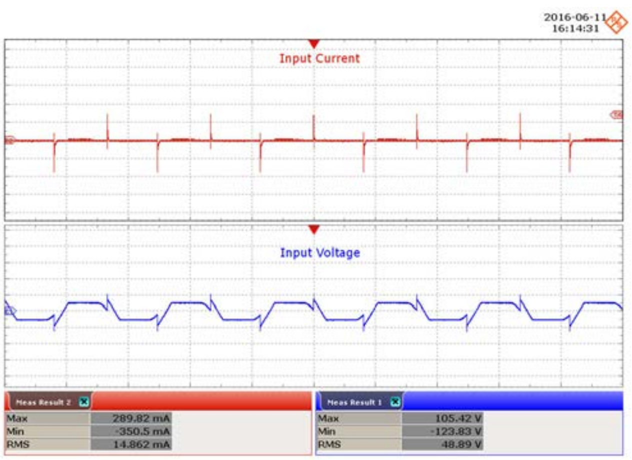

Figure 64 – 120 VAC, 60 Hz, 60 V LED Load.
Minimum Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

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15 AC Cycling Test

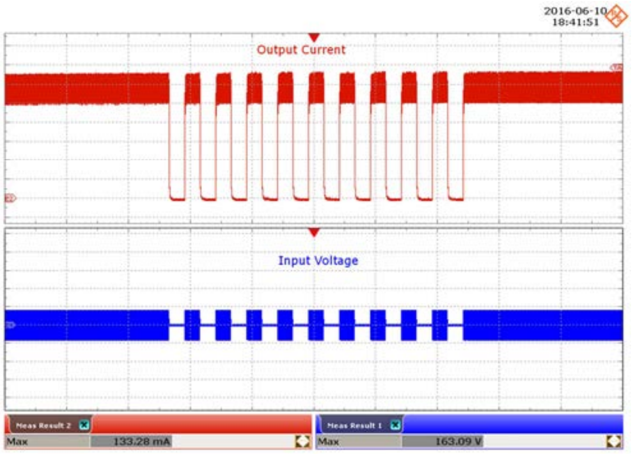

Figure 65 – 115 VAC, 60 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 4 s / div.

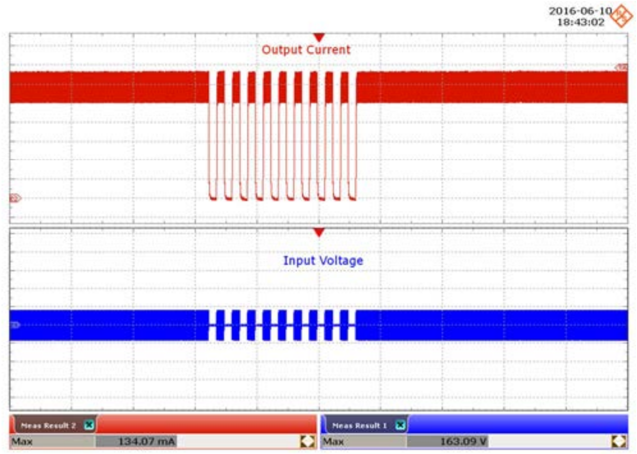

Figure 66 – 115 VAC, 60 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 4 s / div.

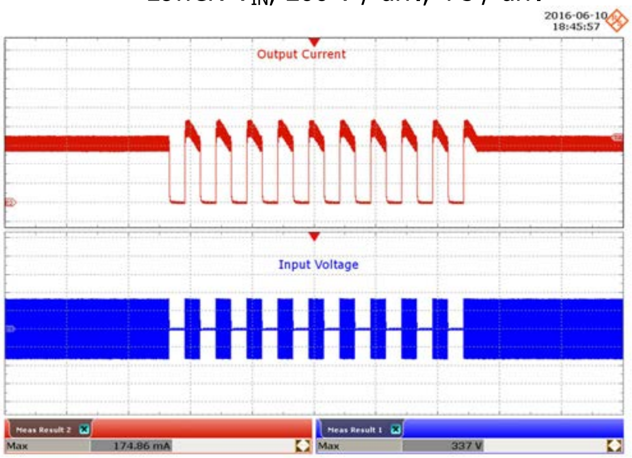

Figure 67 – 230 VAC, 60 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 200 V / div., 4 s / div.

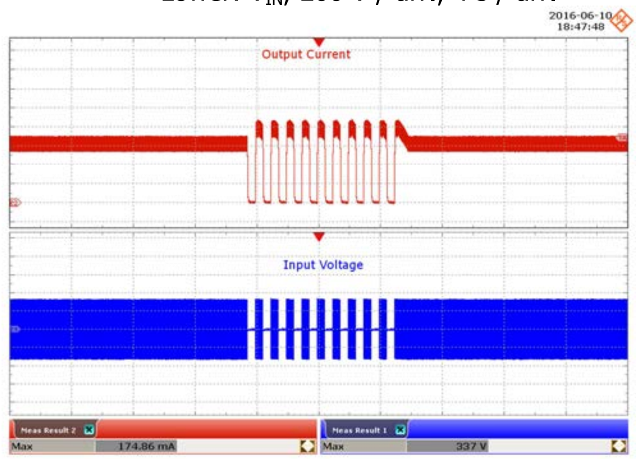

Figure 68 – 230 VAC, 60 V LED Load.
0.5 s On – 0.5 s Off.
Upper: I_{OUT}, 40 mA / div.
Lower: V_{IN}, 200 V / div., 4 s / div.

16 Conducted EMI

16.1 *Test Set-up*

16.1.1 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 115VAC and 230 VAC.

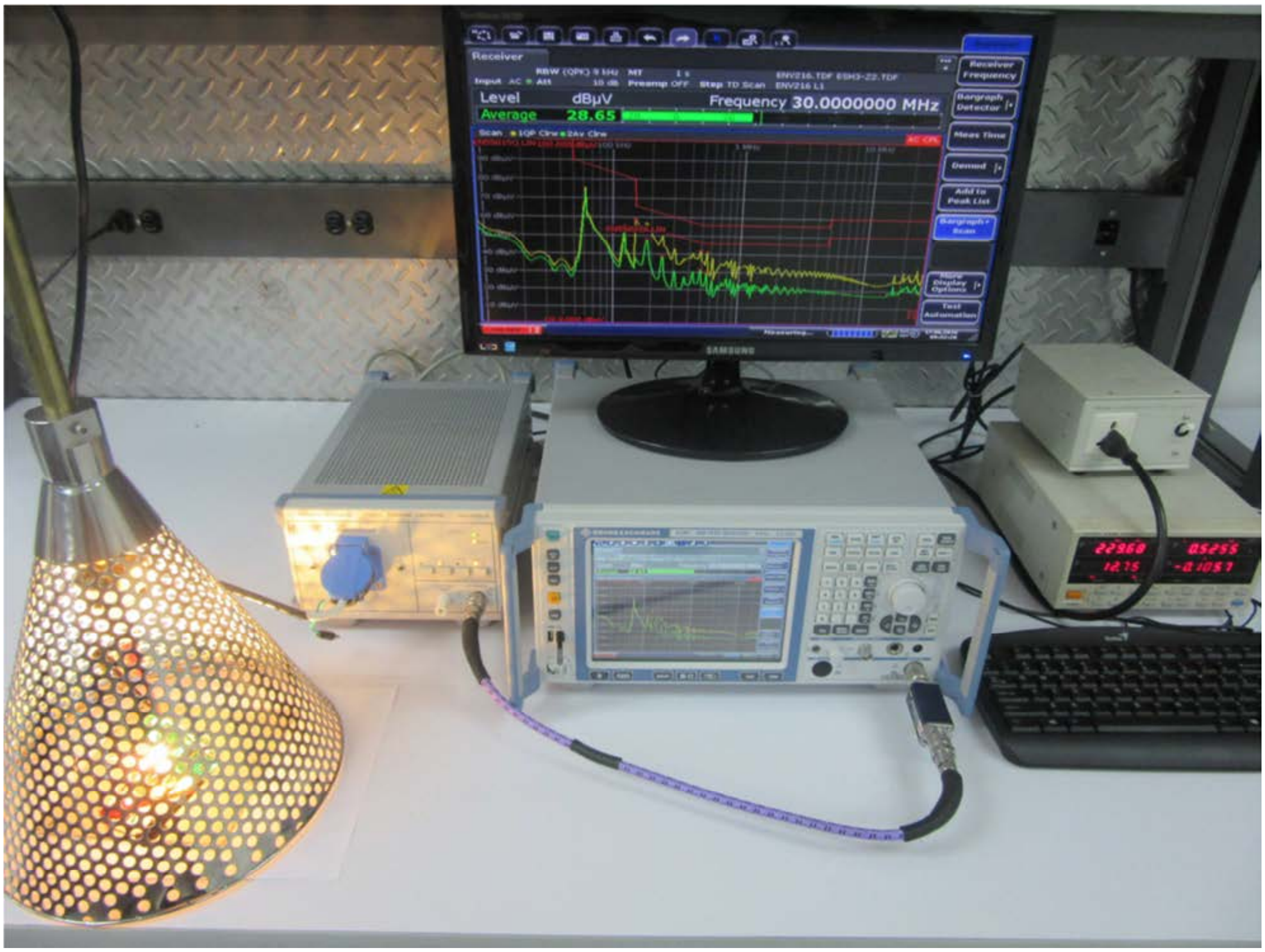

Figure 69 – Conducted EMI Test Set-up.

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16.2 *EMI Test Result*

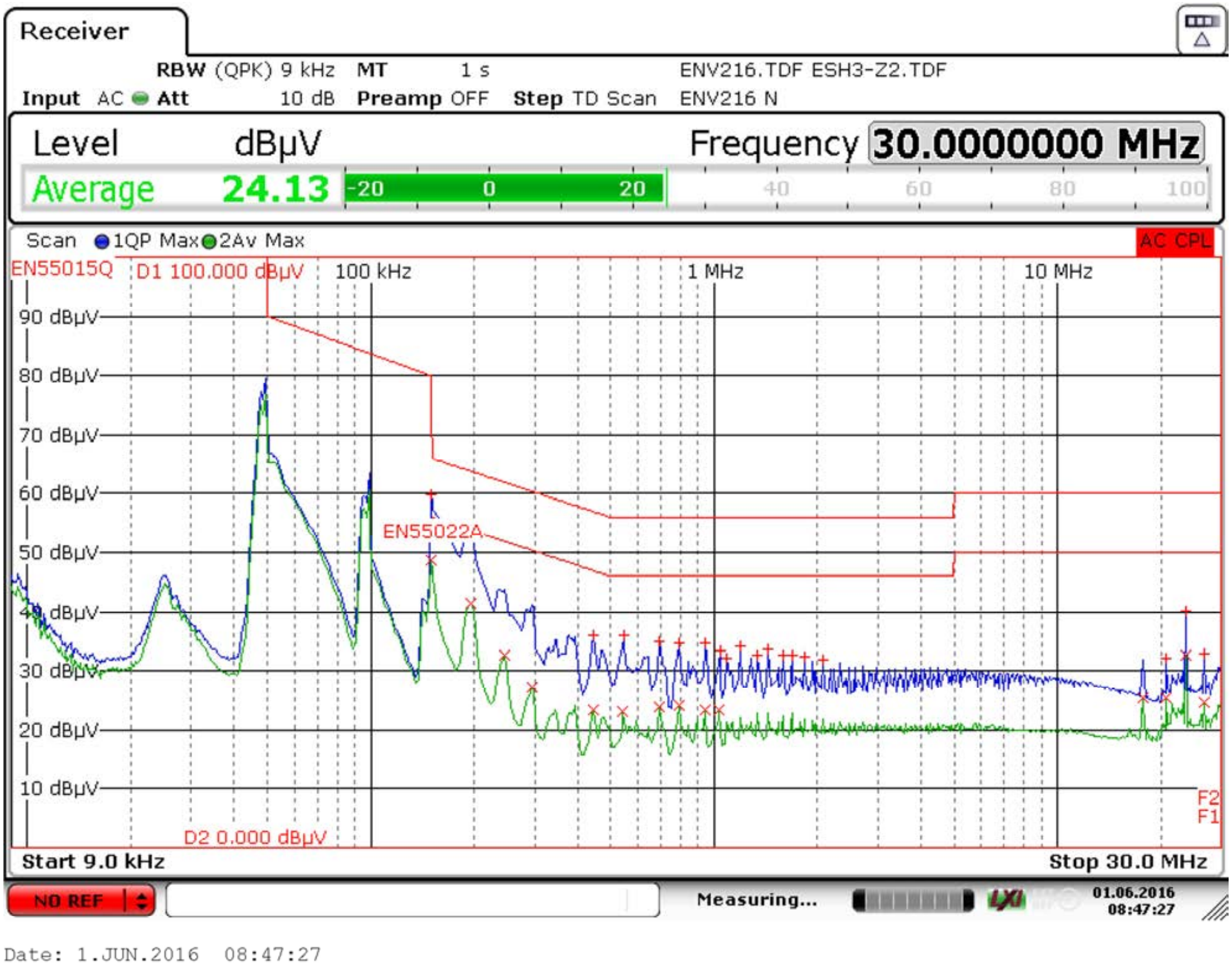

Figure 70 – Conducted EMI QP Scan at 60 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q Trace2: EN55022A

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	150.0000 kHz	59.81 N	-6.19 dB
2 Average	150.0000 kHz	48.61 N	-7.39 dB
2 Average	195.0000 kHz	41.45 N	-12.37 dB
2 Average	23.6963 MHz	32.64 N	-17.36 dB
2 Average	244.5000 kHz	32.60 L1	-19.34 dB
1 Quasi Peak	23.7053 MHz	40.09 N	-19.91 dB
1 Quasi Peak	546.0000 kHz	35.91 L1	-20.09 dB
1 Quasi Peak	447.0000 kHz	35.93 L1	-21.00 dB
1 Quasi Peak	694.5000 kHz	34.96 L1	-21.04 dB
1 Quasi Peak	942.0000 kHz	34.70 L1	-21.30 dB
1 Quasi Peak	793.5000 kHz	34.63 L1	-21.37 dB
1 Quasi Peak	1.1895 MHz	34.25 L1	-21.75 dB
2 Average	793.5000 kHz	24.08 L1	-21.92 dB
2 Average	694.5000 kHz	23.83 L1	-22.17 dB

Figure 71 – Conducted EMI Data at 115 VAC, 60 V LED Load.

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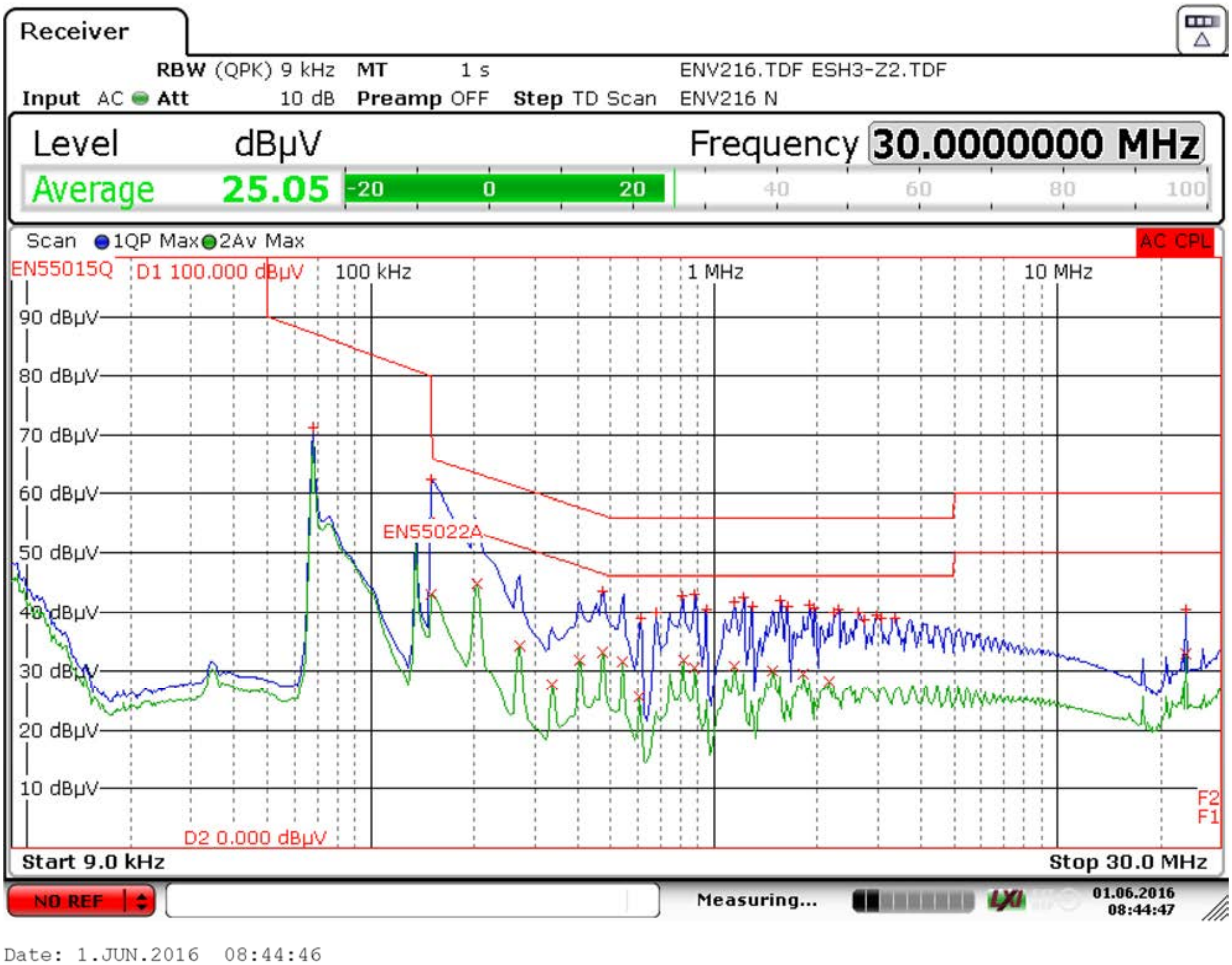

Figure 72 – Conducted EMI QP Scan at 60 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q Trace2: EN55022A

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	150.0000 kHz	62.34 L1	-3.66 dB
2 Average	204.0000 kHz	44.80 L1	-8.65 dB
1 Quasi Peak	474.0000 kHz	43.62 L1	-12.82 dB
2 Average	150.0000 kHz	43.05 N	-12.95 dB
1 Quasi Peak	879.0000 kHz	42.99 L1	-13.01 dB
2 Average	474.0000 kHz	33.14 L1	-13.30 dB
1 Quasi Peak	811.5000 kHz	42.69 L1	-13.31 dB
1 Quasi Peak	1.2165 MHz	42.47 L1	-13.53 dB
1 Quasi Peak	1.5563 MHz	41.88 L1	-14.12 dB
2 Average	813.7500 kHz	31.79 L1	-14.21 dB
2 Average	541.5000 kHz	31.60 L1	-14.40 dB
1 Quasi Peak	1.1490 MHz	41.59 L1	-14.41 dB
1 Quasi Peak	1.8938 MHz	41.07 L1	-14.93 dB
1 Quasi Peak	1.6395 MHz	40.83 L1	-15.17 dB

Figure 73 – Conducted EMI Data at 230 VAC, 60 V LED Load.

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17 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1 kV 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)
+1 kV	230	L to N	0	Pass
-1 kV	230	L to N	0	Pass
+1 kV	230	L to N	90	Pass
-1 kV	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

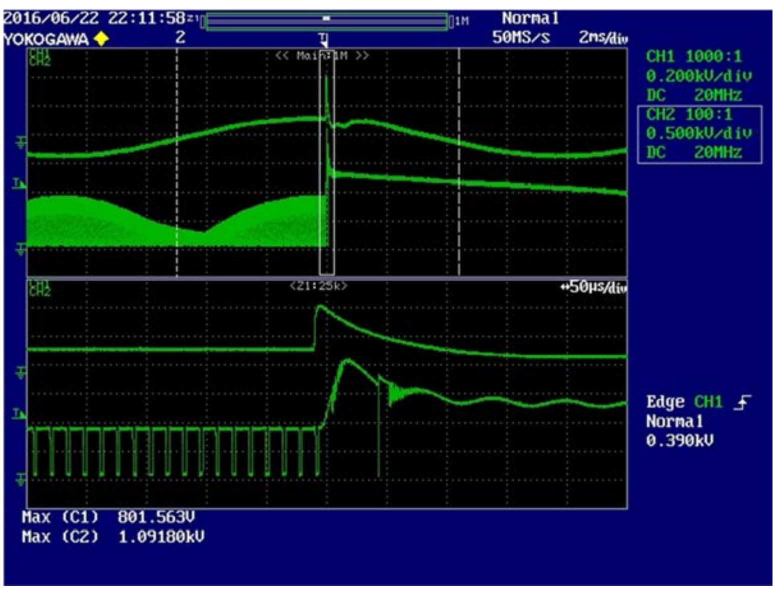

Figure 74 – +1 kV Differential Surge at Worst Case Input (230 VAC), 90º Phase Angle.
V_{DRAIN}, 200 V / div., 100 ms / div.
Peak V_{DRAIN}: 801.56 V.

18 Brown-in / Brown-out Test

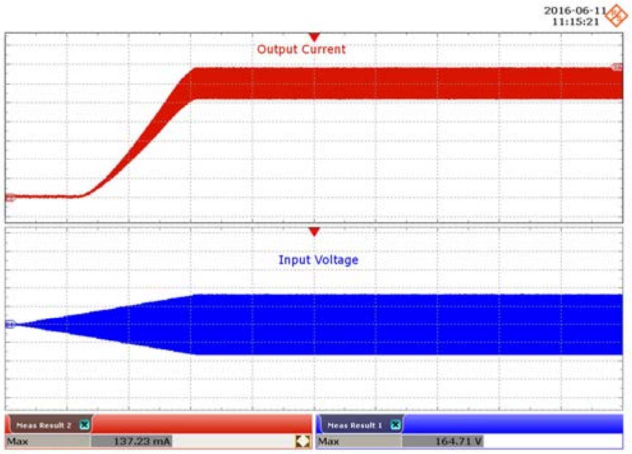

Figure 75 – 115 VAC Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

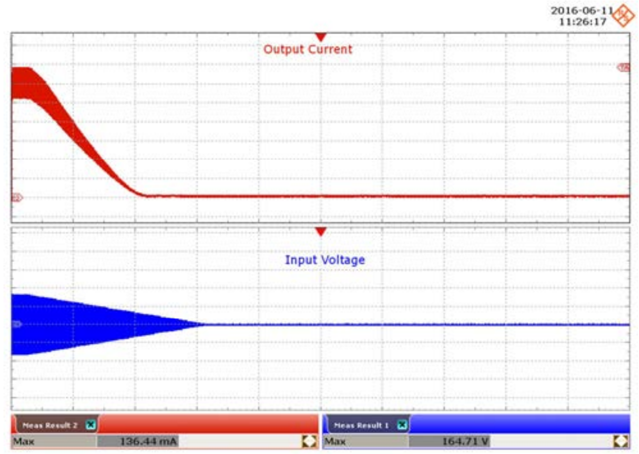

Figure 76 – 115 VAC Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

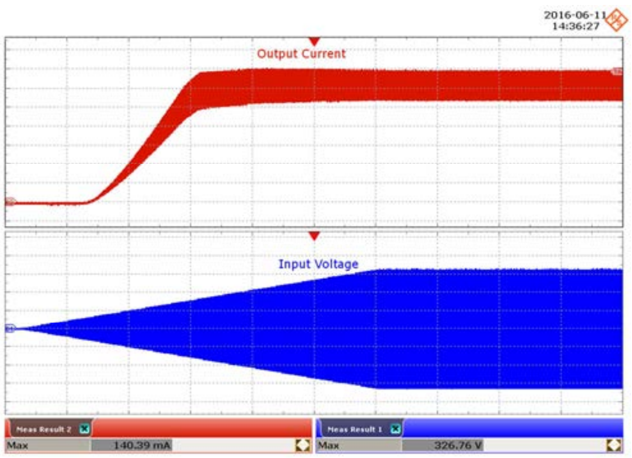

Figure 77 – 230 VAC Brown-in Test at 1 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

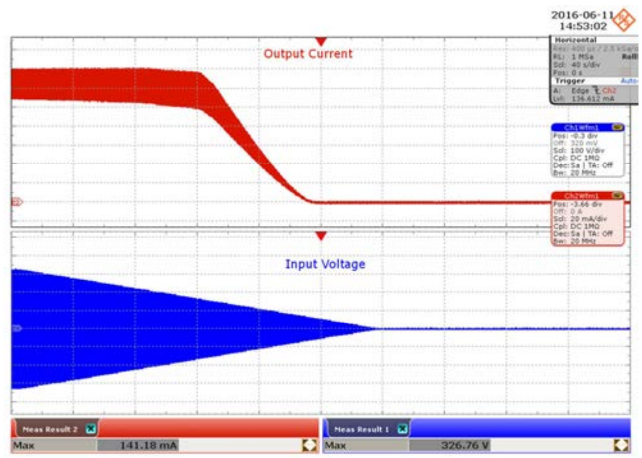

Figure 78 – 230 VAC Brown-out Test at 1 V / s.
Ch1: I_{OUT}, 20 mA / div.
Ch2: V_{IN}, 100 V / div.
Time Scale: 40 s / div.

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19 Revision History

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

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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.power.com. Power Integrations grants its customers a license under certain patent rights as set forth at http://www.power.com/ip.htm.

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