Design Example Report

Title	*9.5 W_{TYP} TRIAC Dimmable High Efficiency Power Factor Corrected Isolated LED Driver Using LYTSwitch™-3 LYT3315D*
Specification	90 VAC – 132 VAC Input; 27 V_{TYP}, 350 mA_{TYP} Output
Application	Downlight LED
Author	Applications Engineering Department
Document Number	DER-502
Date	June 28, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant LED current (CC) regulation, ±5%
- High efficiency
- Low cost and low component count for compact PCB solution
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers
  - Fast start-up time (<500 ms) – no perceptible delay
  - Minimum dead-band or visible pop on effect.
- Integrated protection features
  - Open load and output short-circuit protection
  - Thermal fold-back protection
  - No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 1 kV differential surge and 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.

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1 Introduction

This engineering report describes a TRIAC dimmable, isolated flyback LED driver designed to drive a nominal LED voltage string of 27 V at 350 mA from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT3315D from the LYTSwitch-3 family of devices.

LYTSwitch-3 is a family of devices which are designed especially for TRIAC dimmable LED drivers with a single stage PFC function and accurate LED current control.

DER-502 is a single 9.5 W TRIAC dimmable LED driver with constant current output. Key design goals were high efficiency, compact PCB and excellent dimming compatibility. The design is intended for downlight LED applications.

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

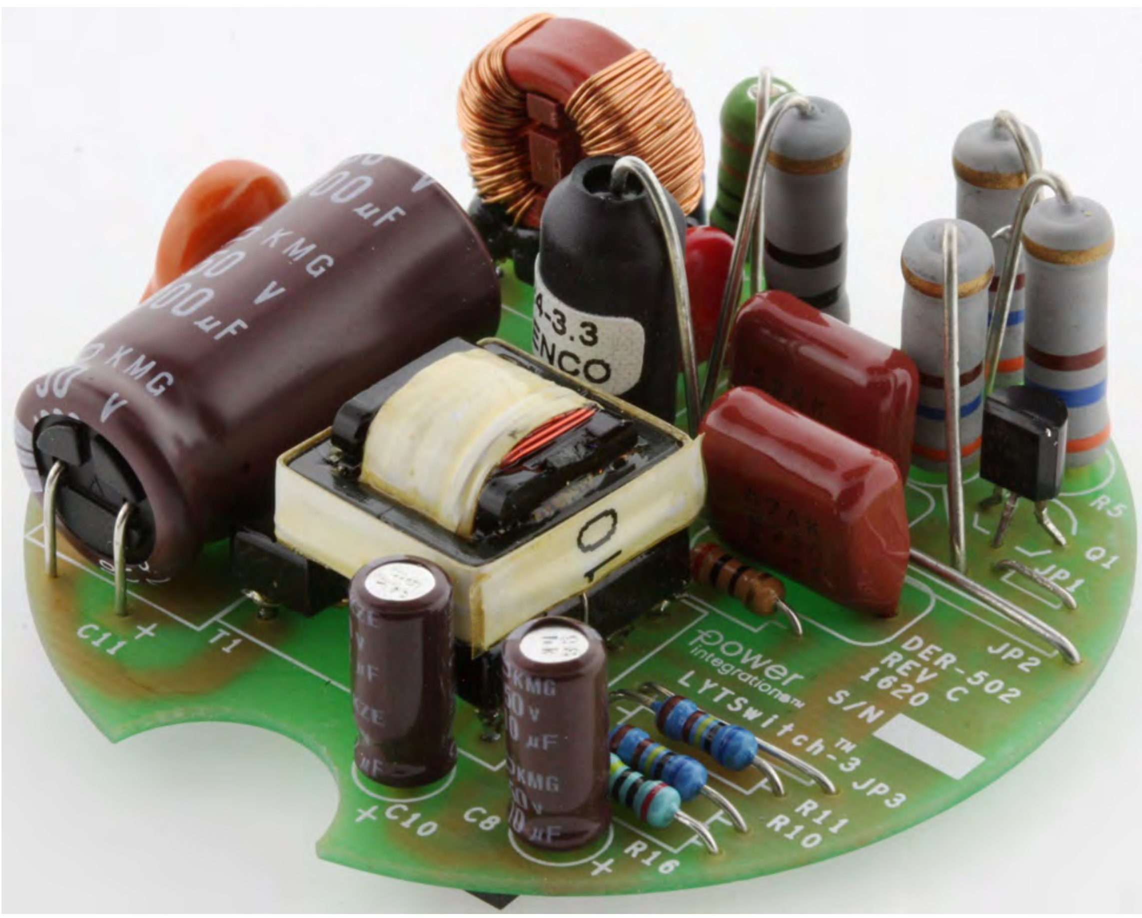

Figure 1 – Populated Circuit Board.

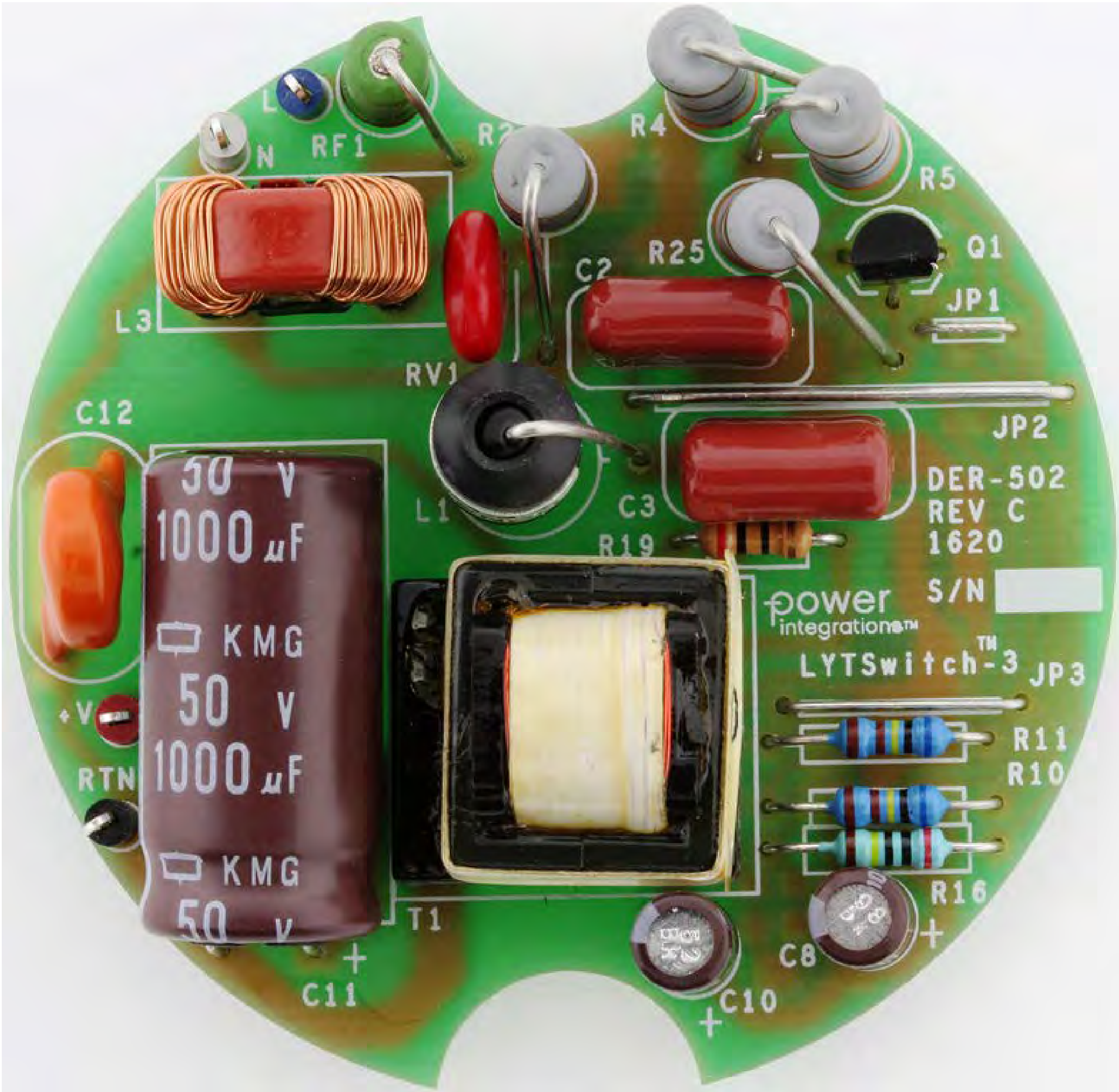

Figure 2 – Populated Circuit Board, Top View.

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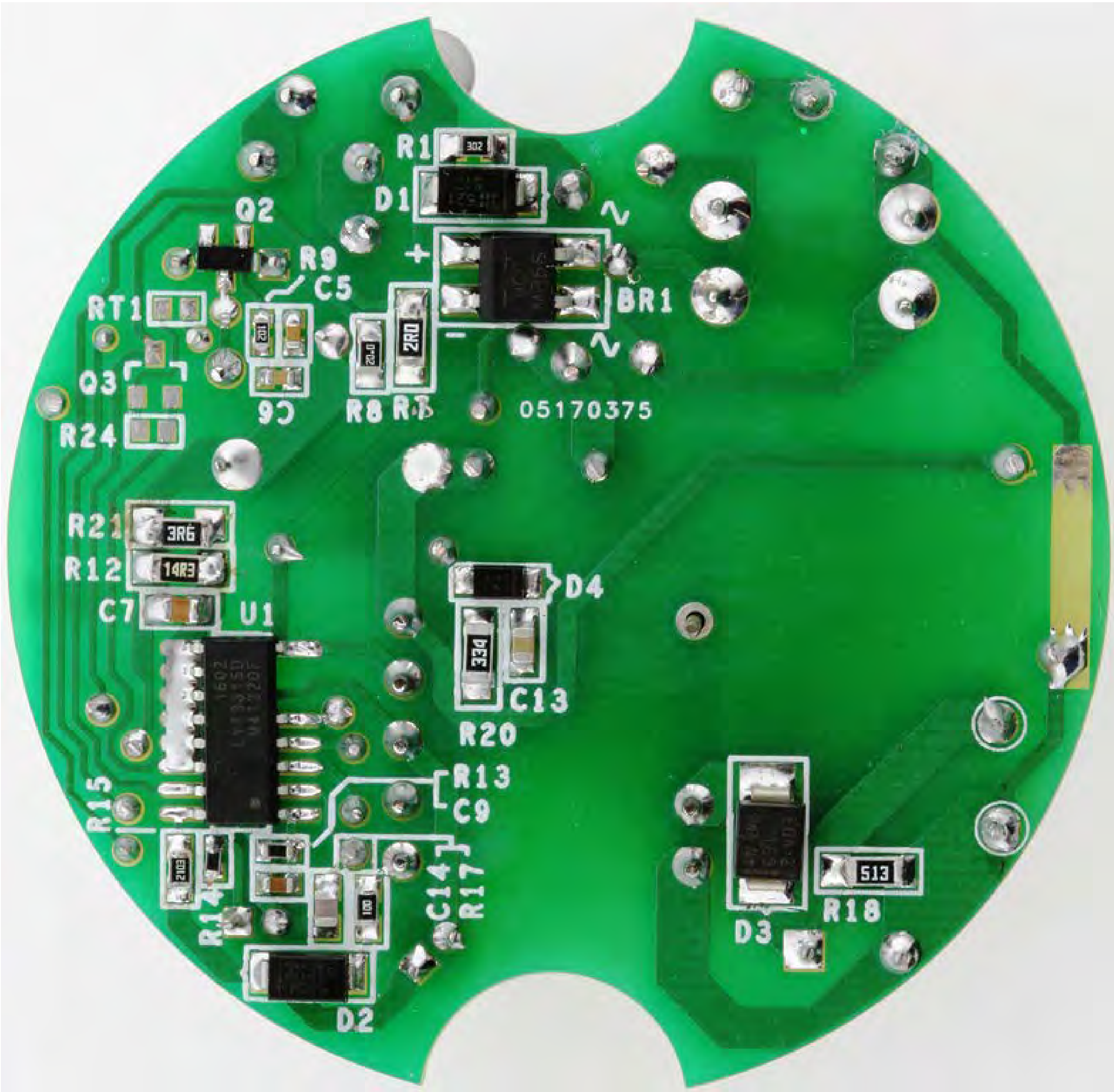

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}	24	27	30	V	
Output Current	I_{OUT}	332	350	367	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		9.5		W	
Efficiency						
Full Load	η		84		%	Measured at 115 VAC, 25 ºC, Nominal Output.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.9			Measured at 230 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			40	ºC	Free Convection, Sea Level.

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3 Schematic

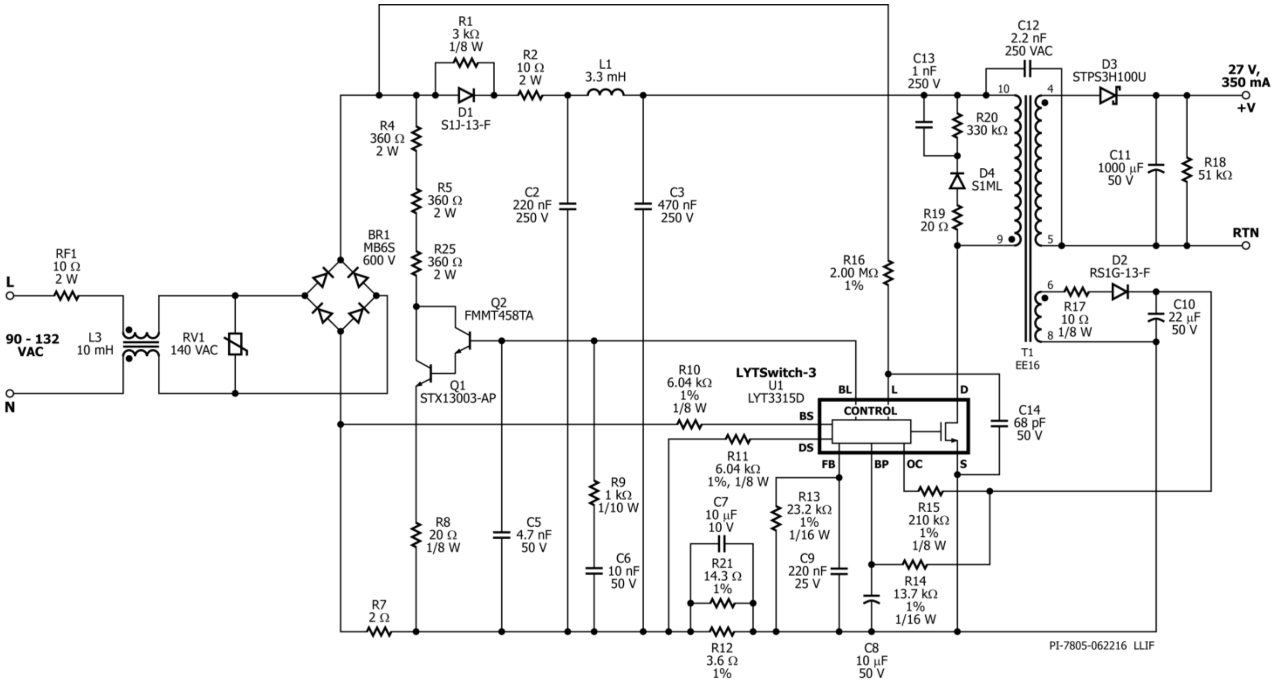

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-3 LYT3315D combines a high-voltage power MOSFET switch with a power supply controller in a single package. The LYTswitch-3 controller provides a single-stage power factor correction, LED current control and dimming control.

4.1 Input Stage

Fusible resistor RF1 provides safety protection against component failures. Varistor RV1 provides clamping during differential line surge events to limit the maximum voltage spike across the primary.

The AC input is rectified by BR1 to provide the pulsating DC input to the pi filter consisting of C2, C3 and L1. Values of C2, C3 and L1 were chosen to provide the best balance between high power factor, EMI performance and dimming compatibility. Inductor L3 is a common mode inductor to provide filtering against common mode noise.

4.2 LYTSwitch-3 Primary Control Circuit

The topology is an isolated flyback converter with primary side regulation. During turn-on of the LYT3315D internal MOSFET, current is fed to the un-dotted end of the primary winding and flows out of the dotted end through the internal MOSFET and back to the input. During this period energy is stored in the magnetizing inductance of the primary winding. This energy is then transferred to the secondary winding and is discharged to the load through the output diode D3 during internal MOSFET turn-off. Output capacitor C11 provides filtering to minimize LED ripple current. R18 serves as pre-load.

Bias supply to the LYT3315D is provided by the bias circuit consisting of R17, D2 and C10 which provides the bias voltage from the auxiliary winding. Resistor R14 limits the current flowing into the BYPASS (BP) pin of LYT3315D with C8 providing both decoupling and energy storage for the device. The value of R14 is chosen such that device dissipation is minimized without compromising device supply cutoff which could occur during dimming conditions where input conduction angle is at a minimum.

The LYTSwitch-3 IC provides excellent dimming performance by directly monitoring the input voltage and actual conduction angle. This information is made available to the device through R16 which connects to the LINE SENSE (L) pin. Overvoltage protection is achieved through this pin together with LED current control with respect to input voltage.

Output current is controlled through the FEEDBACK (FB) pin. A voltage across the parallel combination of R12 and R21 is induced by the drain current. This voltage is compared to the voltage across R13 internally to a reference voltage which varies linearly with the conduction angle when in dimming mode. The reference is 300 mV during full conduction (no dimmer detected). Capacitor C7 filters the voltage across the sense resistors. C14 filters noise from the line sense pin.

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The OUTPUT COMPENSATION (OC) pin of LYT3315D senses the output voltage through the voltage across the bias. This information is used by LYTSwitch-3 to maintain a constant LED current with respect to variation in LED string voltage. Resistor R15 is calculated based on the output overvoltage protection point.

4.3 TRIAC Phase Dimming Control with LYTSwitch-3 Smart Bleeder Drive

LYTSwitch-3 uses an active bleeder control to provide the highest dimmer compatibility possible for LED drivers without sacrificing driver efficiency, power factor and %THD.

Resistor R2 dampens the driver input current ringing when the TRIAC in a dimmer turns on. The fusible resistor RF1 also provides significant damping to the ringing.

Diode D1 serves as a blocking diode to prevent the active bleeder from drawing current from the input capacitors once it turns on. Resistor R1 serves as a discharge path for the input capacitors. This is needed to increase dimmer compatibility of the driver.

The active bleeder and control circuit consists of R4, R5, R7, R8, R9, R25, C5, C6, Q1 and Q2. This network is directly driven by the LYT3315D through the BLEEDER CONTROL (BL) pin. Given that the input current is the sum between the bleeder current when dimming and the converter current, this current flows through R7 and induces a voltage which is then compared through R10 to a 120 mV reference on the BLEEDER SENSE (BS) pin. Based on the input current level, the BL pin drives the bleeder circuit to maintain the input current as programmed by R7.

Resistor R4, R5, and R27 are bleeder resistors with Q1 and Q2 forming a Darlington pair to act as switch for the bleeder resistor. Resistor R8, R9, C5 and C6 form a stabilization network.

5 PCB Layout

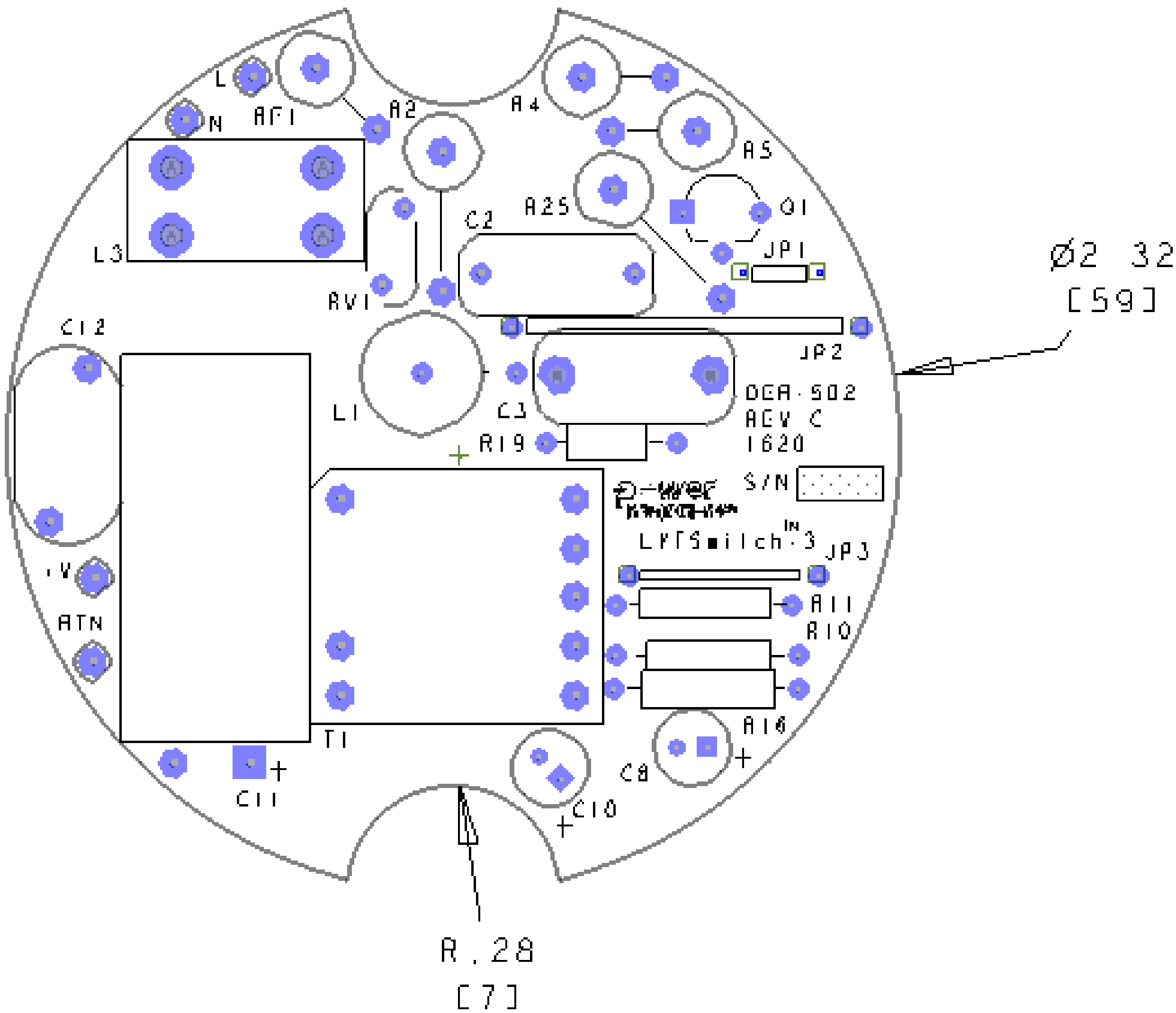

Figure 5 – Top Side.

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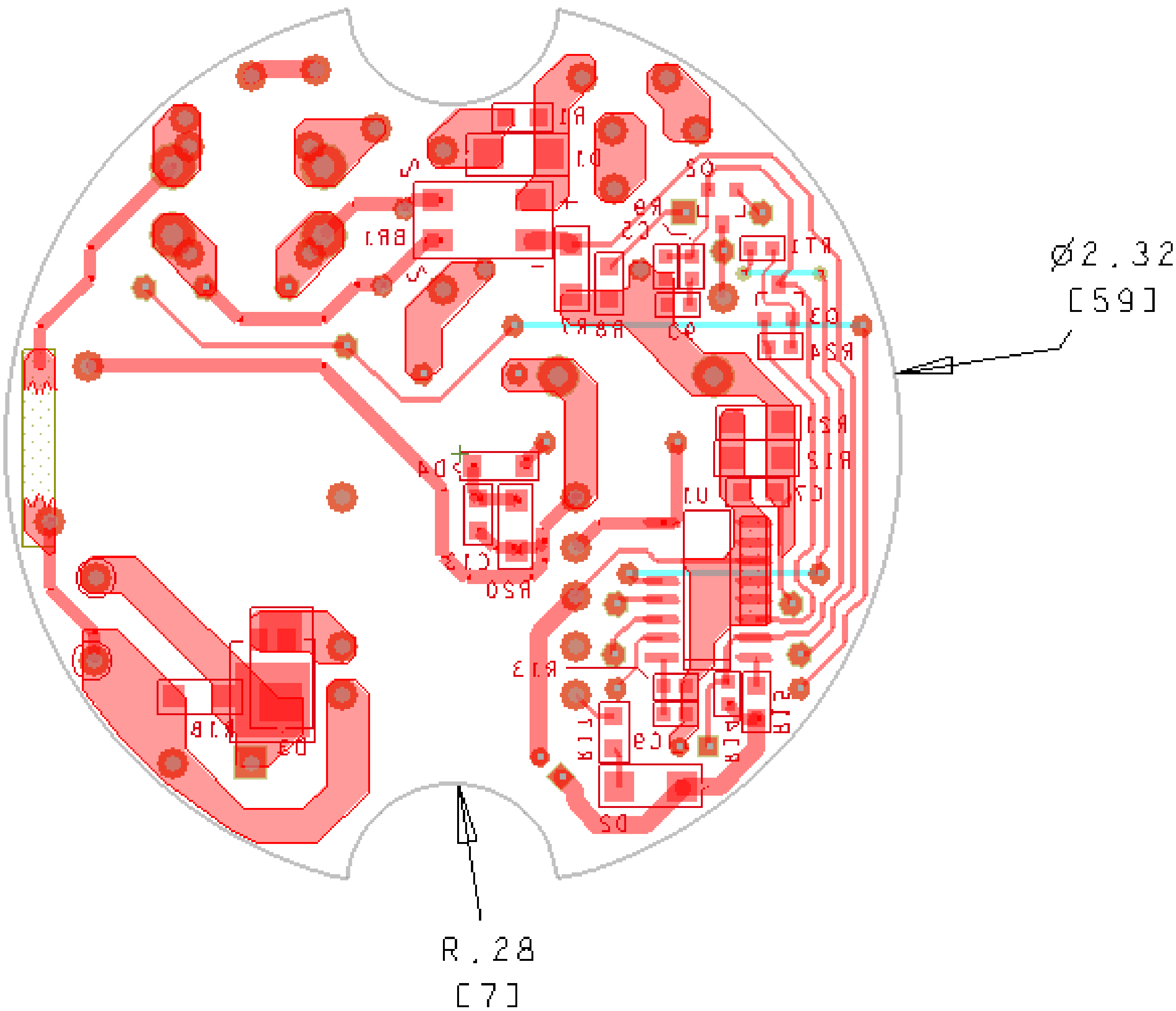

Figure 6 – Bottom Side.

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	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
3	1	C2	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
4	1	C3	470 nF, 250 V, Film	ECQ-E2474KB	Panasonic
5	1	C5	4.7 nF 50 V, Ceramic, X7R, 0603	GRM188R71H472KA01D	Murata
6	1	C6	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
7	1	C7	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
8	1	C8	10 μF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG500ELL100ME11D	Nippon Chemi-Con
9	1	C9	220 nF, 25 V, Ceramic, X7R, 0603	06033D224KAT2A	AVX
10	1	C10	22 μF, 50 V, Electrolytic, Very Low ESR, 340 mΩ, (5 x 11)	EKZE500ELL220ME11D	Nippon Chemi-Con
11	1	C11	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	United Chemi-Con
12	1	C12	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
13	1	C13	1 nF, 250 V, Ceramic, X7R, 0805	GRM21AR72E102KW01D	Murata
14	1	C14	68 pF, ±1%, 50 V, C0G, NP0, Ceramic Capacitor, -55 °C ~ 125 °C, SMT, MLCC 0805 (2012 Metric,) 0.079" L x 0.049" W (2.00 mm x 1.25 mm)	C0805C680F5GACTU	Kemet
15	1	D1	600 V, 1 A, Standard Recovery, SMA	S1J-13-F	Diodes, Inc.
16	1	D2	400 V, 1 A, Fast Recovery, 150 ns, SMA	RS1G-13-F	Diodes, Inc.
17	1	D3	100 V, 3 A, Schottky, DO-214AA	STPS3H100U	ST
18	1	D4	1 kV, 1 A, Standard Recovery, SMA	S1ML	TAIWAN SEMI
19	2	L RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
20	1	L1	3.3 mH, 0.224 A, Radial, 20 %	RL-1124-3.3	Renco
21	1	L3	10 mH, 0.7 A, Common Mode Choke	744821110	Wurth
22	1	N	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
23	1	Q1	NPN, Power BJT, 400 V, 1 A, TO-92	STX13003-AP	ST Micro
24	1	Q2	NPN, HP, 400 V, 225 mA, SOT23-3	FMMT458TA	Diodes, Inc.
25	1	R1	3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
26	1	R2	10 Ω, 5%, 2 W, Metal Oxide	RSF200JB-10R	Yageo
27	3	R4 R5 R25	360 Ω, 5%, 2 W, Metal Oxide	RSF200JB-360R	Yageo
28	1	R7	2 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ2R0V	Panasonic
29	1	R8	20 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ200V	Panasonic
30	1	R9	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
31	2	R10 R11	6.04 kΩ, 1%, 1/8 W, Metal Film	RN55D6041FB14	Vishay
32	1	R12	3.6 Ω, 1%, 1/4 W, 1206	RC1206FR-073R6L	Yageo
33	1	R13	23.2 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2322V	Panasonic
34	1	R14	13.7 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1372V	Panasonic
35	1	R15	210 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2103V	Panasonic
36	1	R16	RES, 2.00 M, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole
37	1	R17	10 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ100V	Panasonic
38	1	R18	51 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ513V	Panasonic
39	1	R19	20 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-20R	Yageo
40	1	R20	330 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ334V	Panasonic
41	1	R21	14.3 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF14R3V	Panasonic
42	1	RF1	10 Ω, 2 W, Fusible/Flame Proof Wire Wound	CRF253-4 10R	Vitrohm
43	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
44	1	T1	Bobbin, EE16 Extended Creepage, Horizontal, 10 pins	TF-1613	Taiwan Shulin
45	1	U1	LYTSwitch-3, SO-16C	LYT3315D	Power Integrations

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7 Inductor Specification

7.1 Electrical Diagram

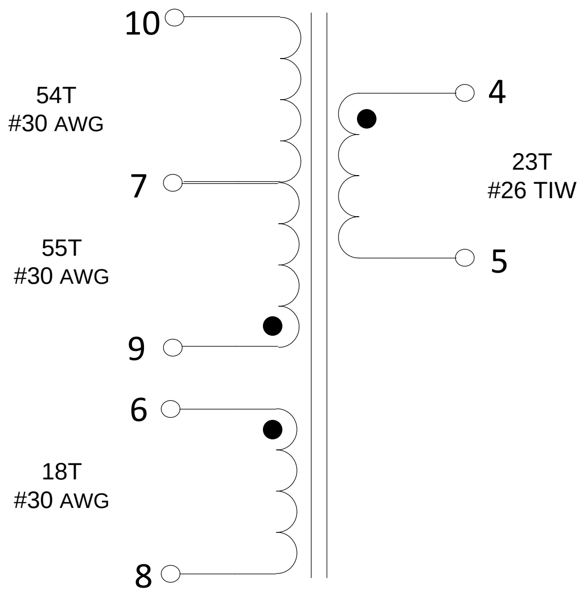

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 9 and pin 10, with all other windings open.	700 µH
Tolerance	Tolerance of primary inductance.	±5%
Primary Leakage Inductance	Pins 9-10, with pins 4-5 shorted, measured at 100 kHz, 0.4 V_{RMS}.	7 µH (Max.)

7.3 Material List

Item	Description
[1]	Core: EE16 PC44 or Equivalent.
[2]	Bobbin: EE16, Horizontal, 10 pins, Part no. 25-00835-00.
[3]	Magnet Wire: #30 AWG.
[4]	Triple Insulated Wire: #26 AWG.
[5]	Non-insulated Wire: #31 AWG.
[6]	Transformer Tape: 9 mm.
[7]	Transformer Tape: 4.8 mm.

7.4 Transformer Build Diagram

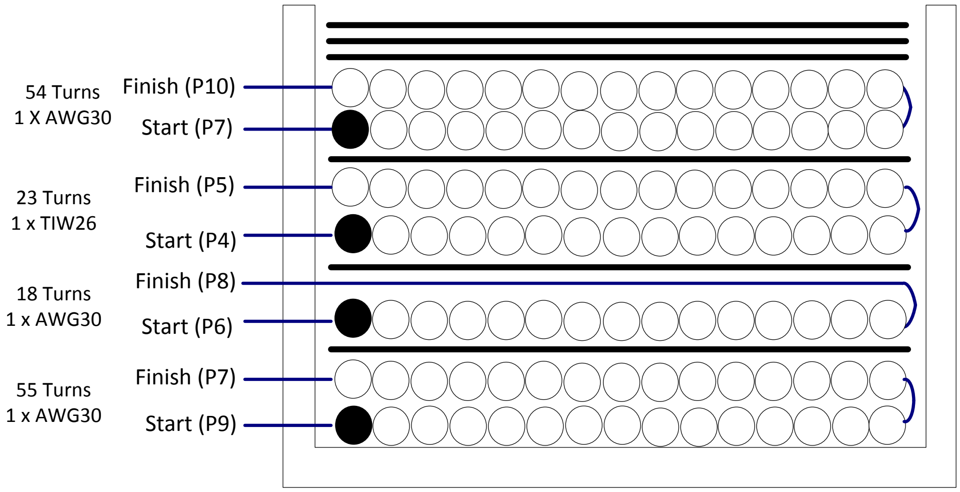

Figure 8 – Transformer Build Diagram.

7.5 Inductor Construction

Bobbin	Place item [2] bobbin on winding machine with pins 6-10 on the left side of the mandrel.
Winding 1	Starting at pin 9 wind 55 turns in two layers of wire item [3] in clockwise direction. Terminate other end of the wire to pin 7.
Insulation	Add 1 layer of tape, item [5], for insulation.
Winding 2	Starting at pin 6 wind 18 turns of wire item [3] in clockwise direction. Spread the winding evenly across the whole bobbin width. Terminate other end of the wire to pin 8.
Insulation	Add 1 layer of tape, item [5], for insulation.
Winding 3	Starting at pin 4 wind 23 turns of wire item [4] in two layers in clockwise direction. Terminate other end of the wire to pin 5.
Insulation	Add 1 layer of tape, item [5], for insulation.
Winding 4	Starting at pin 7 wind 54 turns of wire item [3] in two layers in clockwise direction. Terminate other end of the wire to pin 10.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 700 μH.
Assemble Core	Assemble the core item [1] halves to the bobbin.
Core Grounding	Wrap 2 turns of wire item [5] along the 2 halves of the core. Terminate one end to pin 8.
Fix Core	Fix core with 3 layers of tape item [7]
Pins	Remove pins 2 and 3.
Finish	Dip the transformer assembly in varnish.

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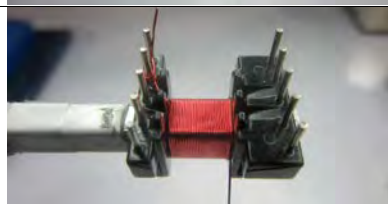
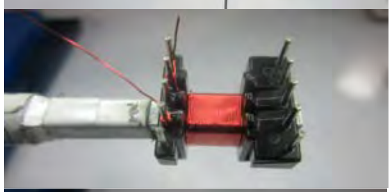
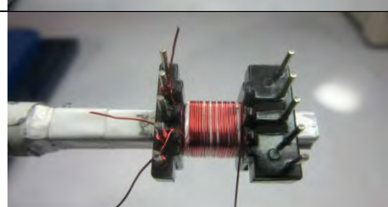
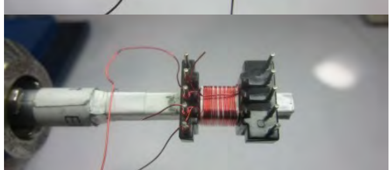
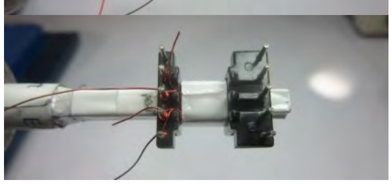
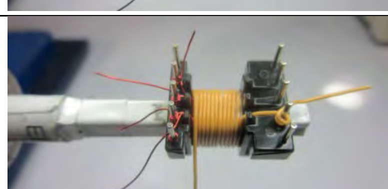
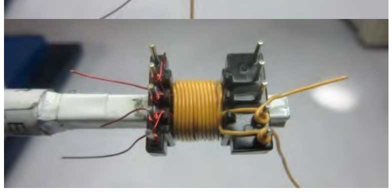
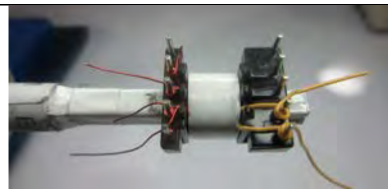
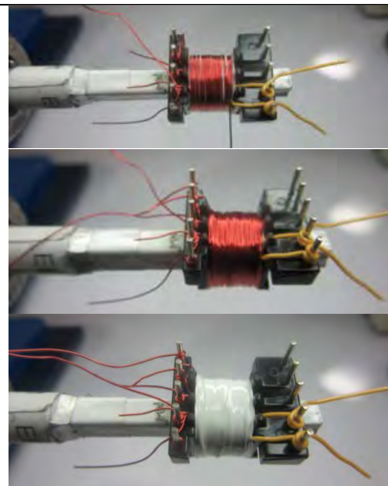
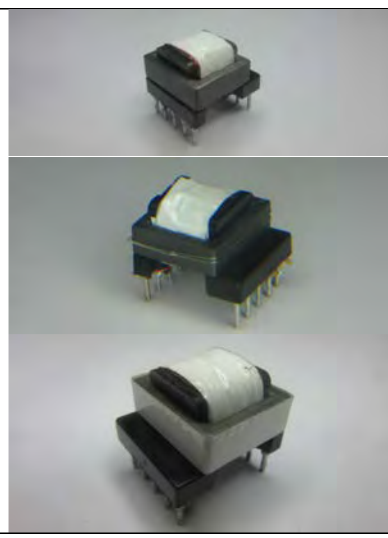
7.6 Inductor Construction Illustrations

Winding Preparation		Place bobbin [item 2] on winding machine with pins 6-10 facing left.
WD1	  	Starting at pin 9 wind 55 turns in two layers of wire [item 3] in clockwise direction. Terminate other end of the wire to pin 7. Fix with 1 layer tape [item 5].
WD2	  	Starting at pin 6 wind 18 turns of wire [item 3] in clockwise direction. Spread the winding evenly across the whole bobbin width. Terminate other end of the wire to pin 8. Fix with 1 layer of tape [item 5].
WD3	 	Starting at pin 4 wind 23 turns of wire [item 4] in two layers in clockwise direction. Terminate other end of the wire to pin 5.

		Fix with 1 layer of tape [item 5].
WD4		Starting at pin 7 wind 54 turns of wire [item 3] in two layers in clockwise direction. Terminate other end of the wire to pin 10. Fix with 3 layers of tape [item 5].
Gap Core		Grind one core half [item 1] center leg to achieve 700 μH inductance.
Final Assembly		Assemble core halves. Wrap 2 turns of wire [item 5] along the 2 halves of the core. Terminate one end to pin 8. Fix core with 3 layers of tape [item 7] and remove pins 2 and 3. Dip the transformer assembly in varnish.

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8 Performance Data

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

8.1 Efficiency

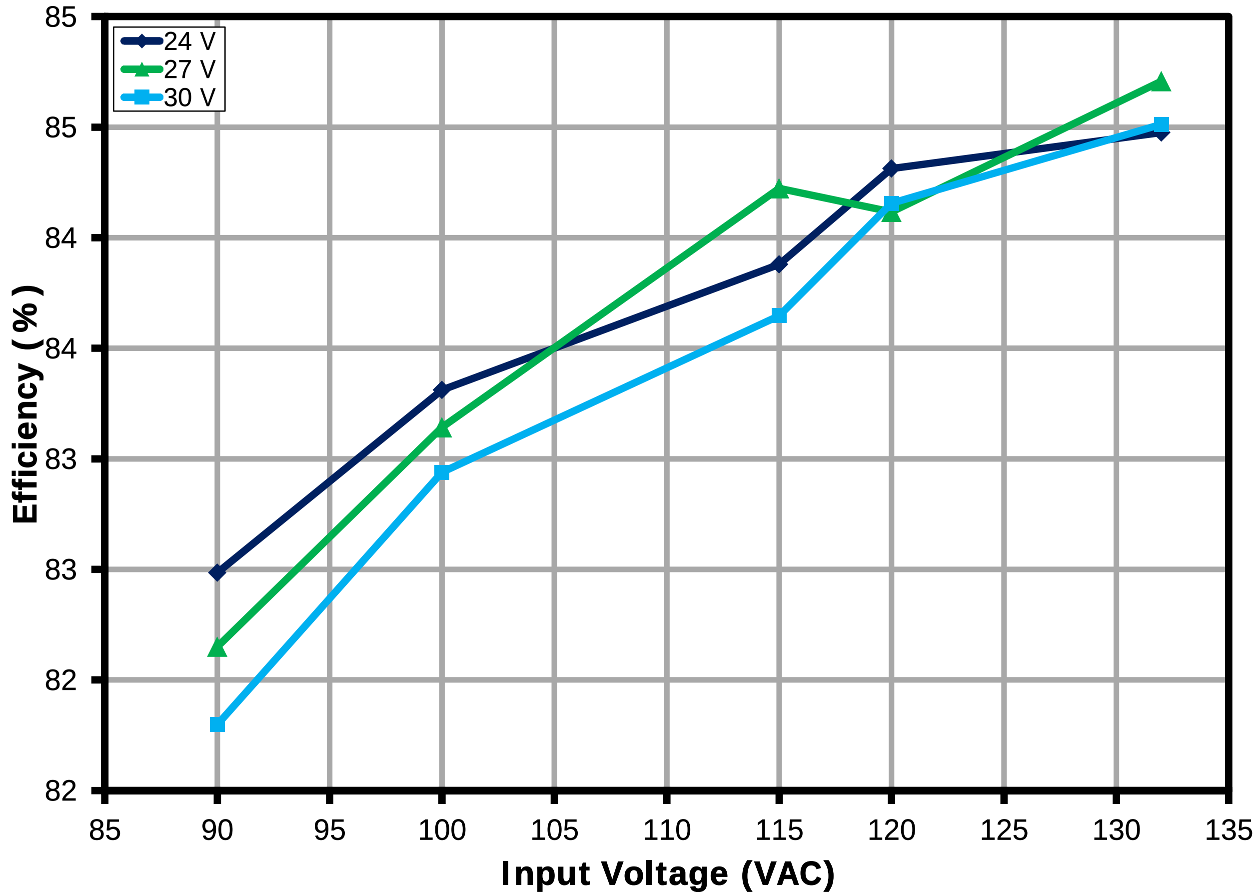

Figure 9 – Efficiency vs. Line and Load.

8.2 Line Regulation

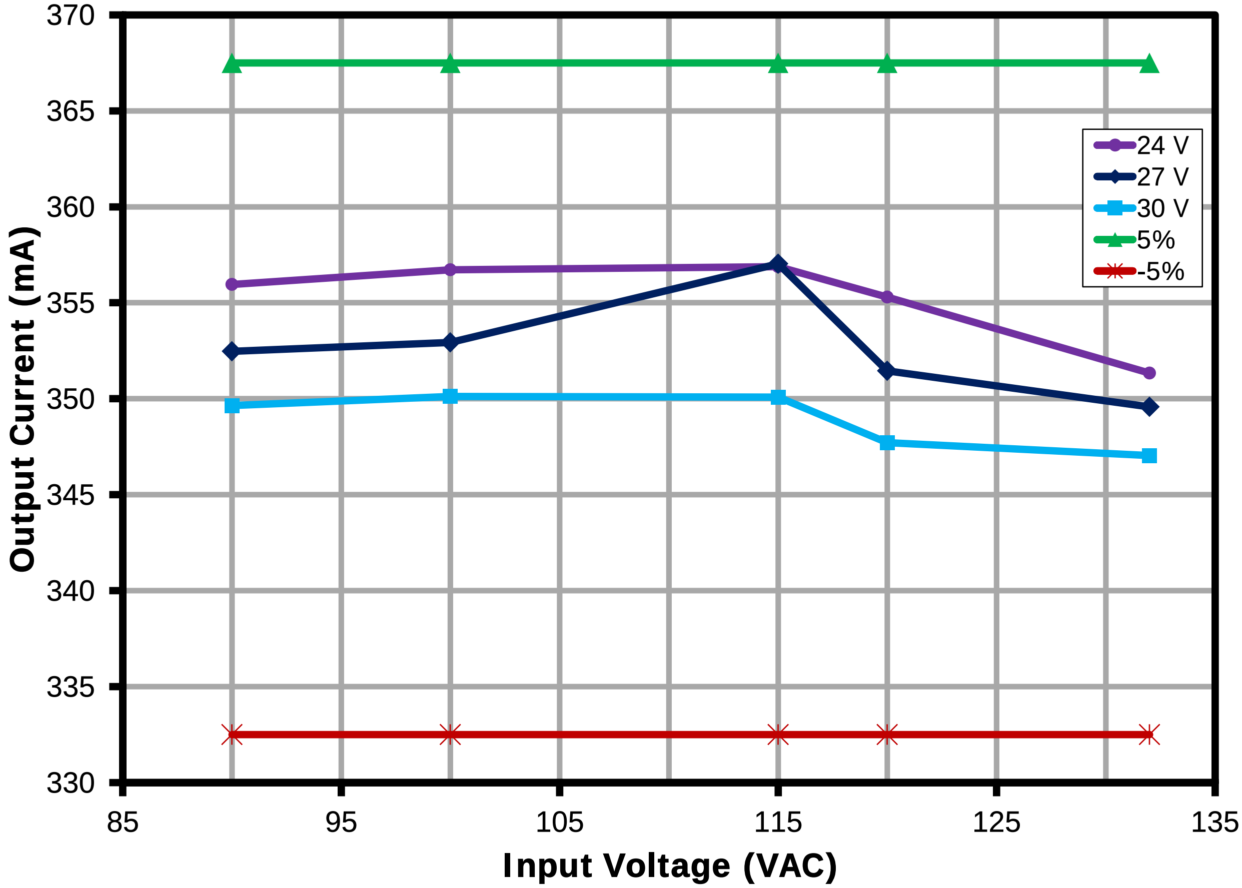

Figure 10 – Regulation vs. Line and Load.

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8.3 Power Factor

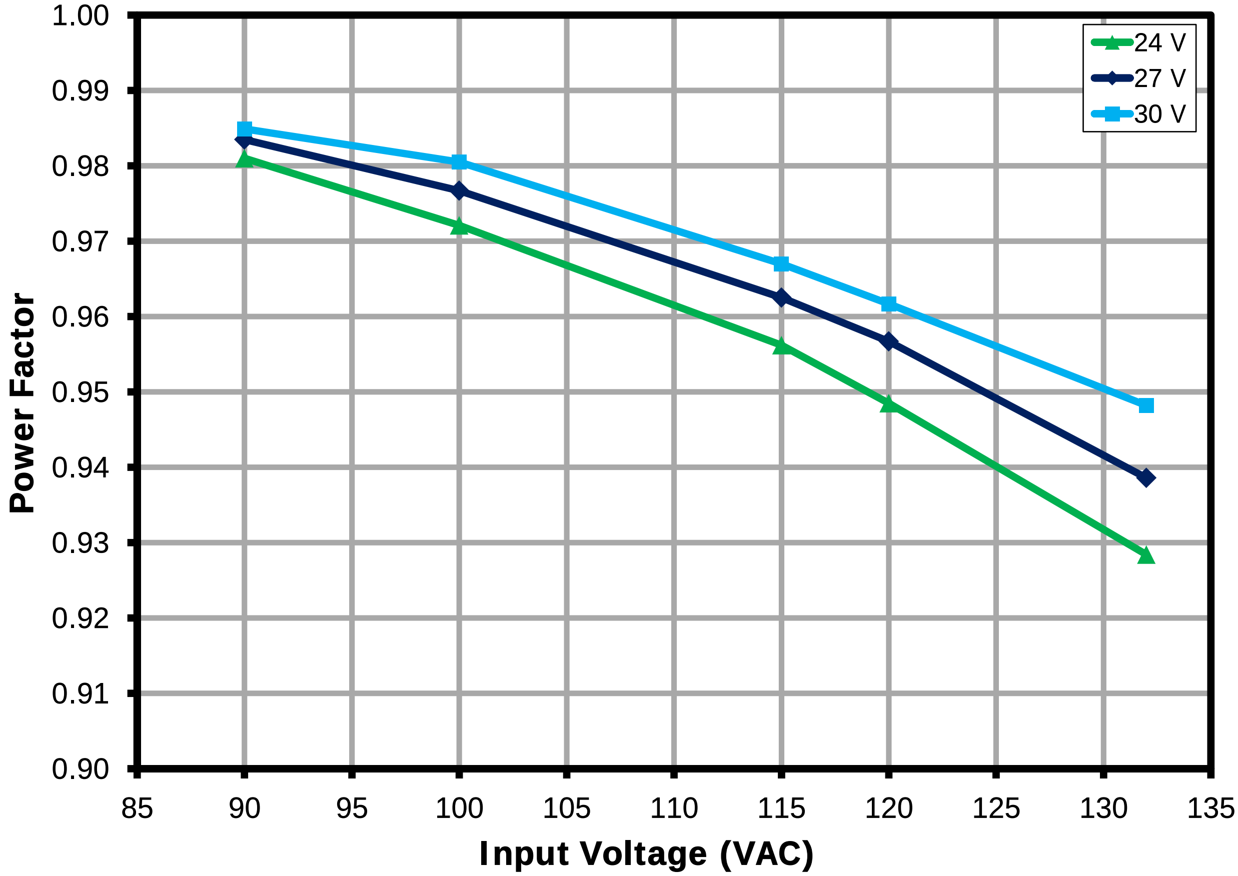

Figure 11 – Power Factor vs. Line and Load.

8.4 %ATHD

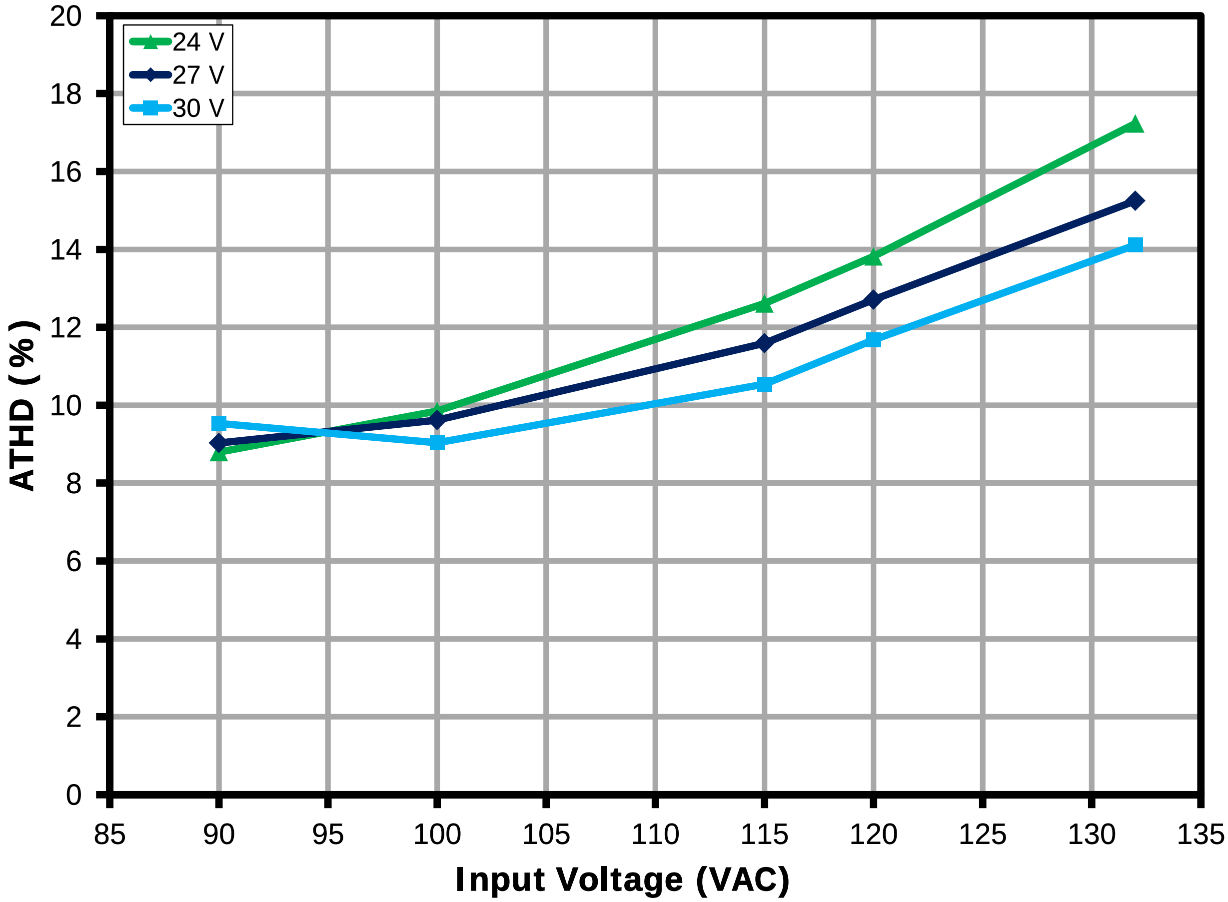

Figure 12 – %ATHD vs. Line and LED Load.

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8.5 Harmonics

8.5.1 24 V Output

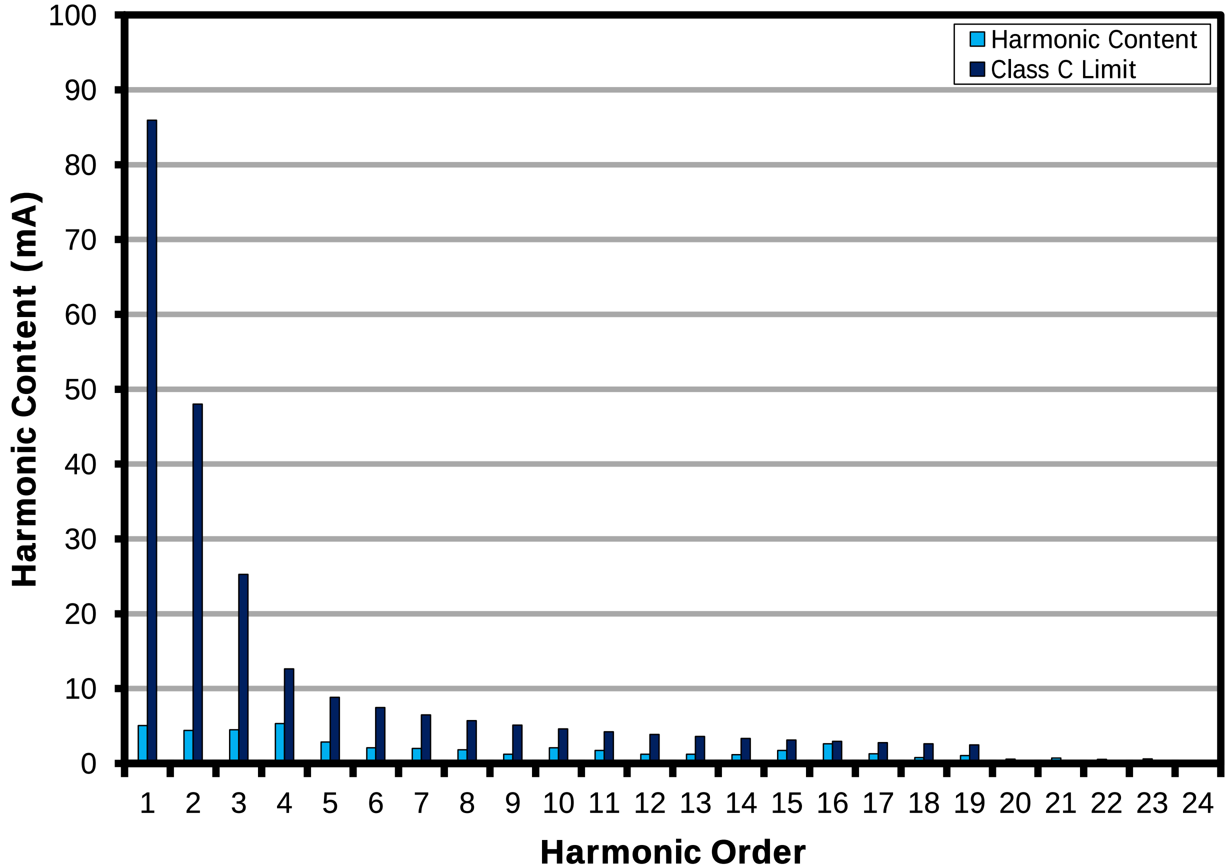

Figure 13 – 24 V Input Current Harmonics at 115 VAC, 60 Hz.

8.5.2 27 V Output

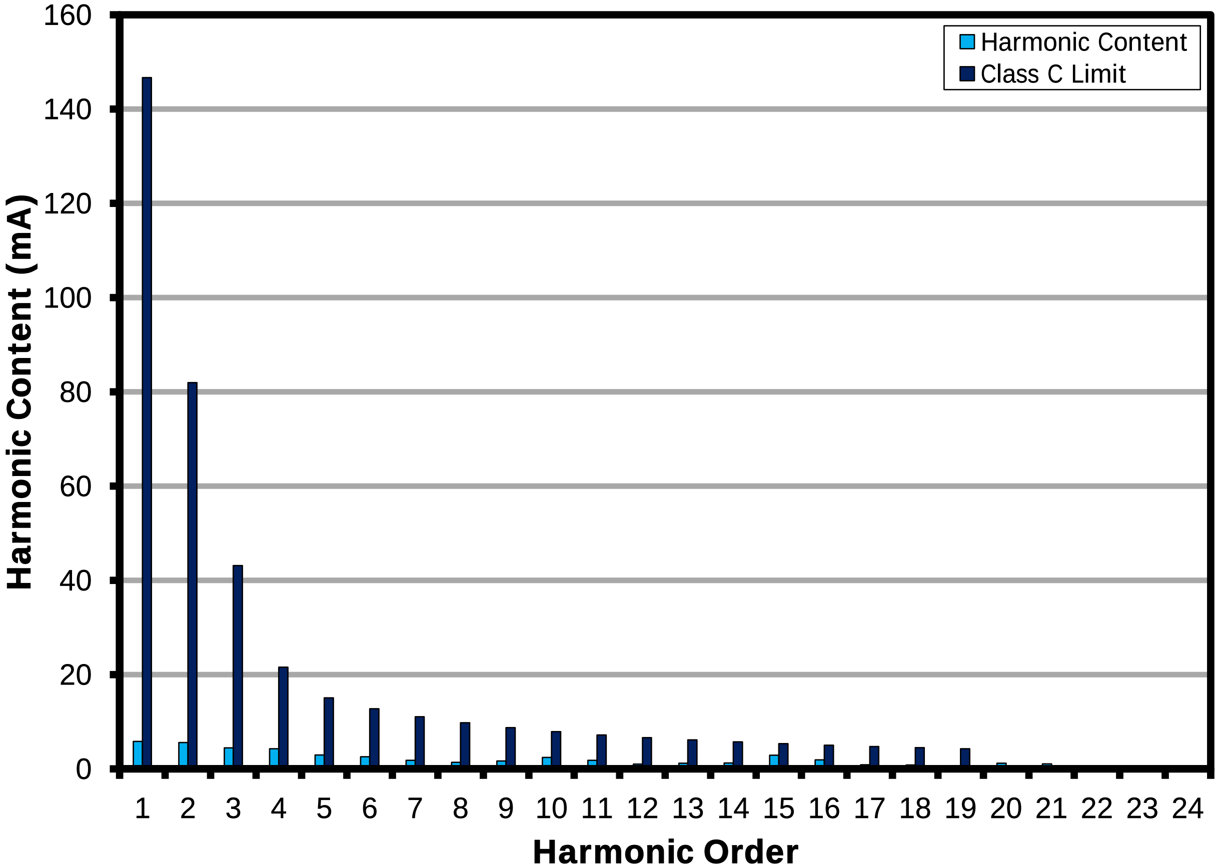

Figure 14 – 27 V Input Current Harmonics at 115 VAC, 60 Hz.

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8.5.3 30 V Output

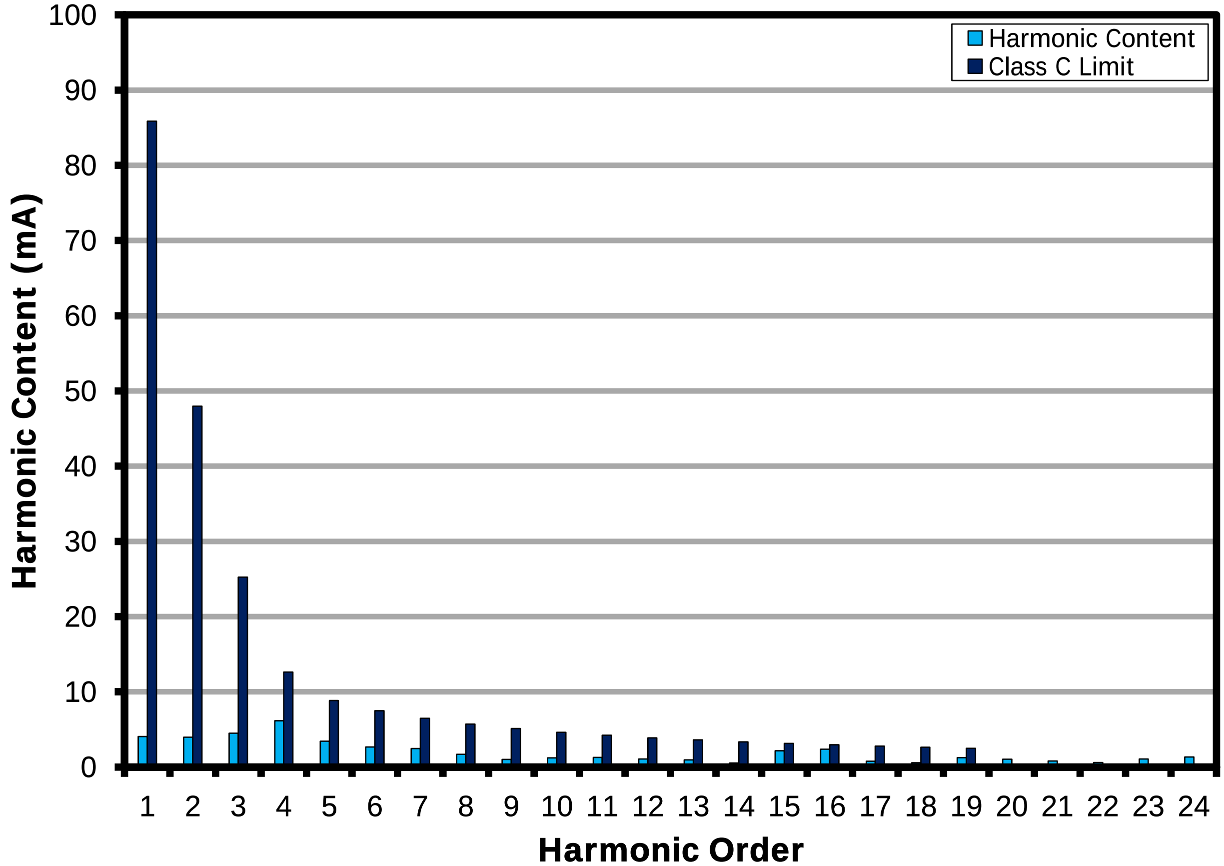

Figure 15 – 30 V Input Current Harmonics at 115 VAC, 60 Hz.

9 Test Data

9.1 Test Data, 24 V 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	89.84	119.91	10.57	0.981	8.80	24.41	355.96	8.72	82.48
100	60	99.87	108.01	10.49	0.972	9.85	24.41	356.72	8.74	83.31
115	60	114.87	95.00	10.43	0.956	12.61	24.45	356.88	8.75	83.88
120	60	119.92	90.67	10.31	0.949	13.82	24.40	355.30	8.70	84.31
132	60	131.91	83.06	10.17	0.928	17.23	24.38	351.33	8.59	84.48

9.2 Test Data, 27 V 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	89.83	132.54	11.71	0.984	9.03	27.22	352.47	9.62	82.15
100	60	99.86	118.84	11.59	0.977	9.62	27.23	352.93	9.64	83.14
115	60	114.85	104.75	11.58	0.963	11.59	27.24	357.03	9.75	84.22
120	60	119.91	99.40	11.40	0.957	12.71	27.22	351.45	9.59	84.12
132	60	131.90	90.96	11.26	0.939	15.25	27.22	349.58	9.54	84.71

9.3 Test Data, 30 V 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	89.82	145.57	12.88	0.985	9.53	30.06	349.65	10.53	81.80
100	60	99.85	129.91	12.72	0.981	9.037	30.06	350.12	10.55	82.94
115	60	114.85	113.80	12.64	0.967	10.54	30.13	350.09	10.57	83.65
120	60	119.90	107.89	12.44	0.962	11.67	30.04	347.71	10.47	84.16
132	60	131.89	98.83	12.36	0.948	14.11	30.03	347.04	10.45	84.51

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9.4 Harmonic Content at 115 VAC

9.4.1 24 V Load

V	Freq	I (mA$_{RMS}$)	P	PF	%THD
115	60.00	95.00	10.434	0.956	12.61
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	93.87				
2	0.04	0.04%		2.00%	
3	5.08	3.60%	85.95	29.01%	Pass
5	4.40	3.51%	48.03	10.00%	Pass
7	4.51	3.98%	25.28	7.00%	Pass
9	5.33	5.46%	12.64	5.00%	Pass
11	2.87	3.05%	8.85	3.00%	Pass
13	2.10	2.36%	7.49	3.00%	Pass
15	2.02	2.19%	6.49	3.00%	Pass
17	1.82	1.49%	5.73	3.00%	Pass
19	1.24	0.89%	5.12	3.00%	Pass
21	2.09	1.08%	4.63	3.00%	Pass
23	1.73	1.14%	4.23	3.00%	Pass
25	1.24	0.95%	3.89	3.00%	Pass
27	1.24	0.83%	3.60	3.00%	Pass
29	1.17	0.47%	3.36	3.00%	Pass
31	1.73	1.91%	3.14	3.00%	Pass
33	2.63	2.11%	2.95	3.00%	Pass
35	1.30	0.68%	2.78	3.00%	Pass
37	0.79	0.51%	2.63	3.00%	Pass
39	1.06	1.11%	2.50	3.00%	Pass
41	0.59	0.93%			
43	0.74	0.71%			
45	0.55	0.53%			
47	0.62	0.96%			
49	0.31	1.18%			

9.4.2 27 V Load

V	Freq	I (mA_{RMS})	P	PF	%THD
115	60.00	104.75	11.5800	0.9625	11.591
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	98.13				
2	0.03	0.06%		2.00%	
3	5.84	6.80%	146.7032	29.52%	Pass
5	5.60	3.06%	81.9812	10.00%	Pass
7	4.45	2.99%	43.1480	7.00%	Pass
9	4.29	4.11%	21.5740	5.00%	Pass
11	2.97	3.44%	15.1018	3.00%	Pass
13	2.56	2.96%	12.7784	3.00%	Pass
15	1.83	2.27%	11.0747	3.00%	Pass
17	1.40	1.32%	9.7718	3.00%	Pass
19	1.68	0.67%	8.7431	3.00%	Pass
21	2.42	0.99%	7.9105	3.00%	Pass
23	1.84	0.91%	7.2226	3.00%	Pass
25	1.02	1.39%	6.6448	3.00%	Pass
27	1.21	1.01%	6.1526	3.00%	Pass
29	1.28	0.84%	5.7283	3.00%	Pass
31	2.89	0.57%	5.3587	3.00%	Pass
33	1.91	0.36%	5.0339	3.00%	Pass
35	0.87	0.25%	4.7463	3.00%	Pass
37	0.85	0.30%	4.4897	3.00%	Pass
39	0.70	0.66%	4.2595	3.00%	Pass
41	1.21	0.50%			
43	1.08	0.51%			
45	0.42	0.42%			
47	0.37	0.40%			
49	0.53	0.29%			

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9.4.3 30 V Load

V	Freq	I (mA$_{RMS}$)	P	PF	%THD
115	60.00	113.80	12.640	0.967	10.54
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	112.71				
2	0.04	0.04%		2.00%	
3	4.06	3.58%	85.88	29.01%	Pass
5	3.96	3.31%	47.99	10.00%	Pass
7	4.49	3.95%	25.26	7.00%	Pass
9	6.15	6.07%	12.63	5.00%	Pass
11	3.44	3.54%	8.84	3.00%	Pass
13	2.66	2.30%	7.48	3.00%	Pass
15	2.47	2.16%	6.48	3.00%	Pass
17	1.68	1.43%	5.72	3.00%	Pass
19	1.00	1.20%	5.12	3.00%	Pass
21	1.22	1.01%	4.63	3.00%	Pass
23	1.29	1.11%	4.23	3.00%	Pass
25	1.07	1.09%	3.89	3.00%	Pass
27	0.94	0.72%	3.60	3.00%	Pass
29	0.53	0.57%	3.35	3.00%	Pass
31	2.15	1.83%	3.14	3.00%	Pass
33	2.38	1.93%	2.95	3.00%	Pass
35	0.77	0.73%	2.78	3.00%	Pass
37	0.58	1.16%	2.63	3.00%	Pass
39	1.25	0.42%	2.49	3.00%	Pass
41	1.05	0.81%			
43	0.80	1.13%			
45	0.60	1.09%			
47	1.08	0.55%			
49	1.33	0.27%			

10 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 115 VAC, 60 Hz line frequency, room temperature, and a nominal 27 V LED load.

10.1 Dimming Curve

Agilent 6812B AC source programmed as perfect leading edge dimmer.

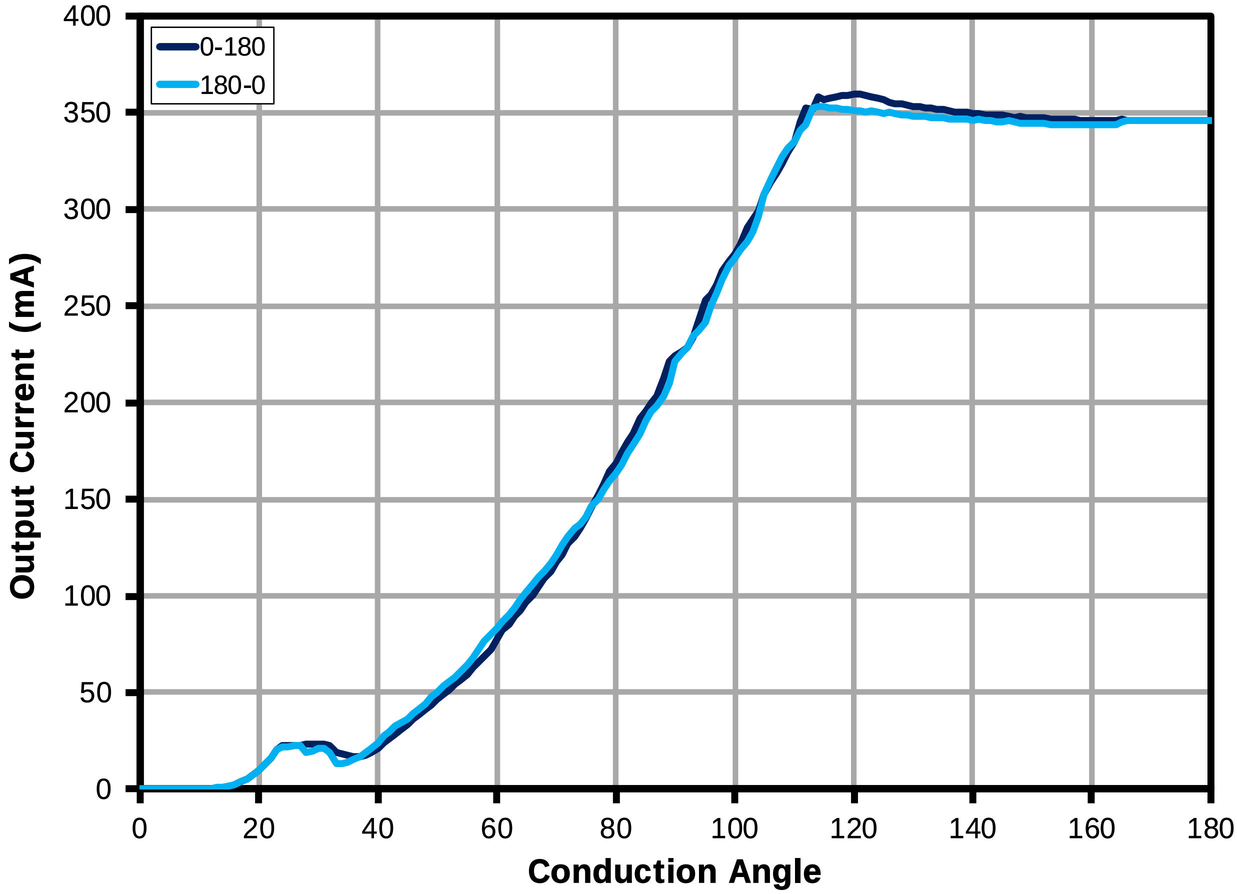

Figure 16 – Dimming Curve at 115 VAC, 60 Hz Input.

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10.2 Dimming Efficiency

Measurements were made using a programmable AC source to provide the leading edge chopped AC input. For this test, the bleeder is already active.

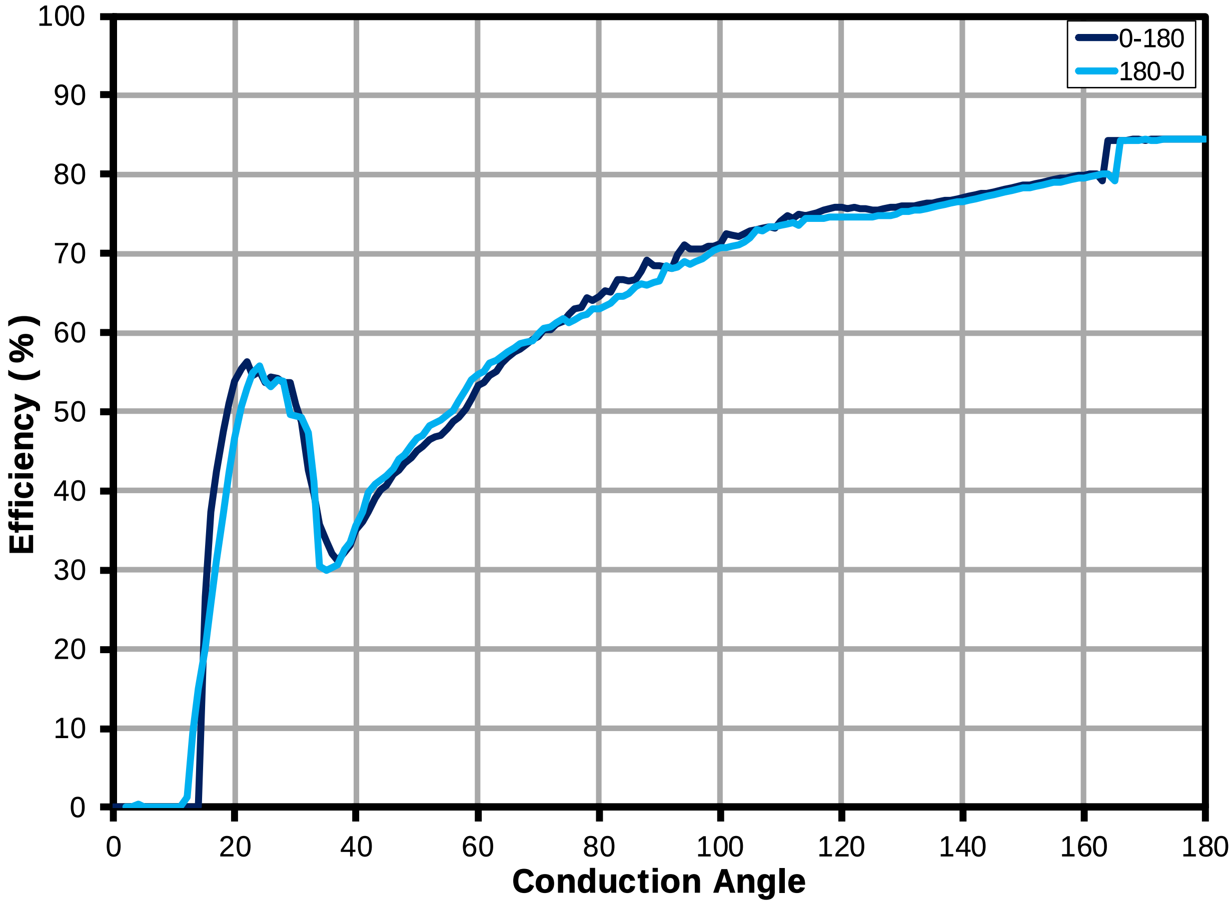

Figure 17 – Dimming Efficiency at 115 VAC, 60 Hz Input.

10.3 Driver Power Loss During Dimming

Measurements were made using a programmable AC source to provide the leading edge chopped AC input. For this test, the bleeder is already active.

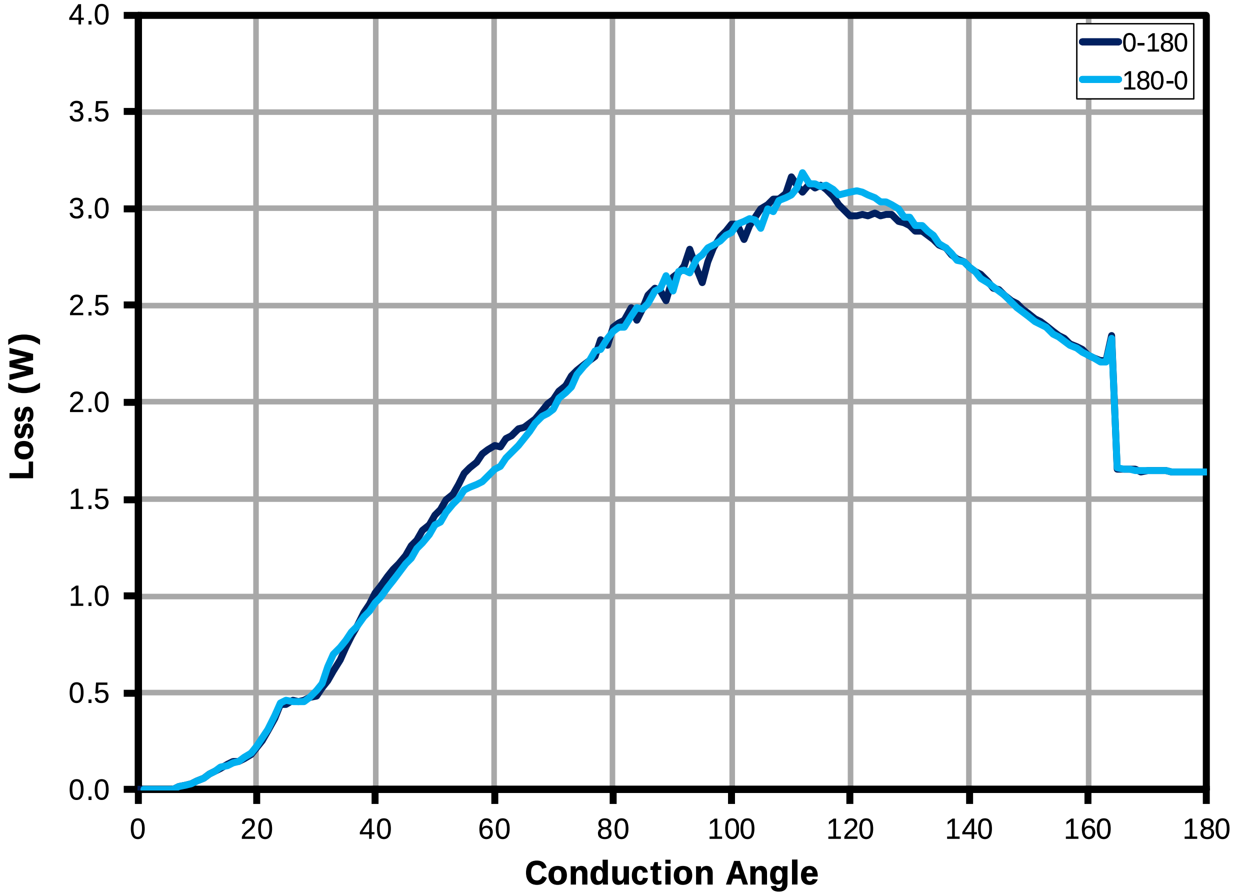

Figure 18 – Dimming Power Loss at 115 VAC, 60 Hz Input.

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10.4 Dimmer Compatibility List

The following dimmers were tested at 25 ºC ambient temperature with utility line input (~115 VAC, 60 Hz) and 27 V LED load.

No	Panel	Brand	Model	Type	Max (mA)	Min (mA)	Remarks
1	9	LEGRAND	HCL453PTCCCV6	L	356.73	82.29	No flicker
2	9	LEVITON	1PE04-1LZ	T	374.17	25.096	No flicker
3	9	LUTRON	AYCL-153P-WH	L	358.1	21.41	No flicker
4	9	LUTRON	SCL-153P-WH	L	358.04	21.605	No flicker
5	9	LUTRON	RRD-10ND-WH	L	363.14	24.701	No flicker
6	9	LUTRON	RRD-6NA-WH	T	378.05	20.554	No flicker
7	10	LUTRON	N-600-WH	L	360.01	22.103	No flicker
8	10	LUTRON	NTELV-600-WH	T	355.82	19.946	No flicker
9	10	LUTRON	NT-603P-WH	L	358.92	10.64	No flicker
10	10	LEVITON	1PSD6-1LZ	L	356.41	23.28	No flicker
11	10	LEVITON	1PVD6-1LZ	L	358.29	9.91	No flicker
12	10	LEVITON	1PL06-10Z	L	356.99	10.342	No flicker
13	10	LEVITON	6672	L	357.97	10.012	No flicker
14	11	LEVITON	6674	L	358.77	10.00	No flicker
15	11	LEVITON	6641	L	359.11	15.42	No flicker
16	11	LEVITON	6602	L	359.52	8.29	No flicker
17	11	LEVITON	TBL03	L	358.92	9.54	No flicker
18	11	LEVITON	6615	T	367.04	48.43	No flicker
19	11	LUTRON	CTCL-153P-WH	L	358.91	10.94	No flicker
20	1	COOPER	R106PL-W-K	L	356.67	54.76	No flicker
21	1	COOPER	9530WS-K	L	358.82	14.64	No flicker
22	1	LEVITON	601-6631-1	L	358.66	1.083	No flicker
23	1	LEVITON	6683	L	359.6	38.81	No flicker
24	1	LEVITON	1P106-1LZ	L	360.16	15.45	No flicker
25	1	LEVITON	6681	L	359.70	4.787	No flicker
26	1	LEVITON	6633_PLW	L	358.55	1.698	No flicker
27	2	G.E.	18023	L	341	9.44	No flicker
28	2	G.E.	18022	L	319.07	9.69	No flicker
29	2	LUTRON	MRF2-6ND-120-BI	L	342.87	7.09	No flicker
30	2	LUTRON	RRD-6NA-WH	T	368.28	6.5	No flicker
31	2	LUTRON	D-600P-WH	L	341.21	3.25	No flicker
32	2	LUTRON	DVCL-153P-WH	L	342.2	21.53	No flicker
33	2	LUTRON	AY-600PNL-WH	L	340	8.07	No flicker
34	4	LUTRON	LGCL-153PLH-WH	L	346.56	23.02	No flicker
35	4	LEVITON	6681	L	337.2	5.09	No flicker
36	4	LUTRON	S-600P-WH	L	338.74	2.19	No flicker
37	4	LUTRON	MACL-753-WH	L	342.09	17.77	No flicker
38	3	LUTRON	S-600P-WH	L	357.54	1.84	No flicker
39	3	LUTRON	MA-600-WH	L	357.43	22.53	No flicker
40	3	LUTRON	LXELV-600PL-WH	T	379.04	14.43	No flicker
41	3	LUTRON	NTELV-300-WH	T	374.04	15.48	No flicker
42	3	LUTRON	NT-600-WH	L	359.4	10.94	No flicker
43	3	LUTRON	DVELV-300P-WH	T	359.71	14.71	No flicker
44	3	LUTRON	SELV-300P-WH	T	378.01	14.76	No flicker
45	3	LUTRON	CTCL-153P-WH	L	357.67	18.01	No flicker

11 Thermal Performance

Thermal measurements were performed with the power supply operating at 25 ºC ambient temperature with maximum output of 27 V LED load. The power supply was soaked for 1 hour to allow component temperatures to stabilize.

11.1 Non-Dimming

Normal Operation	90 VAC	115 VAC	132 VAC
Ambient	25 °C		
Bleeder Resistor (R4)	30.80 °C	29.70 °C	30.40 °C
Bleeder Resistor (R5)	34.00 °C	32.50 °C	33.10 °C
Bleeder Resistor (R25)	36.00 °C	35.00 °C	35.20 °C
Bleeder Transistor	33.50 °C	31.70 °C	32.20 °C
Damper (R2)	47.70 °C	42.50 °C	41.60 °C
Fusible Resistor	47.60 °C	41.50 °C	40.50 °C
Output Diode	46.40 °C	45.80 °C	46.60 °C
LYTSwitch-3	44.70 °C	42.50 °C	42.60 °C
Transformer	48.20 °C	48.10 °C	49.50 °C
Ambient	23.70 °C	23.40 °C	24.50 °C

11.2 Dimming

Component	115 VAC
Ambient Temperature	75 °C
Bleeder Resistor (R4)	109.90 °C
Bleeder Resistor (R5)	116.60 °C
Bleeder Resistor (R25)	116.80 °C
Bleeder Transistor	105.50 °C
Damper (R2)	117.30 °C
Fusible Resistor	102.00 °C
Output Diode	94.30 °C
LYTSwitch-3	108.50 °C
Transformer	104.40 °C

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12 Waveforms

12.1 Input Voltage and Input Current Waveforms

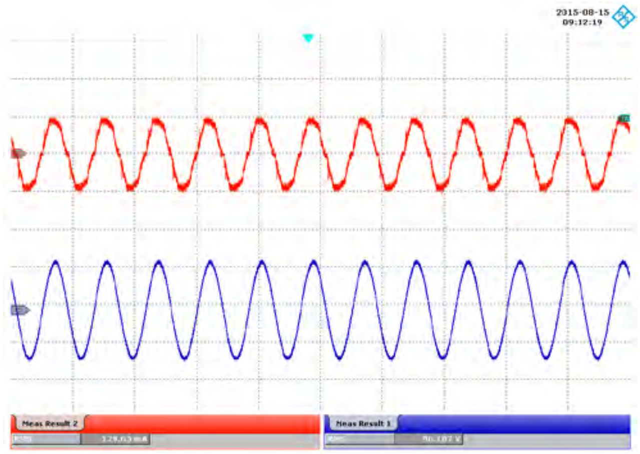

Figure 19 – 90 VAC, 27 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

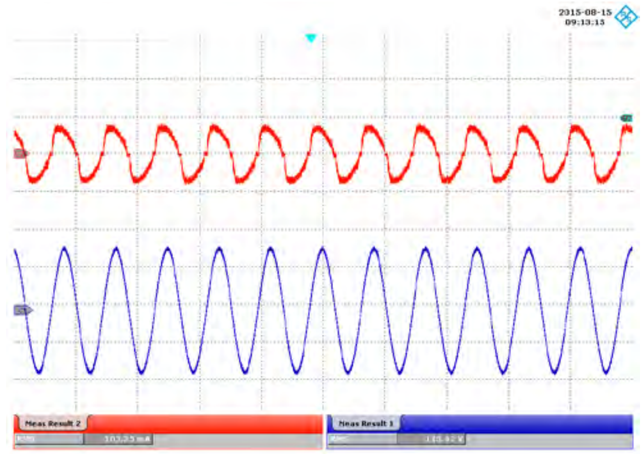

Figure 20 – 115 VAC, 27 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

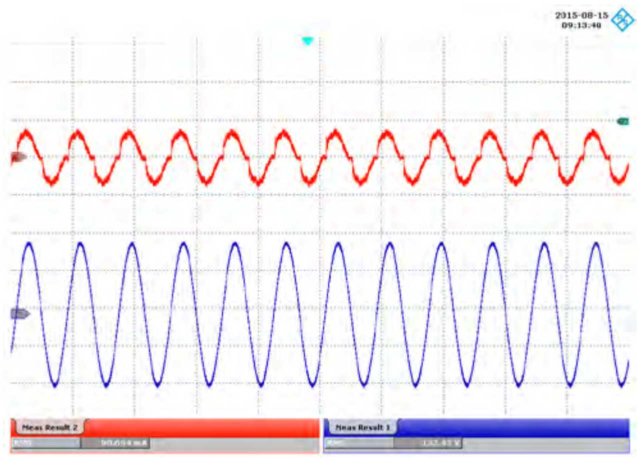

Figure 21 – 132 VAC, 27 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

12.2 Output Current Rise and Fall

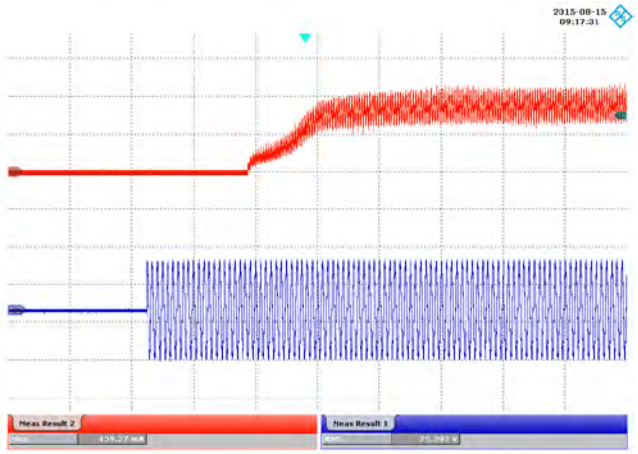

Figure 22 – 90 VAC, 27 V LED Load, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

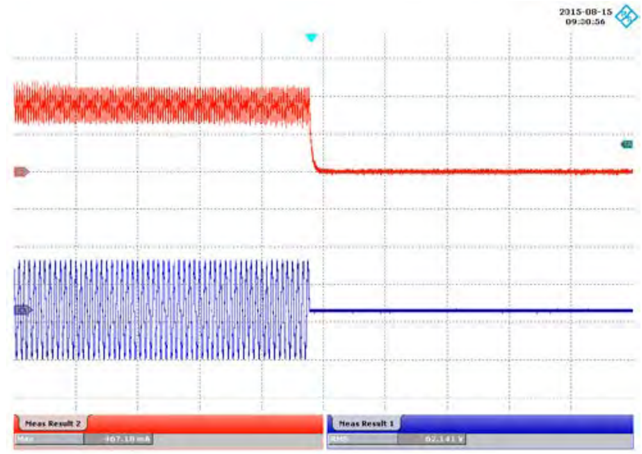

Figure 23 – 90 VAC, 27 V LED Load, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

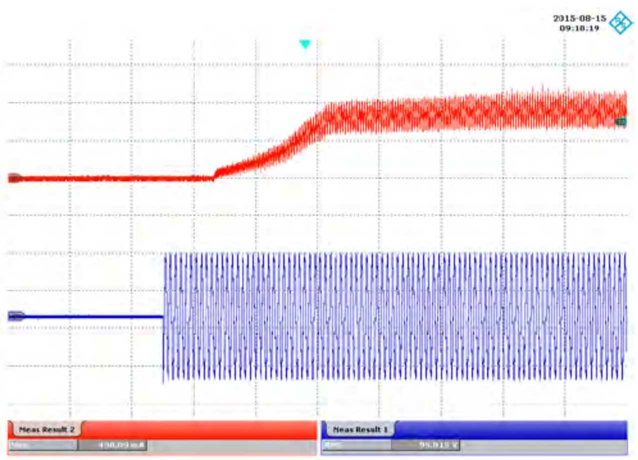

Figure 24 – 115 VAC, 27 V LED Load, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

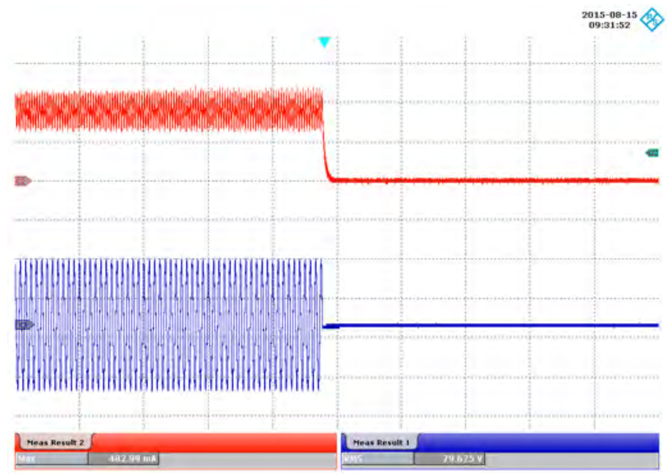

Figure 25 – 115 VAC, 27 V LED Load, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

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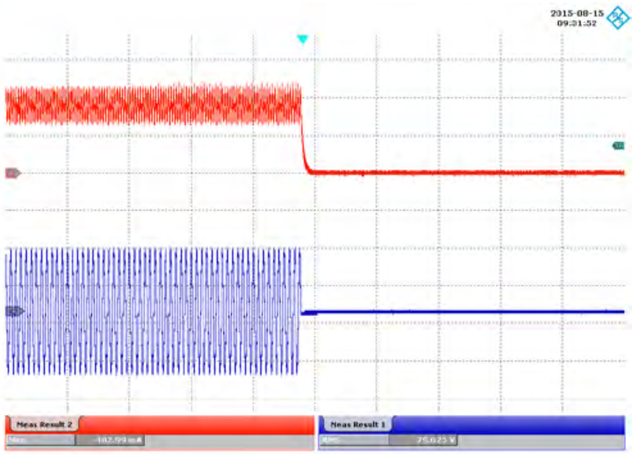

Figure 26 – 132 VAC, 27 V LED Load, Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

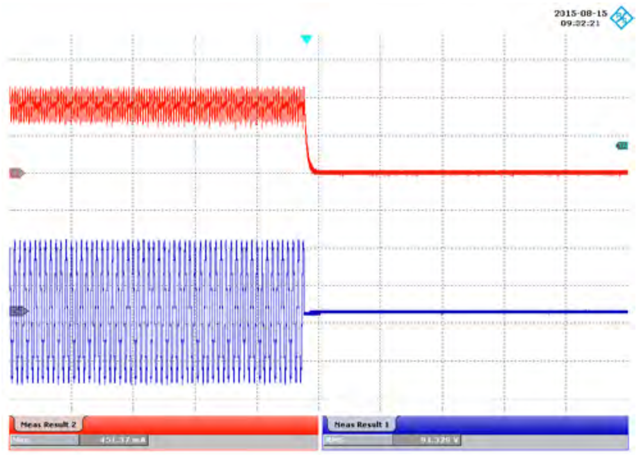

Figure 27 – 132 VAC, 27 V LED Load, Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

12.3 Drain Voltage and Current in Normal Operation

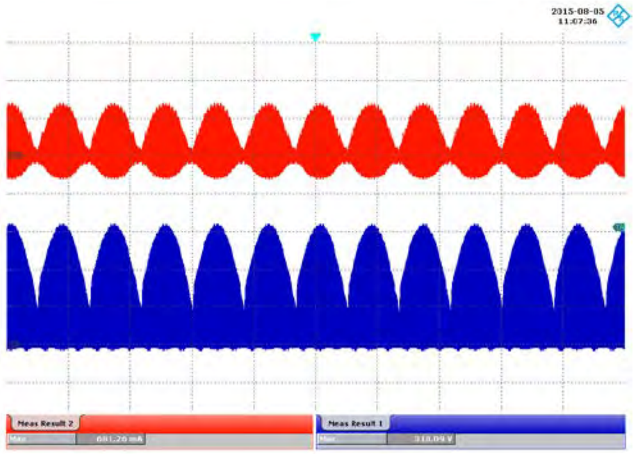

Figure 28 – 90 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 ms / div.

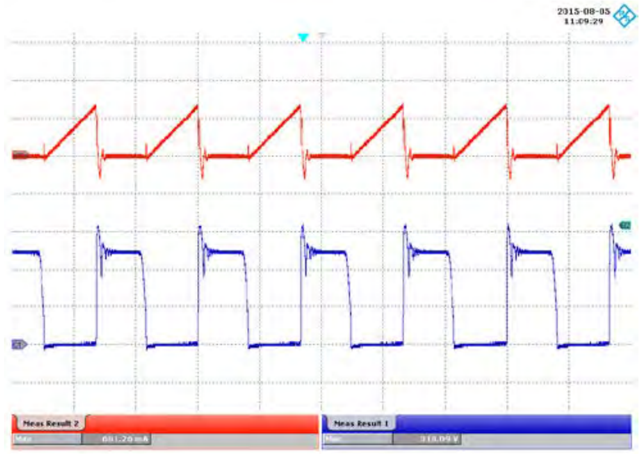

Figure 29 – 90 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

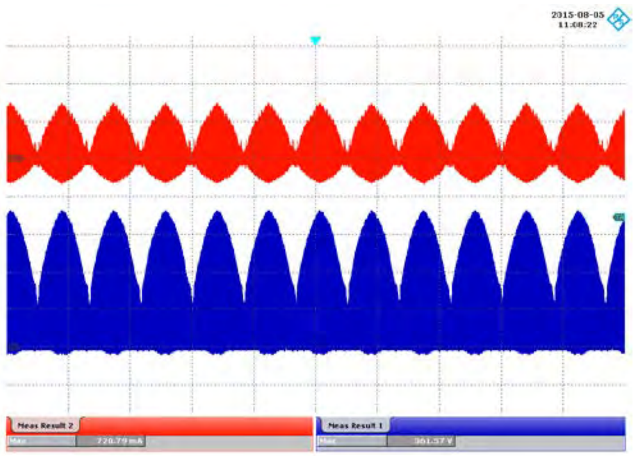

Figure 30 – 115 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 ms / div.

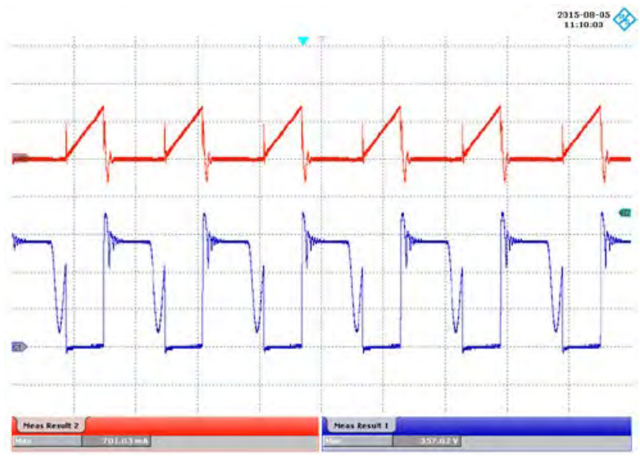

Figure 31 – 115 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

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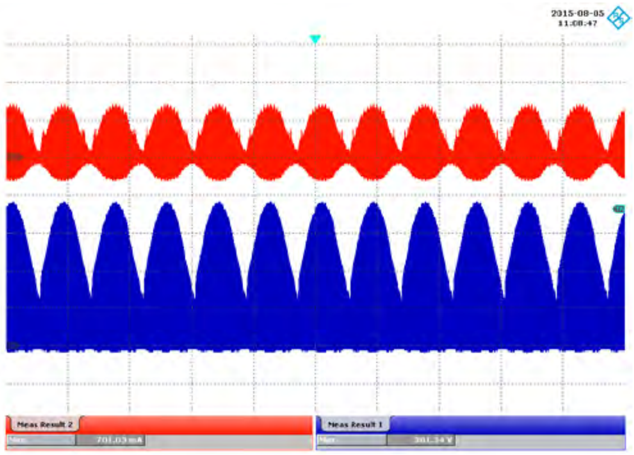

Figure 32 – 132 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 10 ms / div.

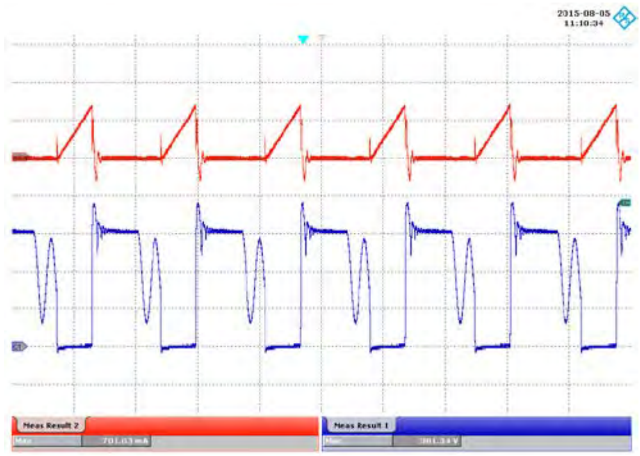

Figure 33 – 132 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

12.4 Drain Voltage and Current Start-up Profile

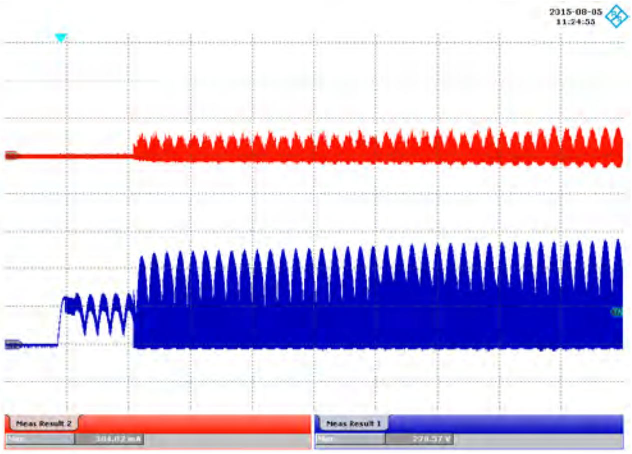

Figure 34 – 90 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms /div.

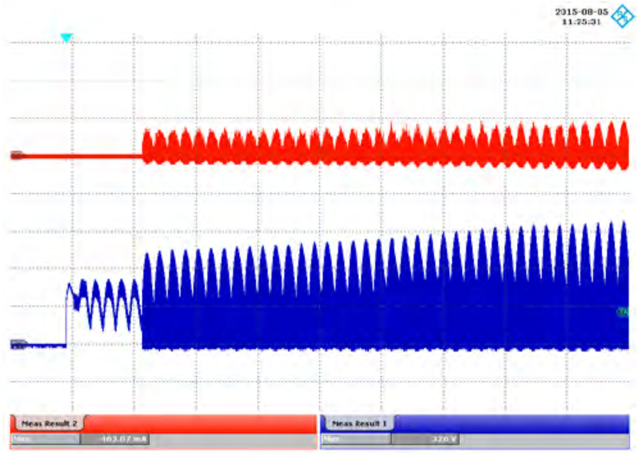

Figure 35 – 115 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms /div.

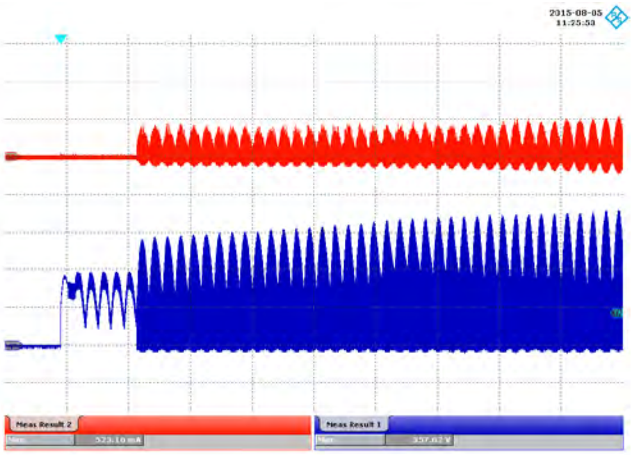

Figure 36 – 132 VAC, 27 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 20 ms /div.

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12.5 Drain Voltage and Current During Output Short-Circuit Condition

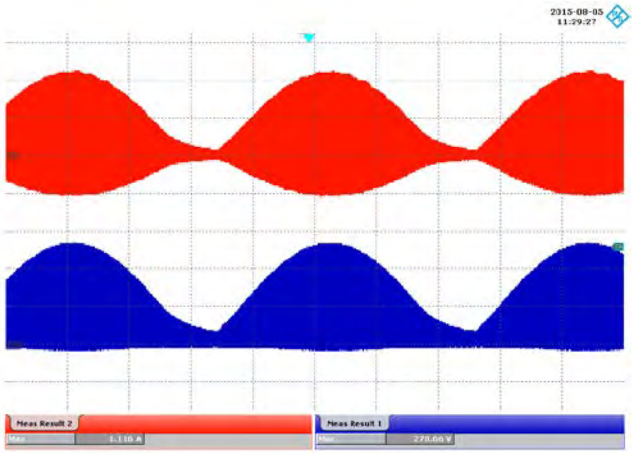

Figure 37 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 ms / div.

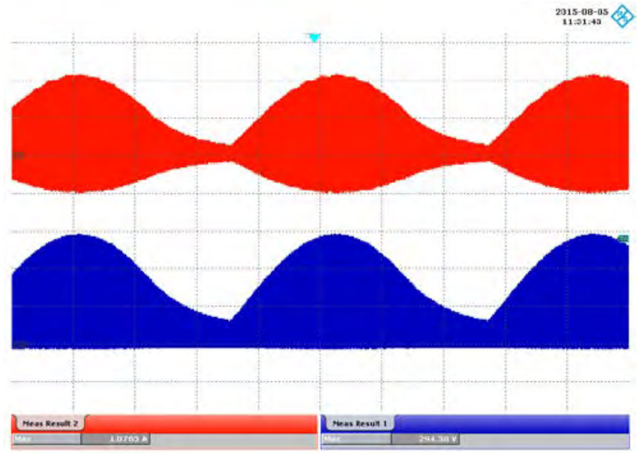

Figure 38 – 115 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 ms / div.

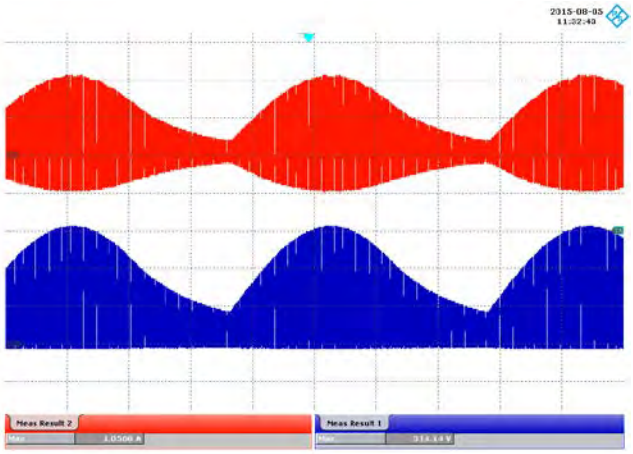

Figure 39 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 ms / div.

12.6 Output Diode Voltage and Current in Normal Operation

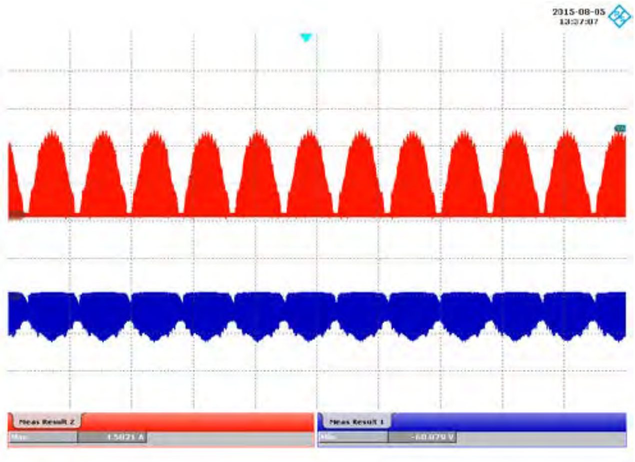

Figure 40 – 90 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 ms / div.

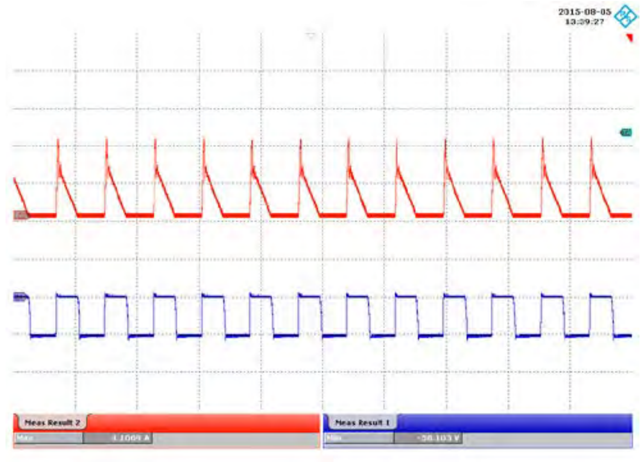

Figure 41 – 90 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 µs / div.

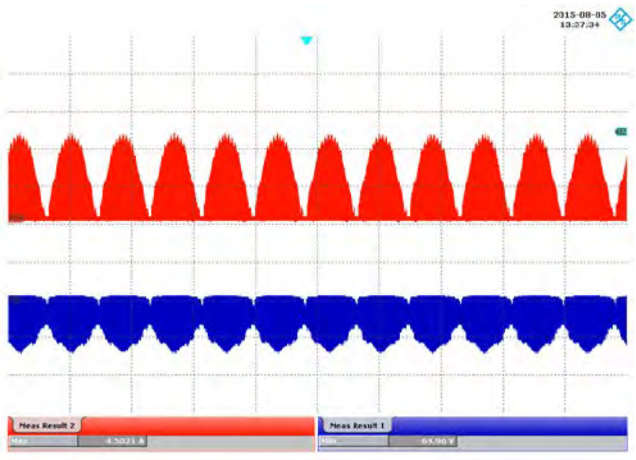

Figure 42 – 115 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 ms / div.

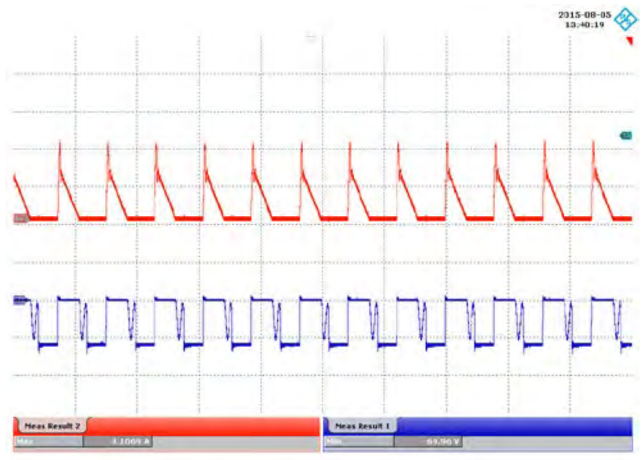

Figure 43 – 115 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 µs / div.

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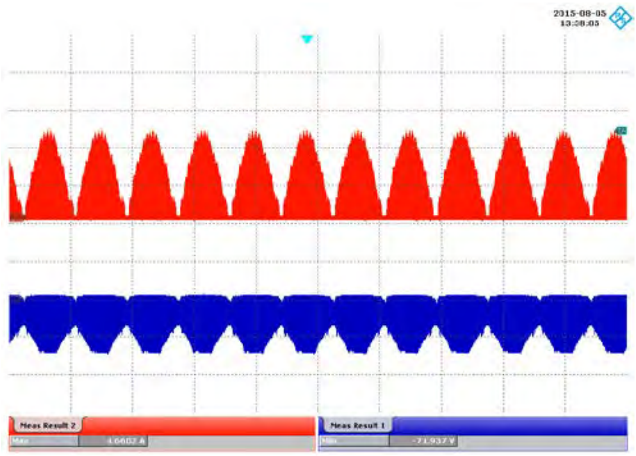

Figure 44 – 132 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 ms / div.

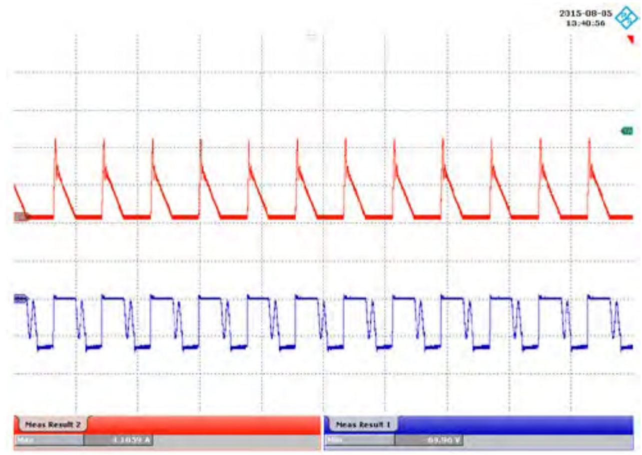

Figure 45 – 132 VAC, 27 V LED Load.
Upper: I_{DIODE}, 2 A / div.
Lower: V_{DIODE}, 50 V / div., 10 µs / div.

12.7 Output Voltage and Current – Open LED Load

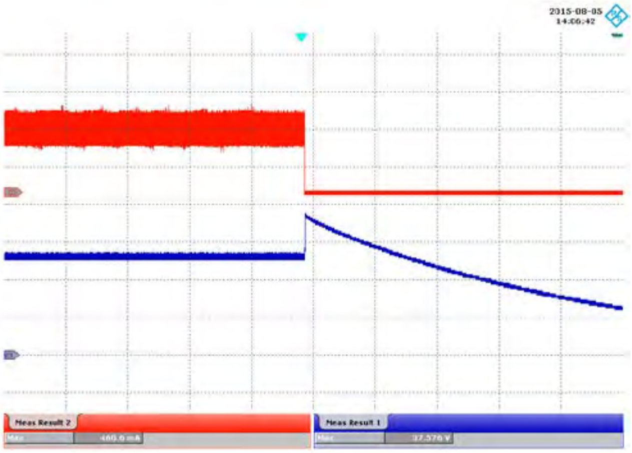

Figure 46 – 90 VAC, 27 V LED Load,
Running Open Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

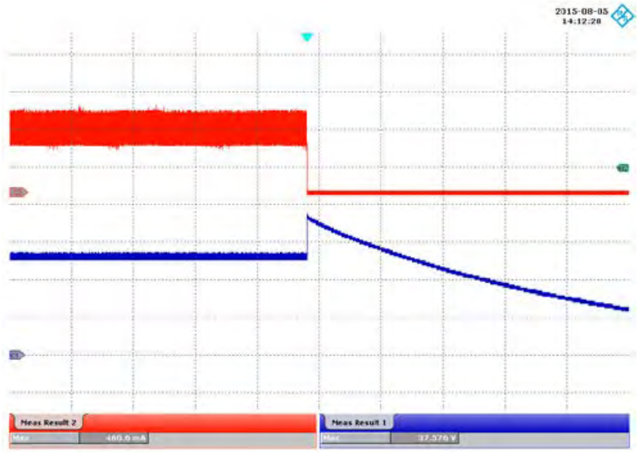

Figure 47 – 115 VAC, 27 V LED Load,
Running Open Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

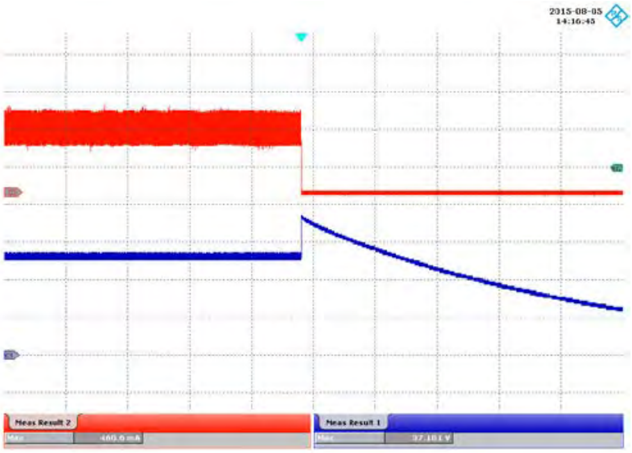

Figure 48 – 132 VAC, 27 V LED Load,
Running Open Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V / div., 10 s / div.

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12.8 Output Ripple Current

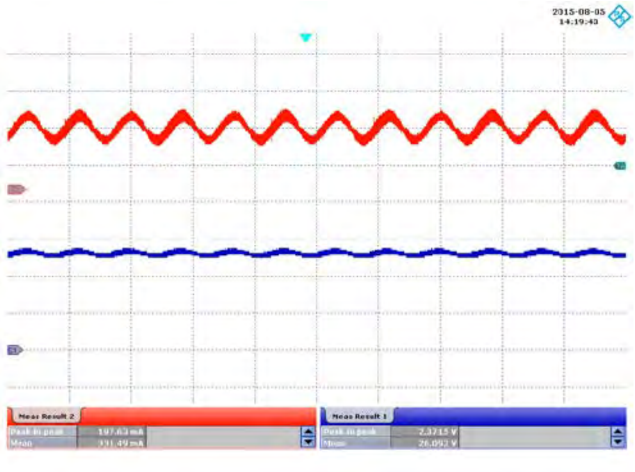

Figure 49 – 90 VAC, 60 Hz, 27 V LED Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10V / div., 10 ms / div.

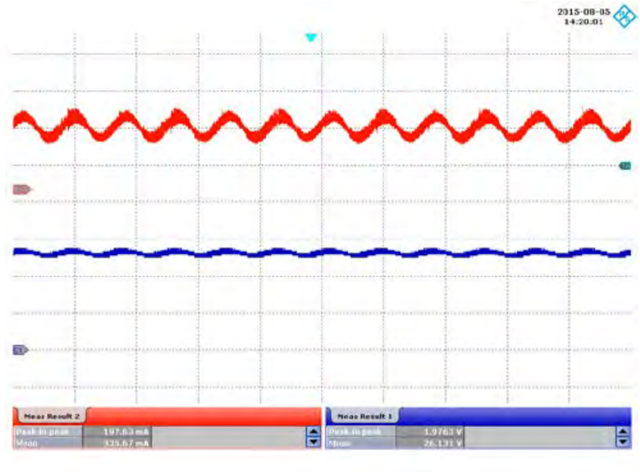

Figure 50 – 115 VAC, 60 Hz, 27 V LED Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10V / div., 10 ms / div.

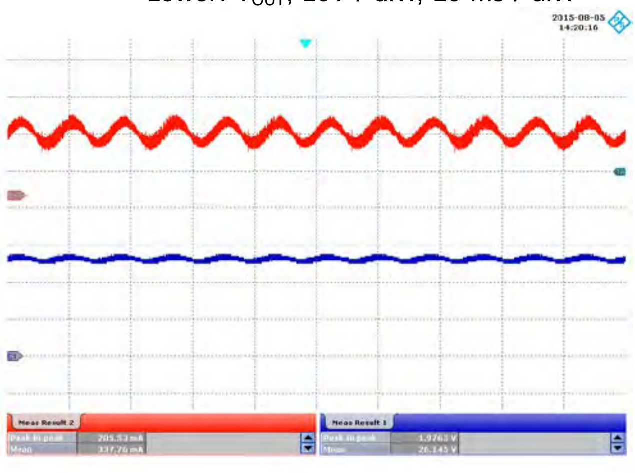

Figure 51 – 132 VAC, 60 Hz, 27 V LED Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10V / div., 10 ms / div.

12.9 Input Voltage and Input Current Dimming Waveforms

12.9.1 LEVITON 6602 L-Type

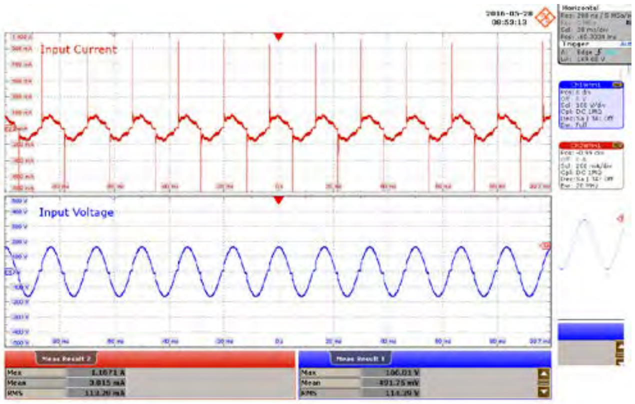

Figure 52 – 115 VAC, 60 Hz, 27 V LED Load,
180° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

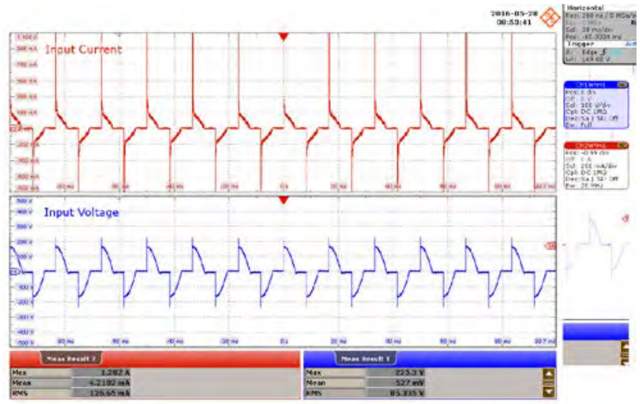

Figure 53 – 115 VAC, 60 Hz, 27 V LED Load,
90° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

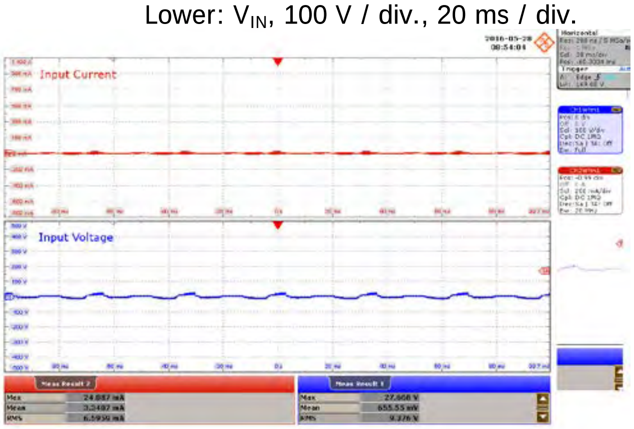

Figure 54 – 115 VAC, 60 Hz, 27 V LED Load,
Minimum Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 20 ms / div.

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12.9.2 LEVITON 6615 T-Type

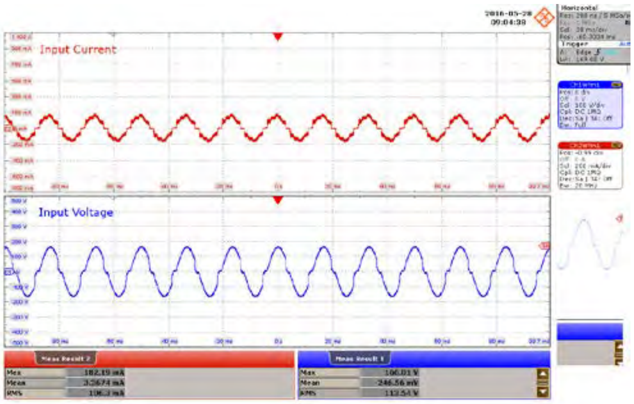

Figure 55 – 115 VAC, 60 Hz, 27 V LED Load,
180° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100V / div., 20 ms / div.

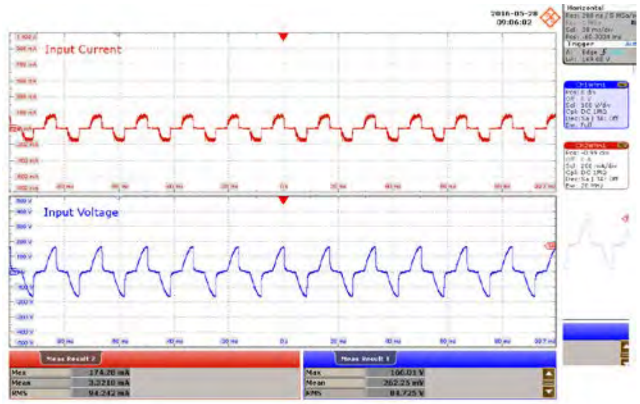

Figure 56 – 115 VAC, 60 Hz, 27 V LED Load,
90° Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100V / div., 20 ms / div.

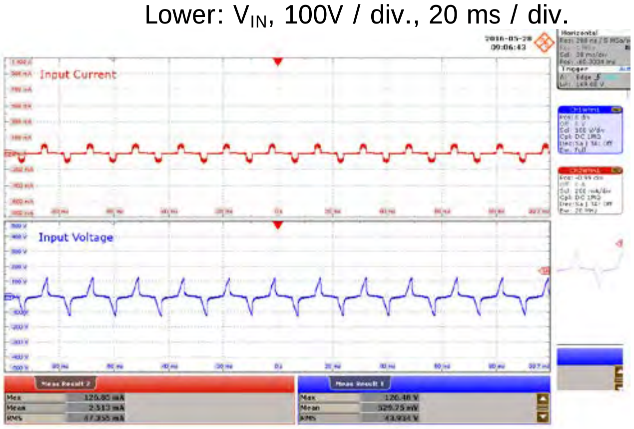

Figure 57 – 115 VAC, 60 Hz, 27 V LED Load,
Minimum Conduction Angle.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100V / div., 20 ms / div.

13 AC Cycling Test

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

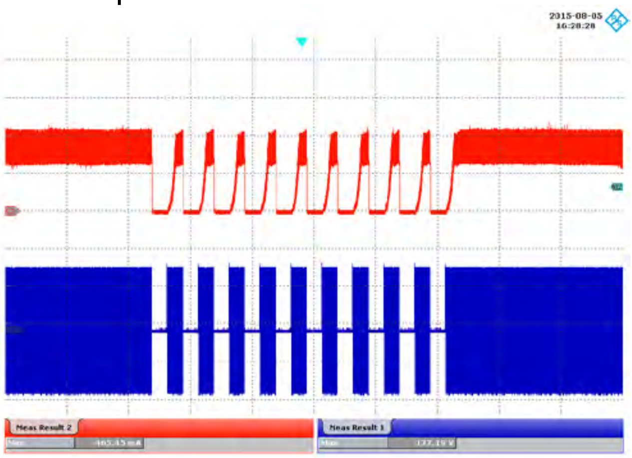

Figure 58 – 115 VAC, 27 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

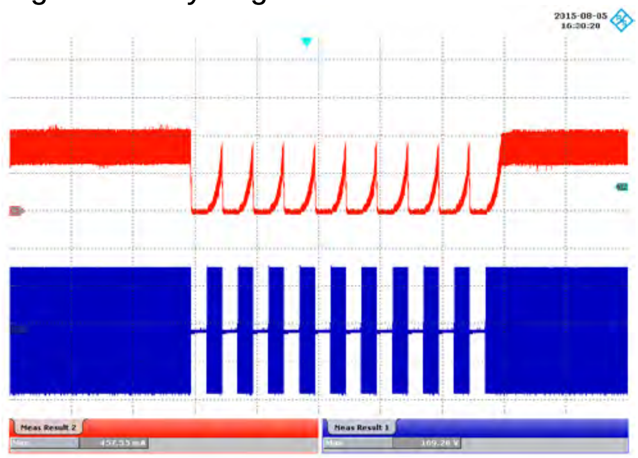

Figure 59 – 115 VAC, 27 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

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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. 27 V LED load with input voltage set at 115 VAC.

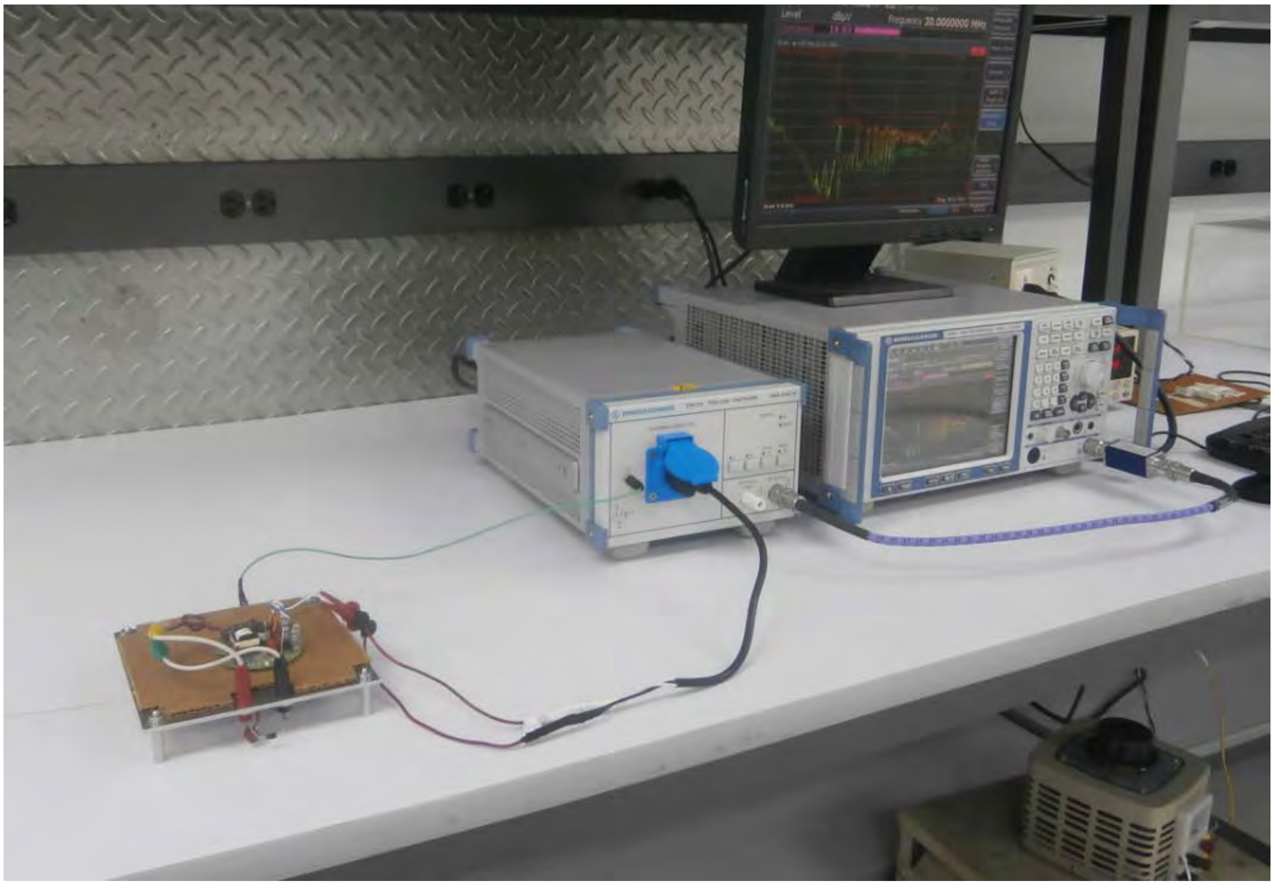

Figure 60 – Conducted EMI Test Set-up.

14.2 EMI Test Result

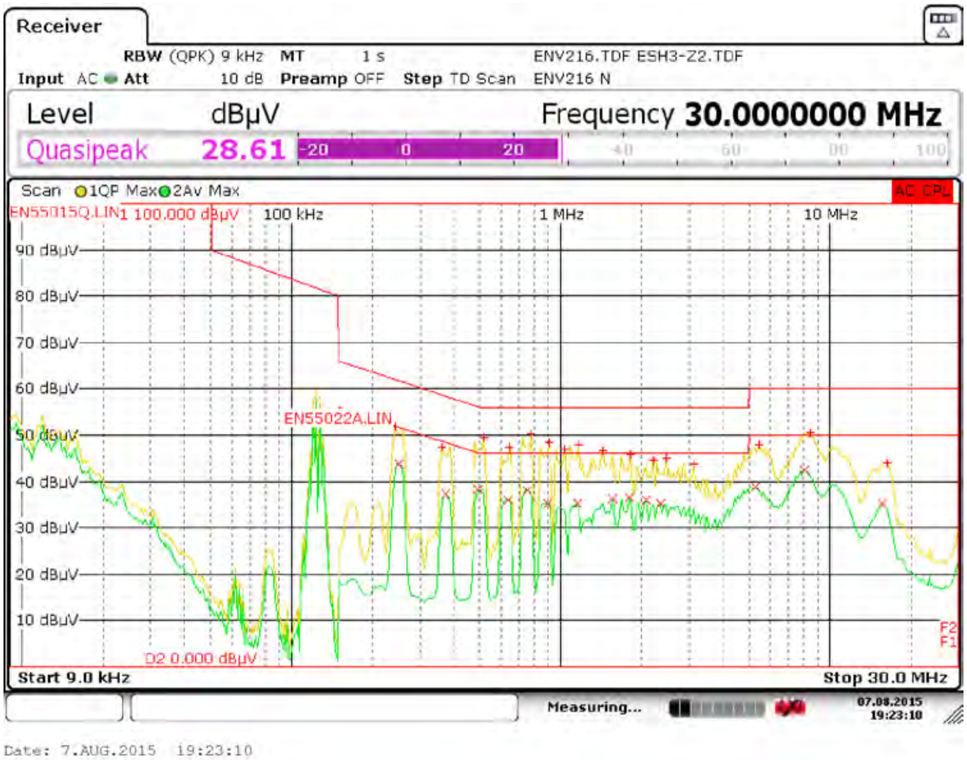

Figure 61 – Conducted EMI, 27 V LED Load with metal heatsink grounded, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	777.7500 kHz	50.35 L1	-5.65 dB
1 Quasi Peak	519.0000 kHz	49.45 L1	-6.55 dB
1 Quasi Peak	908.2500 kHz	48.56 L1	-7.44 dB
2 Average	8.0948 MHz	42.39 L1	-7.61 dB
2 Average	494.2500 kHz	38.31 L1	-7.79 dB
2 Average	251.2500 kHz	43.90 N	-7.82 dB
2 Average	748.5000 kHz	38.03 L1	-7.97 dB
1 Quasi Peak	1.1670 MHz	47.80 L1	-8.20 dB
1 Quasi Peak	647.2500 kHz	47.37 L1	-8.63 dB
1 Quasi Peak	1.0388 MHz	46.82 L1	-9.18 dB
1 Quasi Peak	8.4773 MHz	50.60 L1	-9.40 dB
2 Average	1.8038 MHz	36.58 L1	-9.42 dB
1 Quasi Peak	1.4303 MHz	46.52 L1	-9.48 dB
2 Average	1.5608 MHz	36.37 L1	-9.63 dB
[illegible]	[illegible]	[illegible]	[illegible]

Figure 62 – Conducted EMI, 27 V LED Load with metal heatsink grounded, Final Measurement Results.

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15 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass

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

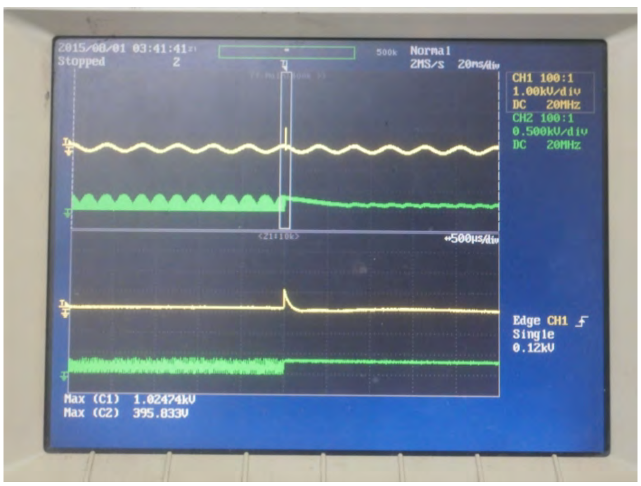

Figure 63 – +1000 kV Differential Surge, 90 ºC Phase.

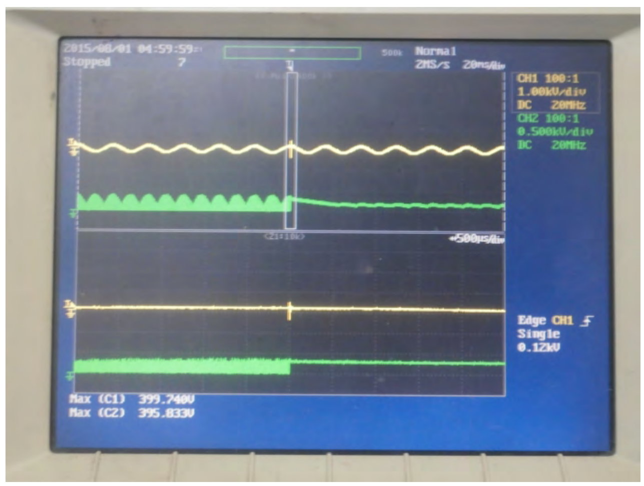

Figure 64 – +2500 kV Ring Wave, 90 ºC Phase.

16 Brown-in/Brown-out Test

No failure of any component was seen during brownout test of 0.5 V / sec AC cut-in and cut-off.

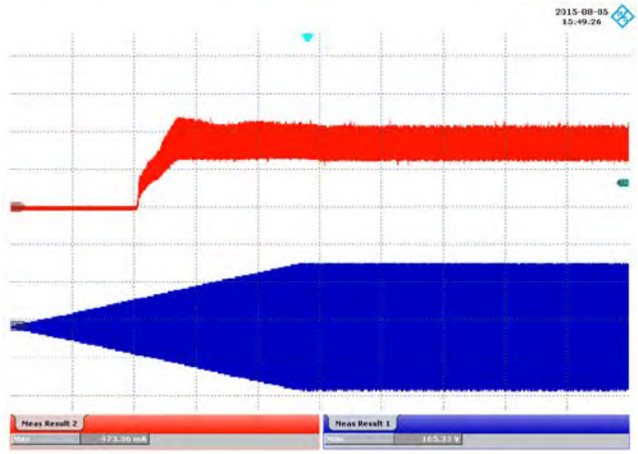

Figure 65 – Brown-in Test at 0.5 V / s.
The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

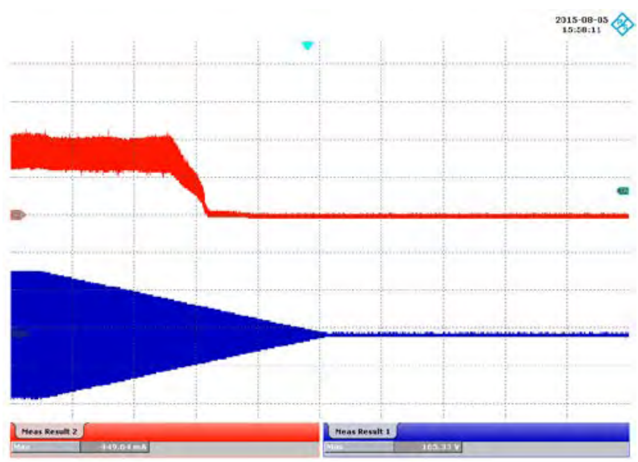

Figure 66 – Brown-out Test at 0.5 V / s.
The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

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17 Revision History

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

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

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