Design Example Report

Title	***7 W TRIAC Dimmable, High Efficiency, Power Factor Corrected Non-Isolated Buck LED Driver Using LYTSwitch™-3 LYT3315D***
Specification	90 VAC – 132 VAC Input; 42 V, 165 mA_{TYP} Output
Application	A19 Bulb
Author	Applications Engineering Department
Document Number	DER-511
Date	March 1, 2016
Revision	1.0

Summary and Features

- Combined single-stage conversion
  - Power factor corrected, PF >0.9
  - Accurate constant LED current (CC), combined line and load regulation, ±2%
- Highly energy efficient, >87% at 120 V
- Low component count for compact PCB solution
- Leading-edge and trailing-edge TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers
  - Fast start-up time (<500 ms) – no perceptible delay
- Integrated protection features
  - No load and output short-circuit protection
  - Thermal fold-back and over temperature 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, non-isolated buck LED driver designed to drive a nominal LED voltage string of 42 V at 165 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.

The LYTSwitch-3 is a TRIAC dimmable LED driver IC with a single-stage PFC function and accurate LED current control.

The DER-511 provides a single 6.9 W TRIAC dimmable constant current output. The key design goals were high efficiency to maximize efficacy, small PCB for compact size LED lamps and excellent dimming compatibility.

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

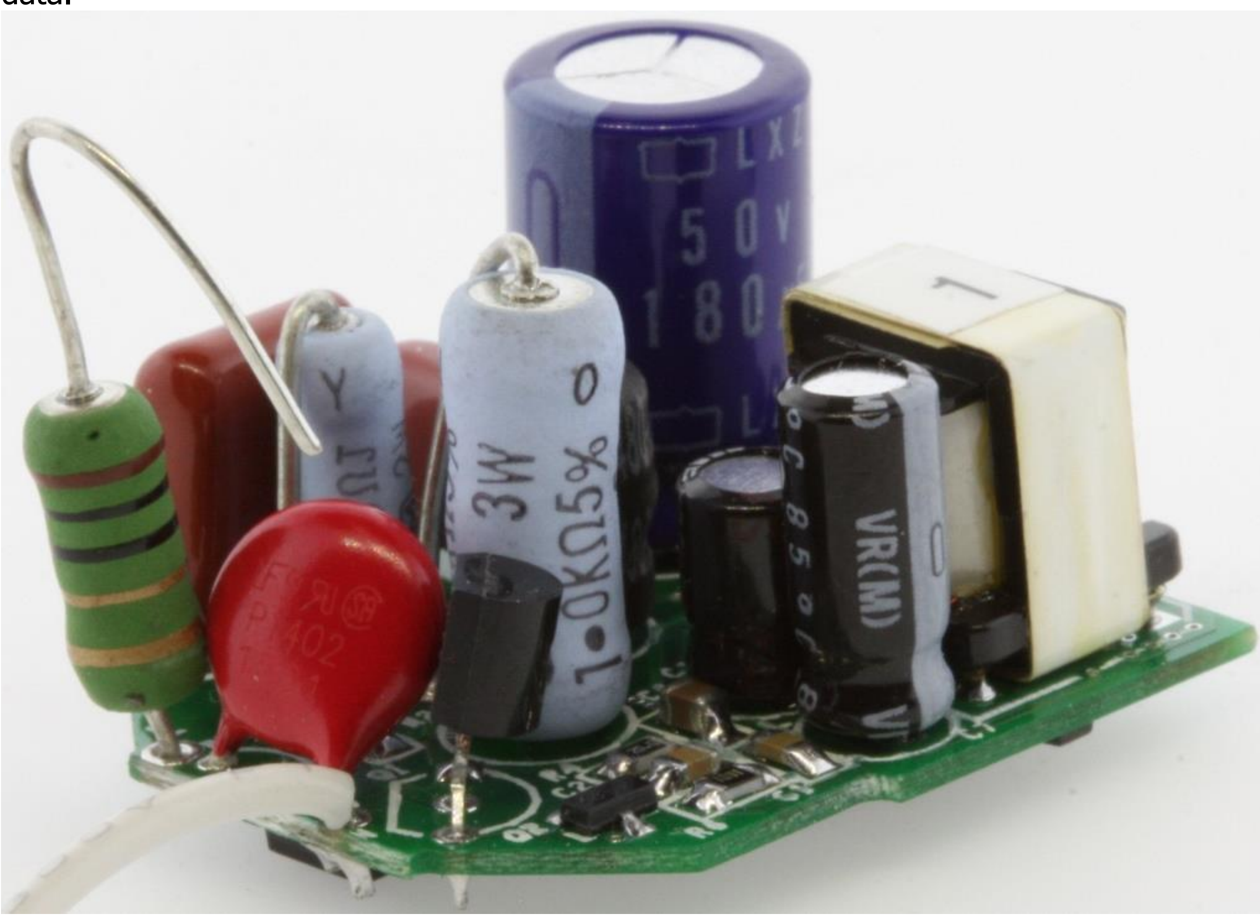

Figure 1 – Populated Circuit Board.

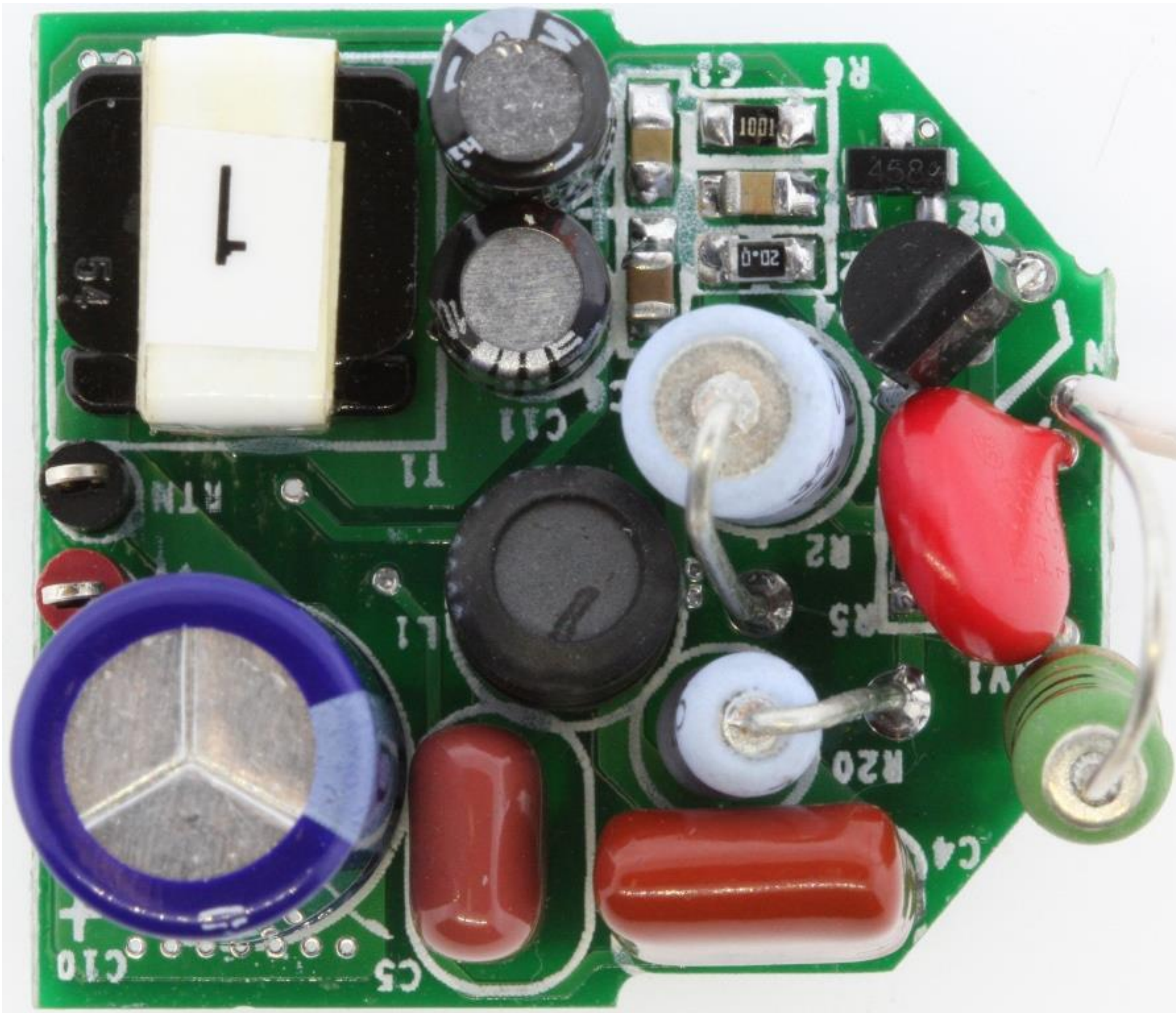

Figure 2 – Populated Circuit Board, Top View.

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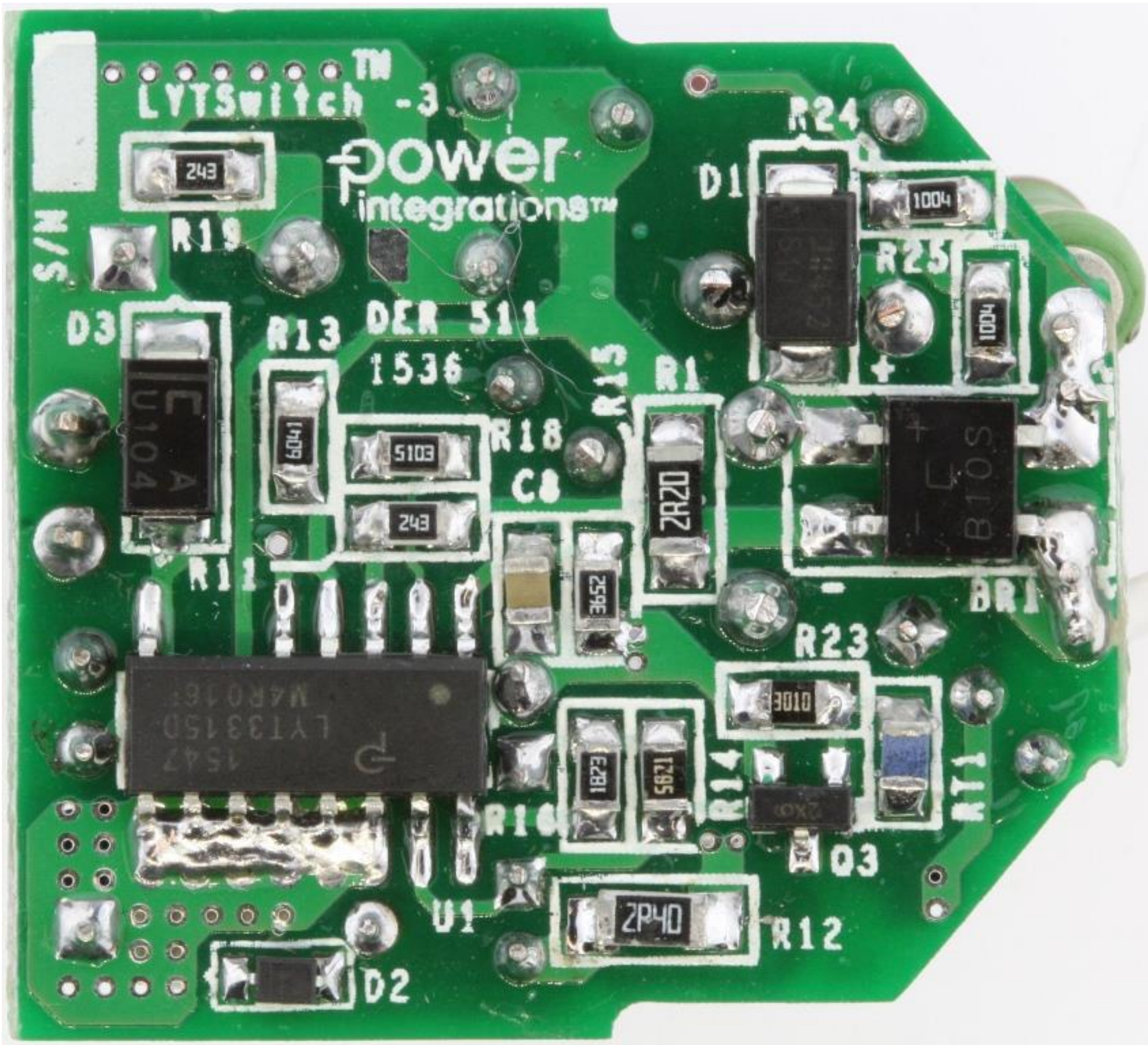

Figure 3 – Populated Circuit Board, Bottom View.

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	120	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}	37	42	47	V	
Output Current	I_{OUT}	160	165	170	mA	±3%
Total Output Power						
Continuous Output Power	P_{OUT}		7		W	
Efficiency						
Full Load	η		87.5		%	Measured at 120 VAC, 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.97			Measured at 240 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			40	°C	Free Convection, Sea Level.

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3 Schematic

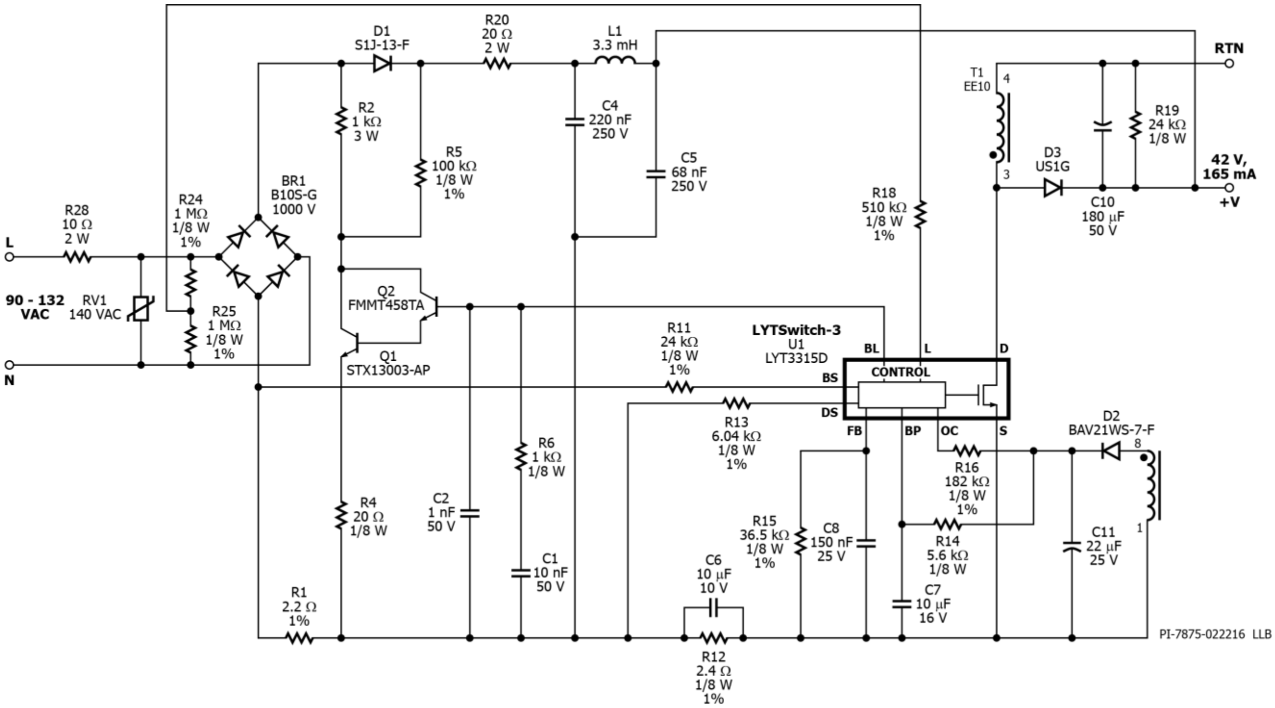

Figure 4 – Schematic.

4 Circuit Description

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

4.1 *Input Stage*

Fusible resistor R28 provides protection against component failure. Varistor RV1 acts as a clamp to limit the maximum voltage spike on the primary during differential line surge events. A 140 VAC rated part was selected, being slightly above the maximum specified operating voltage (132 VAC).

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

The differential choke L1, together with the input filter capacitor C4 and C5 work as an EMI π filter. The EMI filter, together with the LYTSwitch-3 IC's frequency jittering feature ensure compliance with EN55015 Class B emission limits.

4.2 *LYTSwitch-3 Primary Control Circuit*

The topology is a buck converter with a low-side power switch. The primary winding finish terminal (no dot end) of the transformer (T1) is connected to the DC bus and the start (dotted end) terminal to the DRAIN (D) pin of the LYTSwitch-3 IC. During the on-time of the power MOSFET, current ramps through the primary winding storing energy and charging the output capacitor C10 and driving the LED load. The stored energy in the transformer is delivered to the output load via freewheeling diode D3 during the power MOSFET off-time. Output capacitor C10 provides output voltage filtering minimizing the output LED ripple current.

Diode D2 and C11 generate a primary bias supply for U1 from an auxiliary winding on the transformer. The use of an external bias supply (via R14) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming.

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

To provide input line voltage information to U1, the incoming rectified AC is sense directly by the LINE SENSE (L) pin of U1 via resistor R24, R25 and R18. The L pin current is also use to detect an input overvoltage, to detect the presence of dimmer, and to control the output LED current with respect to line voltage. During input overvoltage switching is disabled. Switching will restart automatically when the input voltage returns to safe levels.

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With reference to the FEEDBACK (FB) pin full conduction preset threshold of 300 mV, R12 senses the output LED current which is fed into the DS pin of U1 via R13. This signal is used to keep the output current in regulation. The capacitor C10 provides voltage filtering to generate a DC reference voltage. The FB pin threshold is reduced linearly with respect to input conduction angle.

The OUPUT COMPENSATION (OC) pin of U1 senses the output voltage through R16 for the output OV protection function (open load and helps optimize LED current regulation. When output OVP is triggered (OC pin voltage exceeds the OV threshold) the IC latches off.

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

Due to the low power consumed by LED based lighting, the current drawn by the lamp is below the holding current of the TRIAC found in many dimmers. This causes undesirable behavior such as limited dimming range and/or flicker. The relatively large impedance presented to the line by the LED allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This effect can cause similar undesirable behavior, as the ringing may cause the TRIAC current to fall below its holding current and turn off. To overcome these issues, a passive damper and an active bleeder are used.

Resistor R20 dampens the driver input current ringing when TRIAC dimmer turns on. Diode D1 serves as a blocking diode to prevent current from being drawn from the input capacitor C4 (rather than the line) as the bleeder turns on.

The active bleeder is modulated by the LYTSwitch-3 smart BLEEDER CONTROL (BL) pin in a closed-loop system that senses the input voltage and input current.

Resistor R4, R6, C1, C2, Q1 and Q2 form an external bleeder circuit driven by LYTSwitch-3. Resistor R2 is the bleeder resistor and Q1 is the bleeder switch. Transistor Q2 is connected to form a Darlington-pair with Q1 for a higher bleeder switch current. Resistor R4, C2, R6 and C1 work as stabilization network for the bleeder.

Resistor R1 senses the overall input current and this data is fed to the BLEEDER SENSE (BS) pin via resistor R11. The overall current includes the active bleeder current and the U1 switch current. These currents are sensed in order to keep the TRIAC current above its holding level by modulating the bleeder dissipation in a closed loop system to compensate for changes in the output load current. The BL pin drives the external bleeder switch in order to maintain the driver input current above the holding current of the TRIAC dimmer.

5 PCB Layout

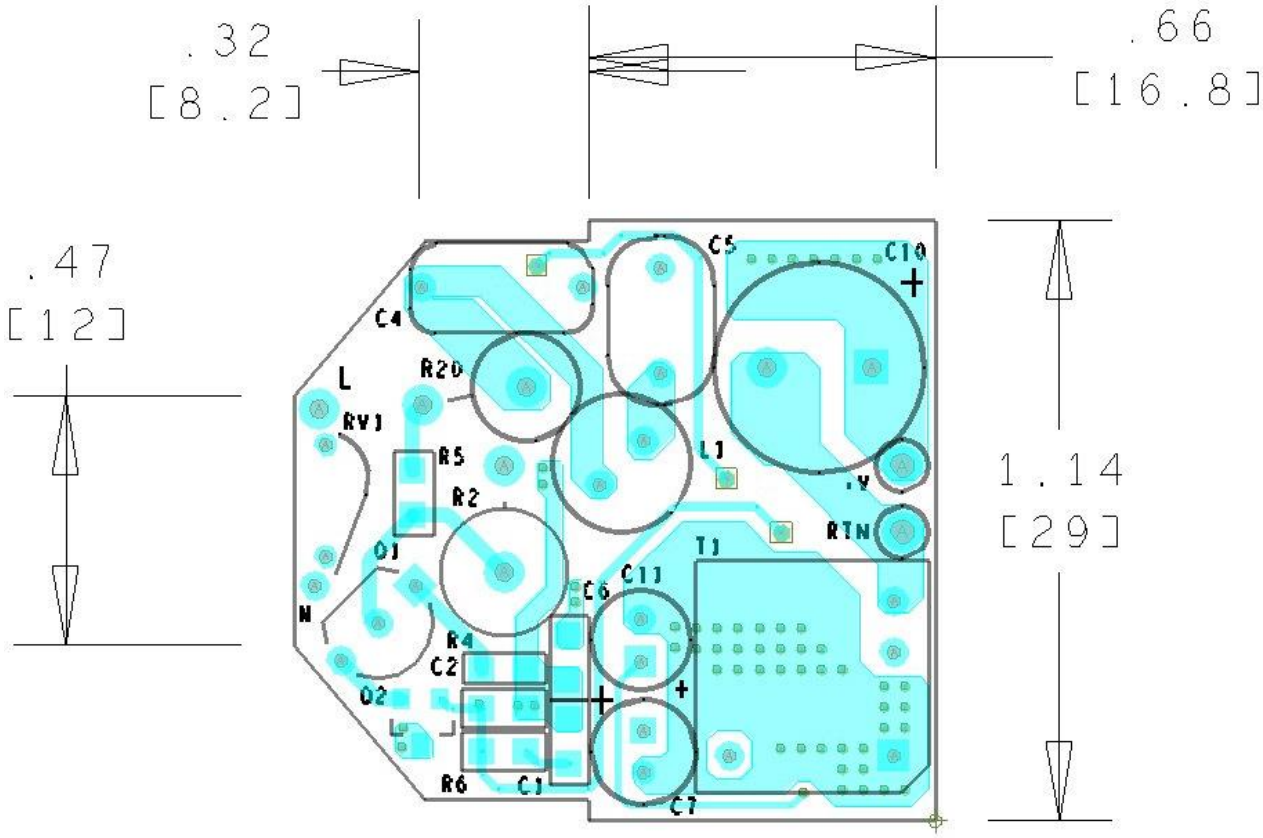

Figure 5 – Top Side.

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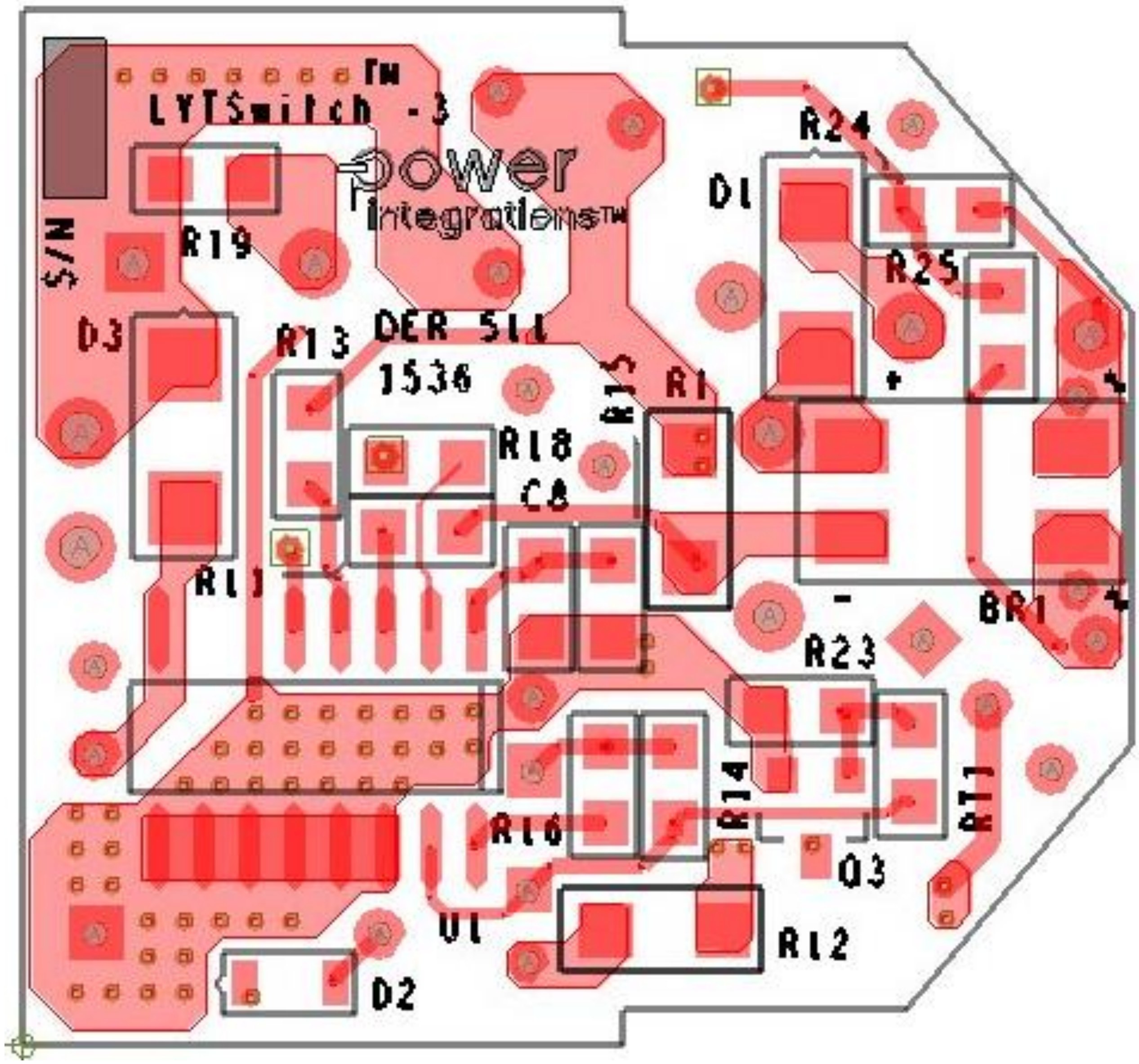

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	10 nF, 50 V, Ceramic, X7R, 0805	C0805C103K5RACTU	Kemet
3	1	C2	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
4	1	C4	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
5	1	C5	68 nF, 250 V, Polyester Film	ECQ-E2683KB	Panasonic
6	1	C6	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
7	1	C7	10 μF, 16 V, Electrolytic, Gen. Purpose, (5 x 11)	UVR1C100MDD	Nichicon
8	1	C8	150 nF, 25 V, Ceramic, X7R, 0805	C0805C154K3RACTU	Kemet
9	1	C10	180 μF, 50 V, Electrolytic, Low ESR, 130 m•, (10 x 16)	ELXZ500ELL181MJ16S	Nippon Chemi-Con
10	1	C11	22 μF, 25 V, Electrolytic, 20 %, Gen. Purpose, (5 x 7 mm)	EEA-GA1E220	Panasonic
11	1	D1	600 V, 1 A, Standard Recovery, SMA	S1J-13-F	Diodes, Inc.
12	1	D2	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
13	1	D3	Diode Ultrafast, GPP, 400 V, 1 A SMA	US1G-13-F	Diodes, Inc.
14	1	L1	3.3 mH, 0.095 A, 20%	RL-5480-2-3300	Renco
15	1	Q1	NPN, Power BJT, 400 V, 1 A, TO-92	STX13003-AP	ST Micro
16	1	Q2	NPN, HP, 400V, 225mA, SOT23-3	FMMT458TA	Diodes-Zetex
17	1	R1	2.2 Ω, 1%, 1/4 W, Thick Film, 1206	RC1206FR-072R2L	Yageo
18	1	R2	1 kΩ, 5%, 3 W, Metal Oxide	ERG-3SJ102	Panasonic
19	1	R4	20 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ200V	Panasonic
20	1	R5	100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
21	1	R6	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
22	1	R11	24 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ243V	Panasonic
23	1	R12	2.4 Ω, 1%, 1/8 W, Thick Film, 1206	RC1206FR-072R4L	Yageo
24	1	R13	6.04 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6041V	Panasonic
25	1	R14	5.6 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ562V	Panasonic
26	1	R15	36.5 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3652V	Panasonic
27	1	R16	182 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1823V	Panasonic
28	1	R18	510 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5103V	Panasonic
29	1	R19	24 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ243V	Panasonic
30	1	R20	20 Ω, 5%, 2 W, Metal Oxide	ERG-2SJ200	Panasonic
31	1	R24	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
32	1	R25	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
33	1	R28	10 Ω, 5%, 2 W, Wirewound, Fusible	FW20A10R0JA	Bourns
34	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
35	1	T1	Bobbin, EE10, Vertical, 8 pins	EE-1016	Yulongxin
36	1	U1	LYTSwitch-3, SO-16C	LYT3315D	Power Integrations
Miscellaneous Part					
1	1	+V	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
2	1	RTN	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
3	1	WIRE	Wire, UL1007, #24 AWG, Blk, PVC, 40 mm	1007-24/7-0	Anixter

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7 Inductor Specification

7.1 *Electrical Diagram*

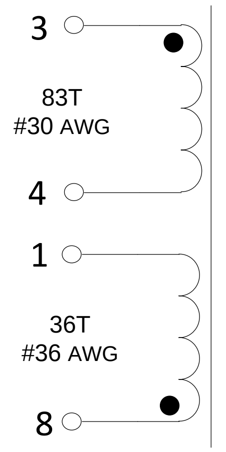

Figure 7 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 3 and pin 4, with all other windings open.	270 μH
Tolerance	Tolerance of primary inductance.	±5%
Primary Leakage Inductance	Pins 3-4, with pins 1-8 shorted, measured at 100 kHz, 0.4 V_{RMS}.	15 μH (Max.)

7.3 *Material List*

Item	Description
[1]	Core: EE10 PC40 (TDK) or Equivalent.
[2]	Bobbin, EE10, Vertical, 8 Pins, Part no. 25-01068-00.
[3]	Magnet Wire: #30 AWG.
[4]	Magnet Wire: #36 AWG.
[5]	Transformer Tape: 7 mm.
[6]	Transformer Tape: 4 mm.

7.4 ***Inductor Build Diagram***

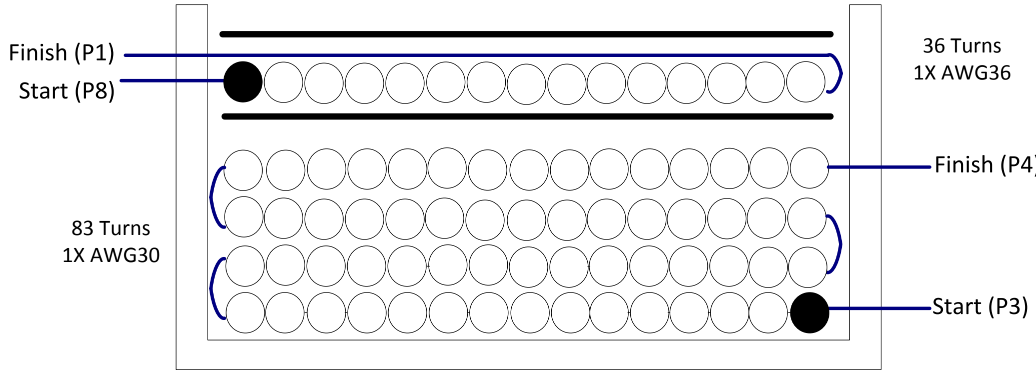

Figure 8 – Transformer Build Diagram.

7.5 ***Inductor Construction***

Winding Directions	Bobbin is oriented on winder jig such that terminal pins are in the right side and the winding direction is clockwise.
Winding 1	Use wire item [3], start at pin 3 and wind 83 turns in 4 layers, then finish the winding on pin 4.
Insulation	Add 2 layers of tape, item [5], for insulation.
Winding 2	Use wire item [4], start at pin 8 and wind 36 turns from left to right, then finish the winding on pin 1.
Insulation	Add 1 layer of tape, item [5], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 270 μH.
Assemble Core	Assemble the 2 cores on the bobbin and wrap with 2 layer of tape, Item (6).
Pins	Pull out Terminal pin nos. 2, 5, 6, 7
Finish	Dip the transformer assembly in varnish.

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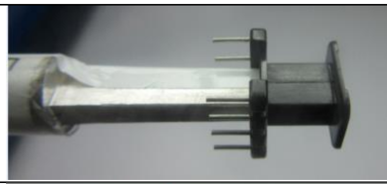
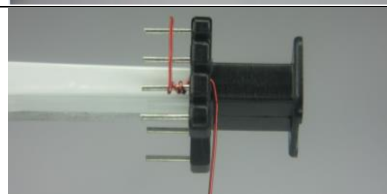
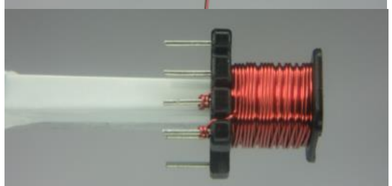
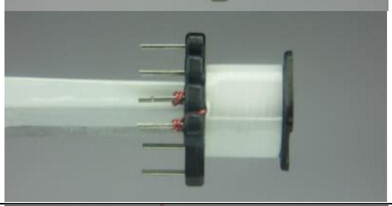
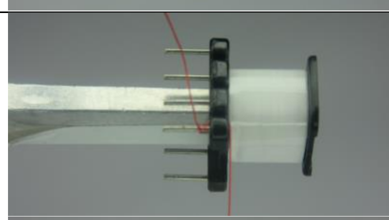
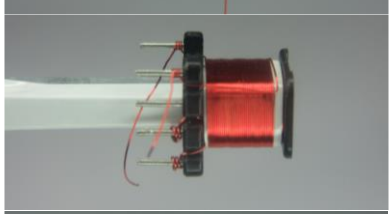
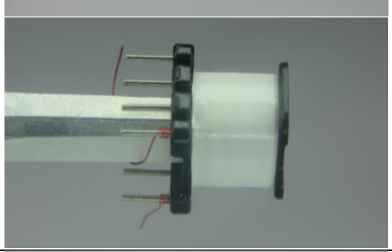
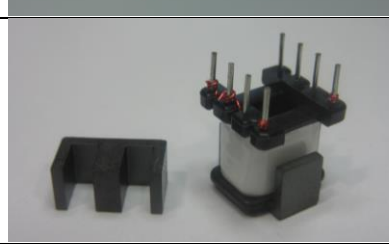
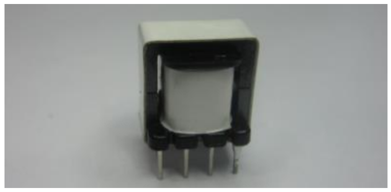
7.6 *Inductor Construction Illustrations*

Winding Preparation		Place item [2] bobbin on winding machine with terminal pins facing left.
WD1	  	Starting at pin 3 wind 83 turns in 4 layers of wire item [3] in counter clockwise direction. Terminate other end of the wire to pin 4. Fix with 1 layer item [5] tape.
WD2	  	Starting at pin 8 wind 36 turns of wire item [4] in counter clockwise direction. Spread the winding evenly across the whole bobbin width. Terminate other end of the wire to pin 1. Fix with 1 layer of item [5] tape.
Gap Core		Grind one core half [item1] center leg to achieve 270 μH inductance.

Final Assembly		Assemble core halves. Fix core with 2 layers of tape item [6] and remove pins 2, 5, 6 and 7. Dip the transformer assembly in varnish.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-3-Buck-Boost_102715; Rev.1.00; Copyright Power Integrations 2015	INPUT	INFO	OUTPUT	UNIT	ACDC_LYTSwitch-3-Buck-Boost_102615; LYTSwitch-3 Buck-Boost Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	90		90	V	Minimum AC Input Voltage
VACNOM	120		120	V	Typical AC Input Voltage
VACMAX	132		132	V	Maximum AC Input Voltage
FL	60.00		60.00	Hz	Minimum line frequency
VO_MIN			37.8	V	Guaranteed minimum VO that maintains output regulation
VO	42.0		42.0	V	Worst case normal operating output voltage
VO_OVP_MIN			51.2	V	Minimum Voltage at which output voltage protection may be activated
IO	165.0		165.0	mA	Average output current specification
n	0.87		0.87	%/100	Total power supply efficiency
Z			0.50		Loss allocation factor
PO			6.93	W	Total output power
VD			0.70	V	Output diode forward voltage drop
LYTSwitch-3 DESIGN VARIABLES					
Select Breakdown Voltage	650V		650V	V	Choose between 650V and 725V
Device	LYT33X5		LYT33X5		Chosen LYTSwitch-3 Device
Final device code			LYT3315		
Select Dimming Curve Option	3		3		Minimum dim curve with Load Shut Down (LSD) enabled
RBS2			24.00	k-ohm	RBS2 resistor to select dimming curve
ILIMITMIN			1.233	A	Minimum device current limit
ILIMITTYP			1.325	A	Typical Current Limit
ILIMITMAX			1.418	A	Maximum Current Limit
TON			2.36	us	Expected on-time of MOSFET at low line and PO
FSW			120.0	kHz	Expected switching frequency at low line and PO
Duty Cycle			28.3	%	Expected operating duty cycle at low line and PO
IRMS			0.219	A	Nominal RMS current through the switch at low line
IPK			1.179	A	Worst Case Peak current (non-dimming)
KDP			1.15		Ratio between off-time of switch and reset time of core at VACNOM
KDP_DIM		Info[1]	0.72		LYTSwitch-3 should operate in discontinuous mode (KDP > 1) for optimal performance. Verify the performance on the bench or consider changing the inductance value
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type	EE10		EE10		Core Type
Core Part Number			PC40EE10-Z		If custom core is used - Enter part number here
Bobbin part number			BE-10-116-CP		Bobbin Part number (if available)
AE			12.10	mm^2	Core Effective Cross Sectional Area
LE			26.10	mm	Core Effective Path Length
AL			850	nH/T^2	Ungapped Core Effective Inductance
BW			6.60	mm	Bobbin Physical Winding Width
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LPMIN			243	uH	Minimum Inductance
LP	270		270	uH	Typical value of Primary Inductance
LP Tolerance			10.0	%	Tolerance of Primary Inductance
N	83		83	Turns	Number of Turns
ALG			39	nH/T^2	Gapped Core Effective Inductance
BM			3169	Gauss	Operating Flux Density. Maintain value below 3300 G
BP			4195	Gauss	Calculated Worst Case Peak Flux Density (BP < 4200

					G)
BAC			1585	Gauss	Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
LG			0.388	mm	Gap Length (Lg > 0.1 mm)
Layers			3.7		Estimated number of winding layers
IL_RMS			0.466	A	Worst case RMS Current through the inductor
AWG			30	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			102	Cmils	Bare conductor effective area in circular mils
CMA			218	Cmils/A	Primary Winding Current Capacity (200 < CMA < 500)
Current Density (J)			9.14	A/mm^2	Inductor Winding Current density (3.8 < J < 9.75 A/mm^2)
Bias Section					
TURNS_BIAS			41.00	Turns	
VBIAS			20.00	V	
PIVBS			112.21	V	
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			28.26	%	Duty cycle measured at minimum input voltage
IAVG			0.10	A	Input average current measured on the Mosfet at the minimum input voltage
IP			1.01	A	Peak Drain current at minimum input voltage
ISW_RMS			0.22	A	MOSFET RMS current measured at the minimum input voltage
ID_RMS			0.15	A	RMS current of freewheeling diode at minimum input voltage
IL_RMS			0.27	A	RMS current of the of the inductor at the minimum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
n_MEASURED			0.87		Measured efficiency (this value is used for resistor calculations only)
VBIAS_MEASURED	17.50		17.50	V	Bias voltage (across the bias capacitor) measured on a prototype unit
VOUT_MEASURED			42.00	V	Load voltage measured on a prototype unit
RDS_T			2.5027	ohm	Theoretical calculation for RDS sense resistor
RDS			2.49	ohm	Rds resistor calculation assuming E96 / 1%
CDS			10.00	uF	Cds Capacitor Calculation
ROVP	182.00		182.00	k-ohm	OC pin resistor (E96 / 1%)
RL			1.96	M-ohm	L pin resistor (E96 / 1%)
RFB_T			33628.78	ohm	Calculated value of RFB, using standard values for RDS, ROVP, and RL
RFB			34.00	k-ohm	Feedback pin resistor (E96 / 1%)
CFB_T			151.27	nF	Feedback pin capacitor (for 6ms time constant)
CFB			150	nF	Feedback pin capacitor E12 standard value
RSUP			11.30	k-ohm	Bias supply resistor assuming 1mA current necessary to supply BP
IOUT_MEASURED			165.0	mA	Measured average output current on the LEDs
Output Parameters					
VDRAIN			269	V	Estimated worst case drain voltage at VACMAX and VO_MAX
PIVD			262.4	V	Peak Inverse Voltage at VO_MAX on output diode
BLEEDER COMPONENTS					
I_HOLD	55.00		55.00	mA	Required bleeder holding current
RBS1			2.18	Ohm	Exact value of RBS1 resistor
RDAMPER	20		20	Ohm	Value of damper resistor
VDAMPER_RMS			2.03	V	Estimated RMS voltage drop on damper (without a bleeder present)

Note 1: Actual units were tested under a brown-in and brown-out . Output current regulation is good down to 60 VAC input.

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9 Performance Data

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

9.1 *Efficiency*

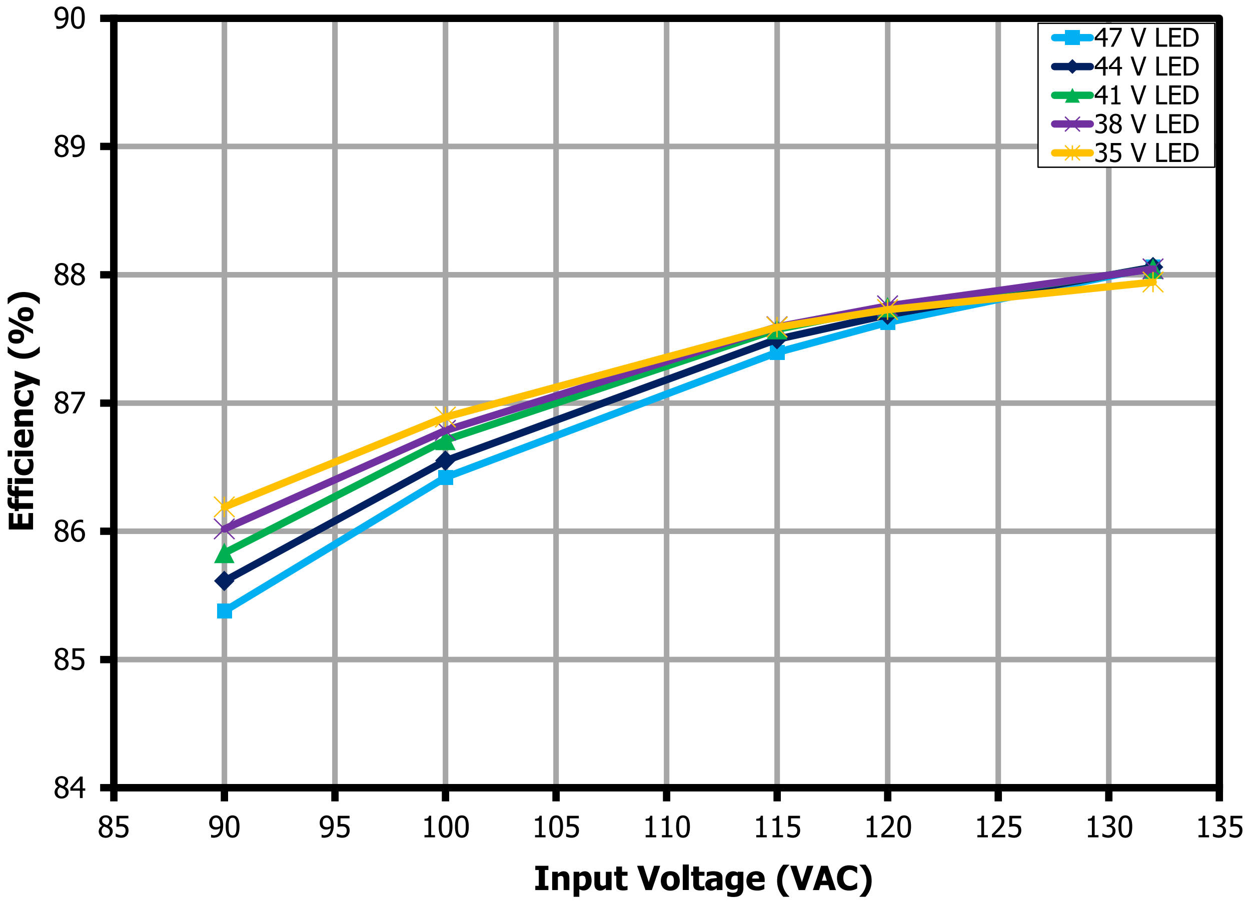

Figure 9 – Efficiency vs. Line and LED Load.

9.2 *Output Current Regulation*

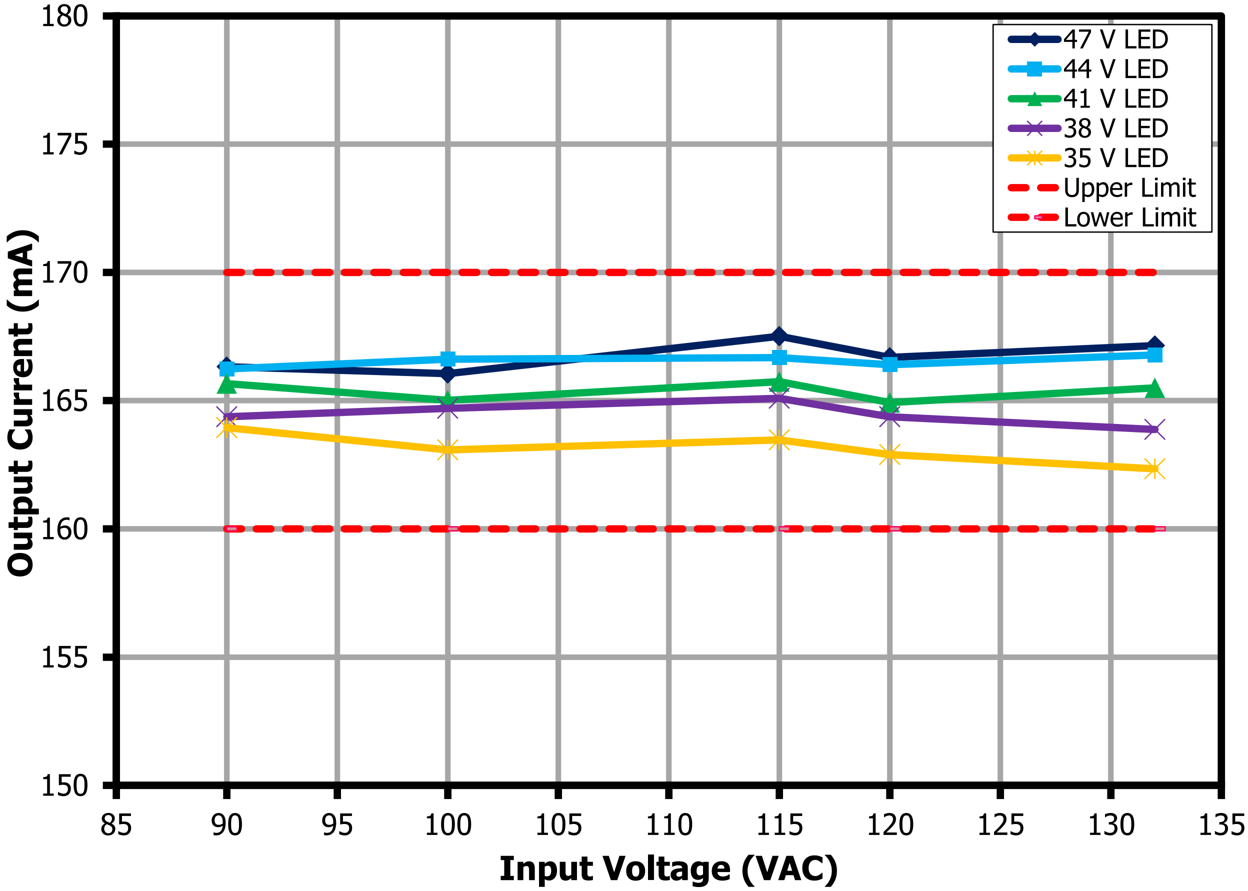

Figure 10 – Regulation vs. Line and LED Load.

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9.3 *Power Factor*

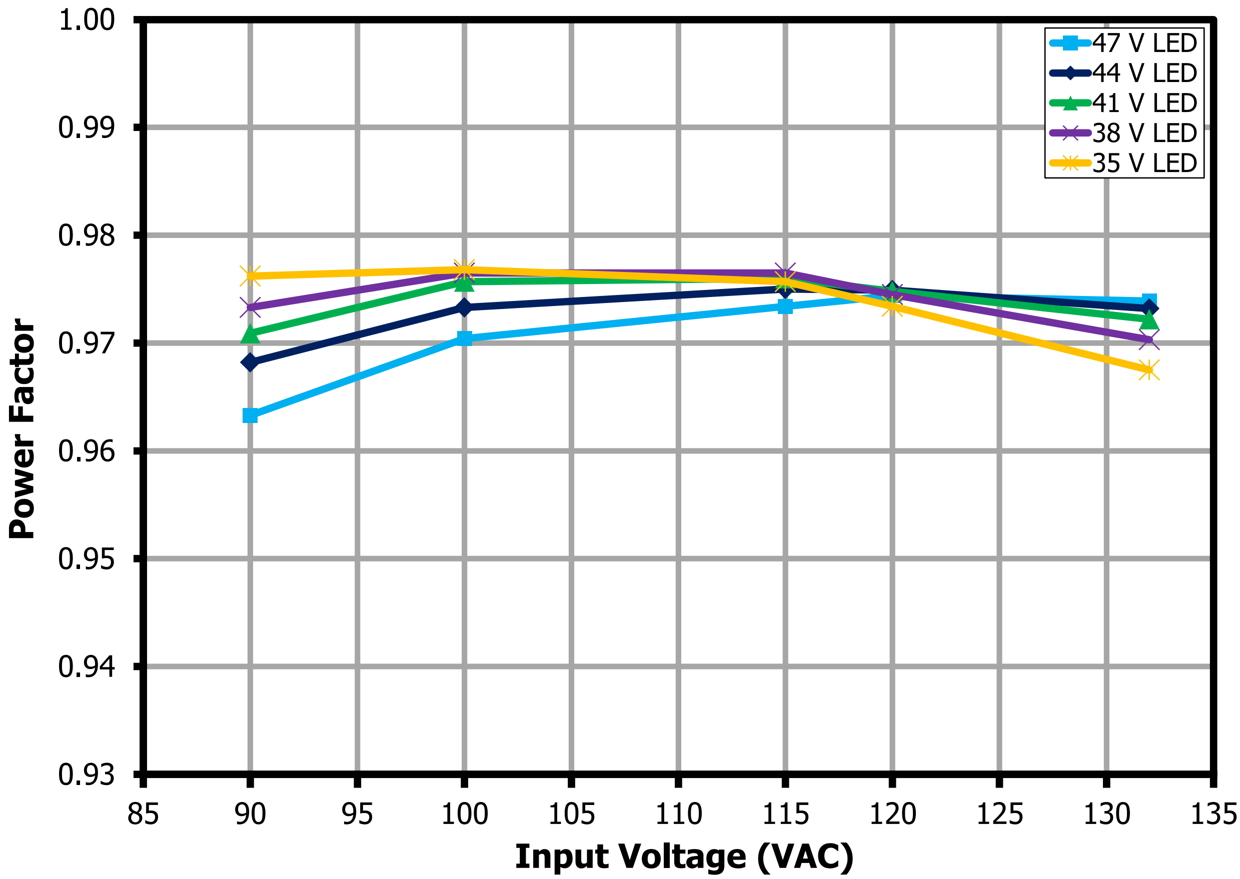

Figure 11 – Power Factor vs. Line and LED Load.

9.4 *%ATHD*

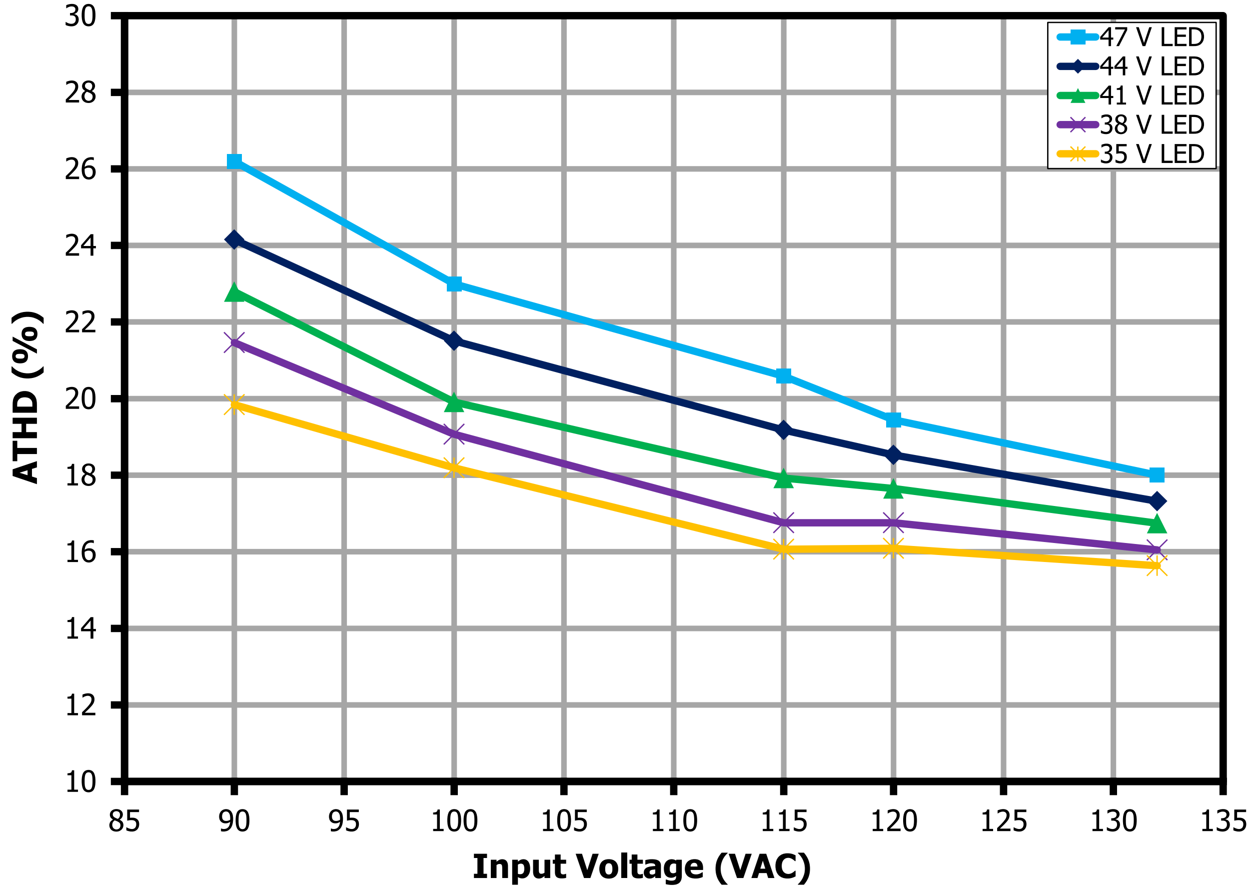

Figure 12 – %ATHD vs. Line and LED Load.

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9.5 *Harmonics*

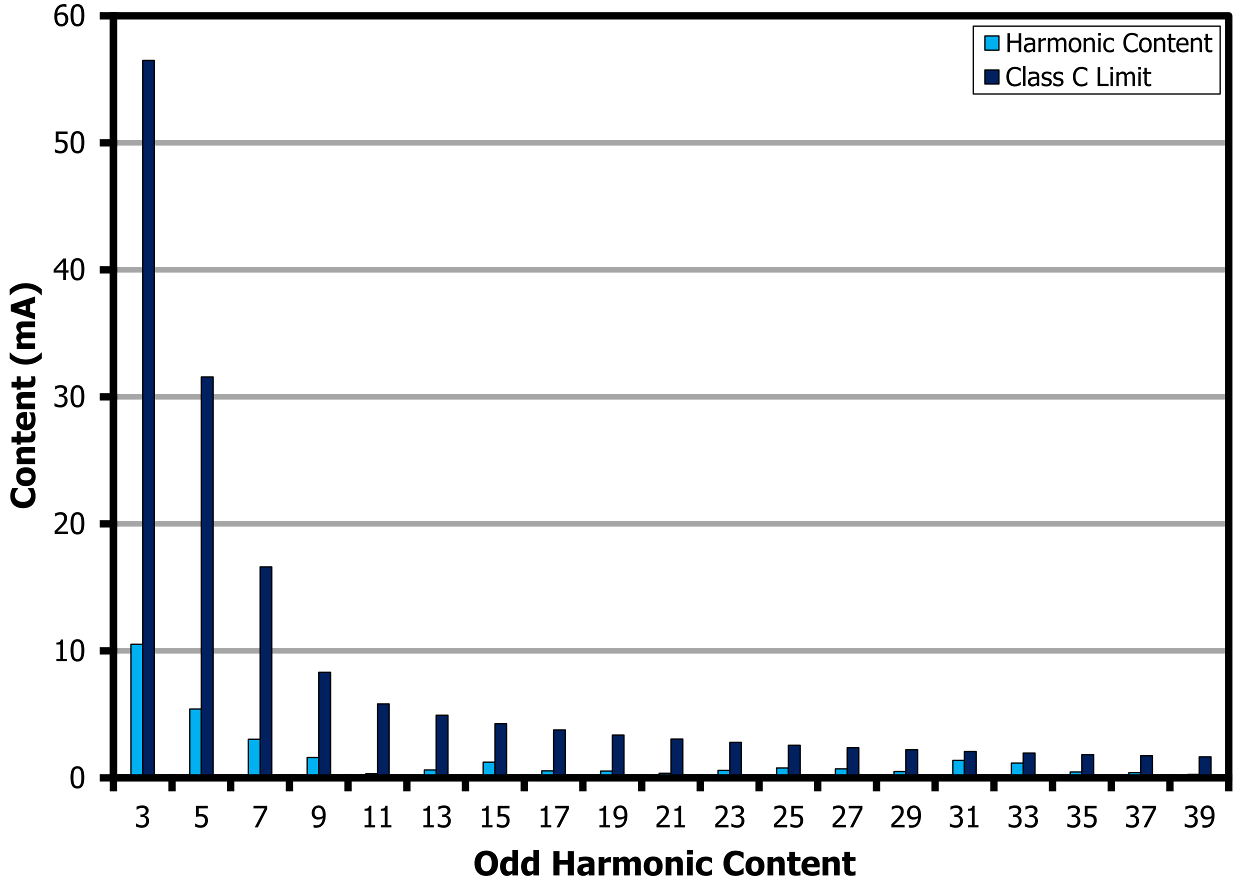

Figure 13 – 42 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

10 Test Data

10.1 *Test Data, 35 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	89.96	79.10	6.95	0.976	19.84	36.22	163.95	5.99	86.19
100	60	99.90	70.19	6.85	0.977	18.19	36.20	163.08	5.95	86.89
115	60	114.98	60.68	6.81	0.976	16.07	36.21	163.47	5.96	87.59
120	60	119.94	57.99	6.77	0.973	16.09	36.20	162.90	5.94	87.73
132	60	131.92	52.72	6.73	0.968	15.64	36.19	162.34	5.92	87.94

10.2 *Test Data, 38 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	89.90	85.81	7.51	0.973	21.46	38.99	164.37	6.46	86.02
100	60	99.86	76.44	7.45	0.977	19.07	38.99	164.70	6.47	86.79
115	60	114.94	65.93	7.40	0.977	16.76	38.99	165.09	6.48	87.59
120	60	119.91	62.91	7.35	0.975	16.76	38.98	164.37	6.45	87.76
132	60	131.89	57.06	7.30	0.970	16.05	38.97	163.88	6.43	88.04

10.3 *Test Data, 41 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	89.93	93.19	8.14	0.971	22.79	41.85	165.66	6.98	85.83
100	60	99.88	82.24	8.01	0.976	19.91	41.83	165.01	6.95	86.71
115	60	114.96	71.01	7.97	0.976	17.92	41.82	165.74	6.98	87.58
120	60	119.92	67.65	7.91	0.975	17.65	41.80	164.93	6.94	87.75
132	60	131.90	61.65	7.91	0.972	16.75	41.80	165.50	6.96	88.05

10.4 *Test Data, 44 V LED Load*

Input		Input Measurement					LED Load Measurement			Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	89.95	100.39	8.74	0.968	24.15	44.72	166.24	7.49	85.61
100	60	99.89	89.10	8.66	0.973	21.51	44.70	166.62	7.50	86.55
115	60	114.97	76.41	8.57	0.975	19.18	44.67	166.68	7.50	87.50
120	60	119.93	72.93	8.53	0.975	18.53	44.67	166.40	7.48	87.69
132	60	131.91	66.27	8.51	0.973	17.32	44.66	166.78	7.49	88.06

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10.5 *Test Data, 47 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	107.74	9.34	0.963	26.20	47.61	166.32	7.97	85.38
100	60	99.89	94.89	9.20	0.970	23.00	47.58	166.05	7.95	86.42
115	60	114.96	81.95	9.17	0.973	20.59	47.57	167.51	8.02	87.40
120	60	119.92	77.82	9.09	0.974	19.45	47.54	166.69	7.97	87.63
132	60	131.89	70.61	9.07	0.974	18.00	47.53	167.15	7.99	88.06

10.6 *Test Data, Harmonic Content at 115 VAC with 42 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
115	60.00	74.12	8.31	0.975	18.84
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	69.07				
2	0.12	0.17%		2.00%	
3	10.52	15.23%	56.4876	29.25%	Pass
5	5.41	7.83%	31.5666	10.00%	Pass
7	3.03	4.39%	16.6140	7.00%	Pass
9	1.60	2.32%	8.3070	5.00%	Pass
11	0.32	0.46%	5.8149	3.00%	Pass
13	0.62	0.90%	4.9203	3.00%	Pass
15	1.23	1.78%	4.2643	3.00%	Pass
17	0.55	0.80%	3.7626	3.00%	Pass
19	0.52	0.75%	3.3665	3.00%	Pass
21	0.35	0.51%	3.0459	3.00%	Pass
23	0.58	0.84%	2.7810	3.00%	Pass
25	0.78	1.13%	2.5586	3.00%	Pass
27	0.70	1.01%	2.3690	3.00%	Pass
29	0.49	0.71%	2.2057	3.00%	Pass
31	1.36	1.97%	2.0634	3.00%	Pass
33	1.16	1.68%	1.9383	3.00%	Pass
35	0.46	0.67%	1.8275	3.00%	Pass
37	0.41	0.59%	1.7288	3.00%	Pass
39	0.26	0.38%	1.6401	3.00%	Pass

11 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 120 VAC, 60 Hz line frequency, room temperature, and a nominal 42 V LED load.

11.1 *Dimming Curve*

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

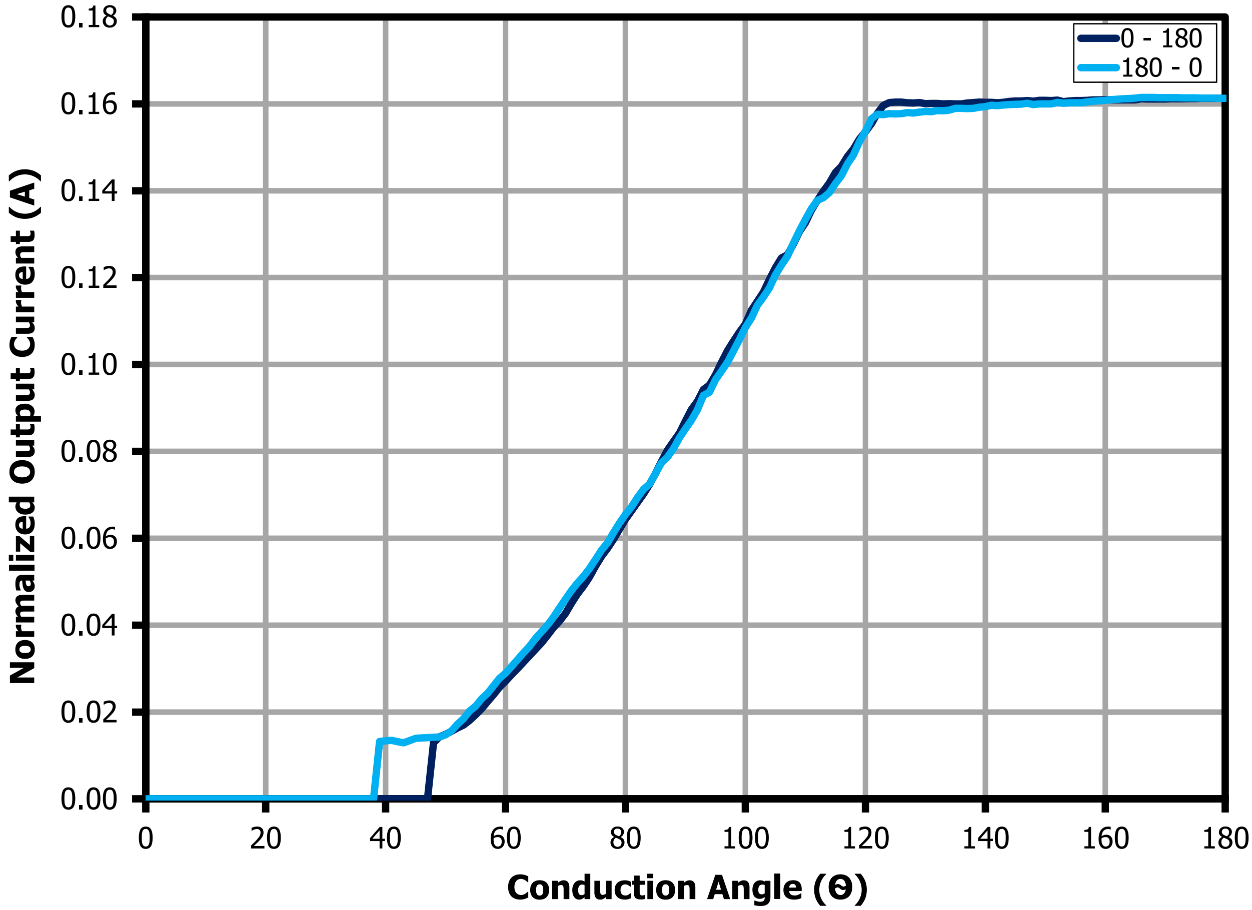

Figure 14 – Dimming Curve at 120 VAC, 60 Hz Input.

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11.2 *Dimming Efficiency*

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

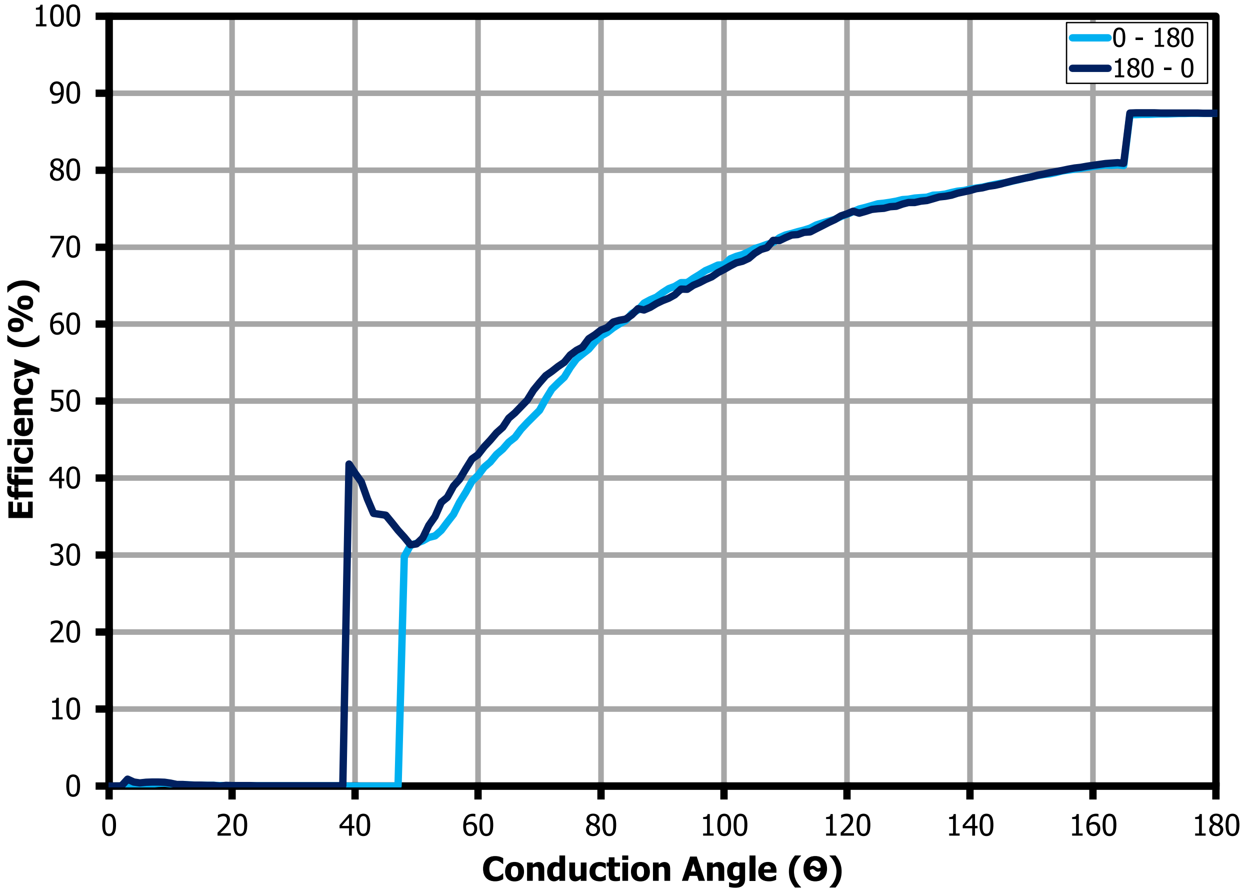

Figure 15 – Driver Efficiency at 120 VAC, 60 Hz Input.

11.3 *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 circuit becomes active.

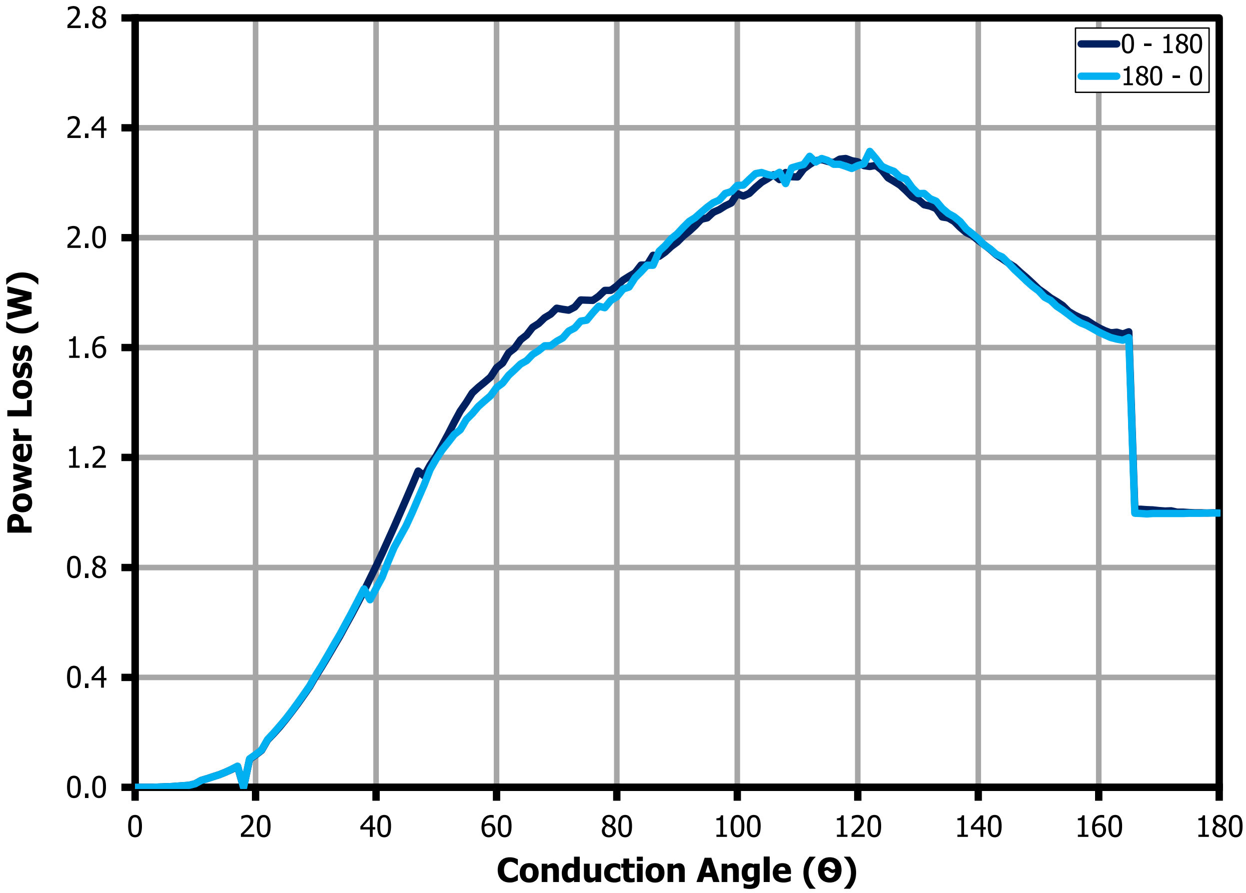

Figure 16 – Driver Power Loss at 120 VAC, 60 Hz Input.

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11.4 *Dimming Compatibility with Available Dimmers*

The following dimmers were tested at 30 ºC external ambient temperature (inside the LED bulb casing) with utility line input (~120 VAC, 60 Hz) and 42 V LED load.

No	Panel	Brand	Model	Type	Max (mA)	Min (mA)	Pass/Fail
1	PHILS L1	LUTRON	AY-603PG-WH	L	122.05	11.39	Pass
2	PHILS L1	LUTRON	AY-600P-WH	L	162.56	10.83	Pass
3	PHILS L1	LUTRON	AYLV-603P-WH	L	161.46	10.39	Pass
4	PHILS L1	LUTRON	GLV-600-IV	L	163.91	9.13	Pass
5	PHILS L1	LUTRON	LG-600PH-WH	L	161.27	11.78	Pass
6	PHILS L2	LUTRON	DV-600P-WH	L	162.65	9.23	Pass
7	PHILS L2	LUTRON	DV-603P-WH	L	162.91	9.61	Pass
8	PHILS L2	LUTRON	DVLV-103P-WH	L	161.87	12.91	Pass
9	PHILS L2	LUTRON	DVPDC-203P-WH	L	163.94	37.02	Pass
10	PHILS L2	LUTRON	DVW-603PGH-WH	L	134.72	11.50	Pass
11	PHILS L2	LUTRON	DVWCL-153PH-WH	L	162.27	9.89	Pass
12	PHILS L2	LUTRON	GL-600-WH	L	162.26	10.50	Pass
13	PHILS L2	LUTRON	LG-603PGH-WH	L	132.47	10.59	Pass
14	PHILS L3	LUTRON	MACL-153M-WH	L	161.70	11.21	Pass
15	PHILS L3	LEVITON	R02-06613-PLW	L	160.22	9.55	Pass
16	PHILS L3	LEVITON	R62-RP106-1LW	L	162.31	13.71	Pass
17	PHILS L4	LUTRON	S-1000-WH	L	163.48	10.56	Pass
18	PHILS L4	LUTRON	S-103PNL-WH	L	161.87	11.71	Pass
19	PHILS L4	LUTRON	S-600PH-WH	L	162.51	10.91	Pass
20	PHILS L4	LUTRON	S-600PNLH-WH	L	161.88	11.78	Pass
21	PHILS L4	LUTRON	S-600P-WH	L	162.43	11.61	Pass
22	PHILS L4	LUTRON	S-600-WH	L	162.92	10.91	Pass
23	PHILS L4	LUTRON	S-603PGH-WH	L	132.31	12.06	Pass
24	PHILS L4	LUTRON	S-603PNLH-WH	L	162.81	10.92	Pass
25	PHILS L5	LUTRON	SPSELV-600-WH	T	169.57	17.91	Pass
26	US PANEL 1	COOPER	9530WS-K	L	164.11	13.61	Pass
27	US PANEL 1	LEVITON	601-6631-1	L	163.43	9.40	Pass
28	US PANEL 1	LEVITON	6683	L	164.05	13.30	Pass
29	US PANEL 1	LEVITON	1P106-1LZ	L	164.57	14.37	Pass
30	US PANEL 1	LEVITON	6681	L	164.21	10.50	Pass
31	US PANEL 1	LEVITON	6683-PLW	L	164.87	11.21	Pass
32	US PANEL 2	GE	18019	L	163.16	13.03	Pass
33	US PANEL 2	GE	18023	L	163.34	11.18	Pass
34	US PANEL 2	GE	18022	L	162.02	12.50	Pass
35	US PANEL 2	LUTRON	RRD-6NA-WH	T	170.28	14.51	Pass
36	US PANEL 3	LUTRON	LXELV-600PL-WH	T	170.18	19.91	Pass
37	US PANEL 3	LUTRON	NTELV-300-WH	T	167.95	15.09	Pass
38	US PANEL 3	LUTRON	DVELV-300P-WH	T	163.49	14.34	Pass

Table 1 – Dimming Compatibility with Available Dimmers.

12 Thermal Performance

Thermal measurements were performed with the power supply operating at a 40 ºC external ambient temperature inside bulb casing (A600) with 42 V LED load.

12.1 *Non-Dimming Thermal Performance at 90 VAC with a 42 V LED Load*

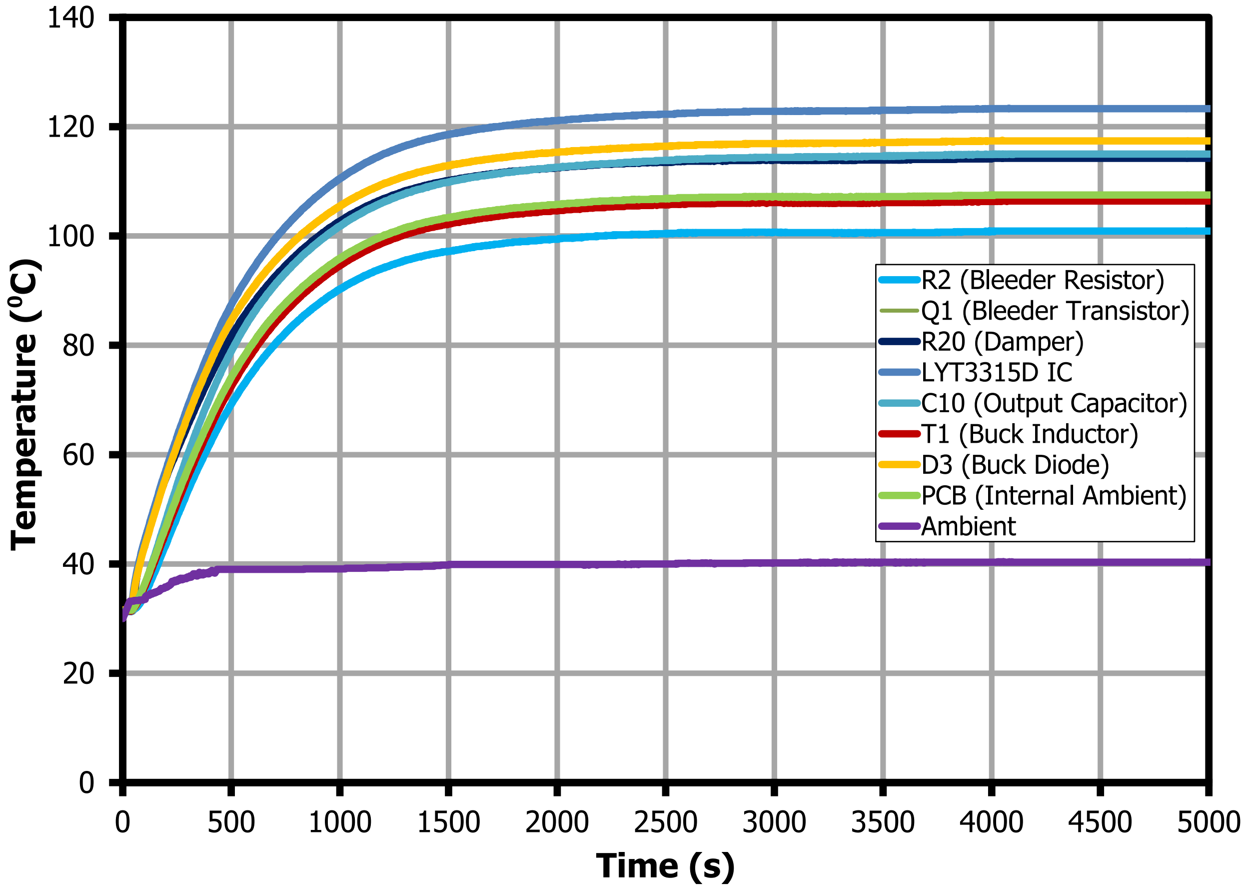

Figure 17 – Component Temperature at 90 VAC, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	100.9
2	Q1	BLEEDER TRANSISTOR	106.4
3	R20	DAMPER RESISTOR	114.2
4	U1	LYT3324DG IC	123.3
5	C10	OUTPUT CAPACITOR	115.0
6	T1	BUCK INDUCTOR	106.4
7	D3	BUCK DIODE	117.4
8	PCB	PCB (HOTEST SPOT)	107.5
9	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	40.3

Table 2 – Components Temperature at 90 VAC, 40 ºC Ambient, Non-Dimming.

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12.2 *Non-Dimming Thermal Performance at 132 VAC with a 42 V LED Load*

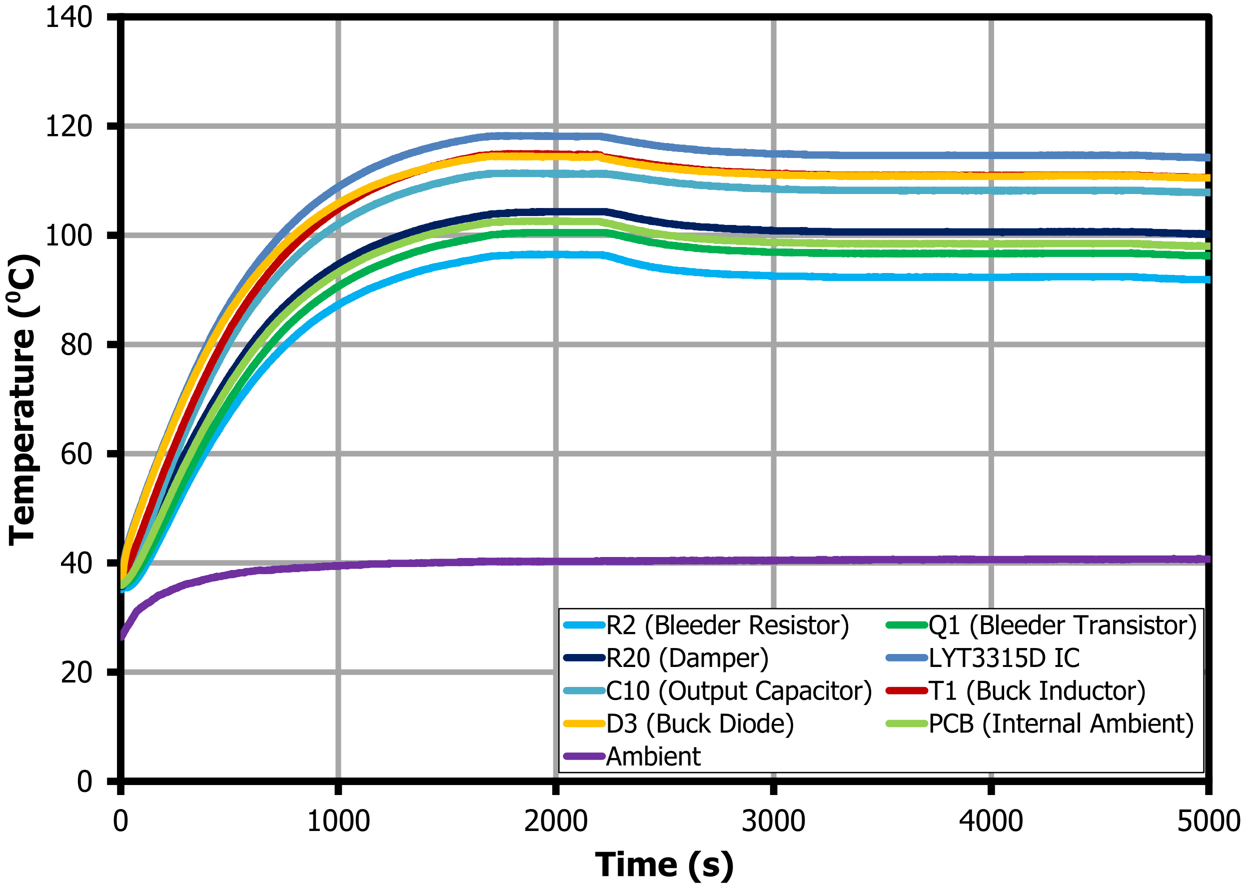

Figure 18 – Component Temperature at 132 VAC, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	91.6
2	Q1	BLEEDER TRANSISTOR	96.0
3	R20	DAMPER RESISTOR	100.0
4	U1	LYT3324DG IC	113.9
5	C10	OUTPUT CAPACITOR	107.5
6	T1	BUCK INDUCTOR	110.3
7	D3	BUCK DIODE	110.2
8	PCB	PCB (HOTEST SPOT)	97.7
9	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	40.7

Table 3 – Components Temperature at 132 VAC, 40 ºC Ambient, Non-Dimming.

12.3 *Dimming Thermal Performance at 120 VAC, 115º Conduction Angle*

(Worst Conduction Angle)

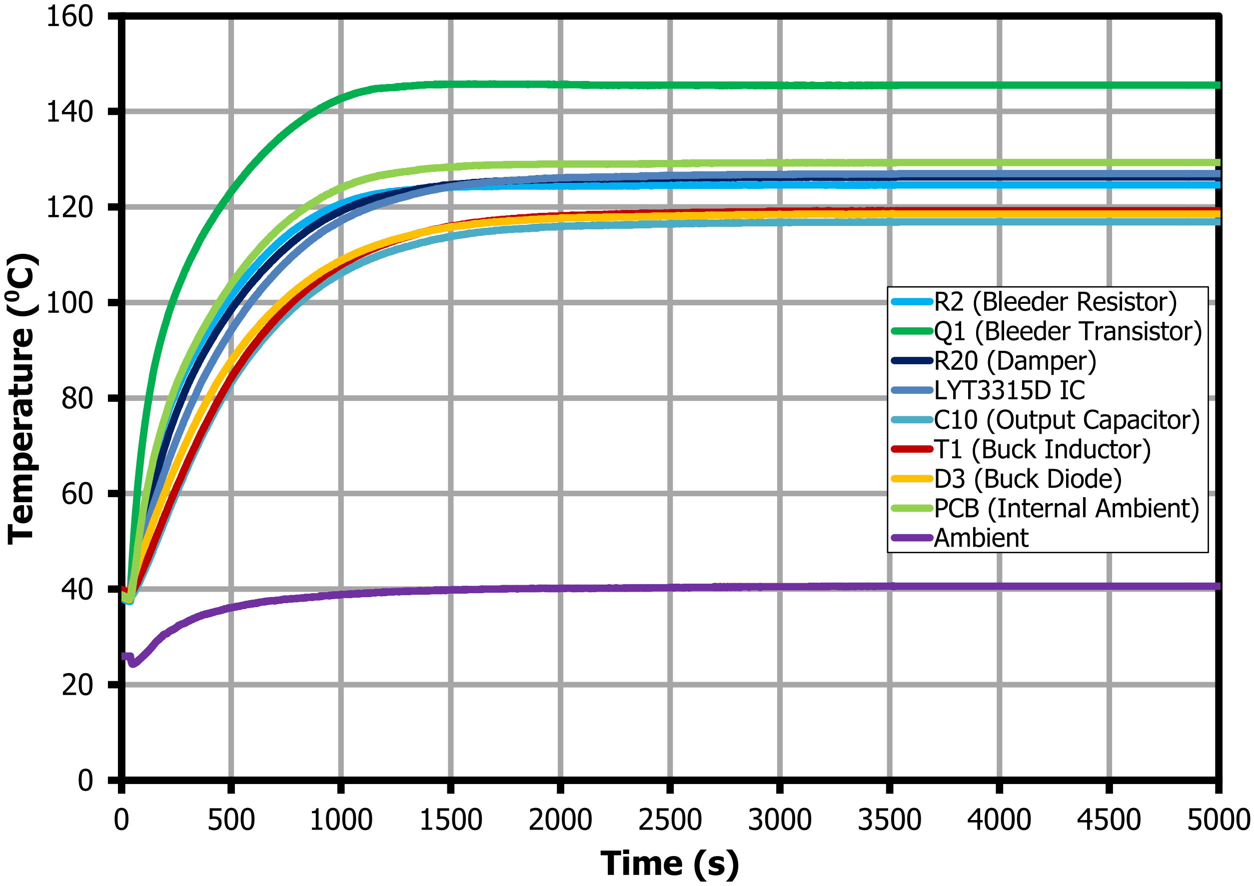

Figure 19 – Component Temperature at 120 VAC, 115º Conduction Angle, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	124.6
2	Q1	BLEEDER TRANSISTOR	145.5
3	R20	DAMPER RESISTOR	126.3
4	U1	LYT3324DG IC	127.0
5	C10	OUTPUT CAPACITOR	116.9
6	T1	BUCK INDUCTOR	119.2
7	D3	BUCK DIODE	118.5
8	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	105.3
9	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	40.6

Table 4 – Components Temperature at 120 VAC, 40 ºC Ambient, Dimming at 115º Conduction Angle.

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13 Waveforms

13.1 *Input Voltage and Input Current Waveforms*

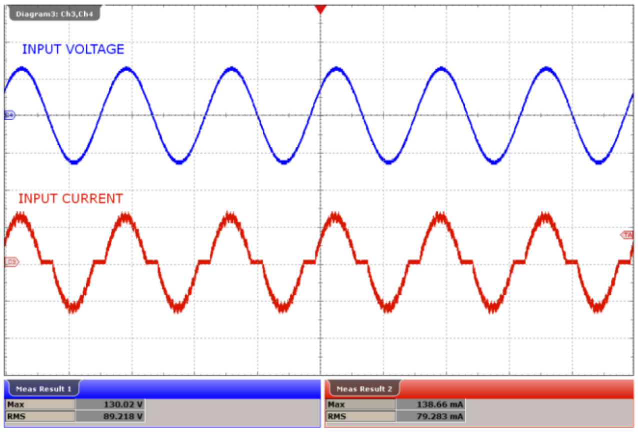

Figure 20 – 90 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak I_{IN}: 138.66 mA_{PK}.
Peak V_{IN}: 130.02 V_{PK}.

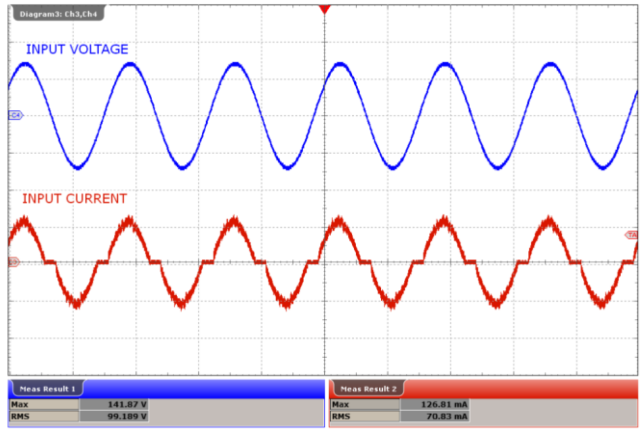

Figure 21 – 100 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak I_{IN}: 126.81 mA_{PK}.
Peak V_{IN}: 141.87 V_{PK}.

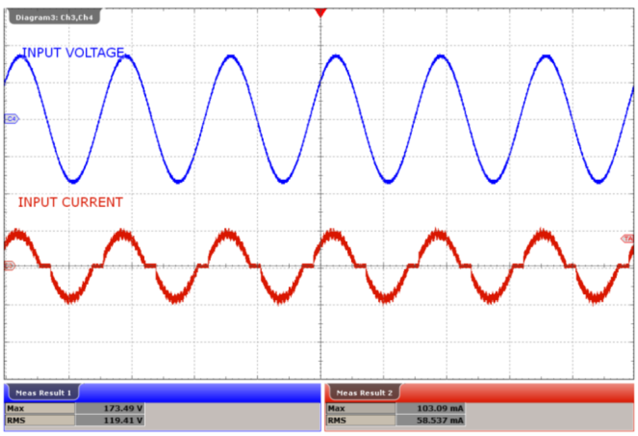

Figure 22 – 120 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak I_{IN}: 103.09 mA_{PK}.
Peak V_{IN}: 173.49 V_{PK}.

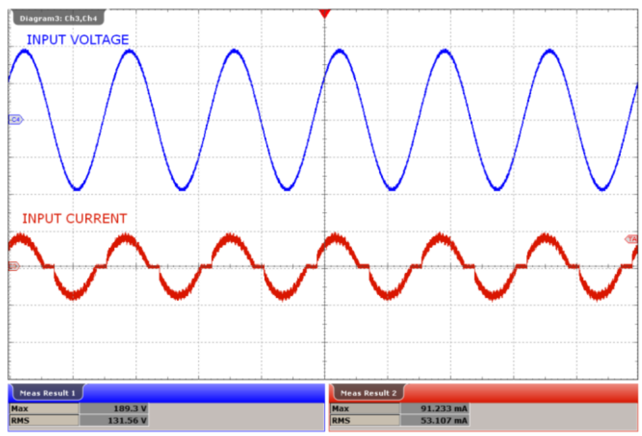

Figure 23 – 132 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak I_{IN}: 91.23 mA_{PK}.
Peak V_{IN}: 189.3 V_{PK}.

13.2 ***Output Current Rise and Fall***

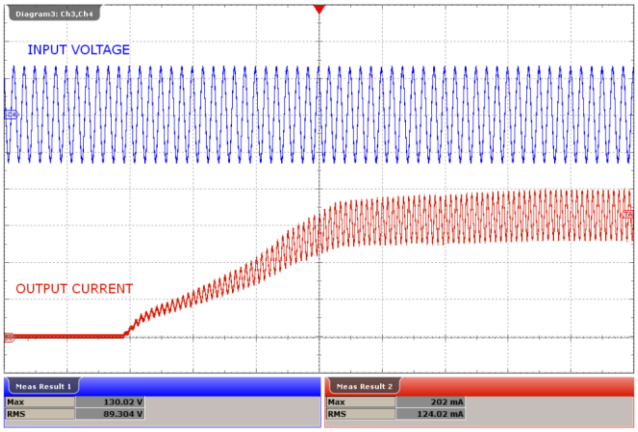

Figure 24 – 90 VAC, 42 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 202 mA_{PK}.
Peak V_{IN}: 130.02 V_{PK}.

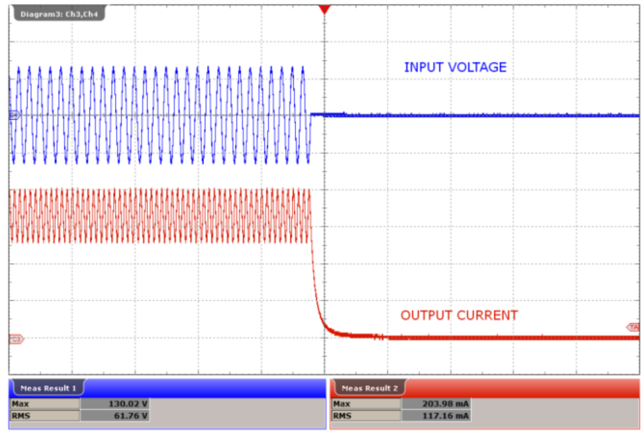

Figure 25 – 90 VAC, 42 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 203.98 mA_{PK}.
Peak V_{IN}: 130.02 V_{PK}.

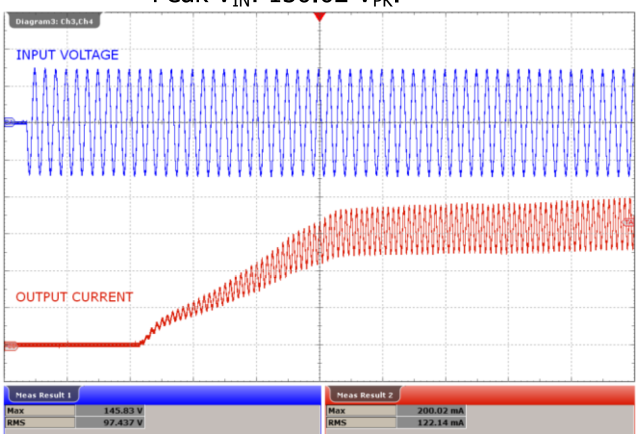

Figure 26 – 100 VAC, 42 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 200.02 mA_{PK}.
Peak V_{IN}: 145.83 V_{PK}.

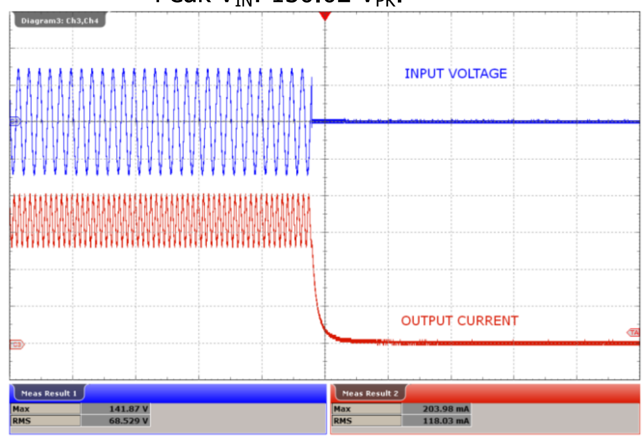

Figure 27 – 100 VAC, 42 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 203.98 mA_{PK}.
Peak V_{IN}: 141.87 V_{PK}.

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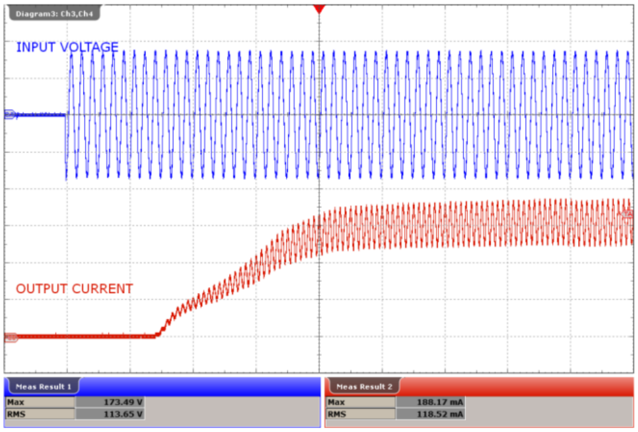

Figure 28 – 120 VAC, 42 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 188.17 mA_{PK}.
Peak V_{IN}: 113.65 V_{PK}.

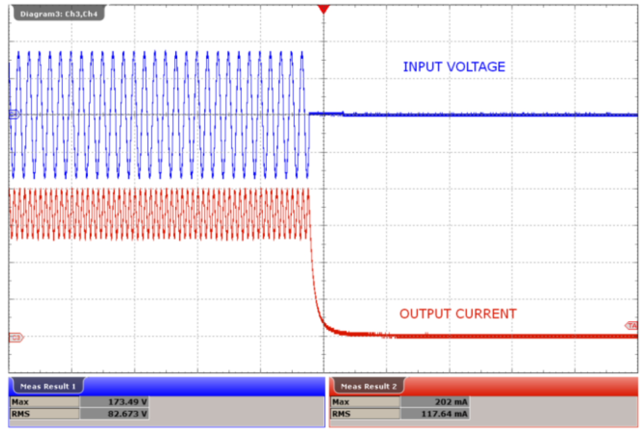

Figure 29 – 120 VAC, 42 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 202 mA_{PK}.
Peak V_{IN}:117.64 V_{PK}.

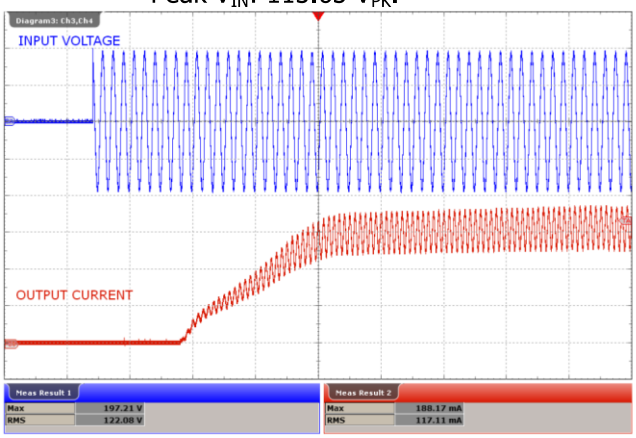

Figure 30 – 132 VAC, 42 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 188.17 mA_{PK}.
Peak V_{IN}: 197.21 V_{PK}.

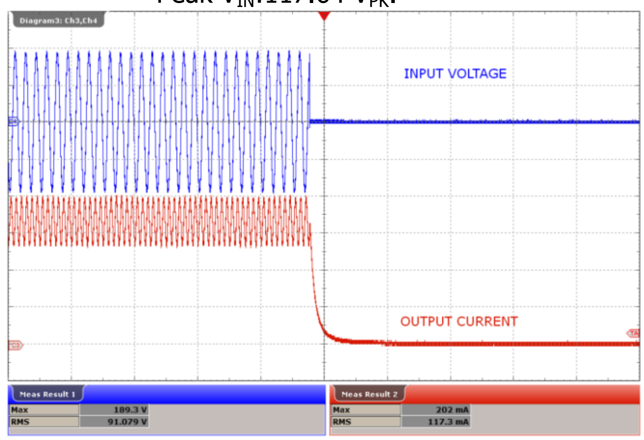

Figure 31 – 132 VAC, 42 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 202 mA_{PK}.
Peak V_{IN}: 189.3 V_{PK}.

13.3 *Drain Voltage and Current in Normal Operation*

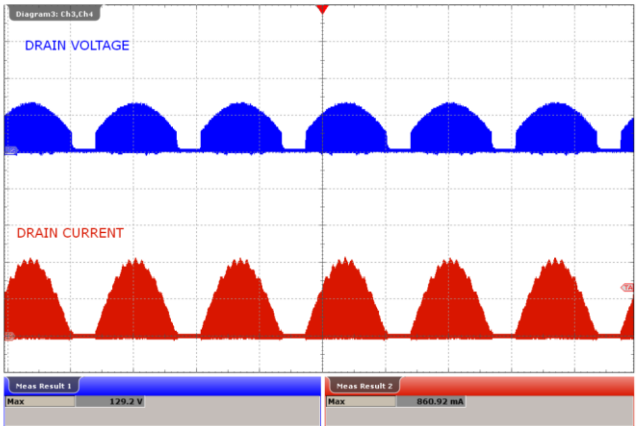

Figure 32 – 90 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 860.92 mA_{PK}.
Peak V_{DRAIN}: 129.2 V_{PK}.

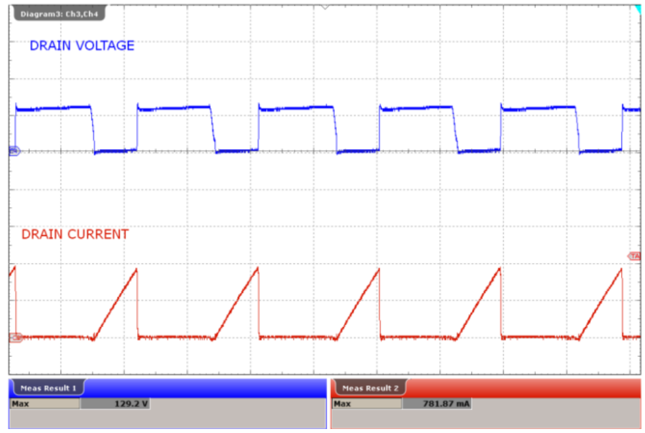

Figure 33 – 90 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 781.97 mA_{PK}.
Peak V_{DRAIN}: 129.2 V_{PK}.

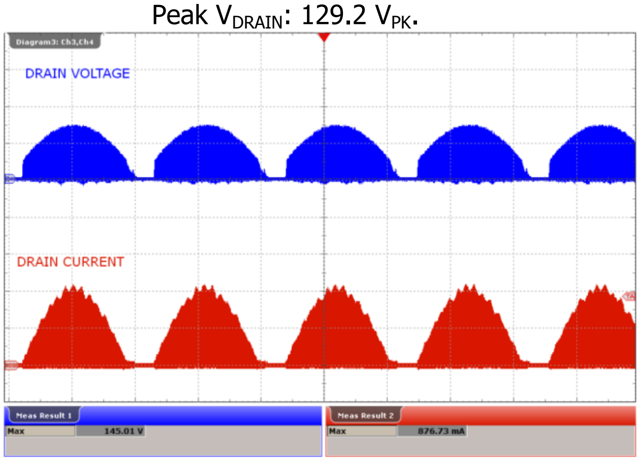

Figure 34 – 100 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 876.73 mA_{PK}.
Peak V_{DRAIN}: 145.01 V_{PK}.

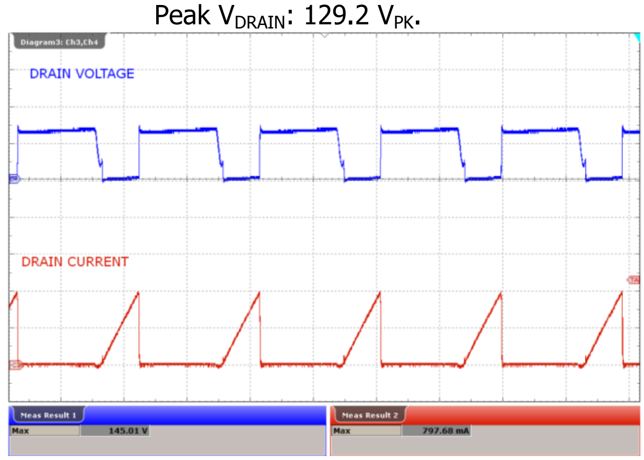

Figure 35 – 100 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 797.68 mA_{PK}.
Peak V_{DRAIN}: 145.01 V_{PK}.

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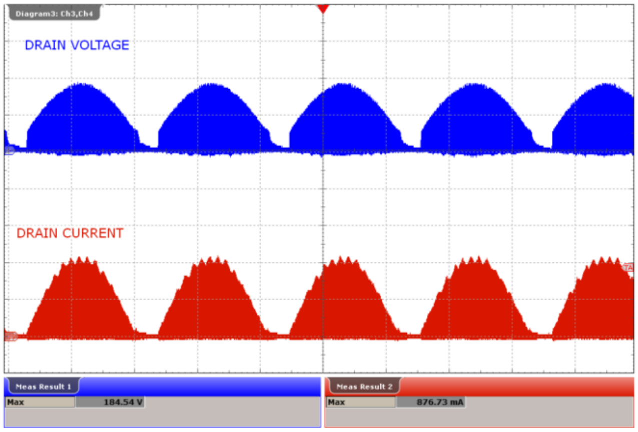

Figure 36 – 120 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 876.73 mA_{PK}.
Peak V_{DRAIN}: 184.54 V_{PK}.

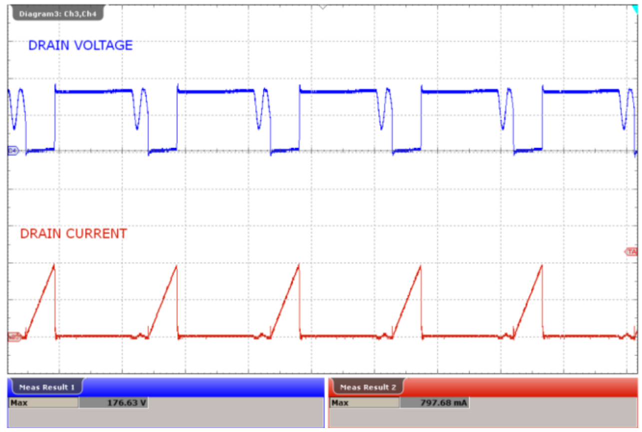

Figure 37 – 120 VAC, 42 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 797.68 mA_{PK}.
Peak V_{DRAIN}: 176.63 V_{PK}.

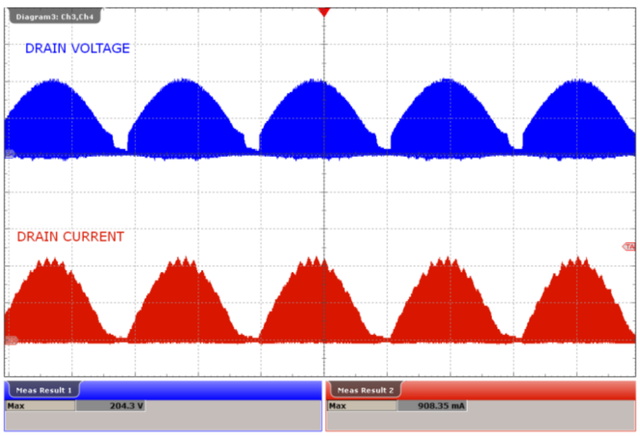

Figure 38 – 132 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 908.35 A_{PK}.
Peak V_{DRAIN}: 204.3 V_{PK}.

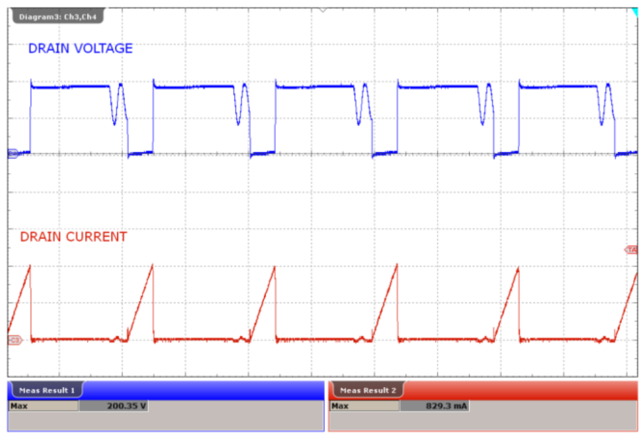

Figure 39 – 132 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 829.3 A_{PK}.
Peak V_{DRAIN}: 200.35 V_{PK}.

13.4 *Drain Voltage and Current Start-up Profile*

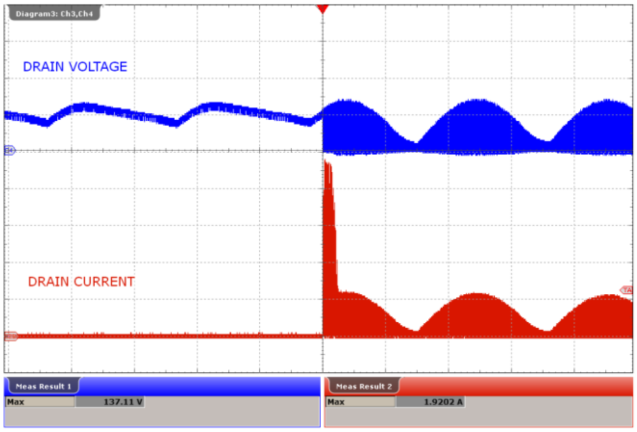

Figure 40 – 90 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 20 ms /div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.92 A_{PK}.
Peak V_{DRAIN}: 137.11 V_{PK}.

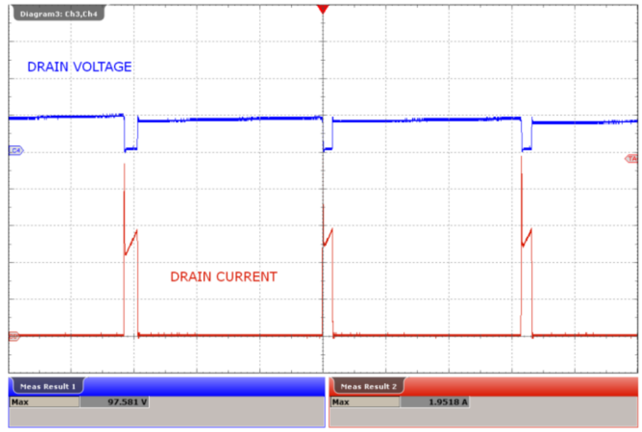

Figure 41 – 90 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 4 μs /div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.951 A_{PK}.
Peak V_{DRAIN}: 97.6 V_{PK}.

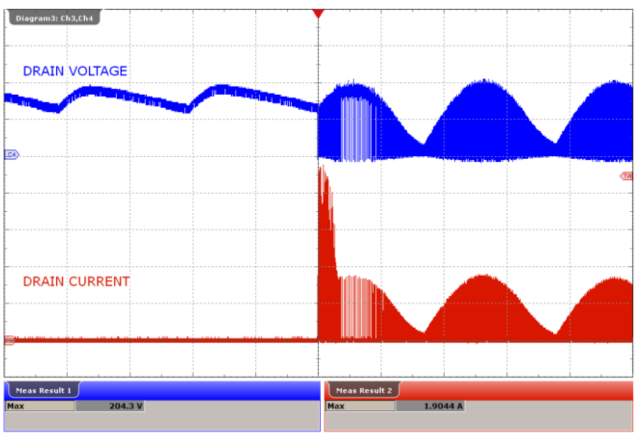

Figure 42 – 132 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 20 ms /div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.9044 A_{PK}.
Peak V_{DRAIN}: 204.3 V_{PK}.

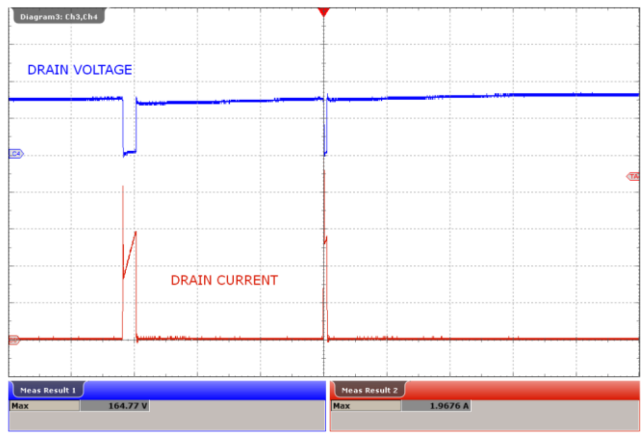

Figure 43 – 132 VAC, 42 V LED Load
Upper: V_{DRAIN}, 100 V / div., 4 μs /div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.968 A_{PK}.
Peak V_{DRAIN}: 164.72 V_{PK}.

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13.5 *Drain Voltage and Current during Output Short-Circuit Condition*

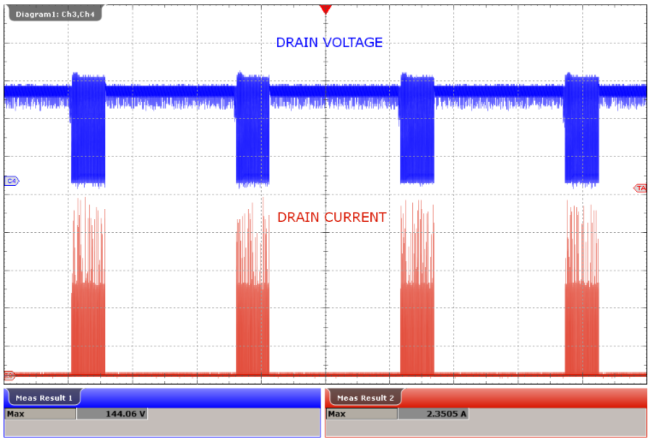

Figure 44 – 90 VAC, Output Short.
Upper: V_{DRAIN}, 50 V / div., 1 s / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 2.35 A_{PK}.
Peak V_{DRAIN}: 144.06 V_{PK}.

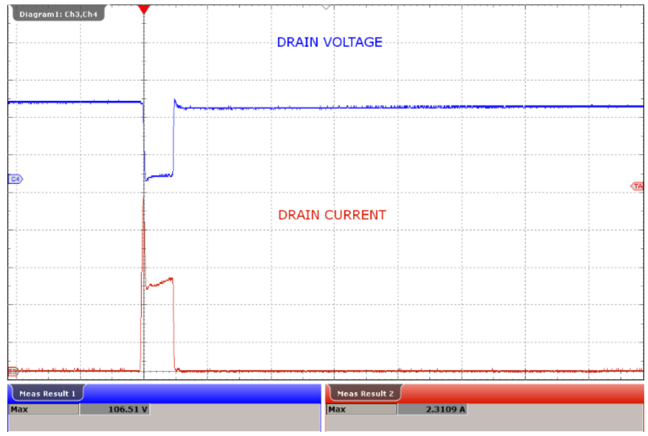

Figure 45 – 90 VAC, Output Short.
Upper: V_{DRAIN}, 50 V / div., 1 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 2.31 A_{PK}.
Peak V_{DRAIN}: 106.51 V_{PK}.

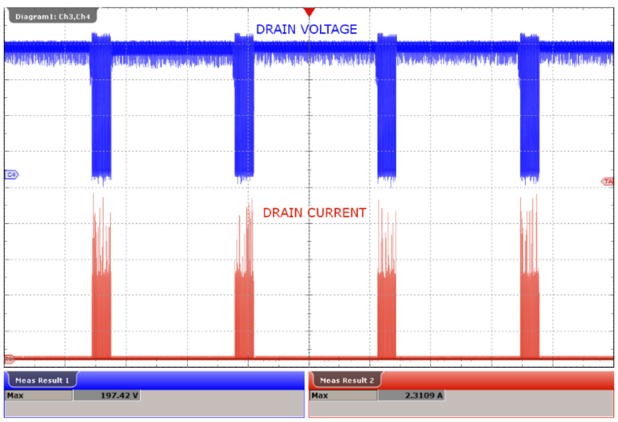

Figure 46 – 132 VAC, Output Short.
Upper: V_{DRAIN}, 50 V / div., 1 s / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 2.31 A_{PK}.
Peak V_{DRAIN}: 197.42 V_{PK}.

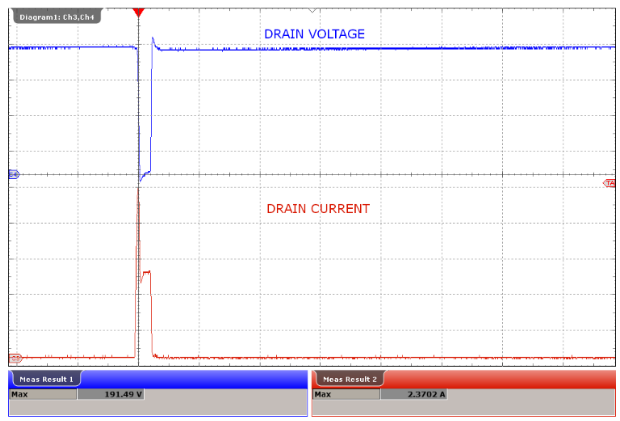

Figure 47 – 132 VAC, Output Short.
Upper: V_{DRAIN}, 50 V / div., 1 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 2.37 A_{PK}.
Peak V_{DRAIN}: 191.49 V_{PK}.

13.6 *Output Diode Voltage and Current in Normal Operation*

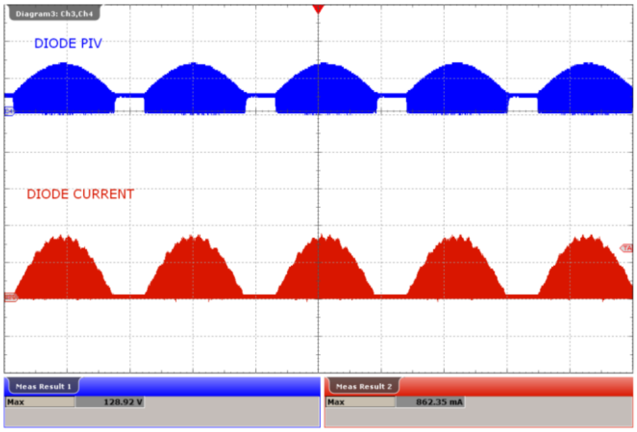

Figure 48 – 90 VAC, 42 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 500 mA / div.
Peak I_{D3}: 862.23 mA_{PK}.
Peak V_{D3}: 128.92 V_{PK}.

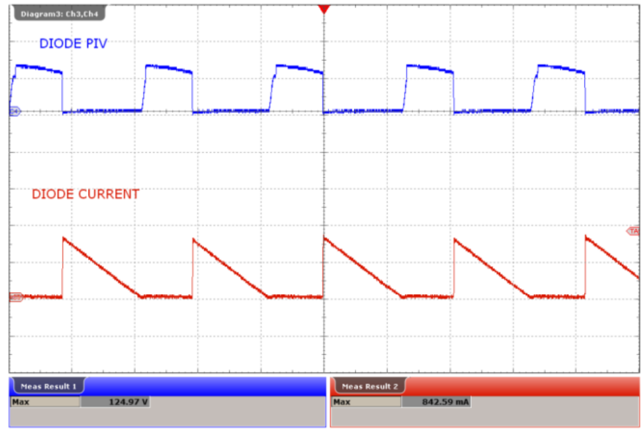

Figure 49 – 90 VAC, 42 V LED Load.
Upper: V_{D3}, 100 V / div., 4 μs / div.
Lower: I_{D3}, 500 mA / div.
Peak I_{D3}: 842.59 mA_{PK}.
Peak V_{D3}: 124.9 V_{PK}.

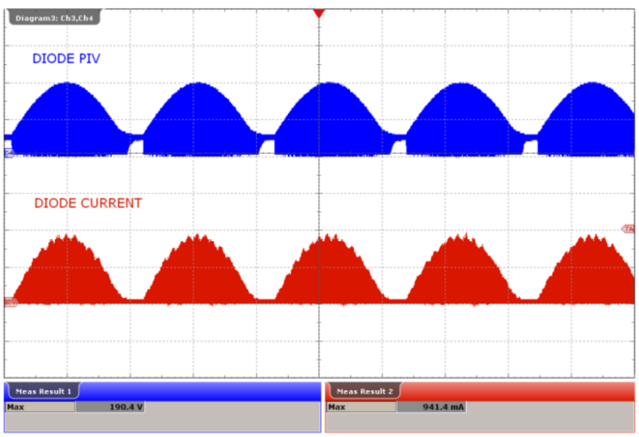

Figure 50 – 132 VAC, 42 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 500 mA / div.
Peak I_{D3}: 941.4 mA_{PK}.
Peak V_{D3}: 190.4 V_{PK}.

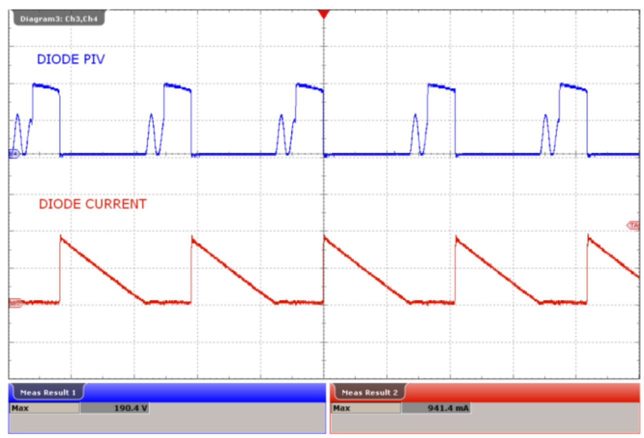

Figure 51 – 132 VAC, 42 V LED Load.
Upper: I_{DRAIN}, 100 V / div., 4 μs / div.
Lower: V_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 941.4 mA_{PK}.
Peak V_{DRAIN}: 190.4 V_{PK}.

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13.7 *Output Voltage and Current – Open LED Load*

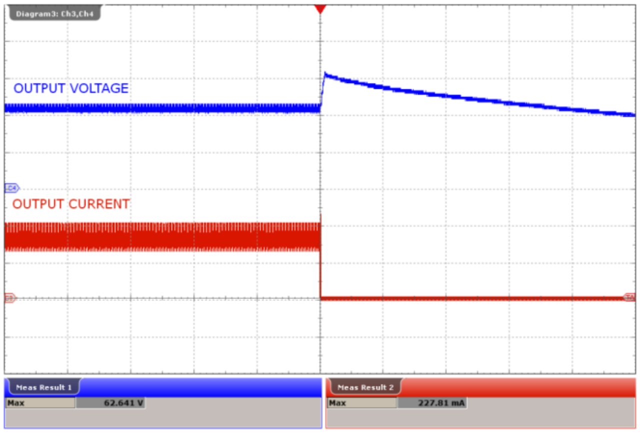

Figure 52 – 90 VAC, 42 V LED Load,
Running Open Load.
Upper: V_{OUT}, 20 V / div., 500 ms / div.
Lower: I_{OUT}, 100 mA / div.
Peak I_{OUT}: 227.81 mA_{PK}.
Peak V_{OUT}: 62.64 V_{PK}.

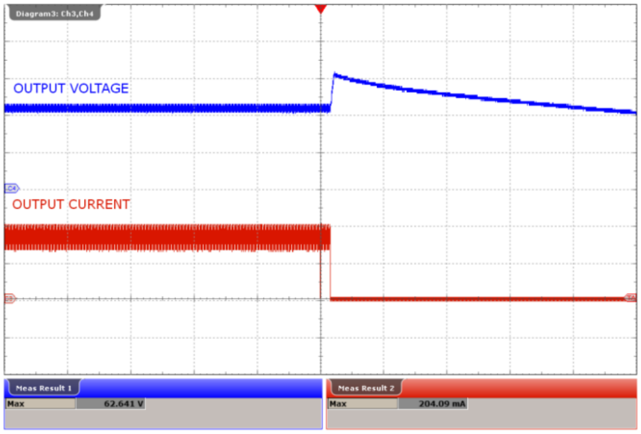

Figure 53 – 132 VAC, 42 V LED Load,
Running Open Load.
Upper: V_{OUT}, 20 V / div., 500 ms / div.
Lower: I_{OUT}, 100 mA / div.
Peak I_{OUT}: 204.09 mA_{PK}.
Peak V_{OUT}: 62.64 V_{PK}.

13.8 *Output Ripple Current*

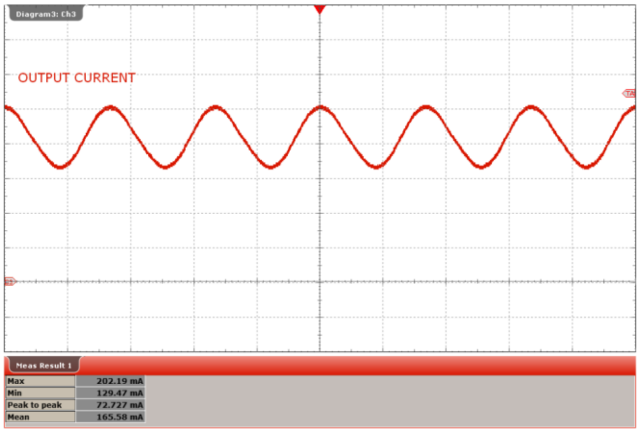

Figure 54 – 90 VAC, 60 Hz, 42 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

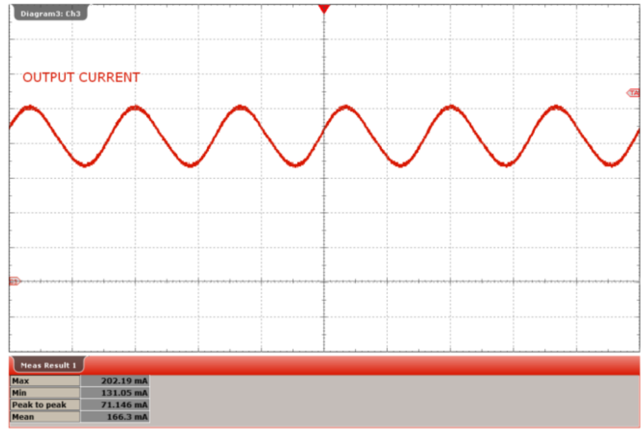

Figure 55 – 100 VAC, 60 Hz, 42 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

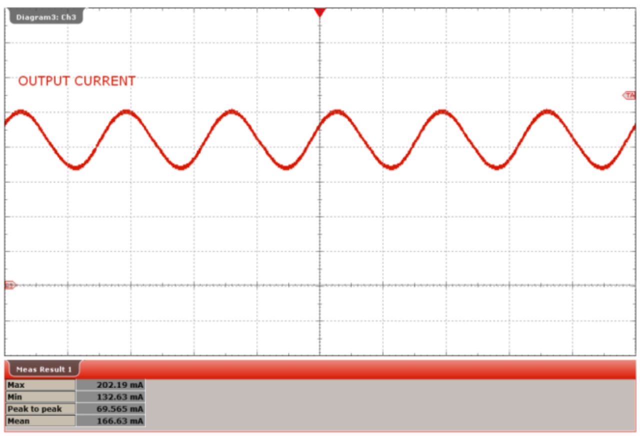

Figure 56 – 120 VAC, 60 Hz, 42 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

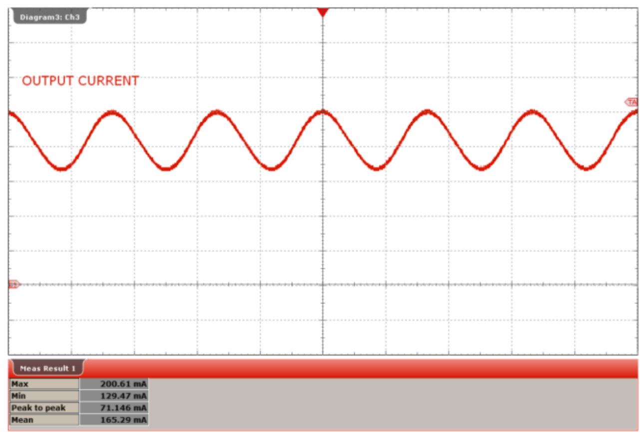

Figure 57 – 132 VAC, 60 Hz, 42 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

V_{IN}	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	$I_{RP-P(PK-PK)}$ (mA)	I_{MEAN}	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}+I_{O(MIN)}$)
90 VAC	202.19	129.47	72.727	165.58	0.44	21.92
100 VAC	202.19	131.05	71.146	166.30	0.43	21.35
120 VAC	202.19	132.63	69.565	166.63	0.42	20.77
132 VAC	200.61	129.47	71.146	165.29	0.43	21.55

Table 5 – Output Current %Flicker Data.

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14 Dimming Waveforms

14.1 *Input Voltage and Input Current Waveforms – Leading Edge Dimmer*

Input: 120 VAC, 60 Hz
Output: 42V LED load
Dimmer: Legrand HCL453PTCCCV6

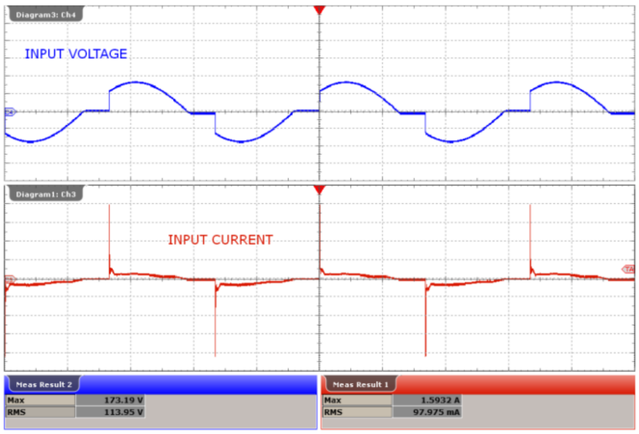

Figure 58 – 140º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 500 mA / div. .
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 113.95 V

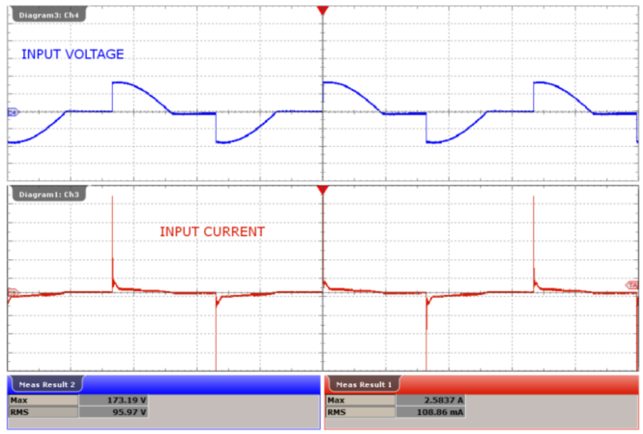

Figure 59 – 110º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 500 mA / div.
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 95.97 V

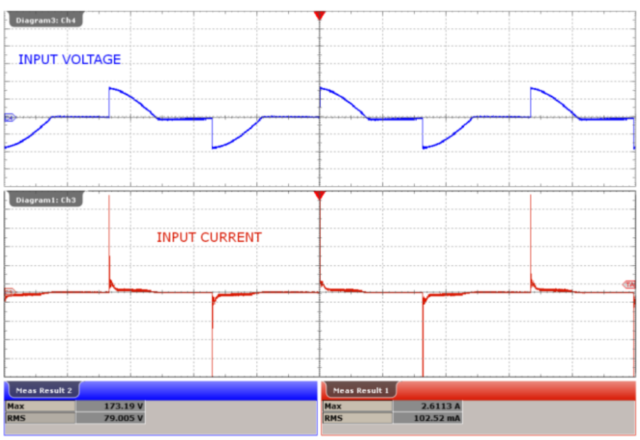

Figure 60 – 90º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 500 mA / div.
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 79.005 V

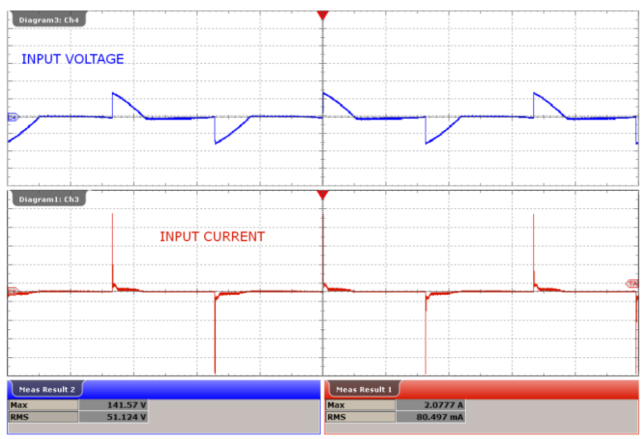

Figure 61 – 45º Conduction Angle.
Upper: V_{IN}, 100 V / div., 5 ms / div.
Lower: I_{IN}, 500 mA / div.
Peak V_{IN}: 141.47 V_{PK}.
V_{RMS}: 51.12 V

14.2 *Output Current Waveforms – Leading Edge Dimmer*

Input: 120 VAC, 60 Hz
Output: 42 V LED load
Dimmer: Lutron SCL-153P-WH

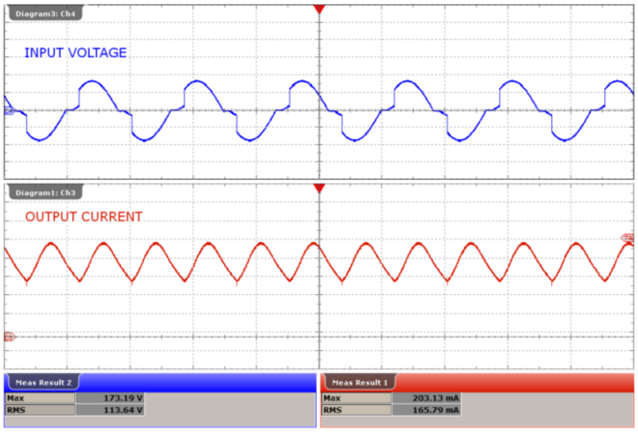

Figure 62 – 140º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 203.13 mA_{PK}.
Peak V_{IN}: 173.2 V_{PK} .

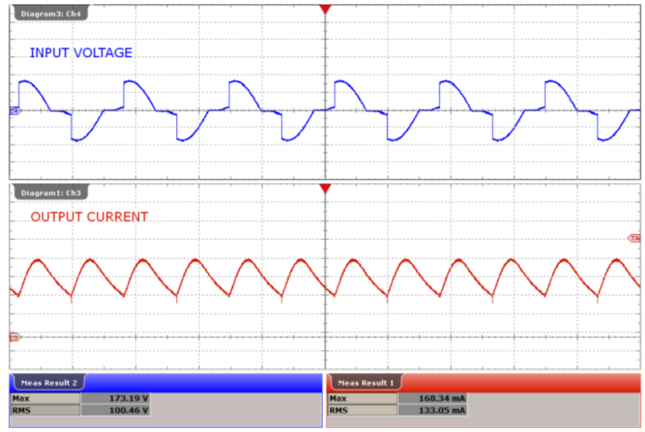

Figure 63 – 110º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 168.34 mA_{PK}.
Peak V_{IN}: 173.2 V_{PK} .

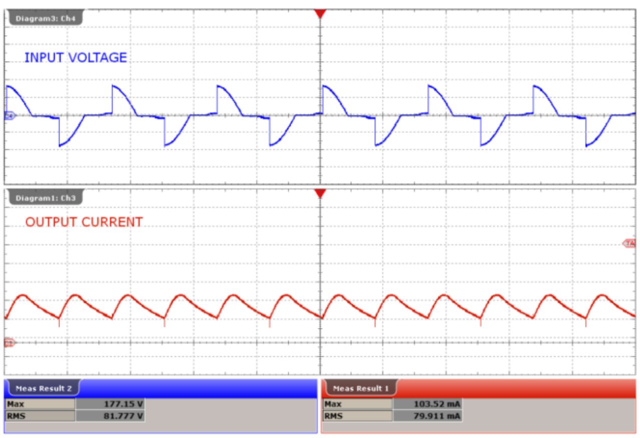

Figure 64 – 90º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 103.52 mA_{PK}.
Peak V_{IN}: 177.15 V_{PK}.

Figure 65 – 45º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 16.566 mA_{PK}.
Peak V_{IN}: 113.91 V_{PK}.

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14.3 *Input Voltage and Input Current Waveforms – Trailing Edge Dimmer*

Input: 120 VAC, 60 Hz
Output: 42 V LED load
Dimmer: Leviton 1PE04-1LZ

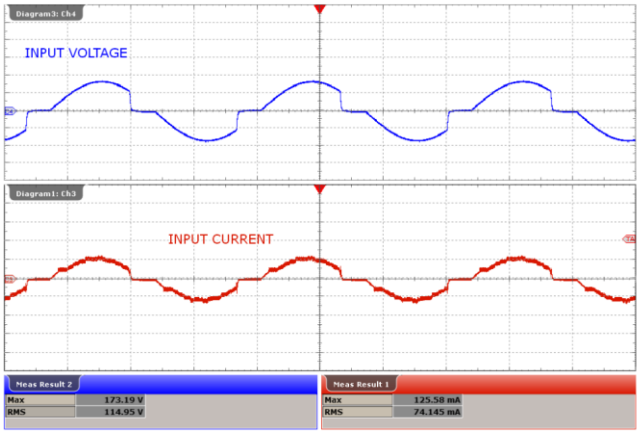

Figure 66 – 140° Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div. .
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 114.95 V.

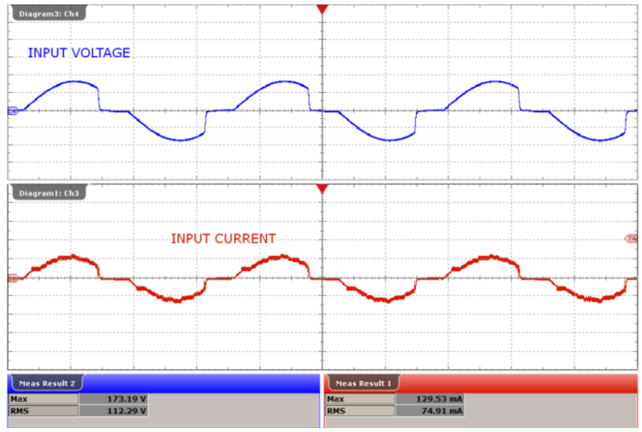

Figure 67 – 110° Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div. .
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 112.3 V.

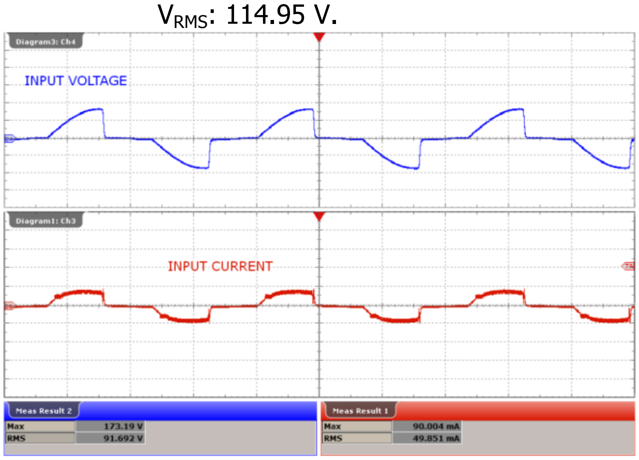

Figure 68 – 90° Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak V_{IN}: 173.2 V_{PK}.
V_{RMS}: 91.69 V.

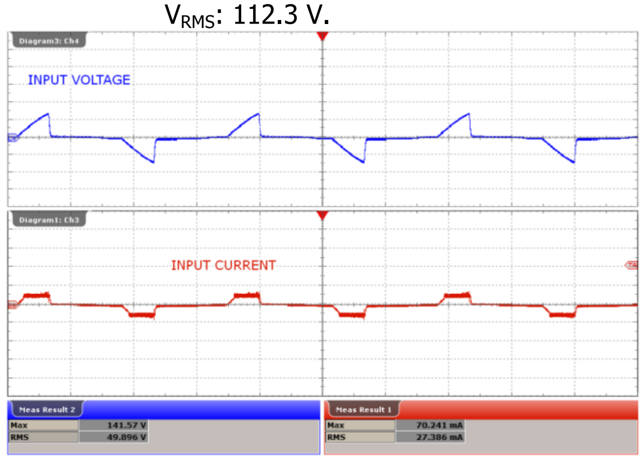

Figure 69 – 45° Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 100 mA / div.
Peak V_{IN}: 141.57 V_{PK}.
V_{RMS}: 49.89 V.

14.4 ***Output Current Waveforms – Trailing Edge Dimmer***

Input: 120 VAC, 60 Hz
Output: 42 V LED load
Dimmer: Leviton 1PE04-1LZ

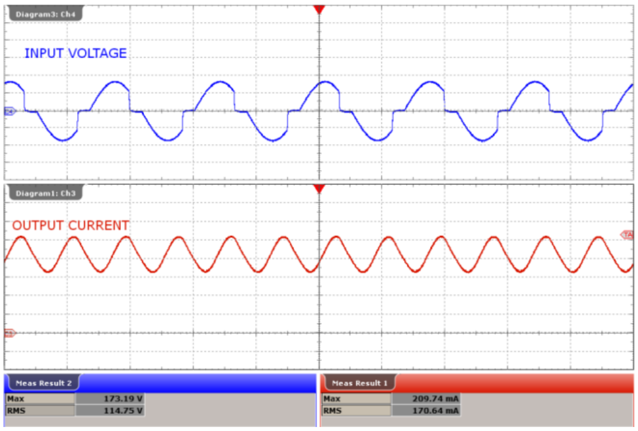

Figure 70 – 140º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 209.74 $mA_{PK.}$
Peak V_{IN}: 114.75 $V_{PK.}$

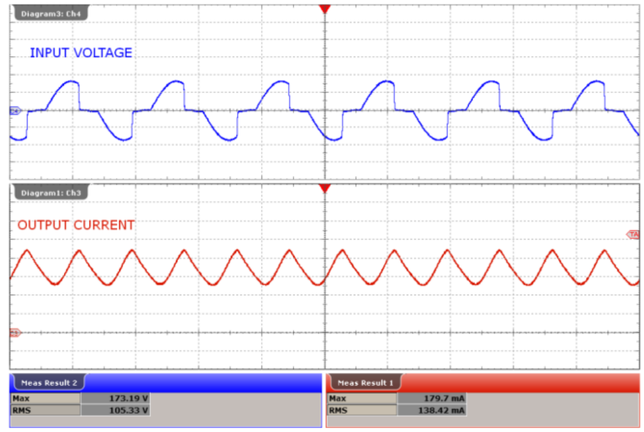

Figure 71 – 110º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 179.7 $mA_{PK.}$
Peak V_{IN}: 105.33 $V_{PK.}$

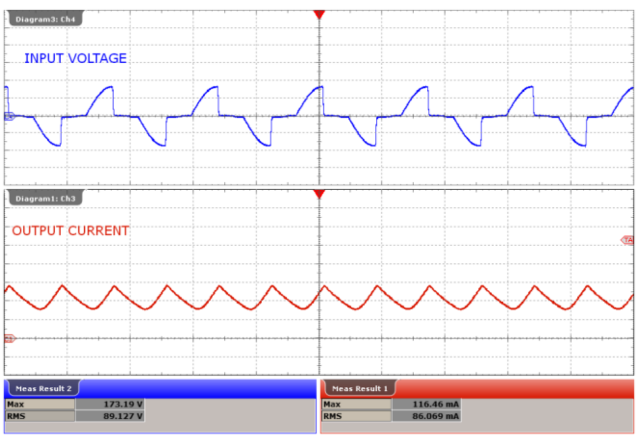

Figure 72 – 90º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 100 mA / div.
Peak I_{OUT}: 116.46 $mA_{PK.}$
Peak V_{IN}: 89.12 $V_{PK.}$

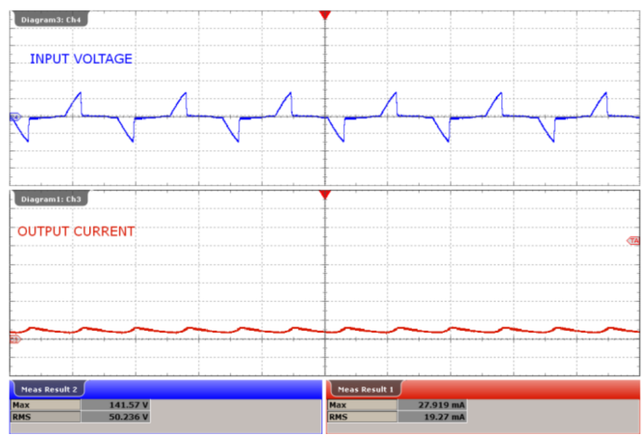

Figure 73 – 45º Conduction Angle.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{OUT}, 100 mA / div.
Peak I_{OUT}: 27.92 $mA_{PK.}$
Peak V_{IN}: 233 $V_{PK.}$

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15 AC Cycling Test

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

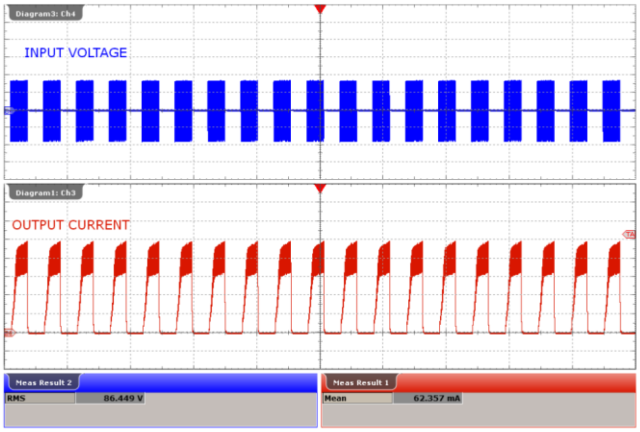

Figure 74 – 90 VAC, 42 V LED Load.
1 s On – 1 Sec Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

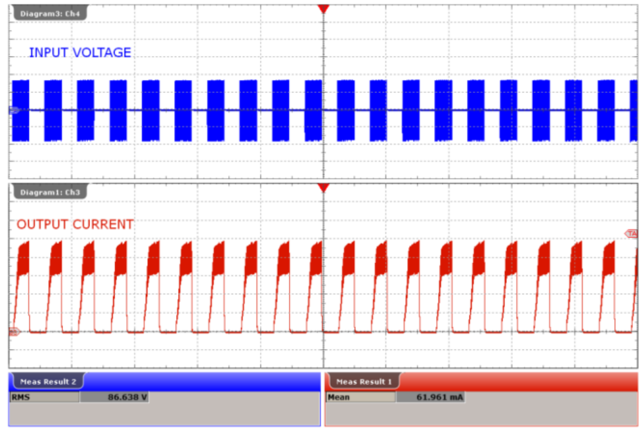

Figure 75 – 100 VAC, 42 V LED Load.
1 s On – 1 Sec Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

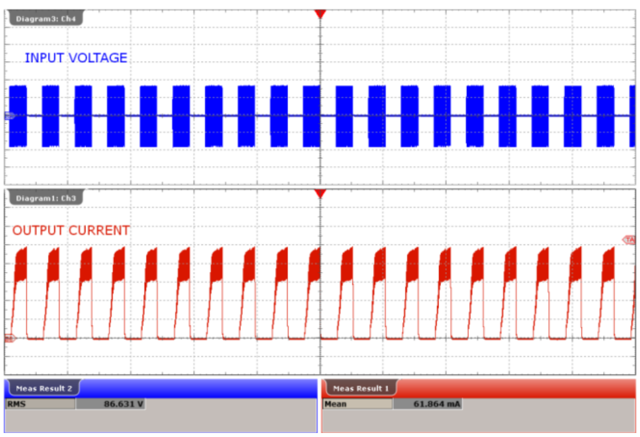

Figure 76 – 120 VAC, 42 V LED Load.
1 s On – 1 Sec Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

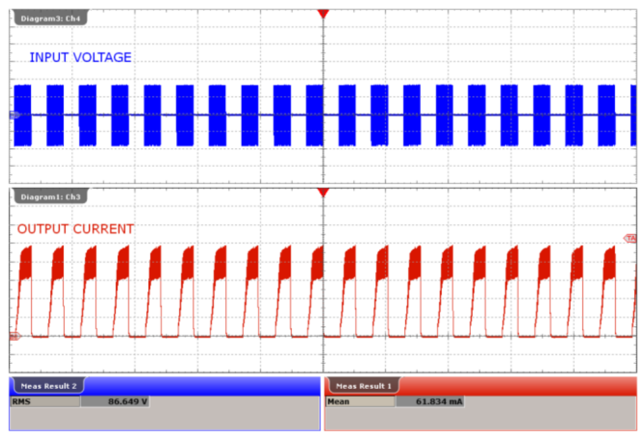

Figure 77 – 132 VAC, 42 V LED Load.
1 s On – 1 Sec Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

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. 42 V LED load with input voltage set at 120 VAC.

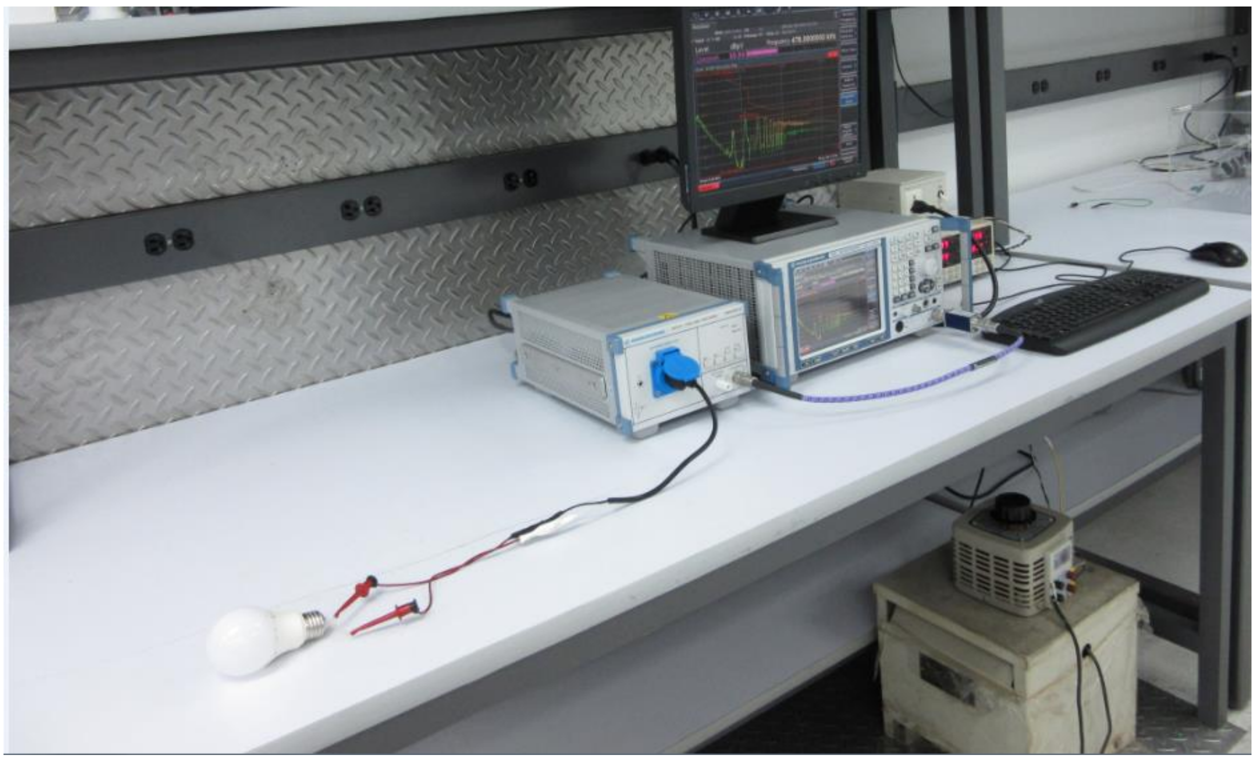

Figure 78 – Conducted EMI Test Set-up.

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16.2 ***EMI Test Result***

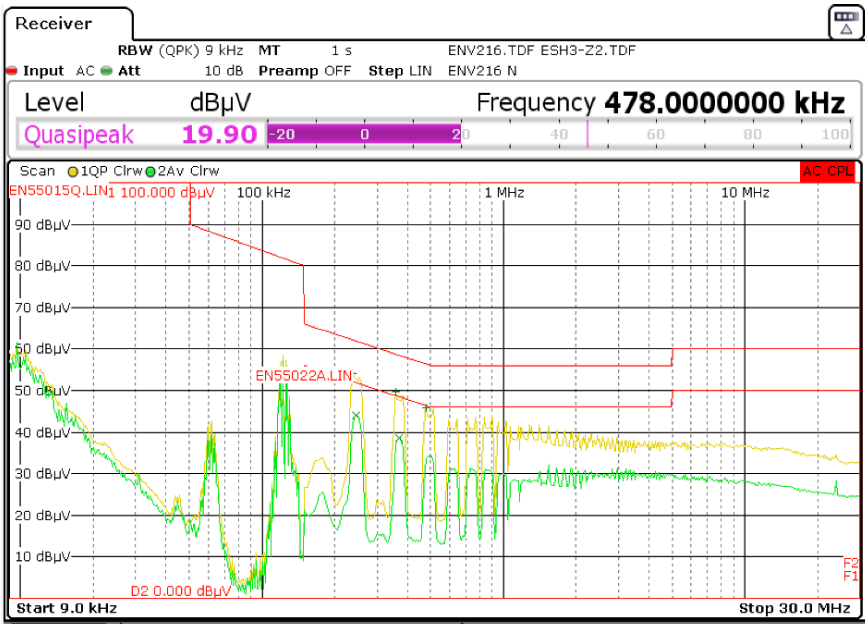

Figure 79 – Conducted EMI AT Line 1, 42 V LED Load, 120 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	238.0000 kHz	54.15 N	-8.02 dB
2 Average	246.0000 kHz	44.09 N	-7.80 dB
1 Quasi Peak	358.0000 kHz	49.75 N	-9.02 dB
2 Average	370.0000 kHz	38.61 N	-9.89 dB
1 Quasi Peak	478.0000 kHz	45.90 N	-10.47 dB

Figure 80 – Conducted EMI at Line 1, 42 V LED Load, Final Measurement Results.

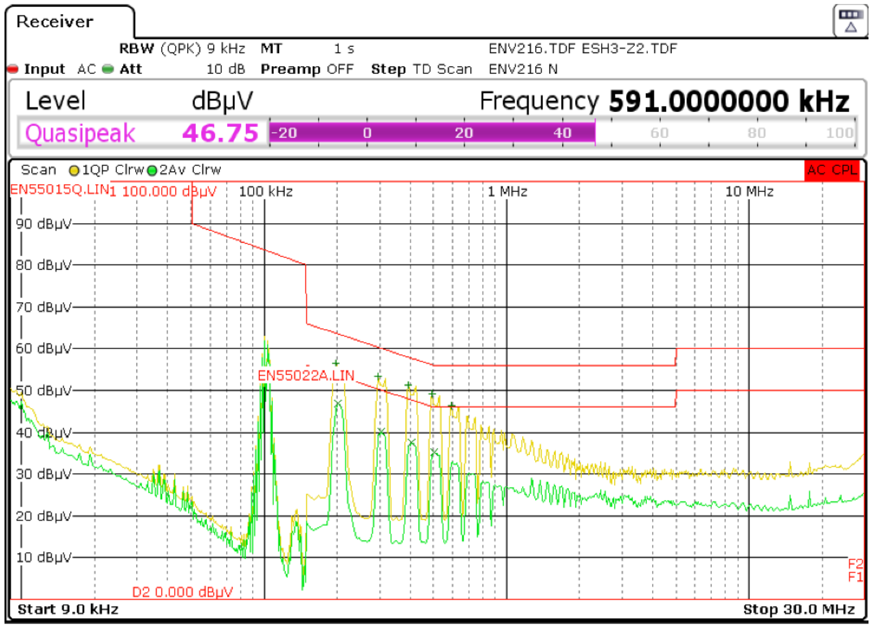

Figure 81 – Conducted EMI AT Line 2, 42 V LED Load, 120 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	197.2500 kHz	56.45 N	-7.28 dB
2 Average	201.7500 kHz	46.95 N	-6.59 dB
1 Quasi Peak	296.2500 kHz	53.35 N	-7.00 dB
2 Average	305.2500 kHz	40.03 N	-10.07 dB
1 Quasi Peak	395.2500 kHz	51.31 N	-6.64 dB
2 Average	404.2500 kHz	37.47 N	-10.30 dB
1 Quasi Peak	492.0000 kHz	49.34 N	-6.79 dB
2 Average	503.2500 kHz	35.16 N	-10.84 dB
1 Quasi Peak	591.0000 kHz	46.43 N	-9.57 dB

Figure 82 – Conducted EMI at Line 2, 42 V LED Load, Final Measurement Results.

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17 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.

17.1 *Differential Surge Test Summary*

Differential Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	110	L to N	0	Pass
-1000	110	L to N	0	Pass
+1000	110	L to N	90	Pass
-1000	110	L to N	90	Pass
+1000	110	L to N	270	Pass
-1000	110	L to N	270	Pass

17.2 *Ring Wave Test Summary*

Ring Wave Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	110	L,N to PE	0	Pass
-2500	110	L,N to PE	0	Pass
+2500	110	L,N to PE	90	Pass
-2500	110	L,N to PE	90	Pass
+2500	110	L,N to PE	270	Pass
-2500	110	L,N to PE	270	Pass

17.3 ***Differential Surge Test Result and Waveform***

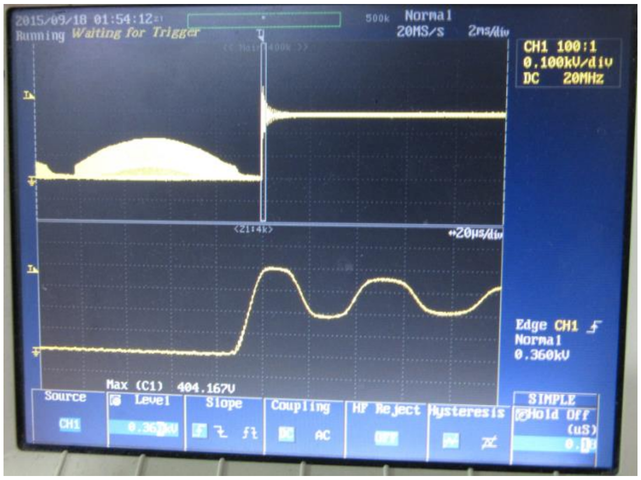

Figure 83 – 120 VAC, 60 Hz, +1000, 0º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 404 $V_{PK.}$

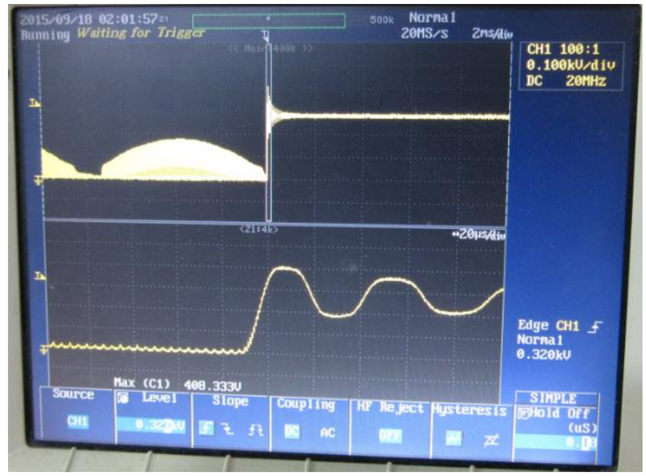

Figure 84 – 120 VAC, 60 Hz, -1000, 0º
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 408 $V_{PK.}$

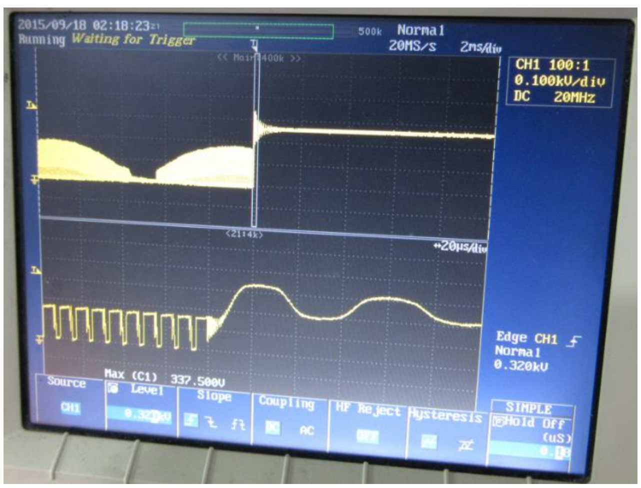

Figure 85 – 120 VAC, 60 Hz, +1000, 90º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 337 $V_{PK.}$

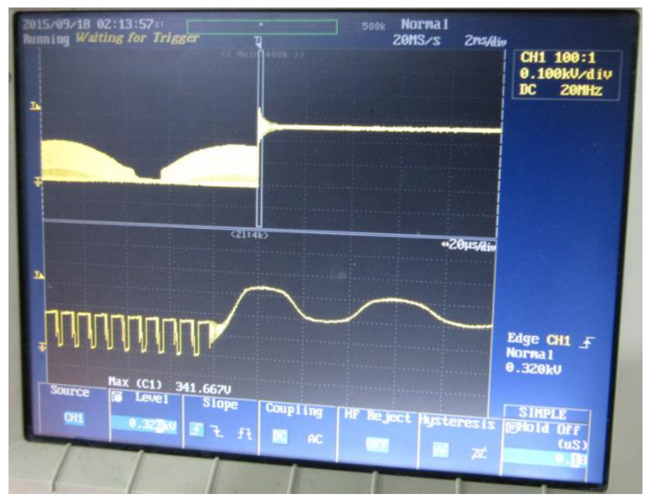

Figure 86 – 120 VAC, 60 Hz, -1000, 90º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div.(Zoomed).
Measured Peak Voltage = 341 $V_{PK.}$

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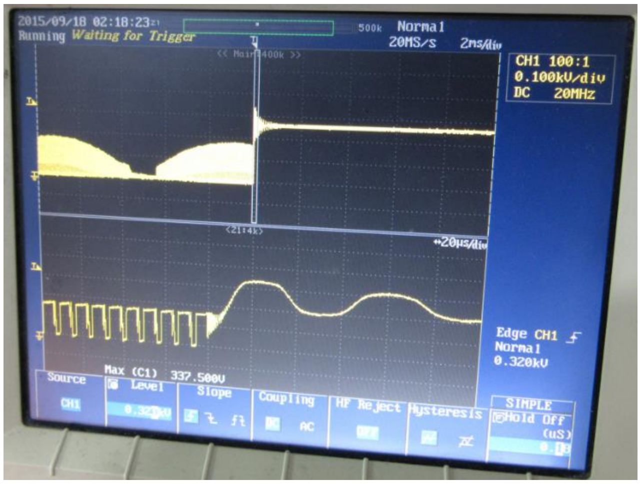

Figure 87 – 120 VAC, 60 Hz, +1000, 270º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 337 $V_{PK.}$

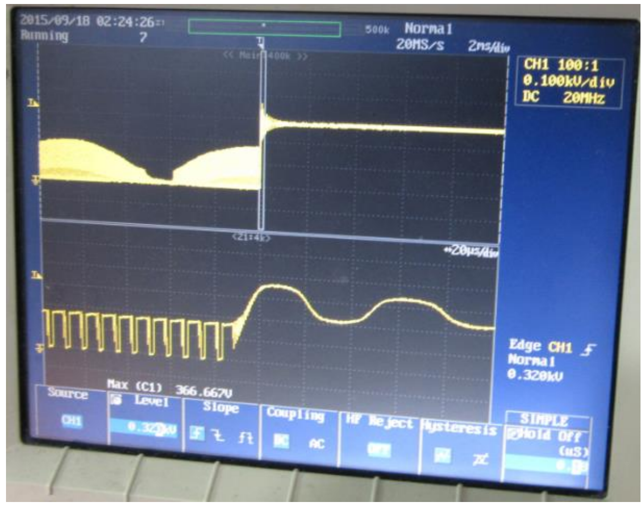

Figure 88 – 120 VAC, 60 Hz, -1000, 270º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 367 $V_{PK.}$

17.4 *Ring Wave Test Result and Waveform*

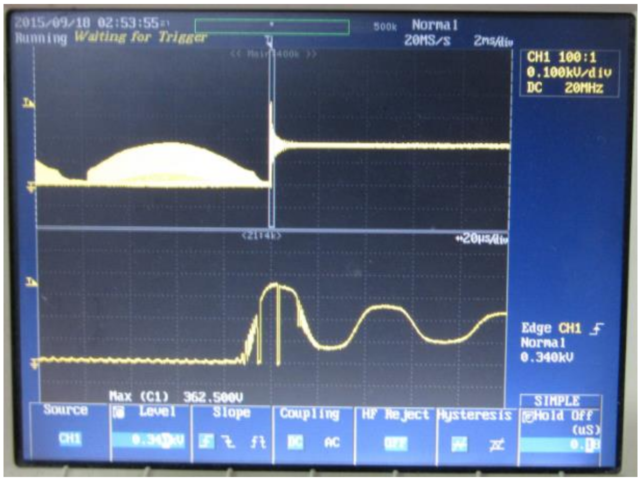

Figure 89 – 120 VAC, 60 Hz, +2500, 0º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 362 $V_{PK.}$

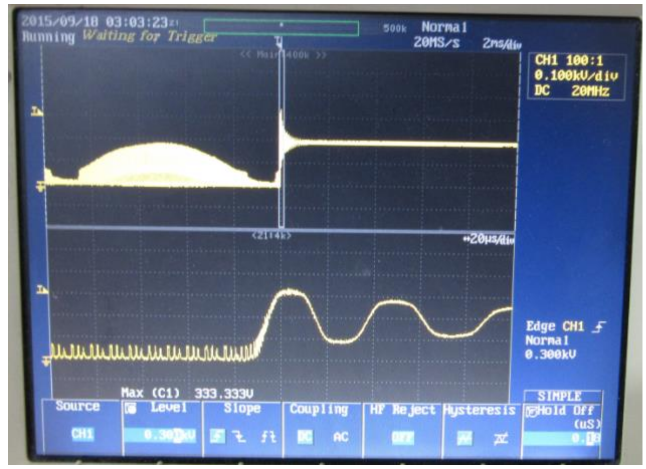

Figure 90 – 120 VAC, 60 Hz, -2500, 0º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 333 $V_{PK.}$

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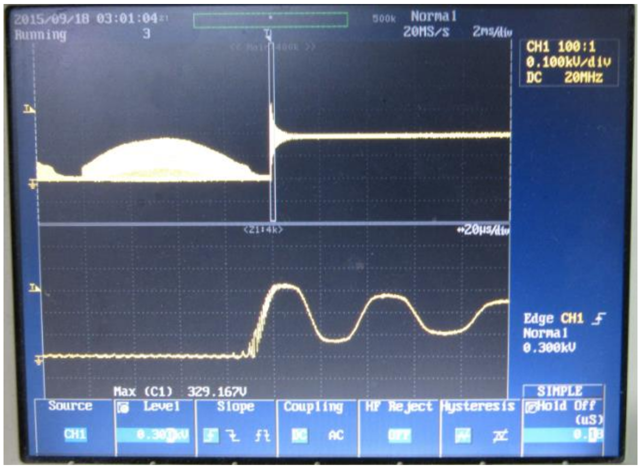

Figure 91 – 120 VAC, 60 Hz, +2500, 90º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 329 $V_{PK.}$

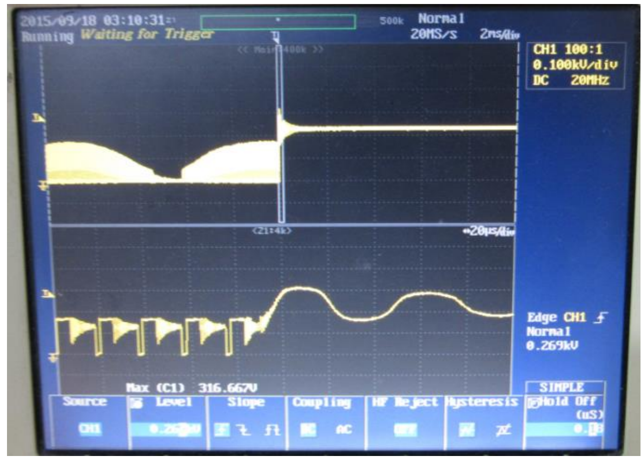

Figure 92 – 120 VAC, 60 Hz, -2500, 90º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 316 $V_{PK.}$

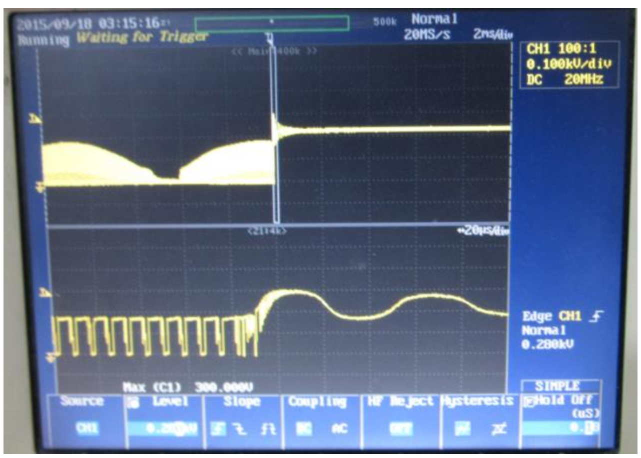

Figure 93 – 120 VAC, 60 Hz, +2500, 270º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 300 $V_{PK.}$

Figure 94 – 120 VAC, 60 Hz, -2500, 270º.
Upper: V_{DRAIN}, 100 V / div.
Lower: V_{DRAIN}, 100 V / div. (Zoomed).
Measured Peak Voltage = 320 $V_{PK.}$

17.5 *Line Surge Test Set-up*

17.5.1 Equipment/Load Used and Test Condition

1. Thermo Scientific surge test equipment
2. Yokogawa DL1740 oscilloscope
3. Yokogawa 701926 differential probe (for measuring drain voltage)
4. 42 V LED string to cater 6.9 W output power
5. Input voltage set at 120 VAC.

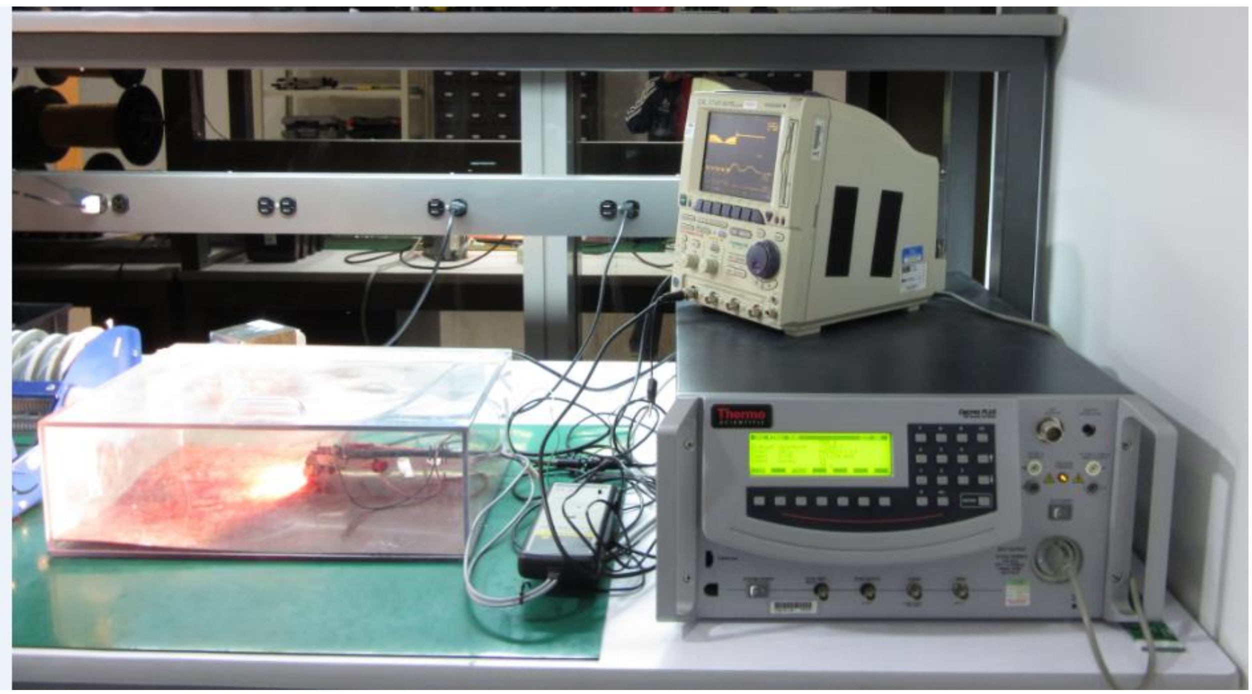

Figure 95 – Line Surge Test Set-up.

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18 Brown-in / Brown-out Test

No failure of any component was seen during brownout test of 1 V / sec AC cut-in and cut-off.

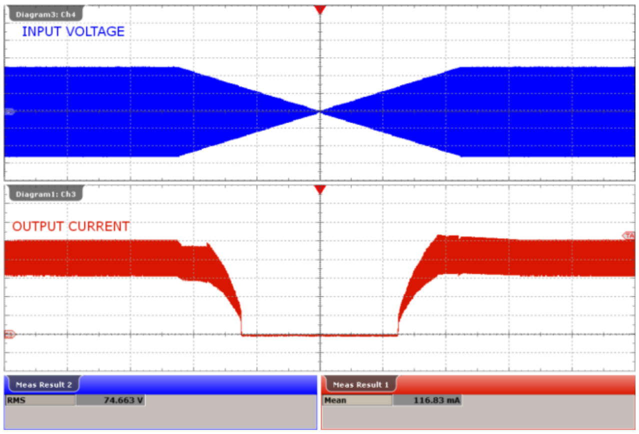

Figure 96 – 90 VAC, 42 V LED Load.
Upper: V_{IN}, 50 V / div., 20 s / div.
Lower: I_{OUT}, 40 mA / div.

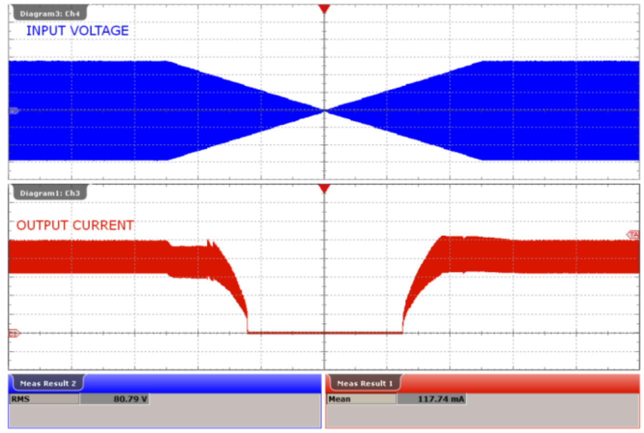

Figure 97 – 100 VAC, 42 V LED Load.
Upper: V_{IN}, 50 V / div., 20 s / div.
Lower: I_{OUT}, 40 mA / div.

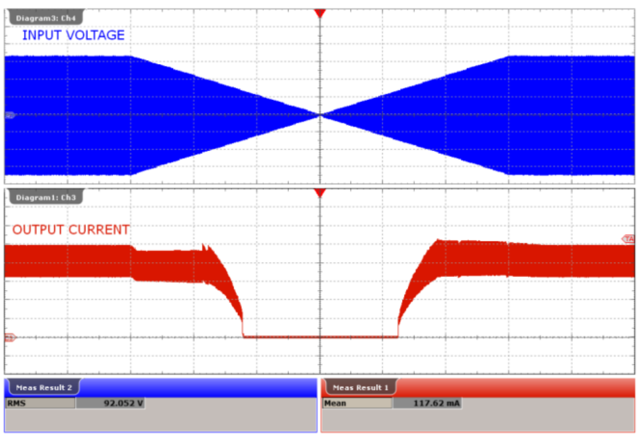

Figure 98 – 120 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 20 s / div.
Lower: I_{OUT}, 40 mA / div.

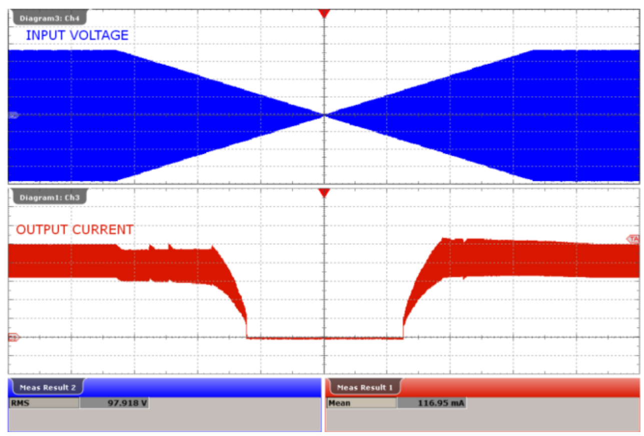

Figure 99 – 132 VAC, 42 V LED Load.
Upper: V_{IN}, 100 V / div., 20 s / div.
Lower: I_{OUT}, 40 mA / div.

19 Revision History

Date	Author	Revision	Description and Changes	Reviewed
01-Mar-16	Ian B.	1.0	Initial release	Apps & Mktg

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