Design Example Report

Title	***6.9 W TRIAC Dimmable, High Efficiency, Power Factor Corrected Buck-Boost LED Driver Using LYTSwitch™-3 LYT3324D***
Specification	195 VAC – 265 VAC Input; 48 V, 145 mA_{TYP} Output
Application	Omni-Directional Bulb
Author	Applications Engineering Department
Document Number	DER-490
Date	August 16, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.9
- Accurate constant LED current (CC) regulation, ±5%
- Highly energy efficient, >85% at 230 V
- 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
  - No-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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PATENT INFORMATION

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

1 Introduction

This engineering report describes a TRIAC dimmable, non-isolated buck-boost LED driver designed to drive a nominal LED voltage string of 48 V at 145 mA from an input voltage range of 195 VAC to 265 VAC. The LED driver utilizes the LYT3324D from the LYTSwitch-3 family of devices.

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

The DER-490 provides a single 6.95 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.

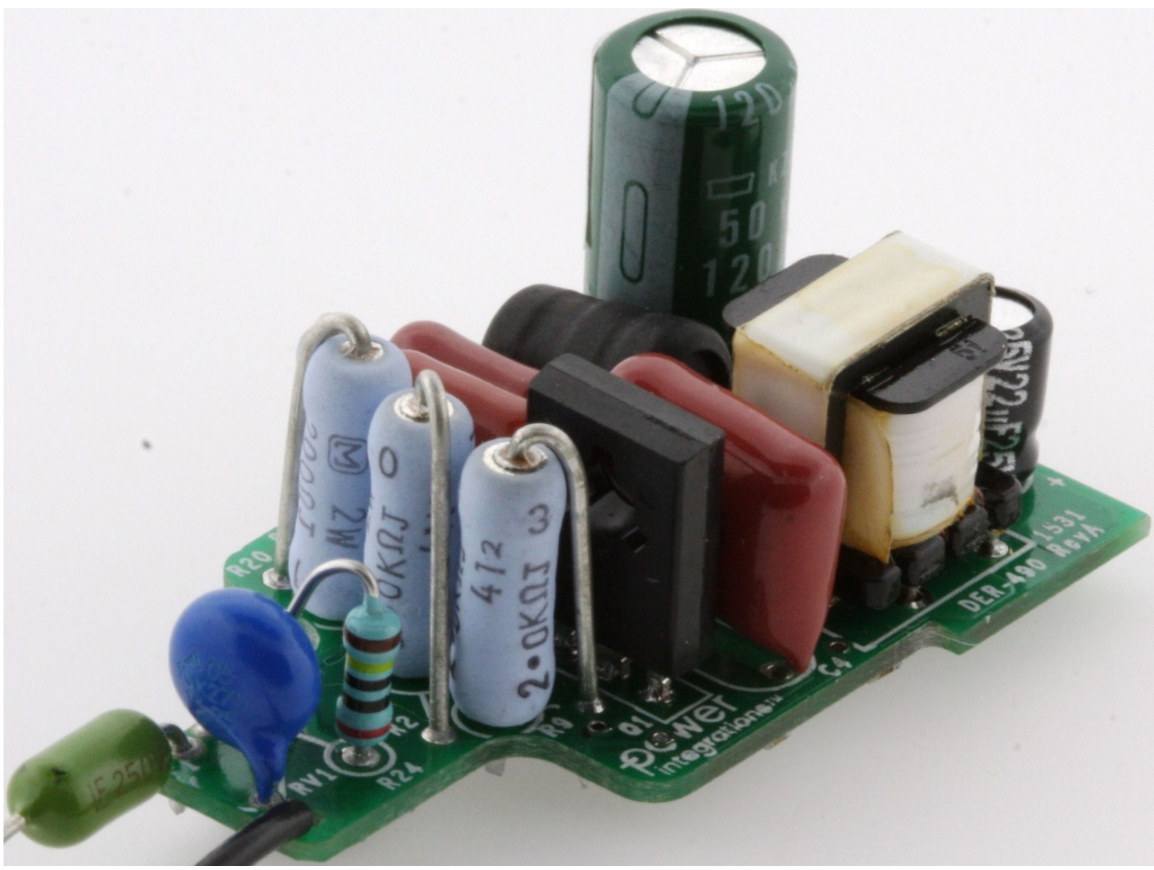

Figure 1 – Populated Circuit Board

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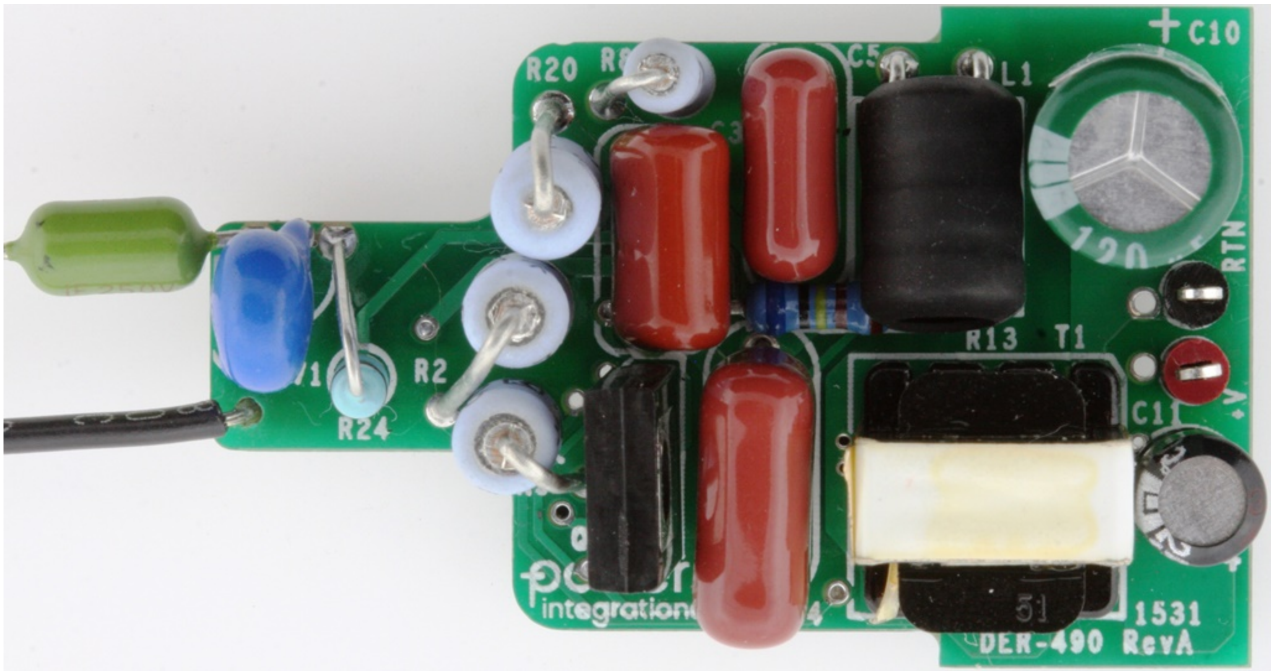

Figure 2 – Populated Circuit Board, Top View.

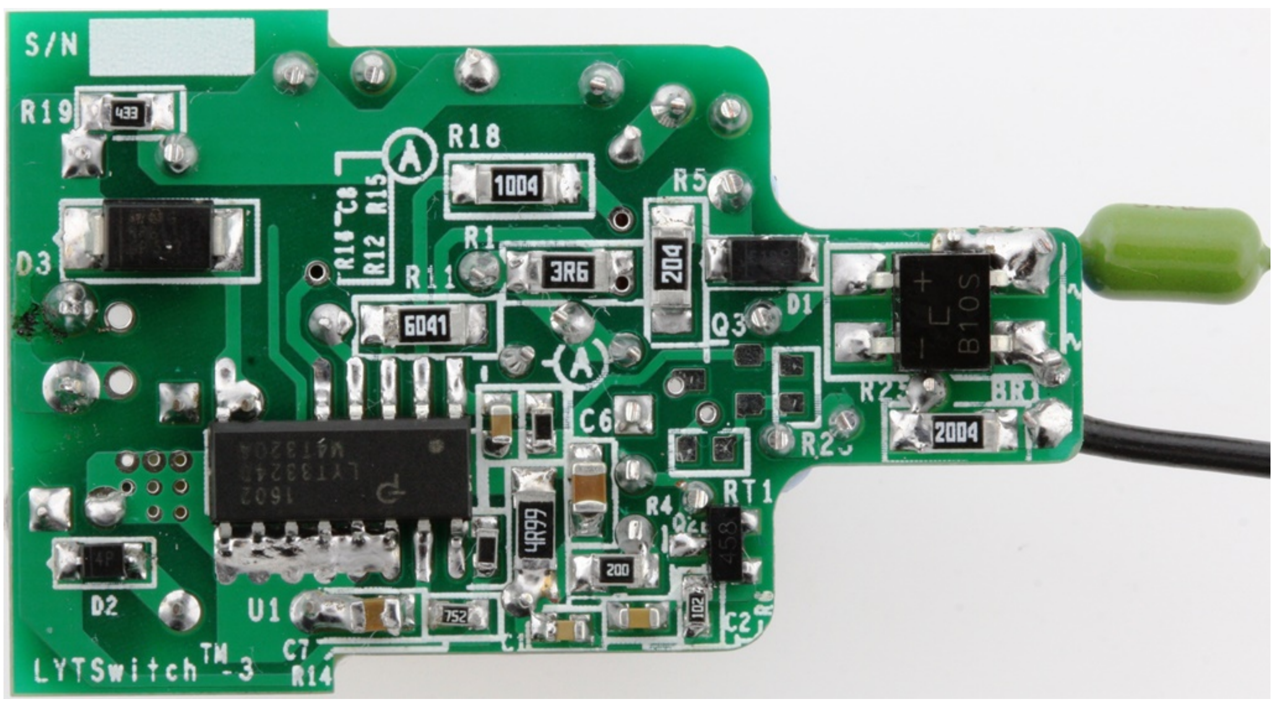

Figure 3 – Populated Circuit Board, Bottom View.

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}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	46	48	50	V	
Output Current	I_{OUT}	137.75	145	152.25	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		6.95		W	
Efficiency						
Full Load	η		85		%	Measured at 230 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			0.9			Measured at 240 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			40	^{o}C	Free Convection, Sea Level.

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3 Schematic

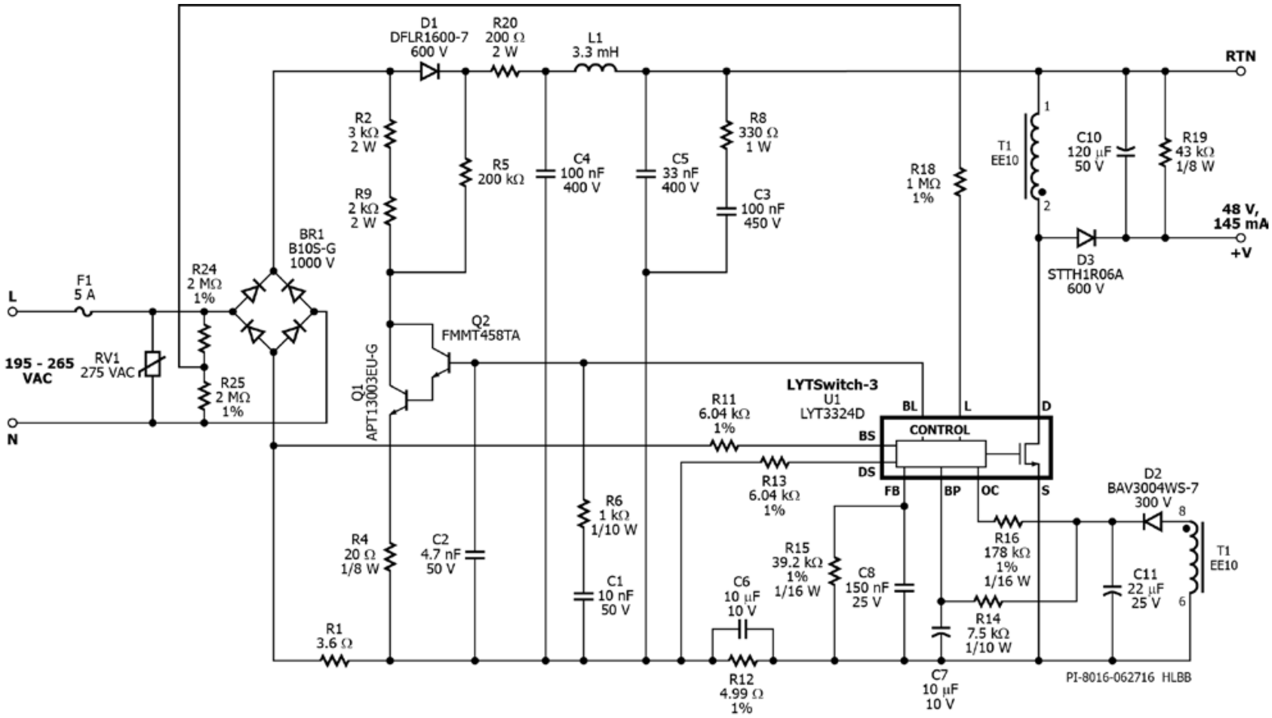

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-3 LYT3324D 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

Fuse F1 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 275 VAC rated part was selected, being slightly above the maximum specified operating voltage (265 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. These EMI filters, together with the LYTSwitch-3 frequency jittering feature ensure compliance with the EN55015 Class B emission limit.

4.2 LYTSwitch-3 Primary Control Circuit

The topology is a buck-boost 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 the LED load. The stored energy in the transformer is then 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 condition.

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 D pin.

To provide input line voltage information to U1, the incoming rectified AC is sense directly by the LINE SENSE (L) pin of U1 through resistor R24, R25 and R18. The L pin current is use to activate input OVP functions, to detect the presence of dimmer and to control the output LED current with respect to line.

With reference to the FEEDBACK (FB) pin full conduction preset threshold of 300 mV, R12 senses the output LED current through U1 drain current and then fed into the U1

DRIVER CURRENT SENSE (DS) pin via R13 to maintain the output constant current 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.

IC U1 OUTPUT COMPENSATION (OC) pin senses the output voltage through R16 for the output OVP functions at open load and for optimized LED current regulation. Output OVP is activated with the IC latching off when the OC pin voltage exceeds the OV threshold.

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

Due to the much lower power consumed by LED based lighting, the current drawn by the lamp is below the holding current of the TRIAC 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 were incorporated.

Resistor R20 dampens the driver input current ringing when TRIAC dimmer turns on. D1 serves as a blocking diode to prevent current to be drawn from the input capacitor C3 as the bleeder turns on.

A passive RC bleeder formed by resistor R8 and capacitor C3 provides latching current and damping to help keep the TRIAC conducting.

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

Resistor R4, R6, C1, C2, Q1 and Q2 form an external bleeder circuit driven by LYTSwitch-3. Series connected R2 and R9 are bleeder resistors and Q1 is the bleeder switch. Transistor Q2 is connected in Darlington connection with Q1 for a higher bleeder switch current. Resistor R4, C2, R6 and C1 work as bleeder stabilizing network.

Resistor R1 senses the overall input current and fed to U1 BS pin through resistor R11. The overall current includes the active bleeder current and the U1 switch current. These current are sensed in order to keep the TRIAC current above its holding level by modulating the bleeder dissipation in a closed loop system. IC U1 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

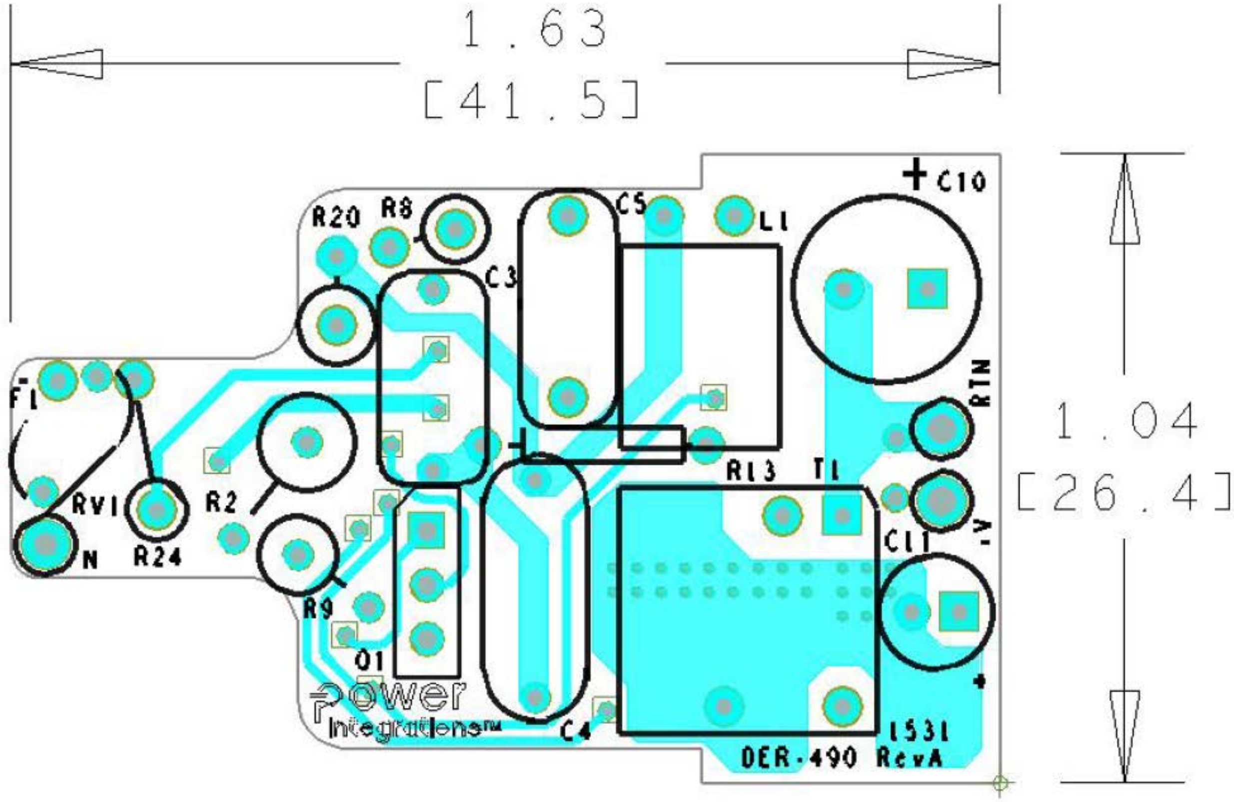

Figure 5 – Top Side.

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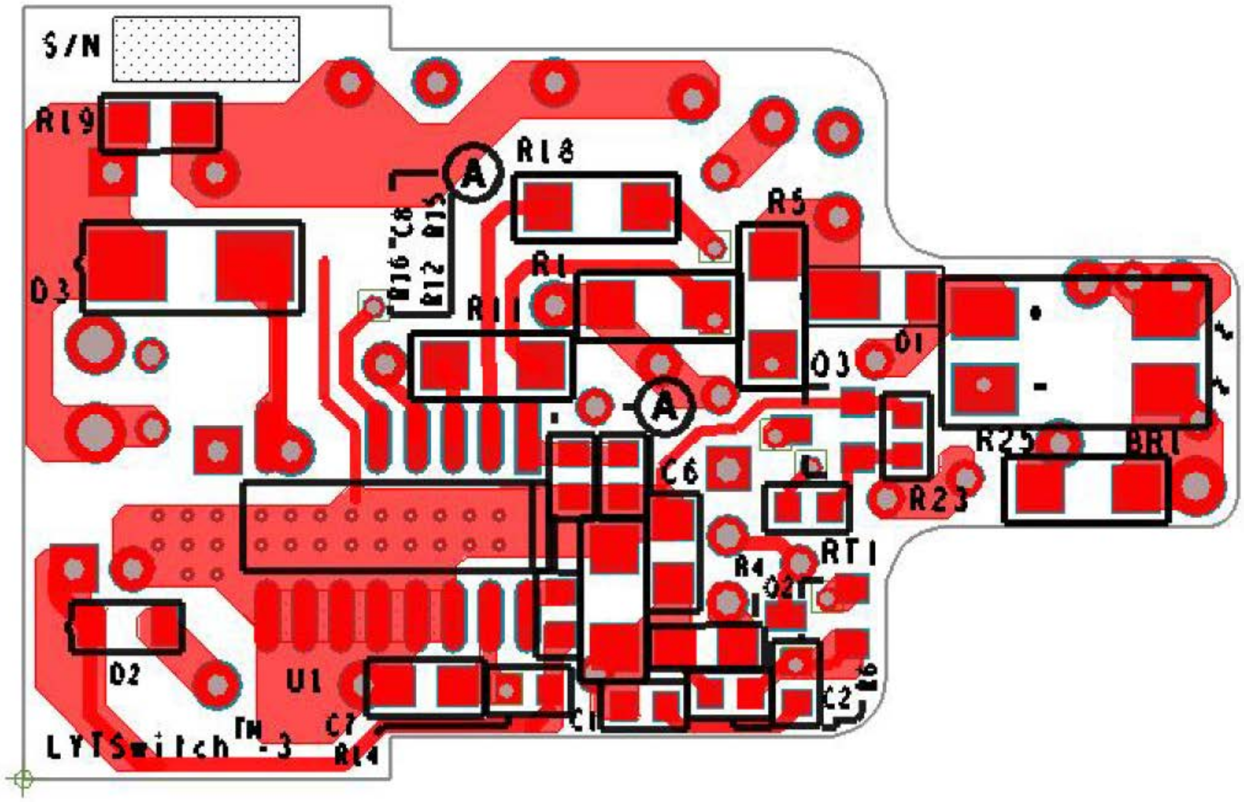

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	BR1	1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	C1	1	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
3	C2	1	4.7 nF 50 V, Ceramic, X7R, 0603	GRM188R71H472KA01D	Murata
4	C3	1	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
5	C4	1	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
6	C5	1	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
7	C6	1	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
8	C7	1	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
9	C8	1	150 nF, 25 V, Ceramic, X7R, 0603	C1608X7R1E154K080AA	TDK
10	C10	1	120 μF, 50 V, Electrolytic, Very Low ESR, 61 mΩ, (8 x 15)	EKZE500ELL121MH15D	Nippon Chemi-Con
11	C11	1	22 μF, 25 V, Electrolytic, 20 %, Gen. Purpose, (5 x 7mm)	EEA-GA1E220	Panasonic
12	D1	1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
13	D2	1	DIODE, GEN PURP, FAST RECOVERY, 300V, 225mA, SOD323	BAV3004WS-7	Diodes Inc.
14	D3	1	600 V, 1 A, Ultrafast Recovery, 45 ns, DO-214AC, SMA	STTH1R06A	ST Micro
15	F1	1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
16	L1	1	3.3 mH, 0.095 A, 20%	RL-5480-2-3300	Renco
17	Q1	1	NPN, 450 V, 1.3 A, TO-126	APT13003EU-G1	Diodes, Inc.
18	Q2	1	NPN, HP, 400 V, 225 mA, SOT23-3	FMMT458TA	Diodes, Inc.
19	R1	1	3.6 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ3R6V	Panasonic
20	R2	1	3 kΩ, 5%, 2 W, Metal Oxide (12 mm lg x 4 mm dia)	ERG-2SJ302	Panasonic
21	R4	1	20 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ200V	Panasonic
22	R5	1	200 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ204V	Panasonic
23	R6	1	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
24	R8	1	330 Ω, 5%, 1 W, Metal Oxide Film	ERG-1SJ331	Panasonic
25	R9	1	2 kΩ, 5%, 2 W, Metal Oxide	RSMF2JT2K00	Stackpole
26	R11	1	6.04 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF6041V	Panasonic
27	R12	1	4.99 Ω, 1%, 1/4 W, Thick Film, 1206	RC1206FR-074R99L	Yageo
28	R13	1	6.04 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-6K04	Yageo
29	R14	1	7.5 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ752V	Panasonic
30	R15	1	39.2 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3922V	Panasonic
31	R16	1	178 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1783V	Panasonic
32	R18	1	1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
33	R19	1	43 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ433V	Panasonic
34	R20	1	200 Ω, 5%, 2 W, Metal Oxide Film	ERG-2SJ201	Panasonic
35	R24	1	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole
36	R25	1	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
37	RV1	1	430 V, 8.6 J, 5 mm, RADIAL	S05K275	Epcos
38	T1	1	Bobbin, EE10, Vertical, 8 pins	EE-1016	Yulongxin
39	U1	1	LYTSwitch-3, SO-16C	LYT3324D	Power Integrations
Miscellaneous Parts					
1	+V	1	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
2	RTN	1	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
3	WIRE	1	Wire, UL1007, #24 AWG, Blk, PVC, 40 mm	1007-24/7-0	Anixter

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7 Inductor Specification

7.1 Electrical Diagram

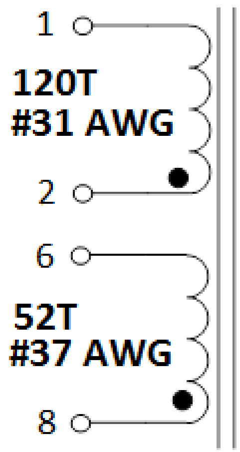

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 2, with all other windings open.	530 µH
Tolerance	Tolerance of primary inductance.	±5%
Primary Leakage Inductance	Pins 1-2, with pins 6-8 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: #31 AWG.
[4]	Magnet Wire: #37 AWG.
[5]	Transformer Tape: 7 mm.
[6]	Transformer Tape: 4 mm.

7.4 Inductor Build Diagram

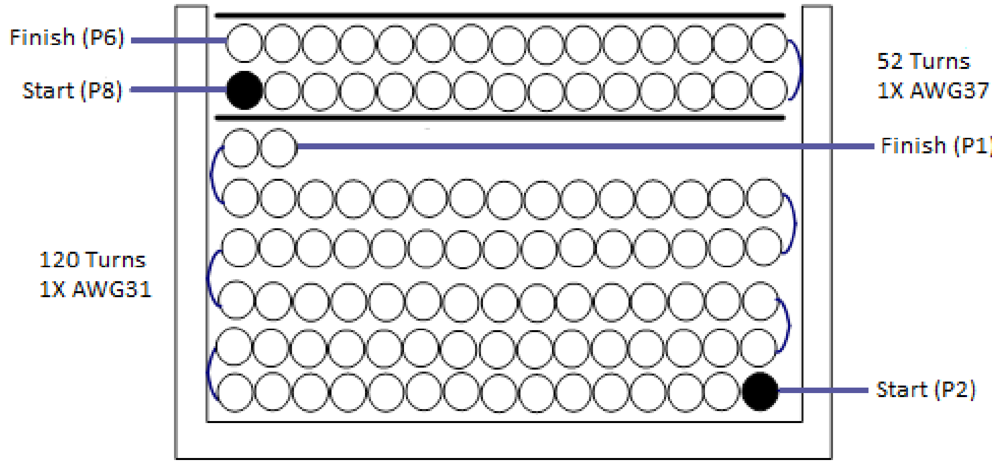

Figure 8 – Transformer Build Diagram.

7.5 Inductor Construction

Winding Directions	Bobbin is oriented on winder jig such that terminal pins are in the left side and the winding direction is counter clockwise.
Winding 1	Use wire item [3], start at pin 2 and wind 120 turns in 5 layers, then finish the winding on pin 1.
Insulation	Add 1 layer of tape, item [5], for insulation.
Winding 2	Use wire item [4], start at pin 8 and wind 52 turns from left to right, then finish the winding on pin 6.
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 530 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. 3, 4, 5, 7.
Finish	Dip the transformer assembly in varnish.

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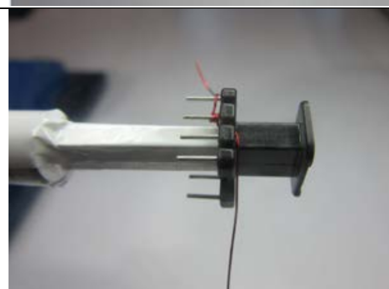
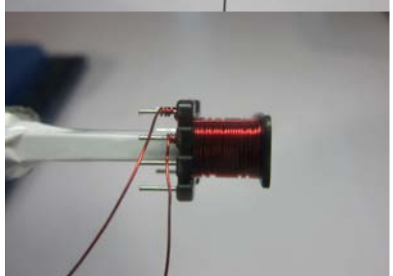
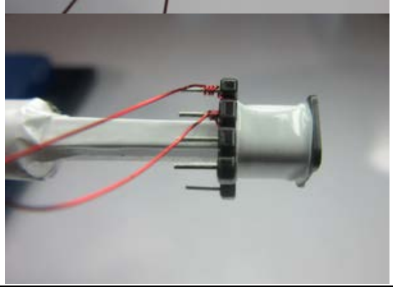
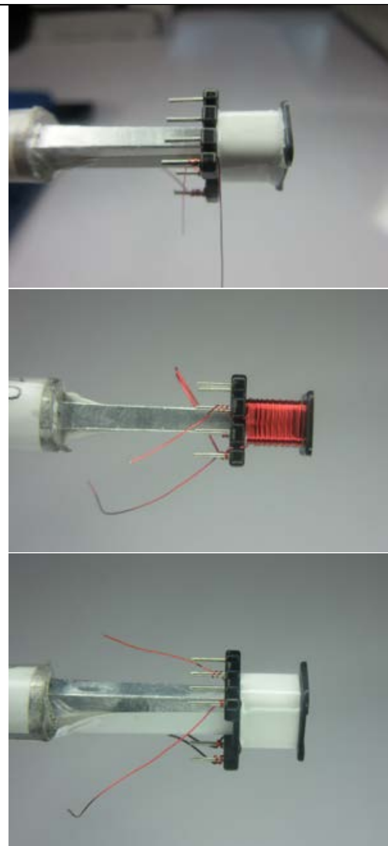
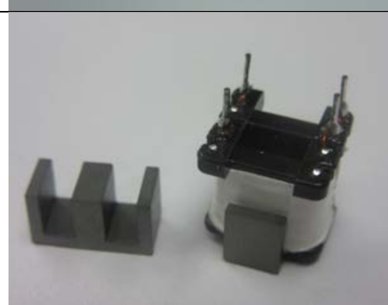
7.7 Inductor Construction Illustrations

Winding Preparation		Place item [2] bobbin on winding machine with terminal pins facing left.
WD1	  	Starting at pin 2 wind 120 turns in 5 layers of wire item [3] in counter clockwise direction. Terminate other end of the wire to pin 1. Fix with 1 layer item [5] tape.

WD2		Starting at pin 8 wind 52 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 6. Fix with 1 layer of item [5] tape.
Gap Core		Grind one core half [item1] center leg to achieve 530 μH inductance.
Final Assembly		Assemble core halves. Fix core with 2 layers of tape item [6] and remove pins 3, 4, 5 and 7. Dip the transformer assembly in varnish.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-3-Buck-Boost_040915; Rev.0.5; Copyright Power Integrations 2015	INPUT	INFO	OUTPUT	UNIT	ACDC_LYTSwitch-3-Buck- Boost_032515; LYTSwitch-3 Buck-Boost Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	195.00		195.00	V	Minimum AC Input Voltage
VACNOM	230.00		230.00	V	Typical AC Input Voltage
VACMAX	265.00		265.00	V	Maximum AC Input Voltage
FL			50.00	Hz	Minimum line frequency
VO_MIN			43.2	V	Guaranteed minimum VO that maintains output regulation
VO	48.0		48.0	V	Worst case normal operating output voltage
VO_OVP_MIN			57.2	V	Minimum Voltage at which output voltage protection may be activated
IO	145.0		145.0	mA	Average output current specification
n	0.85		0.85	%/100	Total power supply efficiency
Z			0.50		Loss allocation factor
PO			6.96	W	Total output power
VD			0.70	V	Output diode forward voltage drop
LYTSwitch-3 DESIGN VARIABLES					
Select Breakdown	725V		725V	V	Choose between 650V and 725V
Device	LYT33X4		LYT33X4		Chosen LYTSwitch-3 Device
Final device code			**LYT3324**		
Select Dimming Curve	1		**1**		Dimming curve 1
RBS2			6.04	k-ohm	RBS2 resistor to select dimming curve
ILIMITMIN			0.844	A	Minimum device current limit
ILIMITTYP			0.908	A	Typical Current Limit
ILIMITMAX			0.971	A	Maximum Current Limit
TON			1.58	us	Expected on-time of MOSFET at low line and PO
FSW			110.8	kHz	Expected switching frequency at low line and PO
Duty Cycle			17.5	%	Expected operating duty cycle at low line and PO
IRMS			0.127	A	Nominal RMS current through the switch at low line
IPK		Warning	0.981	A	The maximum current limit exceeds device ILIM_MIN during operation and may not deliver the necessary power and will adversely affect THD. Choose a larger device or reduce KDP.
KDP			1.16		Ratio between off-time of switch and reset time of core at VACNOM
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			477	uH	Minimum Inductance
LP	530		530	uH	Typical value of Primary Inductance
LP Tolerance			10	%	Tolerance of Primary Inductance
N	120.00		120	Turns	Number of Turns
ALG			37	nH/T^2	Gapped Core Effective Inductance
BM		Info	3579	Gauss	Reduce BM < 3300 G. Decrease BP (increase NP) or increase core size.
BP			3899	Gauss	Calculated Worst Case Peak Flux Density (BP < 4200 G)
BAC			1790	Gauss	Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
LG			0.413	mm	Gap Length (Lg > 0.1 mm)
Layers			4.8		Estimated number of winding layers
IL_RMS			0.378	A	Worst case RMS Current through the inductor
AWG			31	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			81	Cmils	Bare conductor effective area in circular mils
CMA			213	Cmils/A	Primary Winding Current Capacity (200 < CMA < 500)
Current Density (J)			9.36	A/mm^2	Inductor Winding Current density (3.8 < J < 9.75 A/mm^2)
Bias Section					
TURNS_BIAS			52.00	Turns	
VBIAS			20.00	V	
PIVBS			182.40	V	
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			17.48	%	Duty cycle measured at minimum input voltage
IAVG			0.06	A	Input average current measured on the Mosfet at the minimum input voltage
IP			0.75	A	Peak Drain current at minimum input voltage
ISW_RMS			0.13	A	MOSFET RMS current measured at the minimum input voltage
ID_RMS			0.10	A	RMS current of freewheeling diode at minimum input voltage
IL_RMS			0.16	A	RMS current of the of the inductor at the minimum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
n_MEASURED	0.85		0.85		Measured efficiency (this value is used for resistor calculations only)
VBIAS_MEASURED			20.00	V	Bias voltage (across the bias capacitor) measured on a prototype unit
VOUT_MEASURED			48.00	V	Load voltage measured on a prototype unit
RDS_T			5.2681	ohm	Theoretical calculation for RDS sense resistor
RDS			5.23	ohm	Rds resistor calculation assuming E96 / 1%
CDS			10.00	uF	Cds Capacitor Calculation
ROVP	178.00		178.00	k-ohm	OC pin resistor (E96 / 1%)
RL			4.02	M-ohm	L pin resistor (E96 / 1%)
RFB_T			37696.15	ohm	Calculated value of RFB, using RDS_T
RFB			37.40	k-ohm	Feedback pin resistor (E96 / 1%)

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CFB_T			159.17	nF	Feedback pin capacitor (for 6ms time constant)
CFB			150	nF	Feedback pin capacitor E12 standard value
RSUP			13.80	k-ohm	Bias supply resistor assuming 1mA current necessary to supply BP
Output Parameters					
VDRAIN			463	V	Estimated worst case drain voltage at VACMAX and VO_MAX
PIVD			475.9	V	Peak Inverse Voltage at VO_MAX on output diode
BLEEDER COMPONENTS					
I_HOLD	35.00		35.00	mA	Required bleeder holding current
RBS1			3.43	Ohm	Exact value of RBS1 resistor

Note: Actual units were tested with brown in and brown out test. Output current regulation was still okay down to 150 VAC input. THD measured always less than 30% at nominal line.

Note: Actual units were tested at 40 ºC external ambient and bulb inside enclosure at worst case line condition. No saturation seen on transformer.

9 Performance Data

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

9.1 Efficiency

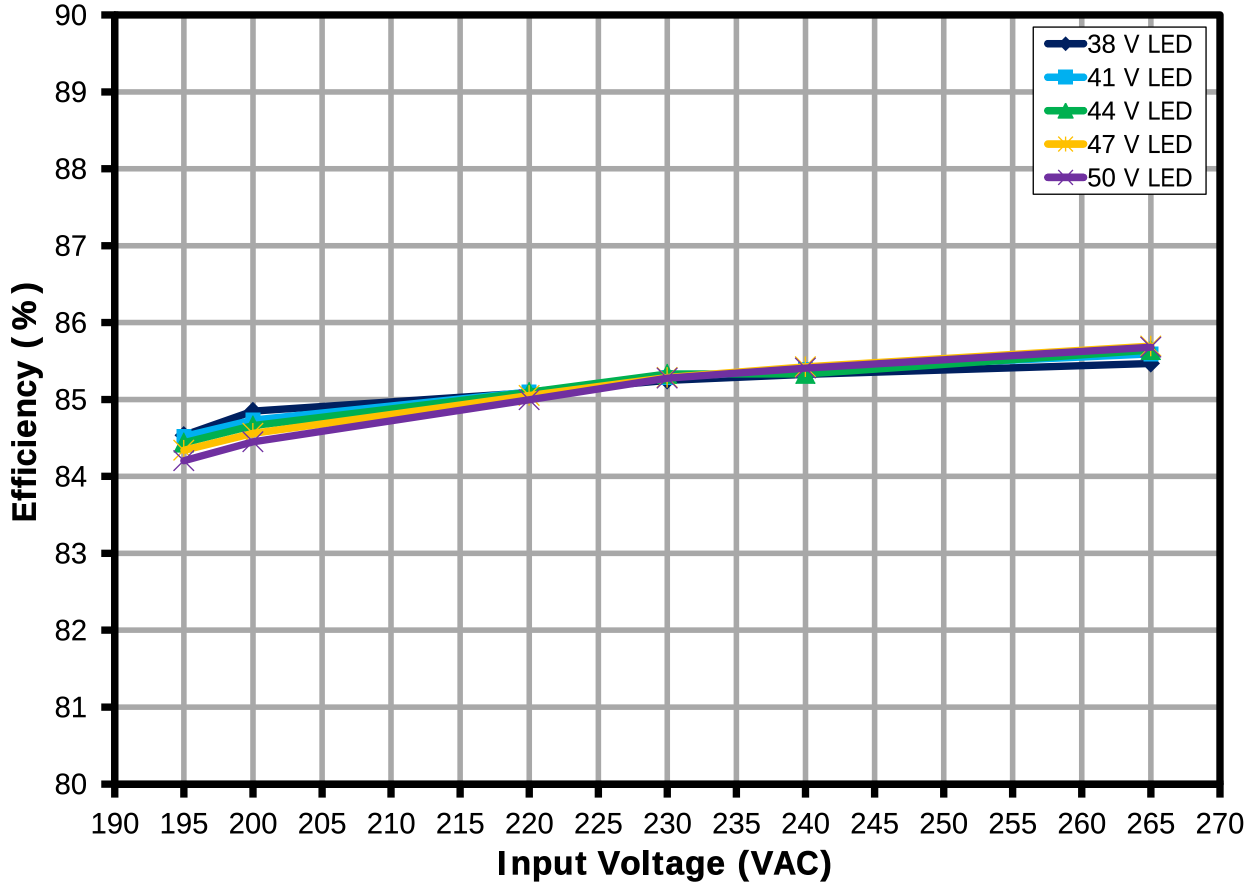

Figure 9 – Efficiency vs. Line and LED Load.

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9.2 Output Current Regulation

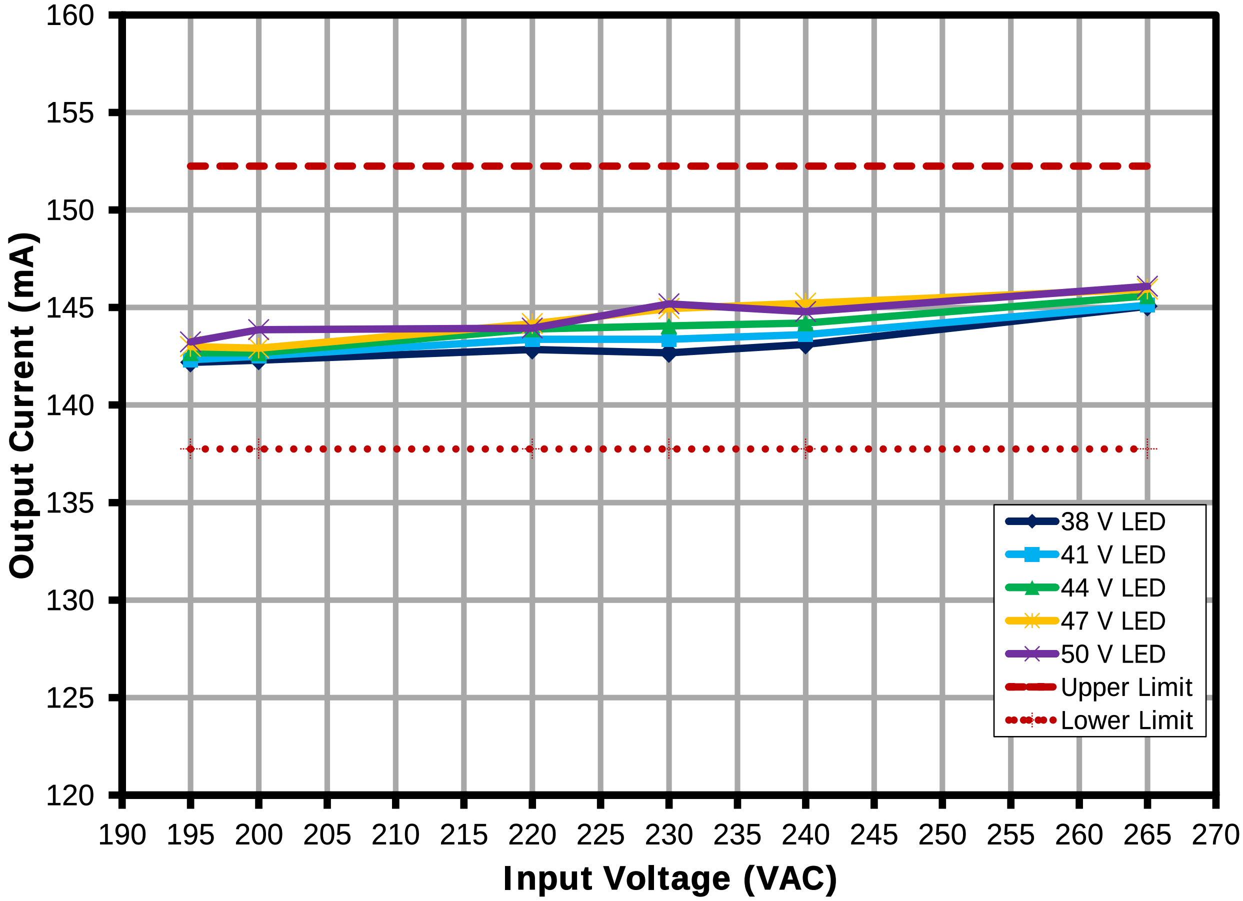

Figure 10 – Regulation vs. Line and LED Load.

9.3 Power Factor

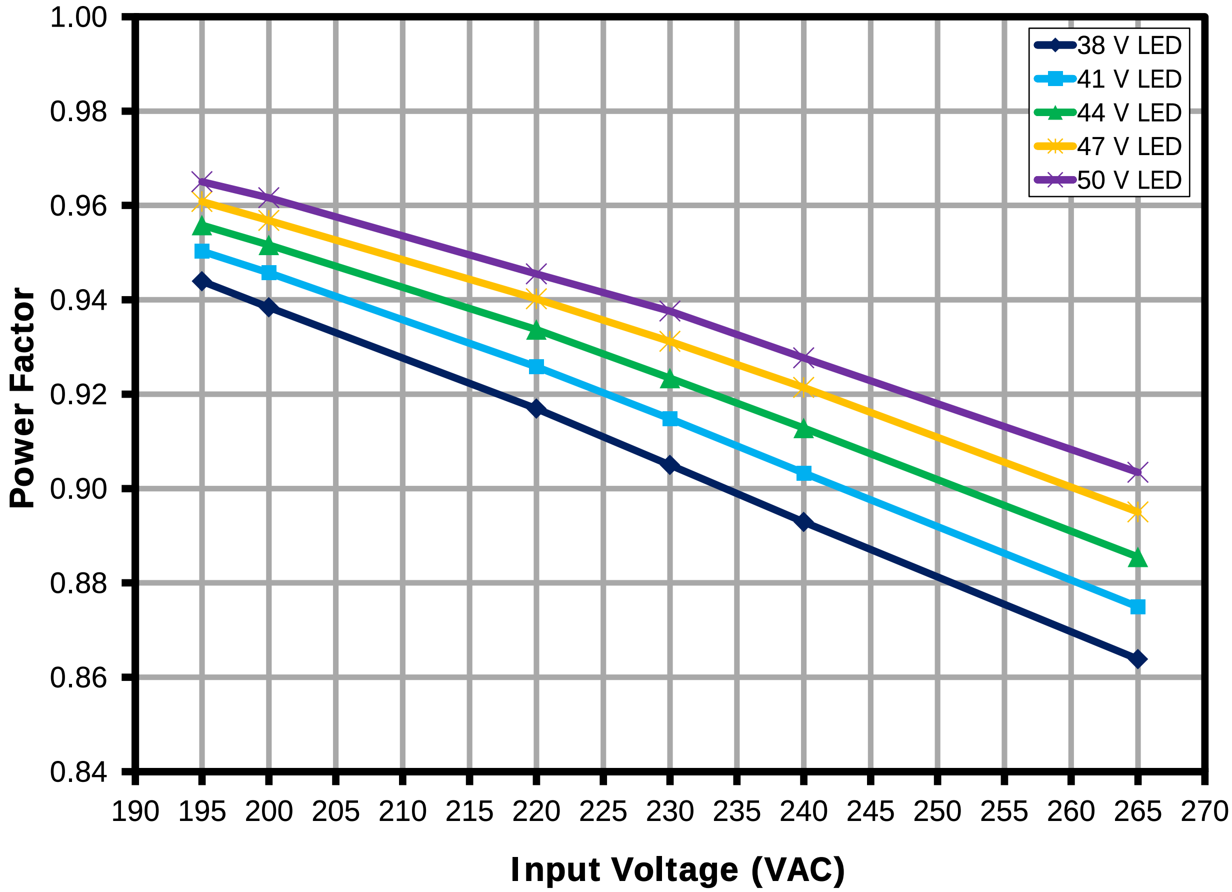

Figure 11 – Power Factor vs. Line and LED Load.

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9.4 %ATHD

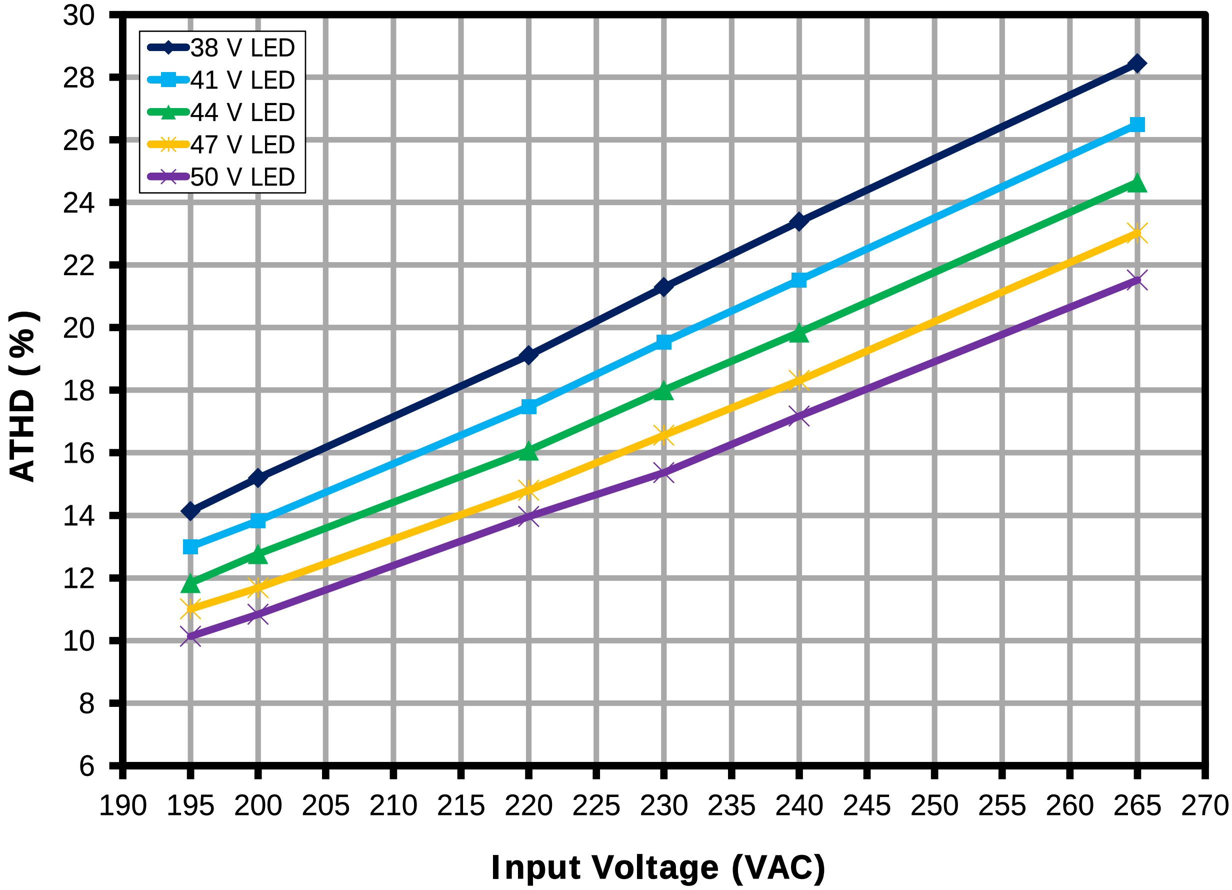

Figure 12 – %ATHD vs. Line and LED Load at 230 VAC, 50 Hz.

9.5 Harmonics

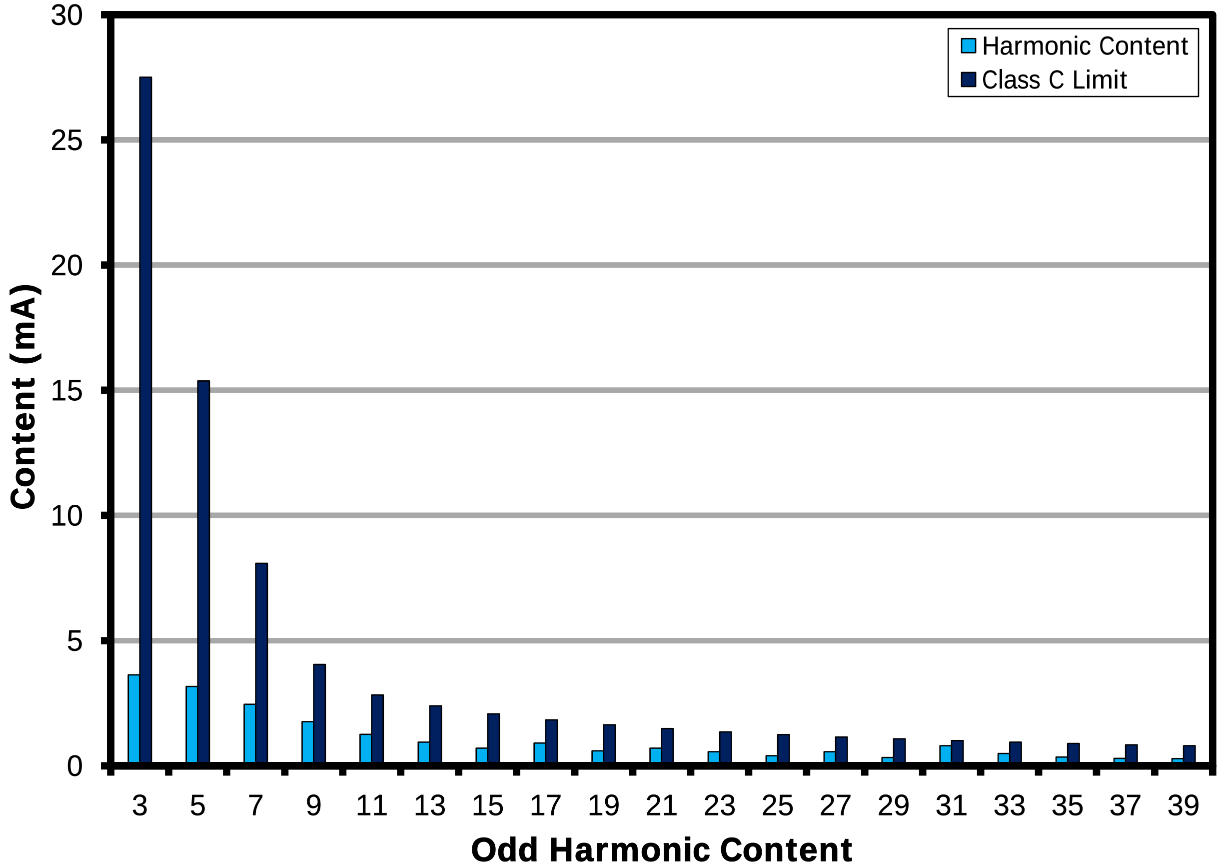

Figure 13 – 48 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10 Test Data

10.1 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)	
195	50	194.93	35.89	6.60	0.944	14.13	38.87	142.18	5.58	84.53
200	50	199.98	35.08	6.58	0.938	15.19	38.86	142.30	5.58	84.85
220	50	219.92	32.67	6.59	0.917	19.12	38.86	142.85	5.61	85.09
230	50	229.93	31.56	6.57	0.905	21.29	38.86	142.68	5.60	85.25
240	50	239.96	30.71	6.58	0.893	23.38	38.86	143.11	5.61	85.33
265	50	264.97	29.09	6.66	0.864	28.44	38.89	145.06	5.69	85.47

10.2 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)	
195	50	194.92	38.25	7.09	0.950	13.00	41.68	142.32	5.99	84.52
200	50	199.97	37.41	7.07	0.946	13.82	41.67	142.50	5.99	84.73
220	50	219.91	34.80	7.09	0.926	17.48	41.68	143.37	6.03	85.10
230	50	229.93	33.61	7.07	0.915	19.54	41.67	143.37	6.03	85.29
240	50	239.95	32.62	7.07	0.903	21.52	41.67	143.61	6.04	85.39
265	50	264.97	30.76	7.13	0.875	26.49	41.69	145.12	6.10	85.59

10.3 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)	
195	50	194.92	40.73	7.59	0.956	11.84	44.52	142.67	6.41	84.44
200	50	199.97	39.77	7.57	0.952	12.77	44.51	142.68	6.41	84.66
220	50	219.91	36.99	7.60	0.934	16.08	44.52	143.90	6.46	85.10
230	50	229.93	35.70	7.58	0.923	18.00	44.52	144.06	6.47	85.33
240	50	239.95	34.64	7.59	0.913	19.85	44.52	144.20	6.48	85.33
265	50	264.96	32.54	7.63	0.886	24.64	44.54	145.60	6.54	85.64

10.4 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)	
195	50	194.92	43.24	8.10	0.961	11.01	47.36	142.99	6.83	84.34
200	50	199.97	42.18	8.07	0.957	11.69	47.35	142.91	6.82	84.56
220	50	219.91	39.15	8.09	0.940	14.80	47.36	144.17	6.88	85.05
230	50	229.93	37.90	8.12	0.931	16.56	47.36	144.94	6.92	85.29
240	50	239.95	36.71	8.12	0.921	18.31	47.36	145.22	6.93	85.42
265	50	264.96	34.28	8.13	0.895	23.02	47.36	145.94	6.97	85.69

10.5 Test Data, 50 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)	
195	50	194.92	45.71	8.60	0.965	10.14	50.16	143.23	7.24	84.20
200	50	199.97	44.78	8.61	0.962	10.84	50.15	143.86	7.27	84.45
220	50	219.91	41.16	8.56	0.946	13.96	50.15	143.94	7.27	85.00
230	50	229.93	39.92	8.61	0.938	15.36	50.15	145.19	7.34	85.28
240	50	239.95	38.48	8.57	0.928	17.17	50.15	144.78	7.32	85.41
265	50	264.96	36.00	8.62	0.903	21.52	50.16	146.09	7.38	85.68

10.6 Test Data, Harmonic Content at 230 VAC with 48 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	37.80	8.090	0.931	16.63
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25W**	**Remarks**
1	37.22				
2	0.01	0.03%		2.00%	
3	3.63	9.76%	27.51	27.93%	Pass
5	3.17	8.51%	15.37	10.00%	Pass
7	2.46	6.60%	8.09	7.00%	Pass
9	1.77	4.75%	4.05	5.00%	Pass
11	1.25	3.37%	2.83	3.00%	Pass
13	0.94	2.54%	2.40	3.00%	Pass
15	0.70	1.88%	2.08	3.00%	Pass
17	0.91	2.45%	1.83	3.00%	Pass
19	0.60	1.61%	1.64	3.00%	Pass
21	0.70	1.89%	1.48	3.00%	Pass
23	0.56	1.52%	1.35	3.00%	Pass
25	0.40	1.07%	1.25	3.00%	Pass
27	0.56	1.50%	1.15	3.00%	Pass
29	0.33	0.88%	1.07	3.00%	Pass
31	0.80	2.16%	1.00	3.00%	Pass
33	0.49	1.32%	0.94	3.00%	Pass
35	0.35	0.94%	0.89	3.00%	Pass
37	0.30	0.79%	0.84	3.00%	Pass
39	0.29	0.77%	0.80	3.00%	Pass

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11 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 230 VAC, 50 Hz line frequency, room temperature, and a nominal 48 V LED load.

11.1 Dimming Curve

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

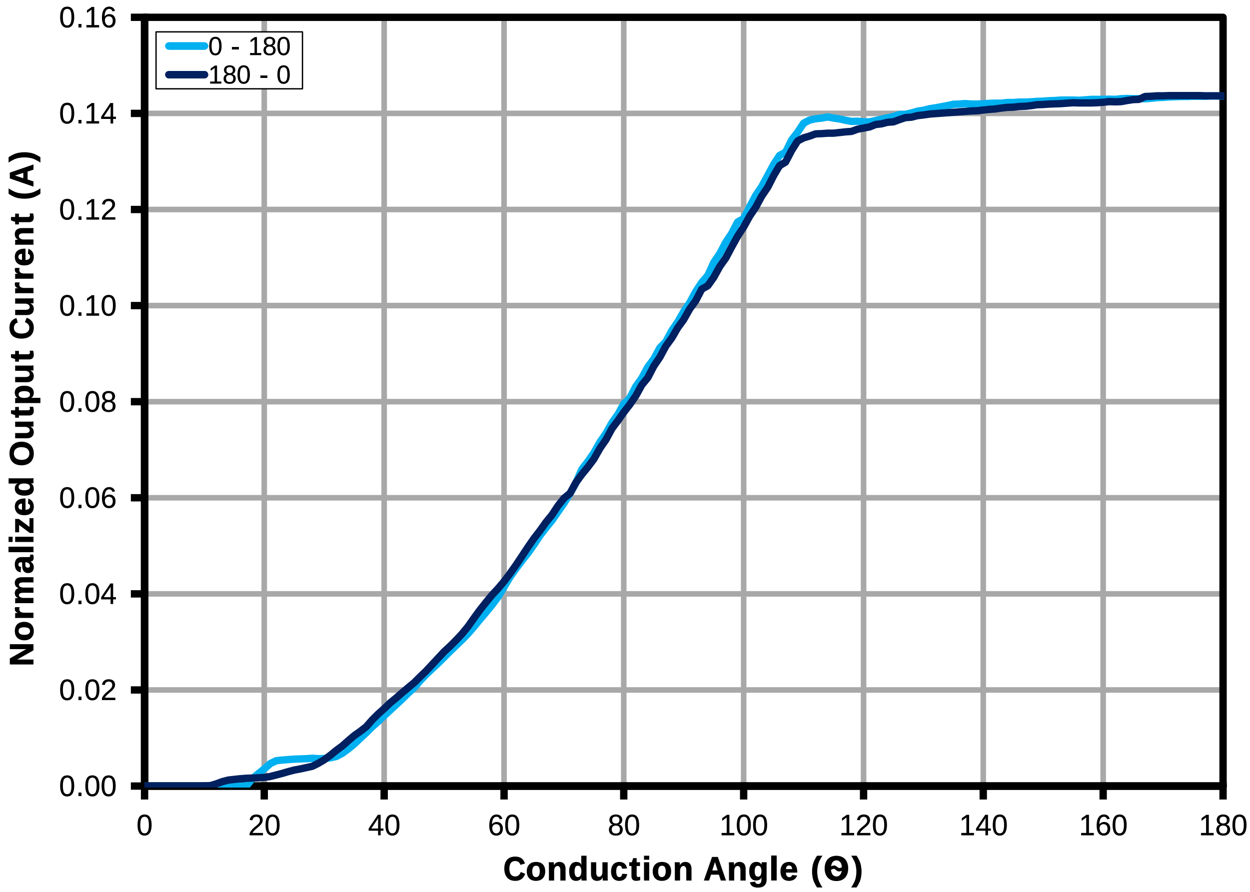

Figure 14 – Dimming Curve at 230 VAC, 50 Hz Input.

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.

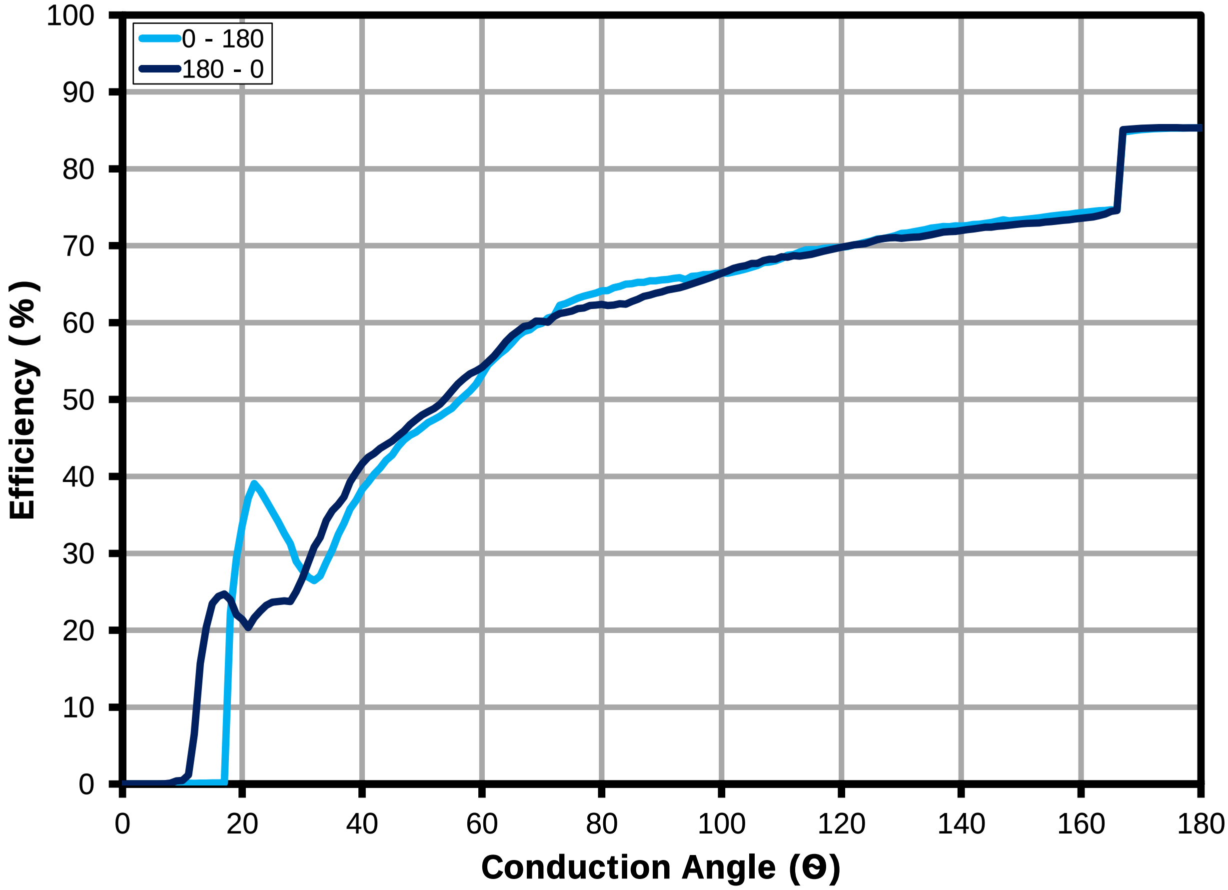

Figure 15 – Driver Efficiency at 230 VAC, 50 Hz Input.

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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.

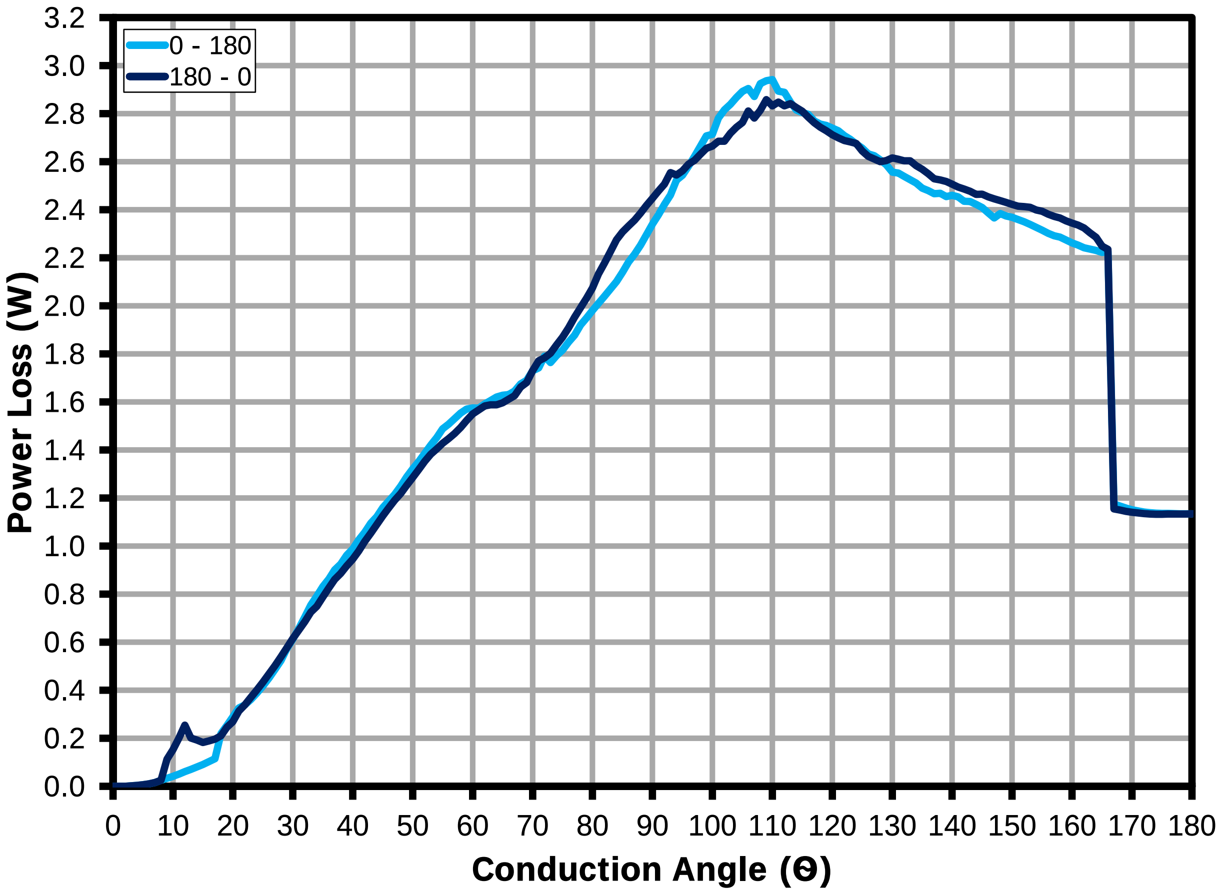

Figure 16 – Driver Power Loss at 230 VAC, 50 Hz Input.

11.4 Driver Compatibility List

The following dimmers were tested at 40 ºC external ambient temperature (inside the LED bulb casing) with utility line input (~230 VAC, 50 Hz) and 48 V LED load.

No	Panel	Brand	Model	Type	Max (mA)	Min (mA)	Pop-on (mA)	Dimming Ratio
1	EU Panel 1	BERKER	2875	L	146.13	23.558	23.112	6
2	EU Panel 1	GIRA	0307 00	T	153.81	22.303	22.771	7
3	EU Panel 1	BERKER	2830	L	145.96	22.043	22.600	7
4	EU Panel 1	GIRA	1176 00	T	150.44	33.86	32.200	4
5	EU Panel 1	GIRA	0302 00	L	145.50	23.316	22.800	6
6	EU Panel 1	GIRA	2262 00	L	145.24	9.282	9.2000	16
7	EU Panel 1	GIRA	0300 00	L	144.38	57.58	57.800	3
8	EU Panel 1	PEHA	433 HAB 0A	T	164.15	23.796	23.890	7
9	EU Panel 2	JUNG	225 TDE	T	153.60	22.529	22.000	7
10	EU Panel 2	JUNG	266 GDE	L	146.40	24.552	21.340	6
11	EU Panel 2	JUNG	225 NVDE	L	144.77	4.493	5.000	32
12	EU Panel 2	JUNG	254 UDIE 1	T	150.45	37.907	35.000	4
13	EU Panel 2	BUSCH	2247 U	L	145.34	25.483	22.340	6
14	EU Panel 2	BUSCH	2250 U	L	146.35	14.48	15.000	10
15	EU Panel3	NIKO	310-01400	L	145.20	19.10	20.100	8
16	EU Panel3	NIKO	310-01700	T	147.36	33.871	32.334	4
17	EU Panel3	LEGRAND	048871-665114	T	146.45	11.256	11.180	13
18	EU Panel3	AURORA	AUDSP400X	L	145.67	0.045	0.289	3237
19	EU Panel4	SCHNEIDER	ALB4X192	L	145.99	15.941	16.000	9
20	EU Panel4	RELCO	RTM 34LED	L	145.56	12.26	13.000	12
21	EU Panel4	IKEA	EED200LRS	L	146.8	0.009	10.581	16311
22	EU Panel4	EAGLE RISE	SED200LRS	L	147.01	0.006	7.656	24502

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12 Thermal Performance

Thermal measurements were performed with the power supply operating at 40 ºC external ambient temperatures inside bulb casing with 48 V LED load.

12.1 Non-Dimming Thermal Performance at 195 VAC with a 48 V LED Load

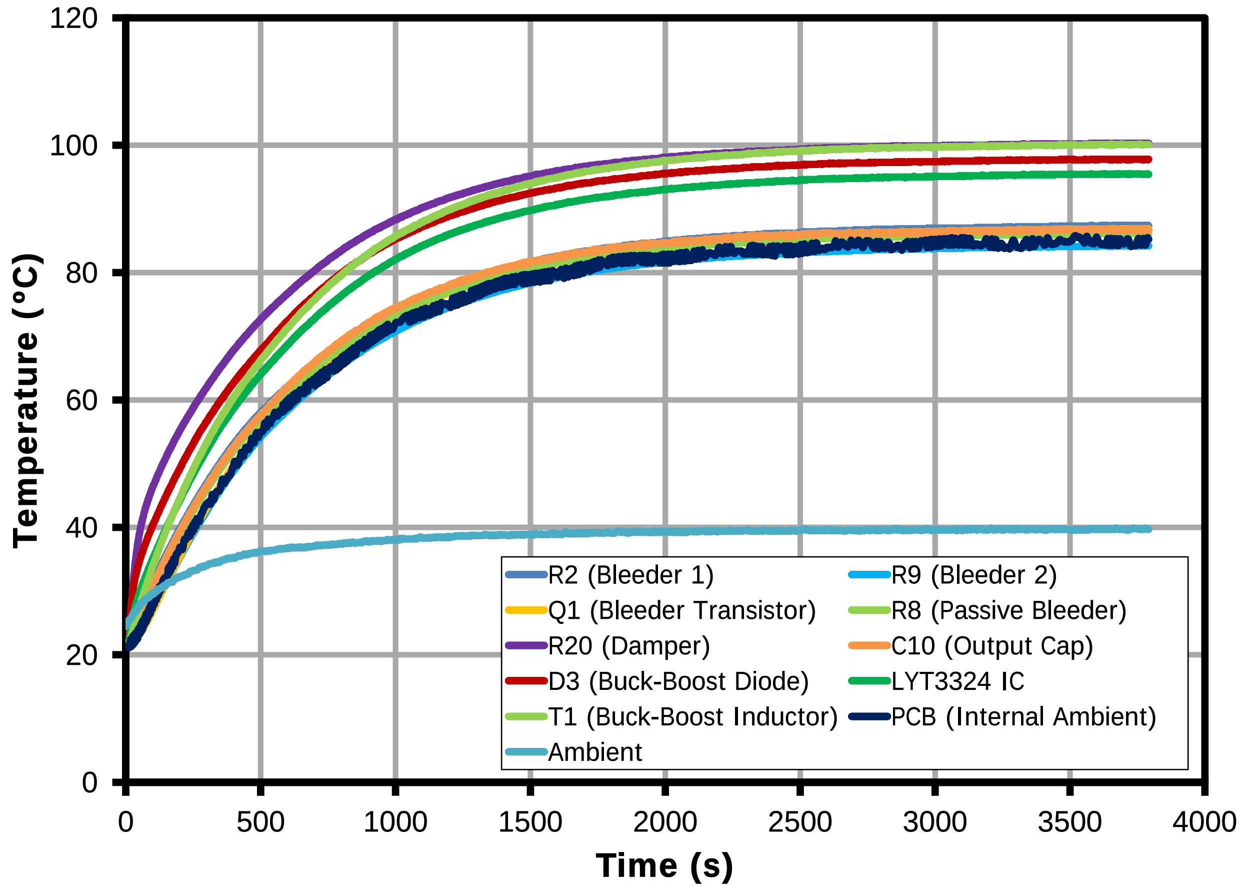

Figure 17 – Component Temperature at 195 VAC, 45 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	87.3
2	R9	BLEEDER RESISTOR	84.2
3	Q1	BLEEDER TRANSISTOR	86.8
4	R8	PASSIVE BLEEDER RESISTOR	86.1
5	R20	DAMPER RESISTOR	100.3
6	C10	OUTPUT CAPACITOR	86.6
7	D3	BUCK-BOOST DIODE	97.8
8	U1	LYT3324D IC	95.4
9	T1	BUCK-BOOST INDUCTOR	100.1
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	39.7

12.2 Non-Dimming Thermal Performance at 265 VAC with a 48 V LED Load

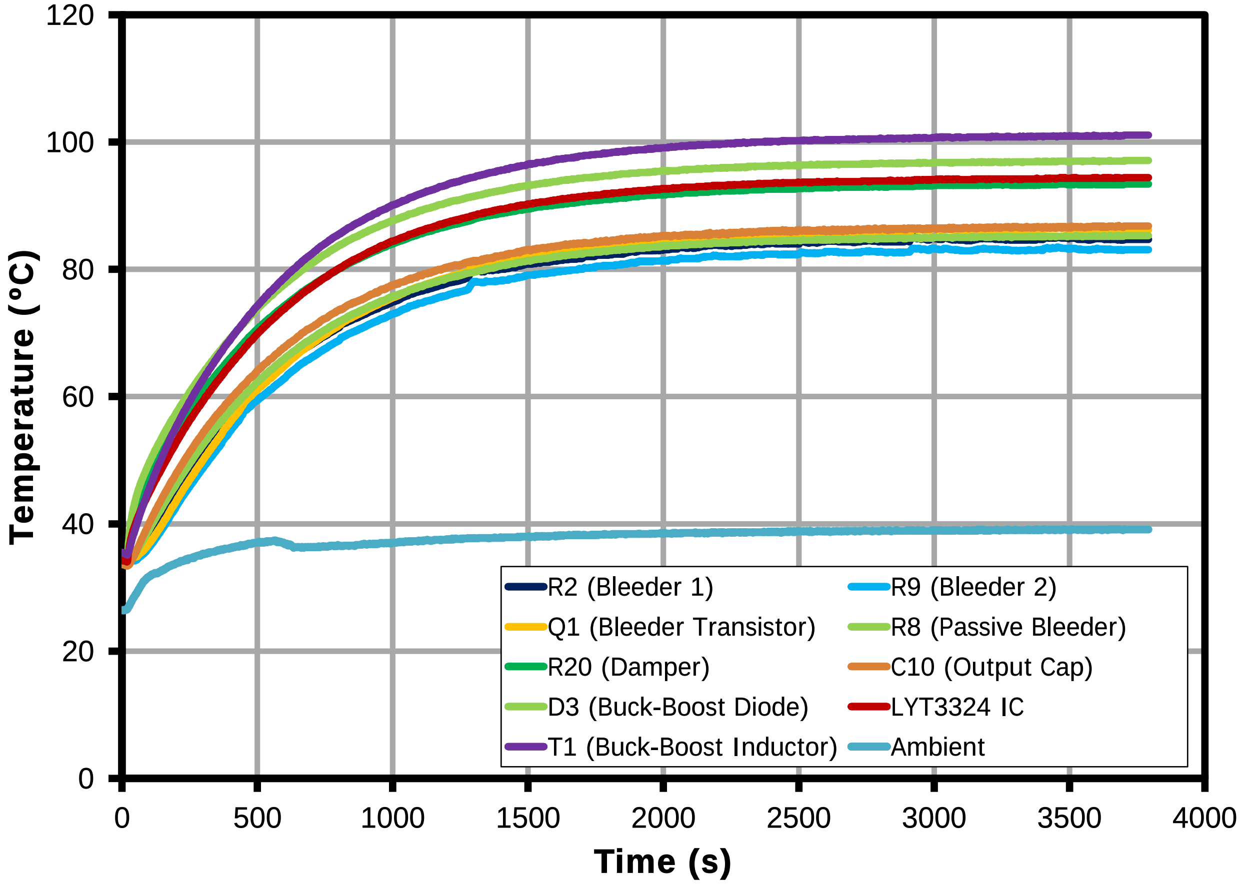

Figure 18 – Component Temperature at 265 VAC, 75 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	84.7
2	R9	BLEEDER RESISTOR	83.1
3	Q1	BLEEDER TRANSISTOR	86.2
4	R8	PASSIVE BLEEDER RESISTOR	85.3
5	R20	DAMPER RESISTOR	93.4
6	C10	OUTPUT CAPACITOR	86.8
7	D3	BUCK-BOOST DIODE	97.1
8	U1	LYT3324D IC	94.4
9	T1	BUCK-BOOST INDUCTOR	101.1
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	39.1

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12.3 Dimming Thermal Performance at 230 VAC, 100º Conduction Angle

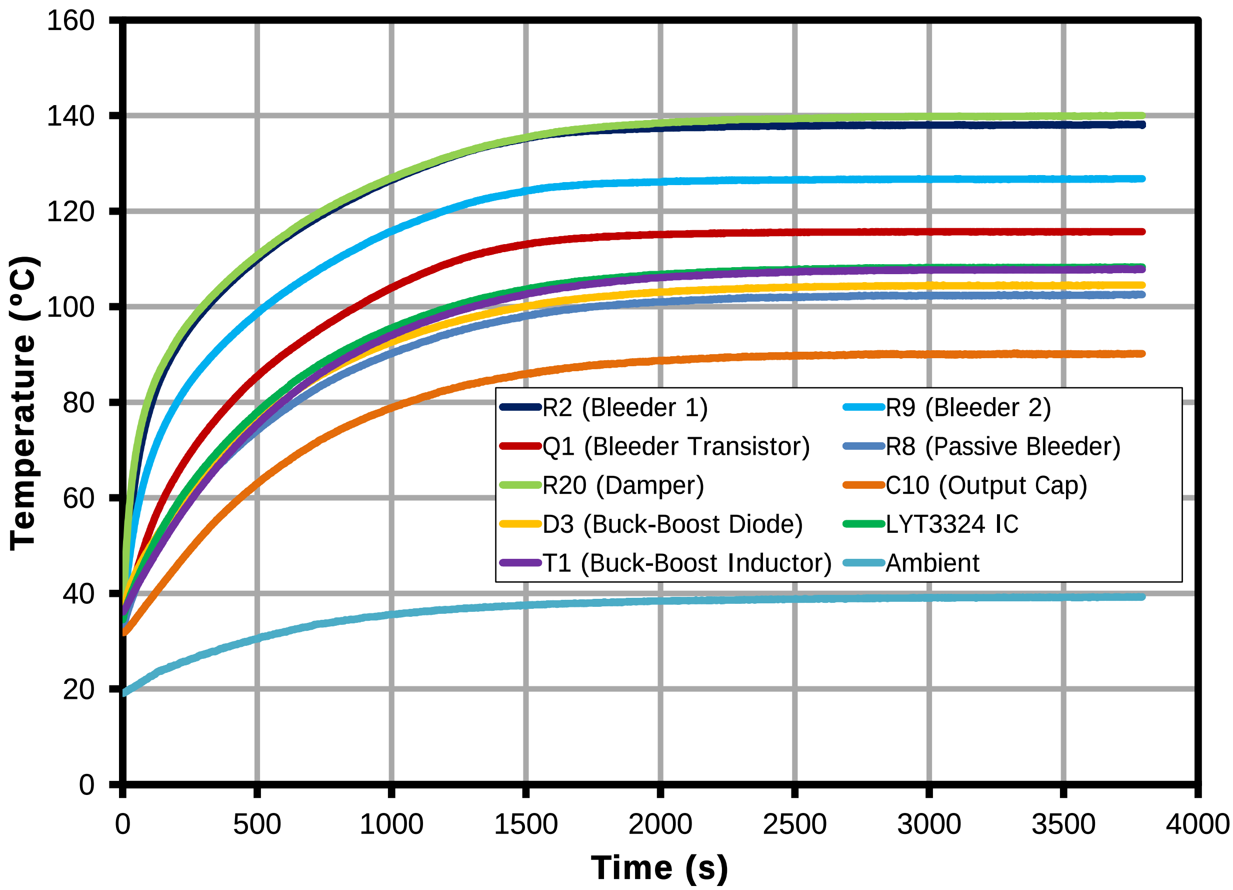

Figure 19 – Component Temperature at 230 VAC, 100º Conduction Angle, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	138.1
2	R9	BLEEDER RESISTOR	126.7
3	Q1	BLEEDER TRANSISTOR	115.6
4	R8	PASSIVE BLEEDER RESISTOR	102.4
5	R20	DAMPER RESISTOR	140.0
6	C10	OUTPUT CAPACITOR	90.0
7	D3	BUCK-BOOST DIODE	104.2
8	U1	LYT3324D IC	108.1
9	T1	BUCK-BOOST INDUCTOR	107.7
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	39.4

12.4 Dimming Thermal Performance at 230 VAC, 110º Conduction Angle

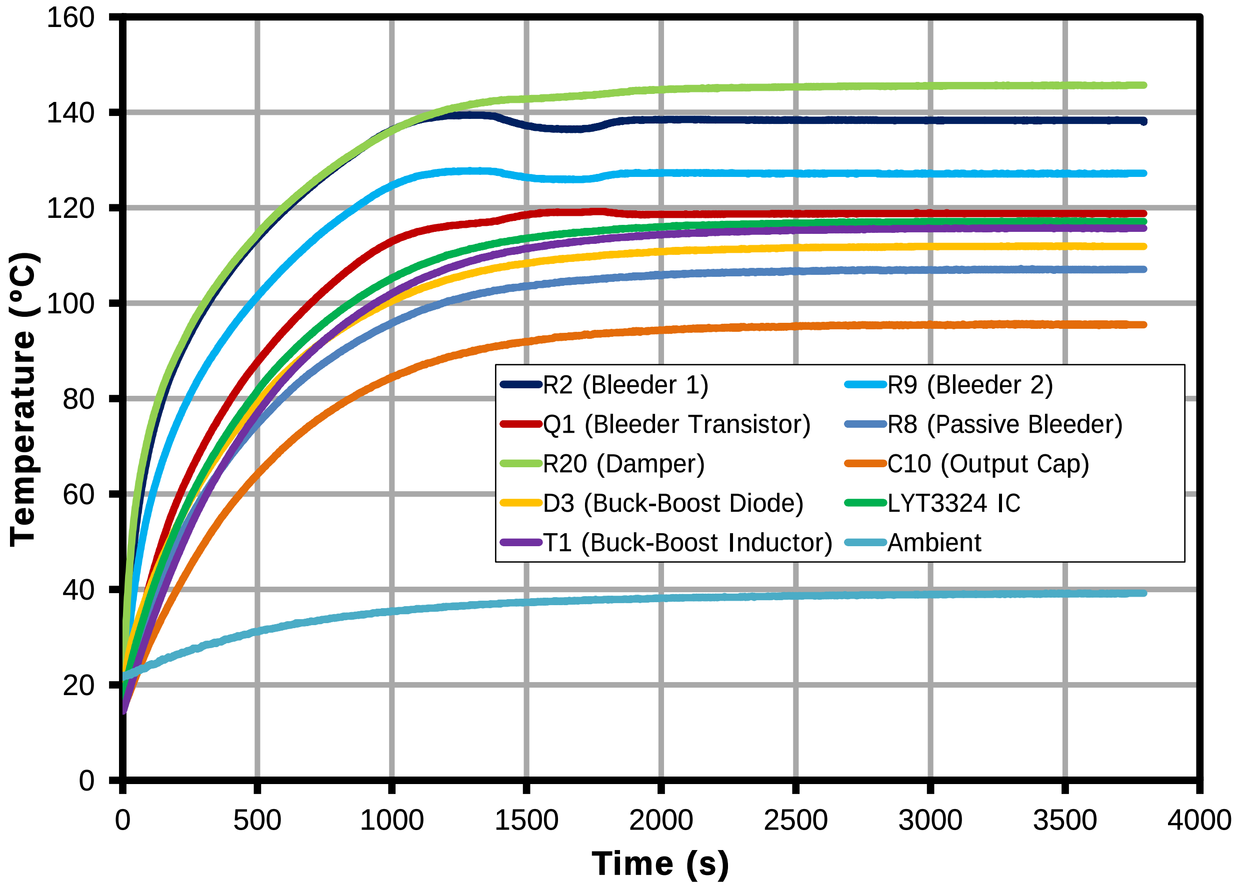

Figure 20 – Component Temperature at 230 VAC, 110º Conduction Angle, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	138.3
2	R9	BLEEDER RESISTOR	127.2
3	Q1	BLEEDER TRANSISTOR	118.8
4	R8	PASSIVE BLEEDER RESISTOR	107.1
5	R20	DAMPER RESISTOR	145.7
6	C10	OUTPUT CAPACITOR	95.5
7	D3	BUCK-BOOST DIODE	111.9
8	U1	LYT3324D IC	117.1
9	T1	BUCK-BOOST INDUCTOR	115.7
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	39.2

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12.5 Dimming Thermal Performance at 230 VAC, 120º Conduction Angle

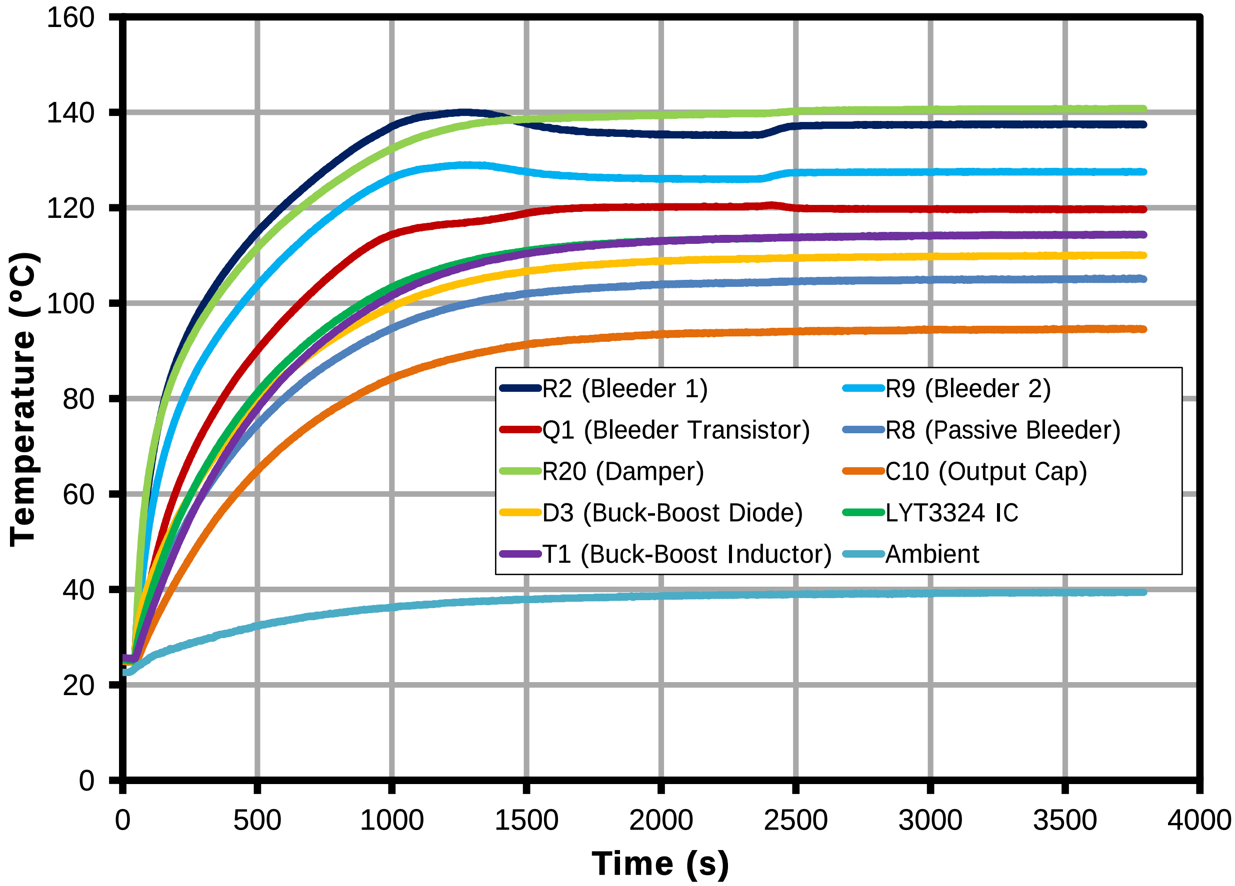

Figure 21 – Component Temperature at 230 VAC, 120º Conduction Angle, 40 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	137.5
2	R9	BLEEDER RESISTOR	127.5
3	Q1	BLEEDER TRANSISTOR	119.6
4	R8	PASSIVE BLEEDER RESISTOR	105.1
5	R20	DAMPER RESISTOR	140.8
6	C10	OUTPUT CAPACITOR	94.6
7	D3	BUCK-BOOST DIODE	110.0
8	U1	LYT3324D IC	114.3
9	T1	BUCK-BOOST INDUCTOR	114.4
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	39.4

13 Waveforms

13.1 Input Voltage and Input Current Waveforms

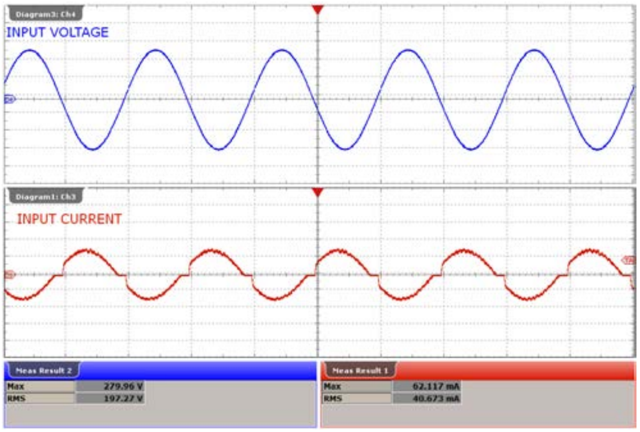

Figure 22 – 195 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 62 mA_{PK}.
Peak V_{IN}: 280 V_{PK}.

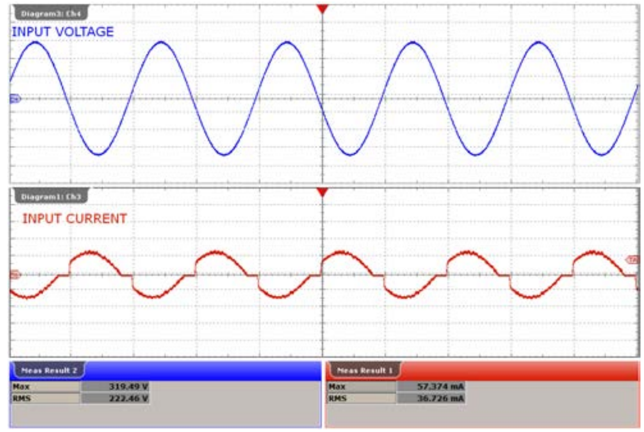

Figure 23 – 220 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 57 mA_{PK}.
Peak V_{IN}: 319 V_{PK}.

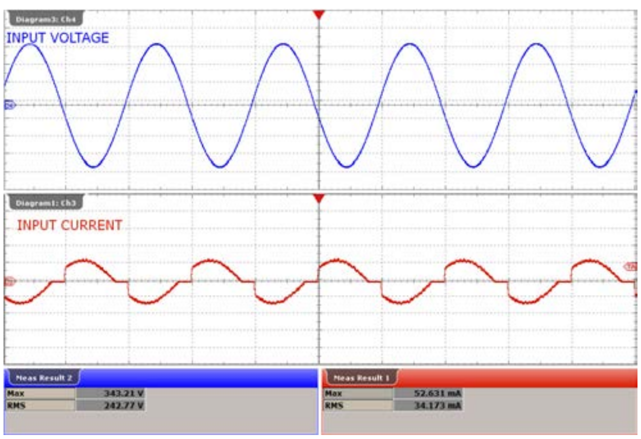

Figure 24 – 240 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 53 mA_{PK}.
Peak V_{IN}: 343 V_{PK}.

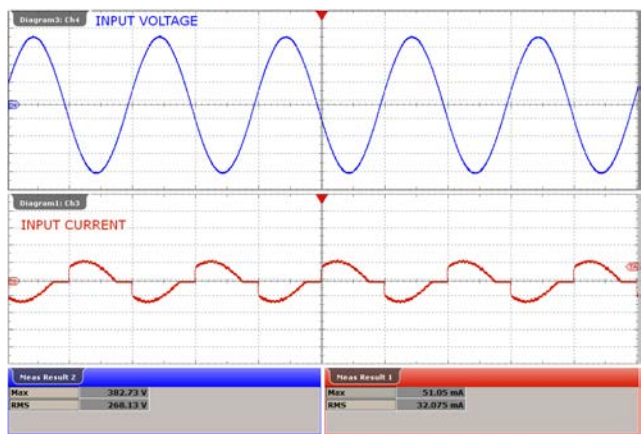

Figure 25 – 265 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 51 mA_{PK}.
Peak V_{IN}: 382 V_{PK}.

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13.2 Output Current Rise and Fall

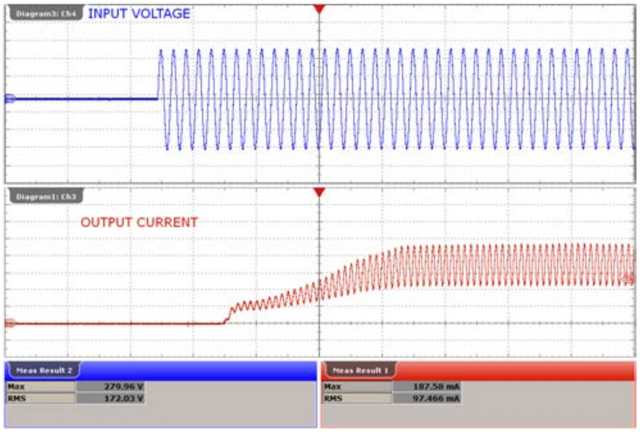

Figure 26 – 195 VAC, 48 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 189 mA_{PK}.
Peak V_{IN}: 280 V_{PK}.

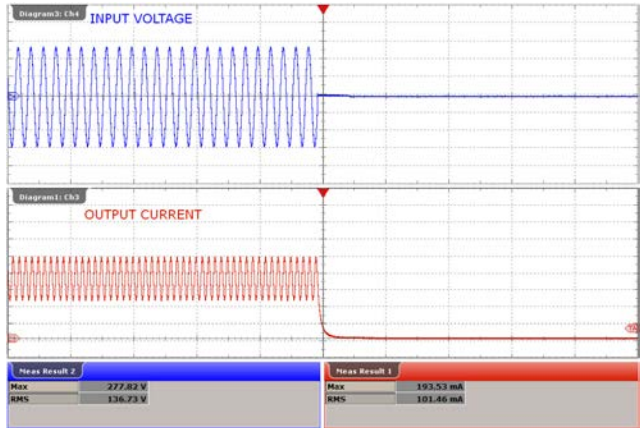

Figure 27 – 195 VAC, 48 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 193 mA_{PK}.
Peak V_{IN}: 277 V_{PK}.

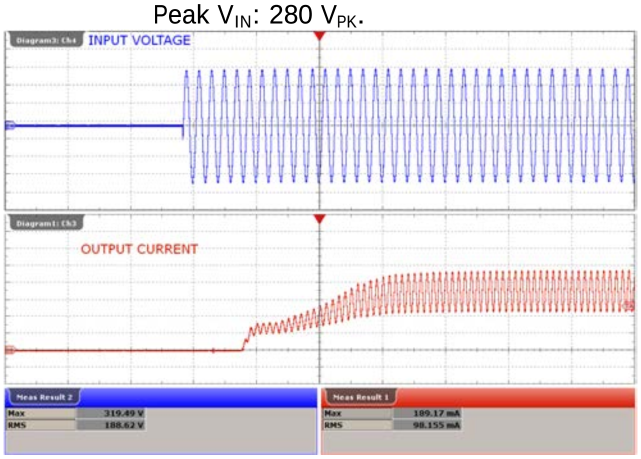

Figure 28 – 220 VAC, 48 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 189 mA_{PK}.
Peak V_{IN}: 319 V_{PK}.

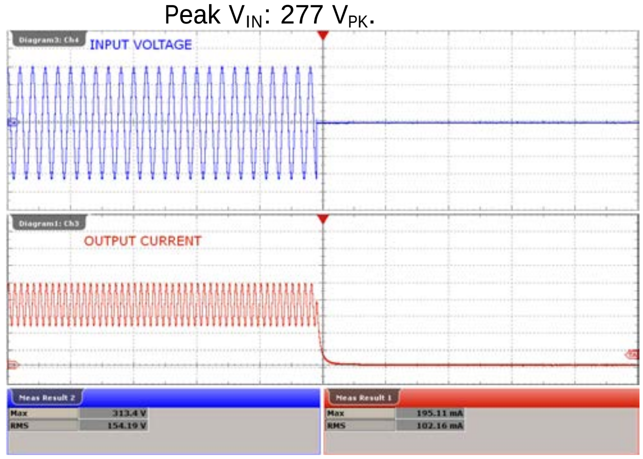

Figure 29 – 220 VAC, 48 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 195 mA_{PK}.
Peak V_{IN}: 313 V_{PK}.

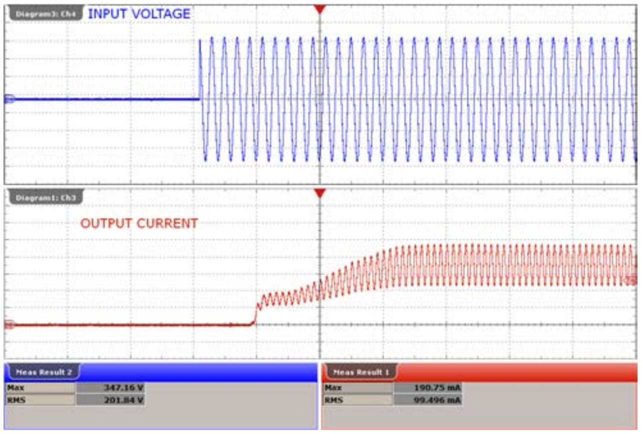

Figure 30 – 240 VAC, 48 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 191 mA_{PK}.
Peak V_{IN}: 347 V_{PK}.

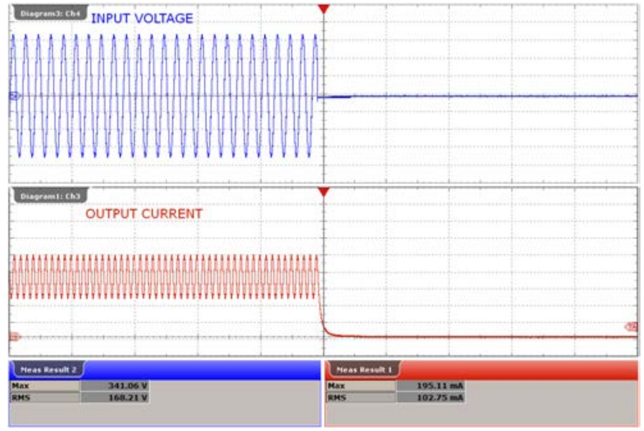

Figure 31 – 240 VAC, 48 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 195 mA_{PK}.
Peak V_{IN}: 341 V_{PK}.

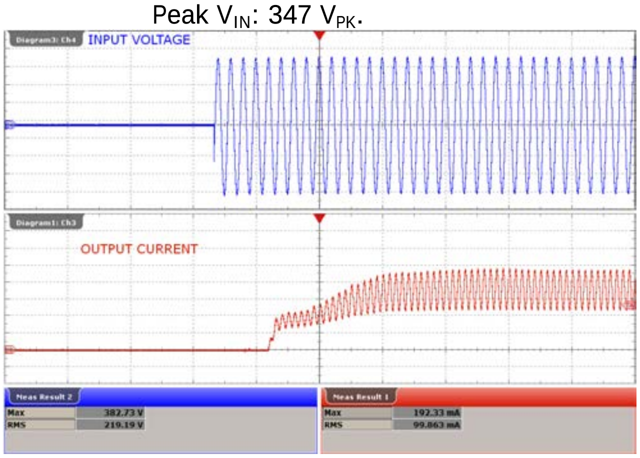

Figure 32 – 265 VAC, 48 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 192 mA_{PK}.
Peak V_{IN}: 383 V_{PK}.

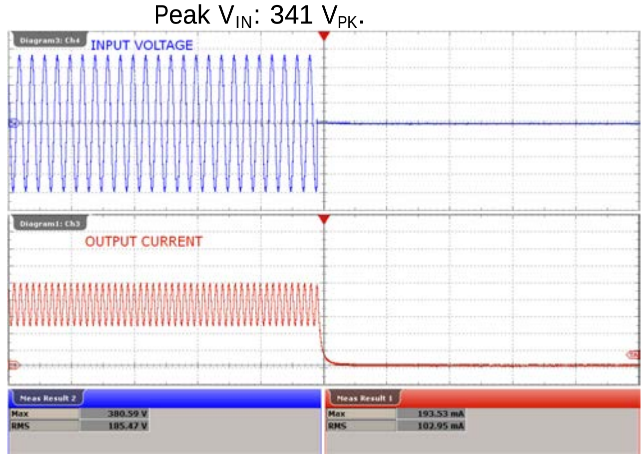

Figure 33 – 265 VAC, 48 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 193 mA_{PK}.
Peak V_{IN}: 381 V_{PK}.

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13.3 Drain Voltage and Current in Normal Operation

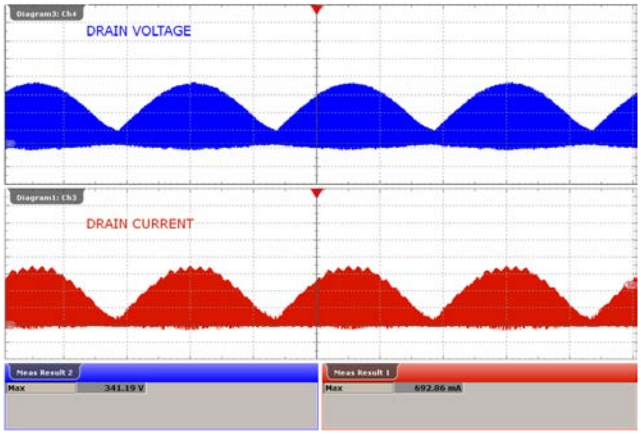

Figure 34 – 195 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 693 mA_{PK}.
Peak V_{DRAIN}: 341 V_{PK}.

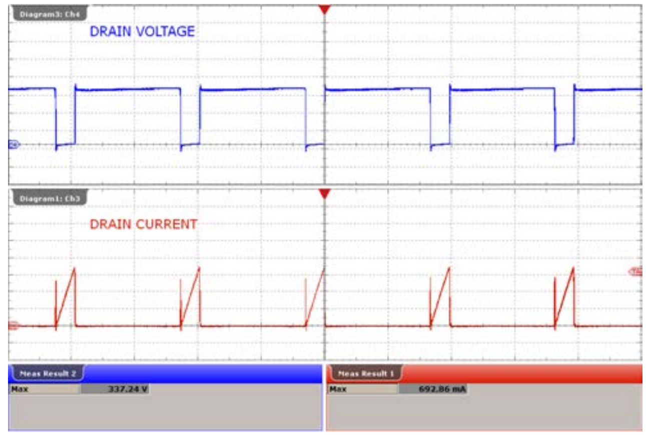

Figure 35 – 195 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 693 mA_{PK}.
Peak V_{DRAIN}: 337 V_{PK}.

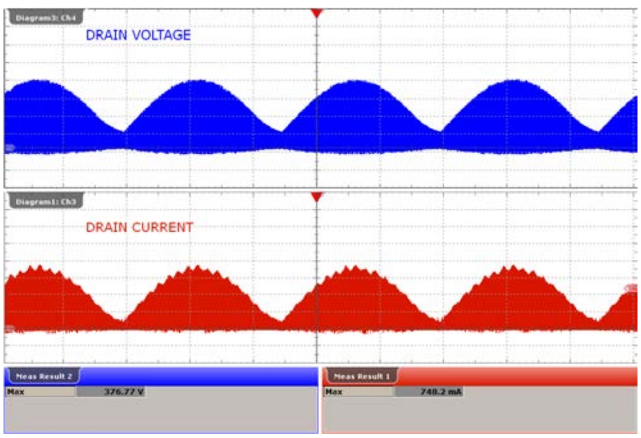

Figure 36 – 220 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 748 mA_{PK}.
Peak V_{DRAIN}: 376 V_{PK}.

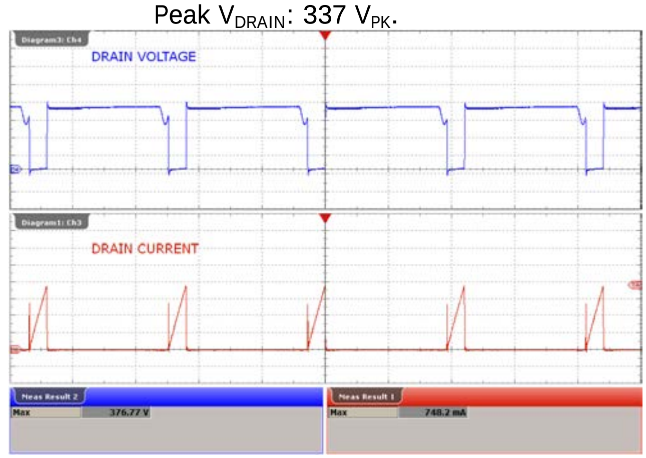

Figure 37 – 220 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 748 mA_{PK}.
Peak V_{DRAIN}: 376 V_{PK}.

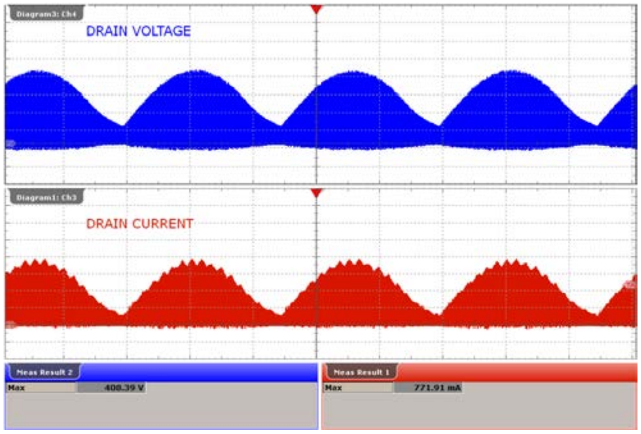

Figure 38 – 240 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 771 mA_{PK}.
Peak V_{DRAIN}: 408 V_{PK}.

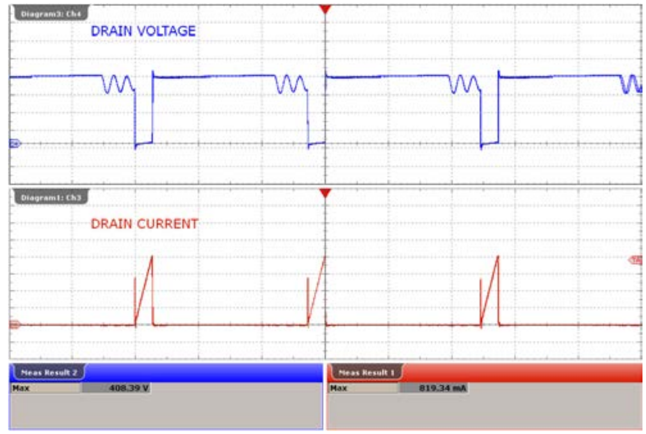

Figure 39 – 240 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 819 mA_{PK}.
Peak V_{DRAIN}: 408 V_{PK}.

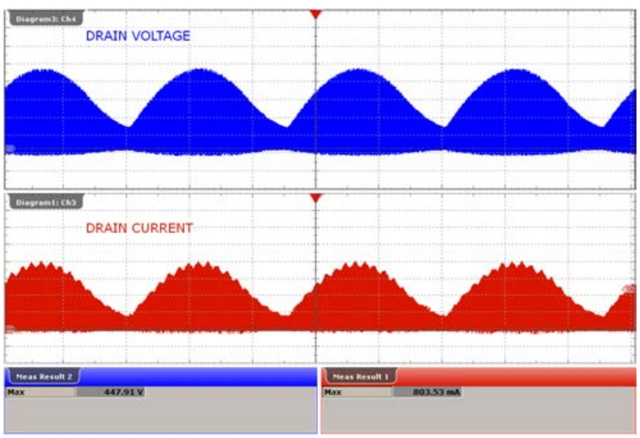

Figure 40 – 265 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 803 A_{PK}.
Peak V_{DRAIN}: 448 V_{PK}.

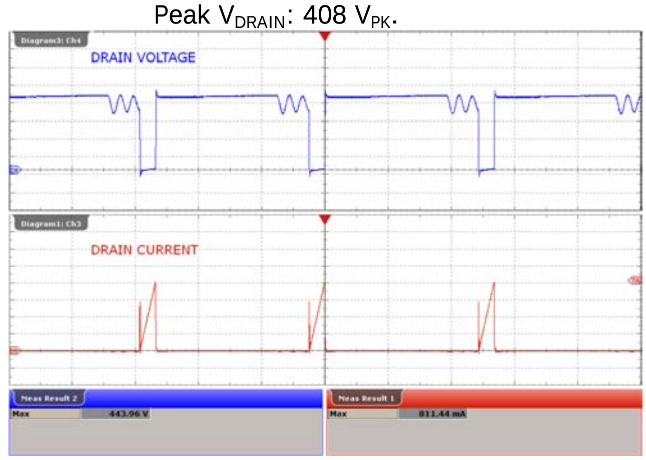

Figure 41 – 265 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 811 A_{PK}.
Peak V_{DRAIN}: 444 V_{PK}.

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13.4 Drain Voltage and Current Start-up Profile

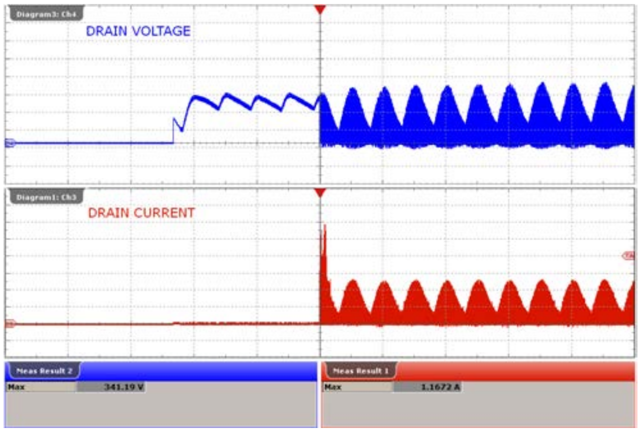

Figure 42 – 195 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 20 ms /div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.18 A_{PK}.
Peak V_{DRAIN}: 342 V_{PK}.

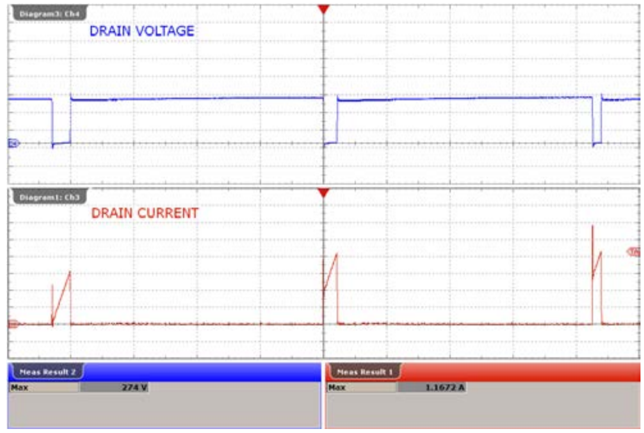

Figure 43 – 195 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs /div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.18 A_{PK}.
Peak V_{DRAIN}: 274 V_{PK}.

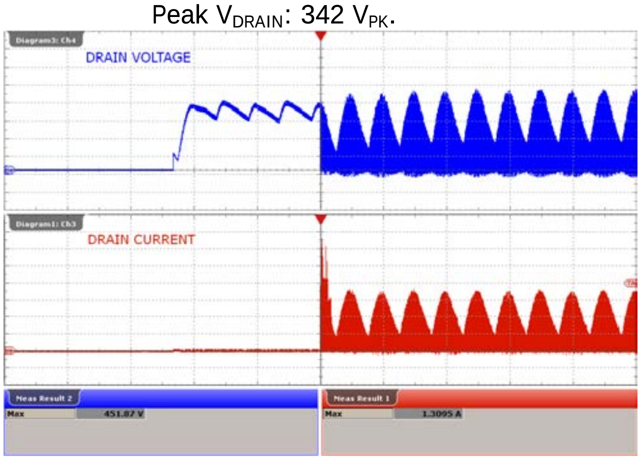

Figure 44 – 265 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 20 ms /div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.31 A_{PK}.
Peak V_{DRAIN}: 452 V_{PK}.

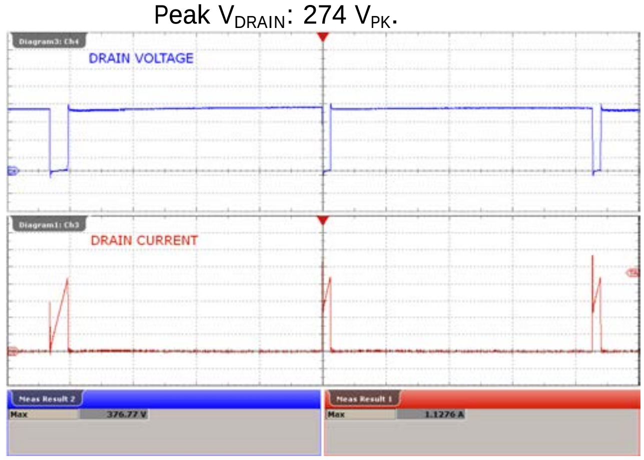

Figure 45 – 265 VAC, 48 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs /div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.13 A_{PK}.
Peak V_{DRAIN}: 376 V_{PK}.

13.5 Drain Voltage and Current during Output Short-Circuit Condition

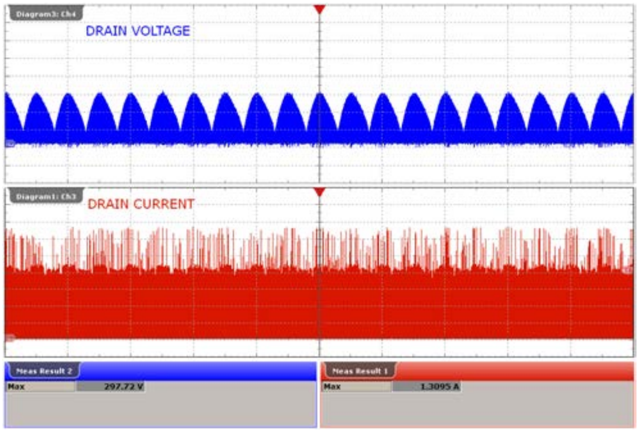

Figure 46 – 195 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 10 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.31 A_{PK}.
Peak V_{DRAIN}: 297 V_{PK}.

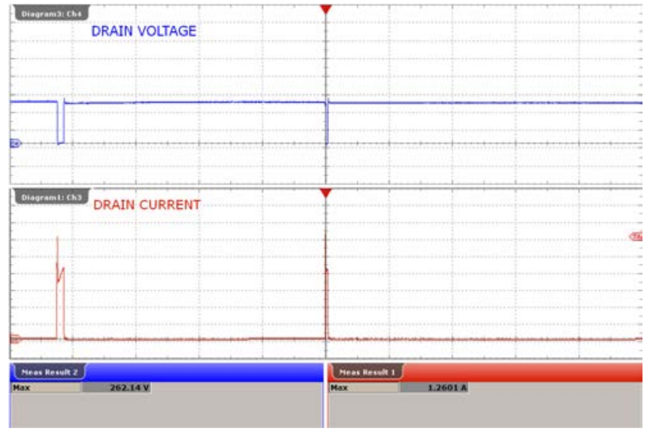

Figure 47 – 195 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 1 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.26 A_{PK}.
Peak V_{DRAIN}: 262 V_{PK}.

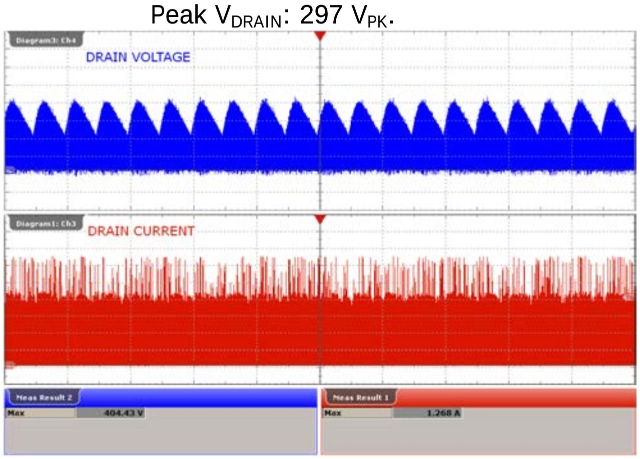

Figure 48 – 265 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 10 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.27 A_{PK}.
Peak V_{DRAIN}: 401 V_{PK}.

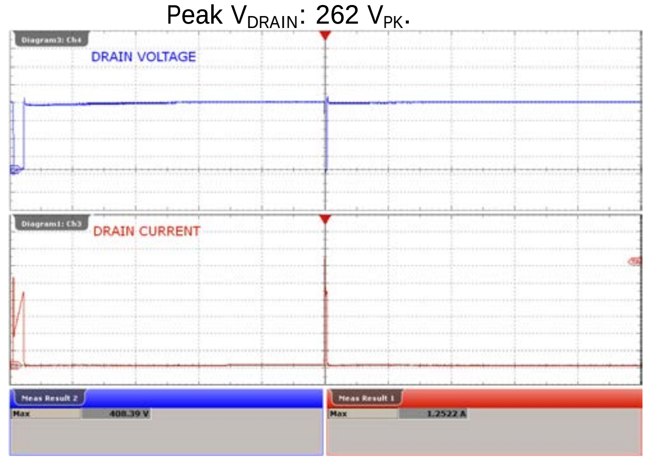

Figure 49 – 265 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 1 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.25 A_{PK}.
Peak V_{DRAIN}: 408 V_{PK}.

Input		**Input Measurement During Output Short**		
VAC (V_{RMS})	**Freq (Hz)**	**V_{IN} (V_{RMS})**	**I_{IN} (mA_{RMS})**	**P_{IN} (W)**
195	50	194.94	12.12	1.73
220	50	219.92	10.20	1.78
240	50	239.97	9.38	1.85
265	50	264.98	8.56	1.92

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13.6 Output Diode Voltage and Current in Normal Operation

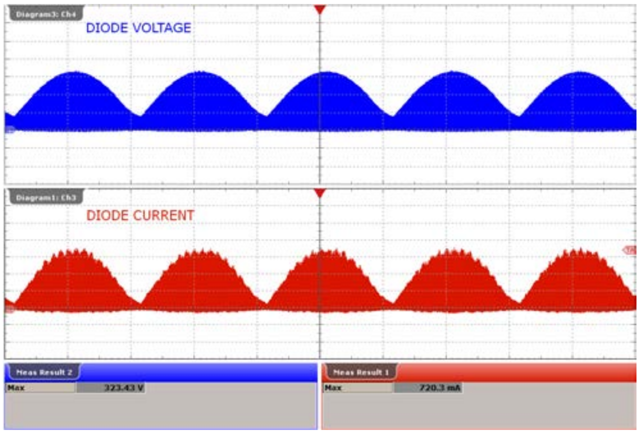

Figure 50 – 195 VAC, 48 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 720 mA_{PK}.
Peak V_{D3}: 323 V_{PK}.

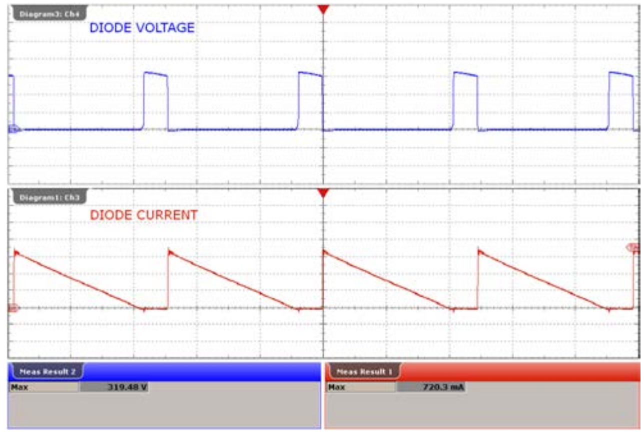

Figure 51 – 195 VAC, 48 V LED Load.
Upper: V_{D3}, 100 V / div., 4 μs / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 720 mA_{PK}.
Peak V_{D3}: 319 V_{PK}.

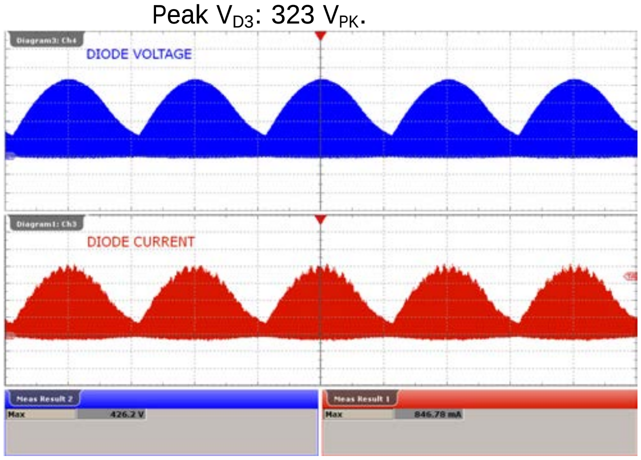

Figure 52 – 265 VAC, 48 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 847 mA_{PK}.
Peak V_{D3}: 426 V_{PK}.

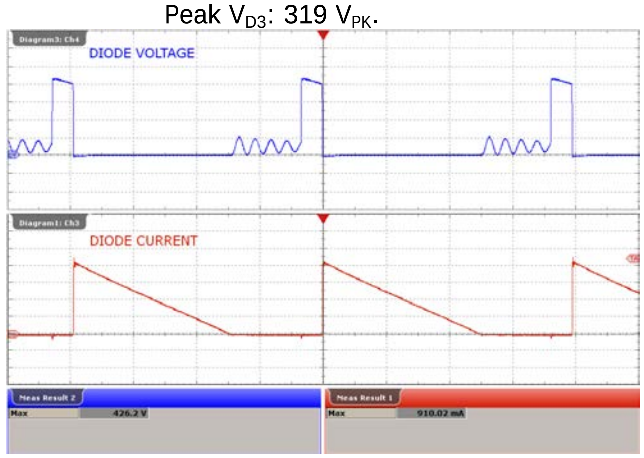

Figure 53 – 265 VAC, 48 V LED Load.
Upper: I_{DRAIN}, 100 V / div., 4 μs / div.
Lower: V_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 910 mA_{PK}.
Peak V_{DRAIN}: 426 V_{PK}.

13.7 Output Voltage and Current – Open LED Load

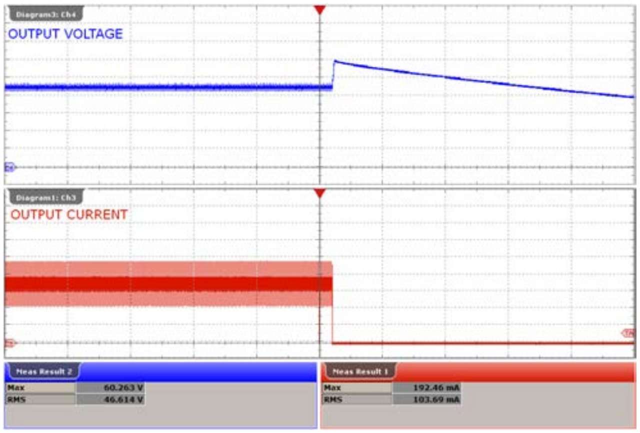

Figure 54 – 195 VAC, 48 V LED Load,
Running Open Load.
Upper: V_{OUT}, 10 V / div., 500 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 193 mA_{PK}.
Peak V_{OUT}: 60.3 V_{PK}.

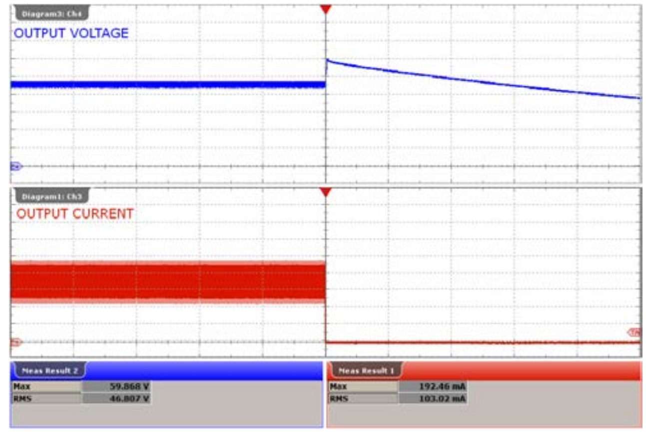

Figure 55 – 265 VAC, 48 V LED Load,
Running Open Load.
Upper: V_{OUT}, 10 V / div., 500 ms / div.
Lower: I_{OUT}, 40 mA / div.
Peak I_{OUT}: 193 mA_{PK}.
Peak V_{OUT}: 59.9 V_{PK}.

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13.8 Output Ripple Current

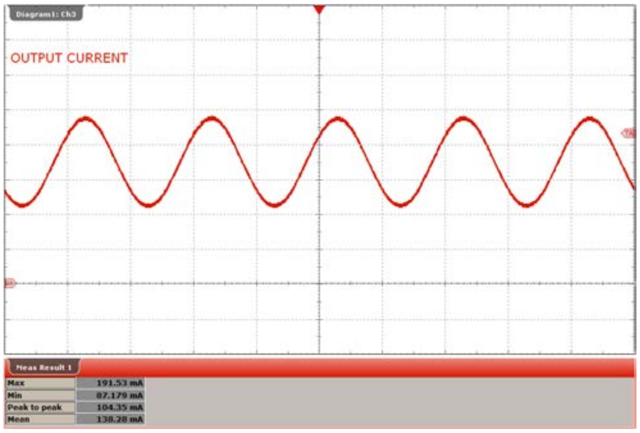

Figure 56 – 195 VAC, 50 Hz, 48 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

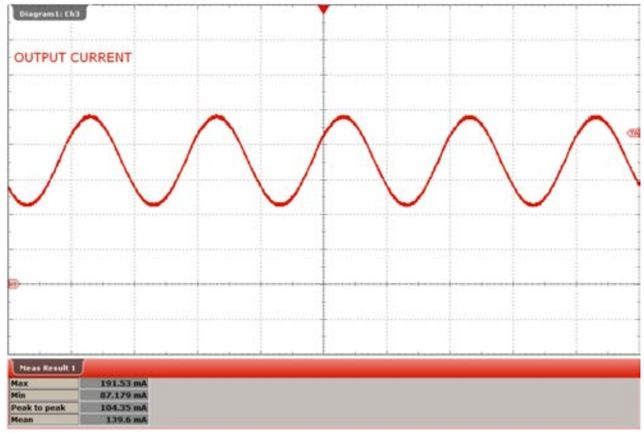

Figure 57 – 220 VAC, 50 Hz, 48 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

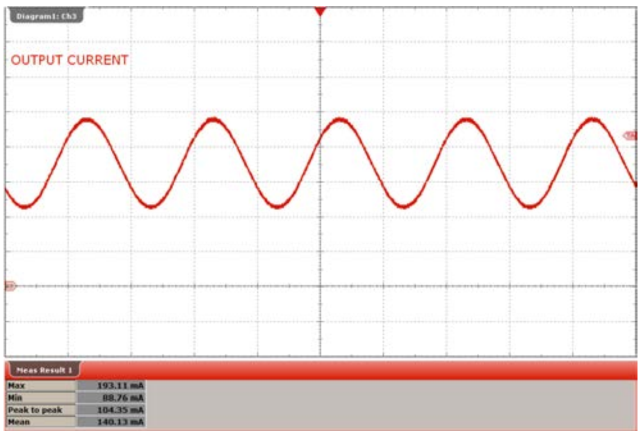

Figure 58 – 240 VAC, 50 Hz, 48 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

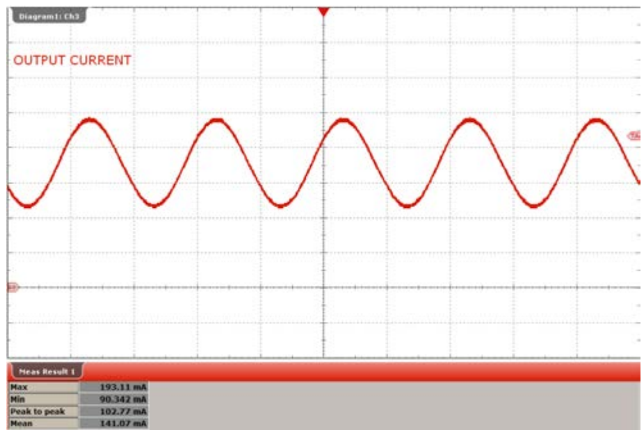

Figure 59 – 265 VAC, 50 Hz, 48 V LED Load.
I_{OUT}, 40 mA / div., 5 ms / div.

V_{IN} (VAC)	$I_{O(MAX)}$ (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} / $I_{O(MAX)}$ + $I_{O(MIN)}$)
195	191.53	87.179	104.35	138.28	0.75	37.44
220	191.53	87.179	104.35	139.61	0.75	37.44
240	193.11	88.760	104.35	140.13	0.75	37.02
265	193.11	90.342	102.77	141.07	0.75	36.23

14 Dimming Waveforms

14.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: Berker 2875

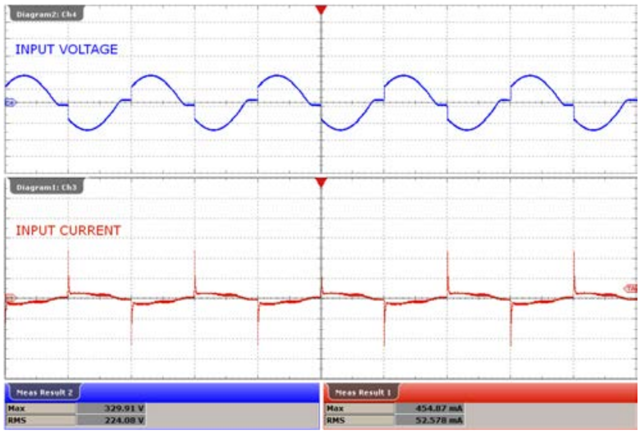

Figure 60 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div. .
Peak V_{IN}: 329 V_{PK}.
V_{RMS}: 224 V.

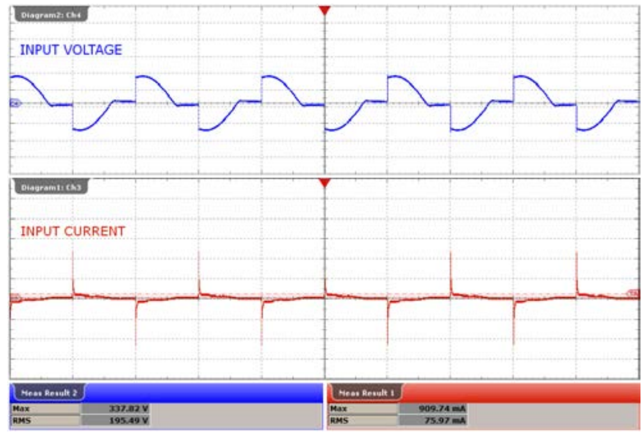

Figure 61 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 400 mA / div.
Peak V_{IN}: 337 V_{PK}.
V_{RMS}: 195 V.

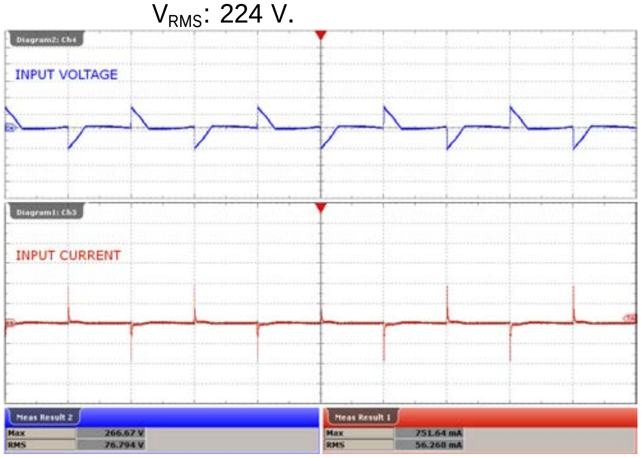

Figure 62 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div.
Peak V_{IN}: 266 V_{PK}.
V_{RMS}: 77 V.

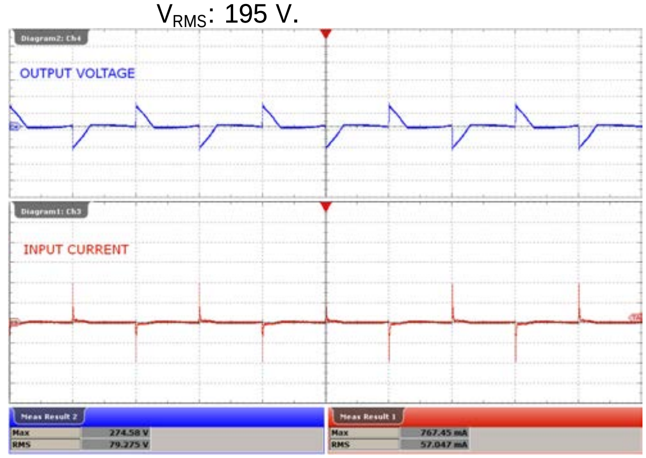

Figure 63 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 400 mA / div.
Peak V_{IN}: 274 V_{PK}.
V_{RMS}: 79 V.

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14.2 Output Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: Berker 2875

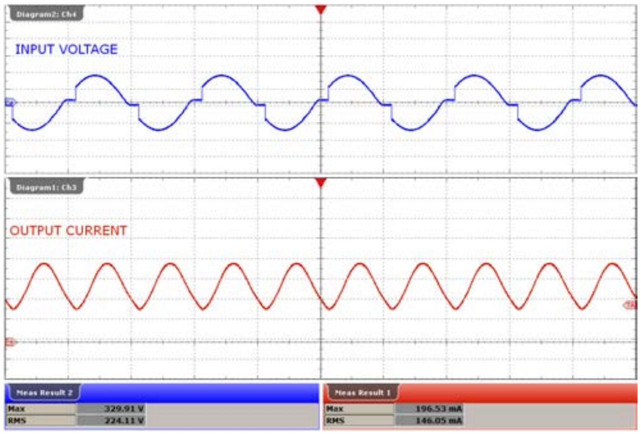

Figure 64 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 197 mA_{PK}.
Peak V_{IN}: 330 V_{PK}.

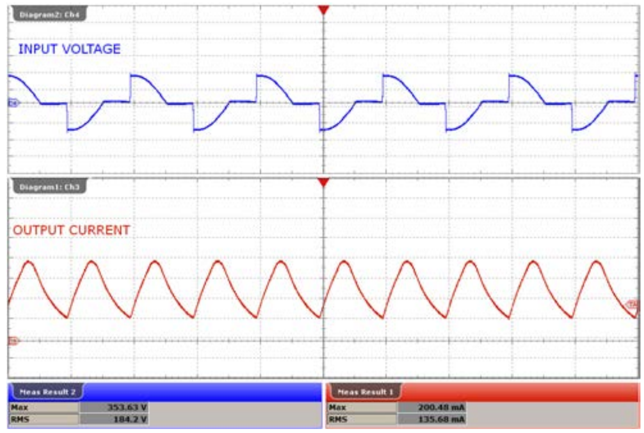

Figure 65 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 200 mA_{PK}.
Peak V_{IN}: 354 V_{PK}.

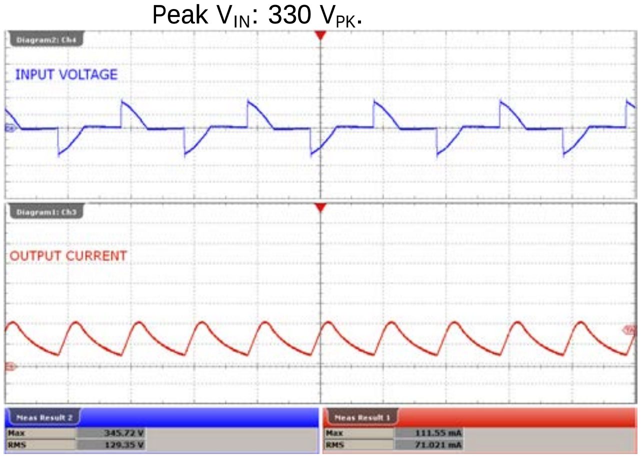

Figure 66 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 111 mA_{PK}.
Peak V_{IN}: 345 V_{PK}.

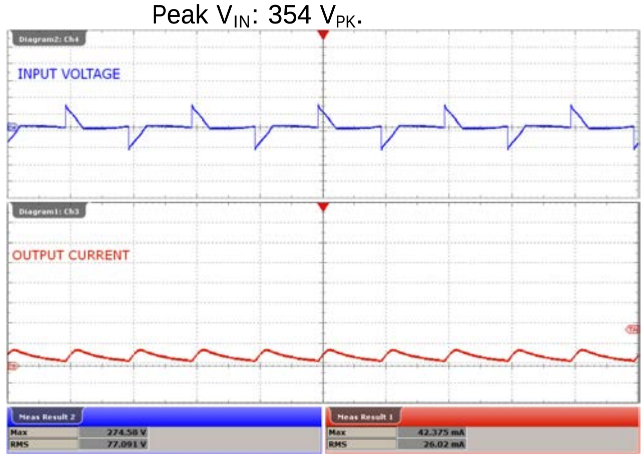

Figure 67 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 42 mA_{PK}.
Peak V_{IN}: 274 V_{PK}.

14.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: GIRA 0307 00

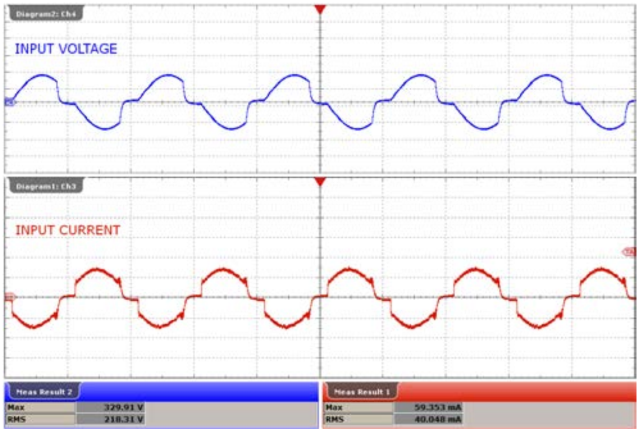

Figure 68 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 50 mA / div. .
Peak V_{IN}: 330 V_{PK}.
V_{RMS}: 218 V.

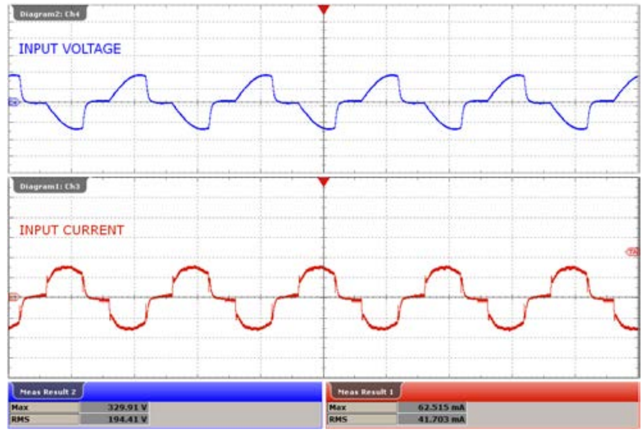

Figure 69 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 50 mA / div. .
Peak V_{IN}: 330 V_{PK}.
V_{RMS}: 194 V.

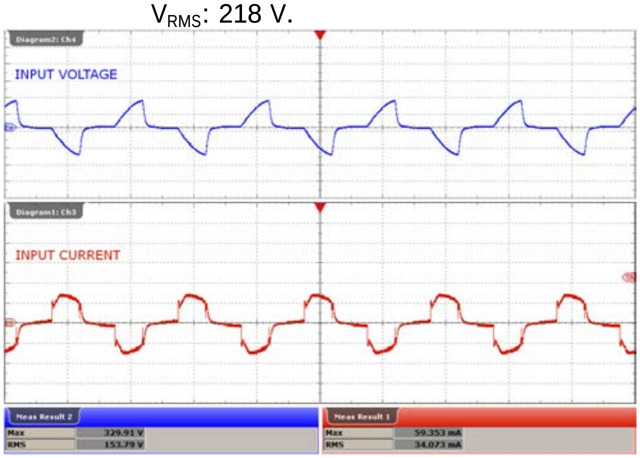

Figure 70 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 50 mA / div. .
Peak V_{IN}: 330 V_{PK}.
V_{RMS}: 154 V.

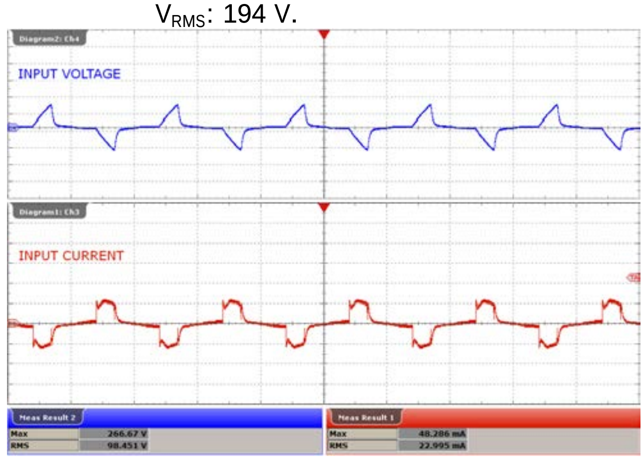

Figure 71 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 50 mA / div. .
Peak V_{IN}: 267 V_{PK}.
V_{RMS}: 98 V.

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14.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: GIRA 0307 00

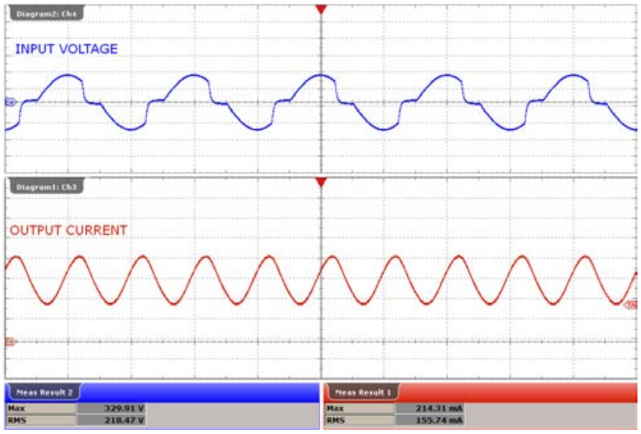

Figure 72 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 214 mA_{PK}.
Peak V_{IN}: 330 V_{PK}.

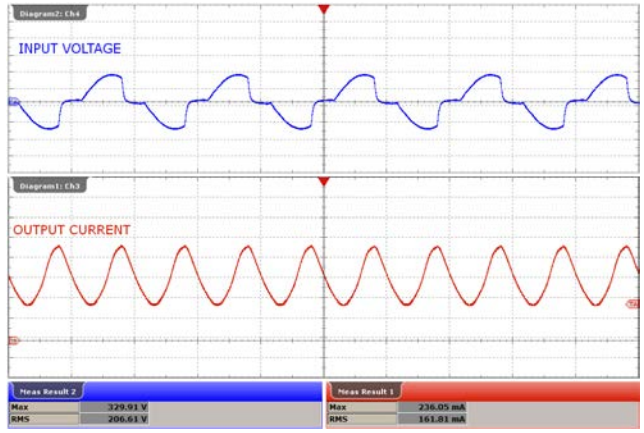

Figure 73 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 236 mA_{PK}.
Peak V_{IN}: 330 V_{PK}.

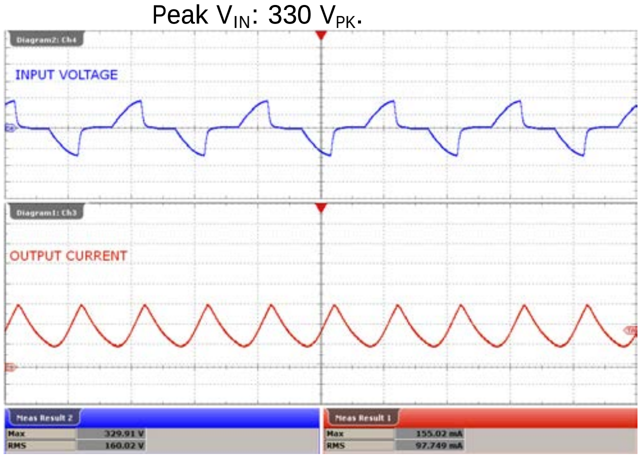

Figure 74 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 155 mA_{PK}.
Peak V_{IN}: 330 V_{PK}.

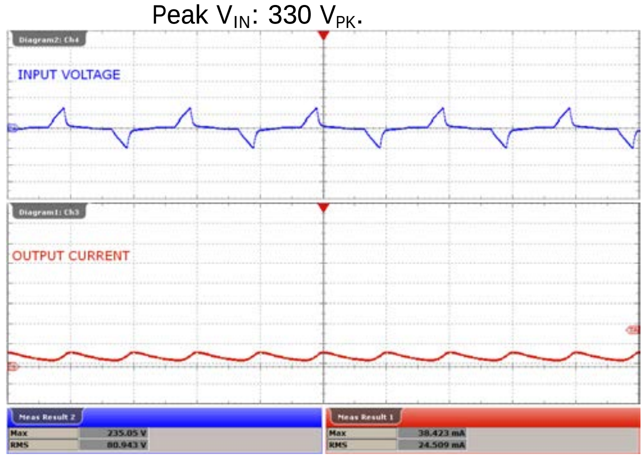

Figure 75 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 50 mA / div.
Peak I_{OUT}: 38 mA_{PK}.
Peak V_{IN}: 235 V_{PK}.

15 AC Cycling Test

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

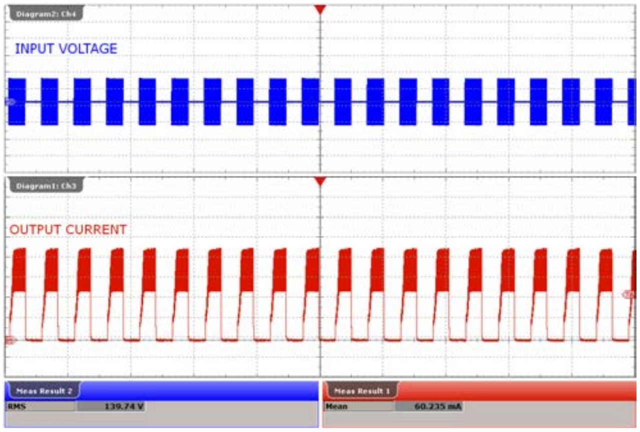

Figure 76 – 195 VAC, 48 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

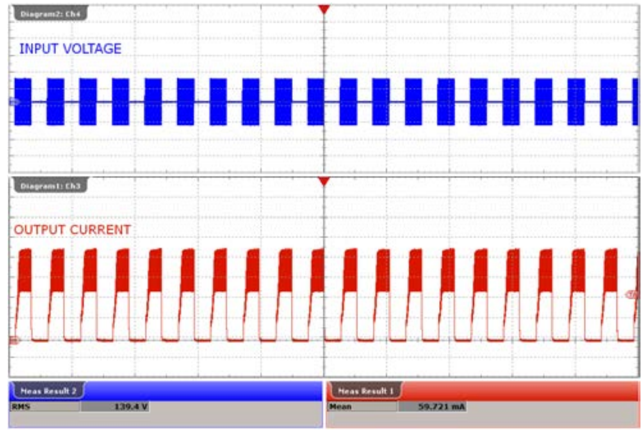

Figure 77 – 220 VAC, 48 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

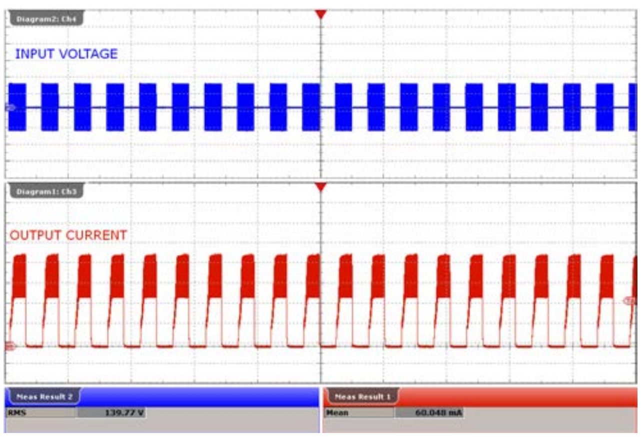

Figure 78 – 240 VAC, 48 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

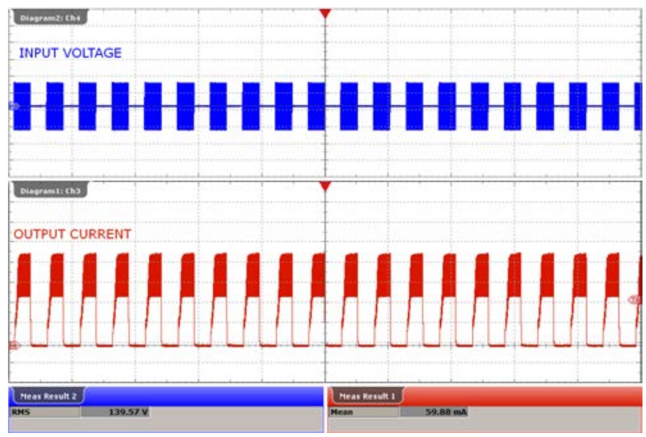

Figure 79 – 265 VAC, 48 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 40 mA / div.

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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. 48 V LED load with input voltage set at 230 VAC.

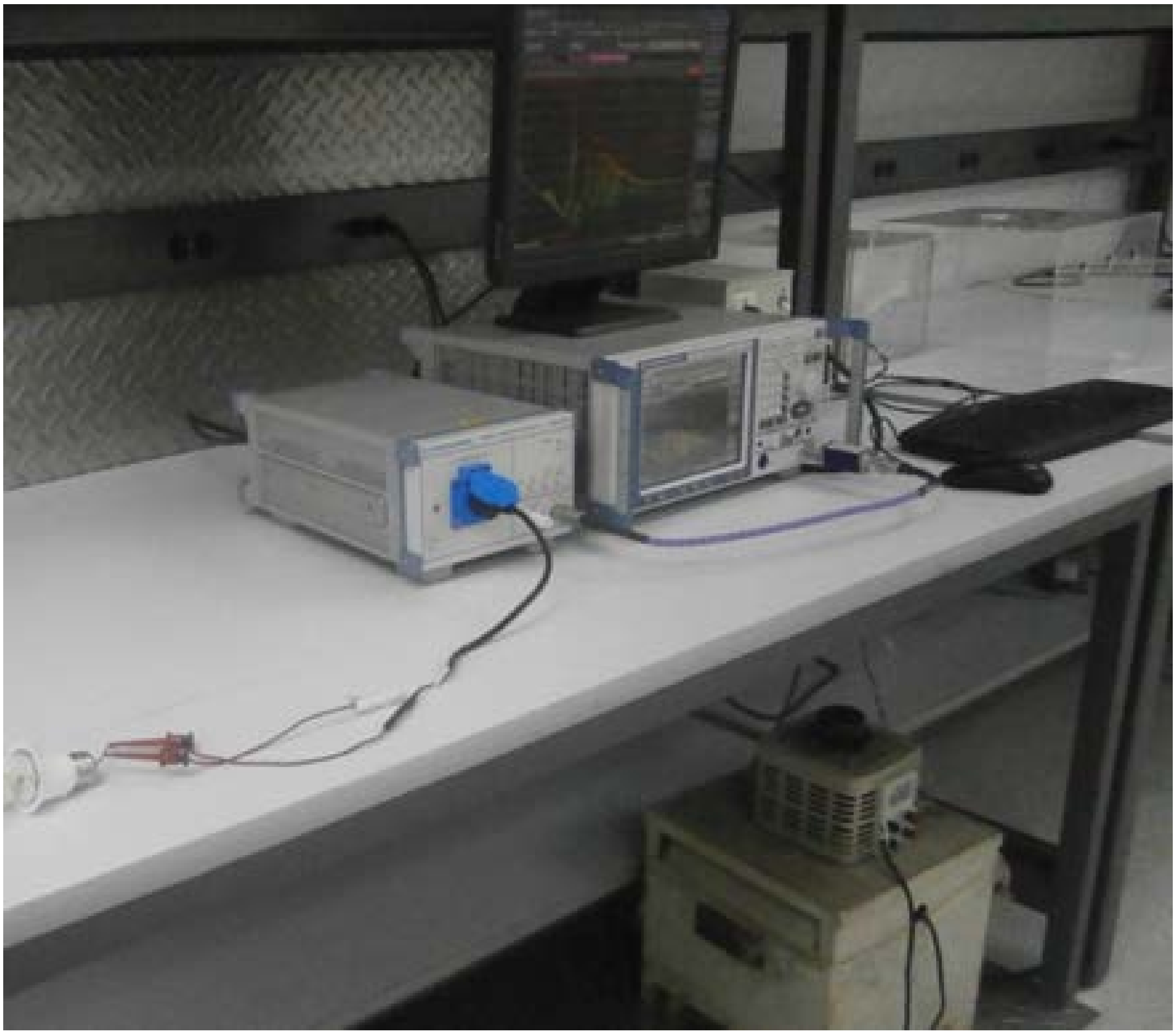

Figure 80 – Conducted EMI Test Set-up.

16.2 EMI Test Result

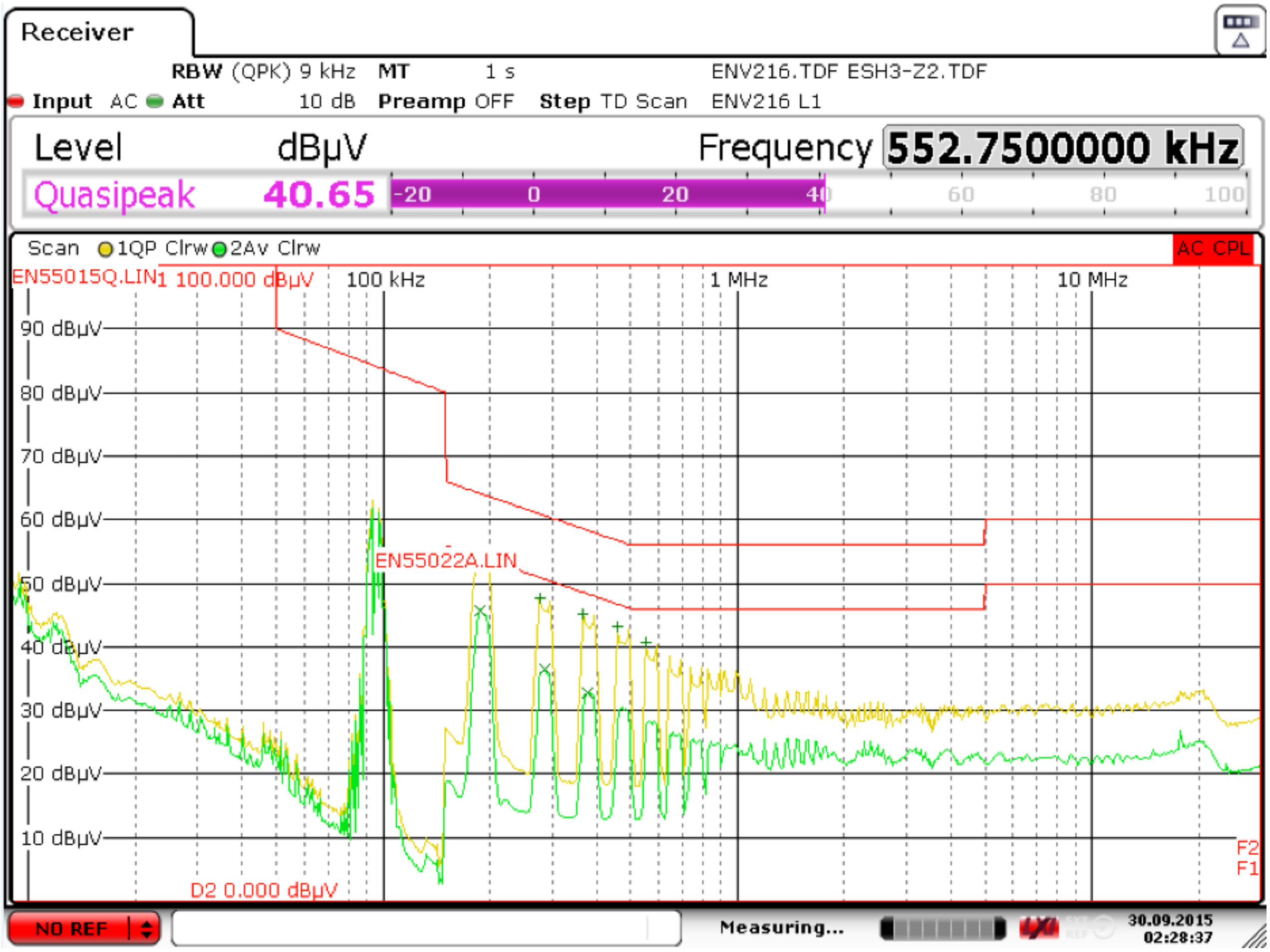

Figure 81 – Conducted EMI AT Line 1, 48 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

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Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	186.0000 kHz	54.28 L1	-9.93 dB
2 Average	188.2500 kHz	45.75 L1	-8.36 dB
1 Quasi Peak	278.2500 kHz	47.70 L1	-13.17 dB
2 Average	287.2500 kHz	36.44 L1	-14.16 dB
1 Quasi Peak	368.2500 kHz	45.25 L1	-13.29 dB
2 Average	379.5000 kHz	32.86 L1	-15.43 dB
1 Quasi Peak	460.5000 kHz	43.10 L1	-13.58 dB
1 Quasi Peak	552.7500 kHz	40.79 L1	-15.21 dB

Figure 82 – Conducted EMI at Line 1, 48 V LED Load, Final Measurement Results.

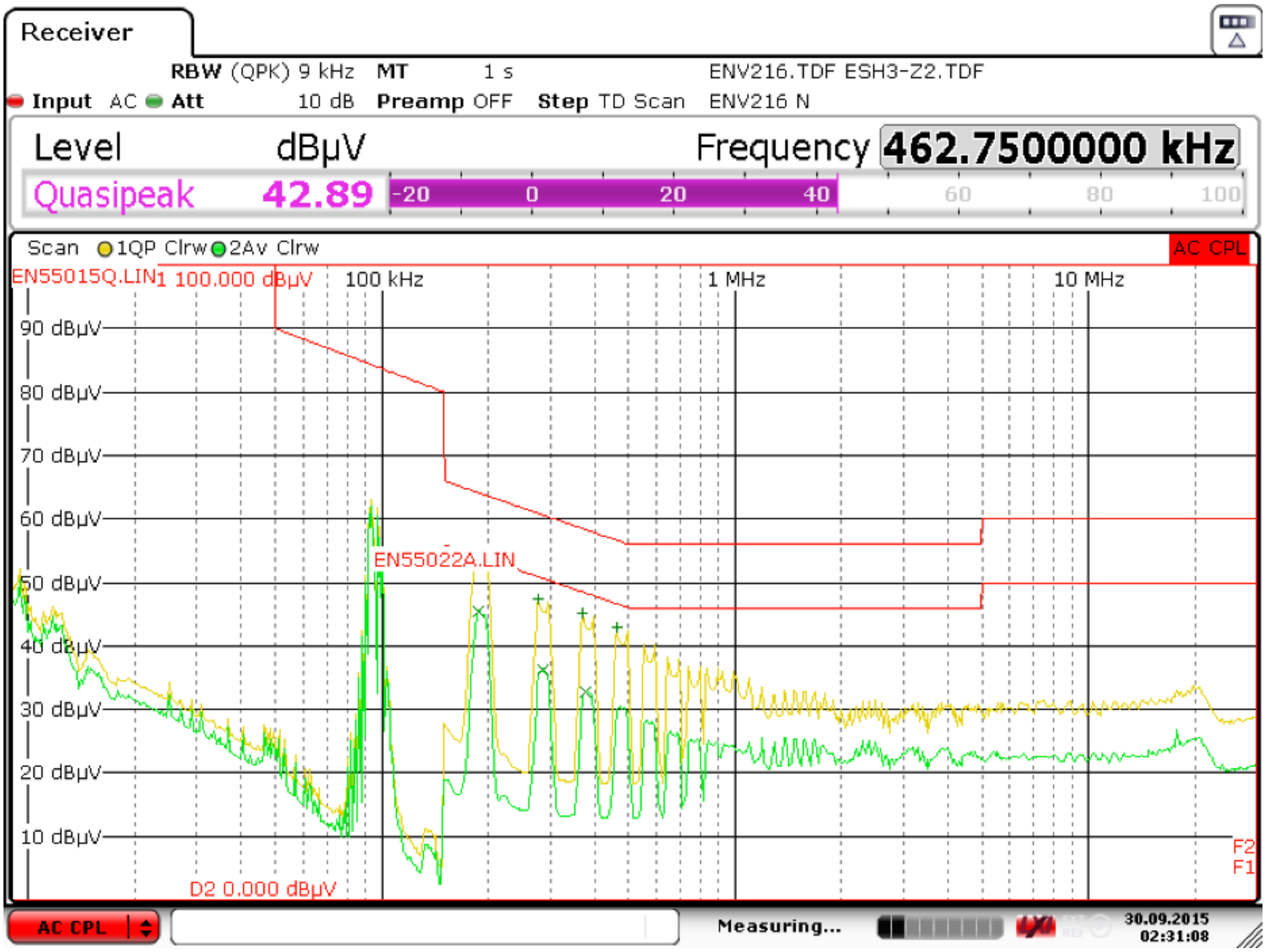

Figure 83 – Conducted EMI AT Line 2, 48 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

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Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	186.0000 kHz	54.22 N	-9.99 dB
2 Average	188.2500 kHz	45.51 N	-8.60 dB
1 Quasi Peak	278.2500 kHz	47.51 N	-13.36 dB
2 Average	287.2500 kHz	36.31 N	-14.29 dB
1 Quasi Peak	370.5000 kHz	45.26 N	-13.23 dB
2 Average	379.5000 kHz	32.75 N	-15.54 dB
1 Quasi Peak	462.7500 kHz	42.98 N	-13.66 dB

Figure 84 – Conducted EMI at Line 2, 48 V LED Load, Final Measurement Results.

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	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
+1000	230	L to N	270	Pass
-1000	230	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	230	L, N to PE	0	Pass
-2500	230	L, N to PE	0	Pass
+2500	230	L, N to PE	90	Pass
-2500	230	L, N to PE	90	Pass
+2500	230	L, N to PE	270	Pass
-2500	230	L, N to PE	270	Pass

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17.3 Differential Surge Test Result and Waveform

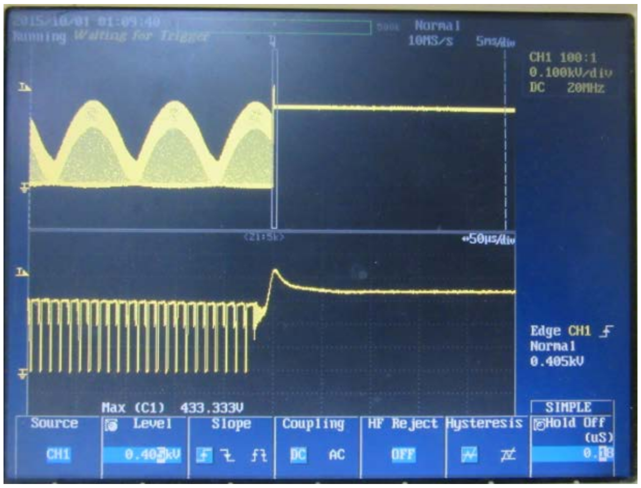

Figure 85 – 230 VAC, 50 Hz, +1000, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 433 V_{PK}.

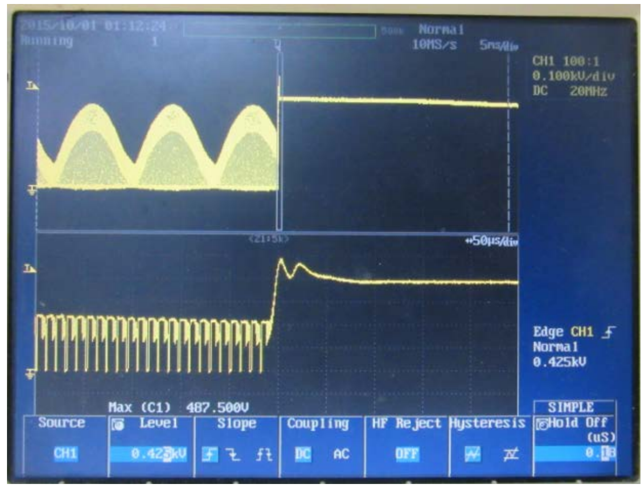

Figure 86 – 230 VAC, 50 Hz, -1000, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 488 V_{PK}.

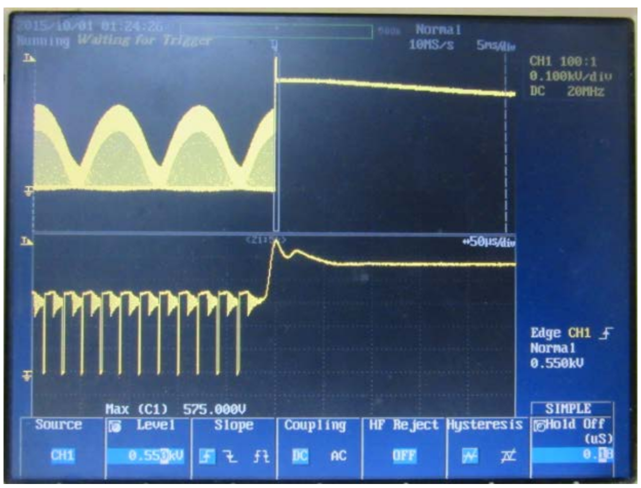

Figure 87 – 230 VAC, 50 Hz, +1000, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 575 V_{PK}.

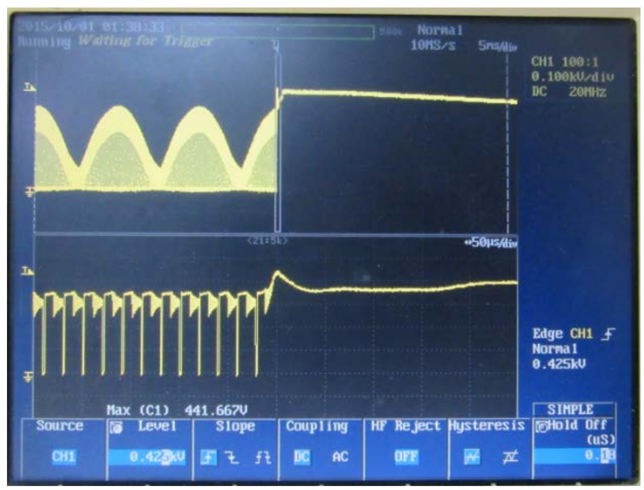

Figure 88 – 230 VAC, 50 Hz, -1000, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div.(Zoomed).
Measured Peak Voltage = 441 V_{PK}.

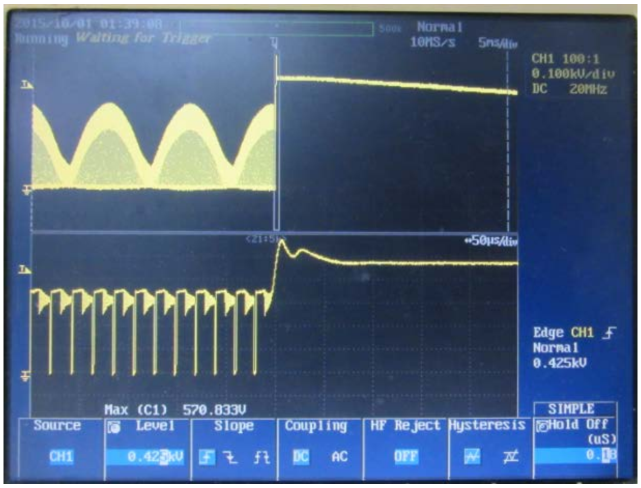

Figure 89 – 230 VAC, 50 Hz, +1000, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 571 V_{PK}.

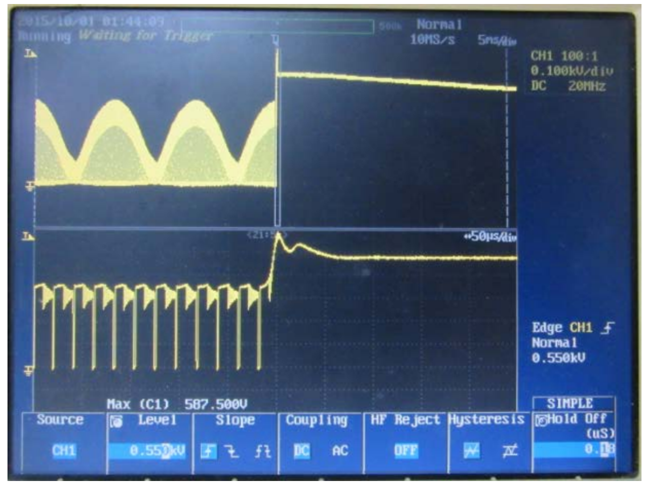

Figure 90 – 230 VAC, 50 Hz, -1000, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 588 V_{PK}.

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17.4 Ring Wave Test Result and Waveform

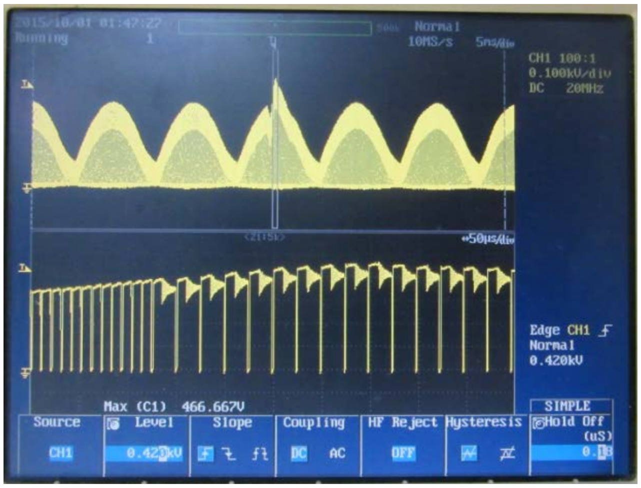

Figure 91 – 230 VAC, 50 Hz, +2500, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 467 V_{PK}.

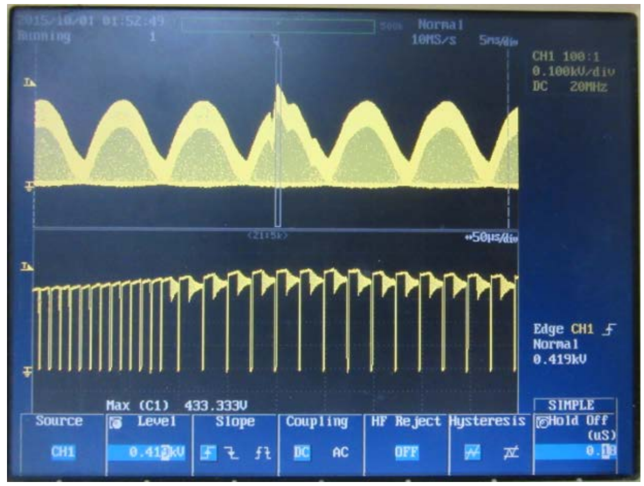

Figure 92 – 230 VAC, 50 Hz, -2500, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 433 V_{PK}.

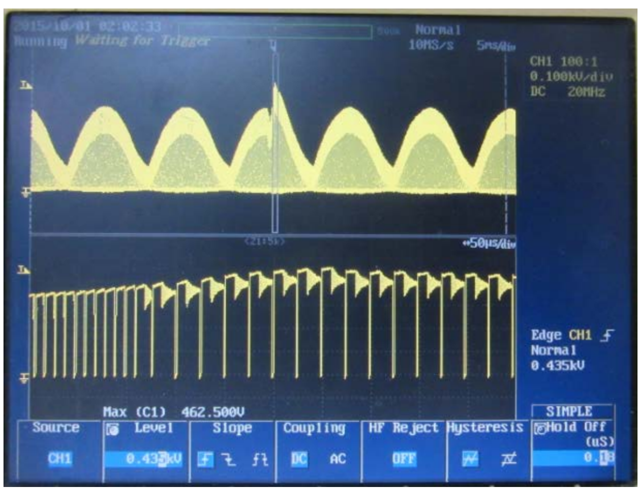

Figure 93 – 230 VAC, 50 Hz, +2500, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 544 V_{PK}.

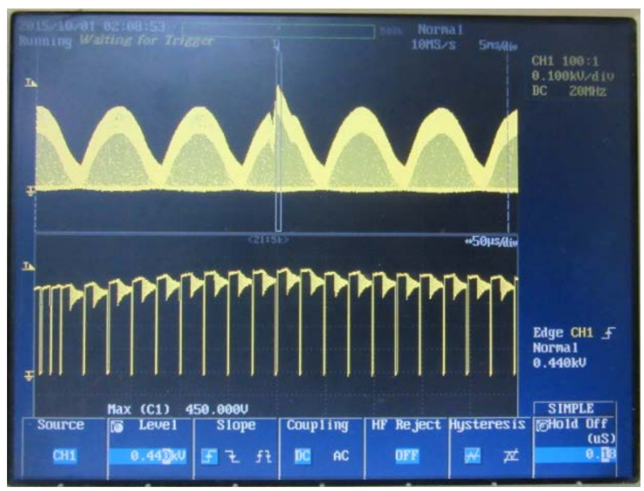

Figure 94 – 230 VAC, 50 Hz, -2500, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 450 V_{PK}.

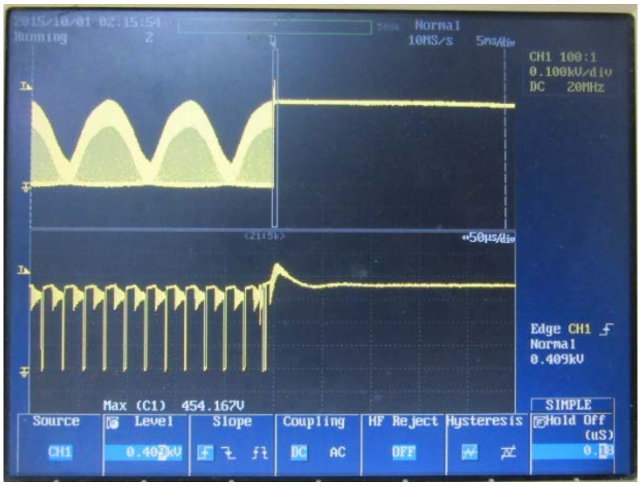

Figure 95 – 230 VAC, 50 Hz, +2500, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 454 V_{PK}.

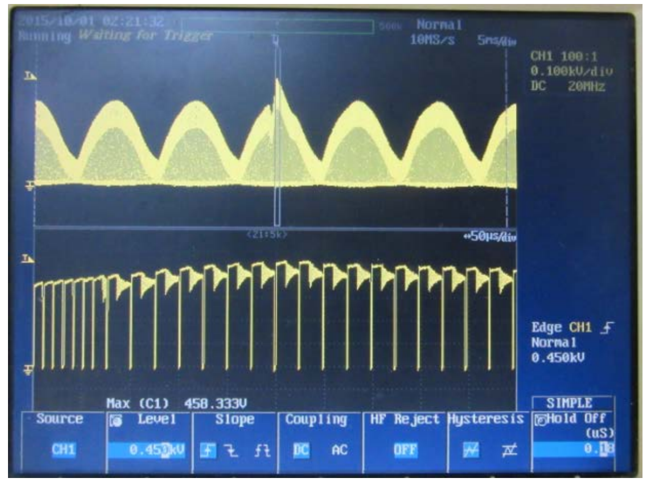

Figure 96 – 230 VAC, 50 Hz, -2500, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 458 V_{PK}.

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17.5 Line Surge Test Set-up

EQUIPMENT/LOAD USED AND TEST CONDITION:

1. THERMO SCIENTIFIC SURGE TEST EQUIPTMENT
2. YOKOGAWA DL1740 OSCILLOSCOPE
3. YOKOGAWA 701926 DIFFERENTIAL PROBE (FOR MEASURING DRAIN VOLTAGE)
4. 48 V LED STRING TO CATER 6.95 W OUTPUT POWER
5. INPUT VOLTAGE SET AT 230 VAC.

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.

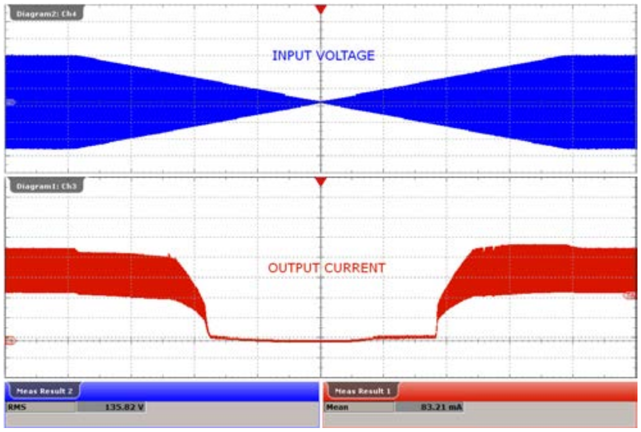

Figure 97 – 195 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 50 mA / div.

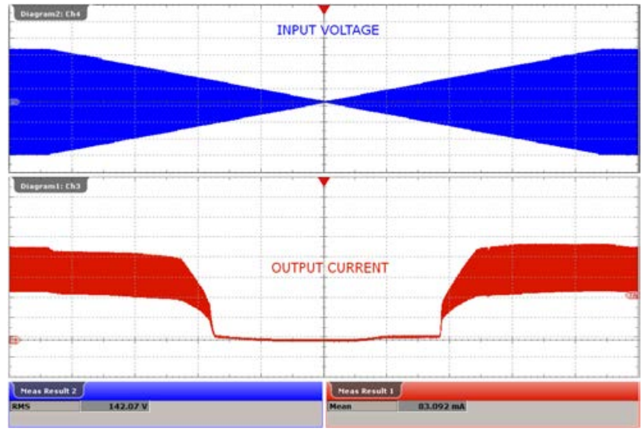

Figure 98 – 220 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 50 mA / div.

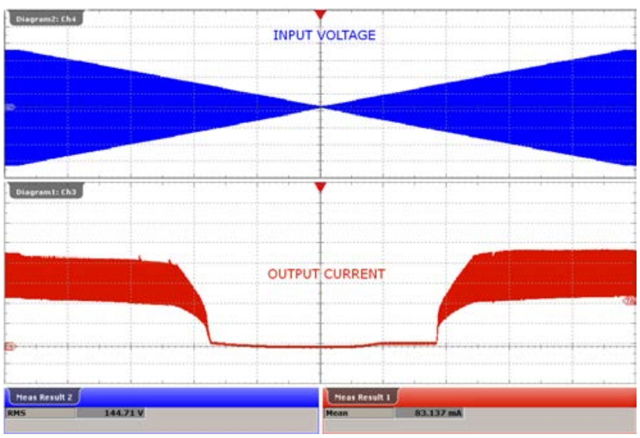

Figure 99 – 240 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 50 mA / div.

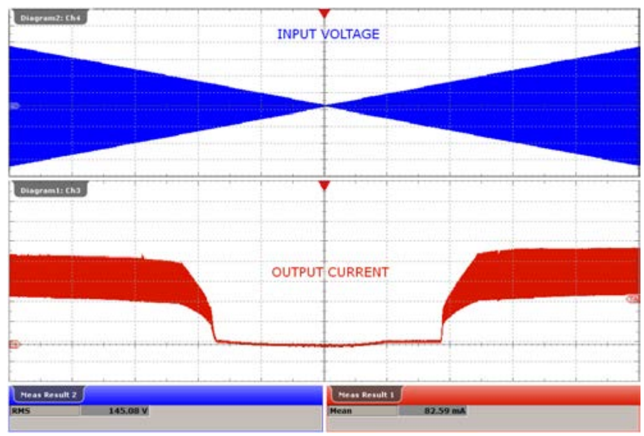

Figure 100 – 265 VAC, 48 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 50 mA / div.

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19 Revision History

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

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