Design Example Report

Title	***7.75 W TRIAC Dimmable, High Efficiency, Power Factor Corrected Buck-Boost LED Driver Using LYTSwitch-3 ™ LYT3324D***
Specification	195 VAC – 265 VAC Input; 141 V, 55 mA_{TYP} Output
Application	Omni Directional Bulb
Author	Applications Engineering Department
Document Number	DER-486
Date	April 18, 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
- 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

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

Table of Contents

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.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

1 Introduction

This engineering report describes a TRIAC dimmable, non-isolated buck-boost LED driver designed to drive a nominal LED voltage string of 141 V at 55 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-486 provides a single 7.75 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.

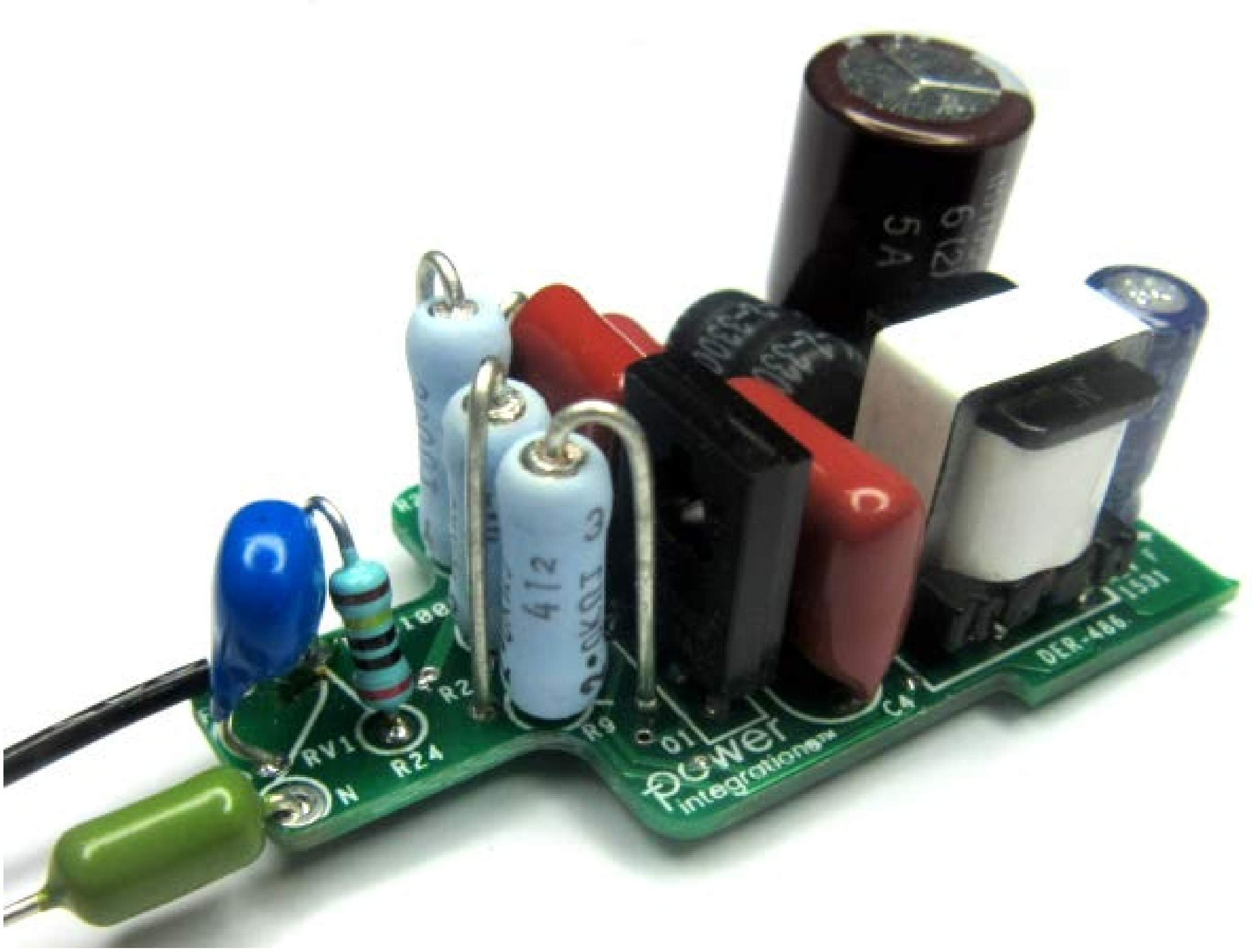


Figure 1 – Populated Circuit Board.

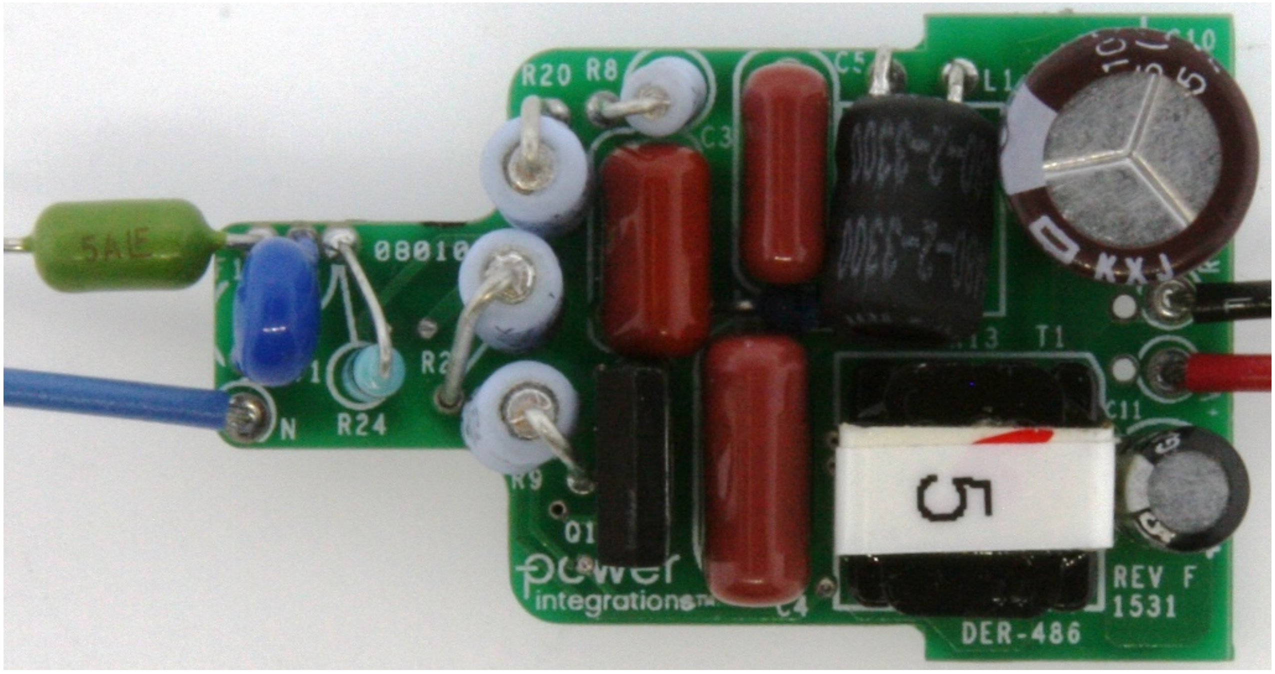


Figure 2 – Populated Circuit Board, Top View.

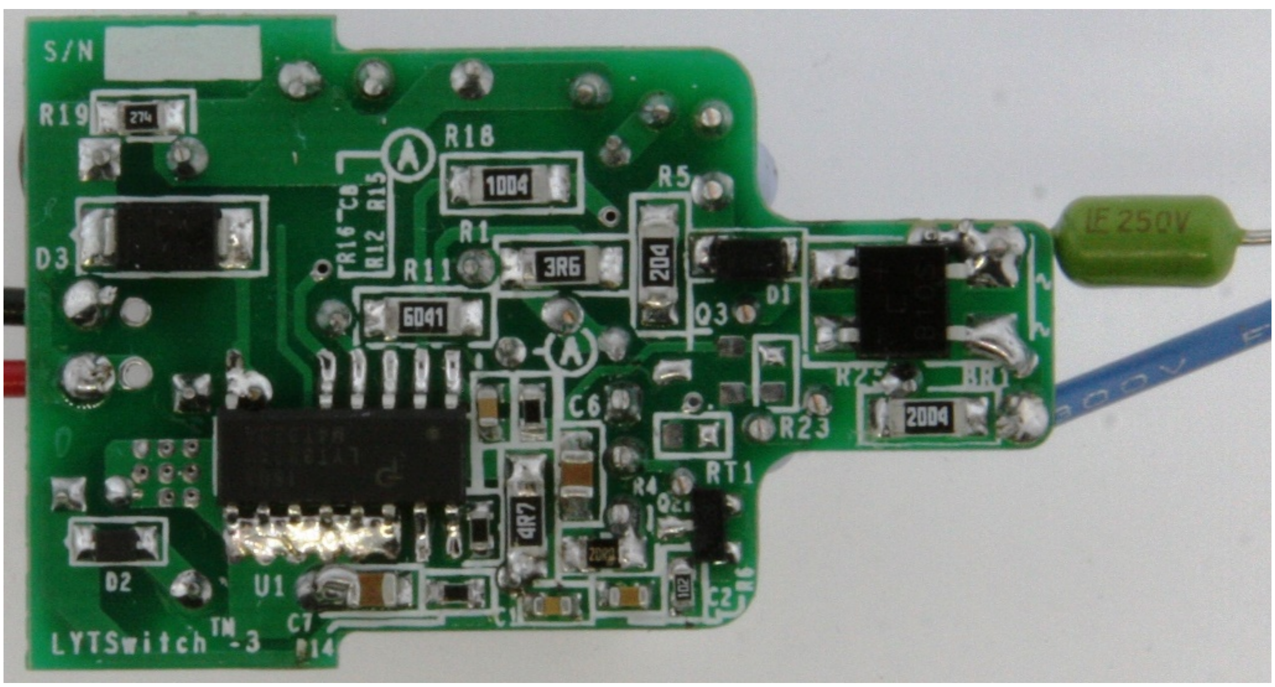


Figure 3 – Populated Circuit Board, Bottom View.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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}	134	141	148	V	
Output Current	I_{OUT}	52.25	55	57.75	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		8		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	ºC	Free Convection, Sea Level.

3 Schematic

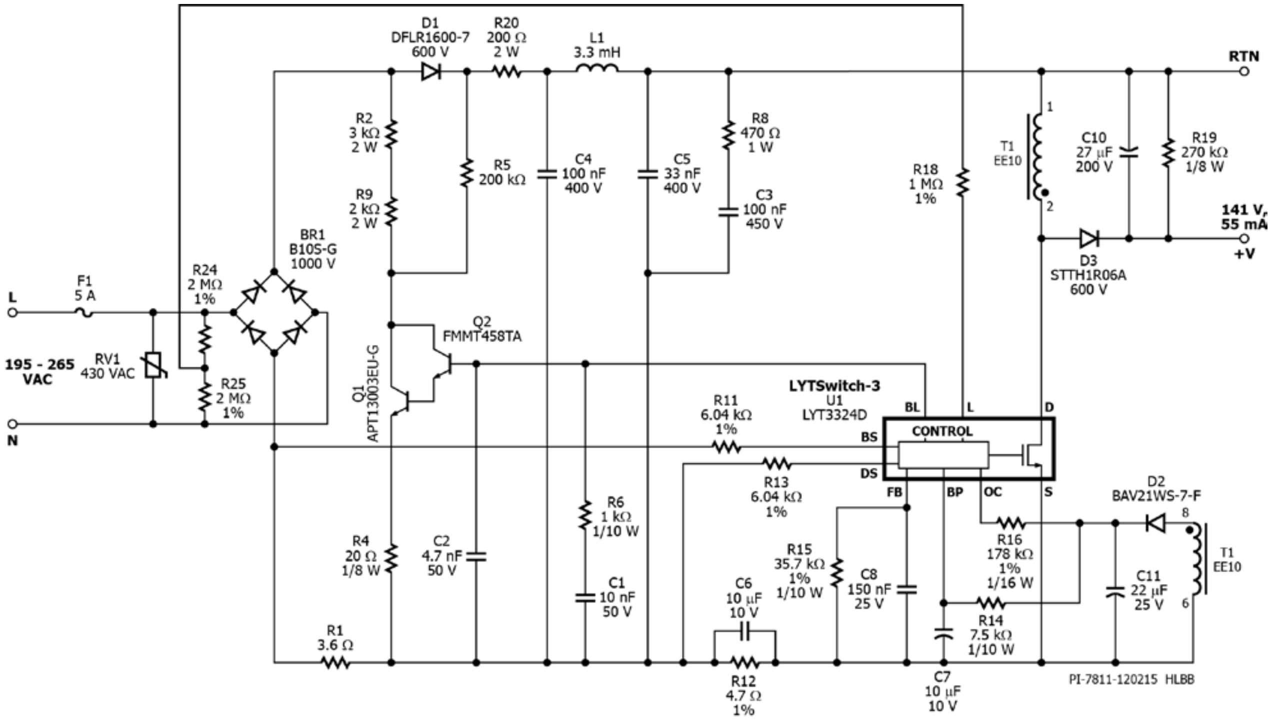


Figure 4 – Schematic.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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 the U1 BLEEDER CURRENT SENSE (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.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

5 PCB Layout

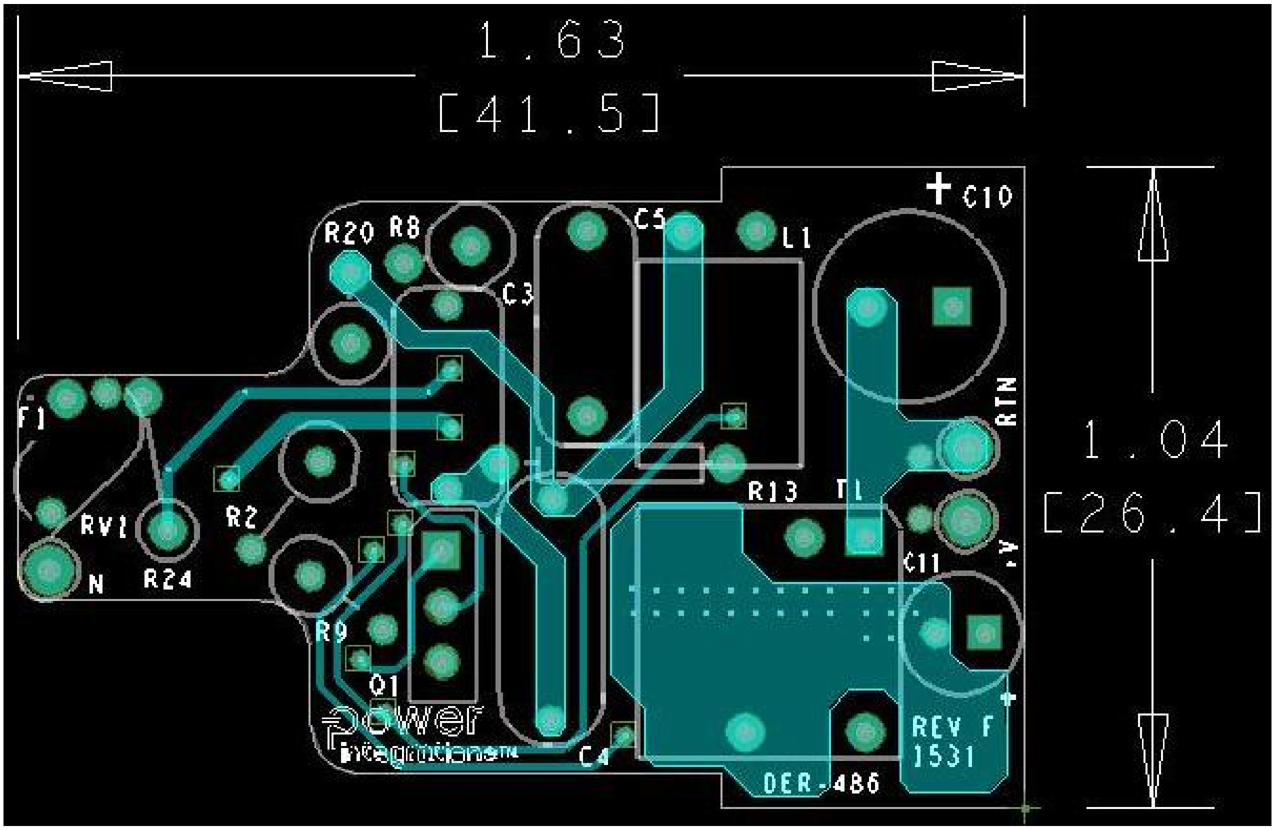


Figure 5 – Top Side.

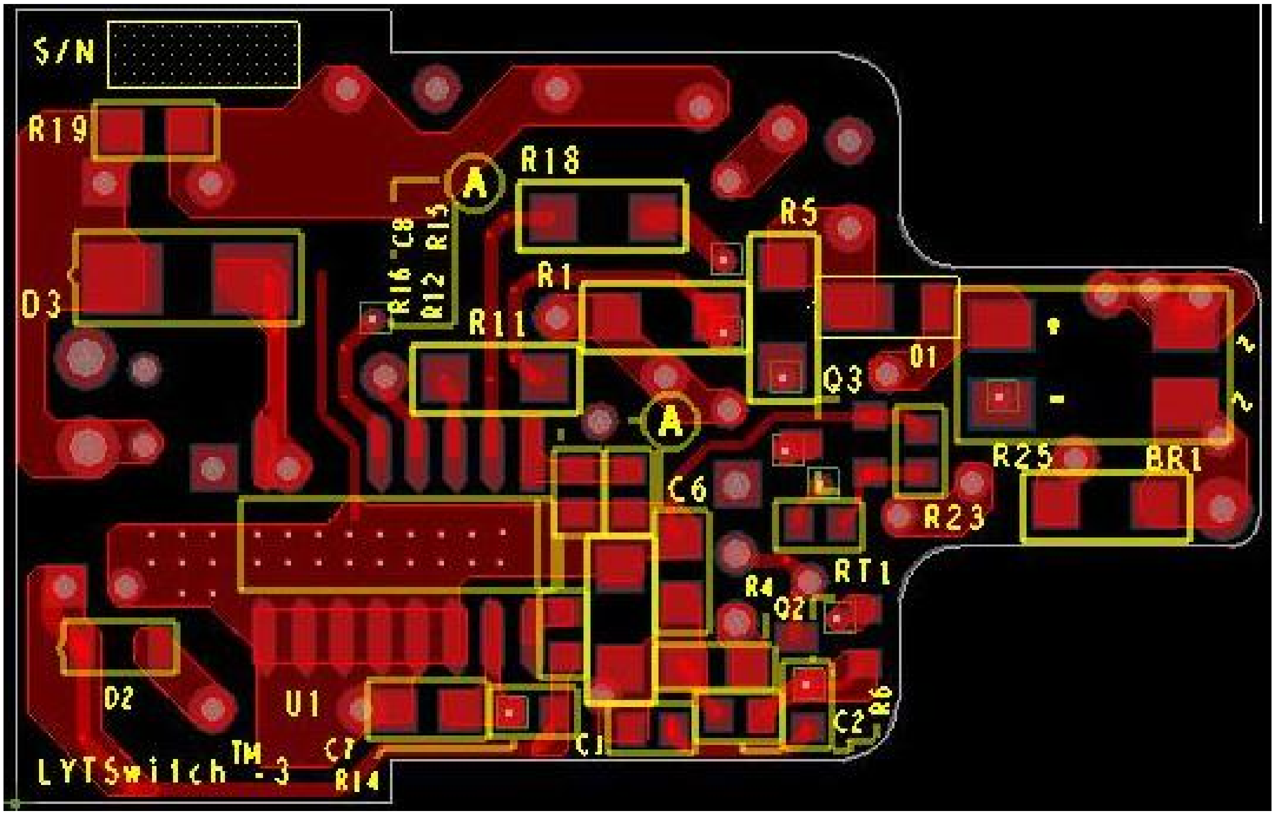


Figure 6 – Bottom Side.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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	27 μF, 200 V, Electrolytic, (10 x 16 mm)	EKXJ201ELL270MJ16S	Nippon Chemi-Con
11	C11	1	22 μF, 25V, Electrolytic, 20 %, Gen. Purpose, (5 x 7 mm)	EEA-GA1E220	Panasonic
12	D1	1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
13	D2	1	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	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-Zetex
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	470 Ω, 5%, 1 W, Metal Oxide Film	ERG-1SJ471	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	4.7 Ω, 1%, 1/4 W, Thick Film, 1206	RERJ-8RQF4R7V	Panasonic
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	35.7 kΩ, 1%, 1/10 W, Thick Film, 0603	ERJ-3EKF3572V	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	270 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ274V	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
37	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

7 Inductor Specification

7.1 Electrical Diagram

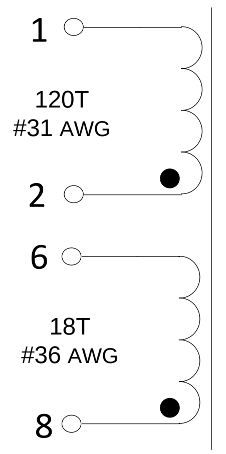


Figure 7 – Inductor Electrical Diagram.

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: #36 AWG.
[5]	Transformer tape: 7 mm.
[6]	Transformer tape: 4 mm.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

7.4 Inductor Build Diagram

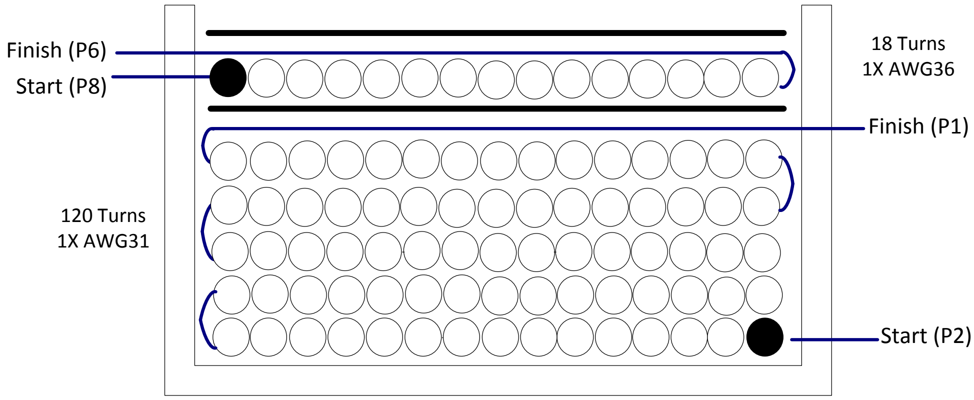
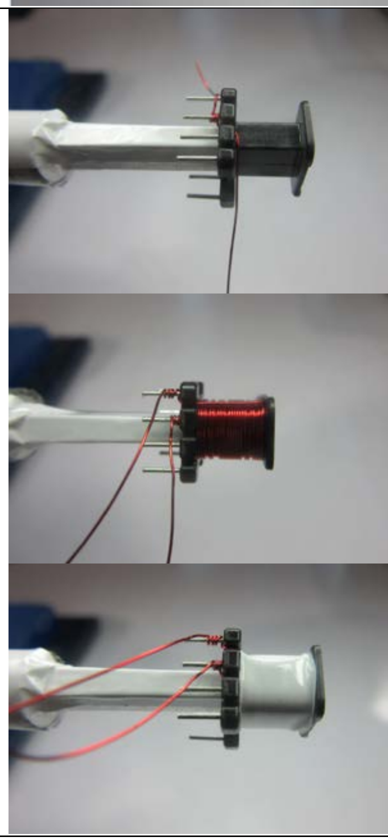


Figure 8 – Transformer Build Diagram.

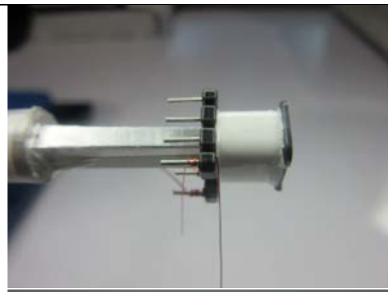
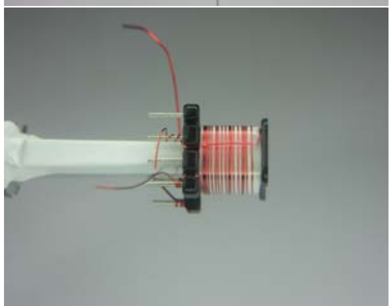
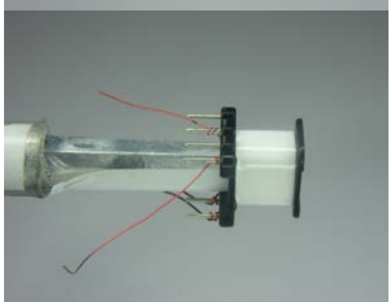
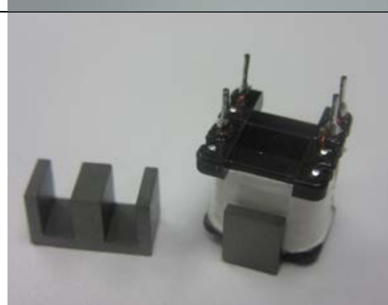
7.5 Inductor Construction

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 18 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, 6, 7.
Finish	Dip the transformer assembly in varnish.

7.6 Inductor Construction Photos

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.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

WD2	  	Starting at pin 8 wind 18 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 item [1] 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.

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	195		195	V	Minimum AC Input Voltage
VACNOM	230		230	V	Typical AC Input Voltage
VACMAX	265		265	V	Maximum AC Input Voltage
FL	50.00		50.00	Hz	Minimum line frequency
VO_MIN			126.9	V	Guaranteed minimum VO that maintains output regulation
VO	141.0		141.0	V	Worst case normal operating output voltage
VO_OVP_MIN			165.2	V	Minimum Voltage at which output voltage protection may be activated
IO	55.0		55.0	mA	Average output current specification
n	0.85		0.85	%/100	Total power supply efficiency
Z			0.50		Loss allocation factor
PO			7.76	W	Total output power
VD			0.70	V	Output diode forward voltage drop
LYTSwitch-3 DESIGN VARIABLES					
Select Breakdown Voltage	725V		725V	V	Choose between 650V and 725V
Device	LYT33X4		LYT33X4		Chosen LYTSwitch-3 Device
Final device code			LYT3324		
Select Dimming Curve Option	1		1		Maximum dim curve with Load Shut Down (LSD) disabled
RBS2			6.04	k-ohm	RBS2 resistor to select dimming curve
ILIMITMIN			0.844	A	Minimum device current limit
ILIMITTYP			0.907	A	Typical Current Limit
ILIMITMAX			0.971	A	Maximum Current Limit
TON			1.63	us	Expected on-time of MOSFET at low line and PO
FSW			114.4	kHz	Expected switching frequency at low line and PO
Duty Cycle			18.6	%	Expected operating duty cycle at low line and PO
IRMS			0.135	A	Nominal RMS current through the switch at low line
IPK		Warning[1]	1.004	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			2.89		Ratio between off-time of switch and reset time of core at VACNOM
KDP_DIM			2.19		Ratio between off-time of switch and reset time of core at VACNOM at the edge of dimming
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			10.0	%	Tolerance of Primary Inductance
N	120		120	Turns	Number of Turns
ALG			37	nH/T^2	Gapped Core Effective Inductance
BM		Info[2]	3664	Gauss	Reduce BM < 3300 G. Decrease BP (increase NP) or

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

					increase core size.
BP			3899	Gauss	Calculated Worst Case Peak Flux Density (BP < 4200 G)
BAC			1832	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	5.0		5.0		The actual number of layers that fits the input value after standardizing the wire size is 4.85
IL_RMS			0.257	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			313	Cmils/A	Primary Winding Current Capacity (200 < CMA < 500)
Current Density (J)			6.37	A/mm^2	Inductor Winding Current density (3.8 < J < 9.75 A/mm^2)
Bias Section					
TURNS_BIAS			18.00	Turns	
VBIAS			20.00	V	
PIVBS			76.21	V	
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			18.59	%	Duty cycle measured at minimum input voltage
IAVG			0.06	A	Input average current measured on the Mosfet at the minimum input voltage
IP			0.77	A	Peak Drain current at minimum input voltage
ISW_RMS			0.14	A	MOSFET RMS current measured at the minimum input voltage
ID_RMS			0.06	A	RMS current of freewheeling diode at minimum input voltage
IL_RMS			0.15	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			141.00	V	Load voltage measured on a prototype unit
RDS_T			4.7374	ohm	Theoretical calculation for RDS sense resistor
RDS			4.75	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			36113.21	ohm	Calculated value of RFB, using standard values for RDS, ROVP, and RL
RFB			36.50	k-ohm	Feedback pin resistor (E96 / 1%)
CFB_T			169.57	nF	Feedback pin capacitor (for 6ms time constant)
CFB			180	nF	Feedback pin capacitor E12 standard value
RSUP			13.80	k-ohm	Bias supply resistor assuming 1mA current necessary to supply BP
IOUT_MEASURED			55.0	mA	Measured average output current on the LEDs
Output Parameters					
VDRAIN			571	V	Estimated worst case drain voltage at VACMAX and VO_MAX
PIVD			594.8	V	Peak Inverse Voltage at VO_MAX on output diode
BLEEDER COMPONENTS					
I_HOLD	33.00		33.00	mA	Required bleeder holding current
RBS1			3.64	Ohm	Exact value of RBS1 resistor
RDAMPER			200	Ohm	Value of damper resistor
VDAMPER_RMS			8.63	V	Estimated RMS voltage drop on damper (without a bleeder present)

Note 1: 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 2: Actual units were tested at 40 ºC external ambient and bulb inside enclosure at worst case line condition. No saturation seen on transformer.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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

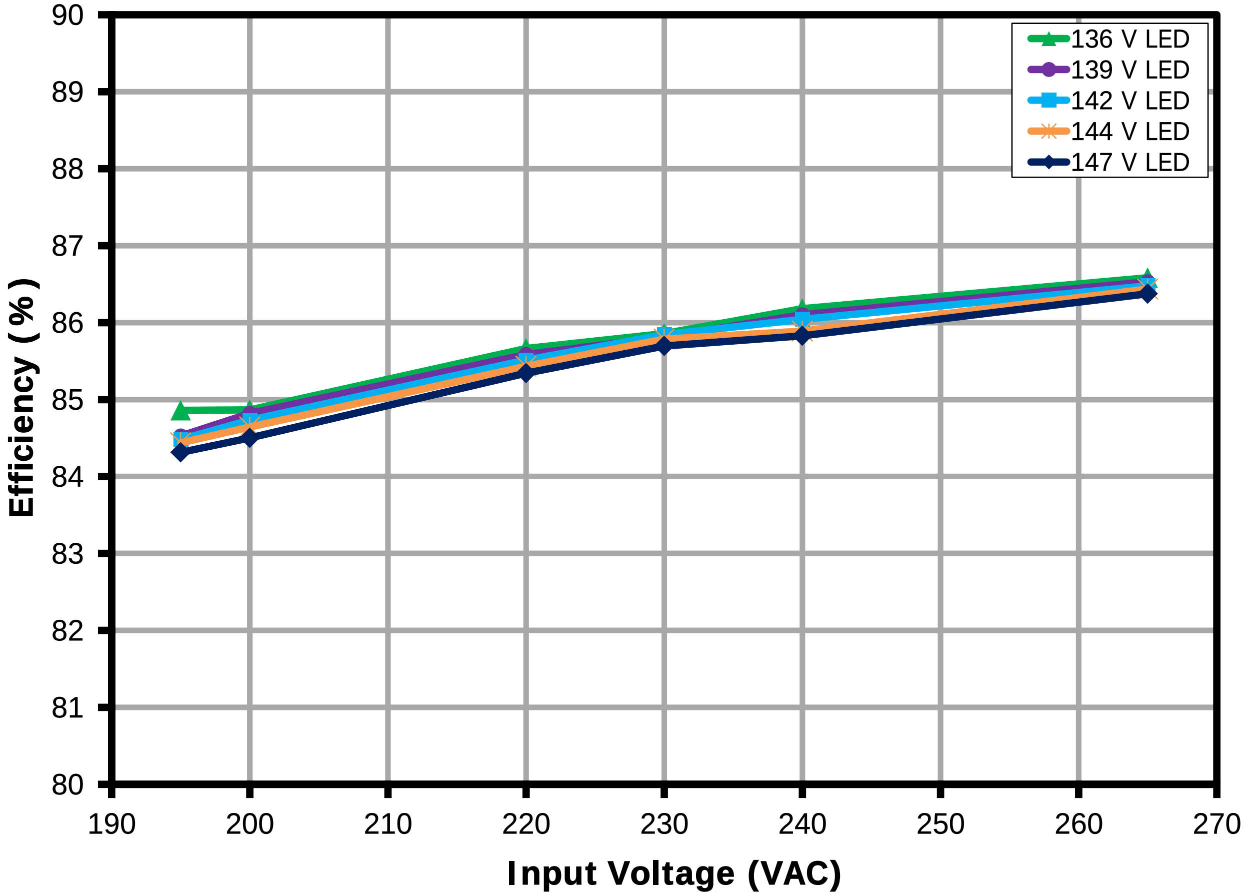


Figure 9 – Efficiency vs. Line and LED Load.

9.2 Output Current Regulation

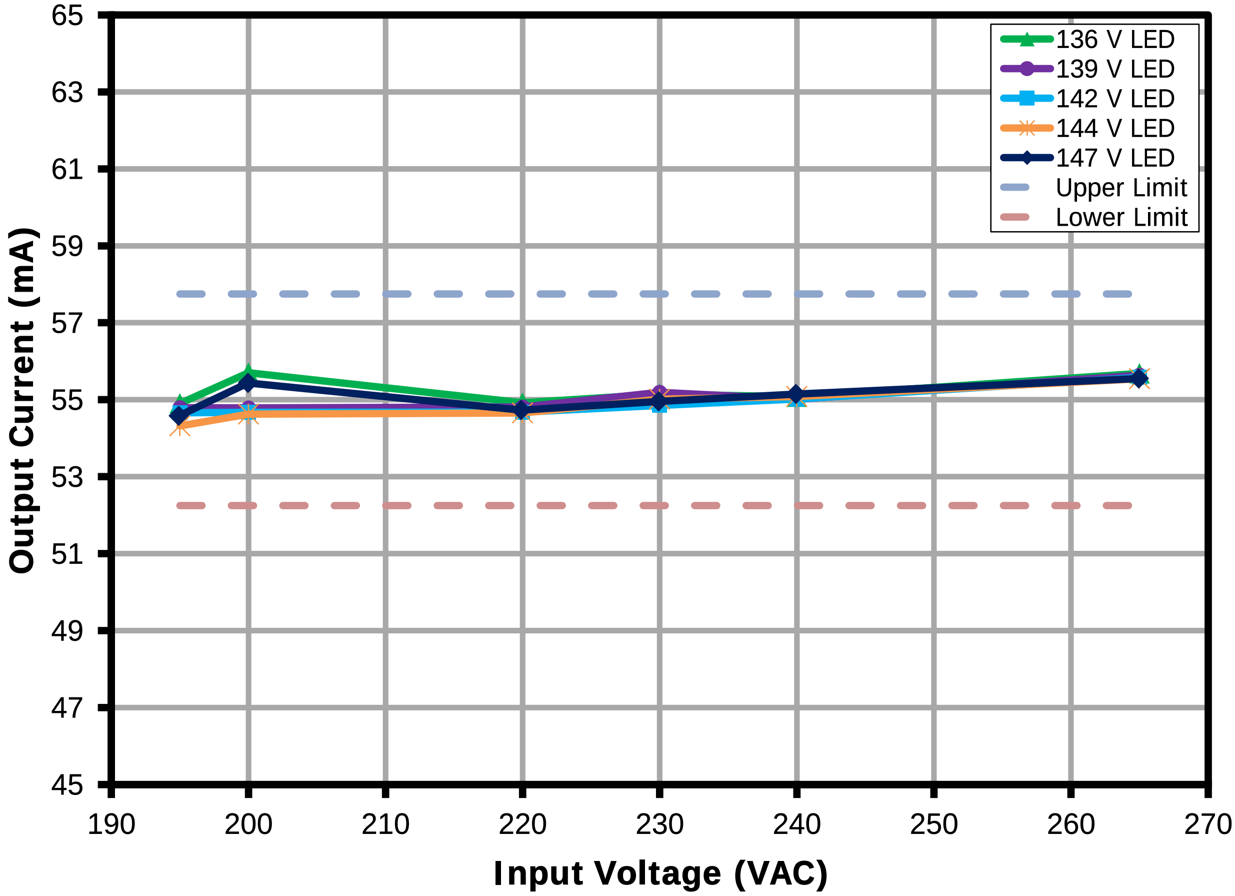


Figure 10 – Regulation vs. Line and LED Load.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

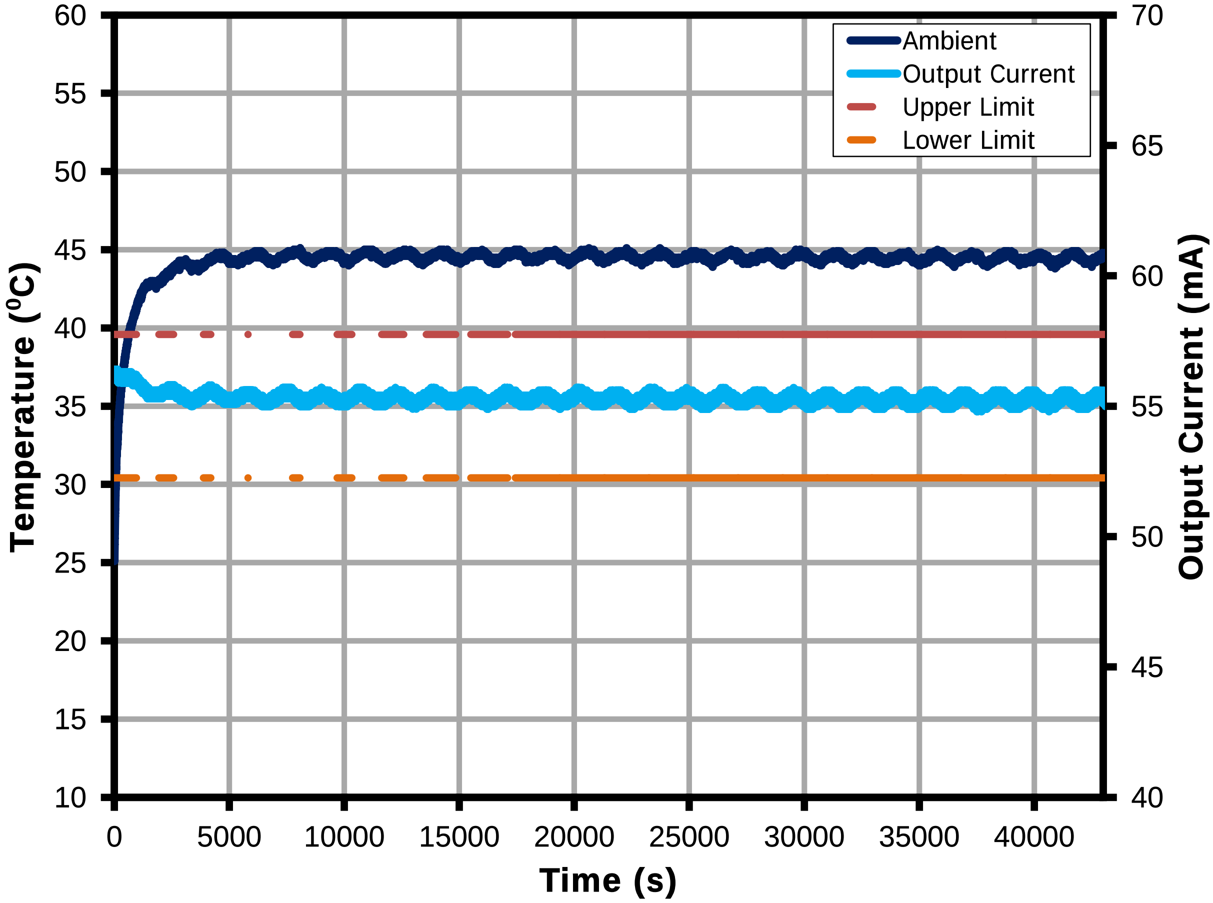


Figure 11 – Regulation vs. Time at 45 ºC Ambient.

9.3 Power Factor

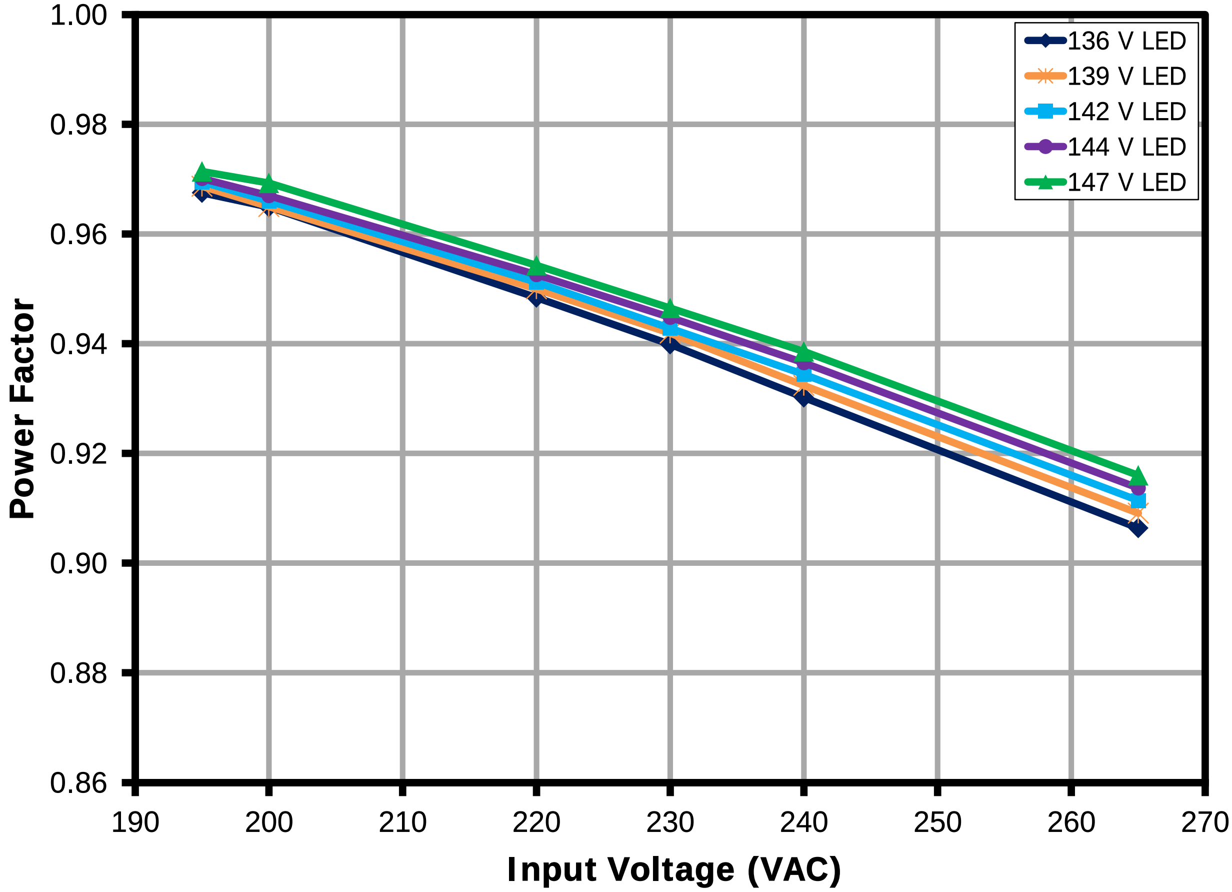


Figure 12 – Power Factor vs. Line and LED Load.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

9.4 %ATHD

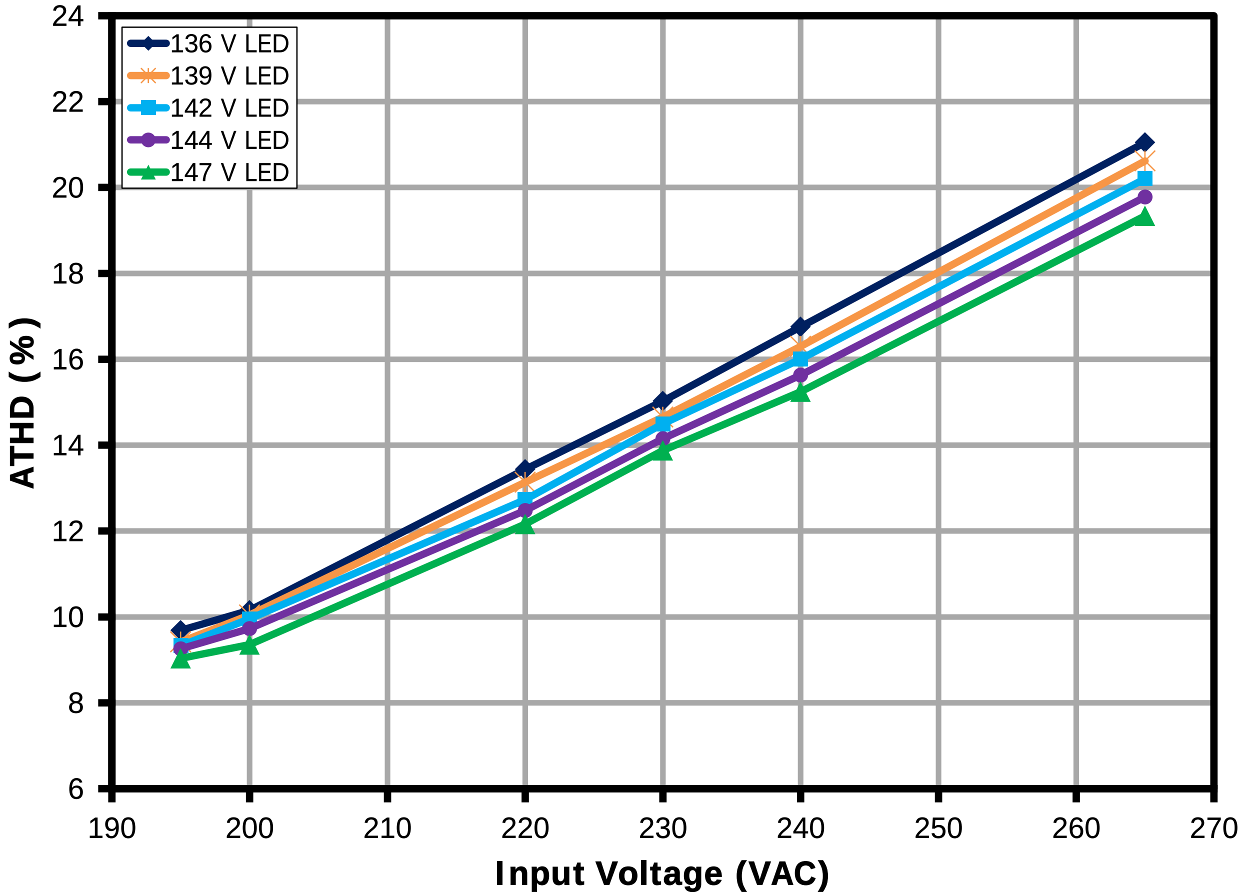


Figure 13 – %ATHD vs. Line and LED Load at 230 VAC, 50 Hz.

9.5 Harmonics

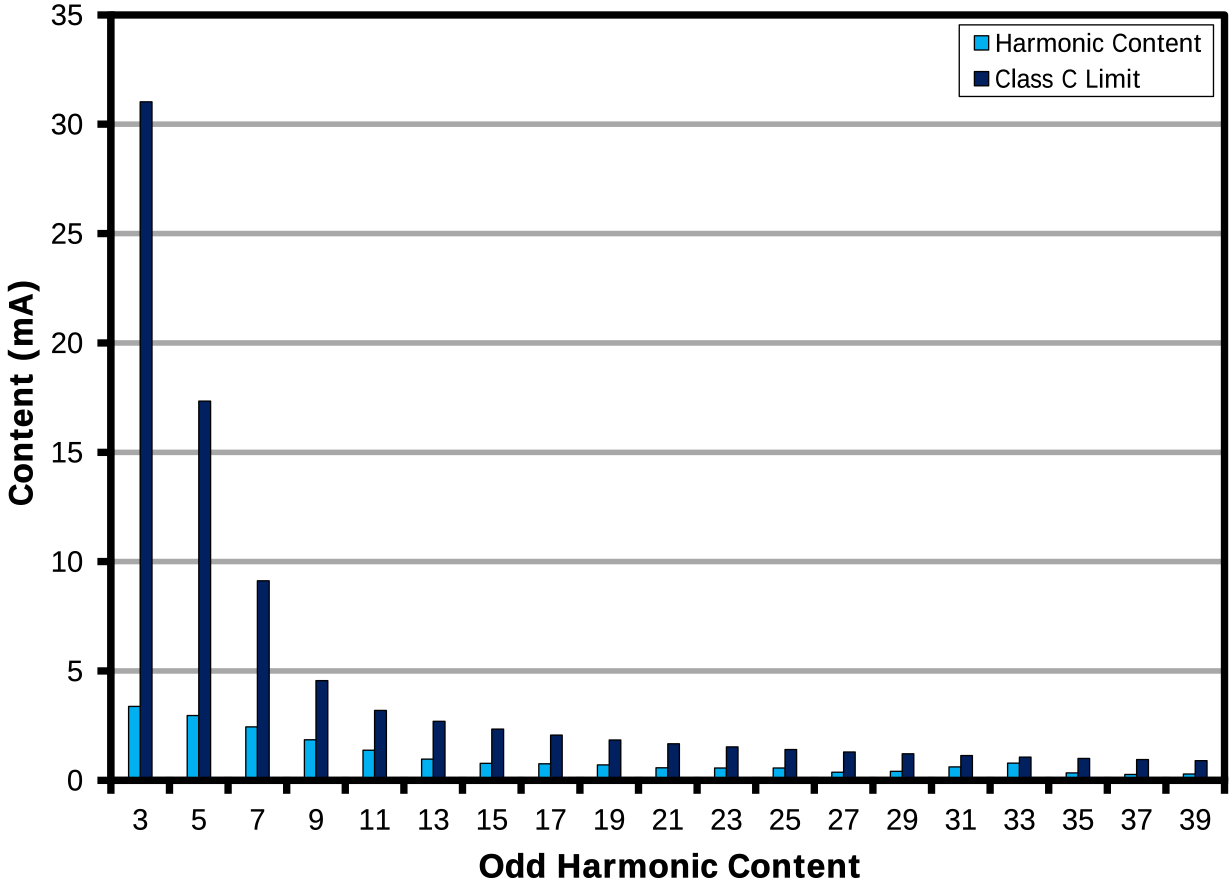


Figure 14 – 141 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

10 Test Data

10.1 Test Data, 136 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	194.90	47.57	8.97	0.968	9.69	138.20	54.90	7.61	84.86
200	50	199.95	47.03	9.07	0.965	10.16	137.80	55.70	7.70	84.86
220	50	219.88	42.37	8.84	0.948	13.44	137.40	54.92	7.57	85.66
230	50	229.90	40.92	8.84	0.940	15.02	137.23	55.14	7.59	85.86
240	50	239.92	39.37	8.79	0.930	16.75	137.04	55.08	7.57	86.18
265	50	264.93	36.81	8.84	0.906	21.05	137.01	55.69	7.65	86.58

10.2 Test Data, 139 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	194.91	48.45	9.15	0.969	9.42	140.70	54.80	7.73	84.53
200	50	199.96	47.09	9.09	0.965	10.05	140.25	54.79	7.71	84.82
220	50	219.89	43.08	9.00	0.950	13.14	140.10	54.81	7.70	85.59
230	50	229.91	41.72	9.03	0.942	14.66	140.03	55.20	7.75	85.81
240	50	239.93	40.07	8.96	0.932	16.3	139.88	55.01	7.72	86.10
265	50	264.93	37.45	9.02	0.909	20.62	139.88	55.64	7.81	86.53

10.3 Test Data, 142 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	194.91	49.06	9.27	0.970	9.33	142.87	54.66	7.83	84.48
200	50	199.96	47.76	9.23	0.966	9.96	142.55	54.67	7.82	84.73
220	50	219.89	43.68	9.14	0.951	12.73	142.44	54.68	7.81	85.51
230	50	229.91	42.10	9.13	0.943	14.50	142.40	54.85	7.83	85.84
240	50	239.93	40.72	9.13	0.934	16.00	142.34	55.02	7.85	86.04
265	50	264.94	38.01	9.18	0.911	20.21	142.40	55.58	7.94	86.48

10.4 Test Data, 144 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	49.47	9.35	0.970	9.26	144.98	54.32	7.90	84.44
200	50	199.97	48.51	9.38	0.967	9.73	144.94	54.63	7.94	84.64
220	50	219.90	44.38	9.30	0.953	12.48	144.88	54.66	7.94	85.43
230	50	229.92	42.90	9.32	0.945	14.15	144.90	55.02	7.99	85.78
240	50	239.94	41.46	9.32	0.937	15.63	144.87	55.08	8.00	85.89
265	50	264.95	38.58	9.34	0.914	19.78	144.92	55.55	8.07	86.44

10.5 Test Data, 147 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	50.69	9.60	0.971	9.03	147.84	54.58	8.09	84.31
200	50	199.97	50.16	9.72	0.969	9.36	147.78	55.44	8.22	84.50
220	50	219.90	45.22	9.49	0.954	12.16	147.53	54.73	8.10	85.34
230	50	229.92	43.59	9.49	0.947	13.88	147.50	54.96	8.13	85.70
240	50	239.94	42.20	9.50	0.939	15.24	147.48	55.15	8.16	85.83
265	50	264.95	39.19	9.51	0.916	19.34	147.50	55.55	8.22	86.38

10.6 Test Data, Harmonic Content at 230 VAC with 141 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	42.10	9.126	0.943	14.498
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	41.65				
2	0.02	0.05%		2.00%	
3	3.38	8.12%	31.03	28.28%	Pass
5	2.97	7.13%	17.34	10.00%	Pass
7	2.45	5.88%	9.13	7.00%	Pass
9	1.85	4.45%	4.56	5.00%	Pass
11	1.37	3.30%	3.19	3.00%	Pass
13	0.97	2.33%	2.70	3.00%	Pass
15	0.78	1.88%	2.34	3.00%	Pass
17	0.76	1.82%	2.07	3.00%	Pass
19	0.71	1.69%	1.85	3.00%	Pass
21	0.57	1.37%	1.67	3.00%	Pass
23	0.56	1.34%	1.53	3.00%	Pass
25	0.56	1.34%	1.41	3.00%	Pass
27	0.37	0.89%	1.30	3.00%	Pass
29	0.41	0.98%	1.21	3.00%	Pass
31	0.62	1.49%	1.13	3.00%	Pass
33	0.79	1.89%	1.06	3.00%	Pass
35	0.34	0.83%	1.00	3.00%	Pass
37	0.27	0.66%	0.95	3.00%	Pass
39	0.29	0.68%	0.90	3.00%	Pass

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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 141 V LED load.

11.1 Dimming Curve

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

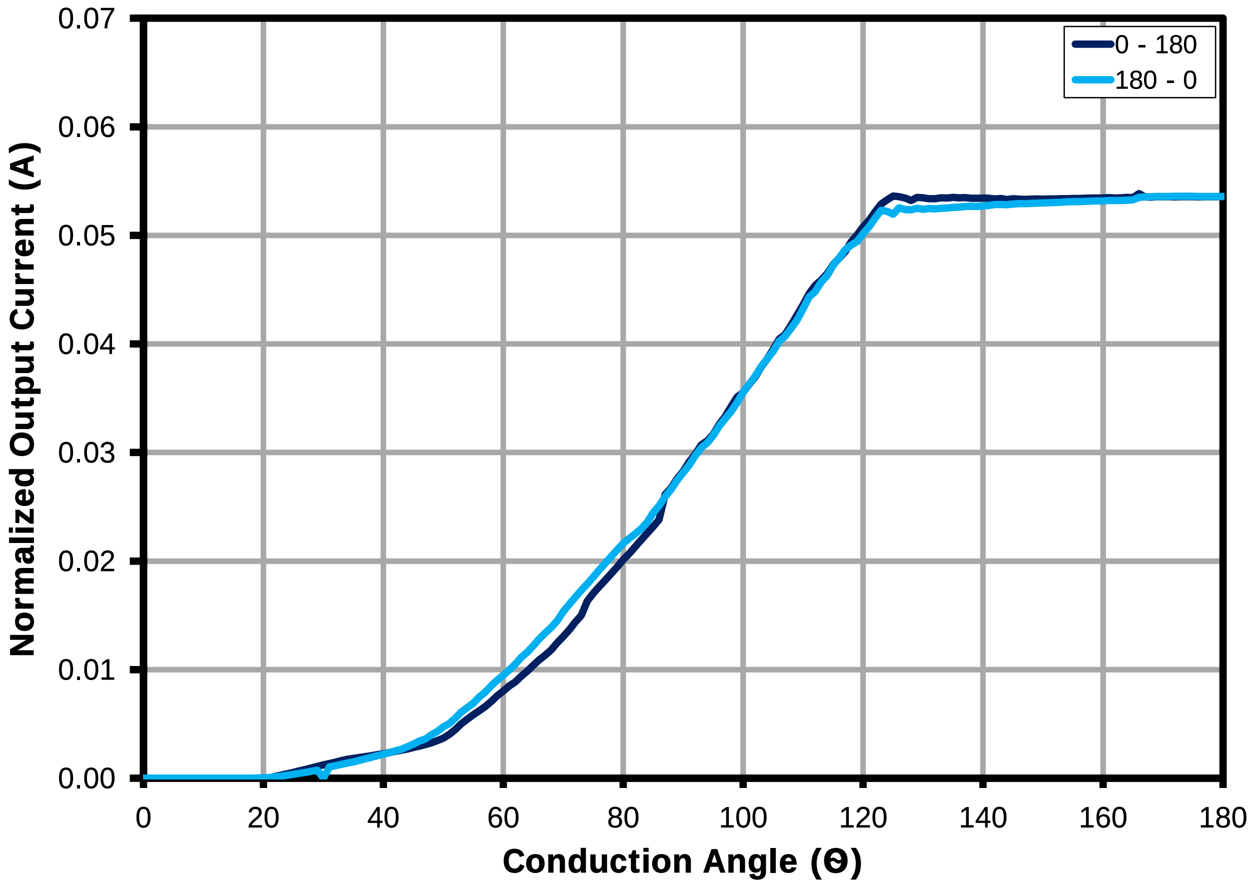


Figure 15 – Dimming Curve at 230 VAC, 50 Hz Input.

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.

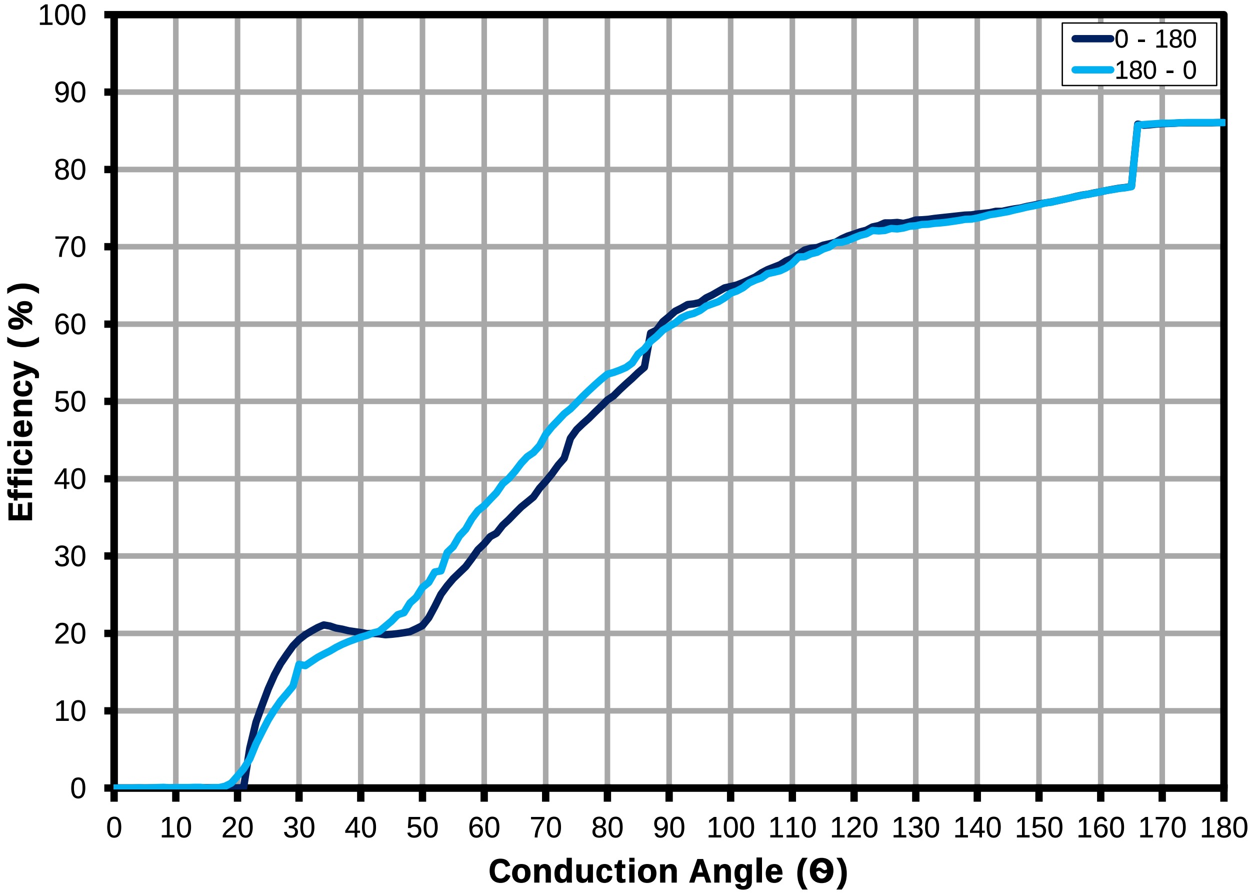


Figure 16 – Driver Efficiency at 230 VAC, 50 Hz Input.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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.

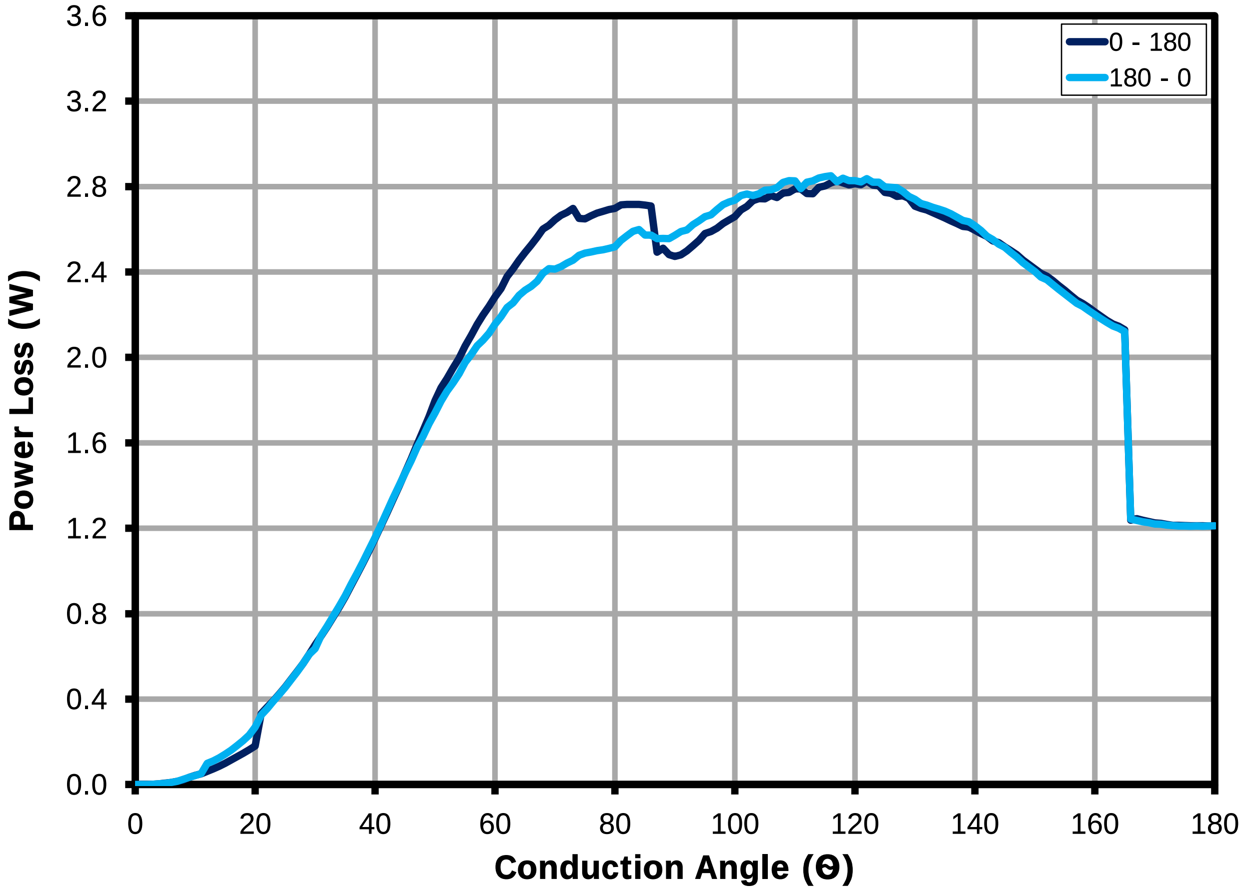


Figure 17 – Driver Power Loss at 230 VAC, 50 Hz Input.

11.4 Compatibility Example with Available Dimmers

The following dimmers were tested at 45 ºC external ambient temperature (inside the LED bulb casing) with utility line input (~230 VAC, 50 Hz) and 141 V LED load.

No	Panel	Brand	Model	Type	Max (mA)	Min (mA)
1	EU Panel 1	BERKER	2875	L	54.116	9.676
2	EU Panel 1	GIRA	0307 00	T	56.858	7.814
3	EU Panel 1	BERKER	2830	L	54.362	9.741
4	EU Panel 1	GIRA	1176 00	T	55.838	13.315
5	EU Panel 1	GIRA	0302 00	L	53.268	8.098
6	EU Panel 1	GIRA	2262 00	L	54.297	2.633
7	EU Panel 1	GIRA	0300 00	L	53.645	21.075
8	EU Panel 1	PEHA	433 HAB 0A	T	59.385	7.979
9	EU Panel 2	JUNG	225 TDE	T	57.235	9.247
10	EU Panel 2	JUNG	266 GDE	L	54.921	8.875
11	EU Panel 2	JUNG	225 NVDE	L	54.455	4.972
12	EU Panel 2	JUNG	254 UDIE 1	T	56.664	12.686
13	EU Panel 2	BUSCH	6591 U-101	T	31.739	7.602
14	EU Panel 2	BUSCH	6513-102	L	54.821	12.208
15	EU Panel 2	BUSCH	2247 U	L	54.748	10.151
16	EU Panel 2	BUSCH	2250 U	L	57.235	9.247
17	EU Panel3	NIKO	310-01400	L	54.753	12.649
18	EU Panel3	NIKO	310-01700	T	58.328	16.661
19	EU Panel3	LEGRAND	048871-665114	T	58.689	3.079
20	EU Panel3	AURORA	AUDSP400X	L	54.602	0.0469
21	EU Panel4	SCHNEIDER	ALB4X192	L	54.769	4.649
22	EU Panel4	RELCO	RTM 34LED	L	54.588	3.501

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

12 Thermal Performance

Thermal measurements were performed with the power supply operating at 45 ºC external ambient temperature inside bulb casing with 141 V LED load.

12.1 Non-Dimming Thermal Performance at 195 VAC with a 141 V LED Load

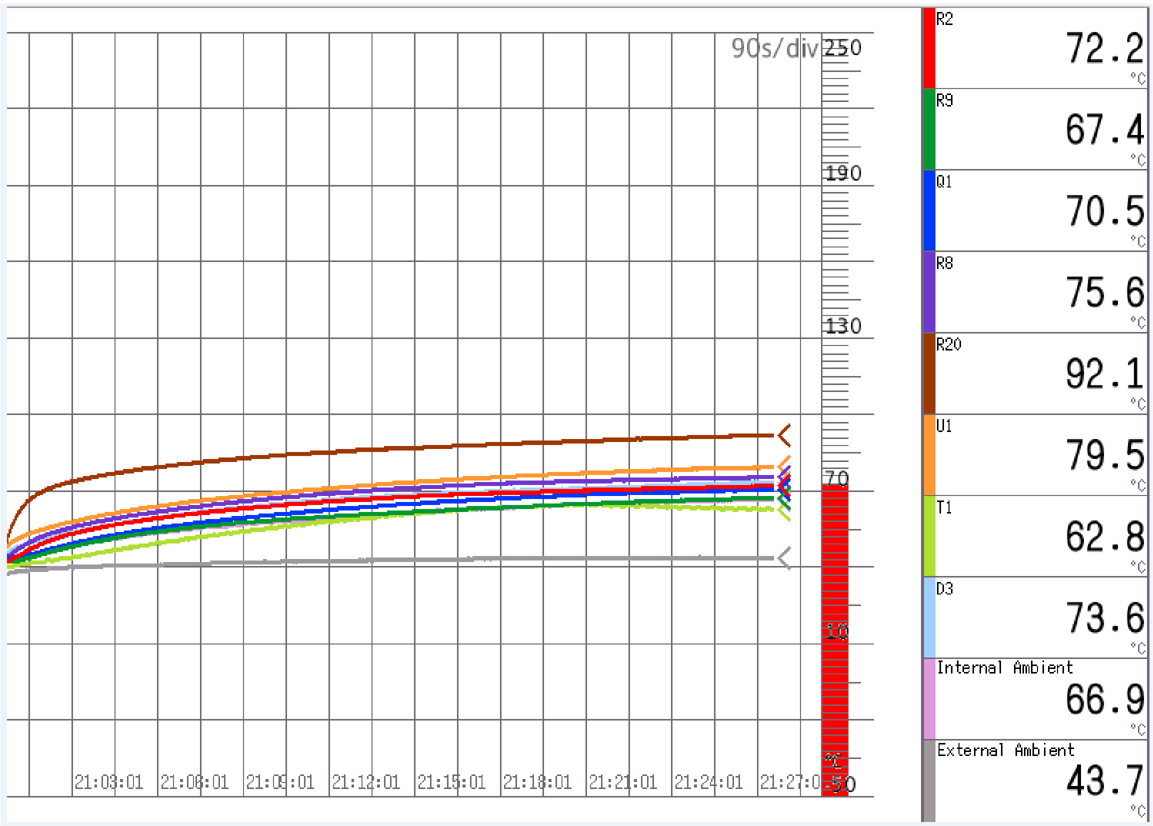


Figure 18 – Component Temperature at 195 VAC, 45 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	72.2
2	R9	BLEEDER RESISTOR	67.4
3	Q1	BLEEDER TRANSISTOR	70.5
4	R8	PASSIVE BLEEDER RESISTOR	75.6
5	R20	DAMPER RESISTOR	92.1
6	U1	LYT3324D IC	79.5
7	T1	BUCK-BOOST INDUCTOR	62.8
8	D3	BUCK-BOOST DIODE	73.6
9	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	66.9
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	43.7

12.2 Non-Dimming Thermal Performance at 265 VAC with a 141 V LED Load

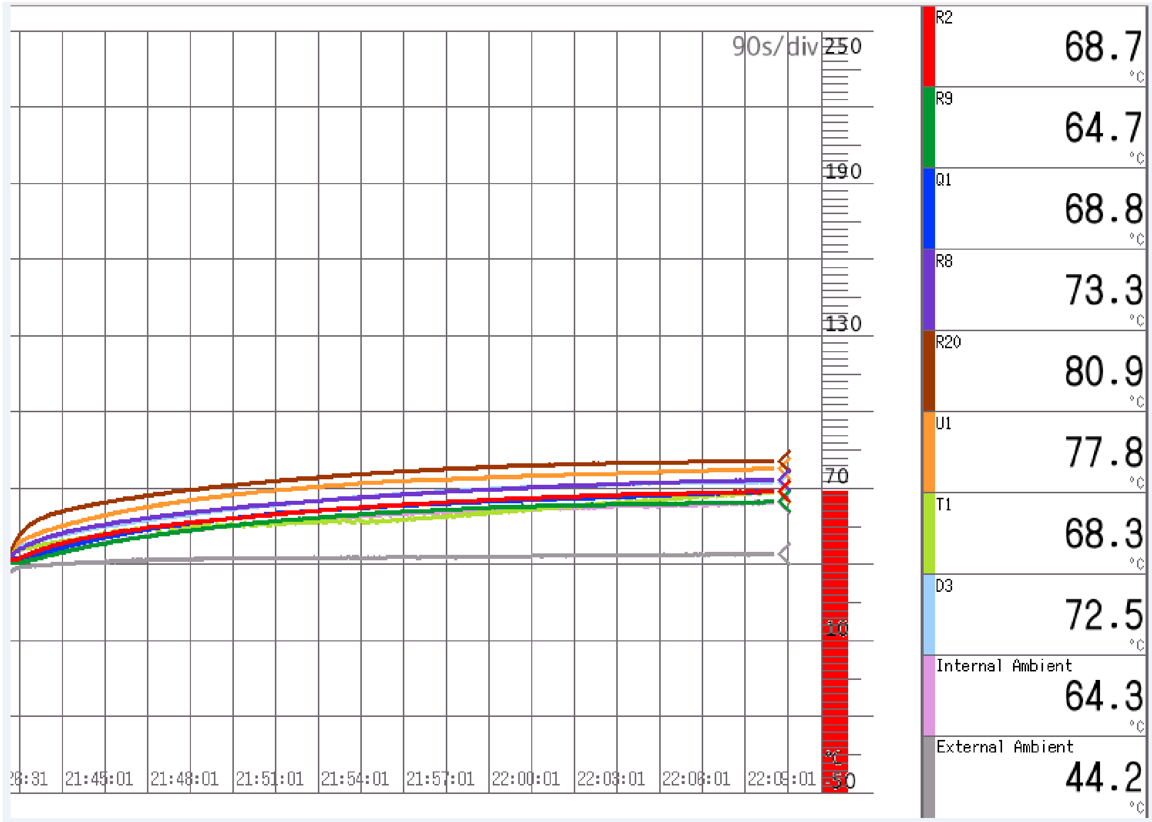


Figure 19 – Component Temperature at 265 VAC, 75 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	68.7
2	R9	BLEEDER RESISTOR	64.7
3	Q1	BLEEDER TRANSISTOR	68.8
4	R8	PASSIVE BLEEDER RESISTOR	73.3
5	R20	DAMPER RESISTOR	80.9
6	U1	LYT3324D IC	77.8
7	T1	BUCK-BOOST INDUCTOR	68.3
8	D3	BUCK-BOOST DIODE	72.5
9	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	64.3
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	44.2

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

12.3 Dimming Thermal Performance at 240 VAC, 90º Conduction Angle

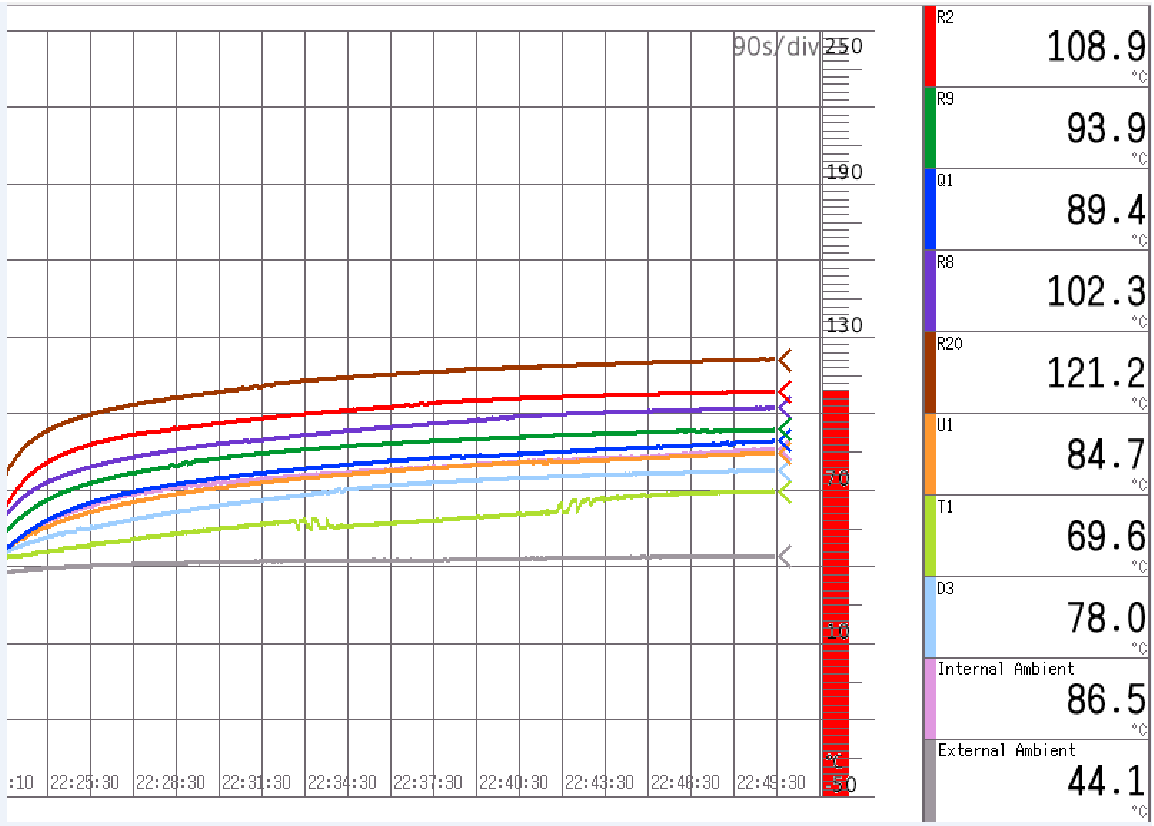


Figure 19 – Component Temperature at 240 VAC, 90º Conduction Angle, 45 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	108.9
2	R9	BLEEDER RESISTOR	93.9
3	Q1	BLEEDER TRANSISTOR	89.4
4	R8	PASSIVE BLEEDER RESISTOR	102.3
5	R20	DAMPER RESISTOR	121.2
6	U1	LYT3324D IC	84.7
7	T1	BUCK-BOOST INDUCTOR	69.6
8	D3	BUCK-BOOST DIODE	78.0
9	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	86.5
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	44.1

12.4 Dimming Thermal Performance at 240 VAC, 110° Conduction Angle

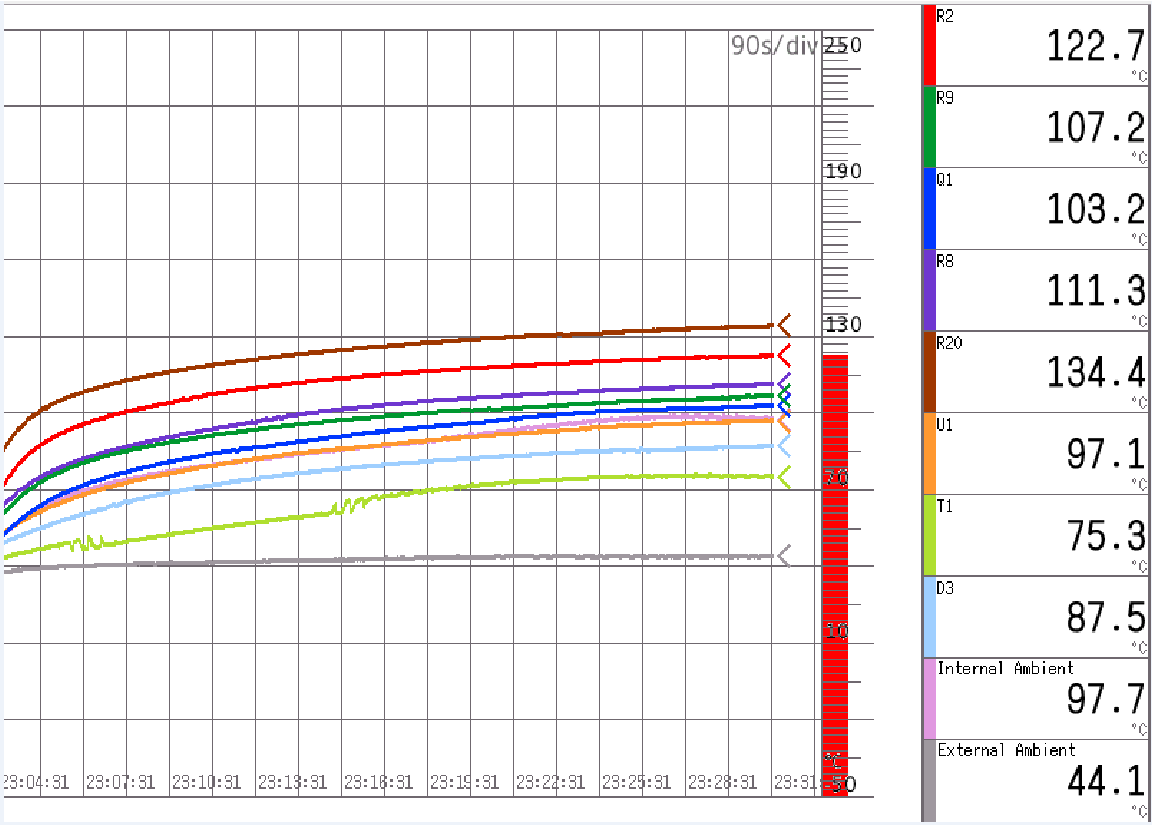


Figure 20 – Component Temperature at 240 VAC, 110° Conduction Angle, 45 °C Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	122.7
2	R9	BLEEDER RESISTOR	107.2
3	Q1	BLEEDER TRANSISTOR	103.2
4	R8	PASSIVE BLEEDER RESISTOR	111.3
5	R20	DAMPER RESISTOR	134.4
6	U1	LYT3324D IC	97.1
7	T1	BUCK-BOOST INDUCTOR	75.3
8	D3	BUCK-BOOST DIODE	87.5
9	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	97.7
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	44.1

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

12.5 Dimming Thermal Performance at 240 VAC, 130º Conduction Angle

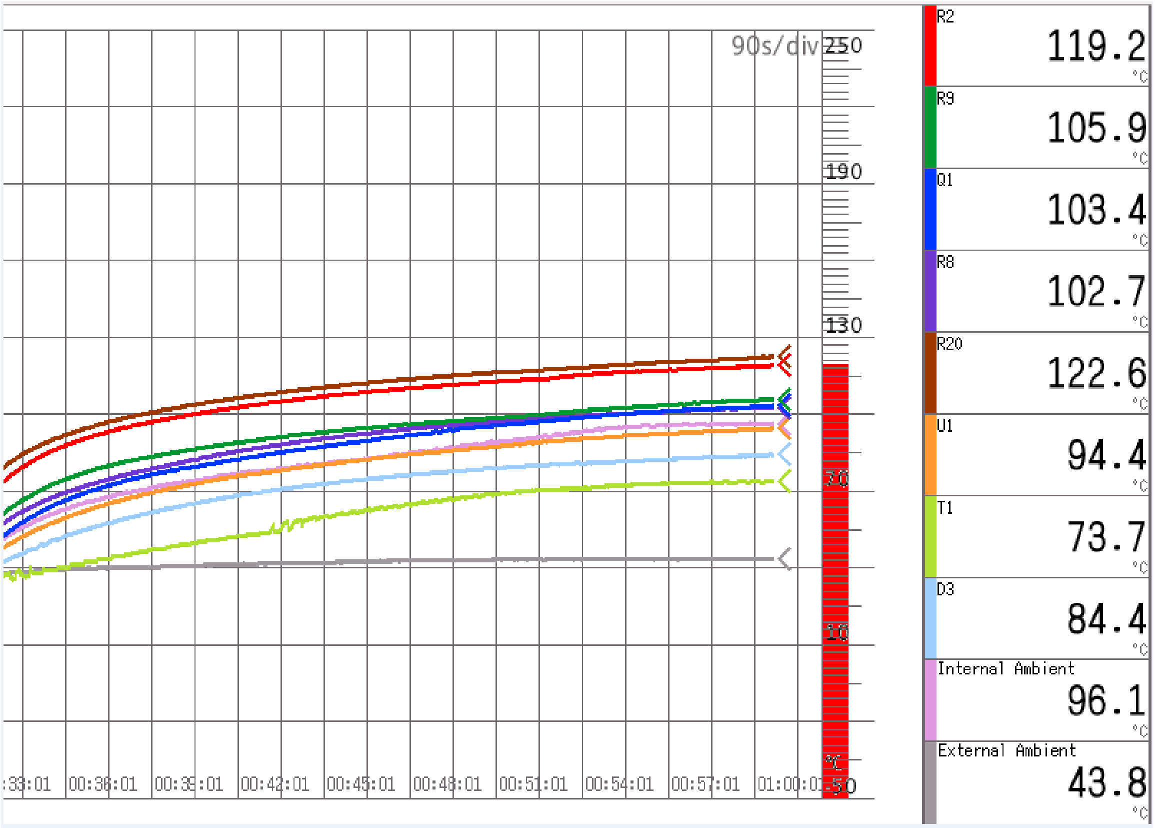


Figure 21 – Component Temperature at 240 VAC, 130º Conduction Angle, 45 ºC Ambient.

CHANNEL	CIRCUIT CODE	DESCRIPTION	MEASURED TEMPERATURE (°C)
1	R2	BLEEDER RESISTOR	119.2
2	R9	BLEEDER RESISTOR	105.9
3	Q1	BLEEDER TRANSISTOR	103.4
4	R8	PASSIVE BLEEDER RESISTOR	102.7
5	R20	DAMPER RESISTOR	122.6
6	U1	LYT3324D IC	94.4
7	T1	BUCK-BOOST INDUCTOR	73.7
8	D3	BUCK-BOOST DIODE	84.4
9	INTERNAL AMB	AMBIENT INSIDE THE LED BULB	96.1
10	EXTERNAL AMB	AMBIENT OUTSIDE THE LED BULB	43.8

13 Waveforms

13.1 Input Voltage and Input Current Waveforms

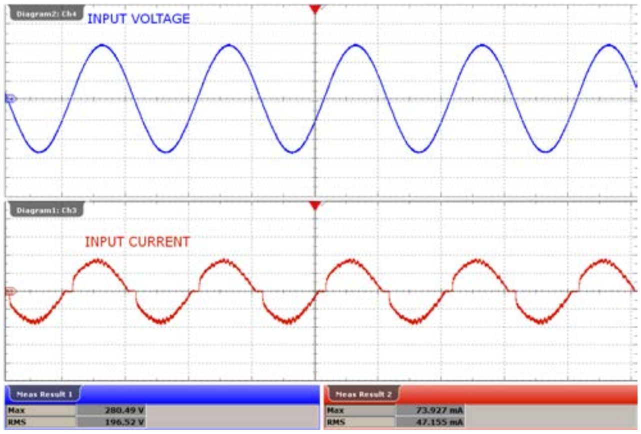


Figure 22 – 195 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 74 mA_{PK}.
Peak V_{IN}: 280 V_{PK}.

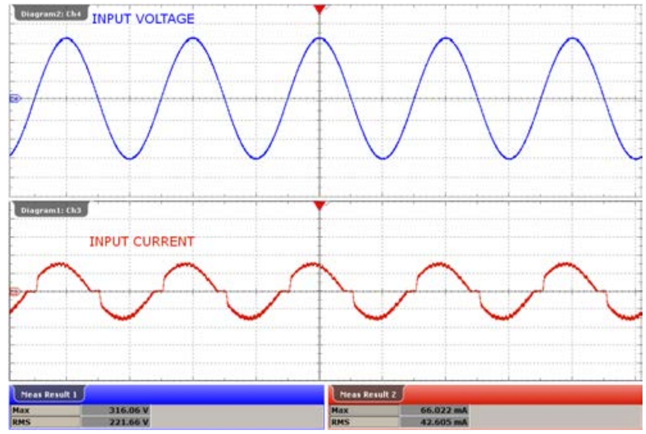


Figure 23 – 220 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 66 mA_{PK}.
Peak V_{IN}: 316 V_{PK}.

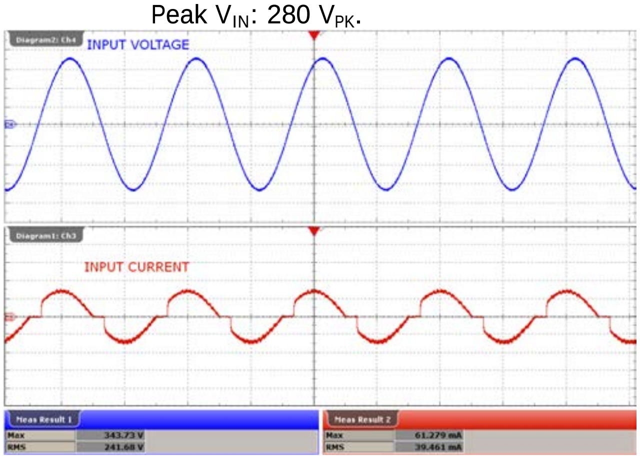


Figure 24 – 240 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 61 mA_{PK}.
Peak V_{IN}: 343 V_{PK}.

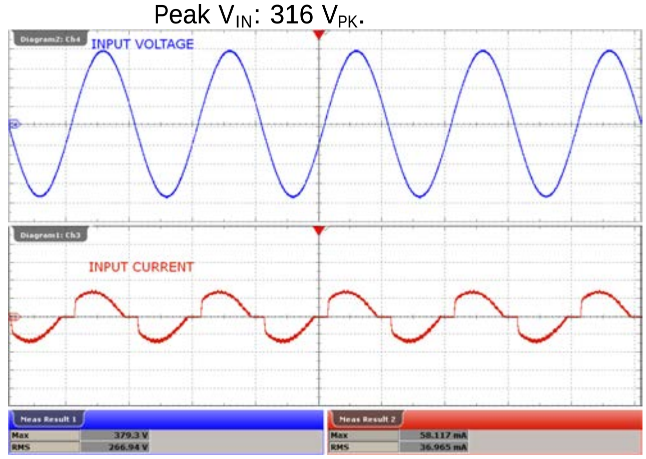


Figure 25 – 265 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 10 ms / div.
Lower: I_{IN}, 40 mA / div.
Peak I_{IN}: 58 mA_{PK}.
Peak V_{IN}: 379 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

13.2 Output Current Rise and Fall

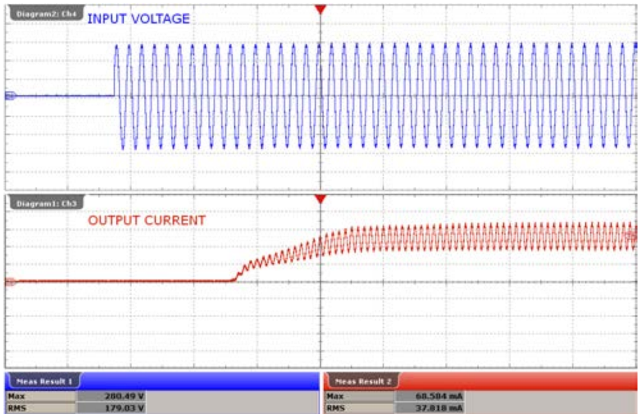


Figure 26 – 195 VAC, 141 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 68 mA_{PK}.
Peak V_{IN}: 280 V_{PK}.

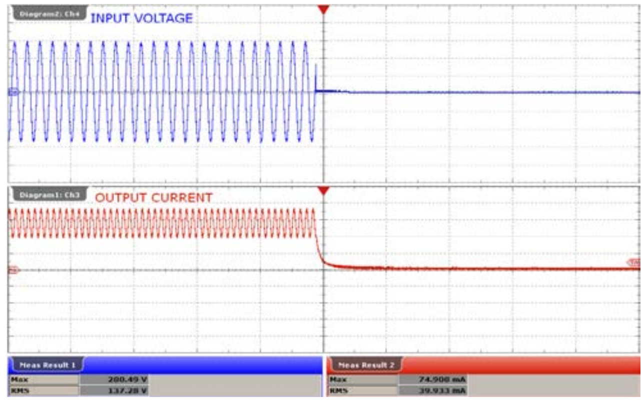


Figure 27 – 195 VAC, 141 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 75 mA_{PK}.
Peak V_{IN}: 280 V_{PK}.

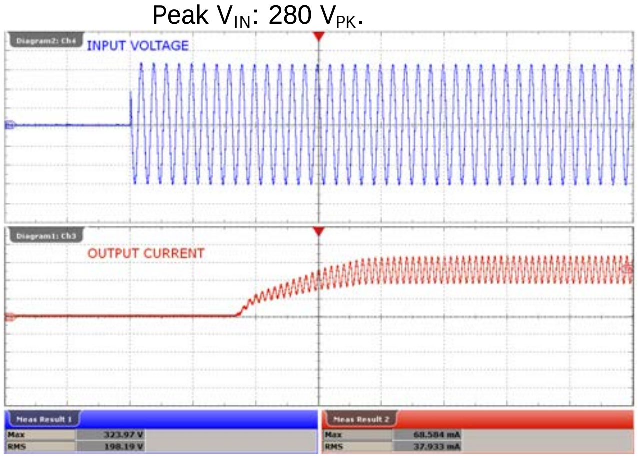


Figure 28 – 220 VAC, 141 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 68 mA_{PK}.
Peak V_{IN}: 323 V_{PK}.

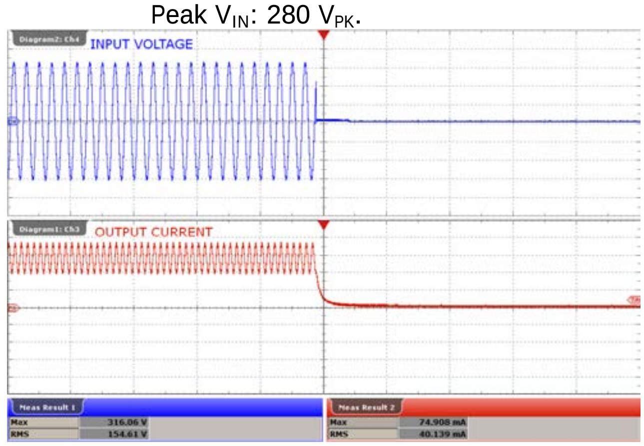


Figure 29 – 220 VAC, 141 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 75 mA_{PK}.
Peak V_{IN}: 316 V_{PK}.

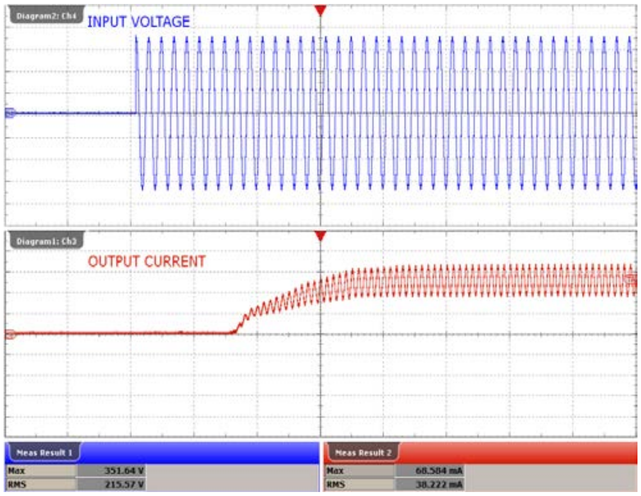


Figure 30 – 240 VAC, 141 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 68 mA_{PK}.
Peak V_{IN}: 351 V_{PK}.

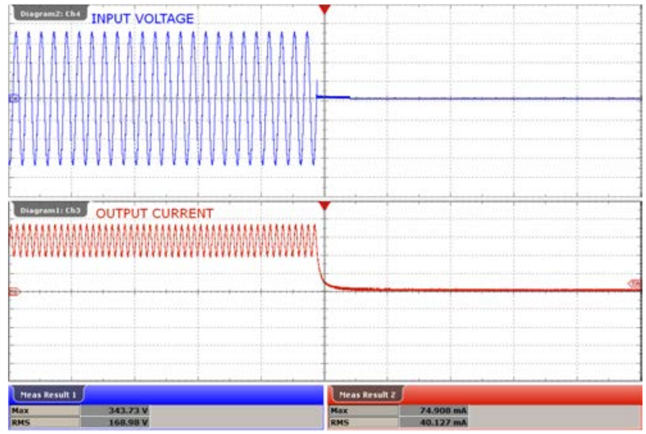


Figure 31 – 240 VAC, 141 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 75 mA_{PK}.
Peak V_{IN}: 343 V_{PK}.

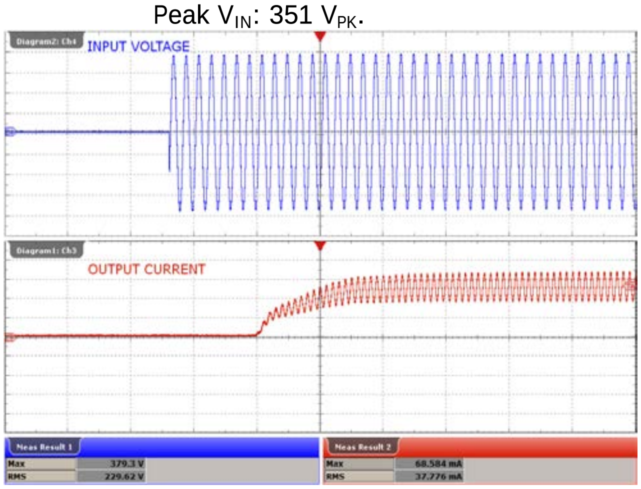


Figure 32 – 265 VAC, 141 V LED Load, Output Rise.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 68 mA_{PK}.
Peak V_{IN}: 379 V_{PK}.

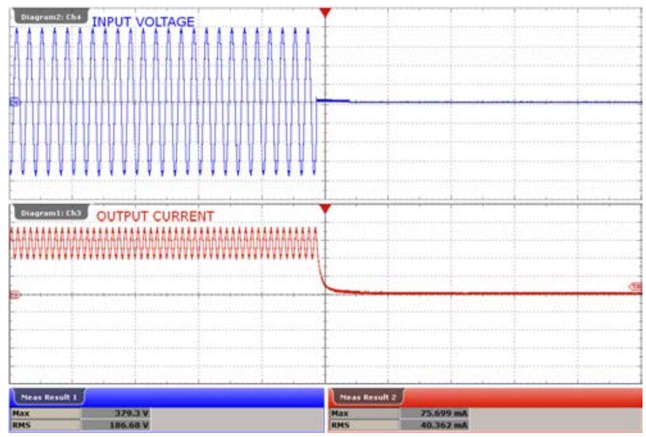


Figure 33 – 265 VAC, 141 V LED Load, Output Fall.
Upper: V_{IN}, 100 V / div., 100 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 75 mA_{PK}.
Peak V_{IN}: 379 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

13.3 Drain Voltage and Current in Normal Operation

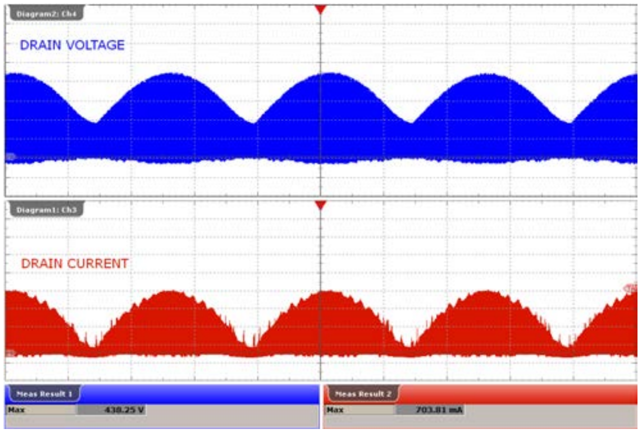


Figure 34 – 195 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 703 mA_{PK}.
Peak V_{DRAIN}: 438 V_{PK}.

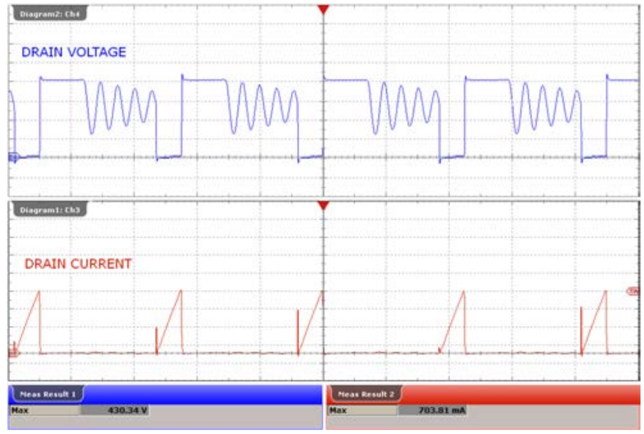


Figure 35 – 195 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 703 mA_{PK}.
Peak V_{DRAIN}: 430 V_{PK}.

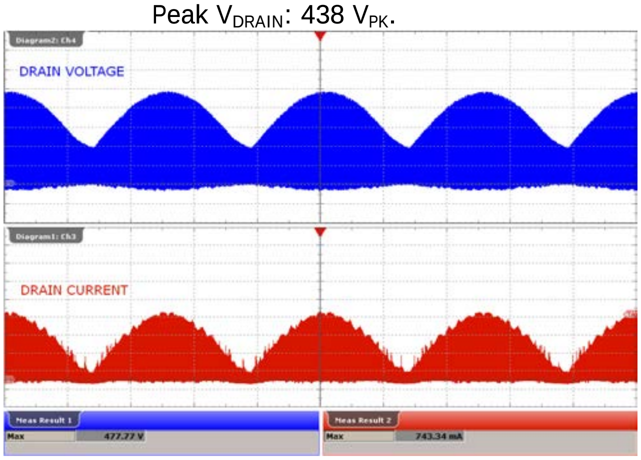


Figure 36 – 220 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 743 mA_{PK}.
Peak V_{DRAIN}: 478 V_{PK}.

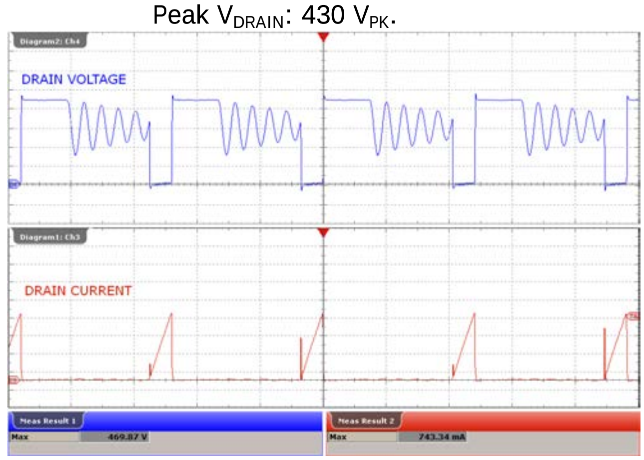


Figure 37 – 220 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 743 mA_{PK}.
Peak V_{DRAIN}: 470 V_{PK}.

Power Integrations, Inc.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

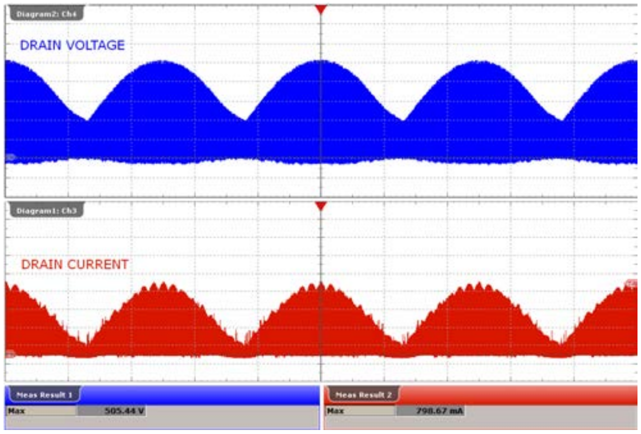


Figure 38 – 240 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 798 mA_{PK}.
Peak V_{DRAIN}: 505 V_{PK}.

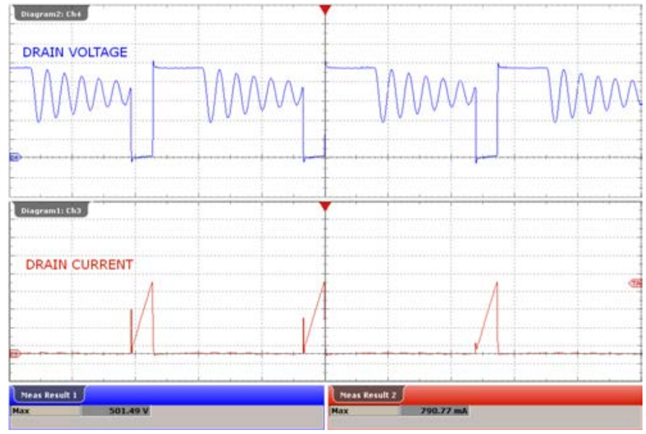


Figure 39 – 240 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 µs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 790 mA_{PK}.
Peak V_{DRAIN}: 501 V_{PK}.

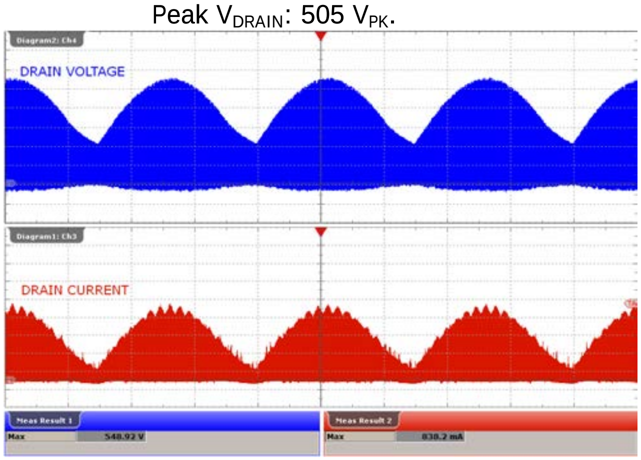


Figure 40 – 265 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 838 A_{PK}.
Peak V_{DRAIN}: 549 V_{PK}.

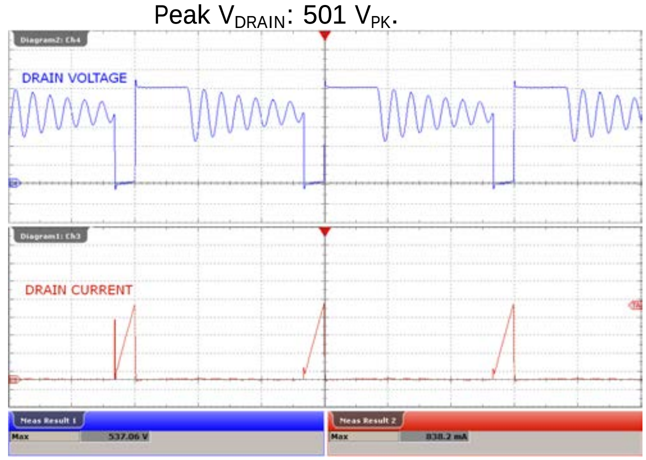


Figure 41 – 265 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 µs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 838 A_{PK}.
Peak V_{DRAIN}: 537 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

13.4 Drain Voltage and Current Start-up Profile

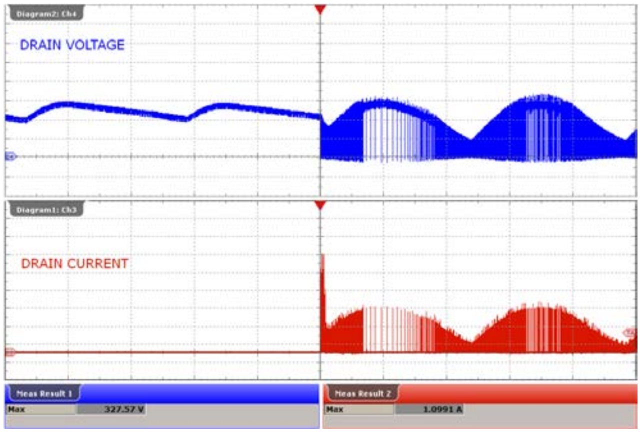


Figure 42 – 195 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 20 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.099 A_{PK}.
Peak V_{DRAIN}: 327 V_{PK}.

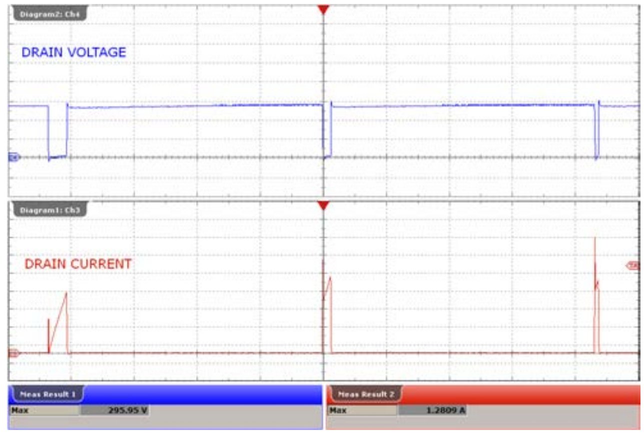


Figure 43 – 195 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.281 A_{PK}.
Peak V_{DRAIN}: 296 V_{PK}.

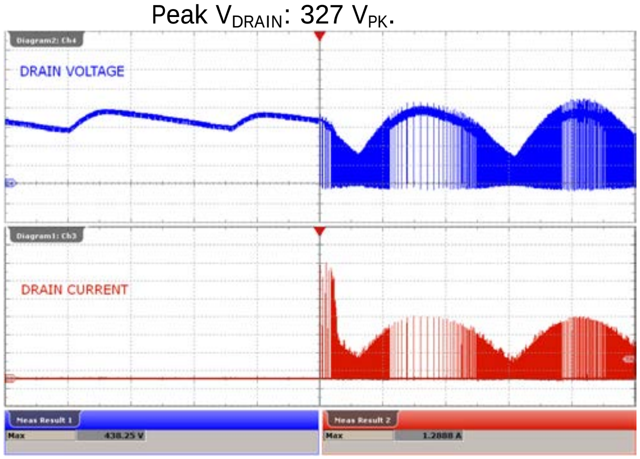


Figure 44 – 265 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 20 ms / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.288 A_{PK}.
Peak V_{DRAIN}: 438 V_{PK}.

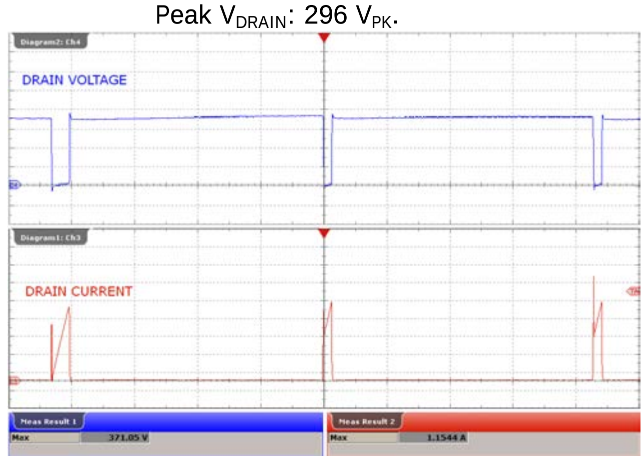


Figure 45 – 265 VAC, 141 V LED Load.
Upper: V_{DRAIN}, 100 V / div., 4 μs / div.
Lower: I_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 1.154 A_{PK}.
Peak V_{DRAIN}: 371 V_{PK}.

13.5 Drain Voltage and Current During Output Short-Circuit Condition

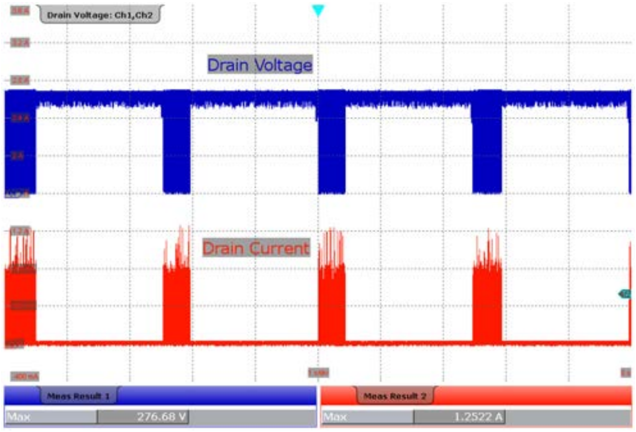


Figure 46 – 195 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.25 A_{PK}.
Peak V_{DRAIN}: 277 V_{PK}.

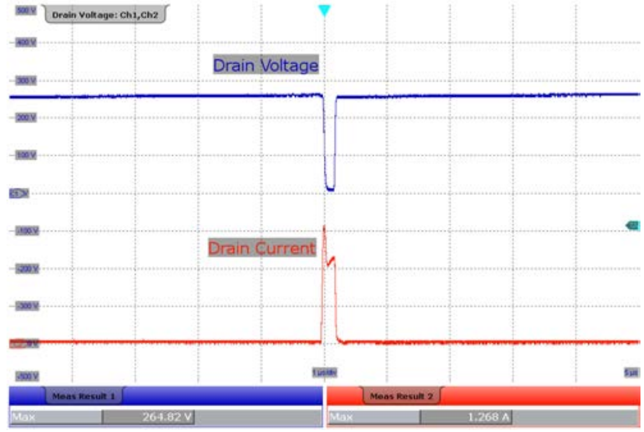


Figure 47 – 195 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 1 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.26 A_{PK}.
Peak V_{DRAIN}: 264 V_{PK}.

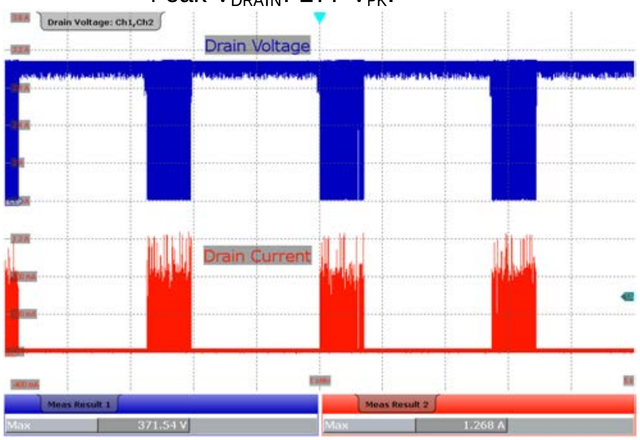


Figure 48 – 265 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 4 ms / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.26 A_{PK}.
Peak V_{DRAIN}: 372 V_{PK}.

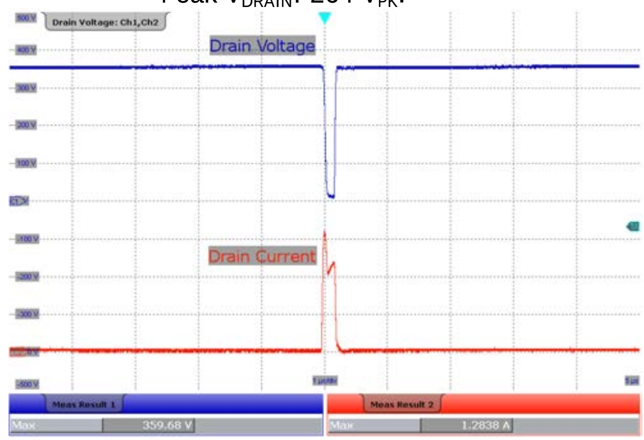


Figure 49 – 265 VAC, Output Short.
Upper: V_{DRAIN}, 100 V / div., 1 μs / div.
Lower: I_{DRAIN}, 400 mA / div.
Peak I_{DRAIN}: 1.24 A_{PK}.
Peak V_{DRAIN}: 359 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

13.6 Output Diode Voltage and Current in Normal Operation

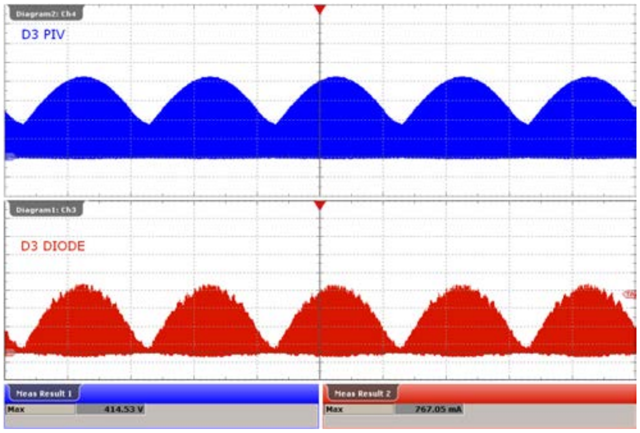


Figure 50 – 195 VAC, 141 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 767 mA_{PK}.
Peak V_{D3}: 414 V_{PK}.

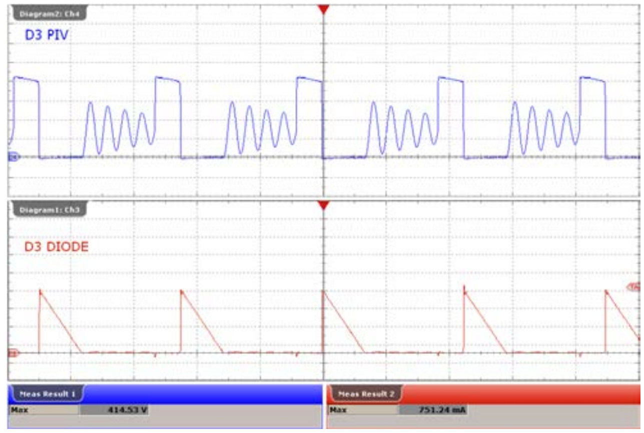


Figure 51 – 195 VAC, 141 V LED Load.
Upper: V_{D3}, 100 V / div., 4 µs / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 751 mA_{PK}.
Peak V_{D3}: 414 V_{PK}.

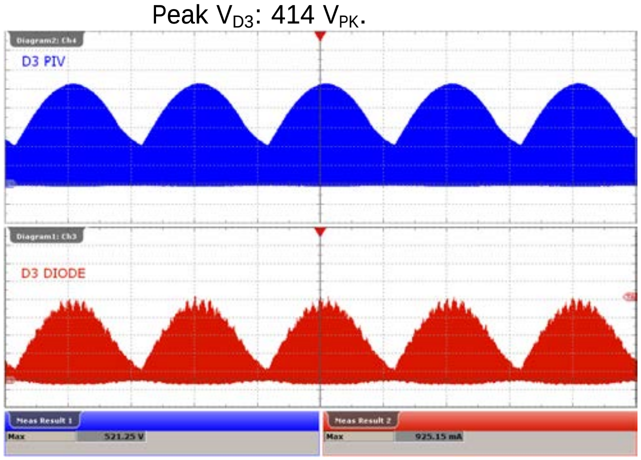


Figure 52 – 265 VAC, 141 V LED Load.
Upper: V_{D3}, 100 V / div., 5 ms / div.
Lower: I_{D3}, 200 mA / div.
Peak I_{D3}: 925 mA_{PK}.
Peak V_{D3}: 521 V_{PK}.

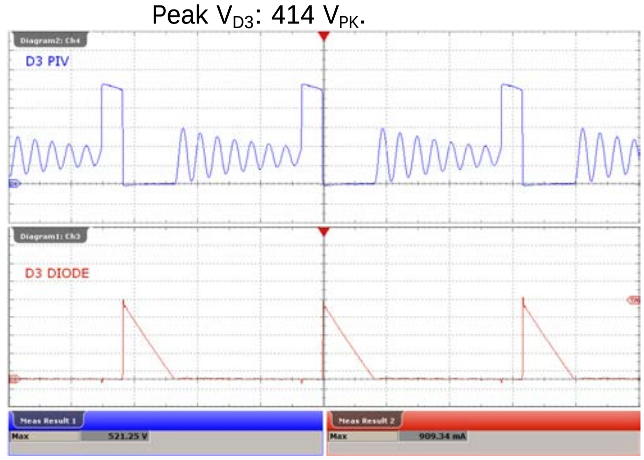


Figure 53 – 265 VAC, 141 V LED Load.
Upper: I_{DRAIN}, 100 V / div., 4 µs / div.
Lower: V_{DRAIN}, 200 mA / div.
Peak I_{DRAIN}: 909 mA_{PK}.
Peak V_{DRAIN}: 521 V_{PK}.

13.7 Output Voltage and Current – Open LED Load

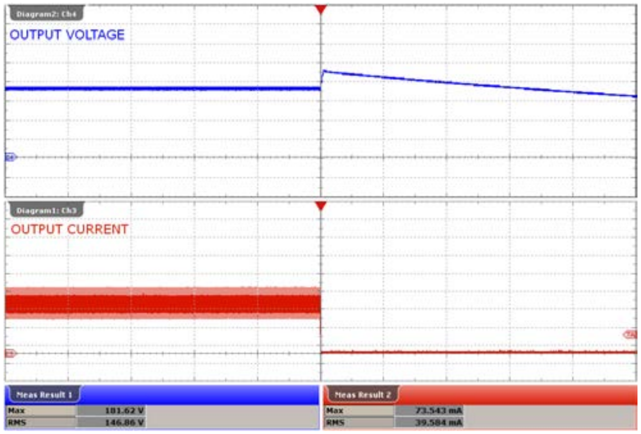


Figure 54 – 195 VAC, 141 V LED Load.
Running Open Load.
Upper: V_{OUT}, 50 V / div., 500 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 73 mA_{PK}.
Peak V_{OUT}: 181 V_{PK}.

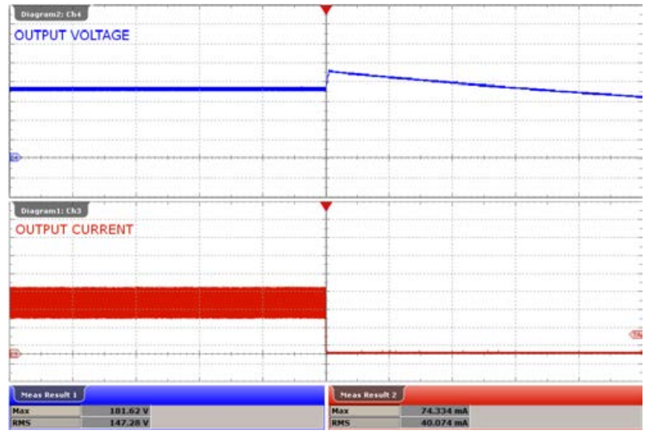


Figure 55 – 265 VAC, 141 V LED Load.
Running Open Load.
Upper: V_{OUT}, 50 V / div., 500 ms / div.
Lower: I_{OUT}, 20 mA / div.
Peak I_{OUT}: 74 mA_{PK}.
Peak V_{OUT}: 181 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

13.8 Output Ripple Current

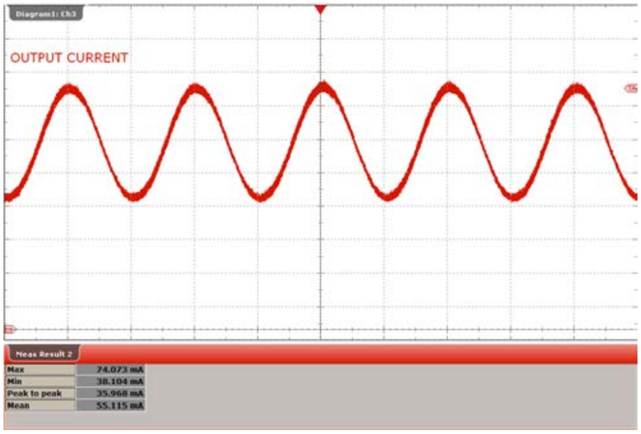


Figure 56 – 195 VAC, 50 Hz, 141 V LED Load.
I_{OUT}, 10 mA / div., 5 ms / div.

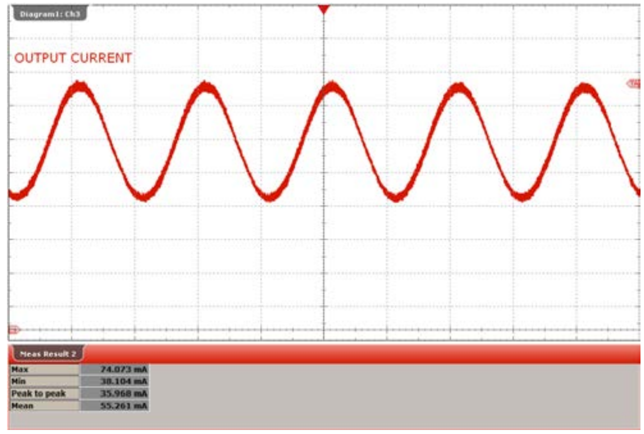


Figure 57 – 220 VAC, 50 Hz, 141 V LED Load.
I_{OUT}, 10 mA / div., 5 ms / div.

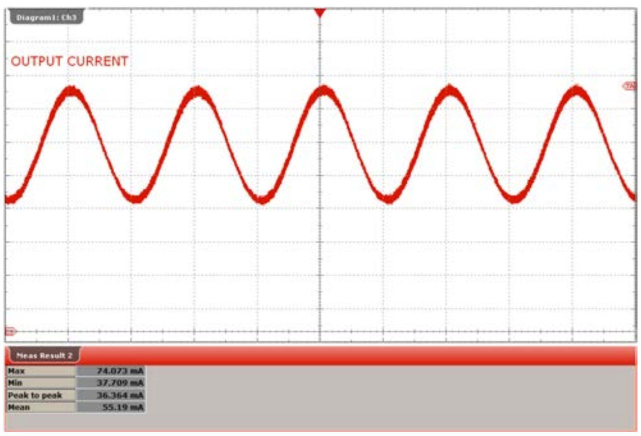


Figure 58 – 240 VAC, 50 Hz, 141 V LED Load.
I_{OUT}, 10 mA / div., 5 ms / div.

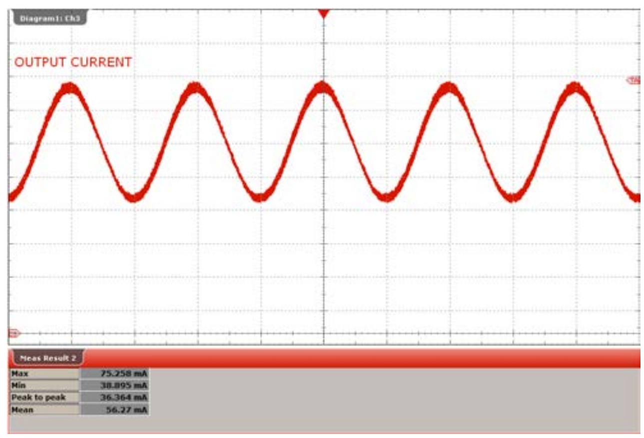


Figure 59 – 265 VAC, 50 Hz, 141 V LED Load.
I_{OUT}, 10 mA / div., 5 ms / div.

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	74.07	38.10	35.97	55.12	0.65	32.06
220V	74.07	38.10	35.97	55.26	0.65	32.06
240	74.07	37.71	36.36	55.19	0.66	32.52
265	75.28	38.89	36.36	56.27	0.65	31.84

14 Dimming Waveforms

14.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 141 V LED load
Dimmer: Berker 2875

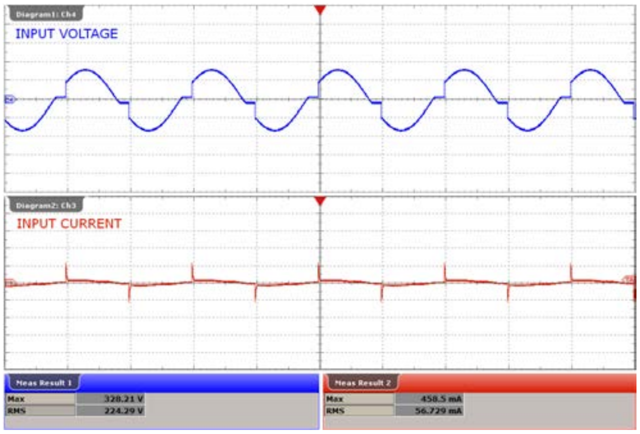


Figure 60 – 140° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div. .
Peak V_{IN}: 328 V_{PK}.
V_{RMS}: 224 V.

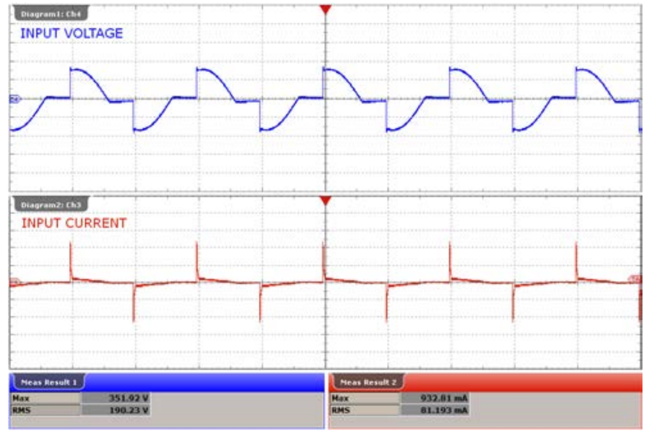


Figure 61 – 110° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div.
Peak V_{IN}: 351 V_{PK}.
V_{RMS}: 190 V.

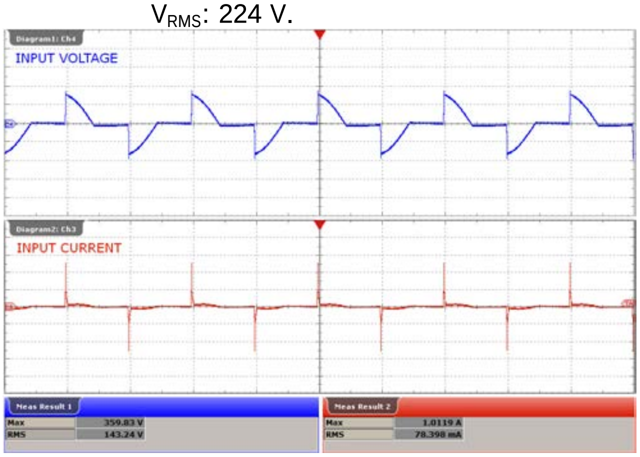


Figure 62 – 90° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div.
Peak V_{IN}: 359 V_{PK}.
V_{RMS}: 143 V.

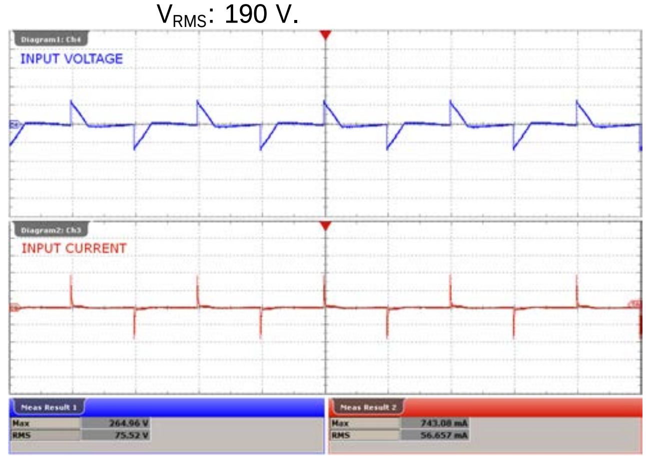


Figure 63 – 45° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 200 mA / div.
Peak V_{IN}: 264 V_{PK}.
V_{RMS}: 75 V.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

14.2 Output Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 141 V LED load
Dimmer: Berker 2875

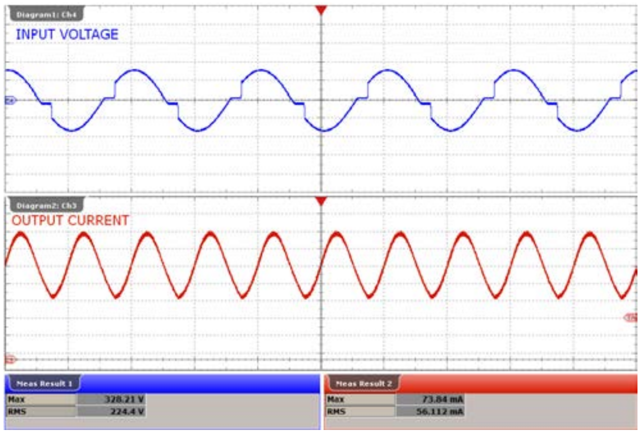


Figure 64 – 140° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 74 mA_{PK}.
Peak V_{IN}: 328 V_{PK}.

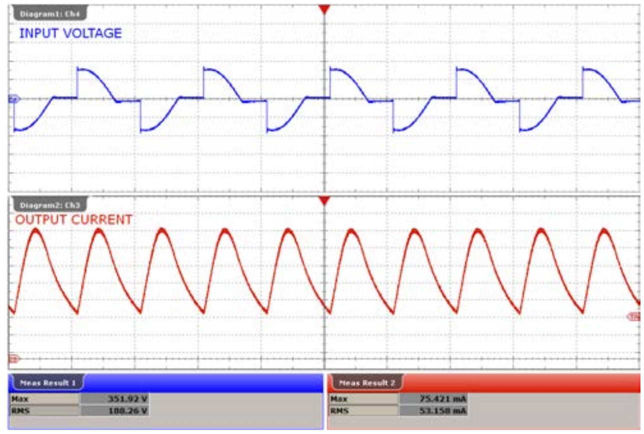


Figure 65 – 110° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 75 mA_{PK}.
Peak V_{IN}: 351 V_{PK}.

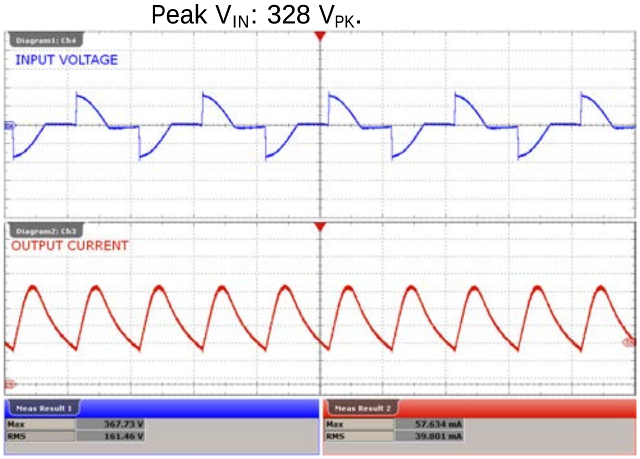


Figure 66 – 90° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 57 mA_{PK}.
Peak V_{IN}: 367 V_{PK}.

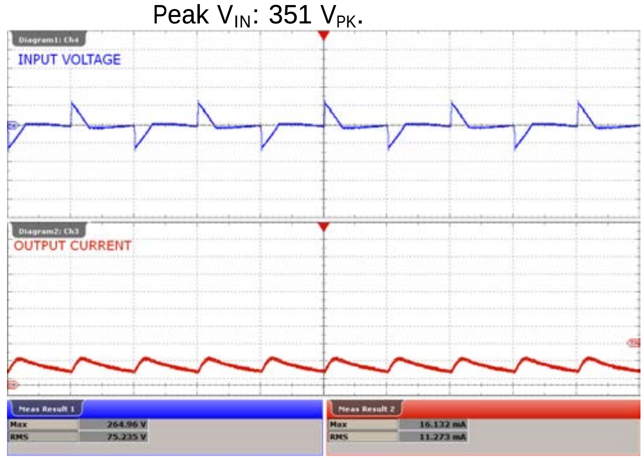


Figure 67 – 45° Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 16 mA_{PK}.
Peak V_{IN}: 264 V_{PK}.

14.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 141 V LED load
Dimmer: GIRA 0307 00

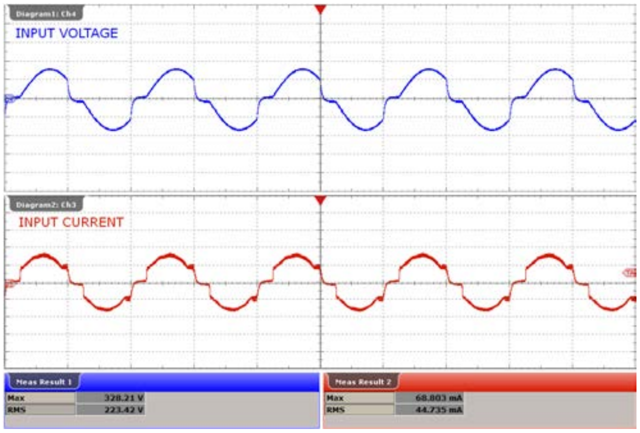


Figure 68 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 10 mA / div. .
Peak V_{IN}: 328 V_{PK}.
V_{RMS}: 223 V.

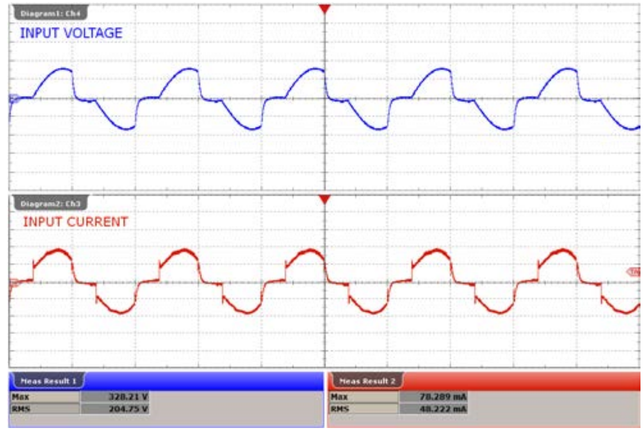


Figure 69 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 10 mA / div. .
Peak V_{IN}: 328 V_{PK}.
V_{RMS}: 205 V

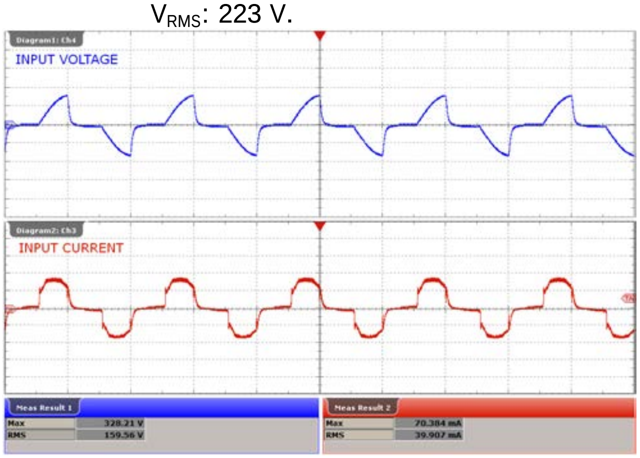


Figure 70 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 10 mA / div. .
Peak V_{IN}: 328 V_{PK}.
V_{RMS}: 159 V.

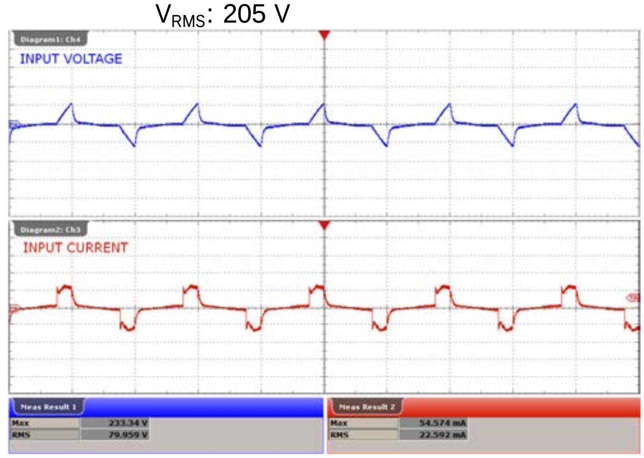


Figure 71 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{IN}, 10 mA / div. .
Peak V_{IN}: 233 V_{PK}.
V_{RMS}: 80 V.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

14.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 141 V LED load
Dimmer: GIRA 0307 00

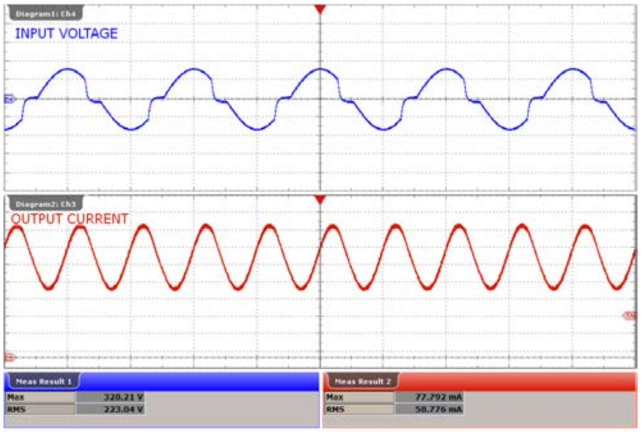


Figure 72 – 140º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 78 mA_{PK}.
Peak V_{IN}: 328 V_{PK}.

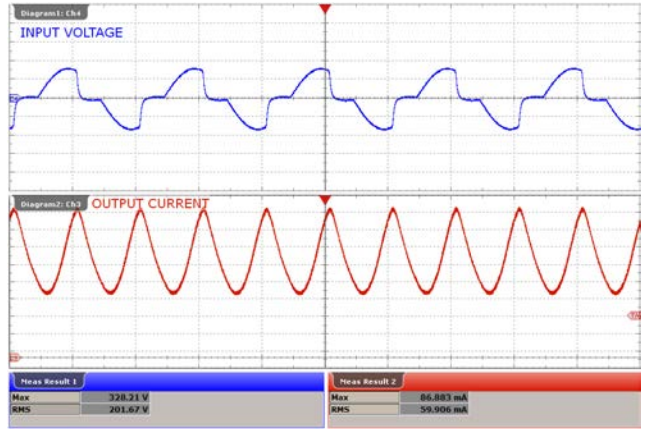


Figure 73 – 110º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 86 mA_{PK}.
Peak V_{IN}: 328 V_{PK}.

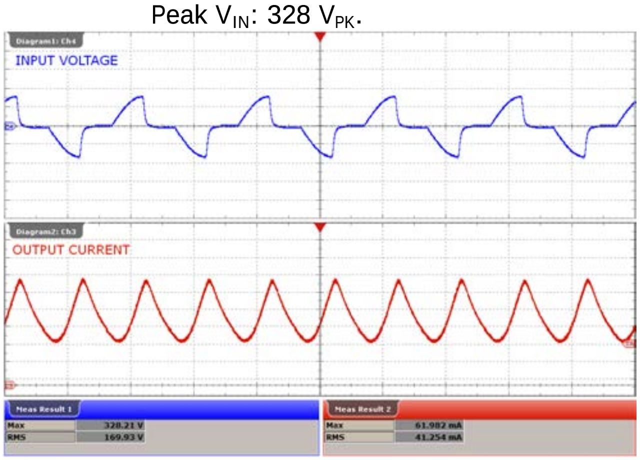


Figure 74 – 90º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 62 mA_{PK}.
Peak V_{IN}: 328 V_{PK}.

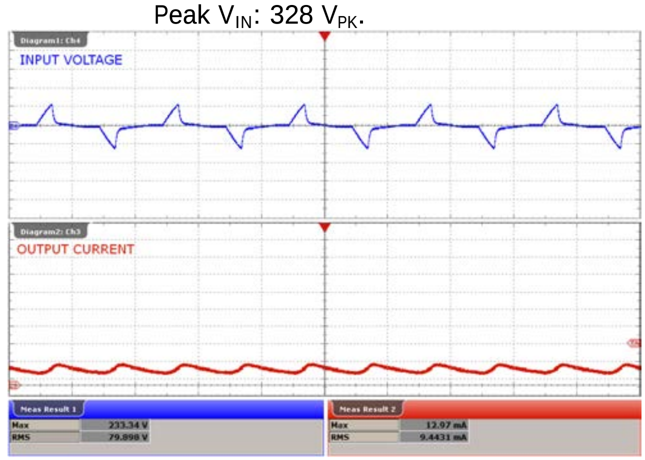


Figure 75 – 45º Conduction Angle.
Upper: V_{IN}, 200 V / div., 10 ms / div.
Lower: I_{OUT}, 10 mA / div.
Peak I_{OUT}: 13 mA_{PK}.
Peak V_{IN}: 233 V_{PK}.

15 AC Cycling Test

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

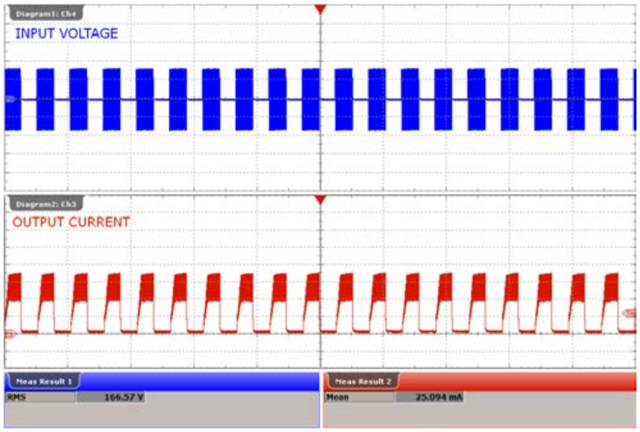


Figure 76 – 195 VAC, 141 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 200 V / div., 4 s / div.
Lower: I_{OUT}, 20 mA / div.

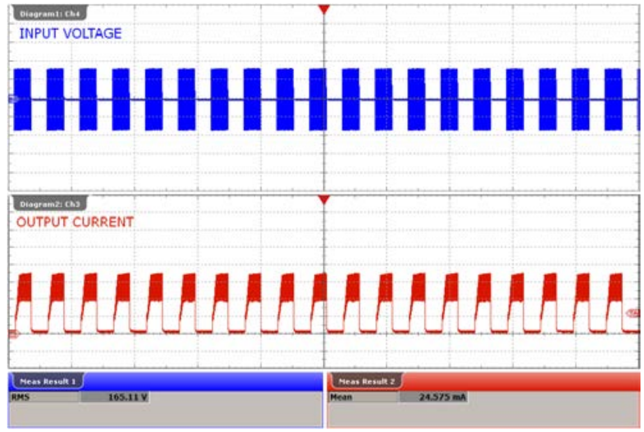


Figure 77 – 220 VAC, 141 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 200 V / div., 4 s / div.
Lower: I_{OUT}, 20 mA / div.

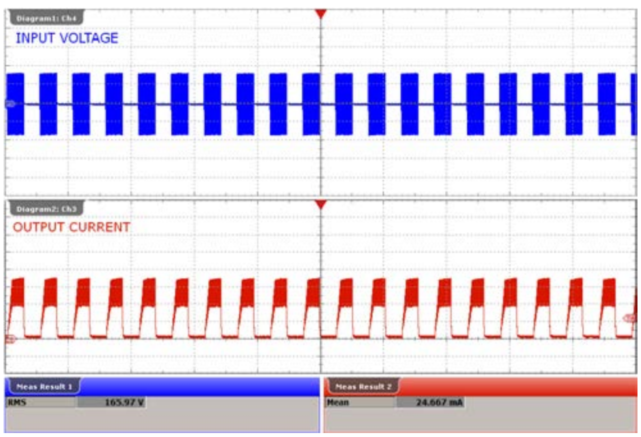


Figure 78 – 240 VAC, 141 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 20 mA / div.

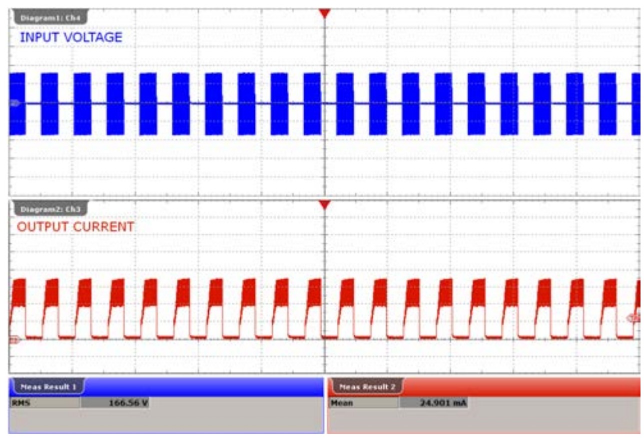


Figure 79 – 265 VAC, 141 V LED Load.
1 s On – 1 s Off.
Upper: V_{IN}, 100 V / div., 4 s / div.
Lower: I_{OUT}, 20 mA / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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

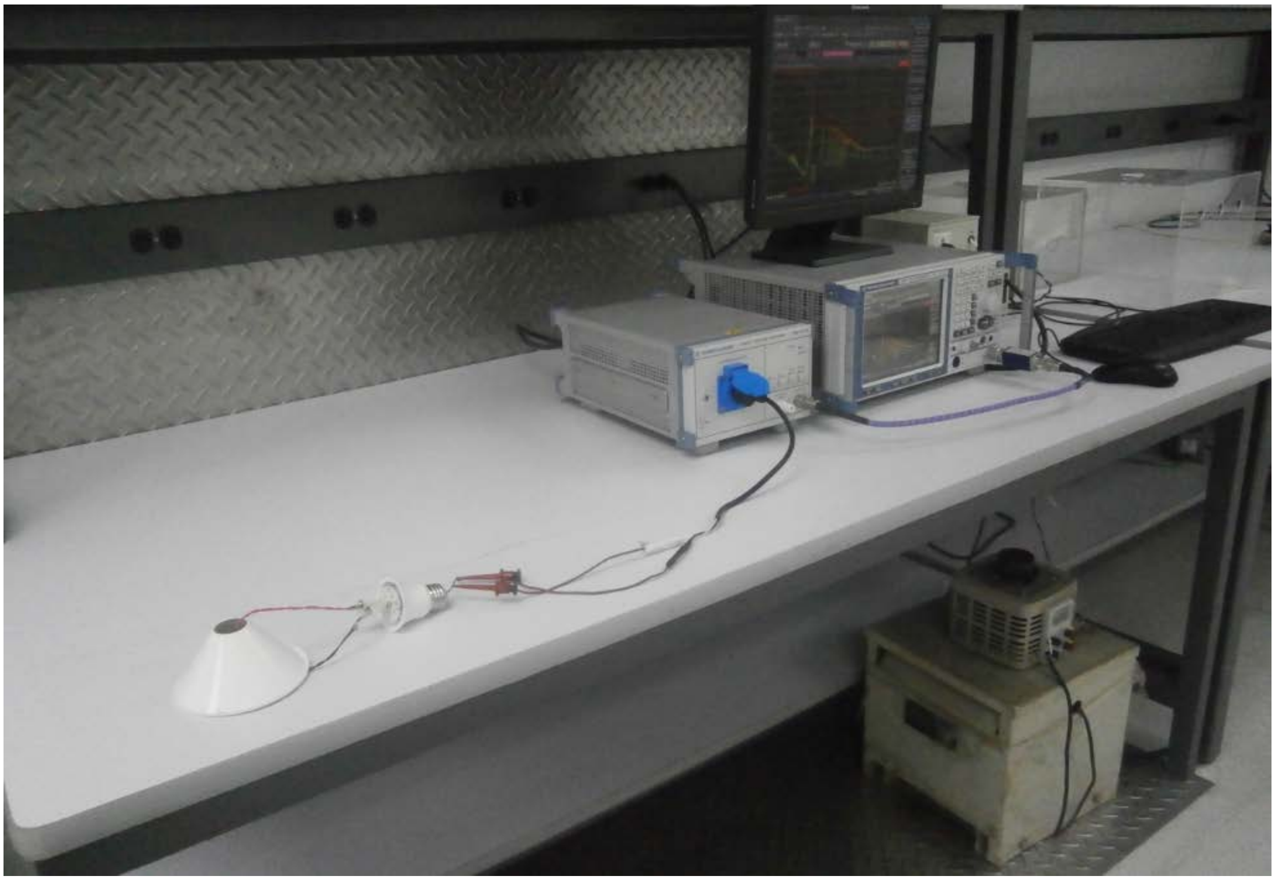


Figure 80 – Conducted EMI Test Set-up.

16.2 EMI Test Result

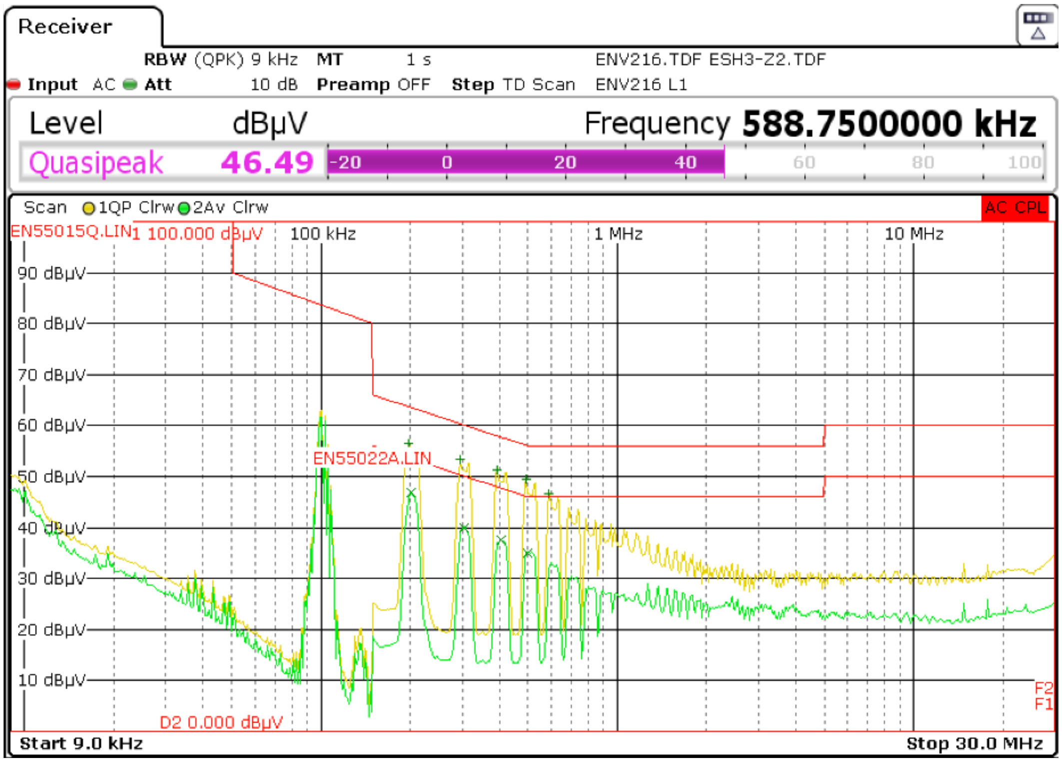


Figure 81 – Conducted EMI AT Line 1, 141 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	197.2500 kHz	56.45 L1	-7.28 dB
2 Average	201.7500 kHz	46.87 L1	-6.67 dB
1 Quasi Peak	296.2500 kHz	53.36 L1	-6.99 dB
2 Average	305.2500 kHz	39.97 L1	-10.13 dB
1 Quasi Peak	393.0000 kHz	51.34 L1	-6.66 dB
2 Average	404.2500 kHz	37.50 L1	-10.27 dB
1 Quasi Peak	492.0000 kHz	49.40 L1	-6.73 dB
2 Average	501.0000 kHz	35.09 L1	-10.91 dB
1 Quasi Peak	588.7500 kHz	46.52 L1	-9.48 dB

Figure 82 – Conducted EMI at Line 1, 141 V LED Load, Final Measurement Results.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

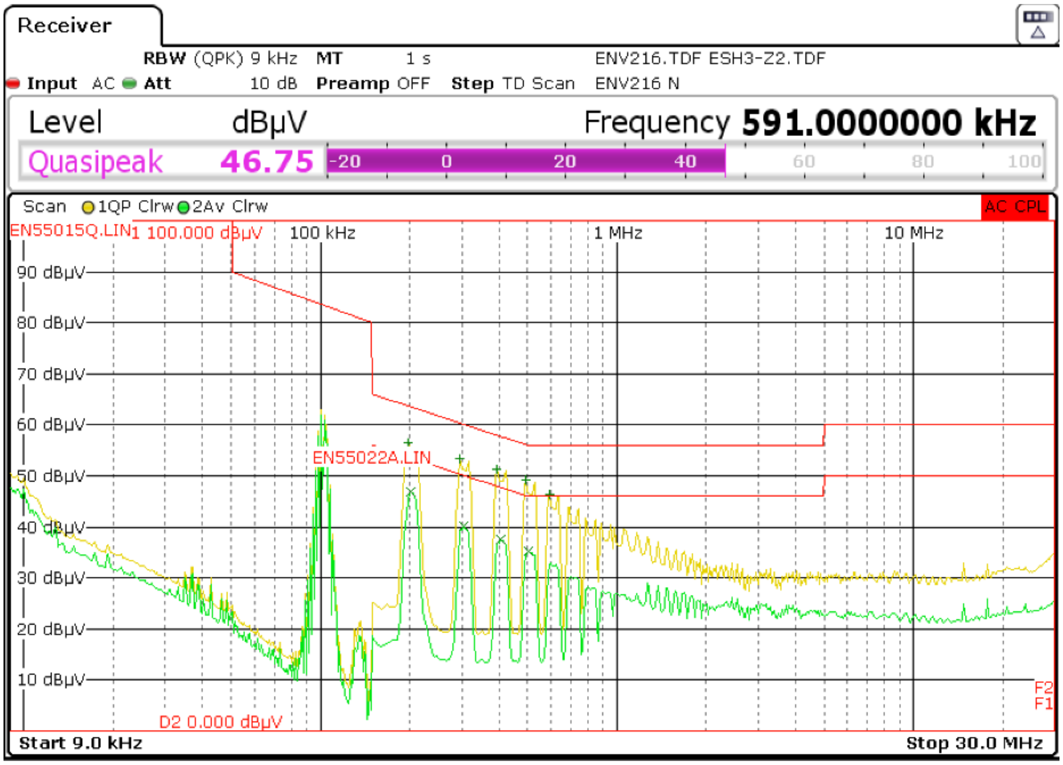


Figure 83 – Conducted EMI AT Line 2, 141 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

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 84 – Conducted EMI at Line 2, 141 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

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

17.3 Differential Surge Test Result and Waveform

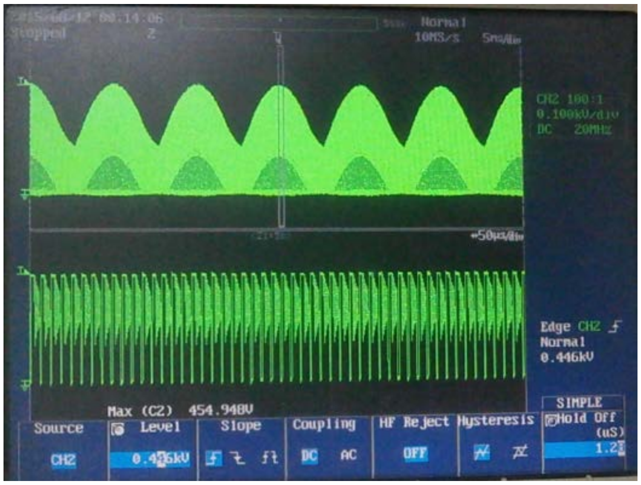


Figure 85 – 230 VAC, 50 Hz, +1000, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 455 V_{PK}.

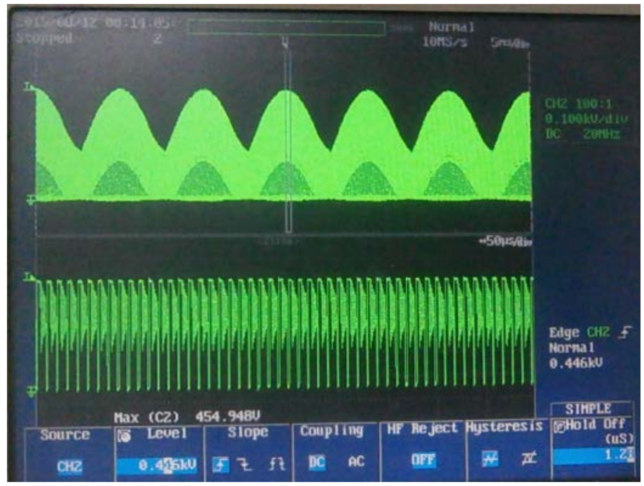


Figure 86 – 230 VAC, 50 Hz, -1000, 0º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div.
Measured Peak Voltage = 455 V_{PK}.

Figure 87 – 230 VAC, 50 Hz, +1000, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 559 V_{PK}.

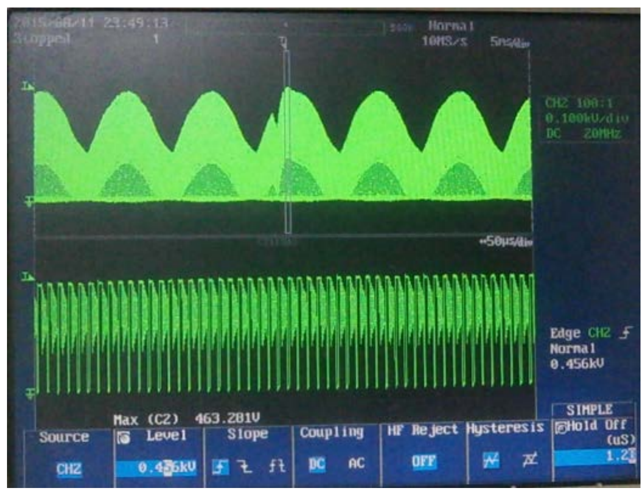


Figure 88 – 230 VAC, 50 Hz, -1000, 90º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div.(Zoomed).
Measured Peak Voltage = 463 V_{PK}.

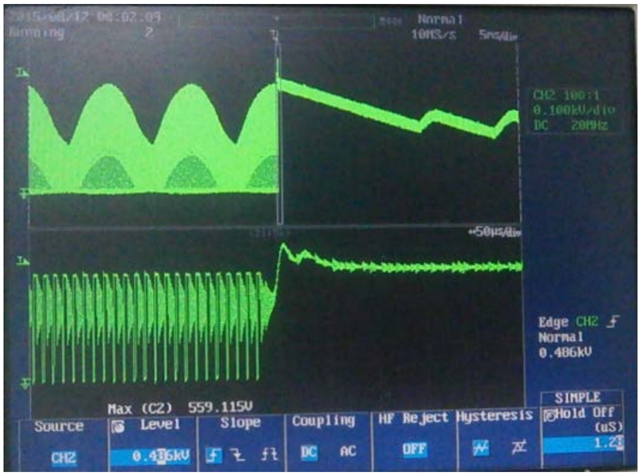


Figure 89 – 230 VAC, 50 Hz, +1000, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 559 V_{PK}.

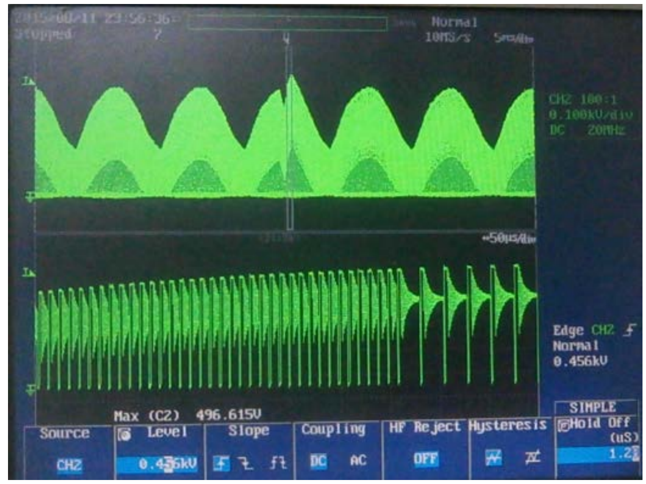


Figure 90 – 230 VAC, 50 Hz, -1000, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 496 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

17.4 Ring Wave Test Result and Waveform

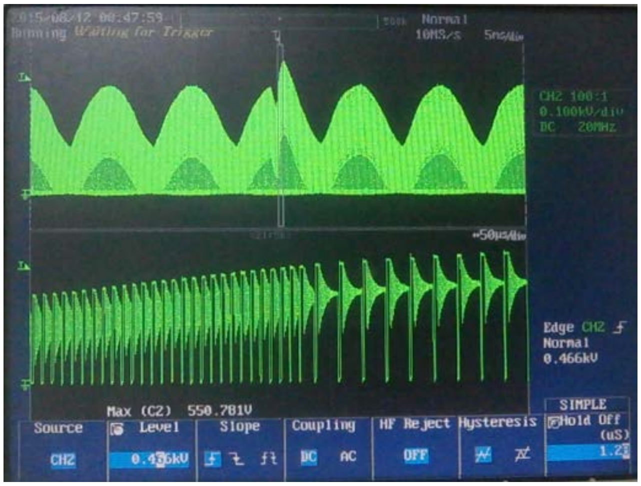


Figure 91 – 230 VAC, 50 Hz, +2500, 0°.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 550 V_{PK}.

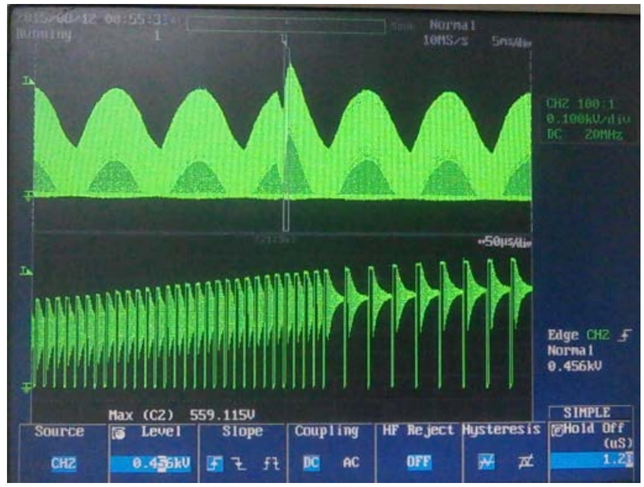


Figure 92 – 230 VAC, 50 Hz, -2500, 0°.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 559 V_{PK}.

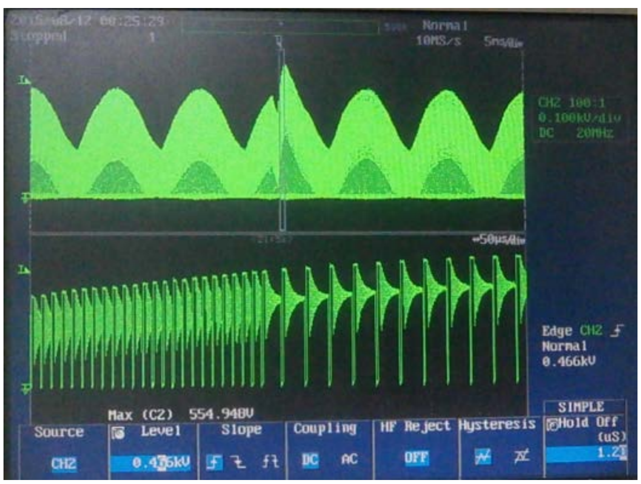


Figure 93 – 230 VAC, 50 Hz, +2500, 90°.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 544 V_{PK}.

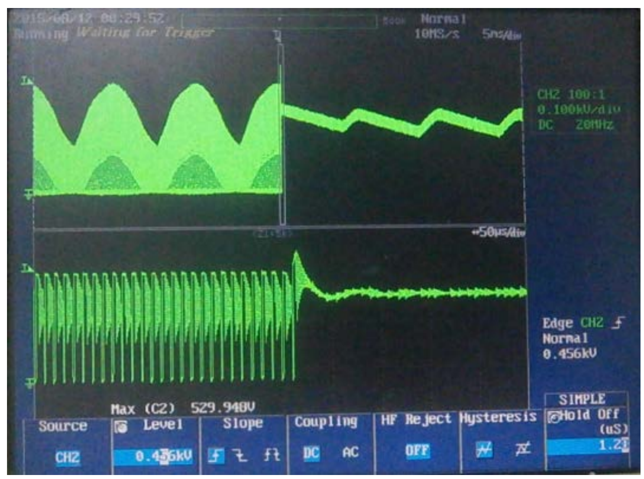


Figure 94 – 230 VAC, 50 Hz, -2500, 90°.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 529 V_{PK}.

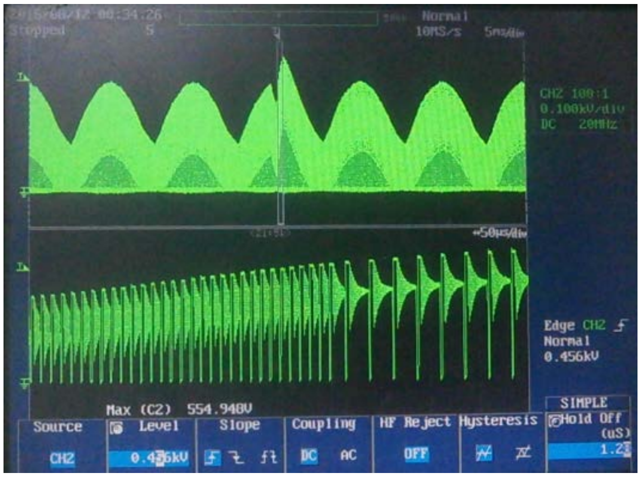


Figure 95 – 230 VAC, 50 Hz, +2500, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 554 V_{PK}.

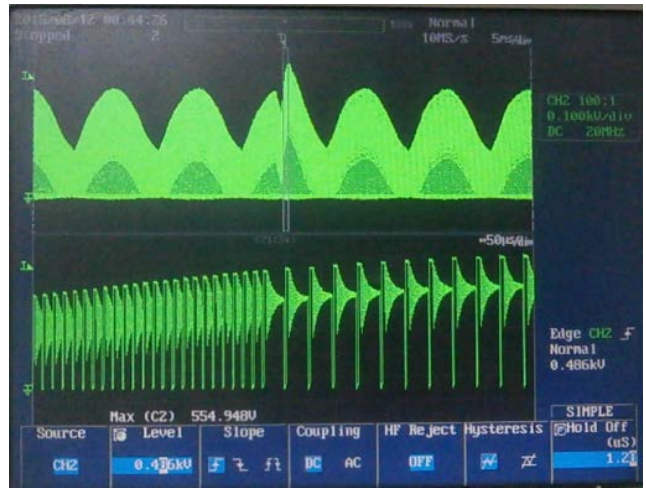
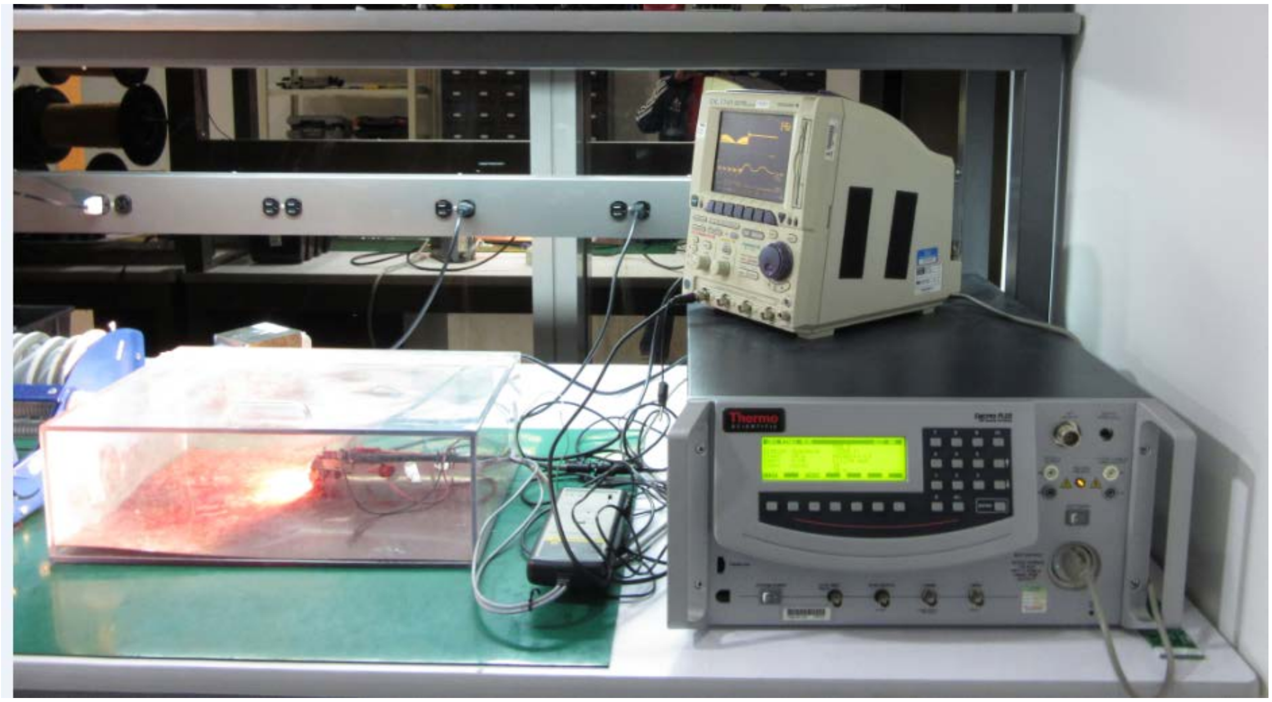


Figure 96 – 230 VAC, 50 Hz, -2500, 270º.
Upper: V_{DRAIN}, 200 V / div.
Lower: V_{DRAIN}, 200 V / div. (Zoomed).
Measured Peak Voltage = 554 V_{PK}.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

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. 141V LED STRING TO CATER 7.7W 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.

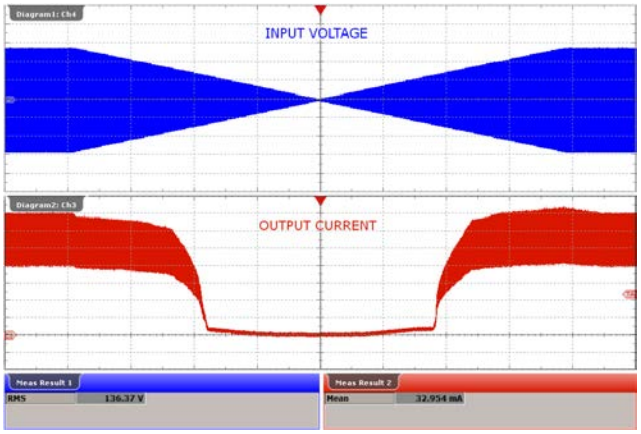


Figure 97 – 195 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 10 mA / div.

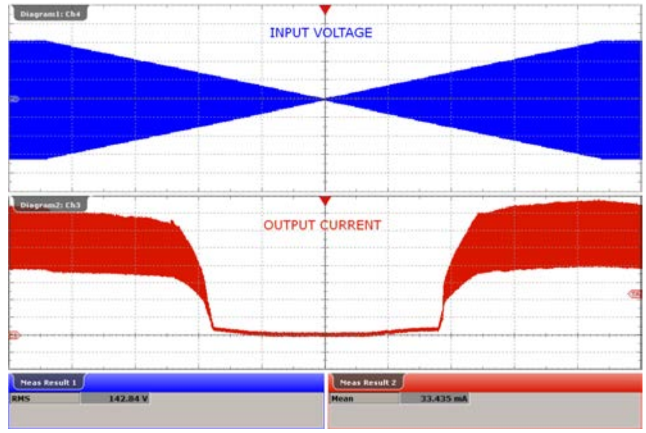


Figure 98 – 220 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 10 mA / div.

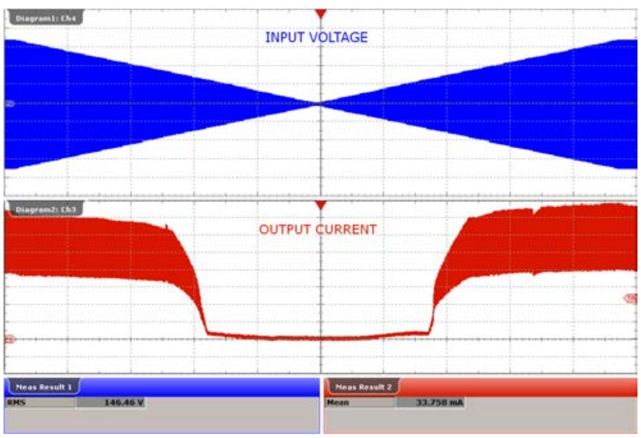


Figure 99 – 240 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 10 mA / div.

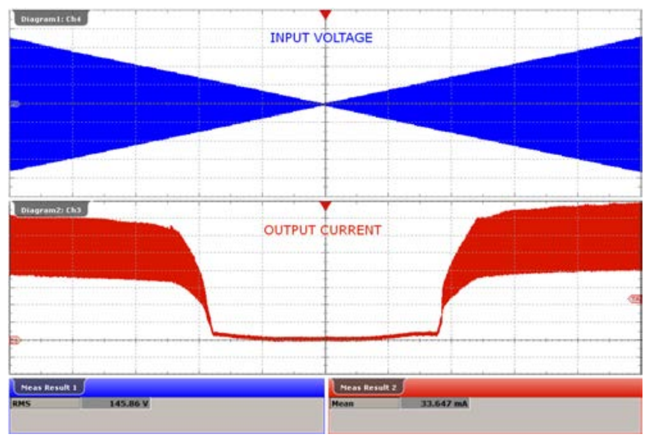


Figure 100 – 265 VAC, 141 V LED Load.
Upper: V_{IN}, 100 V / div., 50 s / div.
Lower: I_{OUT}, 10 mA / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.power.com

19 Revision History

Date	Author	Revision	Description and Changes	Reviewed
18-Apr-16	Ian B.	1.0	Initial Release	Apps & Mktg

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

Patent Information

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@power.com

GERMANY
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@power.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
e-mail: chinasales@power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@power.com

UK
Cambridge Semiconductor,
a Power Integrations company
Westbrook Centre, Block 5,
2nd Floor
Milton Road
Cambridge CB4 1YG
Phone: +44 (0) 1223-446483
e-mail: eurosales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
Fax: +86-755-8672-8690
e-mail: chinasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI)
Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@power.com