Design Example Report

Title	***5.8 W High Power Factor Non-Isolated Buck-Boost, TRIAC Dimmable LED Driver Using LYTSwitch™-4 LYT4311E***
Specification	90 VAC – 132 VAC Input; 48 V_{TYP}, 120 mA Output
Application	A19 LED Driver
Author	Applications Engineering Department
Document Number	DER-407
Date	May 16, 2014
Revision	1.0

Summary and Features

- Combined single-stage power factor correction and constant current (CC) output
- Low component count, highly compact design
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers (300 W to 1200 W)
  - Fast start-up time (<200 ms) – no perceptible delay
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis
  - No damage during brown-out conditions
- PF >0.9 at 120 VAC
- Meets ring wave, differential line surge and EN55015 conducted EMI

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.

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1 Introduction

The document describes a non-isolated, high power factor (PF), TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 48 V at 120 mA from an input voltage range of 90 VAC to 132 VAC (60 Hz typical). The LED driver utilizes the LYT4311E from the LYTSwitch-4 family of ICs.

The topology used is a single-stage non-isolated buck-boost that meets high power factor, constant current regulation, and dimming requirements for this design.

This document contains the LED driver specification, schematic, PCB details, bill of materials, transformer documentation and typical performance characteristics.

2 Populated PCB

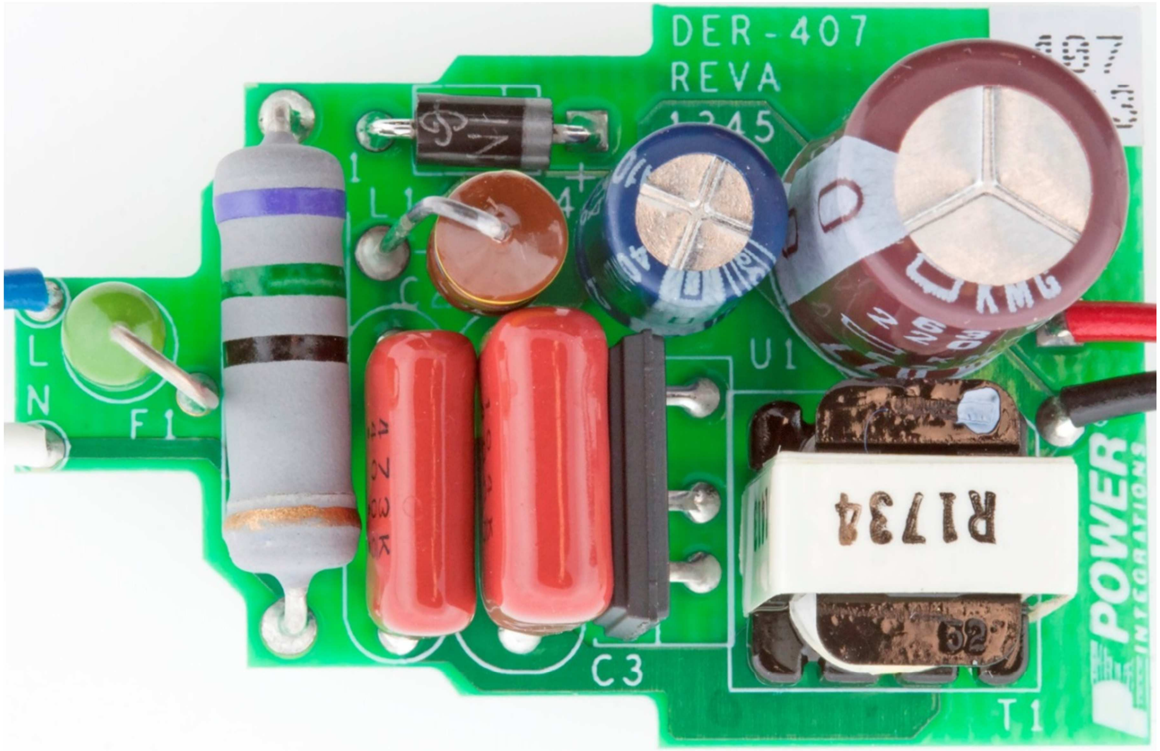

Figure 1 – Populated Circuit Board, Top View.

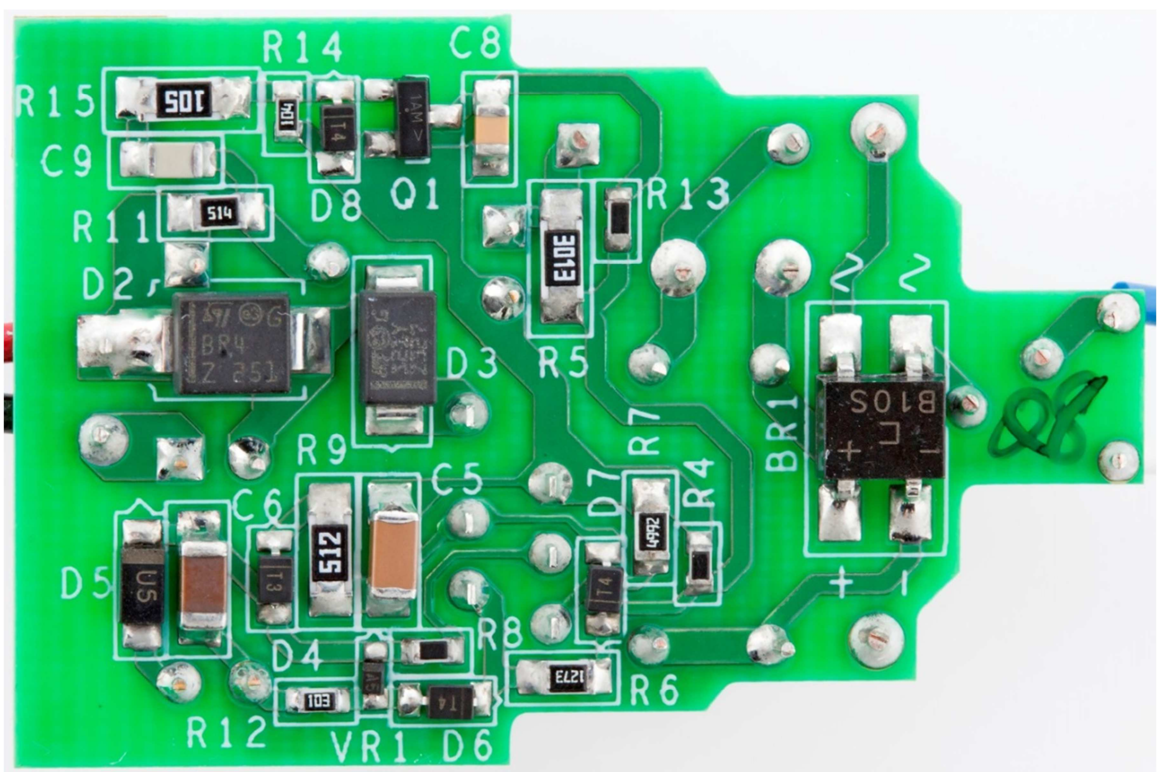

Figure 2 – Populated Circuit Board, Bottom View.

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3 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	120	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}		48		V	
Output Current	I_{OUT}		120		mA	V_{OUT} = 48 V, V_{IN} = 120 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		5.76		W	
Efficiency						
Full Load	η		83		%	Measured at P_{OUT} 25 °C, No Dimmer, 120VAC
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge			500		V	
Power Factor			0.9			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 120 VAC, 50 Hz
Ambient Temperature	T_{AMB}		50		°C	Open Frame, 120 VAC

4 Schematic

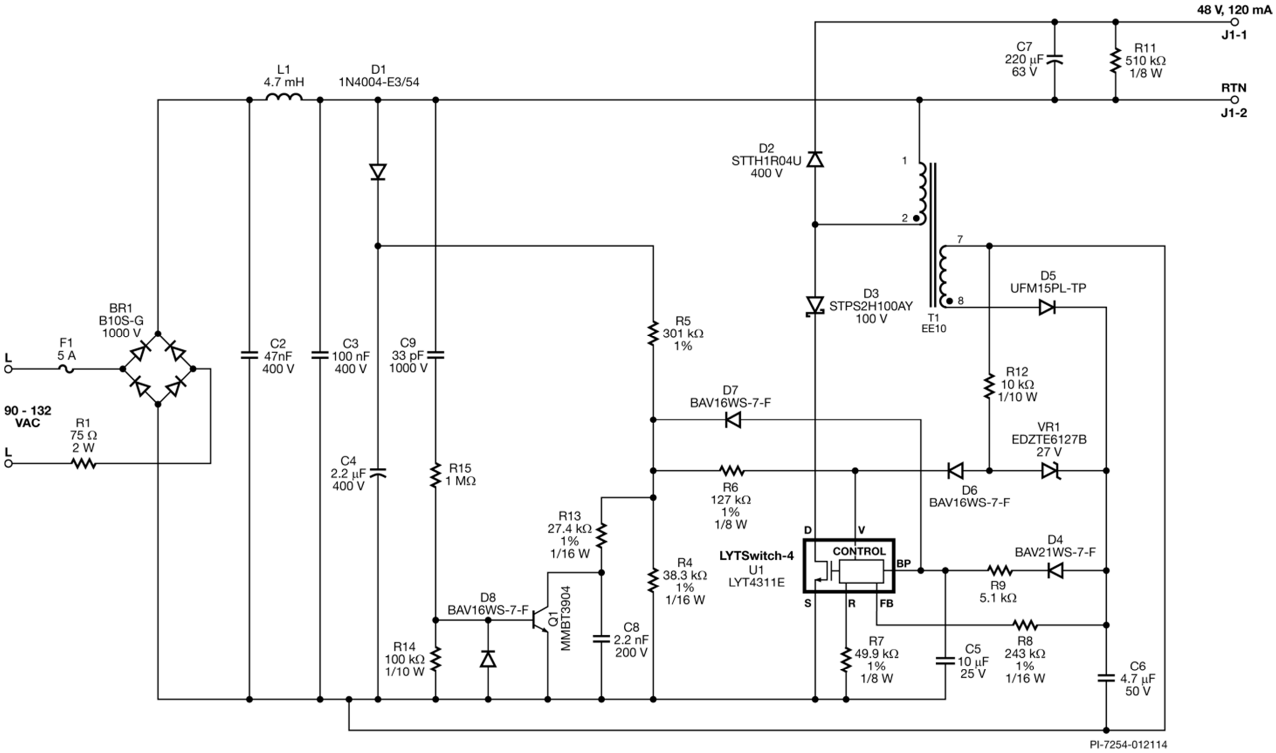

Figure 3 – Schematic Diagram.

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5 Circuit Description

The LYTSwitch-4 LYT4311E device is a controller with an integrated 725 V power MOSFET for use in LED driver applications. The LYTSwitch-4 family can be configured for use in a single-stage buck-boost topology and provides a regulated constant current output while maintaining a high power factor.

5.1 Input EMI Filtering

Fuse F1 provides protection from component failure during abnormal conditions. Diode bridge BR1 rectifies the AC line voltage and capacitor C3 provides a low impedance path (decoupling) for the primary switching current. A low value of input capacitance (sum of C2 and C3) is necessary to maintain a power factor of greater than 0.9. EMI filtering is provided by inductor L1, and capacitors C2 and C3.

5.2 Power Circuit

The topology chosen in this design is a buck-boost with a low-side switch configured to provide high power factor, and constant current output for the input voltage range of 90 VAC to 132 VAC.

Output diode D2 conducts every time U1 is off and transfers energy to the load. Diode D3 is necessary to prevent reverse current from flowing through U1 when the voltage across C3 (rectified input AC) falls below the output voltage.

To provide peak line voltage information to U1, the incoming rectified AC peak charges C4 via D1. The data is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R5, and R6. Resistors R4, R5 and R6 are chosen to give an I_V of ~100 μA at 120 VAC input (from PIXls spreadsheet).

The line overvoltage shutdown function, sensed via the V pin current, extends the rectified line voltage withstand (during surges and line swells) to the 725 BV_{DSS} rating of the internal power MOSFET.

Capacitor C5 provides local decoupling for the BP pin of U1 which is the supply pin for the internal controller. During start-up, C10 is charged to ~6 V from an internal high-voltage current source connected to the D pin of U1.

The REFERENCE pin of U1 is tied to ground (SOURCE) via a 49.9 kΩ resistor R7.

5.3 Output Feedback

The feedback signal is derived from a bias winding rectified and filtered by network comprising diode D5, and capacitor C6. The output voltage information developed across capacitor C6 is converted to feedback current by resistor R8. This current is used by LYT4311E to regulate the output current of the converter.

5.4 TRIAC Phase Dimming Control Compatibility

The requirements to provide output dimming with low cost, TRIAC based, leading edge and trailing edge phase dimmers necessitated some compromises in the design.

Due to the much lower power consumed by LED based lighting, the current drawn by the lamp is below the holding current of most TRIAC dimmers. This can cause undesirable behavior such as limited dimming range and/or flickering. 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 also cause the undesirable behavior described above, as the ringing may cause the TRIAC current to fall to zero and turn off.

To overcome these issues, the passive damper and lossless active bleeder were incorporated.

Resistor R1 is used to damp the input network ring when a TRIAC is connected.

Additional damping is provided by increasing the processed power during the leading edge portion of the ac input cycle. This method emulates the behavior of a passive RC bleeder but without its associated loss and other disadvantages in dimming.

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6 PCB Layout

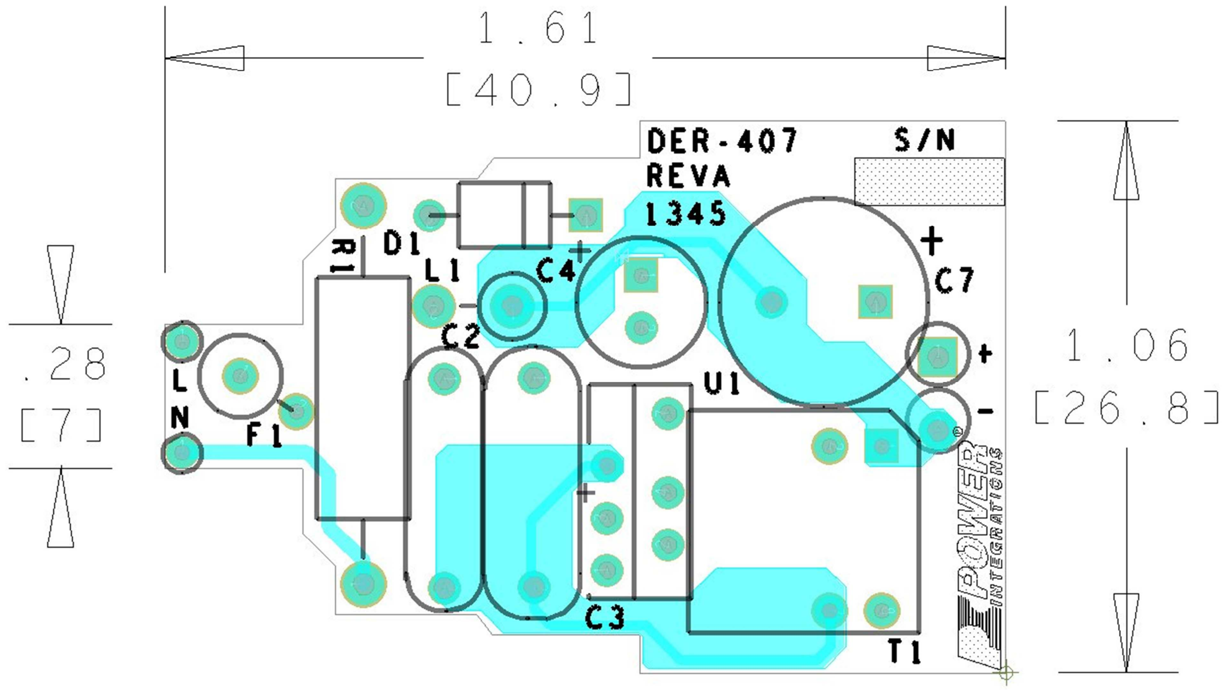

Figure 4 – Top Side.

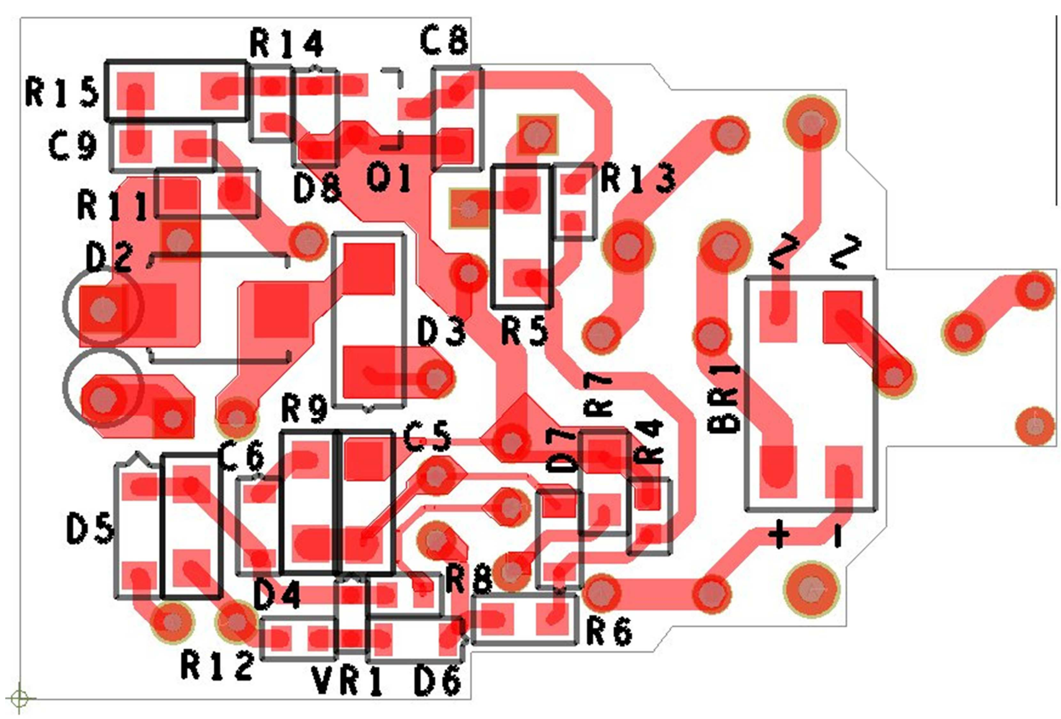

Figure 5 – Bottom Side.

7 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C2	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
3	1	C3	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
4	1	C4	2.2 µF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
5	1	C5	10 µF, 25 V, Ceramic, X7R, 1206	C3216X7R1E106M	TDK Corp
6	1	C6	4.7 µF, 50 V, Ceramic, X7R, 1206	UMK316AB7475KL-T	Taiyo Yuden
7	1	C7	220 µF, 63 V, Electrolytic, (10 x 16)	EKMG630ELL221MJ16S	United Chemi-con
8	1	C8	2.2 nF, 200 V, Ceramic, X7R, 0805	08052C222KAT2A	AVX
9	1	C9	33 pF, 1000 V, Ceramic, COG, 0805	0805AA330KAT1A	AVX
10	1	D1	400 V, 1 A, Rectifier, DO-41	1N4004-E3/54	Vishay
11	1	D2	400 V, 1 A, Ultrafast Recovery, 500 ns, DO-214AA, SMB	STTH1R04U	ST Micro
12	1	D3	100 V, 2 A, Schottky, SMA	STPS2H100AY	ST Micro
13	1	D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
14	1	D5	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	MCC
15	1	D6	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
16	1	D7	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
17	1	D8	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
18	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
19	1	L1	4.7 mH, 90 mA, 20 Ohm, RF Inductor	B82144A2475J	Epcos
20	1	Q1	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
21	1	R1	75 Ω, 5%, 2 W, Metal Oxide	RSF200JB-75R	Yageo
22	1	R4	38.3 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3832V	Panasonic
23	1	R5	301 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3013V	Panasonic
24	1	R6	127 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1273V	Panasonic
25	1	R7	49.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4992V	Panasonic
26	1	R8	243 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2433V	Panasonic
27	1	R9	5.1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ512V	Panasonic
28	1	R11	510 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ514V	Panasonic
29	1	R12	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
30	1	R13	27.4 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2742V	Panasonic
31	1	R14	100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
32	1	R15	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
33	1	T1	Bobbin, EE10, Vertical, 8 pins Transformer	101 SNX-R1734	Hical Magnetics Santronics
34	1	U1	LYTSwitch-4, eSIP-7C	LYT4311E	Power Integrations
35	1	VR1	27 V, 5%, 150 mW, SOD 523	EDZTE6127B	Rohm Semi

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_101813; Rev.1.3; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_101813: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**YES**		**YES**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			90	V	Minimum AC Input Voltage
VACMAX			132	V	Maximum AC input voltage
fL	60		50	Hz	AC Mains Frequency
VO	48.00		48	V	Typical output voltage of LED string at full load
VO_MAX			52.80	V	Maximum expected LED string Voltage.
VO_MIN			43.20	V	Minimum expected LED string Voltage.
V_OVP			58.08	V	Over-voltage protection setpoint
IO	0.12		0.12	A	Typical full load LED current
PO			5.8	W	Output Power
n	0.82		0.82		Estimated efficiency of operation
VB	23		23	V	Bias Voltage
ENTER LYTSwitch-4 VARIABLES					
LYTSwitch-4	**Auto**		**LYT4311**		Selected LYTSwitch-4
Current Limit Mode	**RED**		**RED**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			0.75	A	Minimum current limit
ILIMITMAX			0.85	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			96.7	uA	V pin current
RV	1.65		1.65	M-ohms	Upper V pin resistor
RV2			1000000000000	M-ohms	Lower V pin resistor
IFB	100.00		100.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			200.0	k-ohms	FB pin resistor
VDS			10	V	LYTSwitch on-state Drain to Source Voltage
VD			0.50	V	Output Winding Diode Forward Voltage Drop (0.5 V for Schottky and 0.8 V for PN diode)
VDB			0.70	V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP	1.00		1.00		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			468	uH	Primary Inductance
VOR	48.50		48.5	V	Reflected Output Voltage.
Expected IO (average)			0.12	A	Expected Average Output Current
KP_VACMAX			1.09		Expected ripple current ratio at VACMAX
TON_MIN			1.08	us	Minimum on time at maximum AC input voltage
PCLAMP			0.05	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EE13**		**EE13**		Core Size

Custom Core					Enter custom core part number
AE			0.171	cm^2	Core Effective Cross Sectional Area
LE			3.02	cm	Core Effective Path Length
AL			1130	nH/T^2	Ungapped Core Effective Inductance
BW			7.4	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3		Number of Primary Layers
NS	93		93		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			127	V	Peak input voltage at VACMIN
VMAX			187	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.29		Minimum duty cycle at peak of VACMIN
IAVG			0.08	A	Average Primary Current
IP			0.63	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.16	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			468	uH	Primary Inductance
LP_TOL			10		Tolerance of primary inductance
NP			93		Primary Winding Number of Turns
NB			45		Bias Winding Number of Turns
ALG			54	nH/T^2	Gapped Core Effective Inductance
BM			1844	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			2504	Gauss	Peak Flux Density (BP<3700)
BAC			922	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1588		Relative Permeability of Ungapped Core
LG			0.38	mm	Gap Length (Lg > 0.1 mm)
BWE			22.2	mm	Effective Bobbin Width
OD			0.24	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.19	mm	Bare conductor diameter
AWG			33	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			51	Cmils	Bare conductor effective area in circular mils
CMA			317	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			0.63	A	Peak Secondary Current
ISRMS			0.23	A	Secondary RMS Current
IRIPPLE			0.20	A	Output Capacitor RMS Ripple Current
CMS			47	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			33	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG

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					value)
DIAS			0.18	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.08	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			297	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			245	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			119	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)					
V pin Resistor Fine Tuning					
RV1			1.65	M-ohms	Upper V Pin Resistor Value
RV2			1000000000000	M-ohms	Lower V Pin Resistor Value
VAC1			115.0	V	Test Input Voltage Condition1
VAC2			230.0	V	Test Input Voltage Condition2
IO_VAC1			0.12	A	Measured Output Current at VAC1
IO_VAC2			0.12	A	Measured Output Current at VAC2
RV1 (new)			1.65	M-ohms	New RV1
RV2 (new)			8626.05	M-ohms	New RV2
V_OV			133.4	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			28.9	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			200	k-ohms	Upper FB Pin Resistor Value
RFB2			1000000000000	k-ohms	Lower FB Pin Resistor Value
VB1			20.7	V	Test Bias Voltage Condition1
VB2			25.3	V	Test Bias Voltage Condition2
IO1			0.12	A	Measured Output Current at Vb1
IO2			0.12	A	Measured Output Current at Vb2
RFB1 (new)			200.0	k-ohms	New RFB1
RFB2(new)			1000000000000.0000	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic		Max Current	Limit		
1st Harmonic		65.10	N/A	mA	
3rd Harmonic		16.30	N/A	mA	N/A
5th Harmonic		8.47	N/A	mA	N/A
7th Harmonic		5.09	N/A	mA	N/A
9th Harmonic		3.54	N/A	mA	N/A
11th Harmonic		2.63	N/A	mA	N/A
13th Harmonic		1.97	N/A	mA	N/A
15th Harmonic		1.58	N/A	mA	N/A
THD		29.2	%		Estimated total Harmonic Distortion (THD)

9 Inductor Specification

9.1 Electrical Diagram

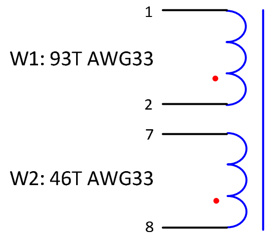

Figure 6 – Inductor Electrical Diagram.

9.2 Electrical Specifications

Primary Inductance	Pins 1-2, all other windings open, measured at 100 kHz, 0.4 RMS. AL= 54.432 nH/n^2	470 µH ±5%
Resonant Frequency	Pins 1-2, all other windings open.	1 MHz (Min.)

9.3 Materials

Item	Description
[1]	Core: TDK PC40EE10/11-Z.
[2]	Bobbin: B-EE10-V-8pins-(4/4)
[3]	Magnet Wire: #33 AWG.
[4]	Tape: 3M 1298 Polyester Film, 6.5 mm wide.
[5]	Dolph BC-359 or equivalent

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9.4 Inductor Build Diagram

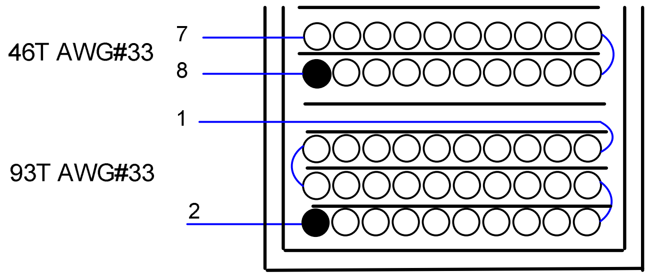

Figure 7 – Inductor Build Diagram.

9.5 Inductor Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel with pin side on the left and winding direction is clockwise direction.
Winding 1	Use wire item [3], start at pin 2 wind 93 turns in ~ 3 layers and at the last turn terminate the wire at pin 1. Apply 1 layer of tape item [4] between layers
Winding 2	Use wire item [3], start at pin 8 wind 46 turns in ~ 2 layers, and at the last turn terminate the wire at pin 7. Apply 1 layer of tape item [4] between layers
Finish	Grind core to get 470 µH inductance, secure the core with tape. Dip impregnate using varnish item[5]
Pins	Cut pins 3, 4, 5, 6.

10 Performance Data

All measurements were performed at room temperature using an LED load. The following data was taken using a custom LED load of ~48 V output voltage. Refer to the table in Section 9.4 for the complete data set.

10.1 Efficiency

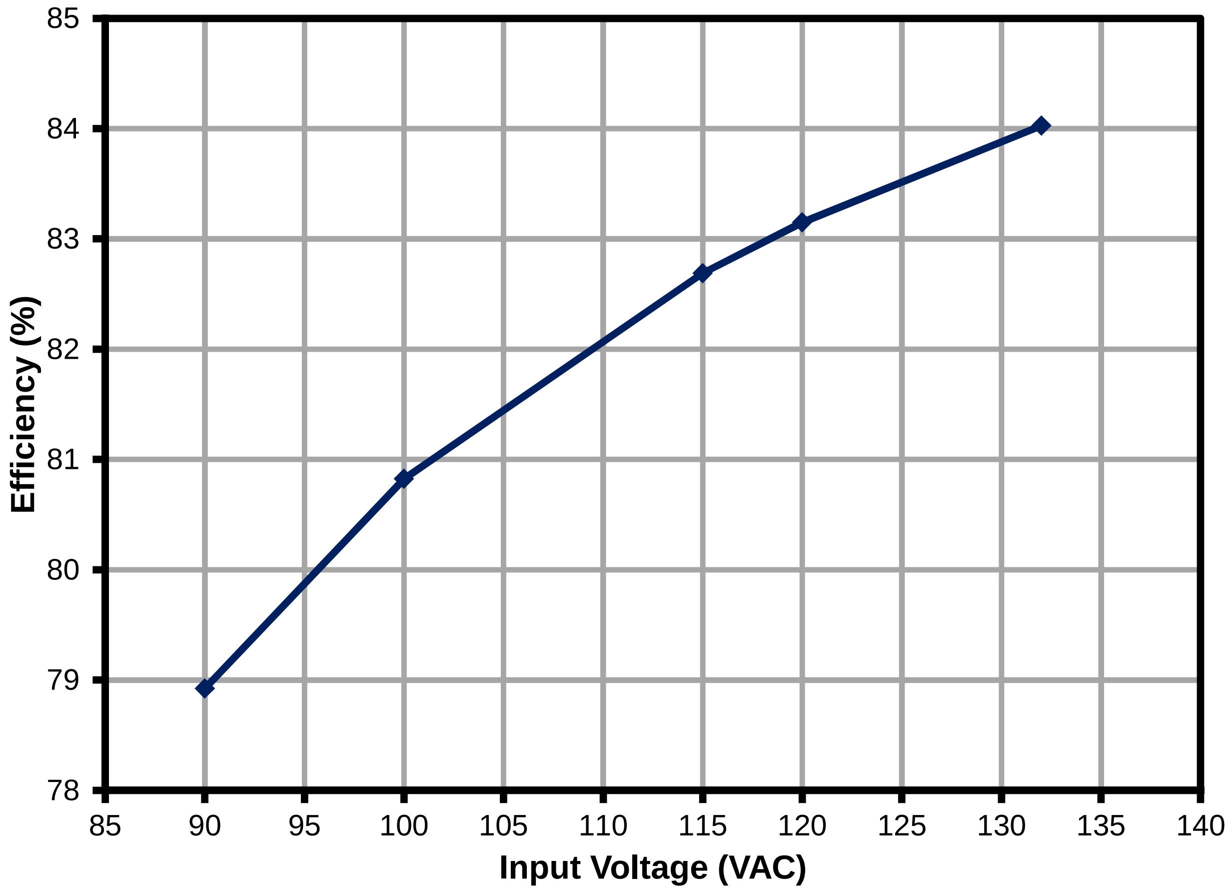

Figure 8 – Efficiency vs. Line.

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10.2 Line Regulation

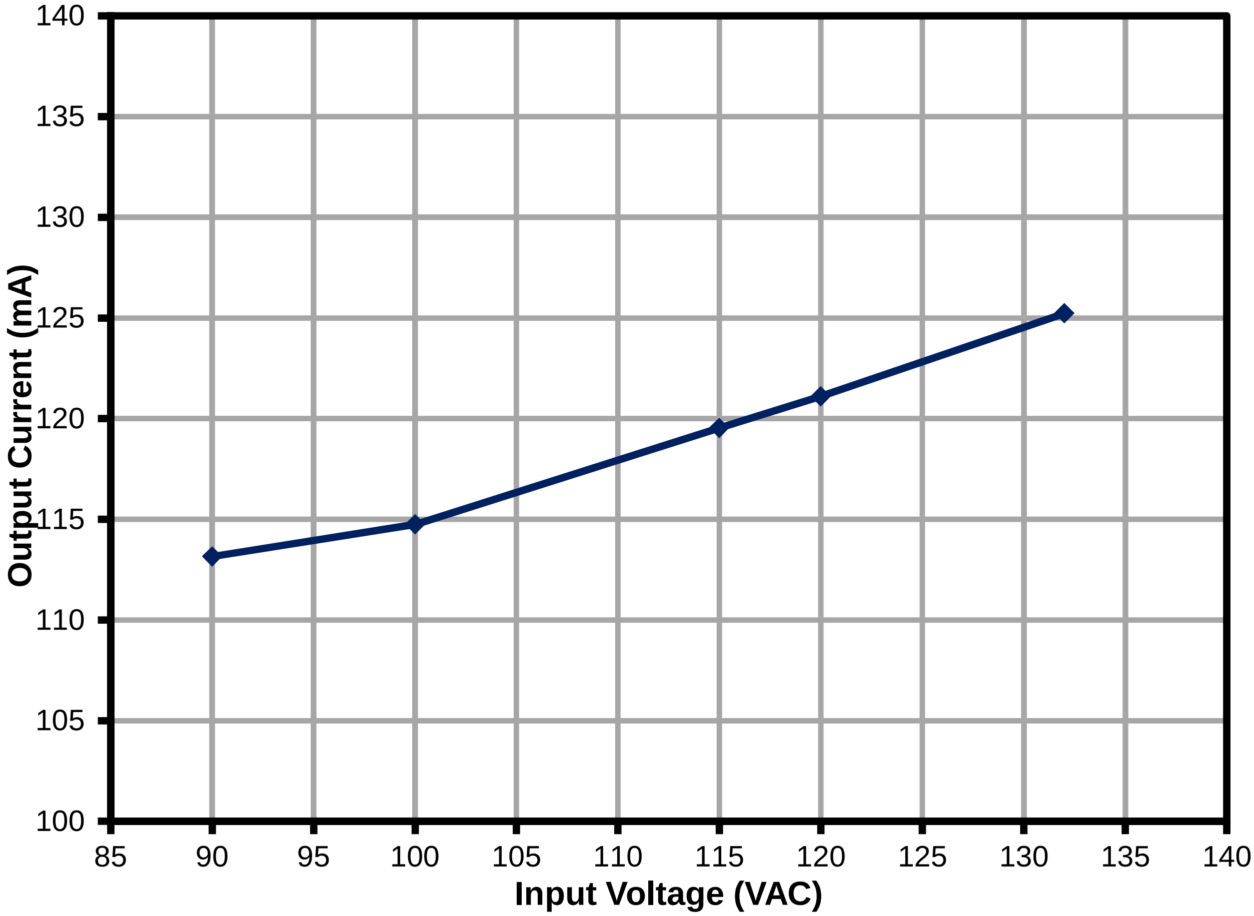

Figure 9 – Regulation vs. Line.

10.3 Power Factor

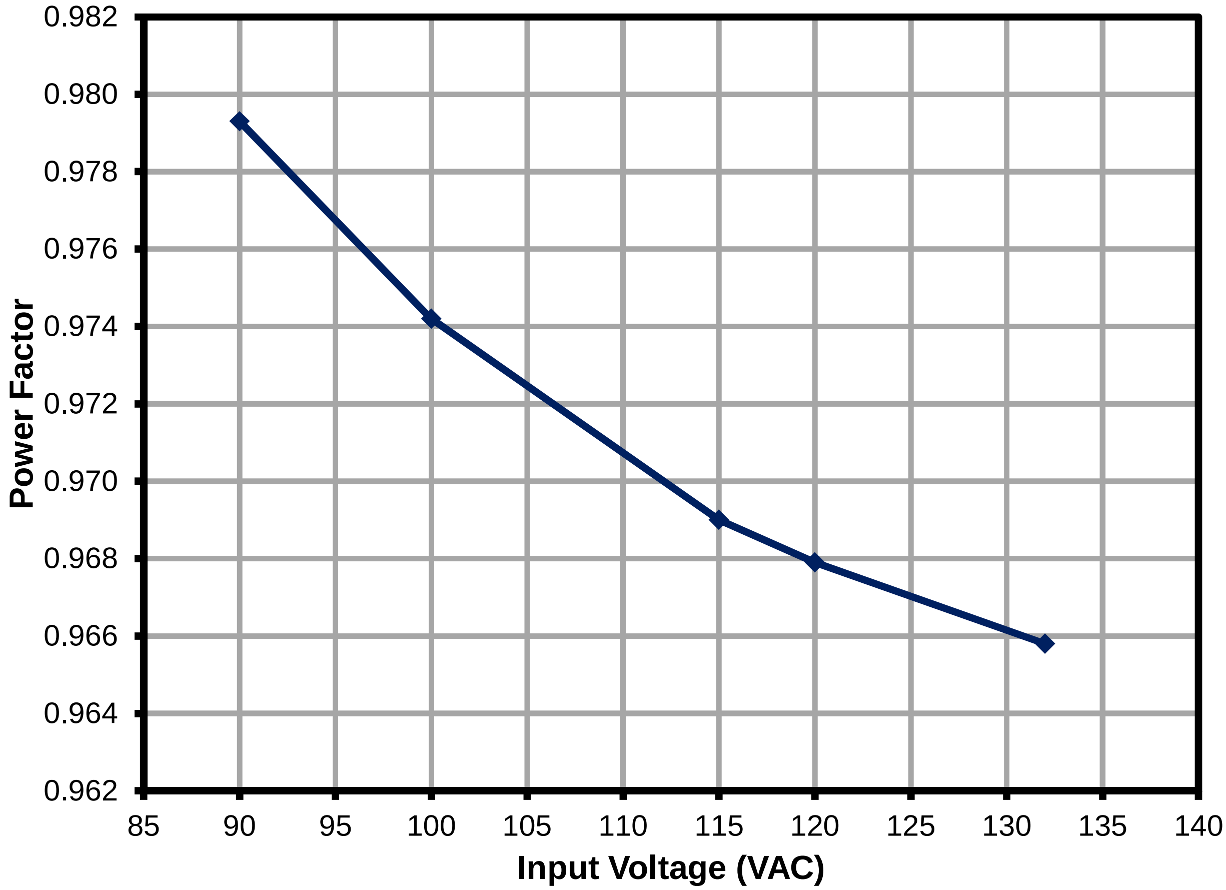

Figure 10 – Power Factor vs. Line.

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10.4 Test Data

All measurements were taken with the board mounted open frame, 25 ºC ambient, 60 Hz line frequency, and with an LED load.

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.06	80.76	7.123	0.979	20.09	49.5970	113.150	5.622	5.61	78.92	1.50
100.03	72.39	7.055	0.974	22.24	49.6110	114.740	5.702	5.69	80.82	1.35
115.07	64.51	7.193	0.969	24	49.6730	119.540	5.948	5.94	82.69	1.25
120.06	62.38	7.249	0.968	24.18	49.6840	121.110	6.028	6.02	83.15	1.22
132.09	58.20	7.425	0.966	24.29	49.7320	125.230	6.239	6.23	84.03	1.19

11 Dimming Performance Data

TRIAC dimming results were taken with input voltage of 120 VAC, 60 Hz line frequency, room temperature, and nominal ~48 V LED load.

11.1 Dimming Curve

Taken using a programmable AC source providing the leading edge chopped AC input.

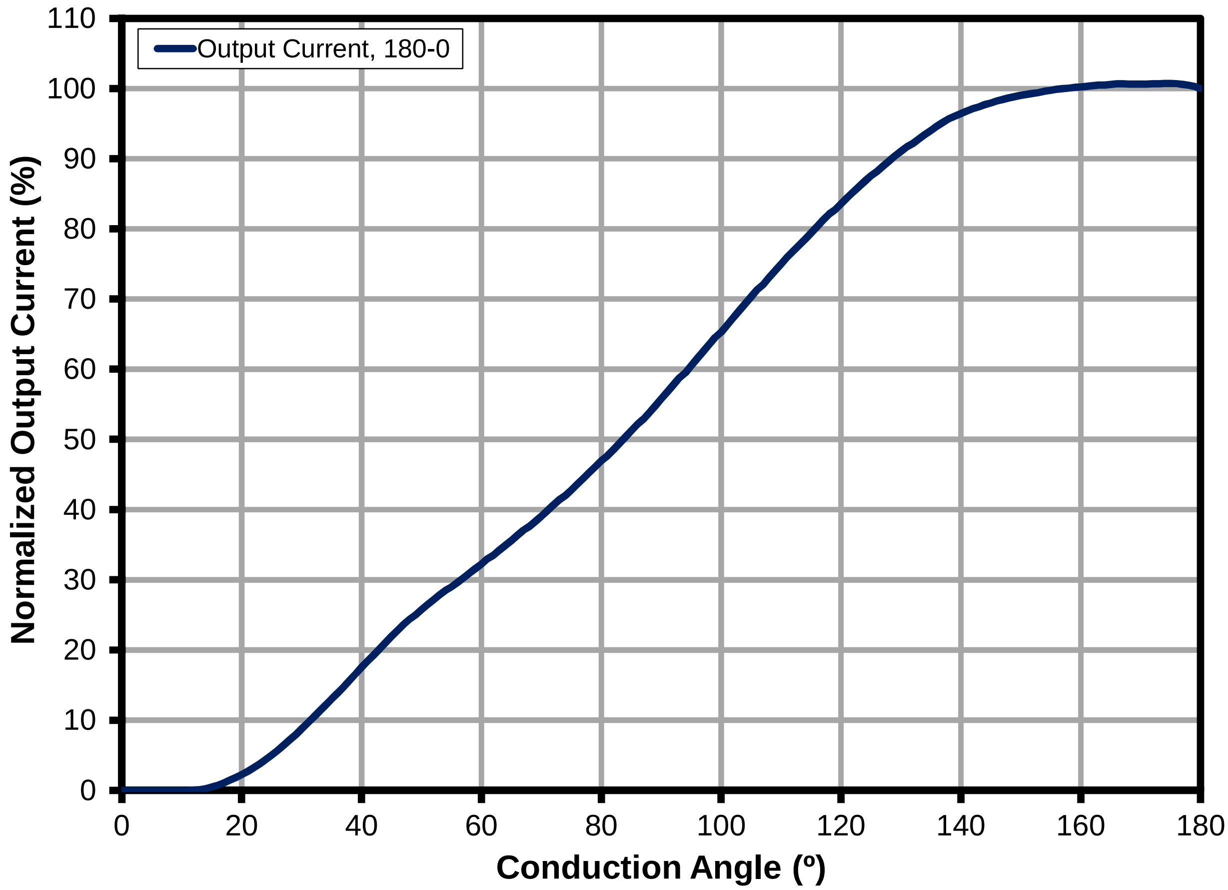

Figure 11 – Leading Edge Dimming Characteristics.

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11.2 Dimming Efficiency

Measured using a programmable AC source providing the leading edge chopped AC input.

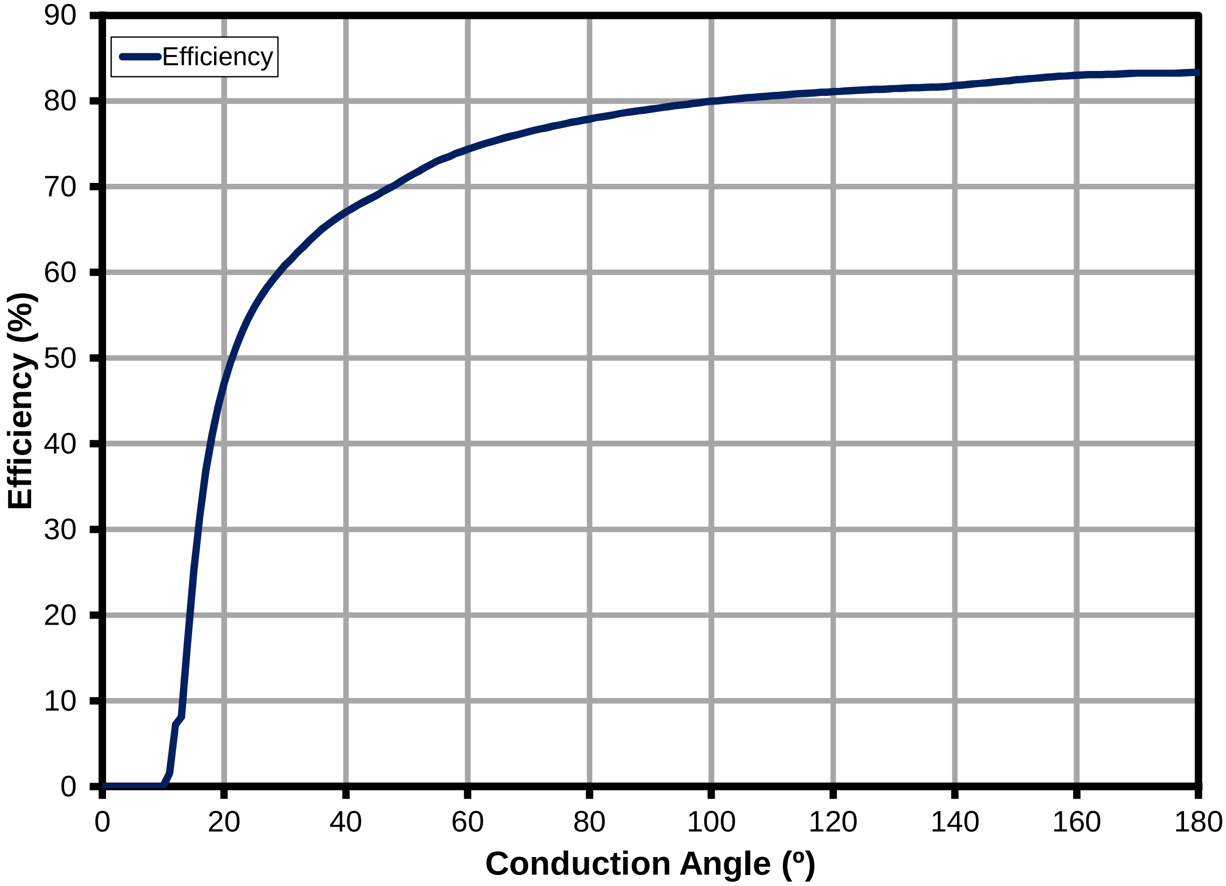

Figure 12 – Driver Efficiency as a Function of Conduction Angle.

11.3 Driver Power Loss during Dimming

Measured using a programmable AC source providing the trailing edge chopped AC input.

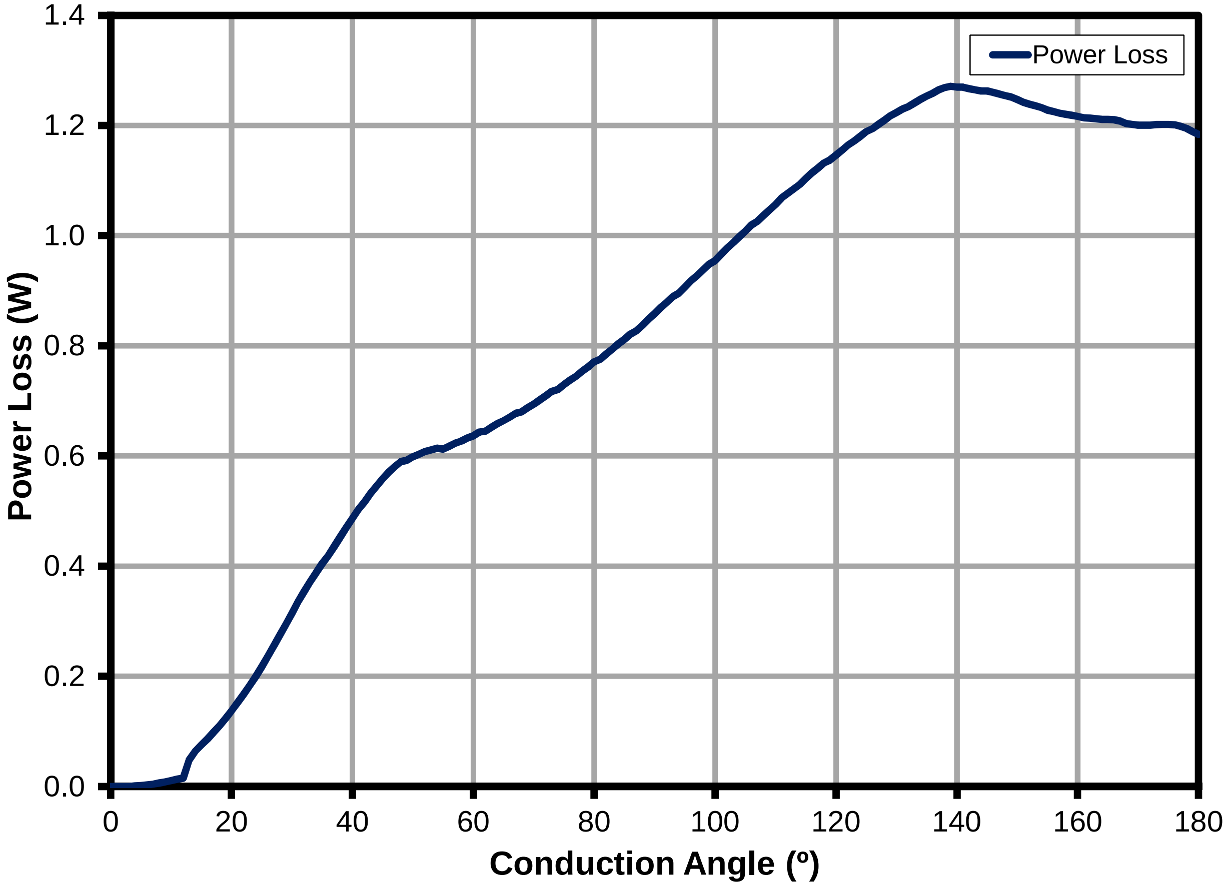

Figure 13 – Driver Power Loss as a Function of Conduction Angle.

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11.4 Dimmer Compatibility List

The unit was tested with the following high-line dimmers at 120 VAC, 60 Hz input and ~48 V LED load.

List of Dimmers	Type	Part Number	Min, mA	Max, mA	DR
LUTRON LG600PH-LA	L	LG-600PH-WH	14	115	8.21
LUTRON S603P	L	S-603P-WH	12	116	9.67
LUTRON SLV600P	T	SLV600P-WH	20	116	5.80
LUTRON S600	L	S-600-WH	18	118	6.56
LUTRON S-600PH-WH	L	S-600PH-WH	11	115	10.45
LUTRON DVCL153P	L	DVWCL-153-PLH-WH	13	114	8.77
LUTRON DV603P	L	DV-603P-WH	14	115	8.21
LUTRON DV600P	L	DV-600P-WH	13	115	8.85
LUTRON TG600PH-IV	L	TG-600PH-WH	29	117	4.03
LUTRON AY600P	T	AY-600P-WH	31	95	3.06
LUTRON GL600P-WH	L	GL-600P-WH	17	116	6.82
LEVITON 6633PLI	L	R62-06633-1LW	13	119	9.15
LEVITON 6631-LI	L	R62-06631-1LW	5	117	23.40
LEVITON IPI06	L	R60-IPI06-1LM	31	118	3.81
LEVITON 6161-I	E	R52-06161-00W	24	116	4.83
LEVITON RP106	L	R52-RPI06-1LW	17	119	7.00
LEVITON 6681	L	R60-06681-0IW	10	119	11.90
LEVITON 6684	L	R60-06684-1IW	3	118	39.33
LEVITON 6683	L	6683	5	119	23.80
LEVITON 6613	L	R02-06613-PLW	10	119	11.90
COOPER SLC03	L	SLC03P-W-K-L	7	117	16.71
LUTRON GL600-WH	L	GL-600-WH	19	119	6.26
LUTRON DVPDC-203P-WH	L	DVPDC-203P-WH	50	118	2.36
LUTRON LX600PL	L	LX-600PL-wh	21	118	5.62
LUTRON D600P	L	D-600P-WH	10	113	11.30
LUTRON CTCL-153PDH	L		10	115	11.50
LUTRON S-600P	L	S-600P	10	115	11.50
LUTRON TGLV-600P	L	TGLV-600P	25	117	4.68
LUTRON TGLV-600PR	L	TGLV-600PR	23	116	5.04
LUTRON TT-300NLH-WH	L	TT-300NLH-WH	18	118	6.56
LUTRON TT-300H-WH	L	TT-300H-WH	12	118	9.83
LUTRON NLV-1000-WH	L	NLV-1000-WH	14	117	8.36
Lutron	E	MAELV-600	20	106	5.30
Lutron	L	S-600P-WH	14	115	8.21
Lutron	E	MIR-600	12	110	9.17
Lutron	L	S-600-WH	11	119	10.82
Cooper	L	S106P	22	119	5.41
Lutron	L	S-103P-WH	23	116	5.04
Lutron	L	S-10P-WH	18	115	6.39
Lutron	L	S-600PNLH-WH	18.5	117	6.32
Lutron	L	S-603PNL-WH	21	116	5.52
Lutron	L	SLV-603P-WH	25	116	4.64
Lutron	L	S-603PGH-WH	12	100	8.33
Lutron	L	AYLV-600P-WH	25	116	4.64
Lutron	L	AYLV-603P-WH	26	116	4.46

Lutron	L	AY-103PNL-WH	20	117	5.85
Lutron	L	AY-10PNL-WH	17	119	7.00
Lutron	L	AY-10P-WH	14	116	8.29
Lutron	L	AY-603PNL-WH	25	115	4.60
Lutron	L	AY-603PG-WH	25	97	3.88
Lutron	L	AY-603P-WH	31	115	3.71
Lutron	L	AY-600PNL-WH	26	117	4.50
Lutron	T	DVELV-300P-WH	16	102	6.38
Lutron	L	DVLV-10P-WH	27	115	4.26
Lutron	L	DVLV-103P-WH	25	115	4.60
Lutron	L	DVLV-603P-WH	24	115	4.79
Lutron	L	S-1000-WH	19	118	6.21
Lutron	T	SELV-300P-WH	15	100	6.67
Lutron	L	S-600P-WH	11	115	10.45
Lutron	L	S-103PNL-WH	24	115	4.79
Lutron	E	SPSLV-1000-WH	23	119	5.17
Lutron	E	SPSLV-600-WH	23	119	5.17
Lutron	E	SPSELV-600-WH	20	106	5.30
Lutron	L	GLV-600-WH	13	119	9.15
Lutron	L	LG-603PGH-WH	16	96.5	6.03
Lutron	L	DVW-603PGH-WH	17	96	5.65
Lutron	L	TG-10PR-WH	25	116	4.64
Lutron	L	NT-600	13	117	9.00
Lutron	L	NT-1000	13	117	9.00
Lutron	L	LGCL-153PLH-WH	18	111	6.17
Lutron	L	CTCL-153PDH-WH	24	111	4.63
Lutron	L	TGCL-153PH-WH	18	113	6.28
Lutron	L	DVWCL-153PH-LA	26	112	4.31
Leviton	L	81000-W	27	117	4.33
Lutron	L	TTCL-100LH-WH	26	111	4.27

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12 Thermal Performance

The following readings were taken with the power supply configured for open frame and room temperature ambient conditions.

12.1 120 VAC, 60 Hz No Dimmer Connected

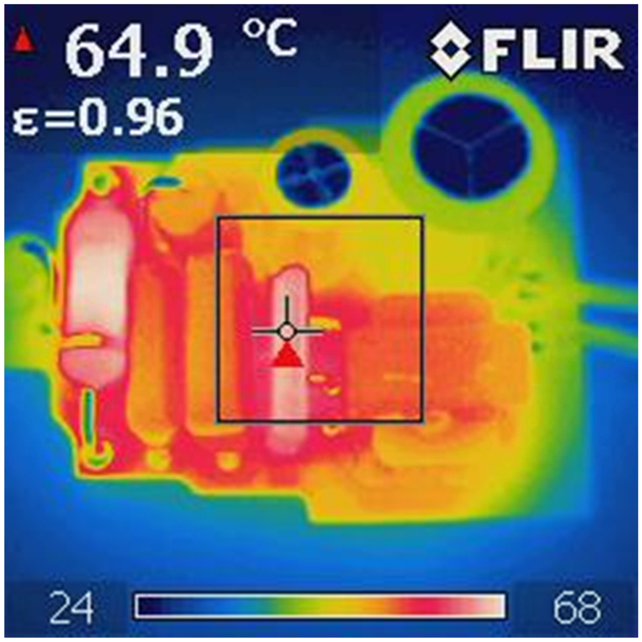

Figure 14 – U1: LYT4311E.

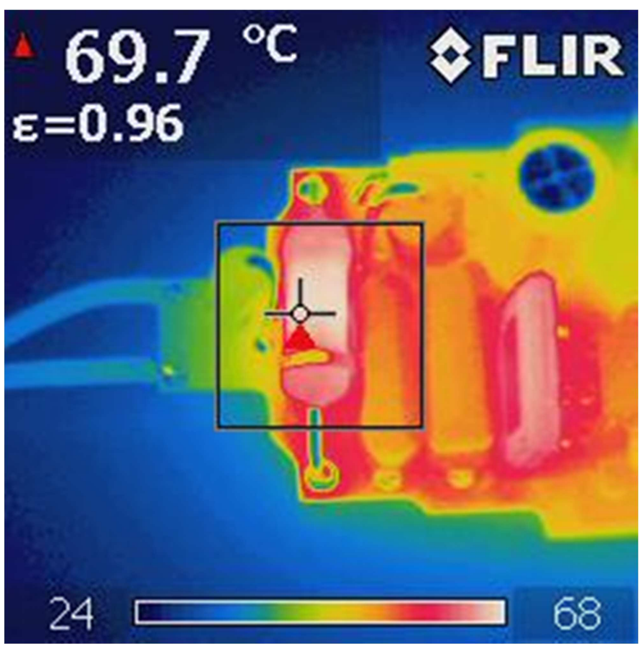

Figure 15 – R1: Damper Resistor.

12.2 120 VAC, 60 Hz Dimmer Connected, 90º Conduction Angle

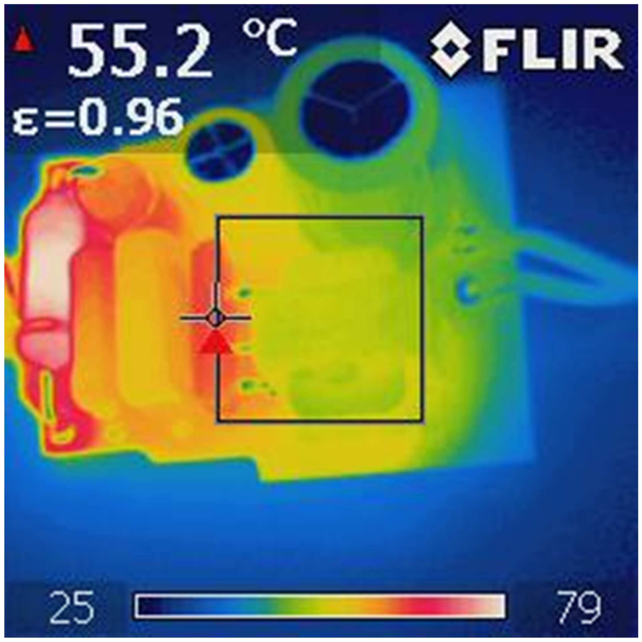

Figure 16 – U1: LYT4311E**.**

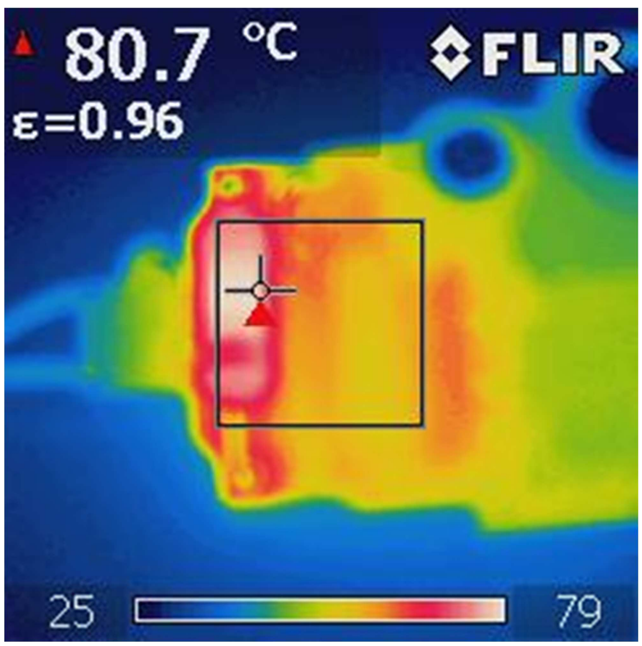

Figure 17 – R1: Damper Resistor.

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13 Non-Dimming (No Dimmer Connected) Waveforms

13.1 Input Voltage and Input Current Waveforms

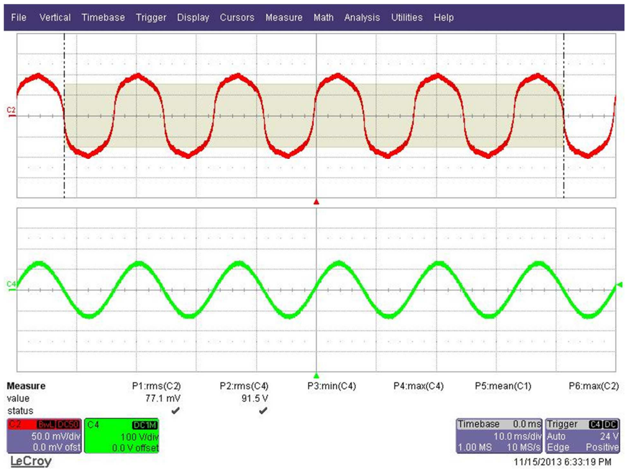

Figure 18 – 90 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

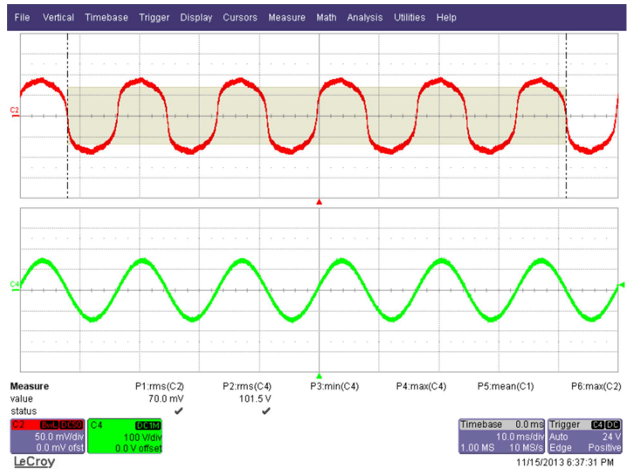

Figure 19 – 100 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

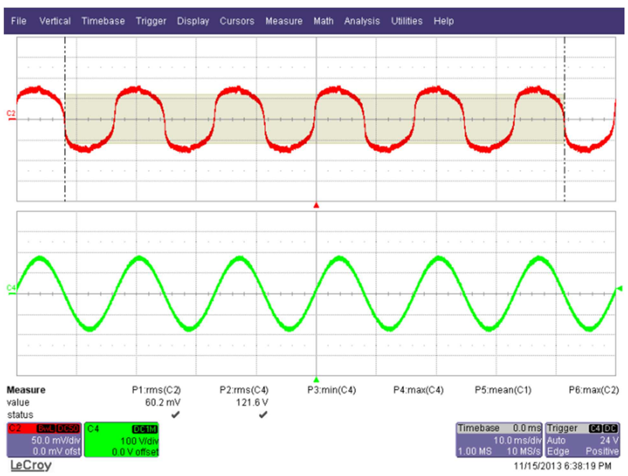

Figure 20 – 120 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

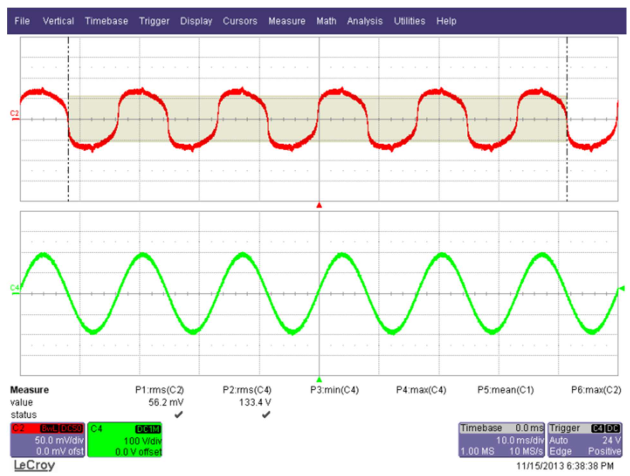

Figure 21 – 132 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

13.2 Output Current and Output Voltage at Normal Operation

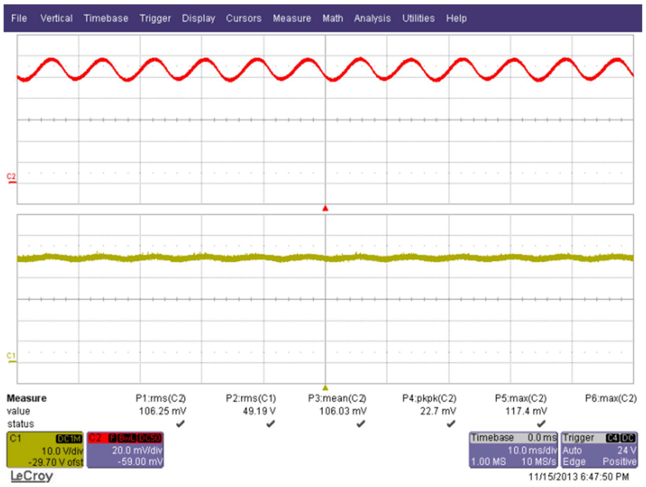

Figure 22 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

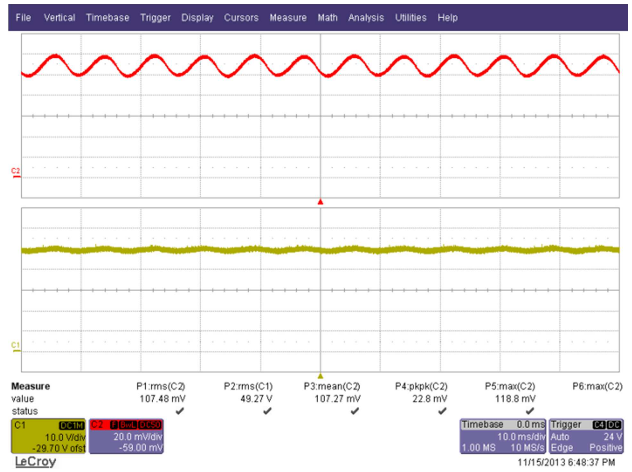

Figure 23 – 100 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

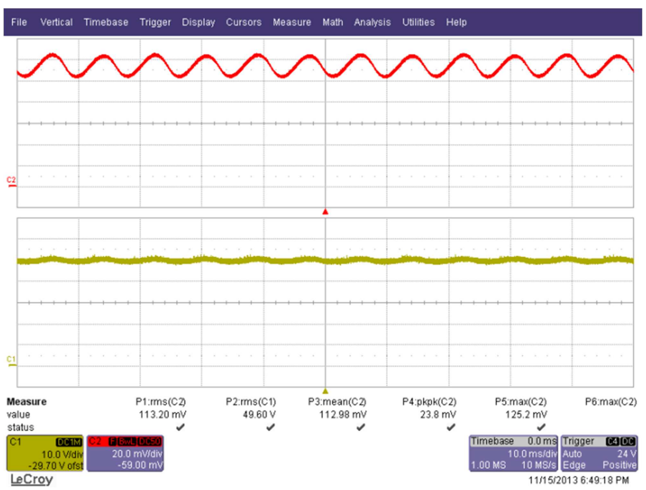

Figure 24 – 120 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

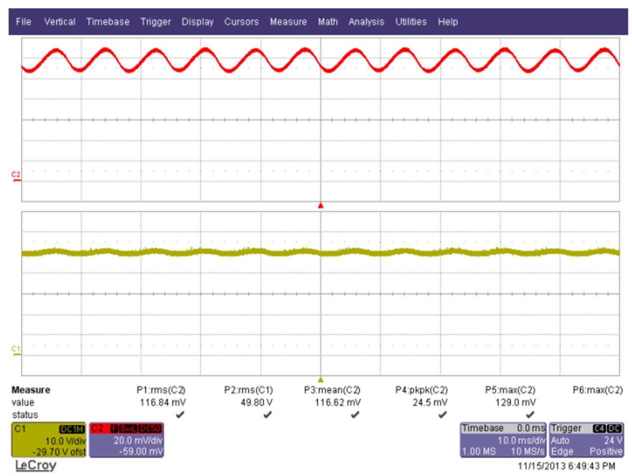

Figure 25 – 132 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

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13.3 Output Current Rise and Fall

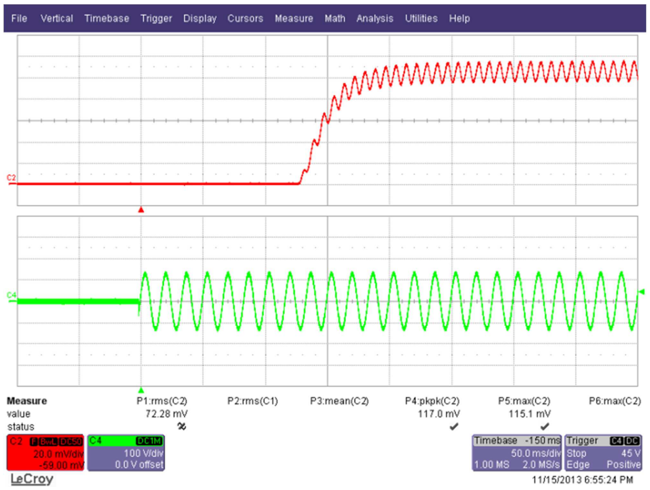

Figure 26 – 90 VAC Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

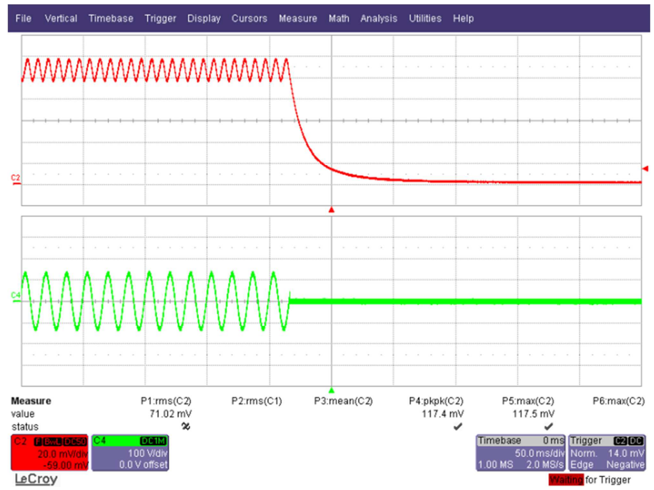

Figure 27 – 90 VAC Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

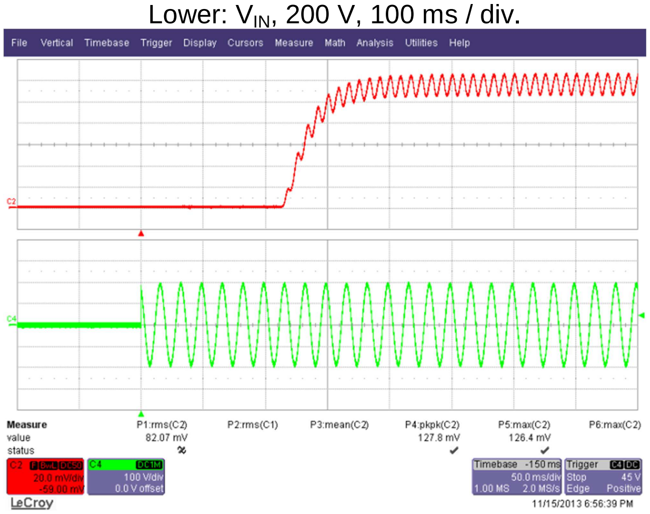

Figure 28 – 132 VAC Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

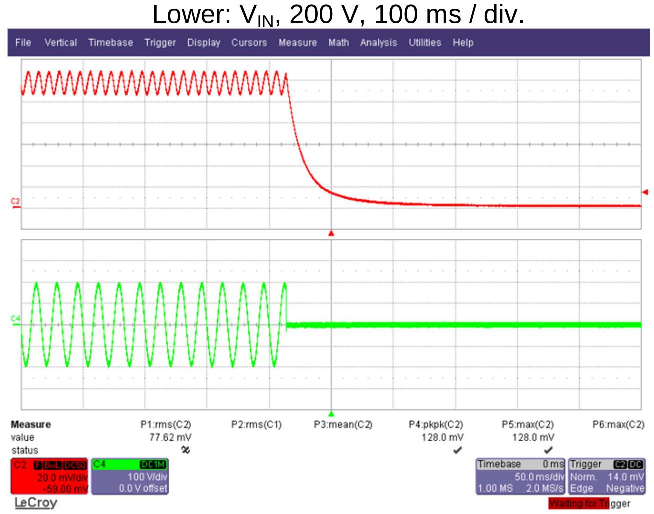

Figure 29 – 132 VAC Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

13.4 Drain Voltage and Current at Normal Operation

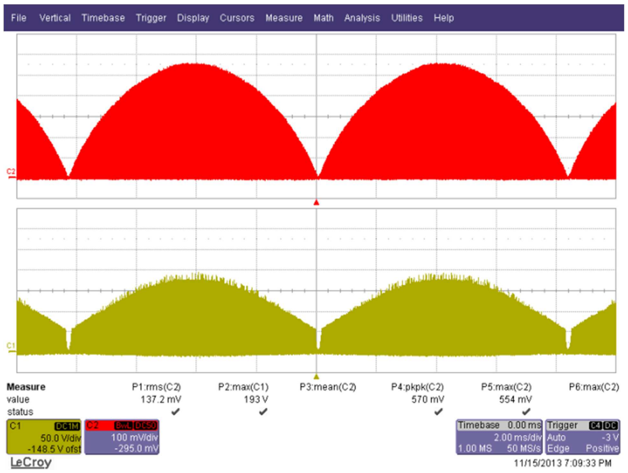

Figure 30 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 50 V, 2 ms / div.

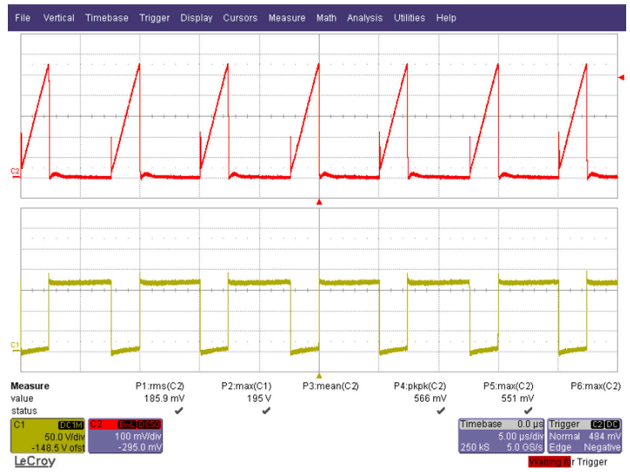

Figure 31 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

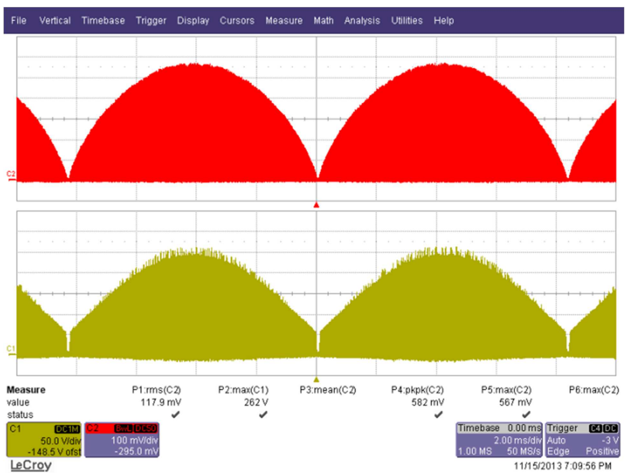

Figure 32 – 132 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 50 V, 2 ms / div.

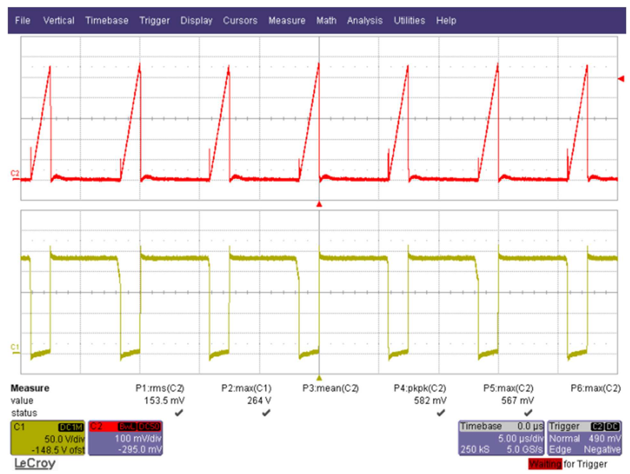

Figure 33 – 132 VAC, 600 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

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13.5 Start-up Drain Voltage and Current

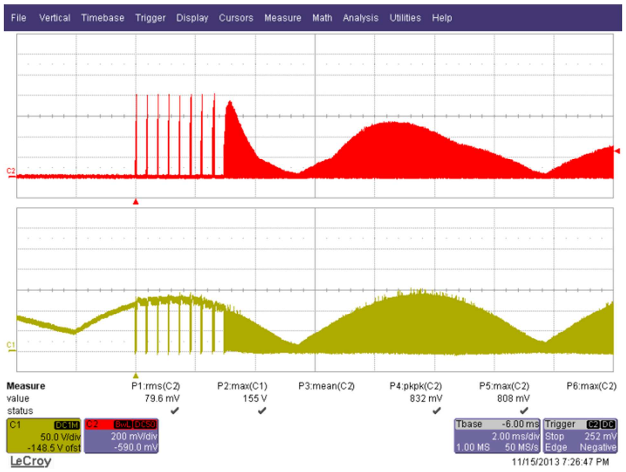

Figure 34 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

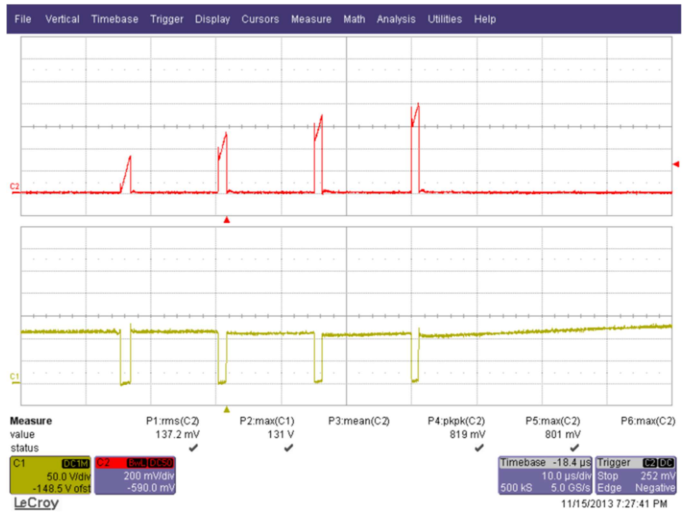

Figure 35 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

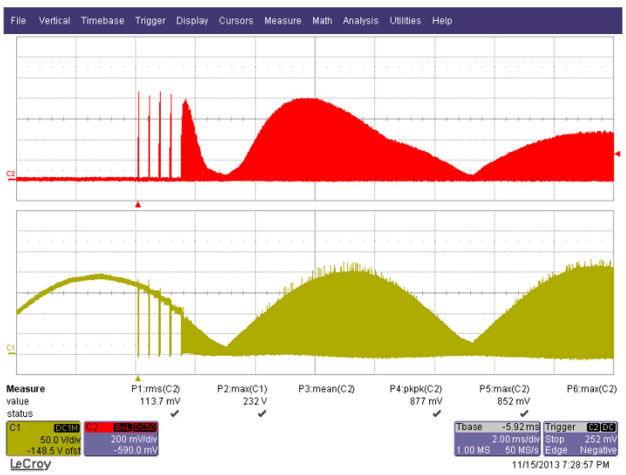

Figure 36 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

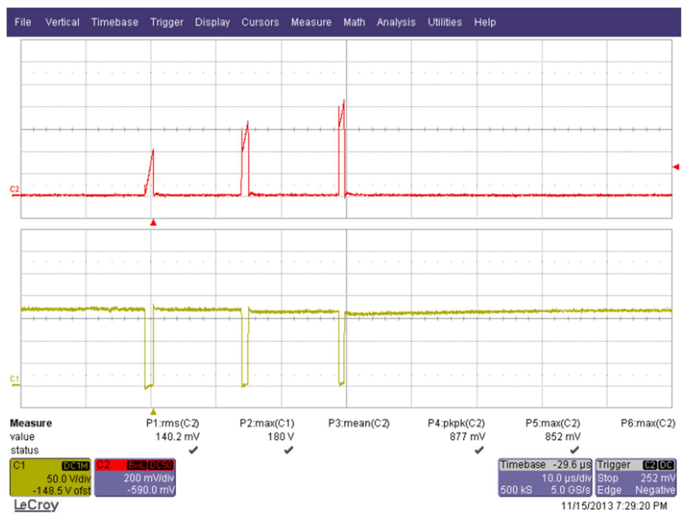

Figure 37 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

13.6 Drain Current and Drain Voltage During Output Short Condition

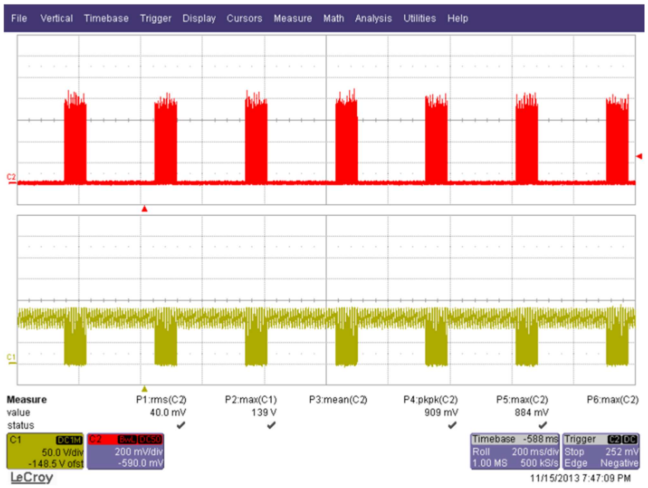

Figure 38 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

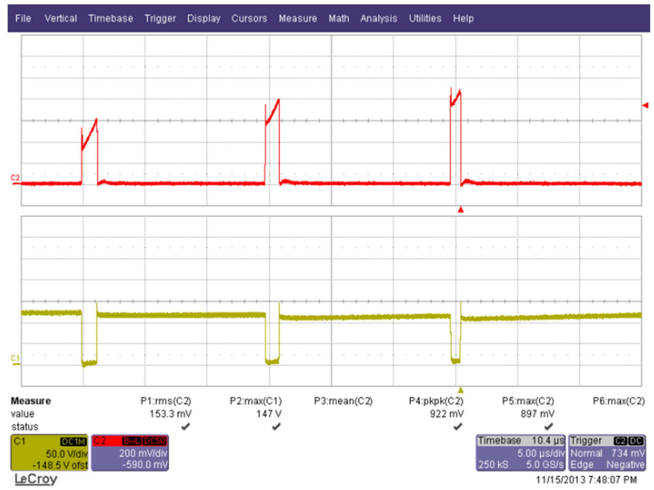

Figure 39 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 0.5 μs / div.

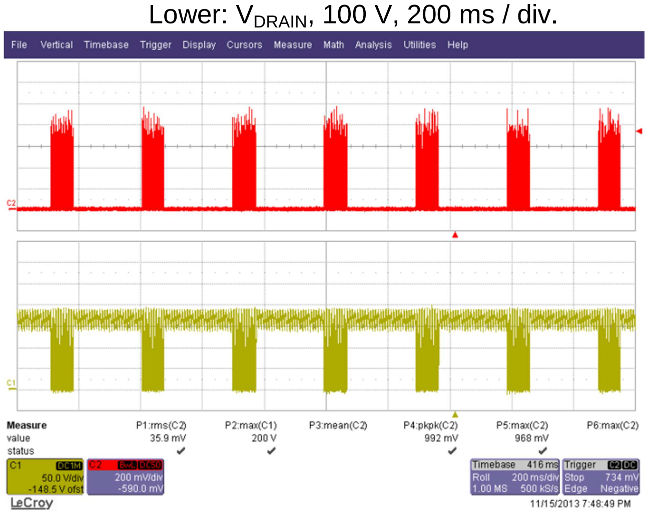

Figure 40 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: $V_{DRAIN,}$ 100 V, 5 ms / div.

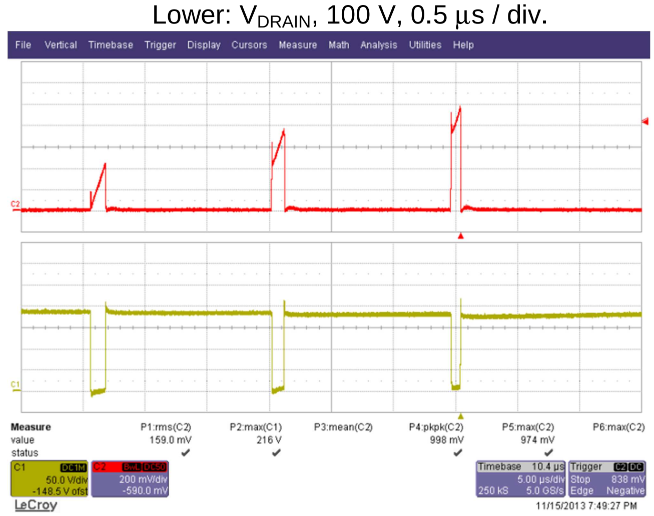

Figure 41 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: $V_{DRAIN,}$ 100 V, 1 μs / div.

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13.7 Open Load Characteristic

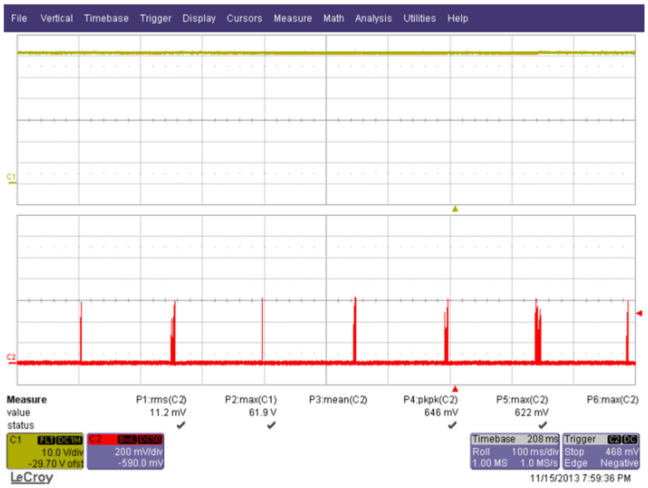

Figure 42 – 90 VAC, 60 Hz Output Short Condition.
Upper: V_{OUT}, 10 V / div.
Lower: I_{DRAIN}, 200 mA, 200 ms / div.

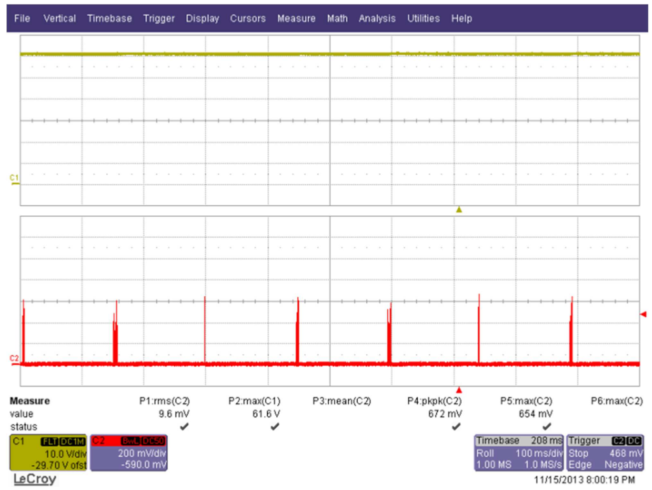

Figure 43 – 132 VAC, 60 Hz Output Short Condition.
Upper: V_{OUT}, 10 V / div.
Lower: I_{DRAIN}, 200 mA, 200 ms / div.

13.8 Brown-out/ Brown-in

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

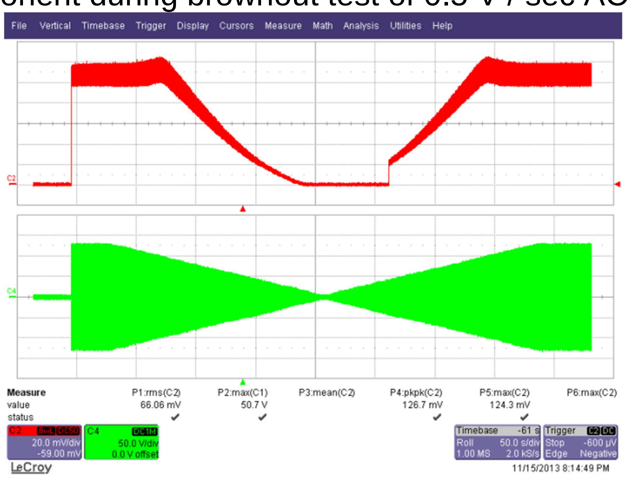

Figure 44 – Brown-out Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}; 50 V / div.
Ch2: I_{OUT}; 20 mA / div.
Time Scale: 50 s / div.

14 Dimming Waveforms

14.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 48 V LED Load
Dimmer: S-600-WH

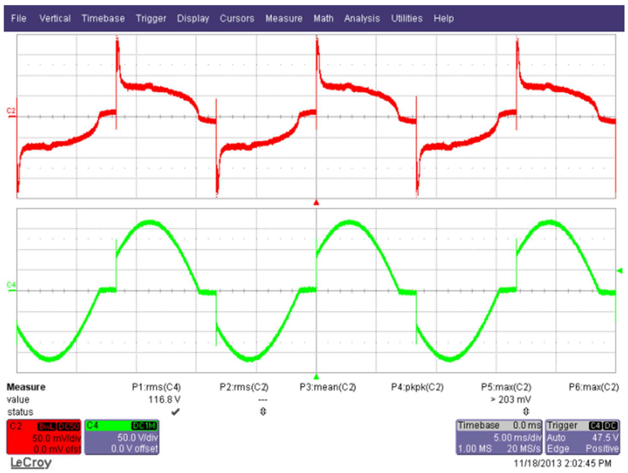

Figure 45 – 147º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

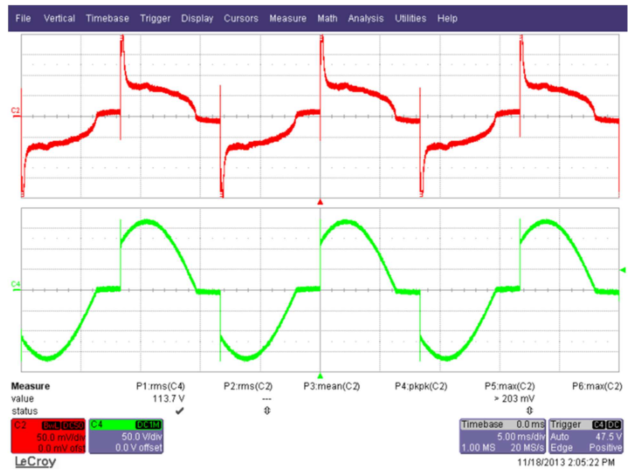

Figure 46 – 135º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

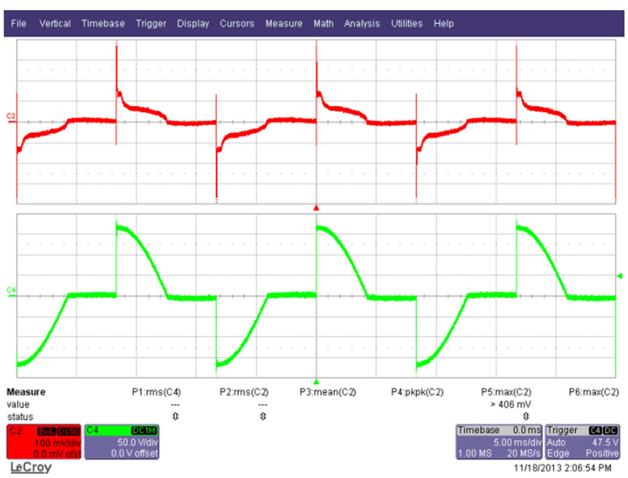

Figure 47 – 90º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

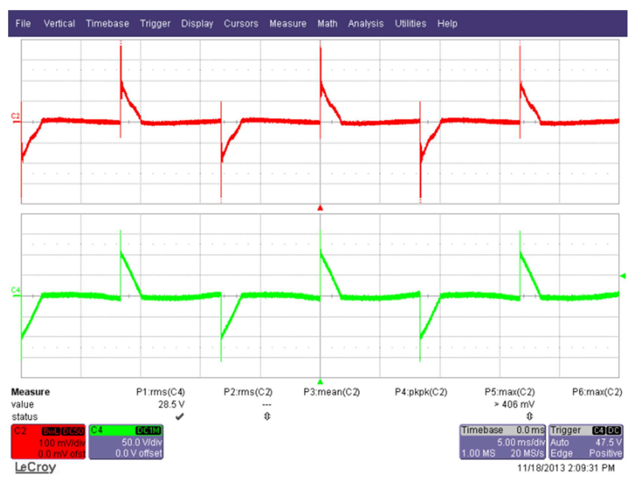

Figure 48 – 36º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

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14.2 Output Current Waveforms – Leading Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 48 V LED Load
Dimmer: S-600-WH

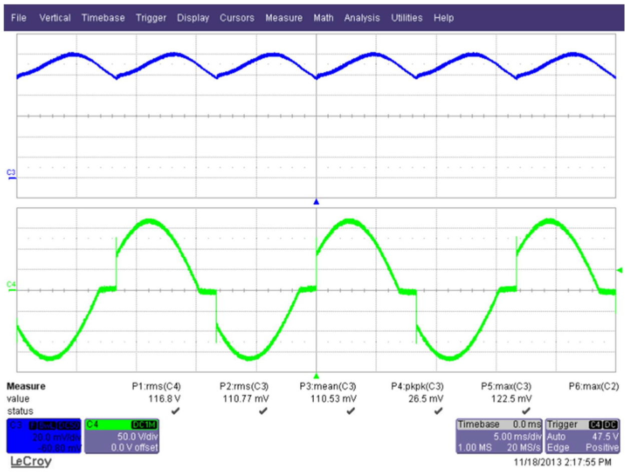

Figure 49 – 147º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

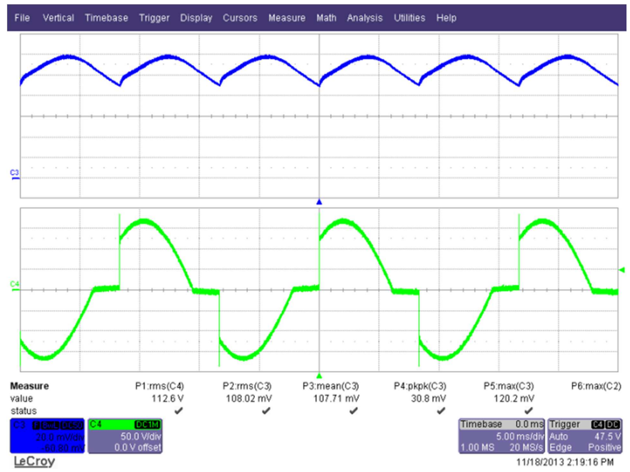

Figure 50 – 135º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

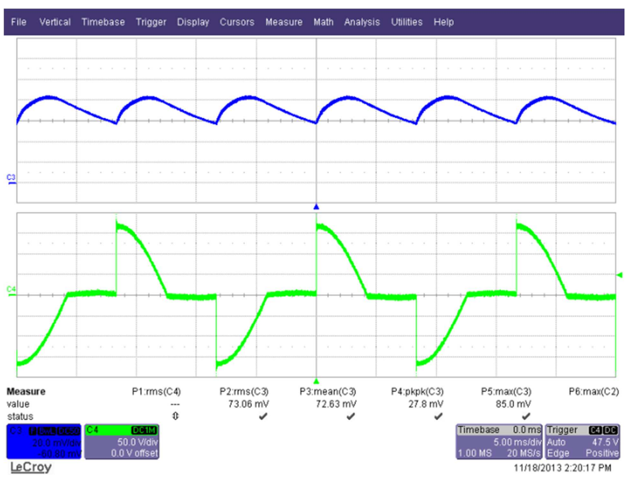

Figure 51 – 90º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

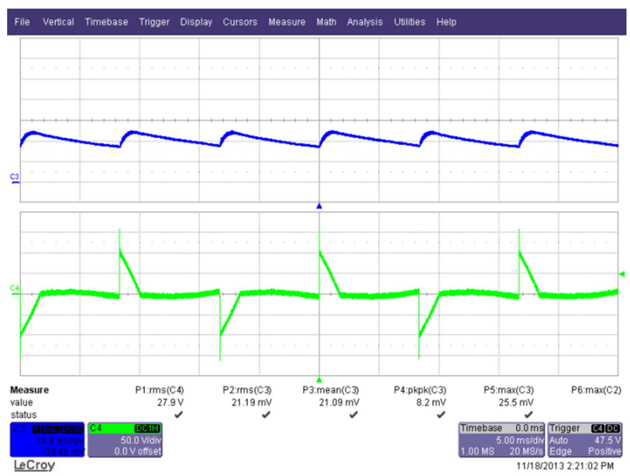

Figure 52 – 36º Conduction Angle.
Upper: I_{OUT}, 10 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

14.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 48 V LED Load
Dimmer: DVELV-300P-WH

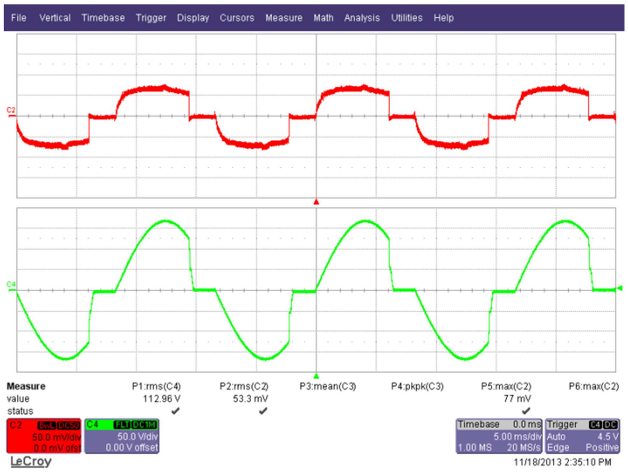

Figure 53 – 131º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

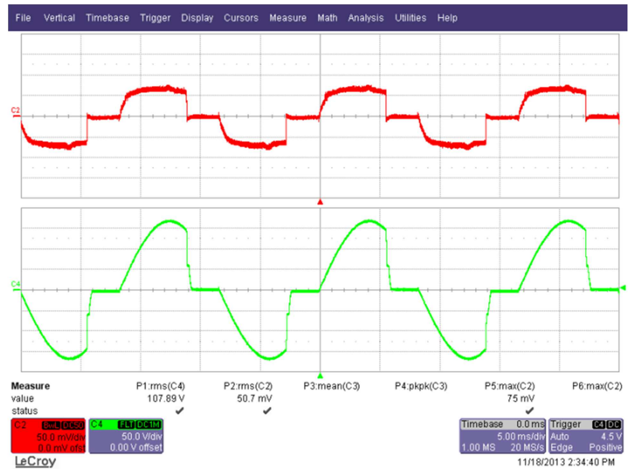

Figure 54 – 120º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

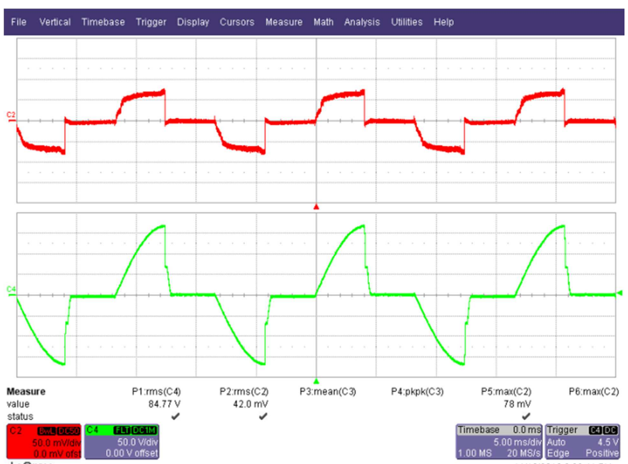

Figure 55 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

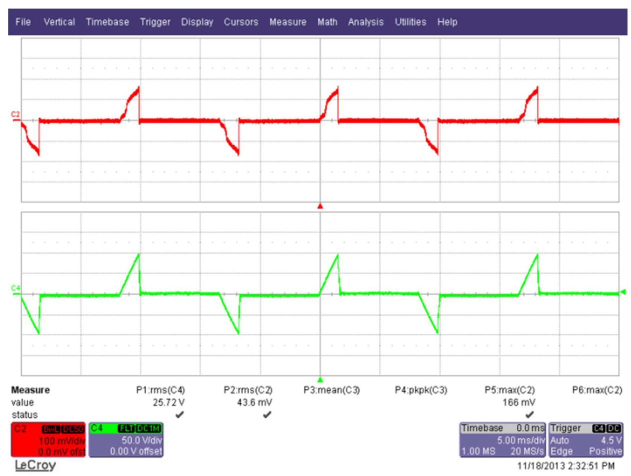

Figure 56 – 40º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

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14.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 120 VAC, 60 Hz
Output: 48 V LED Load
Dimmer: DVELV-300P-WH

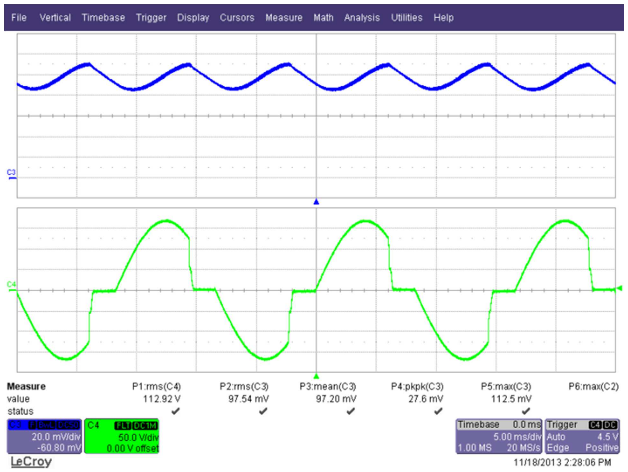

Figure 57 – 131º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

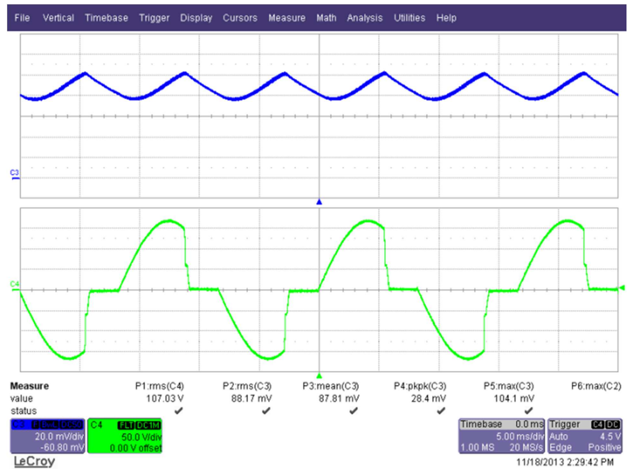

Figure 58 – 120º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

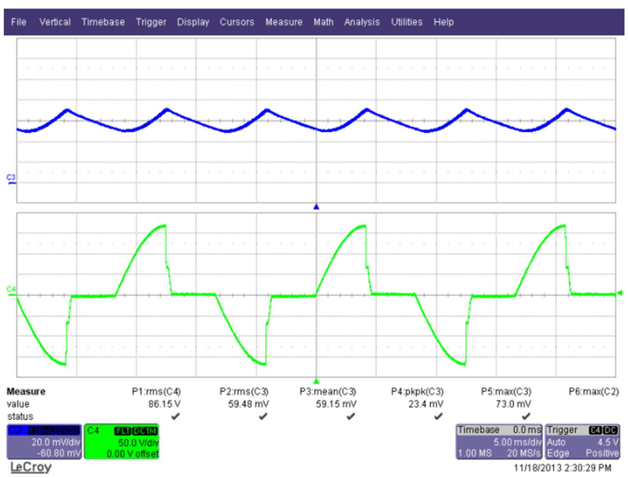

Figure 59 – 90º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

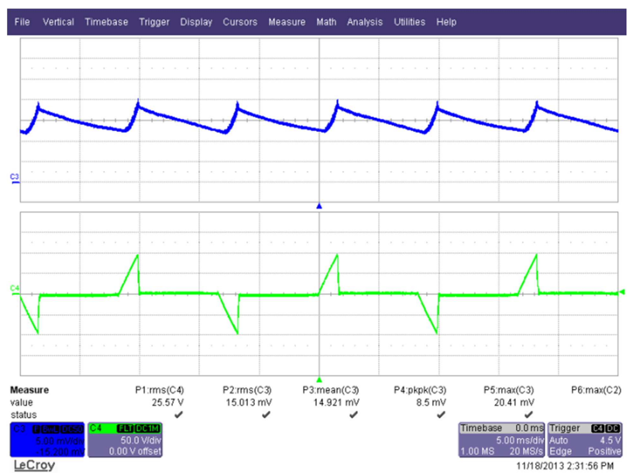

Figure 60 – 40º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

14.5 Drain Current Waveforms – Leading Edge Dimmer

Input: 120V, 60 Hz
Output: 48 V LED Load
Dimmer: S-1000-WH

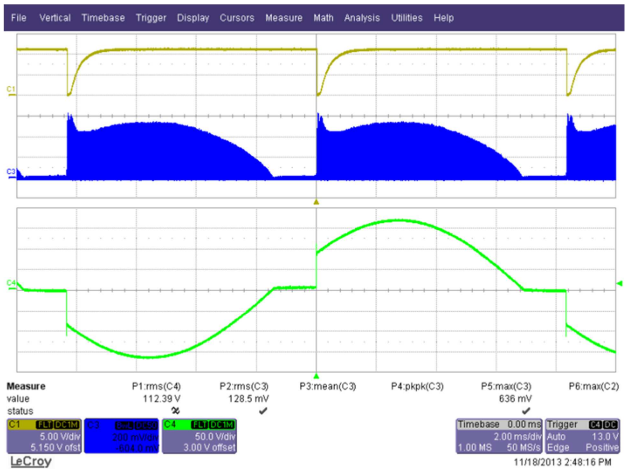

Figure 61 – 150º Conduction Angle.
Upper: U1 I_{DS}, 200 mA / div.
Q1 V_{CE}, 5 V / div.
Lower: V_{IN}, 50 V, 2 ms / div.

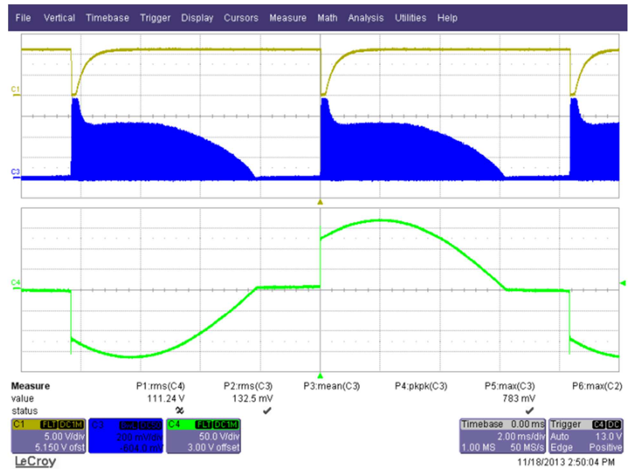

Figure 62 – 135º Conduction Angle.
Upper: U1 I_{DS}, 200 mA / div.
Q1 V_{CE}, 5 V / div.
Lower: V_{IN}, 50 V, 2 ms / div.

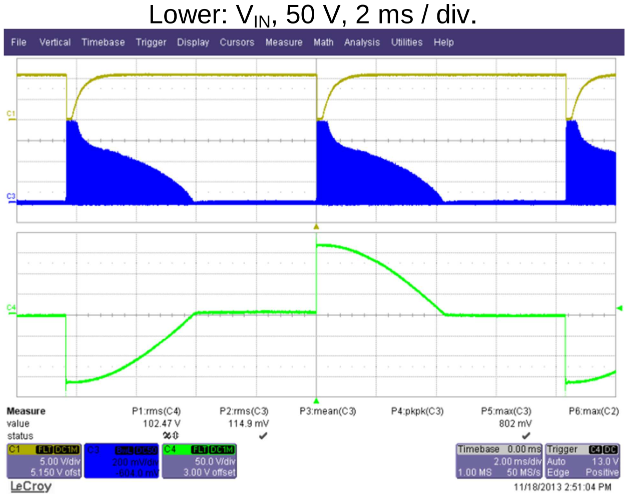

Figure 63 – 90º Conduction Angle.
Upper: U1 I_{DS}, 200 mA / div.
Q1 V_{CE}, 5 V / div.
Lower: V_{IN}, 50 V, 2 ms / div.

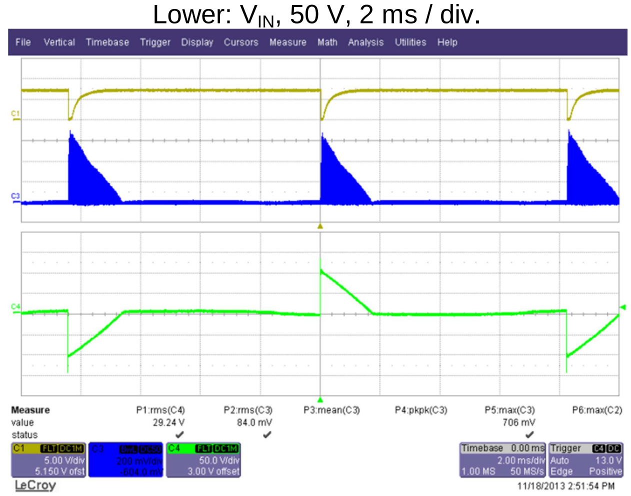

Figure 64 – 40º Conduction Angle.
Upper: U1 I_{DS}, 200 mA / div.
Q1 V_{CE}, 5 V / div.
Lower: V_{IN}, 50 V, 2 ms / div.

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15 Conducted EMI

15.1 Test Set-up

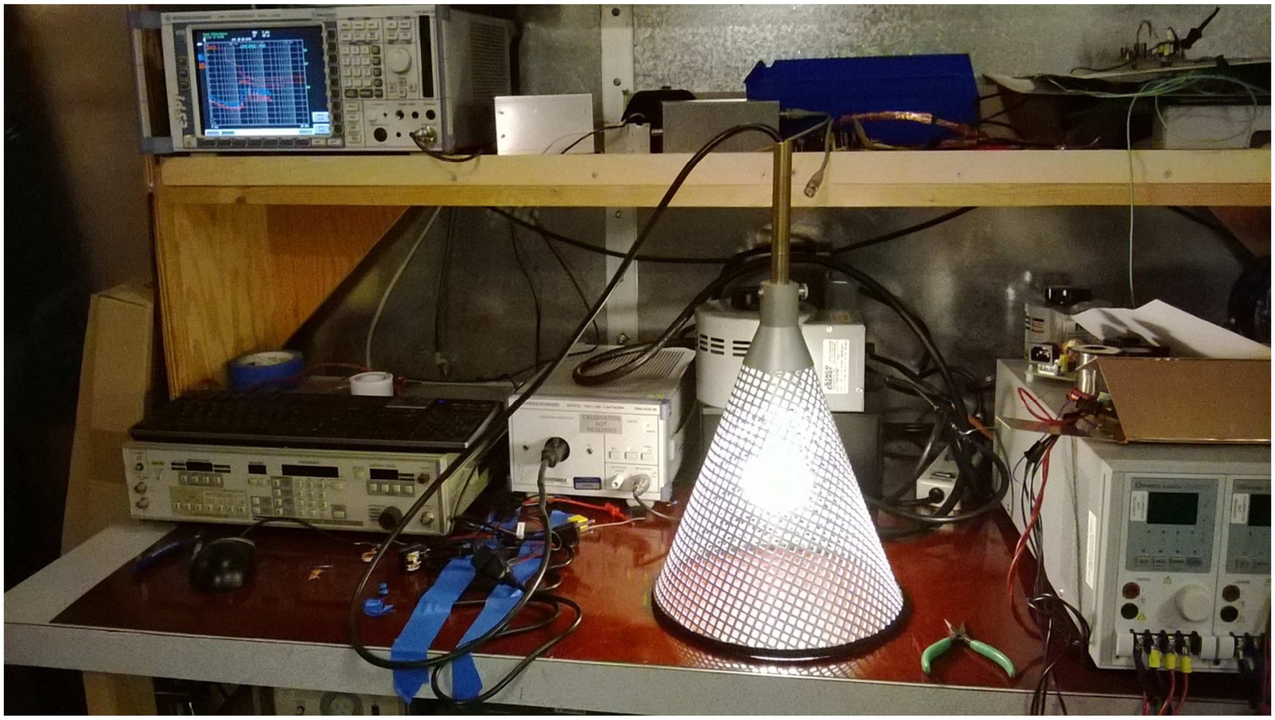

Figure 65 – Conducted EMI Test Set-up.

15.2 Test Result

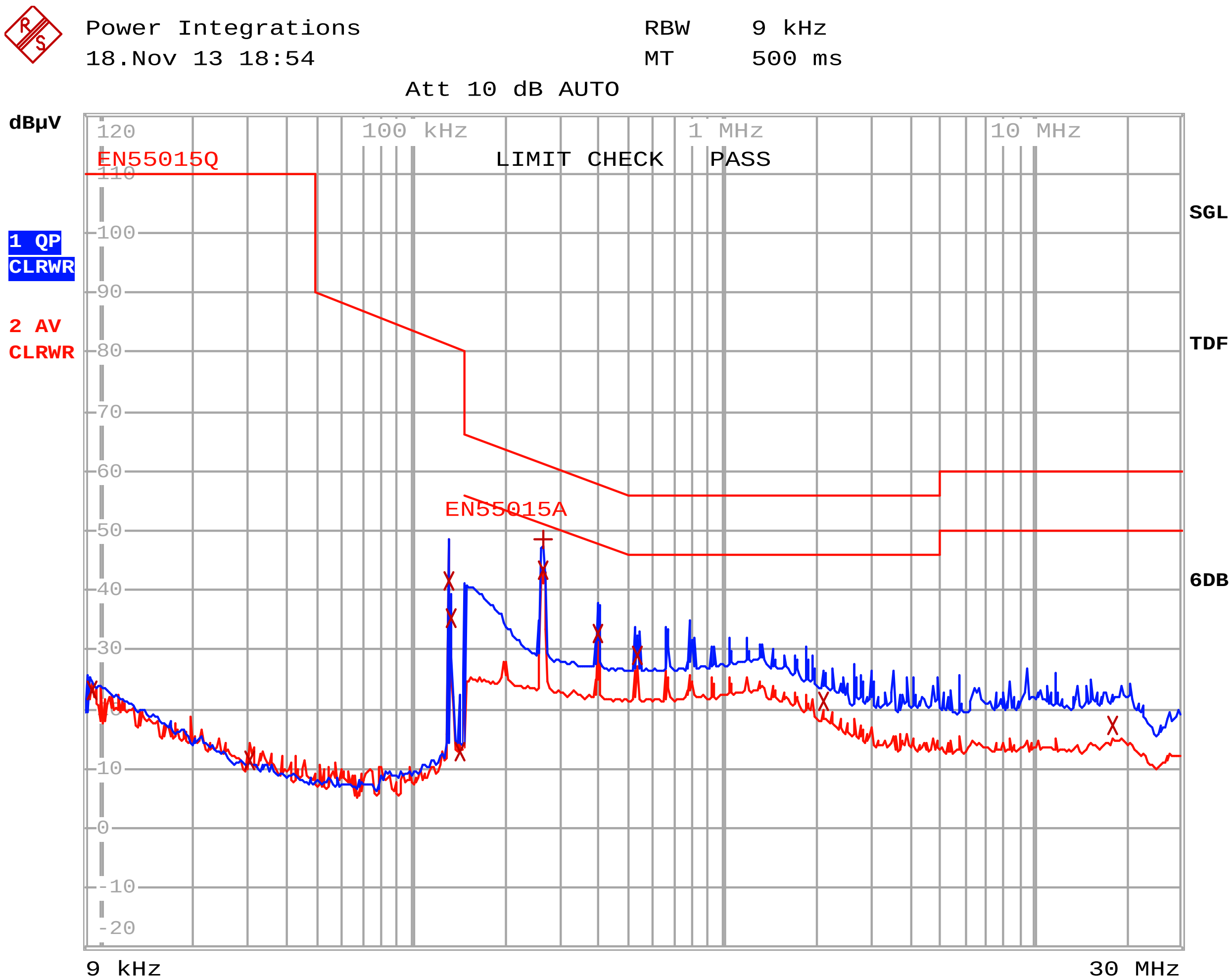

Figure 66 – Conducted EMI, ~48 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

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EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.36543609 kHz	23.00	L1 gnd	
2	Average	30.0005168717 kHz	11.39	N gnd	
2	Average	130.825395691 kHz	41.59	L1 gnd	
2	Average	133.454986145 kHz	35.44	N gnd	
2	Average	141.665156991 kHz	12.79	N gnd	
1	Quasi Peak	264.49018761 kHz	48.51	N gnd	-12.77
2	Average	264.49018761 kHz	43.33	N gnd	-7.95
2	Average	397.727746704 kHz	32.58	N gnd	-15.31
2	Average	530.769219795 kHz	29.10	N gnd	-16.90
2	Average	2.11629733595 MHz	21.43	N gnd	-24.57
2	Average	17.975130353 MHz	17.28	N gnd	-32.71

Figure 67 – Conducted EMI, Final Measurement Results.

16 Line Surge

Differential input line 500 V surge testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 120 VAC / 60 Hz.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+500	120	L to N	90	Pass
-500	120	L to N	90	Pass
+500	120	L to N	0	Pass
-500	120	L to N	0	Pass

Unit passed under all test conditions.

Differential ring input line surge testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 120 VAC / 60 Hz. Output was loaded at full load and operation was verified following each surge event.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	120	L to N	90	Pass
-2500	120	L to N	90	Pass
+2500	120	L to N	0	Pass
-2500	120	L to N	0	Pass

Unit passed under all test conditions.

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17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
16-May-14	CA	1.0	Initial Release	Mktg & Apps

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