Design Example Report

Title	***5.76 W High Power Factor Non-Isolated Buck-Boost, TRIAC Dimmable LED Driver Using LYTSwitch^{TM}-4 LYT4322E***
Specification	185 VAC – 265 VAC Input; 48 V, 120 mA Output
Application	A19 LED Driver
Author	Applications Engineering Department
Document Number	DER-406
Date	August 14, 2014
Revision	1.0

Summary and Features

- Combined single-stage power factor correction and constant current (CC) output
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers from 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 >0.93 at 230 VAC
- Meets ring wave and differential line surge and EN55015 conducted EMI

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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.

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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 185 VAC to 265 VAC (50 Hz typical). The LED driver utilizes the LYT4322E from the LYTSwitch-4 family of ICs.

The topology used is a single-stage non-isolated buck-boost that provides high power factor, constant current regulation, and delivers excellent dimming performance.

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

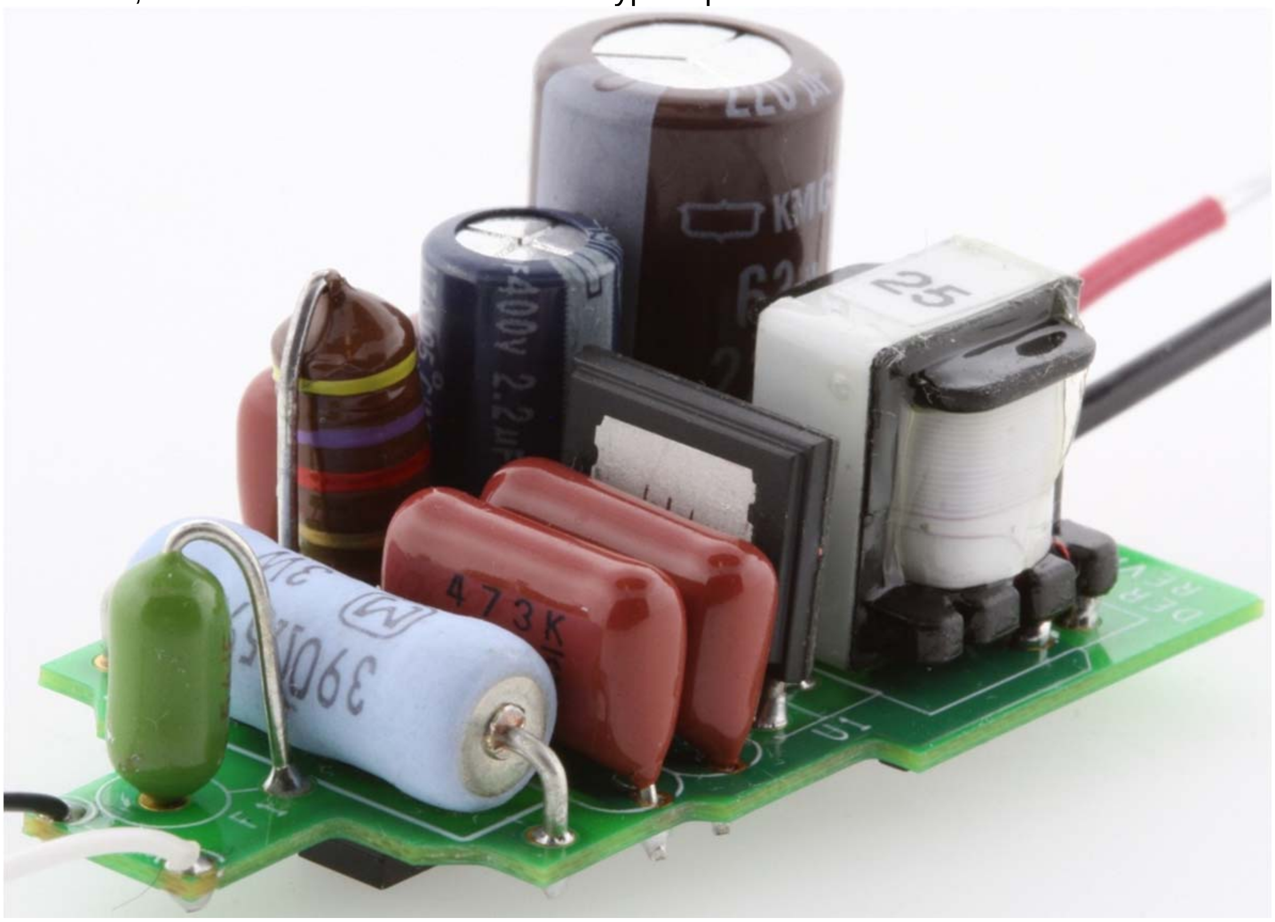

Figure 1 – Populated Circuit Board.

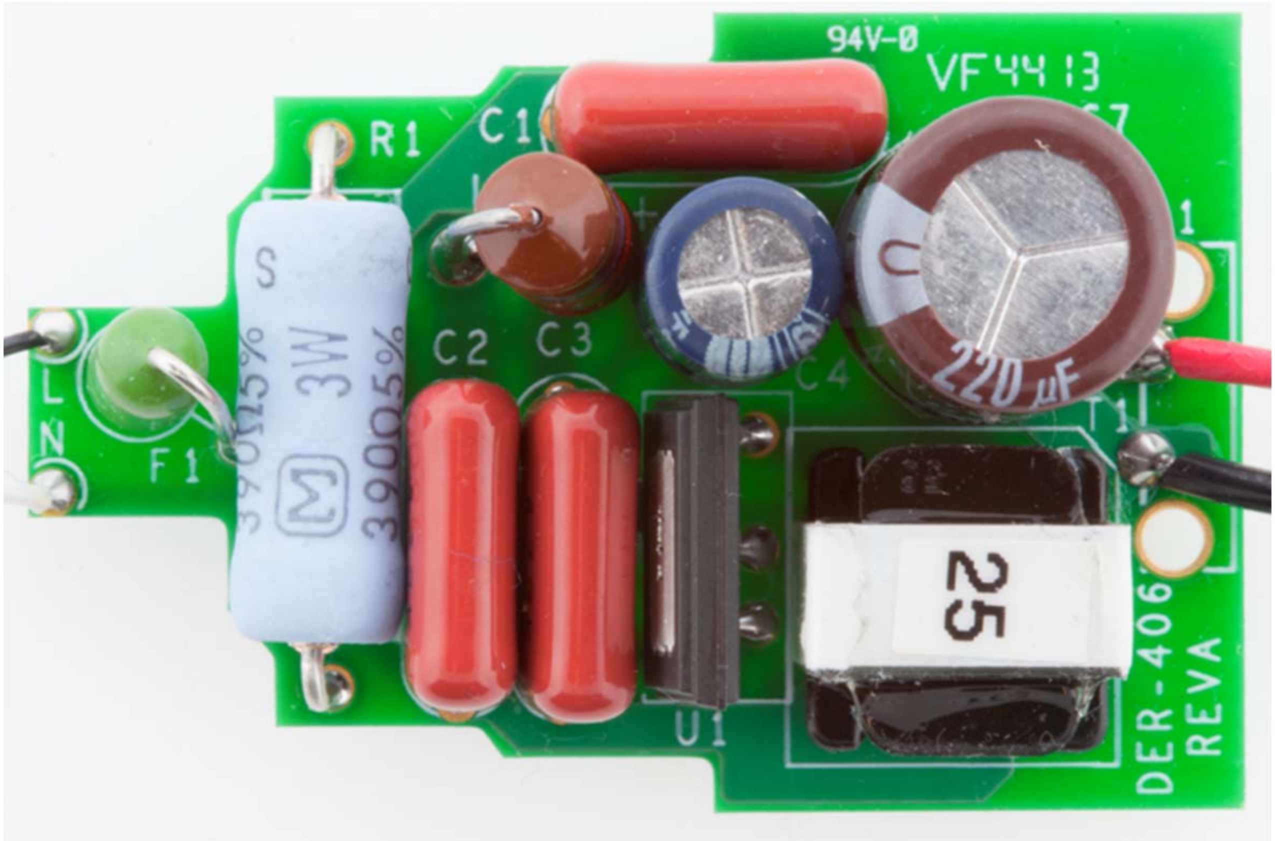

Figure 2 – Populated Circuit Board, Top View.

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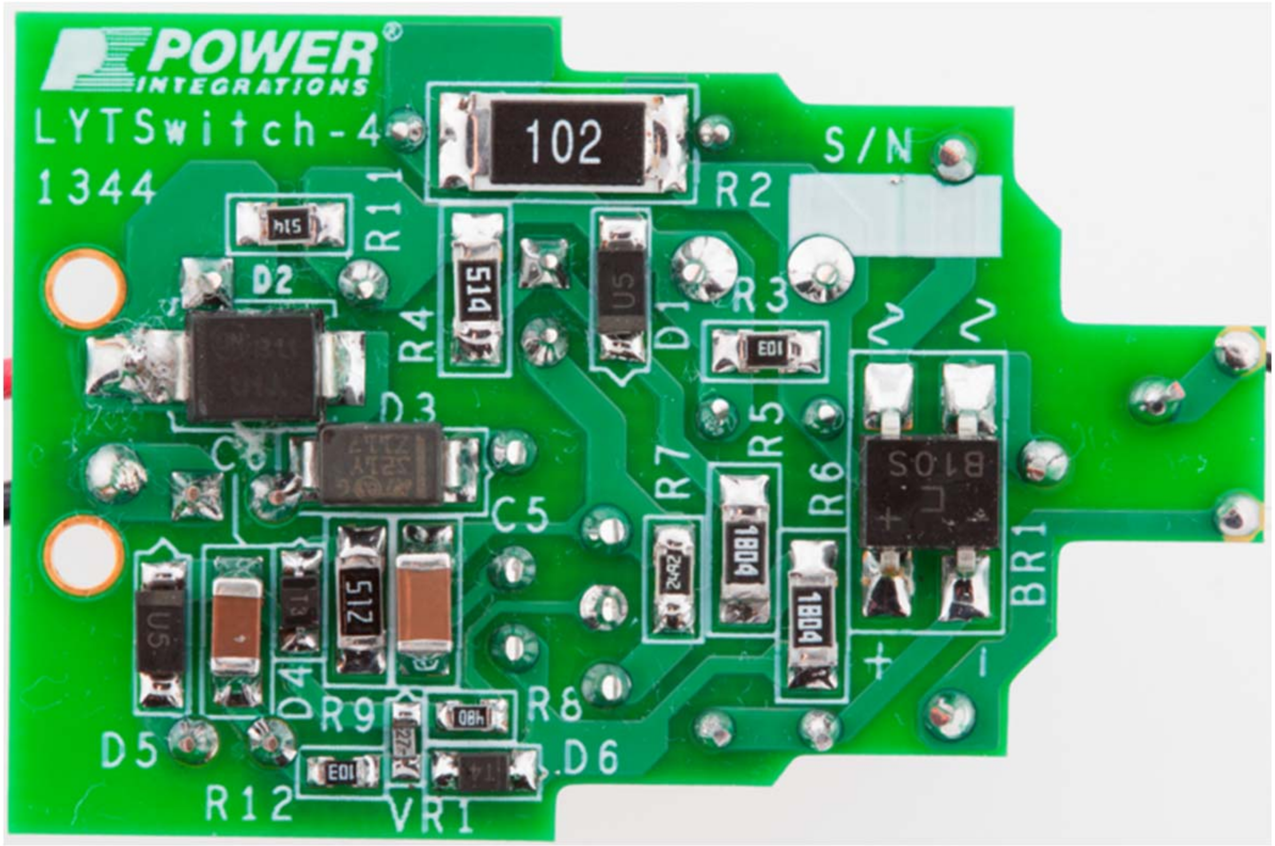

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	185	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		48		V	
Output Current	I_{OUT}		120		mA	V_{OUT} = 48 V, V_{IN} = 230 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		5.76		W	
Efficiency						
Full Load	η		82		%	Measured at P_{OUT} 25 °C, No Dimmer
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			0.93			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Ambient Temperature	T_{AMB}		40		°C	Open Frame, Free convection, sea level

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3 Schematic

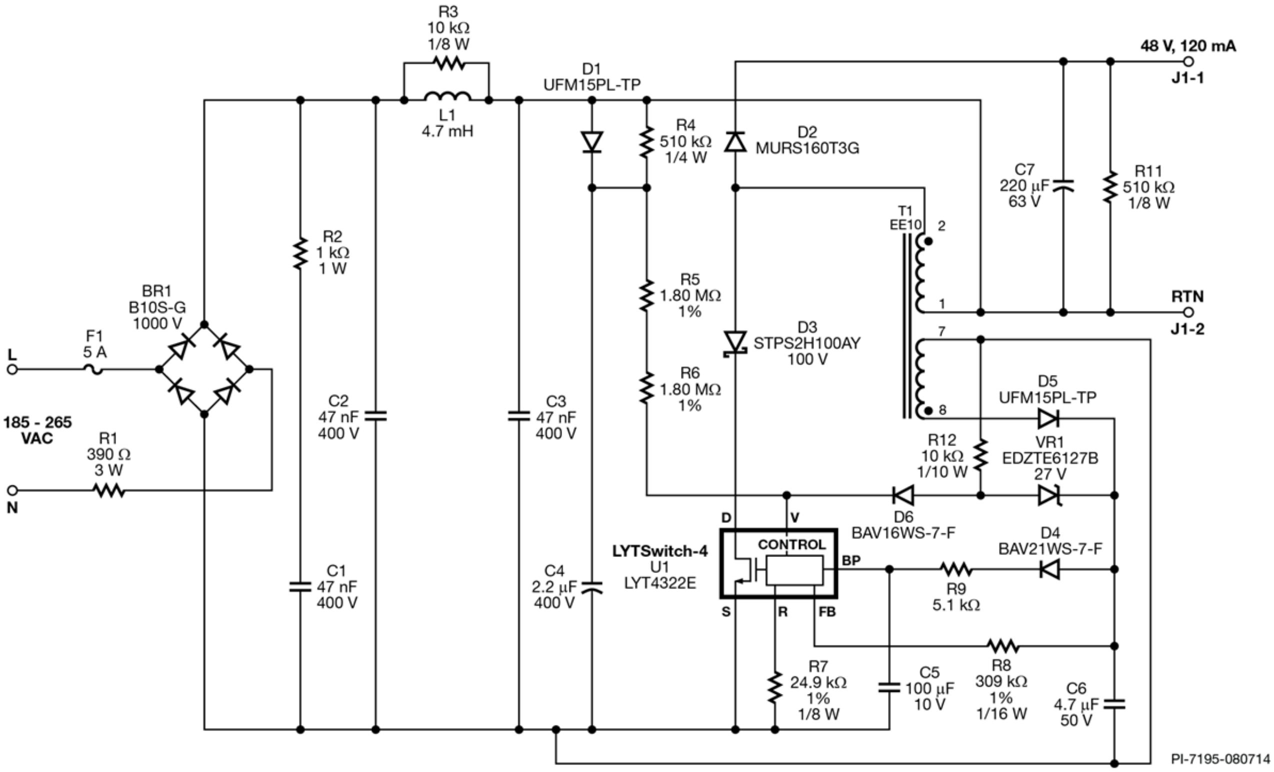

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-4 LYT4322E device is a controller with an integrated 725 V power MOSFET for use in LED driver applications. The LYTSwitch-4 LYT4322E is configured for use in a single-stage buck-boost topology and provides a regulated constant current output while maintaining high power factor from the AC input.

4.1 Input EMI Filtering

Fuse F1 provides protection from component failure during abnormal conditions. Diode bridge BR1 rectifies the AC line voltage with capacitor C3 providing 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.

4.2 Power Circuit

The topology is a buck-boost with a low-side switch configured to provide high power factor, and constant current output for an input voltage range of 185 VAC -265 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. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R5 and R6.

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, C5 is charged to ~6 V from an internal high-voltage current source connected to the D pin of U1. Capacitor C5 is also chosen to be 100 μF to enable the device to operate in reduced-power mode.

The REFERENCE pin of U1 is tied to ground (SOURCE) via 24.9 kΩ value resistor R7.

4.3 Output Feedback

The feedback is derived from a bias winding rectified and filtered by network formed by diode D5 and capacitor C6. The output voltage information across capacitor C6 is converted to feedback current by resistor R8. This current is used by LYT4322E IC to regulate the output current of the converter.

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4.4 TRIAC Phase Dimming Control Compatibility

The requirements to provide output dimming with low cost, TRIAC based, leading edge and trailing-edge phase-cut dimmers introduced some trade-offs 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 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, the passive damper and active bleeder were incorporated. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the driver. For non-dimming applications these components can simply be omitted.

Resistor R1 dampens the input network during TRIAC dimming.

A passive RC bleeder formed by resistor R1 and capacitor C1 provides latching current and damping to keep the TRIAC conducting.

5 PCB Layout

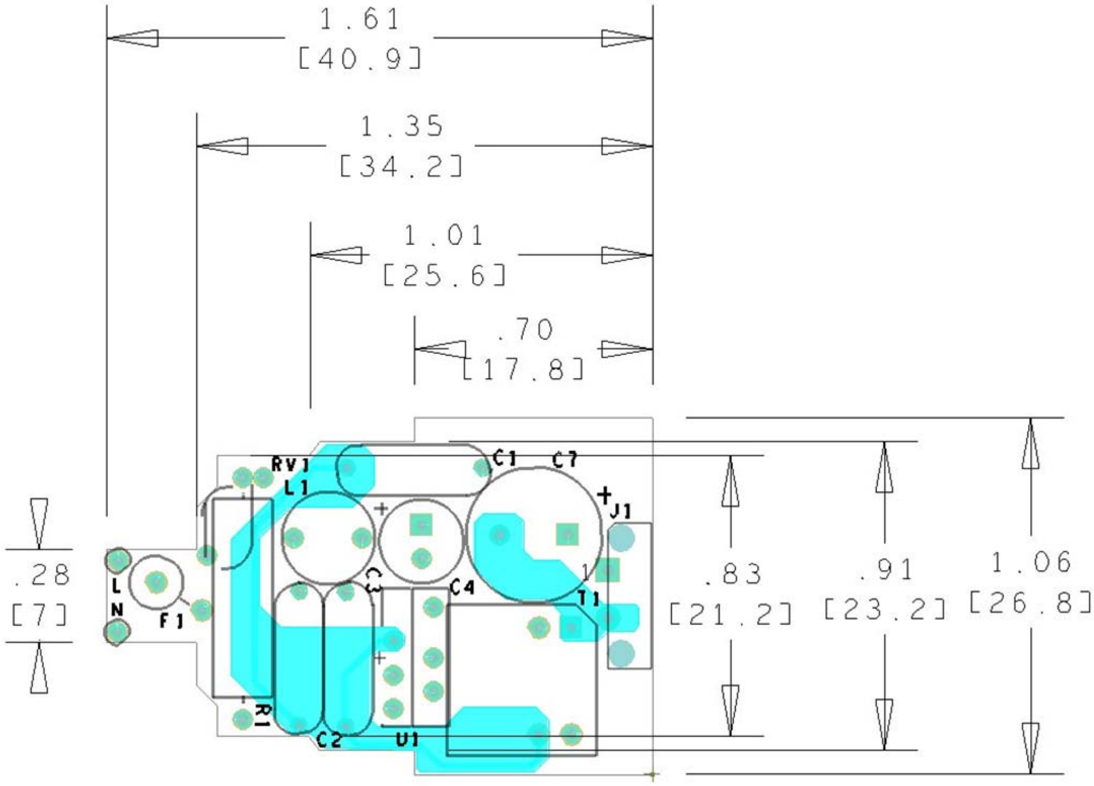

Figure 5 – Top Side.

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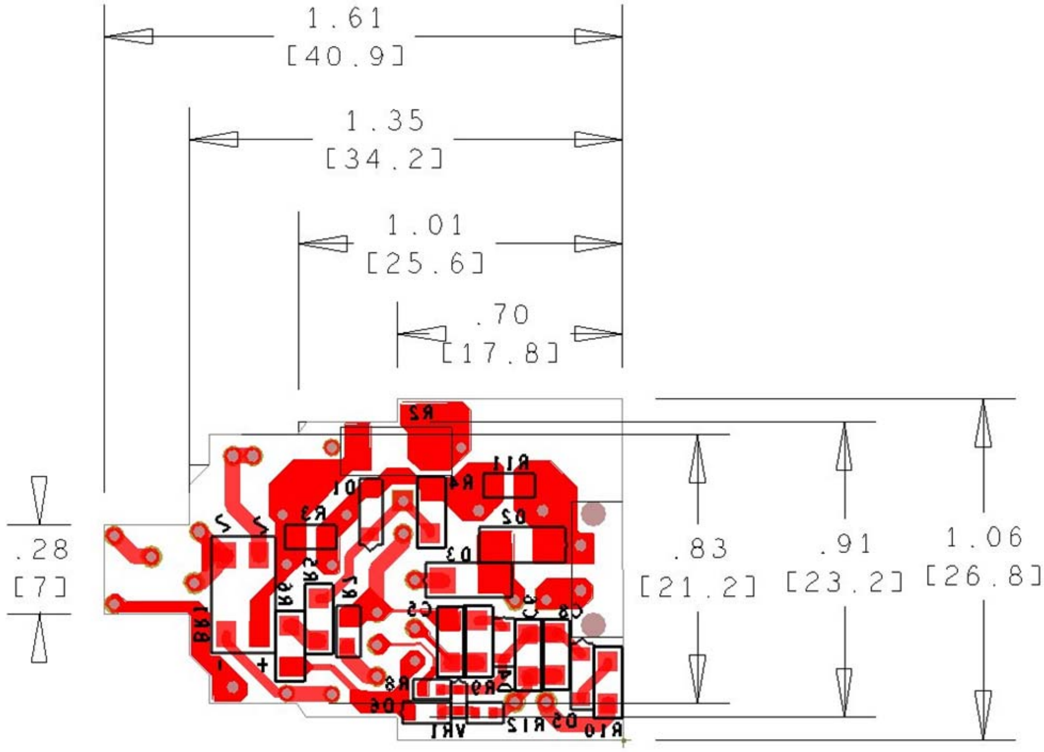

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
3	1	C2	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
4	1	C3	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
5	1	C4	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
6	1	C5	100 μF, 10 V, Ceramic, X5R, 1206	C3216X5R1A107M	TDK
7	1	C6	4.7 μF, 50 V, Ceramic, X7R, 1206	UMK316AB7475KL-T	Taiyo Yuden
8	1	C7	220 μF, 63 V, Electrolytic, (10 x 16)	EKMG630ELL221MJ16S	United Chemi-con
9	1	D1	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	MCC
10	1	D2	600 V, 1 A, Ultrafast Recovery, 35 ns, SMB Case	MURS160T3G	On Semi
11	1	D3	100 V, 2 A, Schottky, SMA	STPS2H100AY	ST Micro
12	1	D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
13	1	D5	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	MCC
14	1	D6	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
15	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
16	1	J1	CONN, MALE		
17	1	L1	4.7 mH, 90 mA, 20 Ω, RF Inductor	B82144A2475J	Epcos
18	1	R1	390 Ω, 5%, 3 W, Metal Oxide	ERG-3SJ391	Panasonic
19	1	R2	1 kΩ, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ102U	Panasonic
20	1	R3	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
21	1	R4	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
22	1	R5	1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
23	1	R6	1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
24	1	R7	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	Panasonic
25	1	R8	309 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3093V	Panasonic
26	1	R9	5.1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ512V	Panasonic
27	1	R11	510 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ514V	Panasonic
28	1	R12	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
29	1	T1	Bobbin, EE10, Vertical, 8 pins	101	Hical Magnetics
30	1	U1	LYTSwitch-4, eSIP-7C	LYT4322E	Power Integrations
31	1	VR1	27 V, 5%, 150 mW, SOD 523	EDZTE6127B	Rohm Semi

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7 Inductor Specification

7.1 Electrical Diagram

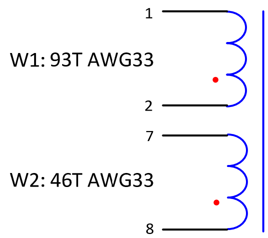

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

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

7.3 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

7.4 Inductor Build Diagram

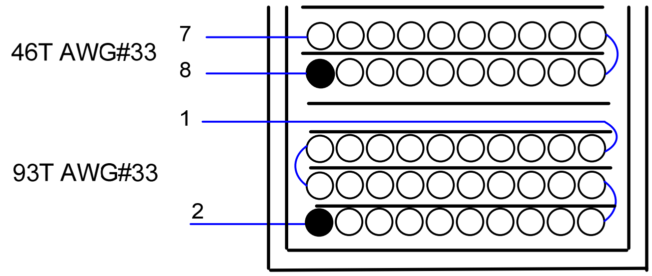

Figure 8 – Inductor Build Diagram.

7.5 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.
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.
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.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_HL_032514; Rev.1.2; Copyright Power Integrations 2014	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_HL_032514: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	YES		YES		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			195.00	V	Minimum AC Input Voltage
VACMAX			265.00	V	Maximum AC input voltage
fL			50.00	Hz	AC Mains Frequency
VO	48.00		48.00	V	Typical output voltage of LED string at full load
VO_MAX			52.80	V	Maximum expected LED string Voltage.
VO_MIN			43.40	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			0.80		Estimated efficiency of operation
VB	23.50		23.50	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	LYT4322		LYT4322		Selected LYTSwitch
Current Limit Mode	RED		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			0.65	A	Minimum current limit
ILIMITMAX			0.76	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			89.5	uA	V pin current
RV	3.60		3.60	M-ohms	Upper V pin resistor
RV2			1e+012	M-ohms	Lower V pin resistor
IFB	94.00		94.00	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			218.1	k-ohms	FB pin resistor
VDS			10.00	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	1.10		1.10		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			472	uH	Primary Inductance
VOR	48.50		48.50	V	Reflected Output Voltage.
Expected IO (average)			0.12	A	Expected Average Output Current
KP_VNOM		Info	1.00		!!! Info. PF at high line may be less than 0.9. Decrease KP for higher PF
TON_MIN			0.87	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	EE10		EE10		Select Core Size
Custom Core					Enter Custom core part number (if applicable)
AE			0.12	cm^2	Core Effective Cross Sectional Area
LE			2.61	cm	Core Effective Path Length
AL			850.00	nH/T^2	Ungapped Core Effective Inductance
BW			6.60	mm	Bobbin Physical Winding Width
M			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3.00		Number of Primary Layers
NS	93.00		93.00		Number of Secondary Turns

DC INPUT VOLTAGE PARAMETERS					
VMIN			276	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.14		Minimum duty cycle at peak of VACMIN
IAVG			0.04	A	Average Primary Current
IP			0.64	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.12	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			472	uH	Primary Inductance
LP_TOL			10.00		Tolerance of primary inductance
NP			93		Primary Winding Number of Turns
NB			46		Bias Winding Number of Turns
ALG			55	nH/T^2	Gapped Core Effective Inductance
BM			2670	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3188	Gauss	Peak Flux Density (BP<3700)
BAC			1335	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1459		Relative Permeability of Ungapped Core
LG			0.26	mm	Gap Length (Lg > 0.1 mm)
BWE			19.8	mm	Effective Bobbin Width
OD			0.21	mm	Maximum Primary Wire Diameter including insulation
INS			0.04	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.17	mm	Bare conductor diameter
AWG			34	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			40	Cmils	Bare conductor effective area in circular mils
CMA			342	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			0.64	A	Peak Secondary Current
ISRMS			0.26	A	Secondary RMS Current
IRIPPLE			0.23	A	Output Capacitor RMS Ripple Current (based on Expected IO)
CMS			53	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			32	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.20	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.07	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			485	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			433	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			215	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			3.60	M-ohms	Upper V Pin Resistor Value
RV2			1e+012	M-ohms	Lower V Pin Resistor Value
VAC1			115.00	V	Test Input Voltage Condition1
VAC2			230.00	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)			3.60	M-ohms	New RV1

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RV2 (new)			18820.47	M-ohms	New RV2
V_OV			287.9	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			60.0	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			218.09	k-ohms	Upper FB Pin Resistor Value
RFB2			1e+012	k-ohms	Lower FB Pin Resistor Value
VB1			21.21	V	Test Bias Voltage Condition1
VB2			25.90	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)			218.1	k-ohms	New RFB1
RFB2(new)			1e+012	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic			Max Current (mA)	Limit (mA)	
1st Harmonic			34.44	N/A	Fundamental (mA)
3rd Harmonic			10.11	24.48	PASS. 3rd Harmonic current content is lower than the limit
5th Harmonic			5.6	13.68	PASS. 5th Harmonic current content is lower than the limit
7th Harmonic			3.7	7.20	PASS. 7th Harmonic current content is lower than the limit
9th Harmonic			2.73	3.60	PASS. 9th Harmonic current content is lower than the limit
11th Harmonic			2.12	2.52	PASS. 11th Harmonic current content is lower than the limit
13th Harmonic			1.70	2.13	PASS. 13th Harmonic current content is lower than the limit
15th Harmonic			1.41	1.85	PASS. 15th Harmonic current content is lower than the limit
THD			35.5	%	Estimated total Harmonic Distortion (THD)

9 Performance Data

All measurements performed at room temperature using an LED load. The following data was taken using a typical LED load with an output voltage of 48 V. Refer to the table on Section 8.4 for the complete set of test data values.

9.1 Efficiency

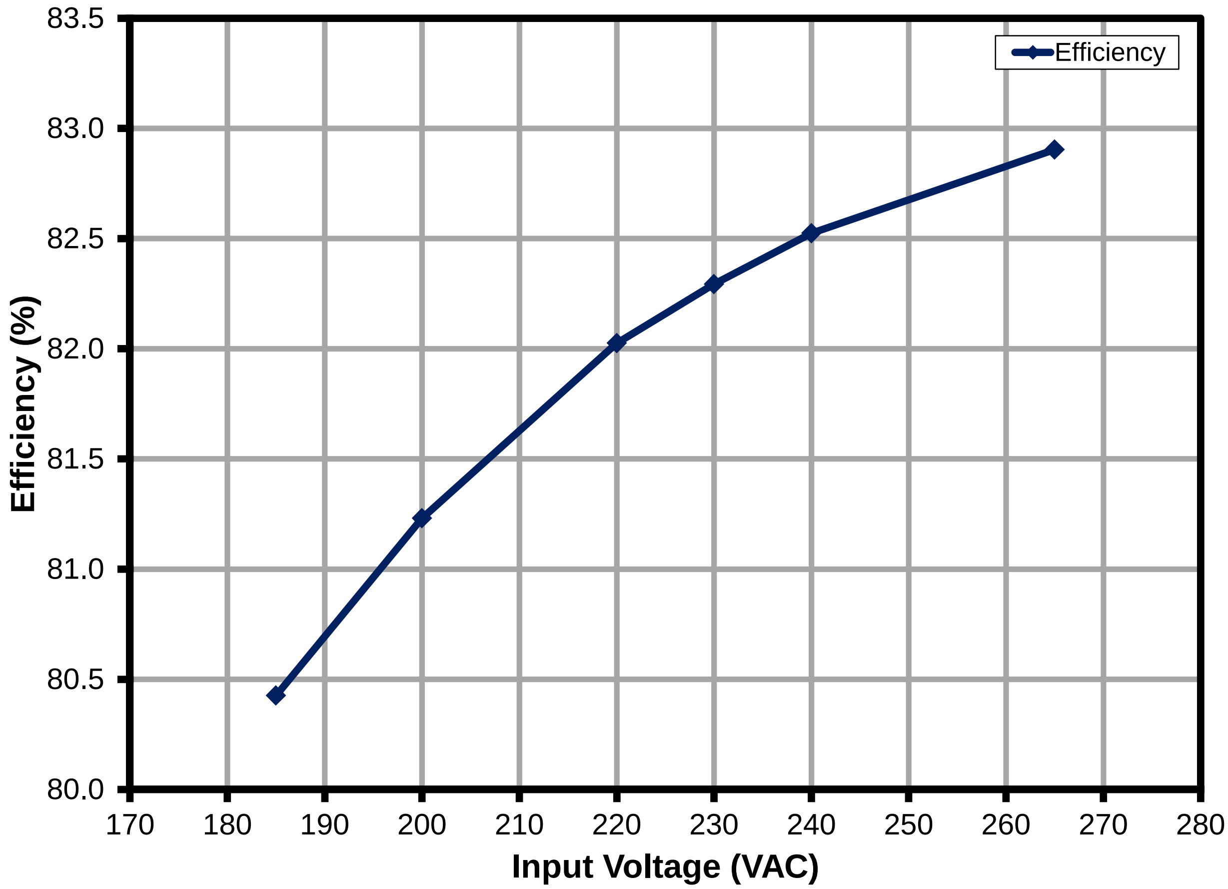

Figure 9 – Efficiency vs. Line

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9.2 Line Regulation

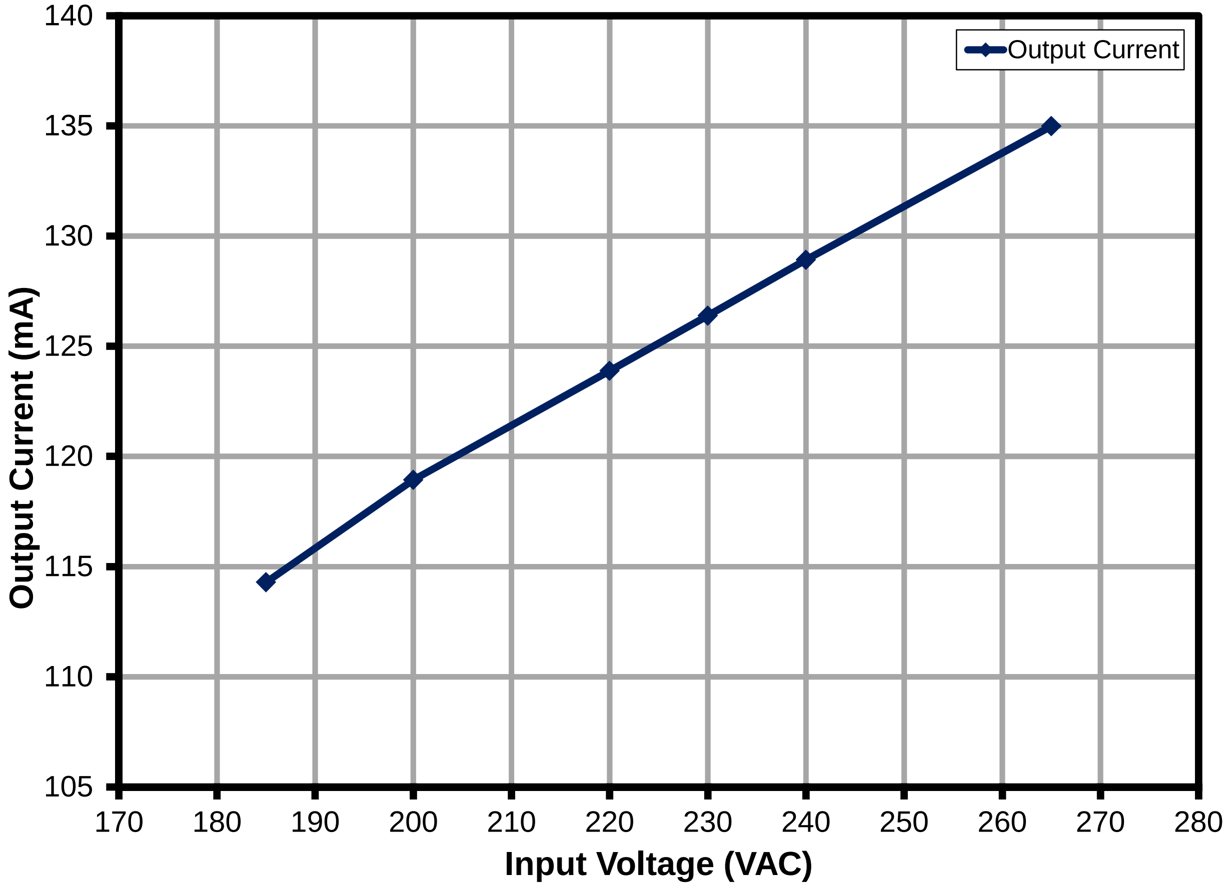

Figure 10 – Regulation vs. Line.

9.3 Power Factor

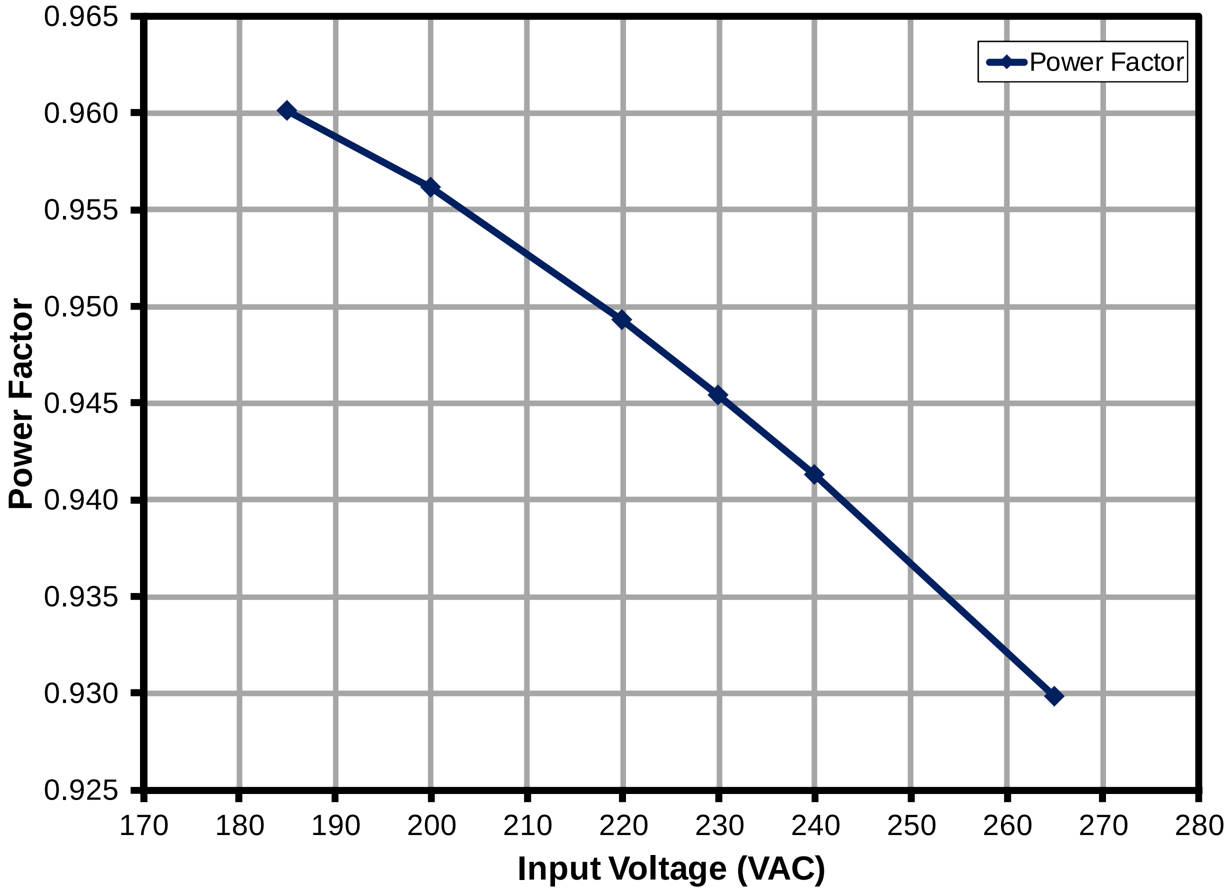

Figure 11 – Power Factor vs. Line.

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9.4 Test Data

All measurements were made with the board at open frame, 25 ºC ambient, 50 Hz line frequency and 48 V 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)
185.05	39.85	7.08	0.96	23.44	49.72	114.29	5.70	5.68	80.43	1.39
200.09	38.18	7.30	0.96	23.04	49.77	118.93	5.93	5.92	81.23	1.37
220.11	36.10	7.54	0.95	22.33	49.83	123.88	6.19	6.17	82.03	1.36
230.16	35.28	7.68	0.95	21.96	49.85	126.39	6.32	6.30	82.29	1.36
240.13	34.56	7.81	0.94	21.59	49.88	128.92	6.45	6.43	82.52	1.37
265.15	33.07	8.15	0.93	20.58	49.95	134.99	6.76	6.74	82.90	1.39

10 Dimming Performance Data

TRIAC dimming was measured with input voltage of 230 VAC, 50 Hz line frequency, room temperature, and nominal 48 V LED load.

10.1 Dimming Curve

Measurement were made with a programmable AC source providing the leading edge chopped AC input.

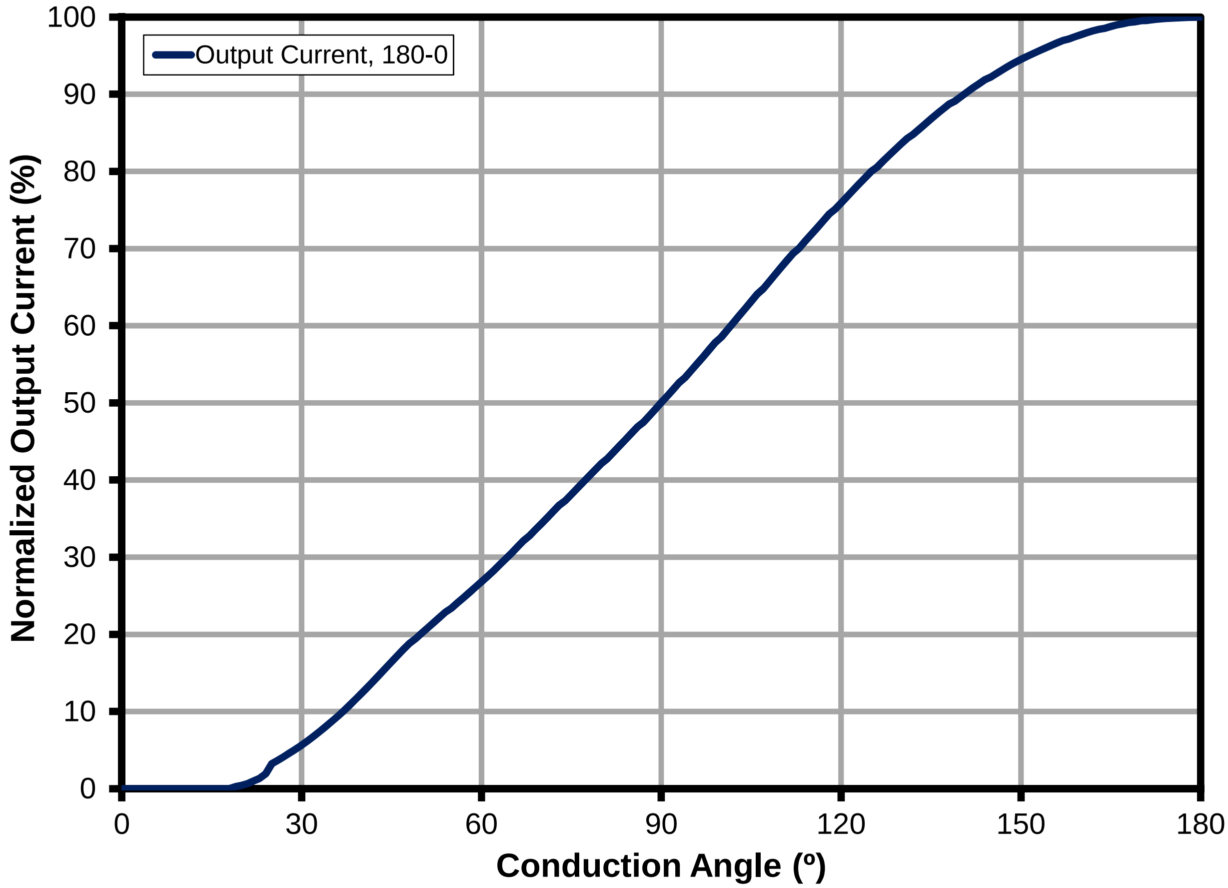

Figure 12 – Leading Edge Dimming Characteristics.

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10.2 Dimming Efficiency

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

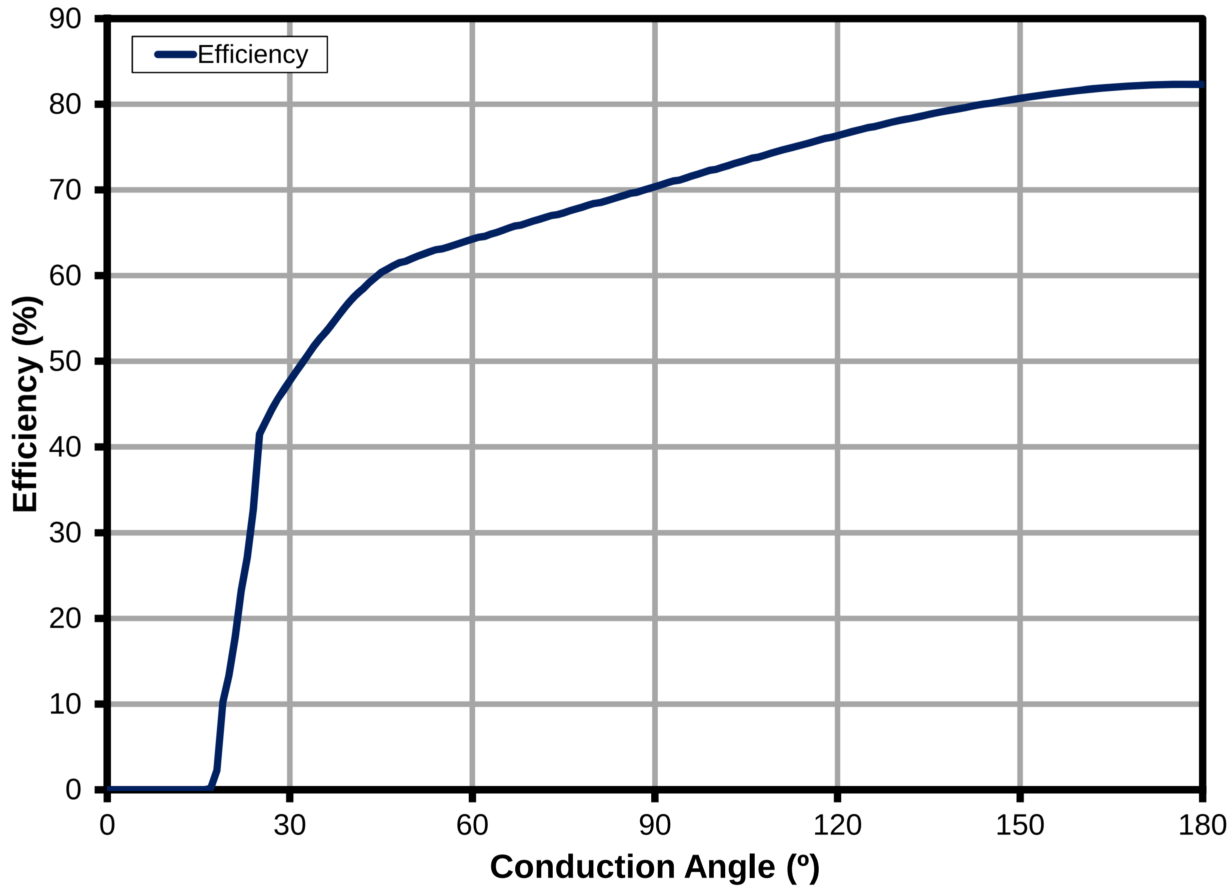

Figure 13 – Driver Efficiency as a function of Conduction Angle.

10.3 Driver Power Loss During Dimming

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

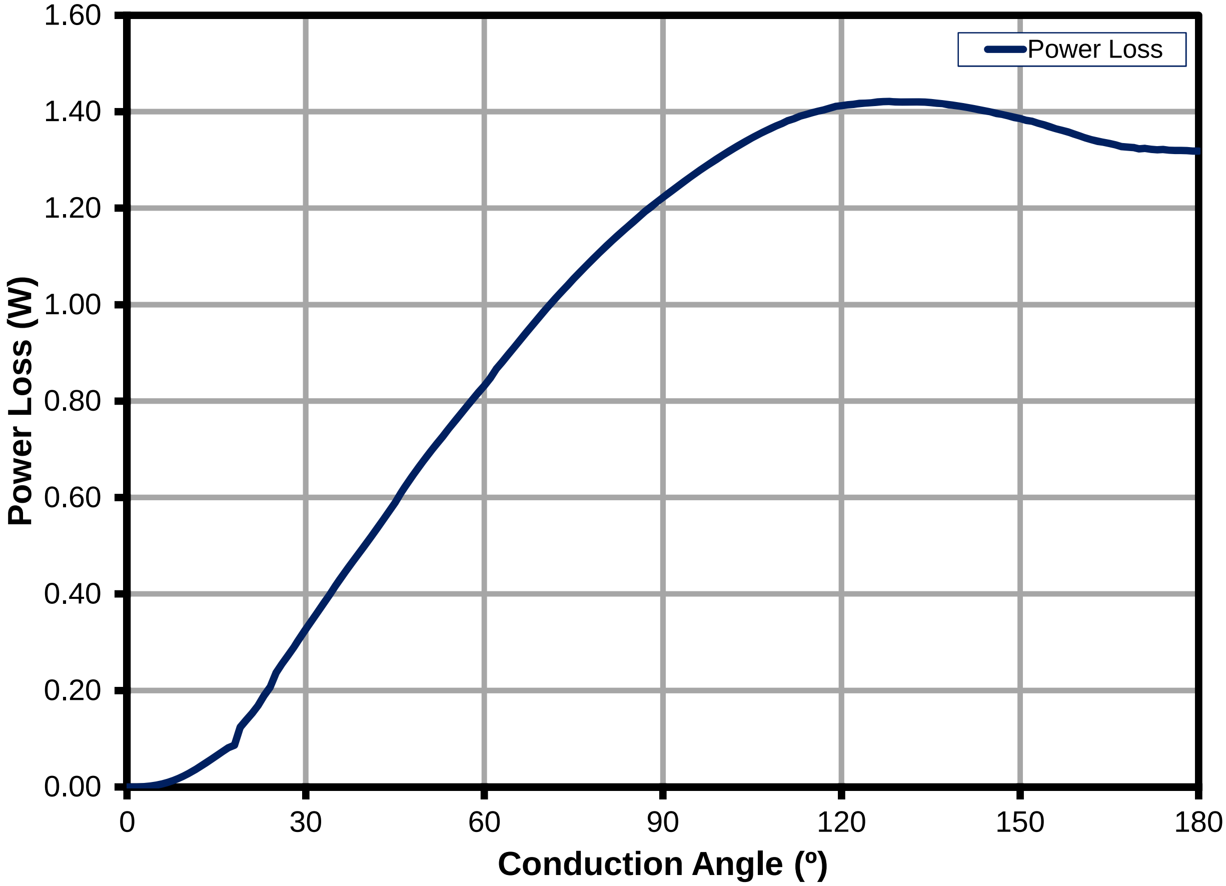

Figure 14 – Driver Power Loss as a function of Conduction Angle.

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10.4 Dimmer Compatibility List

The unit was tested with the following high-line dimmers at 230 VAC, 50 Hz input and ~48 V LED load.

			Clean Sine Waveform	China Waveform
	Dimmers	**Type**	**230 V 50 Hz**	**230 V 50 Hz**
EU Panel 1				
1	BERKER 2830 10	LE	**Y**	**Y**
2	JUNG 225 NV DE	LE	**Y**	**Y**
3	JUNG 254 UDIE 1	TE	**Y**	**Y**
4	JUNG 266 G DE	LE	**Y**	**Y**
5	BUSCH 2200 UJ-212	LE	**Y**	**Y**
6	BUSCH 2250 U	LE	**N**	**N**
7	BUSCH 2247 U	LE	**Y**	**Y**
8	GIRA 2262 00 / IO1	LE	**Y**	**Y**
9	GIRA 0300 00 / IO1	LE	**N**	**N**
10	GIRA 0302 00 / IO1	LE	**Y**	**Y**
EU Panel 2				
1	GIRA 1176 00/I03	TE	**Y**	**Y**
2	310-013	LE	**Y**	**Y**
3	310-017	TE	**N**	**N**
4	310-014	LE	**Y**	**Y**
5	310-016	LE	**Y**	**N**
German1				
1	KOPP 8033	LE	**Y**	**Y**
2	BUSCH 691 U-101	ELEC	**N**	**N**
3	BUSCH 6513 U-102	TE	**Y**	**Y**
4	PEHA 433HAB	TE	**Y**	**Y**
5	PEHA 433HAB Oa	TE	**Y**	**Y**
German2				
1	REV 300W	LE	**X**	**X**
2	2250	LE	N	N
3	400W	LE	N	N
4	572499	LE	**Y**	**Y**
5	6513	TE	**Y**	**Y**
6	2875	LE	**Y**	**Y**
Chinese				
1	TCL	LE	**N**	**N**
2	SEN BO LANG	LE	**Y**	**Y**
3	EBA HUANG	LE	**Y**	**Y**
4	SB ELECT	LE	**Y**	**Y**
5	MYONGBO	LE	**Y**	**Y**
6	KBE	LE	**Y**	**Y**
7	CLIPMEI	LE	**Y**	**Y**
9	MANK	LE	**Y**	**Y**
Australian				
1	32E450LM	LE	**Y**	**Y**
2	32E450TM	TE	**Y**	**Y**
3	32E2CFLDM	TE	**Y**	**Y**
4	32E450UDM	TE	**Y**	**Y**

11 Thermal Performance

11.1 Thermal Set-up

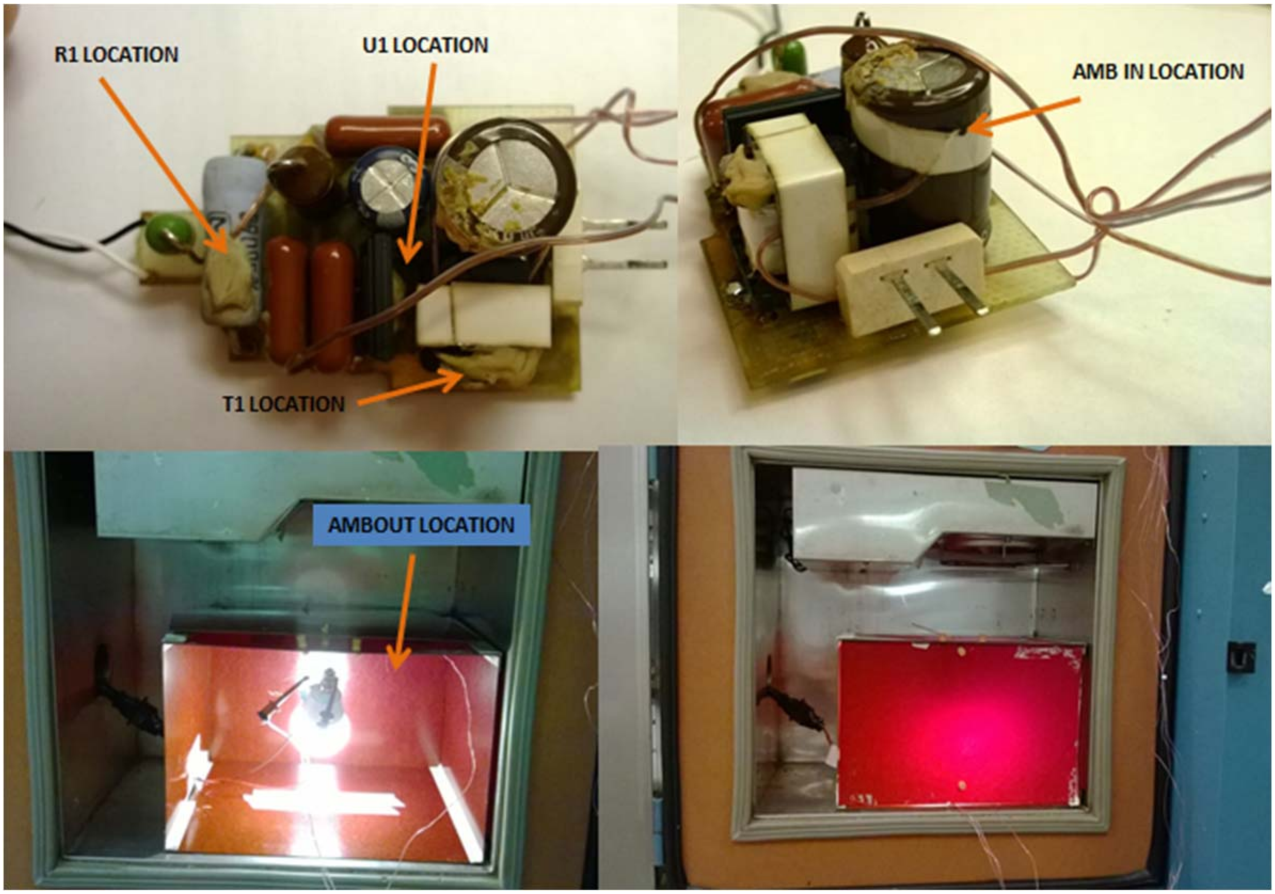

Figure 15 – Thermal Set-up.

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11.1.1 28.7 ºC External Ambient Thermal Measurements

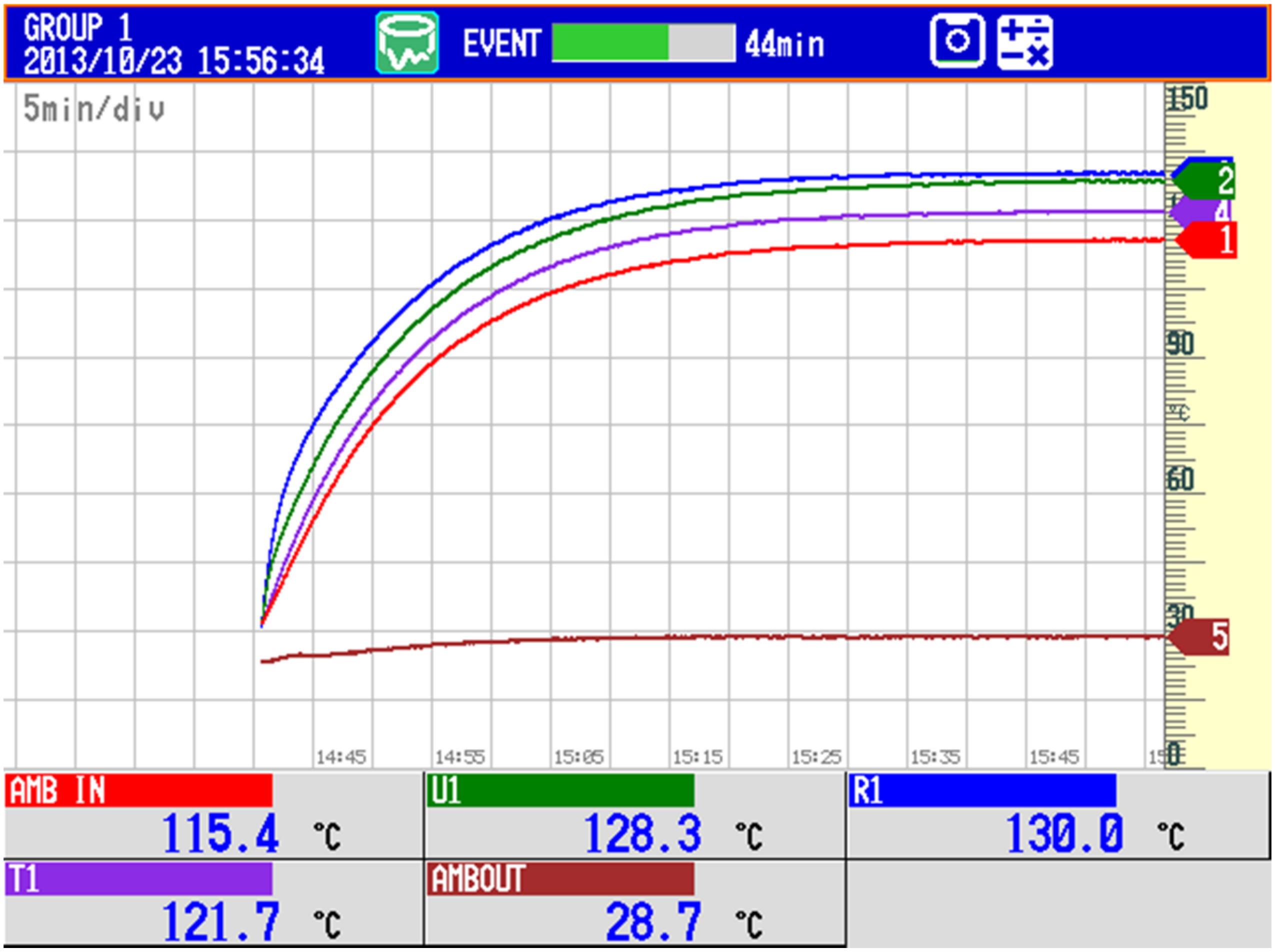

Figure 16 – 28.7 ºC External Ambient Thermal Measurements.

11.1.2 42.5 ºC External Ambient Thermal Measurements

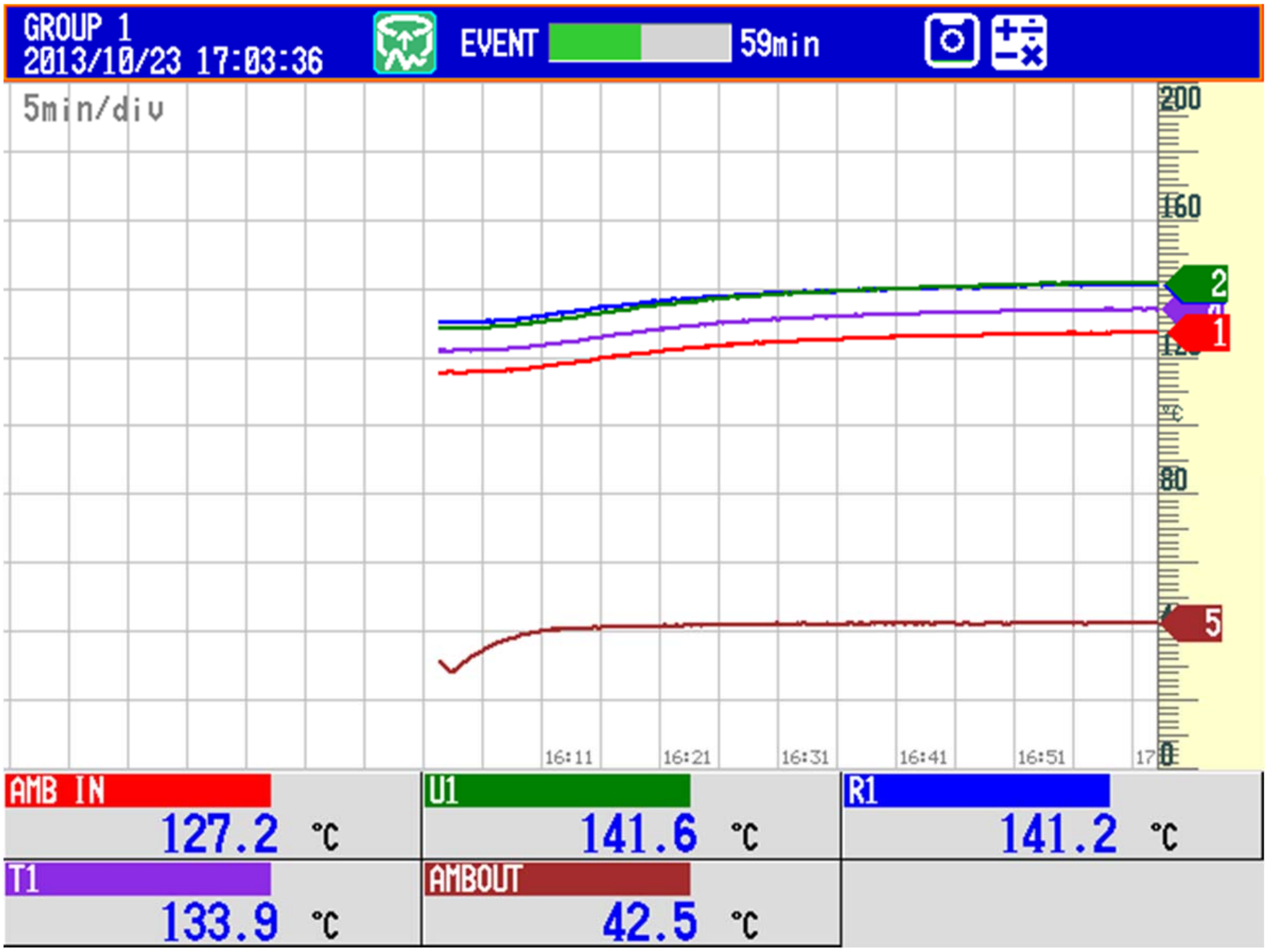

Figure 17 – 42.5 ºC Ambient Thermal Measurements.

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11.1.3 Thermal Shutdown and Recovery

The device shuts down at 49.4 ºC external ambient (AMBOUT) with the device case temperature (U1) reaching a maximum of 143.6 ºC. The device recovers at 89.4 ºC case temperature.

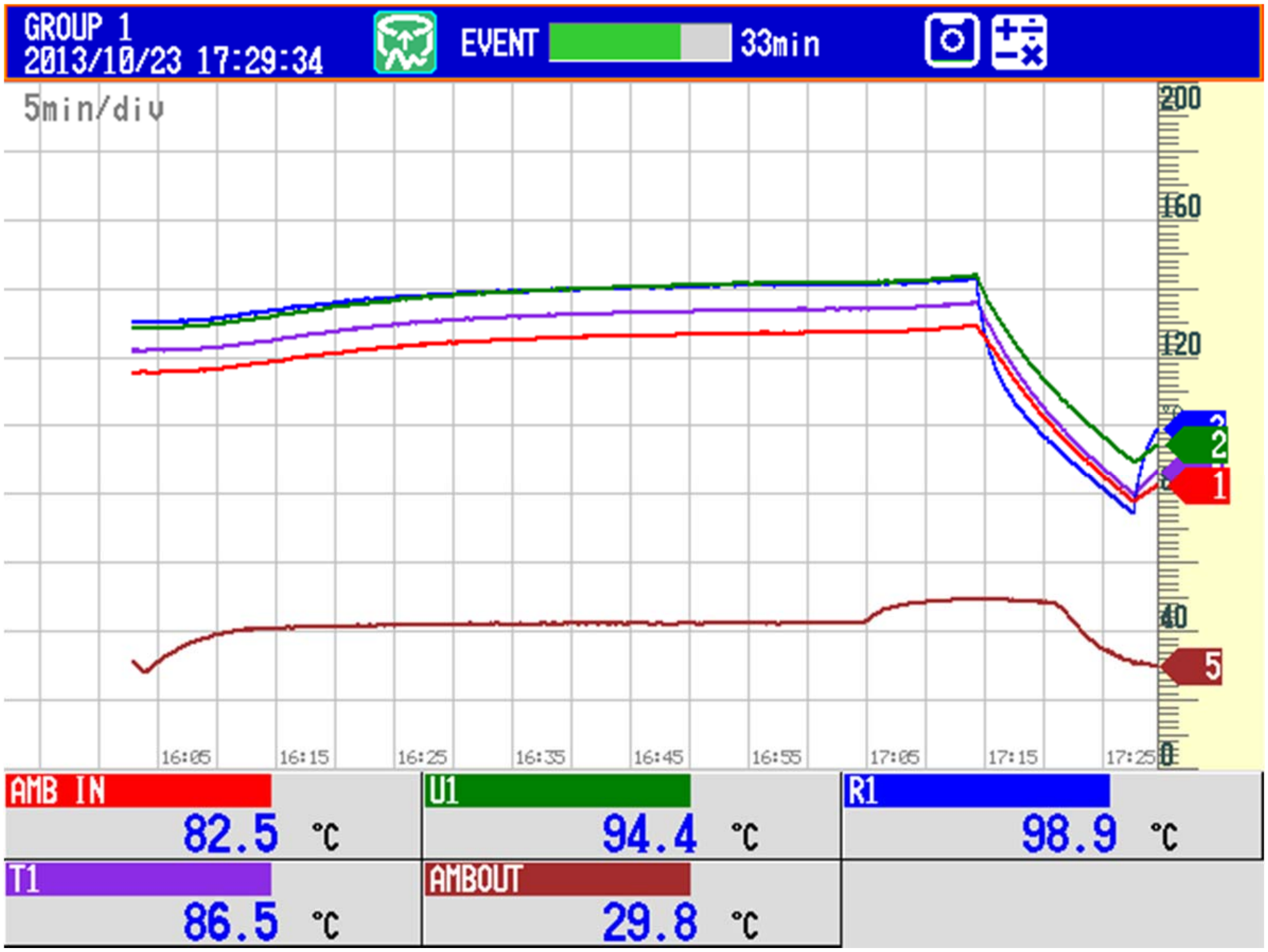

Figure 18 – Thermal Shutdown and Recovery.

12 Non-Dimming (No Dimmer Connected) Waveforms

12.1 Input Voltage and Input Current Waveforms

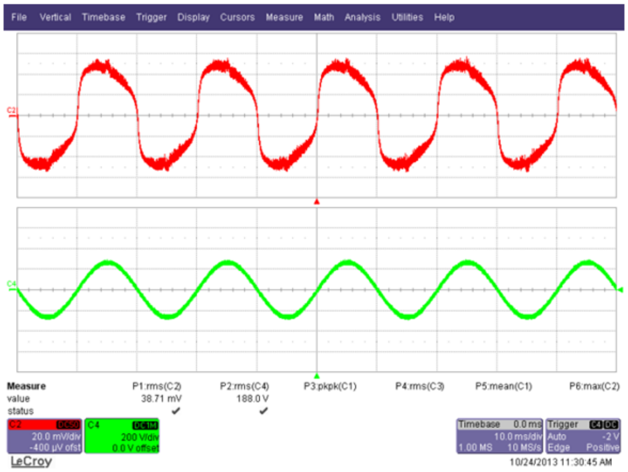

Figure 19 – 185 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

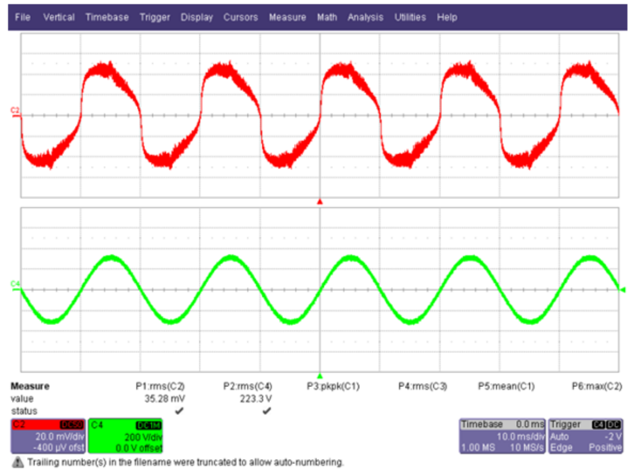

Figure 20 – 220 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

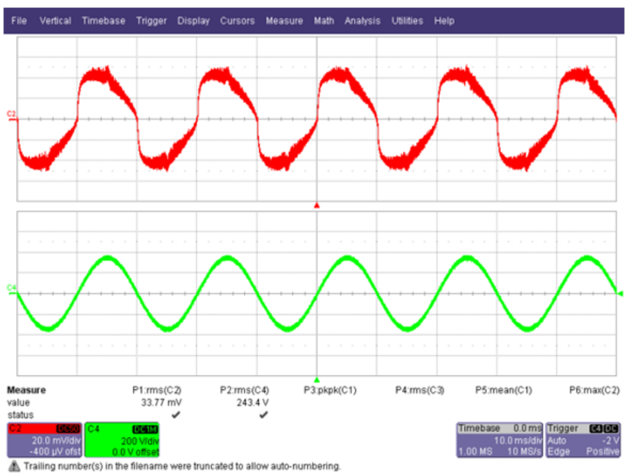

Figure 21 – 240 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

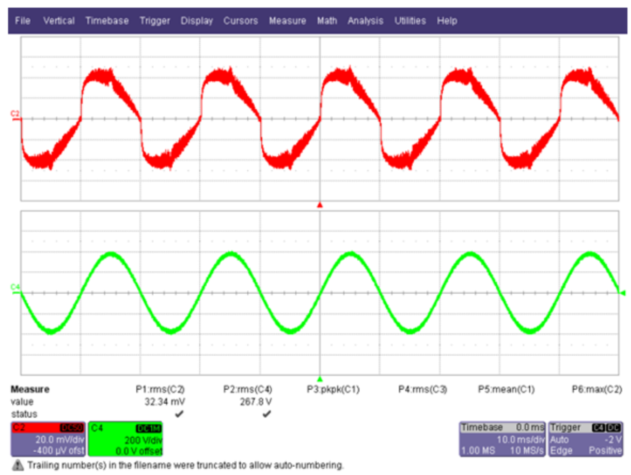

Figure 22 – 265 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

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12.2 Output Current and Output Voltage at Normal Operation

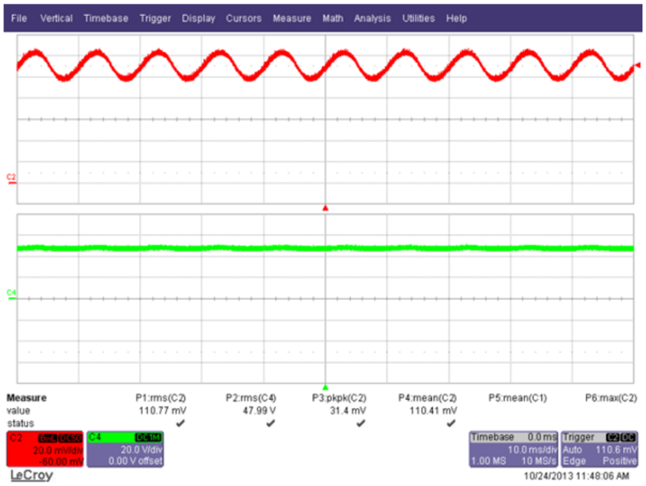

Figure 23 – 185 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

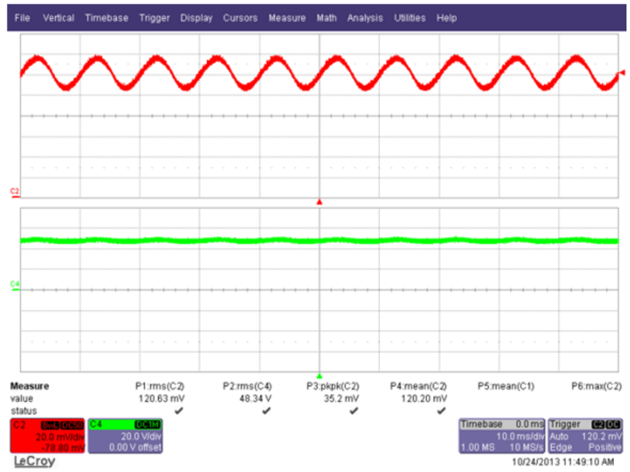

Figure 24 – 220 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

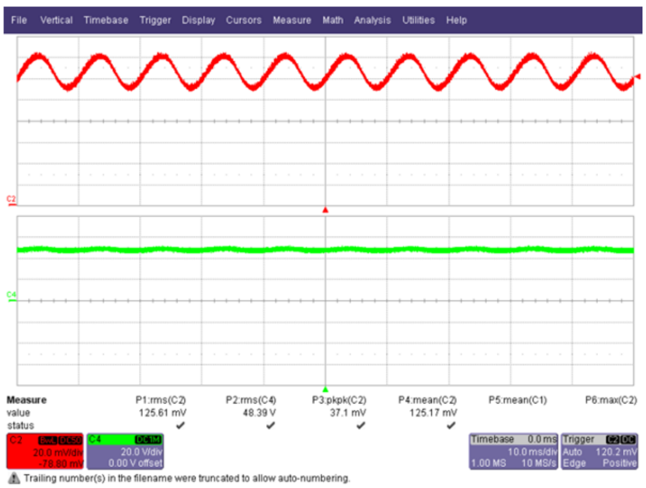

Figure 25 – 240 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

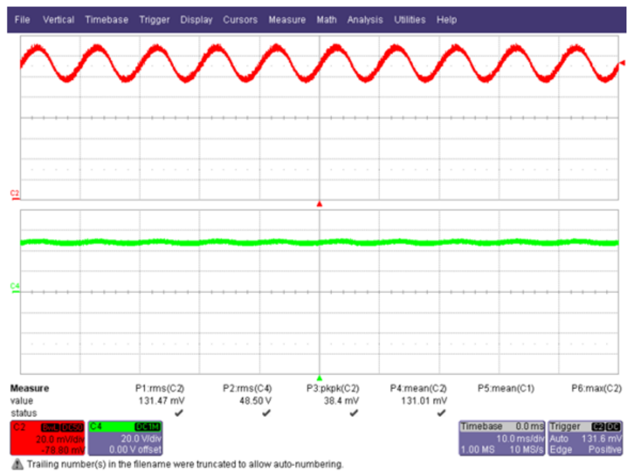

Figure 26 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

12.3 Output Current Rise and Fall

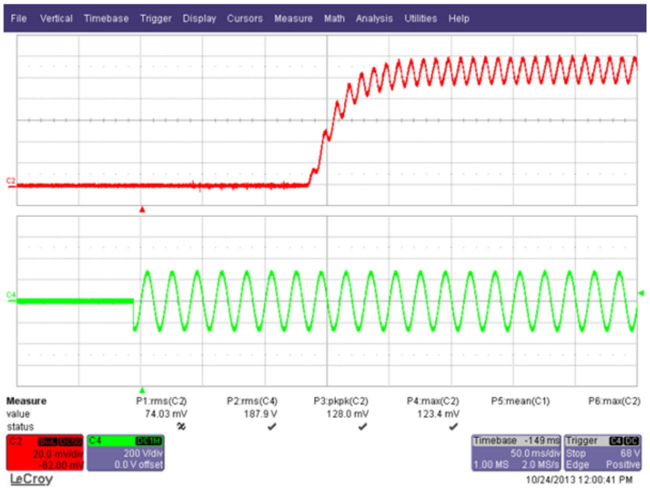

Figure 27 – 185 VAC Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

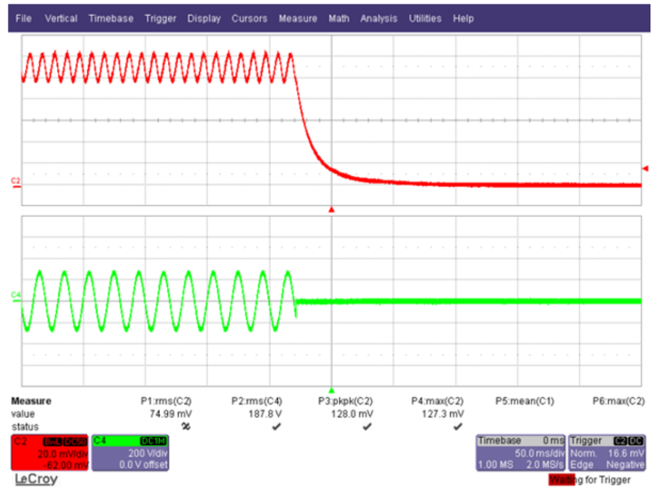

Figure 28 – 185 VAC Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

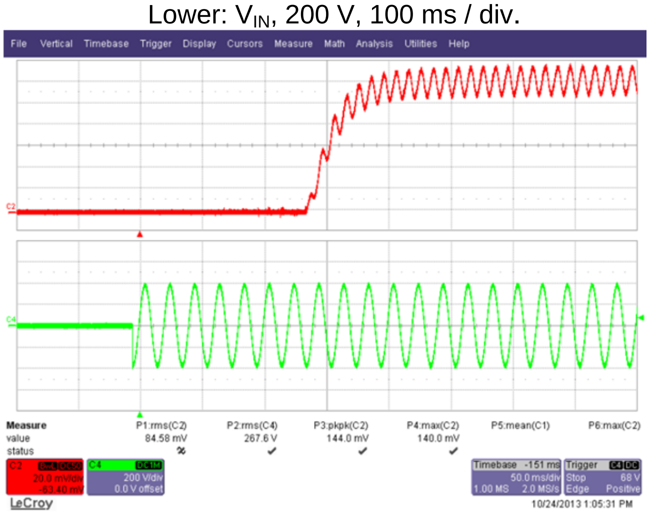

Figure 29 – 265 VAC Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

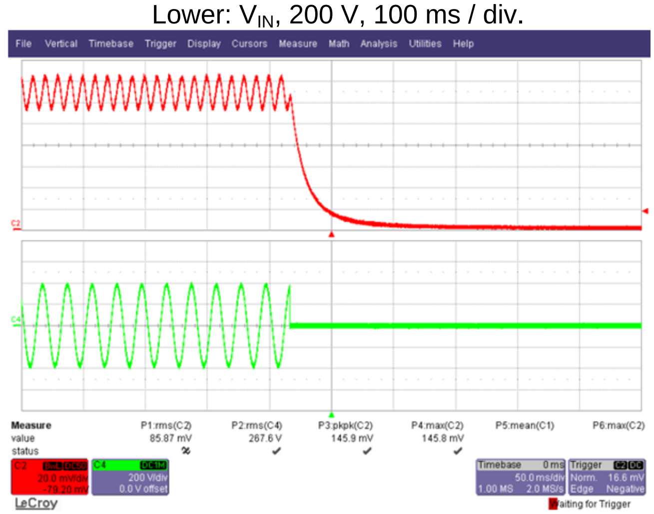

Figure 30 – 265 VAC Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

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12.4 Drain Voltage and Current at Normal Operation

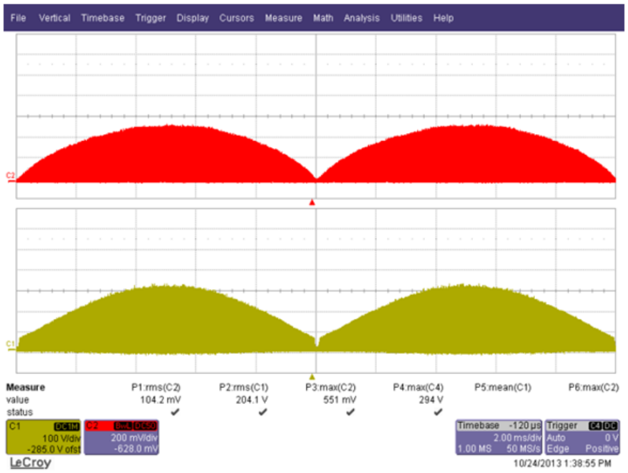

Figure 31 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

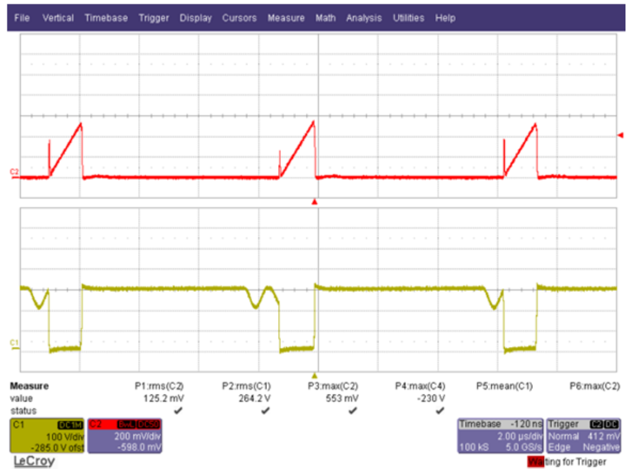

Figure 32 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.

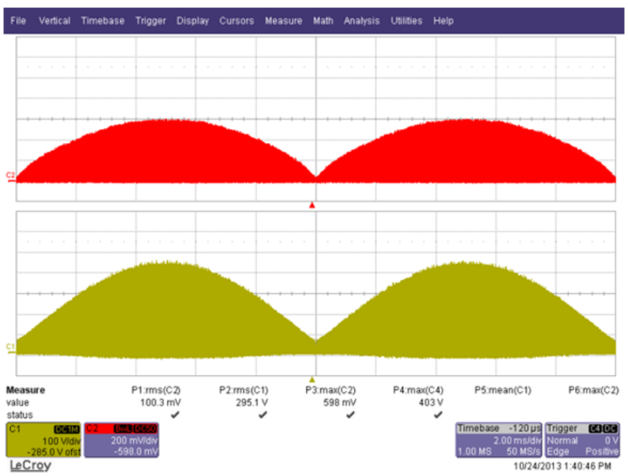

Figure 33 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

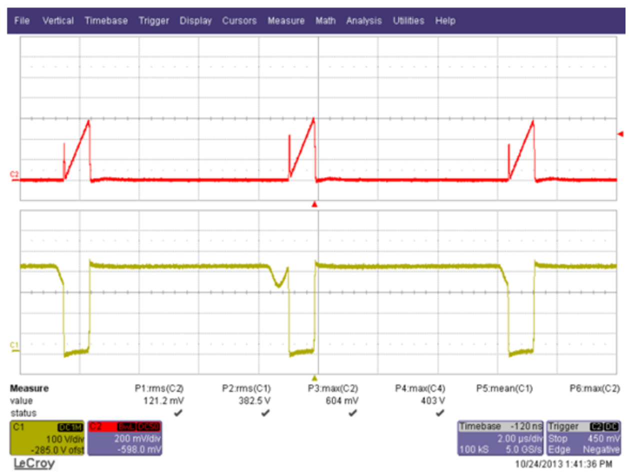

Figure 34 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.

12.5 Start-up Drain Voltage and Current

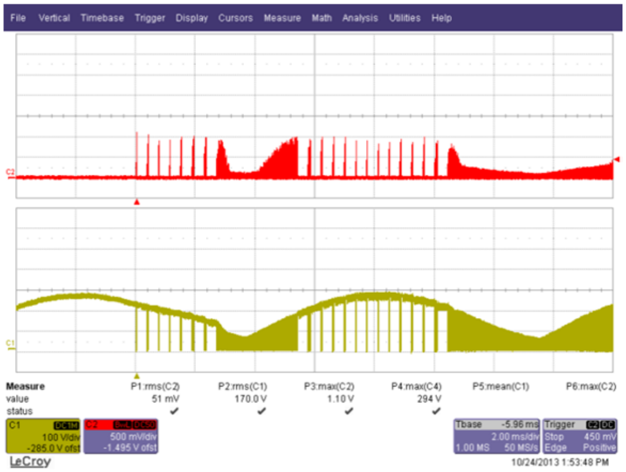

Figure 35 – 185 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

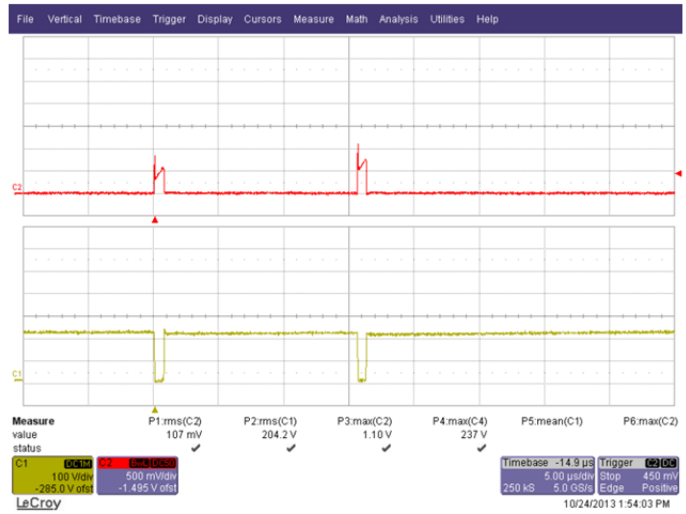

Figure 36 – 185 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

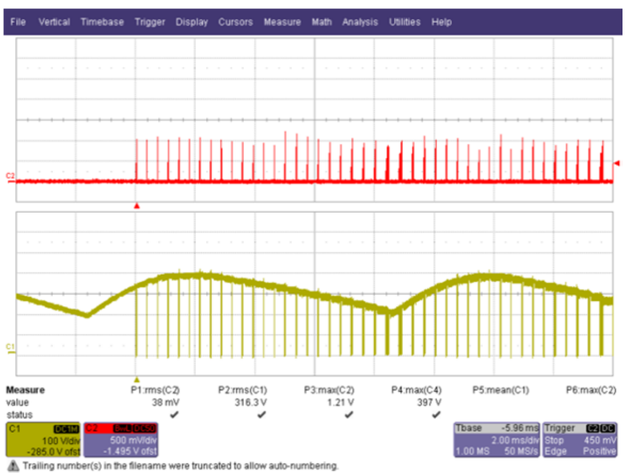

Figure 37 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

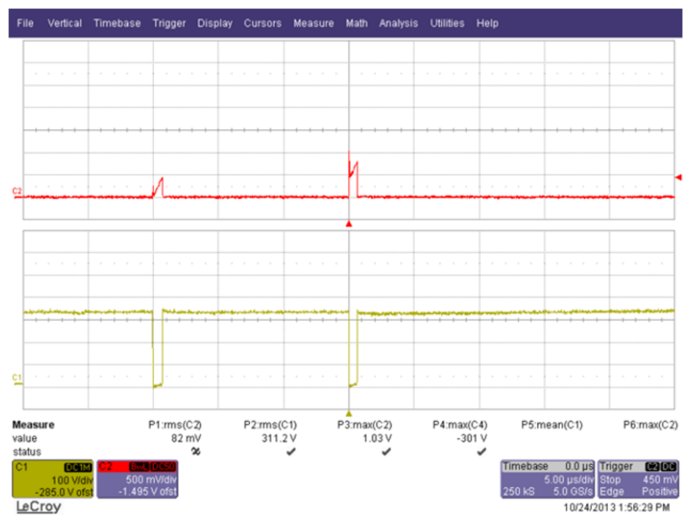

Figure 38 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

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12.6 Drain Current and Drain Voltage During Output Short Condition

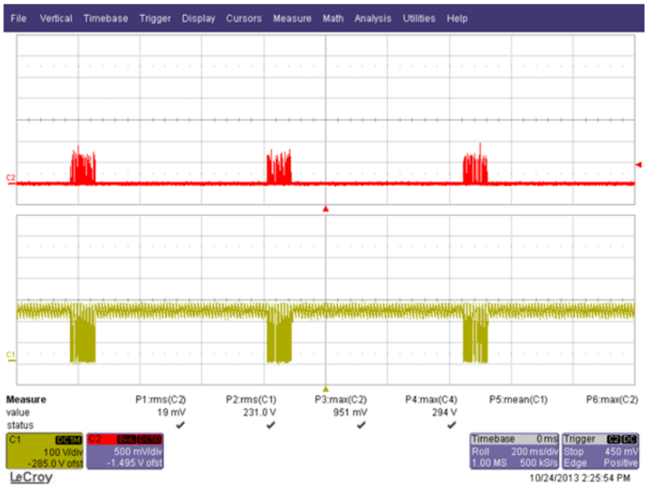

Figure 39 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

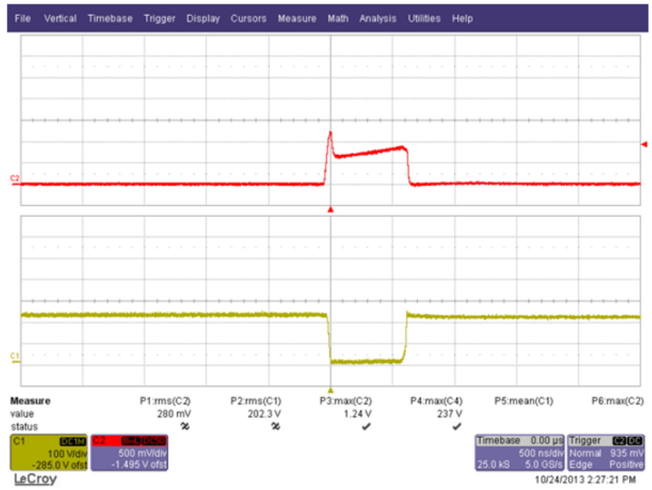

Figure 40 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 0.5 μs / div.

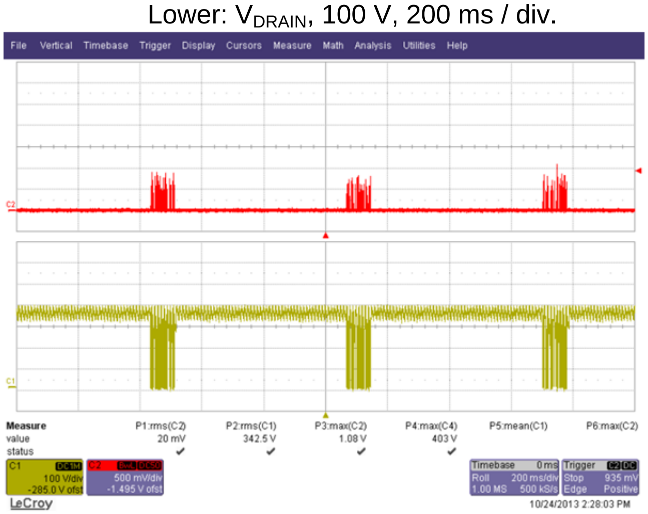

Figure 41 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

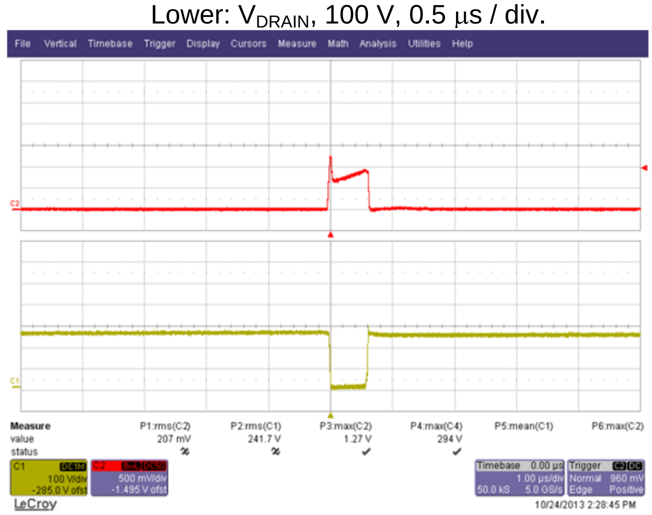

Figure 42 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 1 μs / div.

12.7 Open Load Characteristic

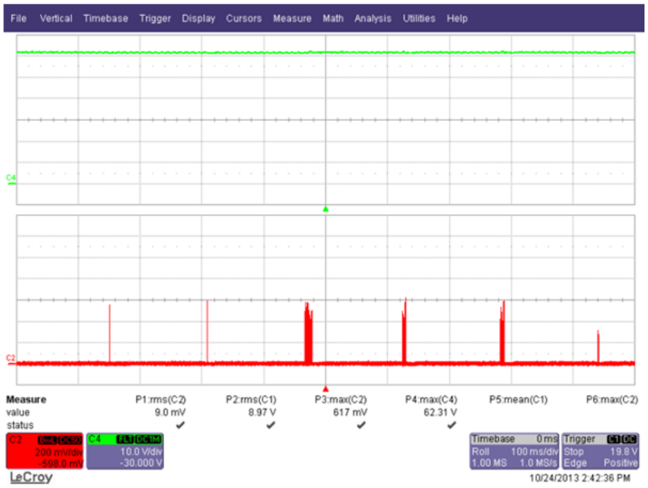

Figure 43 – 185 VAC, 50 Hz Output Short Condition.
Upper: V_{OUT}, 10 V / div.
Lower: I_{DRAIN}, 200 mA, 200 ms / div.

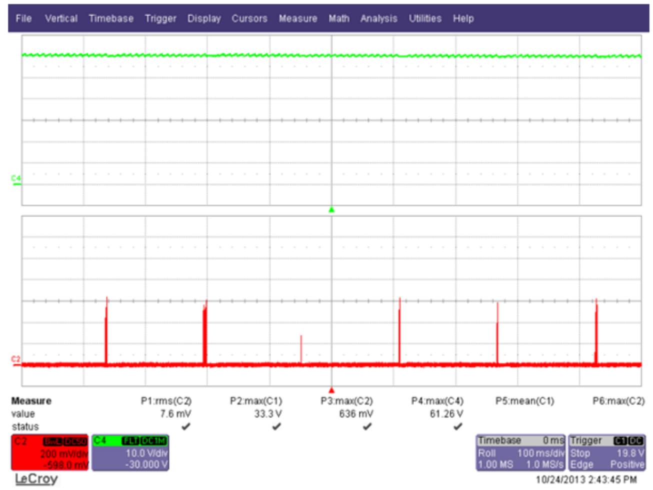

Figure 44 – 265 VAC, 50 Hz Output Short Condition.
Upper: V_{OUT}, 10 V / div.
Lower: I_{DRAIN}, 200 mA, 200 ms / div.

12.8 Brown-out / Brown-in

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

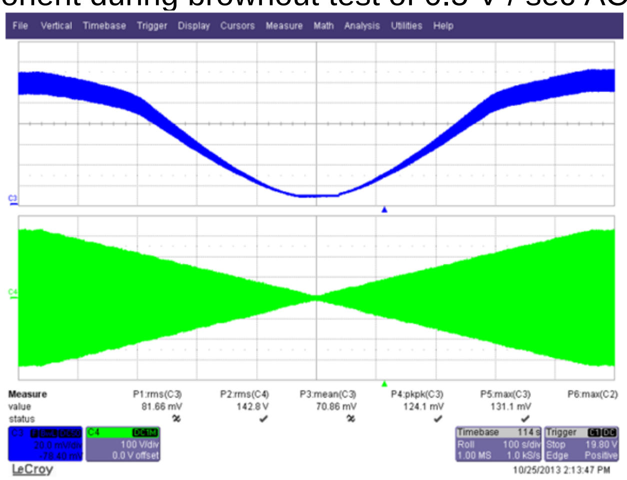

Figure 45 – Brown-out Test at 0.5 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 20 mA / div.
Time Scale: 100 s / div.

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12.9 Line Dropout

No failure of any component during 300 ms on and 300 ms off dropout.

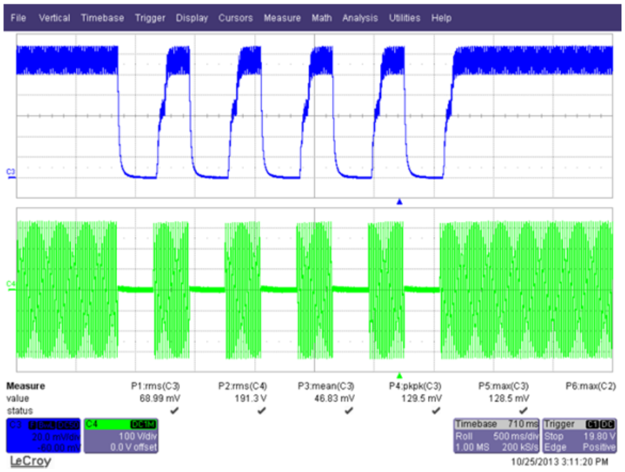

Figure 46 – Dropout Test: 300 ms on and 300 ms off.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 20 mA / div.
Time Scale: 500 ms / div.

13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: 310-013

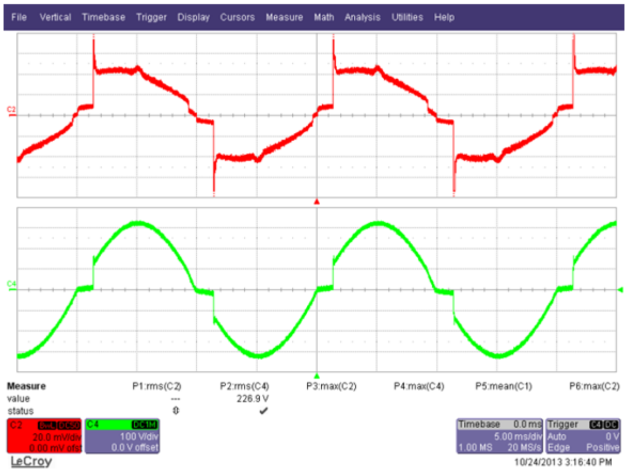

Figure 47 – 150º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

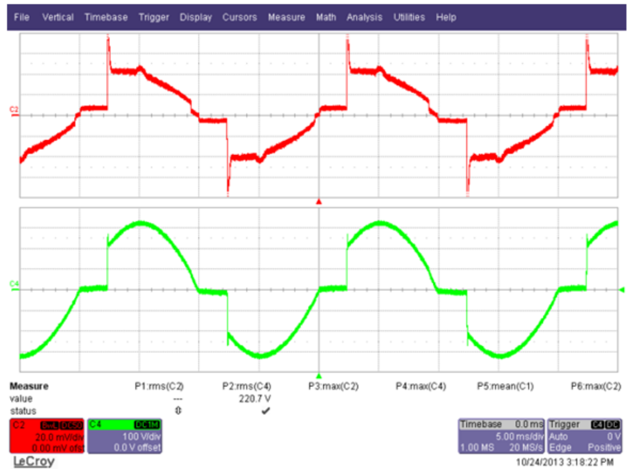

Figure 48 – 135º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

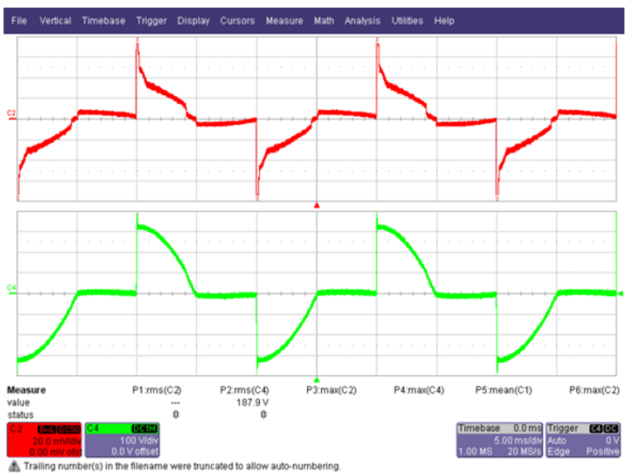

Figure 49 – 90º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

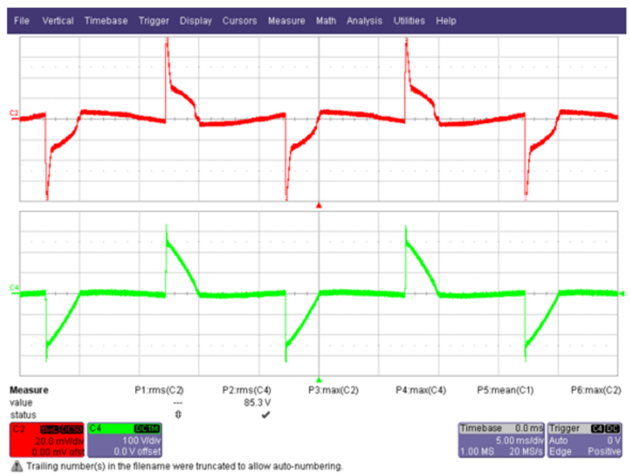

Figure 50 – 49º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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13.2 Output Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: 310-013

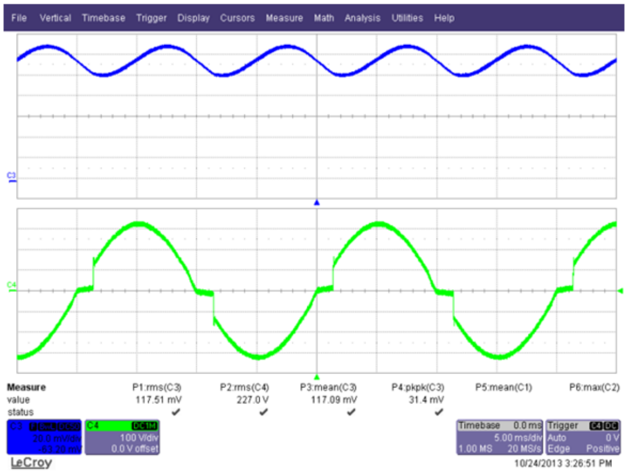

Figure 51 – 150º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

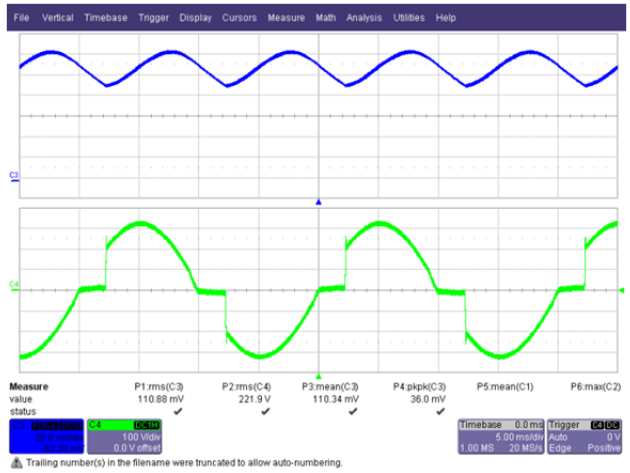

Figure 52 – 135º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

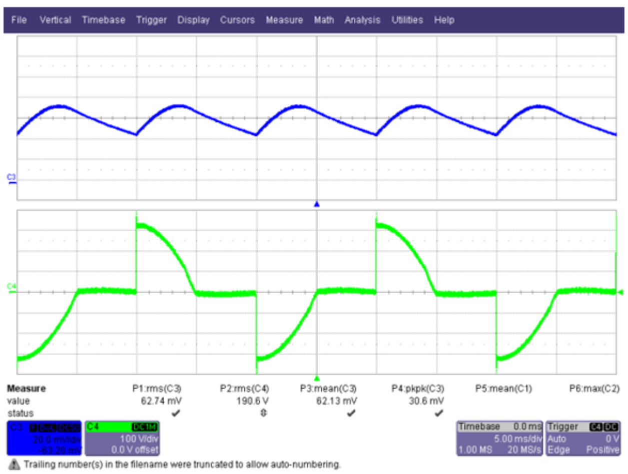

Figure 53 – 90º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

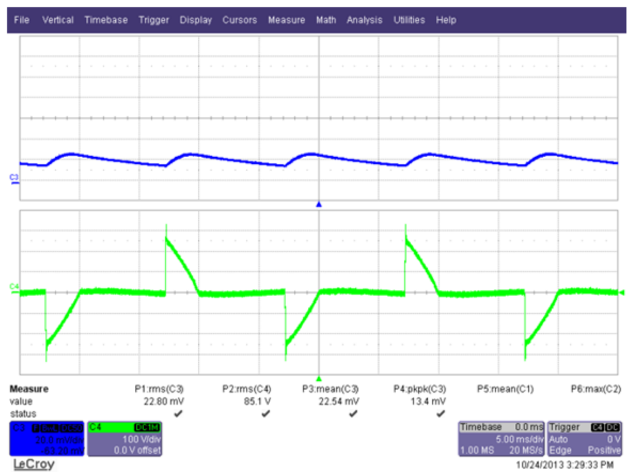

Figure 54 – 45º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

13.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: 32E450TM

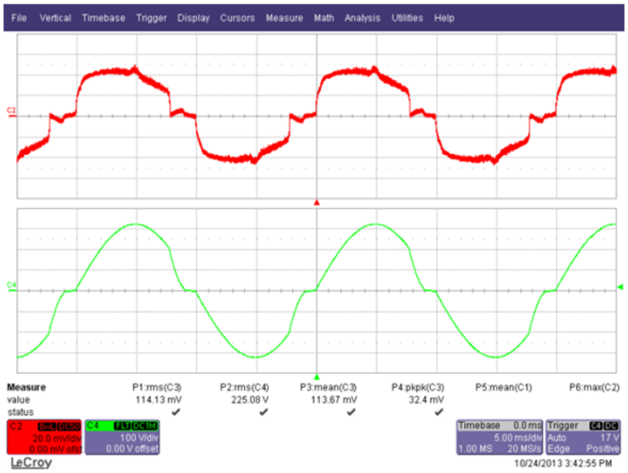

Figure 55 – 139º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

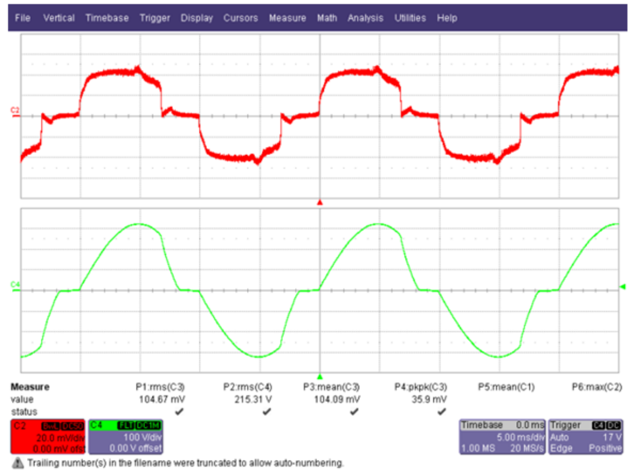

Figure 56 – 120º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

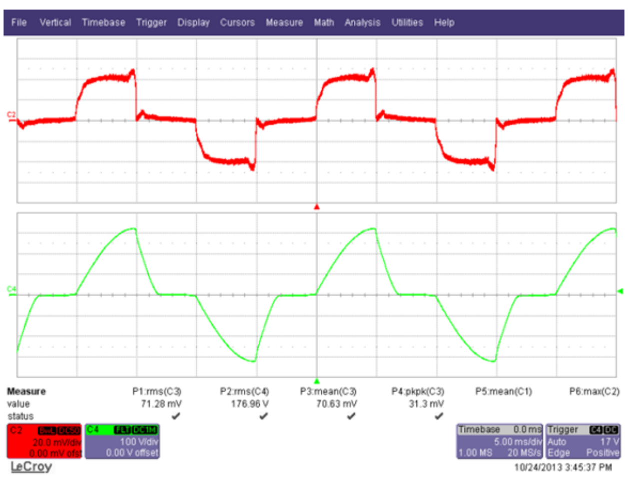

Figure 57 – 90º Conduction Angle.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

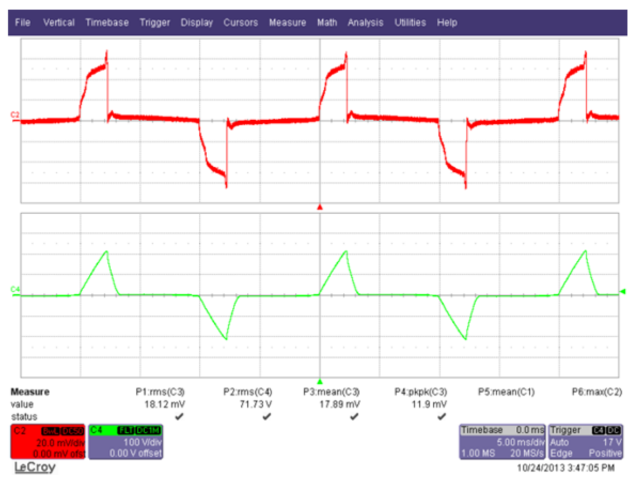

Figure 58 – 40º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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13.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 48 V LED Load
Dimmer: 32E450TM

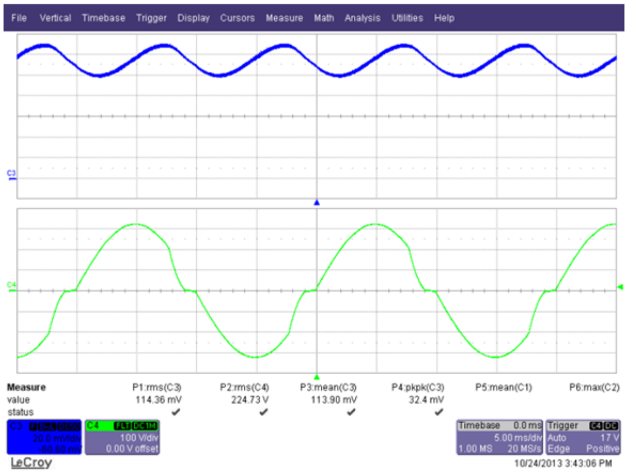

Figure 59 – 139º Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

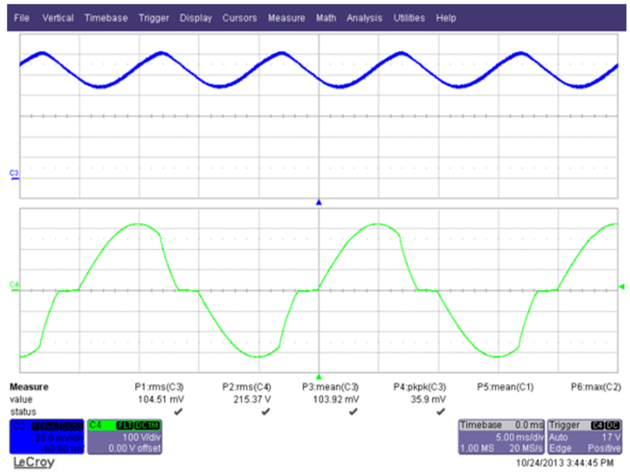

Figure 60 – 120º Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

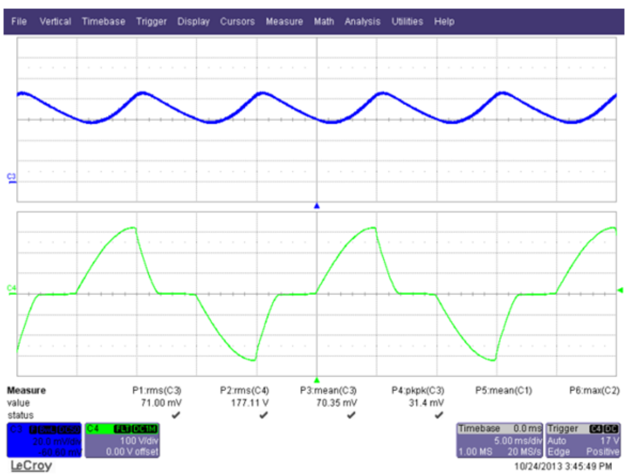

Figure 61 – 90º Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

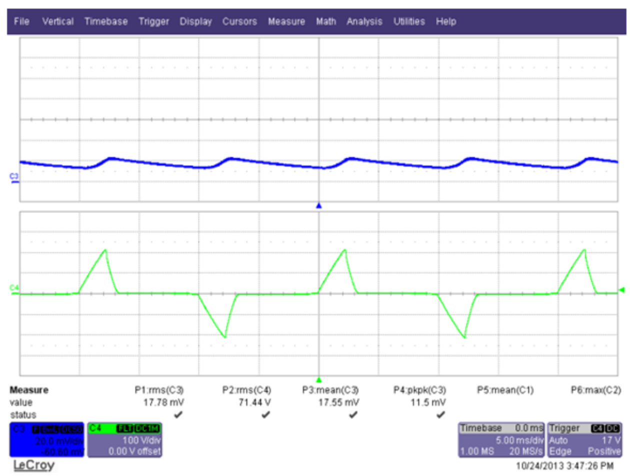

Figure 62 – 40º Conduction Angle.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

14 Conducted EMI

14.1 Test Set-up

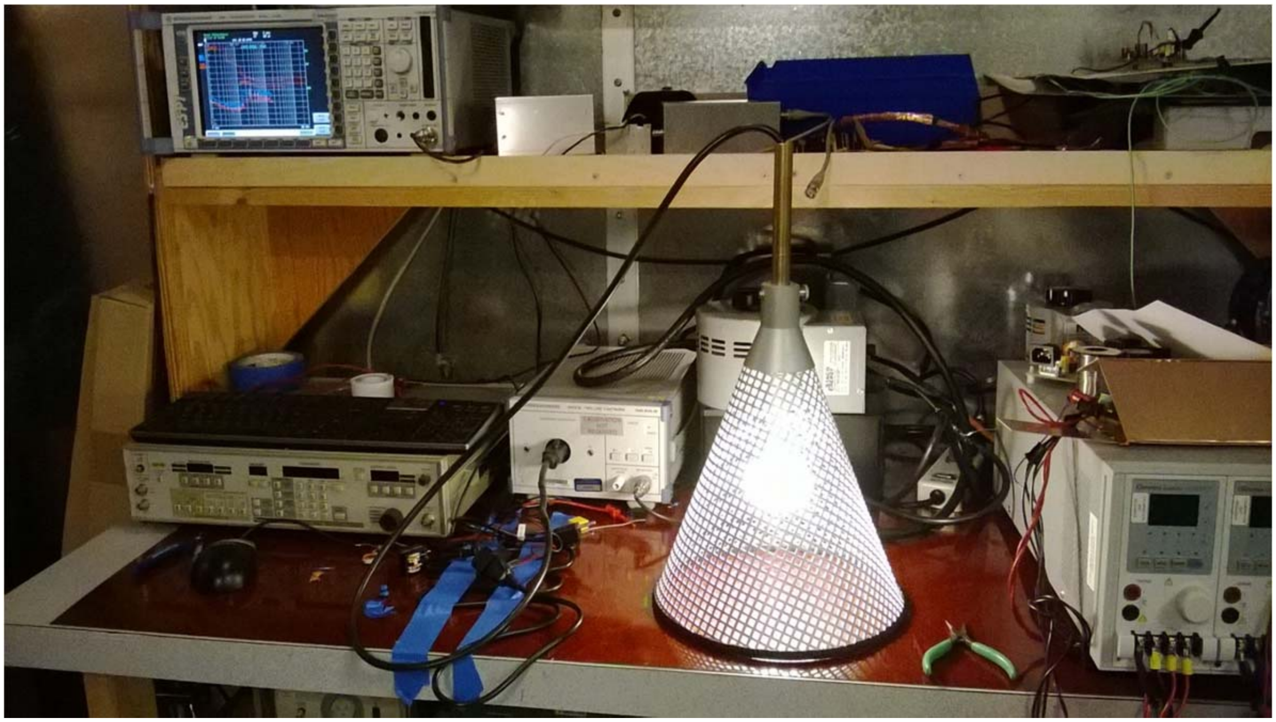

Figure 63 – Conducted EMI Test Set-up.

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14.2 Test Result

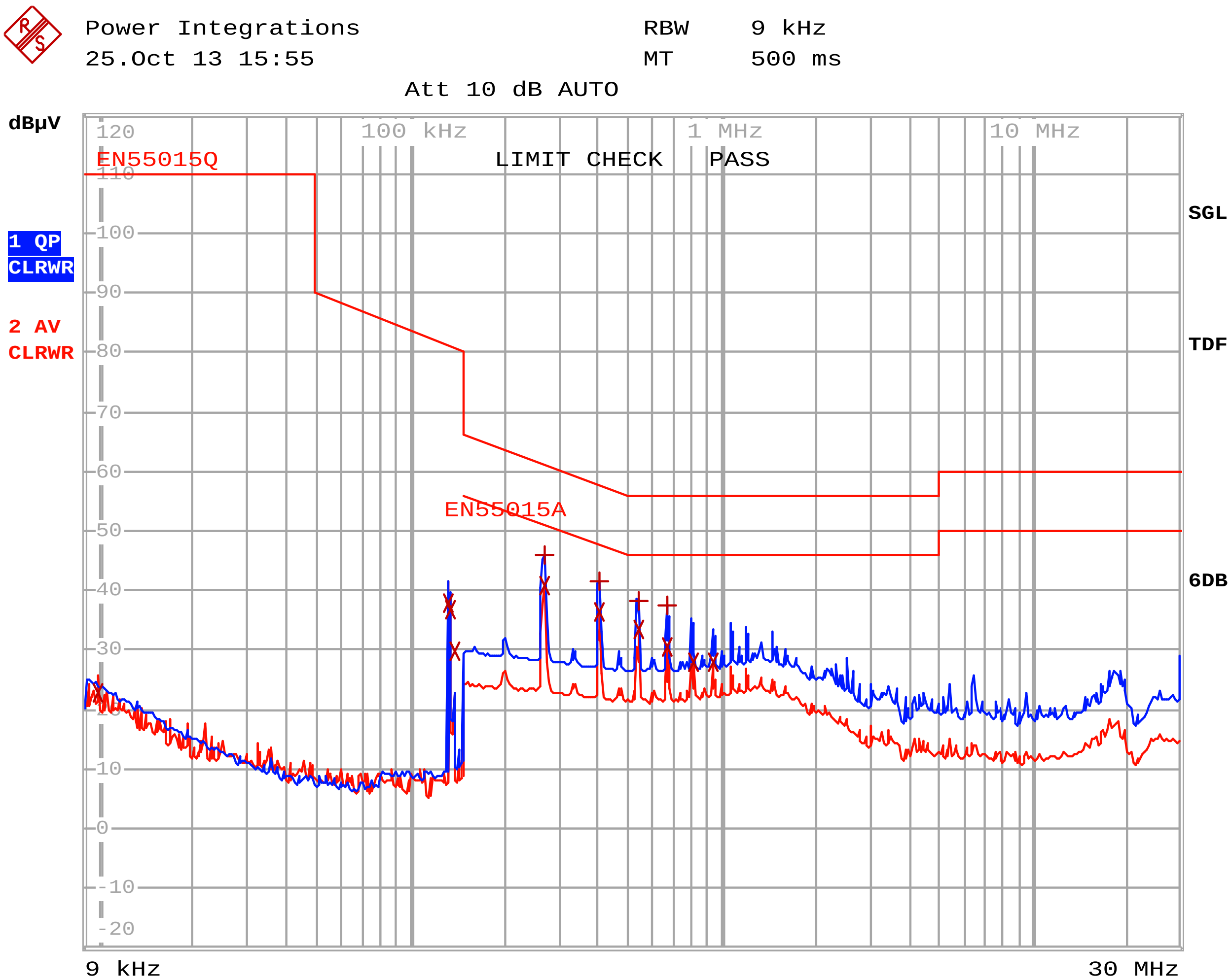

Figure 64 – Conducted EMI, ~48 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.74571035065 kHz	22.97	L1 gnd	
2	Average	132.133649648 kHz	37.98	L1 gnd	
2	Average	134.789536006 kHz	36.71	L1 gnd	
2	Average	138.873793737 kHz	29.74	L1 gnd	
1	Quasi Peak	267.135089486 kHz	46.06	L1 gnd	-15.14
2	Average	269.806440381 kHz	40.96	L1 gnd	-10.15
1	Quasi Peak	401.705024172 kHz	41.52	L1 gnd	-16.29
2	Average	401.705024172 kHz	36.39	L1 gnd	-11.42
2	Average	536.076911993 kHz	33.46	L1 gnd	-12.53
1	Quasi Peak	541.437681113 kHz	38.34	L1 gnd	-17.65
1	Quasi Peak	667.263434405 kHz	37.38	L1 gnd	-18.61
2	Average	667.263434405 kHz	30.63	L1 gnd	-15.37
2	Average	806.126927408 kHz	27.87	L1 gnd	-18.12
2	Average	935.888336808 kHz	27.79	L1 gnd	-18.20

Figure 65 – Conducted EMI, Final Measurement Results.

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15 Line Surge

Differential input line 500V surge testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 230 VAC / 60 Hz.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+500	230	L to N	90	Pass
-500	230	L to N	90	Pass
+500	230	L to N	0	Pass
-500	230	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	230	L to N	90	Pass
-2500	230	L to N	90	Pass
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass

Unit passed under all test conditions.

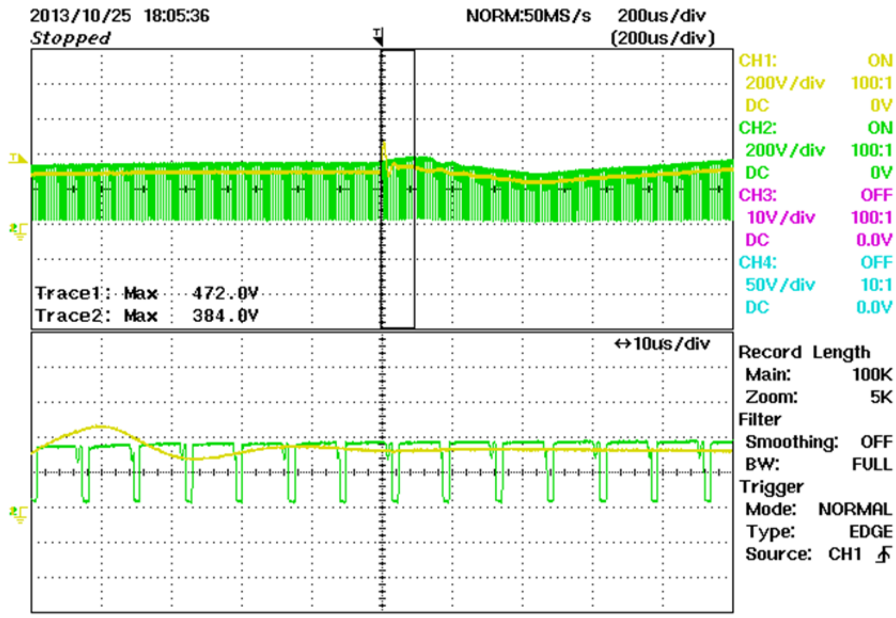

Figure 66 – 500 V Differential Surge at 90º Phase Angle.
CH1: Voltage Across C2.
CH2: Voltage Across Drain to Source of U1.
VDSMAX = 472 V.

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16 Revision History

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

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

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