Design Example Report

Title	***14 W TRIAC Dimmable, High Efficiency >85%, Non-Isolated Buck Converter, Power Factor Corrected (>0.95) LED Driver Using LYTSwitch™ LYT4313E***
Specification	90 VAC – 132 VAC Input; 41 V, 350 mA Output
Application	PAR30 LED Driver
Author	Applications Engineering Department
Document Number	DER-364
Date	April 4, 2013
Revision	1.0

Summary and Features

- High efficiency, ≥85% at 120 VAC
- Broad dimmer compatibility (meets NEMA SSL6 dimming curves) with wide selection of U.S. TRIAC-based dimmers
  - High dim ratio >1000:1
- Enhanced user experience
  - Flicker free, monotonic dimming,
  - Fast monotonic start-up (<200 ms) – no perceptible delay
  - Turn-on and turn-off at almost the same dimming angle (no pop-on)
- Highly integrated low solution cost
  - Single-stage combined PFC and accurate primary-side regulated constant current output
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Fast acting line input overvoltage shutdown extends voltage withstand during line faults
    - ±2500 V ring wave and ±500 V differential surge (without a MOV)
  - Auto-recovering thermal shutdown with large hysteresis protects components and pcb
- Meets IEC 61000-4-5 ring wave, IEC 61000-3-2 C THD and IEC CISPR 15 / EN55015 B conducted EMI

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PATENT INFORMATION
The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <http://www.powerint.com/ip.htm>.

Table of Contents

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

1 Introduction

The document describes an isolated high power factor (PF) TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 41 V at 350 mA from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT4313E from the LYTSwitch family of ICs.

The topology used is a single-stage power factor corrected buck converter that delivers high efficiency, high power factor, low THD, and low component count.

High power factor and low THD is achieved by employing the LYTSwitch IC which also provides a comprehensive range of protection features including auto-restart for open control loop and output short-circuit conditions. Line overvoltage provides extended line fault and surge withstand, and accurate hysteretic thermal shutdown that ensures safe average PCB temperatures under all conditions.

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

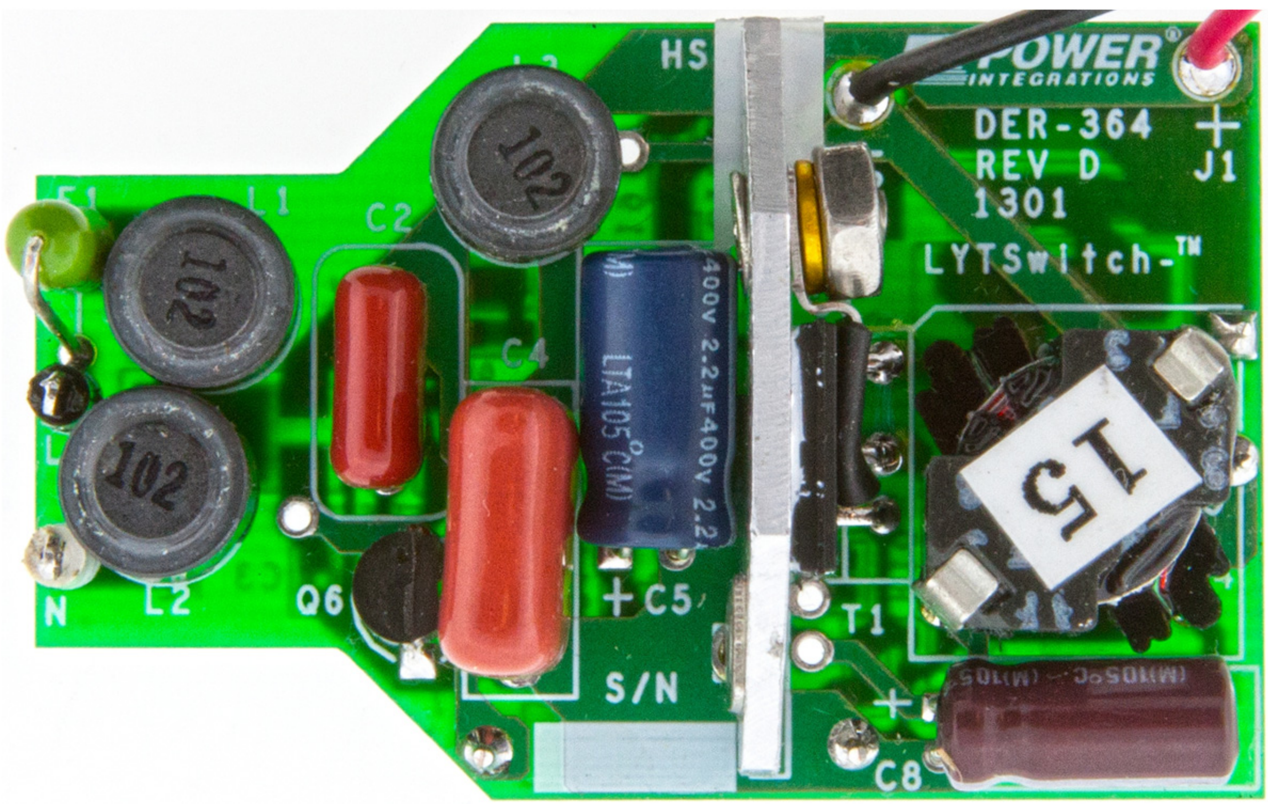

Figure 1 – Populated Circuit Board Photograph (Top).

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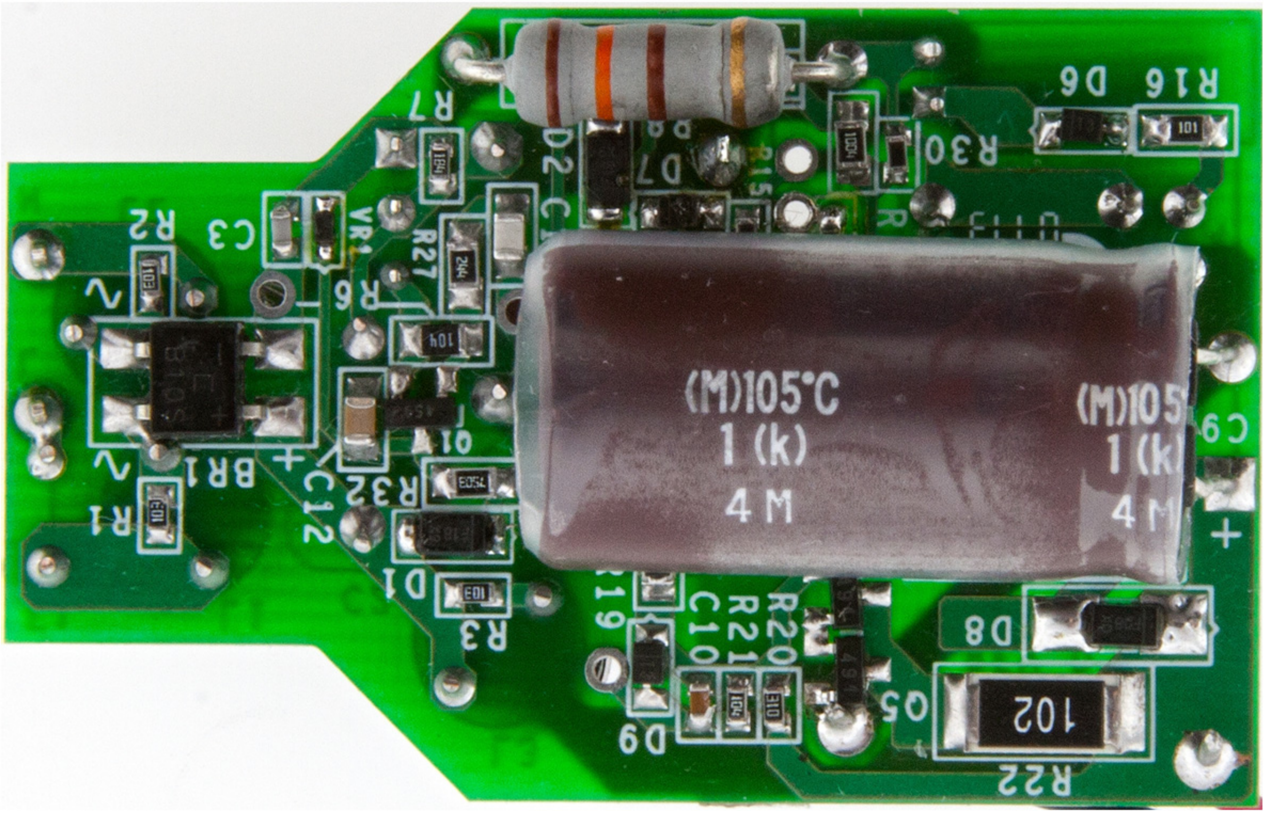

Figure 2 – Populated Circuit Board Photograph (Bottom).

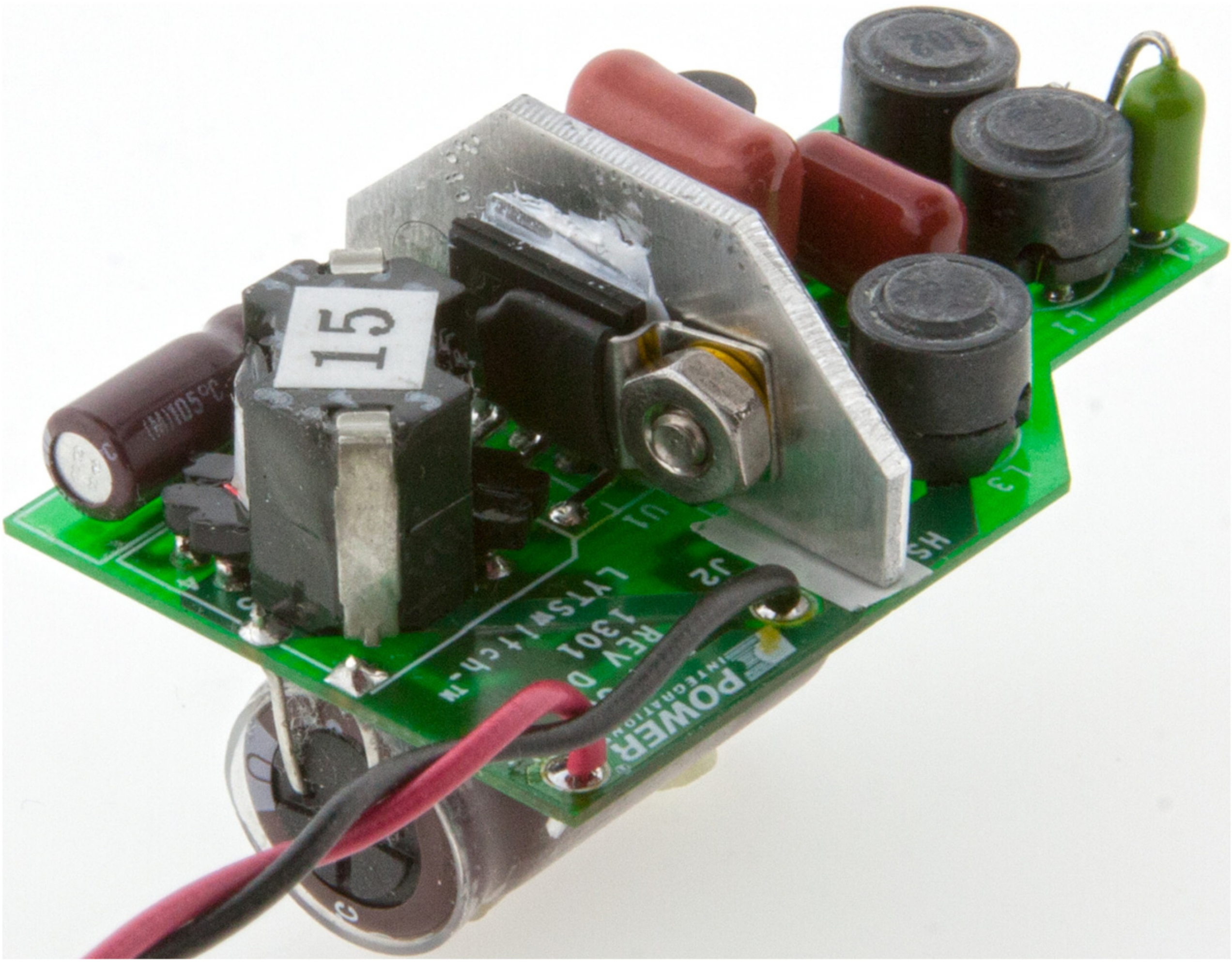

Figure 3 – Populated Circuit Board Photograph (Angle).
Dimensions: 1.99 in [50.6 mm] L x 1.26 in [32 mm] W x 1.19 in [30.2 mm] H.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	120	132	VAC	
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}	38	41	44	V	
Output Current	I_{OUT}		350		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		14		W	
Efficiency						
Full Load	η		85		%	V_{OUT} = 41, V_{IN} = 120 VAC, 25 °C ambient
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge (1.2 / 50 μs)			500		V	
Power Factor			0.99			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 120 VAC, 60 Hz
Harmonic Currents		EN 61000-3-2 Class D (C)				Class C specifies Class D Limits when P_{IN} <25 W
Ambient Temperature	T_{AMB}		45		°C	Free convection, sea level

3 Schematic

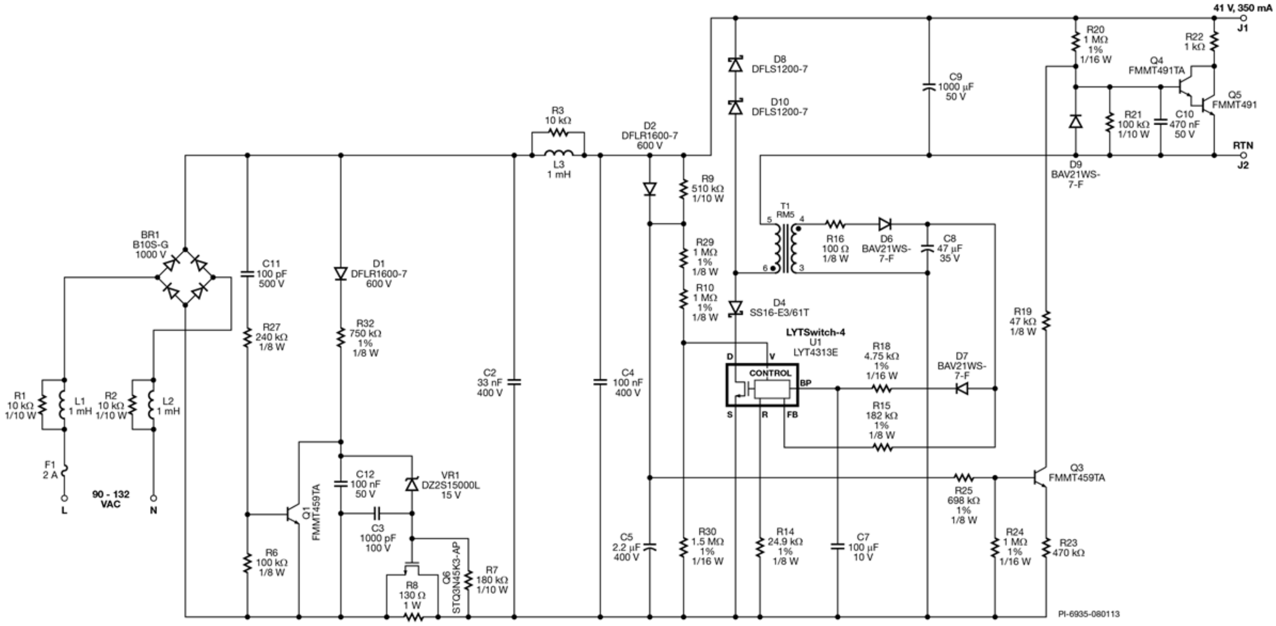

Figure 4 – Schematic.

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4 Circuit Description

The LYTSwitch device is a controller with an integrated 670 V power MOSFET for use in LED driver applications. The LYTSwitch is configured for use in a single-stage buck converter topology which provides a primary-side regulated constant current output while maintaining high power factor from the AC input.

4.1 Input Filtering

Fuse F1 provides protection from component failure. A relatively high current rating was selected to prevent failure during differential (1.2 μs / 50 μs) line surge. Diode bridge BR1 rectifies the AC line voltage with capacitor C4 providing a low impedance path (decoupling) for the primary switching current.

EMI filtering is provided by inductors L1, L2, and L3, and capacitors C2 and C4. Resistor R1, R2 and R3 across L1, L2 and L3 respectively damp any LC resonances due to the filter components and the AC line impedance which would otherwise cause increased conducted EMI measurements.

4.2 LYTSwitch Primary

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

Inductor T1 is the main inductor of the buck converter. It consists of two windings, the primary and the bias windings. The primary winding is the main buck inductor and bias winding is the supply of the IC and helps to prevent flicker and shimmer specially during deep dimming.

Output diode (D8 and D10 in Series) conducts every time U1 is off and transfers energy to the load. These diodes could be replaced by a single Schottky diode with a rated voltage greater than 200 V. Diode D4 is necessary to prevent reverse current from flowing through U1 when the voltage across C4 (rectified input AC) falls below the output voltage.

To provide peak line voltage information to U1, the incoming rectified AC peak charges C5 via D2. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R10 and R29. Resistor R9 is a discharge path for C5 when there is line sag to make the V pin respond quicker in reducing the power.

The line overvoltage shutdown function, sensed via the V pin current, extends the rectified line voltage withstand (during surges and line swells) to the 650 BV_{DSS} rating of the internal power MOSFET. The fast acting line overvoltage detection of LYTSwitch in conjunction with D2 and C5 peak detector capacitor provides a clamp to limit the maximum voltage stress across the power MOSFET of the IC during line surge event. A value of 2.2 μF on C5 can withstand 500 V surges, while 4.7 μF can withstand 1 kV surge. Optional additional 140 VAC rated MOV (Metal Oxide Varistor) can be used for >1000 V differential line surge requirement.

Capacitor C7 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C7 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN (D) pin of U1. The use of an external bias supply (via D7 and R18) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming condition.

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. For phase angle dimming applications a 49.9 kΩ resistor is used on the REFERENCE (R) pin (R14) and 2 MΩ (R10+R29) on the V pin to provide a linear relationship between input voltage and the output current. This maximizes the dimming range when used with TRIAC dimmers. However, in this design 24.9 kΩ value was used for tighter CC regulation. High dimming ratio was accomplished using an active pre-load on the output.

4.3 Feedback

The bias winding voltage is used to sense the output voltage indirectly, eliminating secondary-side feedback components. The voltage on the bias winding is proportional to the output voltage (set by the turn ratio between the bias and primary windings). The flyback voltage on the bias winding is rectified by D6 and filtered by R16 and C8. Resistor R15 converts the bias voltage into a current which is fed into the FB pin of U1. The internal engine within U1 combines the FB pin current, the V pin current, and internal drain current information to provide a constant output current whilst maintaining high input power factor.

Diode D7 and R18 provides path the bias supply to BP pin. Diode D7 is used to isolate C7 from C8 during start-up and resistor R18 limits the current supplied to the BP pin from the bias winding.

4.4 Output Rectification

The transformer secondary winding is rectified by D8 and D10 and filtered by capacitor C9. For designs where low ripple is required such as in this design, high capacitance value should be used, otherwise the value can be reduced.

4.5 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low-cost, TRIAC based, leading edge phase dimmers introduced a number of tradeoffs in the design.

Due to the much lower power consumed by LED based lighting the current drawn by the lamp can fall below the holding current of the TRIAC within the dimmer. This causes undesirable behavior such as the lamp turning off before the end of the dimmer control range and/or flickering as the TRIAC fires inconsistently. The relatively large impedance the LED lamp presents to the line allows significant ringing to occur due to the inrush

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current charging the input capacitance when the TRIAC turns on. This too can cause similar undesirable behavior as the ringing may cause the TRIAC current to fall to zero.

To overcome these issues, active damper and active pre-load circuits were added. A passive RC bleeder circuit connected after the fuse between line and neutral can also be used. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming applications these components can simply be omitted.

The new PI proprietary active damper consists of main components D1, R32, C11, R27, R6, Q1, C12, VR1, Q6, R7, C3 and R8. Where Q6 is fully on when there is no TRIAC connected, bypassing R8 which will keep the power dissipation low thereby making the system efficiency high. A TRIAC is detected through C11, R27 and R6 which will momentarily drive Q1 on keeping C3 grounded and gate Q6 low allowing R8 to be in series with TRIAC to act as damping element to current ringing every time the TRIAC turns on.

4.6 Active Pre-Load

The active pre-load in this driver used for shaping the dimming curve and increasing dimming ratio while maintaining high efficiency during normal operation. The circuit can be used also for non-isolated converters such as buck, buck-boost and tapped-buck.

The active pre-load circuit detects the input peak voltage from C5, via divider R25 and R24 which is proportional to the dimmer's conduction angle; the information is processed via Q3, R23, R19 and C10 to give an average signal which is used to linearly drive a Darlington (Q4, Q5) which loads the output via a resistor (R22).

During non-dimming operation (full conduction), the active bleeder is not connected across the output therefore maintaining high efficiency operation. The bleeder turns on at a programmed dimming angle. The active bleeder will be biased linearly down to the lowest conduction angle the TRIAC can operate, increasing dim ratio.

The circuit also acts as a bleeder for leaky TRIAC as the Darlington will be biased via R20 and loads R22 when a voltage builds up at the output due to the small leakage energy from the TRIAC.

5 PCB Layout

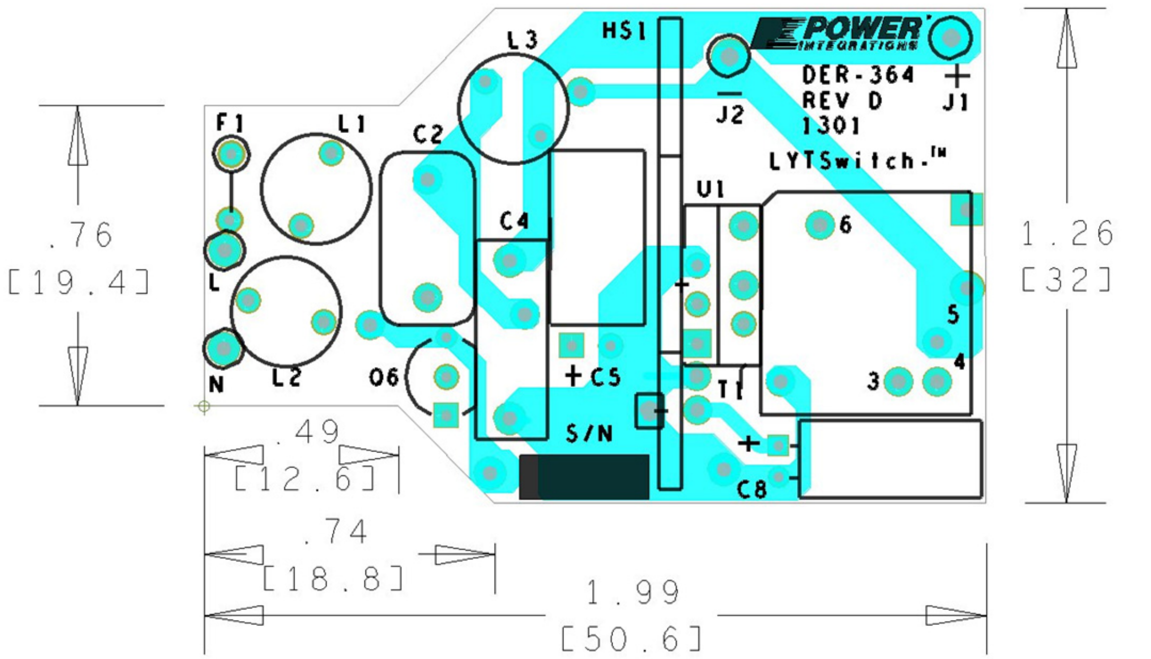

Figure 5 – Top Side.

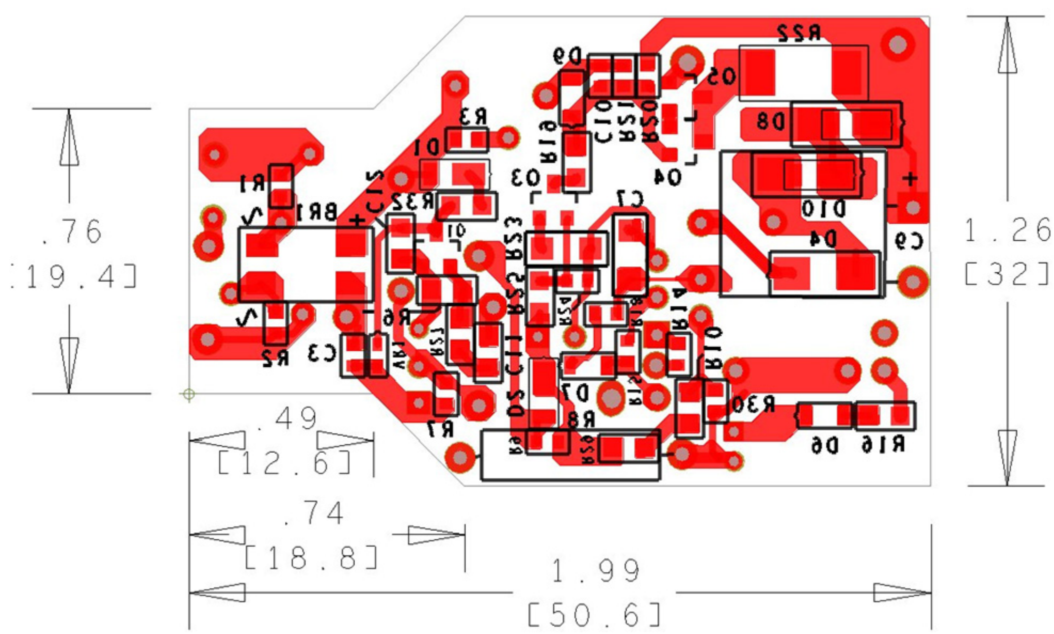

Figure 6 – Bottom Side.

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6 Bill of Materials

6.1 Electrical 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	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
3	1	C3	1000 pF, 100 V, Ceramic, COG, 0603	C1608C0G2A102J	TDK
4	1	C4	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
5	1	C5	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
6	1	C7	100 μF, 10 V, Ceramic, X5R, 1206	C3216X5R1A107M	TDK
7	1	C8	47 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG350ELL470ME11D	Nippon Chemi-Con
8	1	C9	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	Nippon Chemi-Con
9	1	C10	470 nF, 50 V, Ceramic, X7R, 0603	UMK107B7474KA-TR	Taiyo Yuden
10	1	C11	100 pF, 500 V, Ceramic, NPO, 0805	501R15N101KV4T	Johanson Dielectrics
11	1	C12	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
12	2	D1 D2	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
13	1	D4	60 V, 1 A, Schottky, DO-214AC	SS16-E3/61T	Vishay
14	3	D6 D7 D9	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
15	2	D8 D10	200 V, 1 A, Diode Schottky 1 A 200 V PWRDI 123	DFLS1200-7	Diodes, Inc.
16	1	F1	Fuse, Pico, 2 A, 250V, Fast, Axial	0263002.MXL	Littlefuse Inc.
17	1	HS1	Heat sink, Custom, Al, 3003, 0.062" Thk (See Heat sink Spec)		Custom
18	2	L N	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
19	3	L1 L2 L3	1 mH, 0.23 A, Ferrite Core	CTSCH875DF-102K	CT Parts
20	2	Q1 Q3	NPN, Small Signal BJT, 450 V, 0.5 A, 150MA ,SOT-23	FMMT459TA	Diodes, Inc.
21	2	Q4 Q5	NPN,60 V 1000 MA, SOT-23	FMMT491TA	Zetex Inc
22	1	Q6	450 V, 0.6 A, 3.8 Ohms, N-Channel, TO-92	STQ3N45K3-AP	ST Micro
23	3	R1 R2 R3	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
24	1	R6	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
25	1	R7	180 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ184V	Panasonic
26	1	R8	130 Ω, 5%, 1 W, Metal Oxide	RSF100JB-130R	Yageo
27	1	R9	510 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ514V	Panasonic
28	2	R10 R29	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
29	1	R14	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
30	1	R15	182 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1823V	Panasonic
31	1	R16	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
32	1	R18	4.7 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
33	1	R19	47 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ473V	Panasonic
34	2	R20 R24	1 MΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ105V	Panasonic
35	1	R21	100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
36	1	R22	1 kΩ, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ102U	Panasonic
37	1	R23	470 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ474V	Panasonic
38	1	R25	698 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6983V	Panasonic
39	1	R27	240 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ244V	Panasonic
40	1	R30	1.50 MΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1504V	Panasonic
41	1	R32	750 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ754V	Panasonic

42	1	T1	See Inductor Spec	SNX-R1687 TSD-3200	Santronics USA Premier Magnetics
43	1	U1	LYTSwitch, eSIP-7C	LYT4313E	Power Integrations
44	1	VR1	15 V, 5%, 150 mW, SSMINI-2	DZ2S15000L	Panasonic

6.2 Heat Sink Assembly Bill of Materials

Item	Qty	Description
1	1	HEAT SINK, AL-3003, DER364,PI CUSTOM
2	1	RIVET, Al, 0.93 DIA x 0.187 C'sunk
3	1	POST, HEAT SINK, SS, Nickel Plated, 5 mm W x 9.1 mm L
4	1	THERMAL GREASE, SILICONE, 5 OZ TUBE
5	1	EDGE-CLIP-12.33 mm L x 6.35 mm W
6	1	HEAT SHRINK 3/16 IN X 4 FT BLACK
7	1	WASHER, LOCK, #4 SS
8	1	NUT, HEX 4-40, SS
9	1	SCREW PHIL FLAT, HEAD, UNDERCUT 4-40 X .250 (1-4) SST

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7 Inductor Specification

7.1 Electrical Diagram

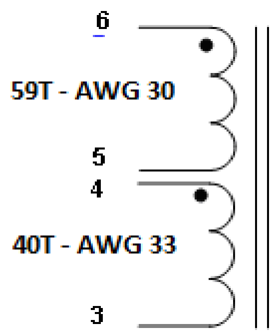

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 5-6 all other windings open, measured at 132 kHz, 0.4 $V_{RMS.}$	380 µH ±2%
Resonant Frequency	Pins 5-6, all other windings open.	2.1 MHz (Min.)

7.3 Materials

Item	Description
[1]	Core: RM5/I-3F3 or equivalent.
[2]	Bobbin: B-RM5-V 6 pins 3/3.
[3]	Magnet Wire, #30 AWG, solderable double coated.
[4]	Magnet Wire, #33 AWG, solderable double coated.
[5]	Tape: 3M 1298 Polyester Film, 4.8 mm wide, 2.0 mil thick, or equivalent.
[6]	Varnish: Dolph BC-359, or equivalent.
[7]	CLI/P-RM4/5 or equivalent.

7.4 Inductor Build Diagram

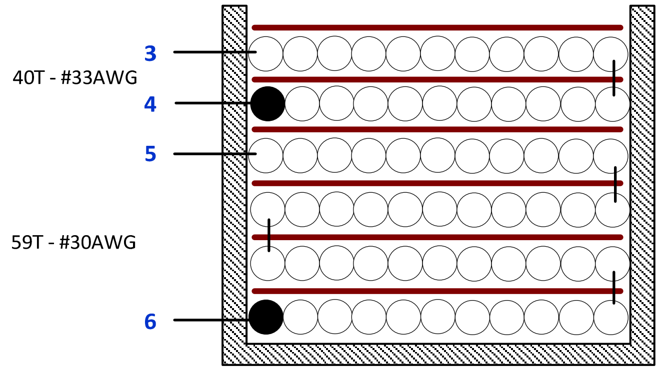

Figure 8 – Inductor Build Diagram.

7.5 Inductor Construction

General Note	For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left.
WD1	Start at pin 6. Wind 59 turns of item [3] as shown in Figure 8. Put 1 layer of tape item [5] every layer. Terminate at pin 5.
WD2	Start at pin 4. Wind 40 turns of item [4]. Put 1 layer of tape item [5] every layer. Terminate the other end at pin 3.
Insulation	Place 2 layers of tape item [5] to secure windings.
Finish	Grind the core to get the specified inductance. Secure with clip item [7]. Varnish with item [6]. Cut pin 1 and pin 2 of the bobbin. Cut transformer clip pin near pin 5 and 6. Refer to Figure 9.

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7.6 Appendix

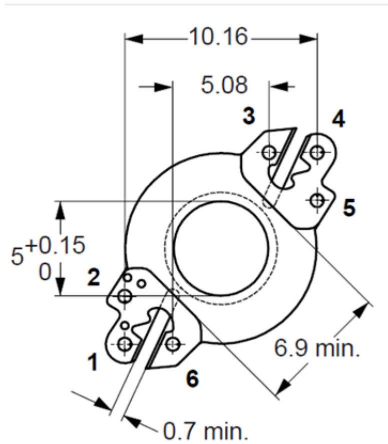

Figure 9 – Bottom View, Transformer Pin Illustration.

Figure 10 – Sample Choke Illustration for Bottom Actual View.

8 Transformer Design Spreadsheet

ACDC_LYTSwitch_Buck_010913; Rev.0.8; Copyright Power Integrations 2012	INPUT	INFO	OUTPUT	UNIT	ACADC_LYTSwitch_010913: LYTSwitch Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	NO		NO		Select "YES" option if dimming is required. Otherwise select "NO".
VACMIN	90		90	V	Minimum AC Input Voltage
VACMAX	132		132	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	41			V	Typical output voltage of LED string at full load
VO_MAX			51.25	V	Maximum LED string Voltage. Ensure that the maximum LED string voltage is below VO_MAX
VO_MIN			30.75	V	Minimum LED string Voltage. Ensure that the minimum LED string voltage is above VO_MIN
V_OVP			56.375	V	Overvoltage setpoint
IO	0.35				Typical full load LED current
PO			14.35	Watts	Output Power
n			0.85		Estimated efficiency of operation
ENTER LYTSwitch VARIABLES					
LYTSwitch	LYT4313				Selected LYTSwitch device. If Dimming is required, select device from LNK42XX family, Otherwise select device from LNK43XX family
Current Limit Mode	RED		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1	A	Minimum current limit
ILIMITMAX			1.16	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			79.8173	uA	V pin current
Rv			2	M-ohms	Upper V pin resistor
VB			25	V	Bias winding voltage
IFB			155.959	uA	FB pin current (75 uA < IFB < 250 uA)
RFB				k-ohms	FB pin resistor (assuming Bias winding feedback)
VDS			10	V	LYTSwitch on-state Drain to Source Voltage
VD	0.6			V	Output Winding Diode Forward Voltage Drop
VDB	0.7			V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP			0.5		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
LP			378.185	uH	Primary Inductance
KP Expected			0.78636		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
Expected IO (average)			0.35006	A	Expected Average Output Current
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	RM5		RM5		Selected Core for inductor
Core		#N/A		P/N:	#N/A
Bobbin		#N/A		P/N:	#N/A
AE	0.25		0.25	cm^2	Core Effective Cross Sectional Area
LE	2.32		2.32	cm	Core Effective Path Length

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AL	1700		1700	nH/T^2	Ungapped Core Effective Inductance
BW	4.7		4.7	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			4		Number of Primary Layers
DC INPUT VOLTAGE PARAMETERS					
VMIN			127.279	V	Peak input voltage at VACMIN
VMAX			186.676	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.32213		Minimum duty cycle at peak of VACMIN
IAVG			0.35006	A	Average input Current
IP			0.88437	A	Peak Current (calculated at minimum input voltage VACMIN)
IP_VMAX			1.01736	A	Peak Current (calculated at maximum input voltage VACMAX)
INDUCTOR PRIMARY DESIGN PARAMETERS					
LP			378.185	uH	Primary Inductance
NP	59		59		Primary Winding Number of Turns
ALG			108.643	nH/T^2	Gapped Core Effective Inductance
BM			2608.46	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			3421.42	Gauss	Peak Flux Density (BP<4200)
BAC			652.116	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1255.41		Relative Permeability of Ungapped Core
LG			0.27069	mm	Gap Length (Lg > 0.1 mm)
BWE			18.8	mm	Effective Bobbin Width
OD			0.31864	mm	Maximum Primary Wire Diameter including insulation
INS			0.0539	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.26475	mm	Bare conductor diameter
AWG			30	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			101.594	Cmils	Bare conductor effective area in circular mils
CMA			290.216	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)

9 U1 Heat Sink Assembly

9.1 U1 Heat Sink Fabrication Drawing

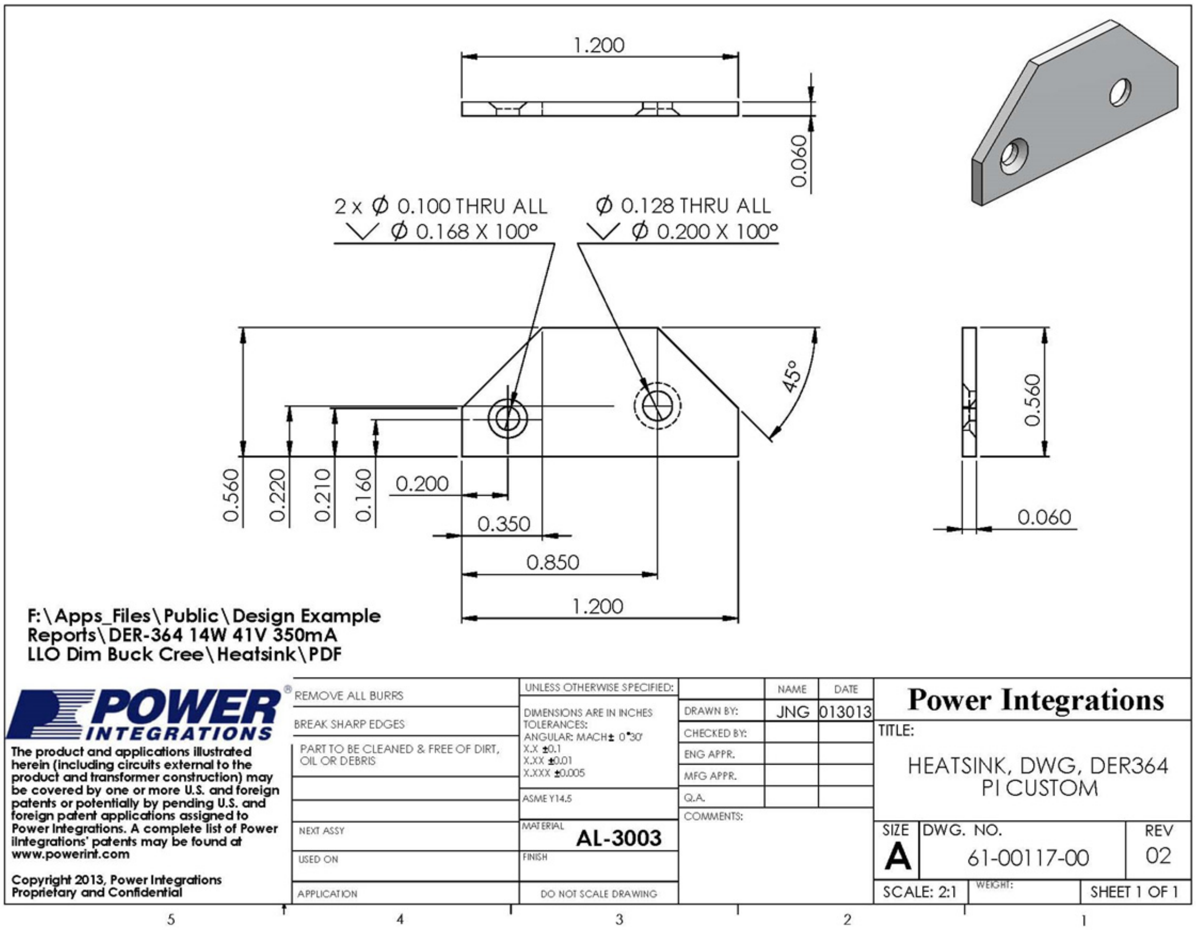

Figure 11 – Heat Sink Fabrication Drawing.

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9.2 *U1 Heat Sink Assembly Drawing*

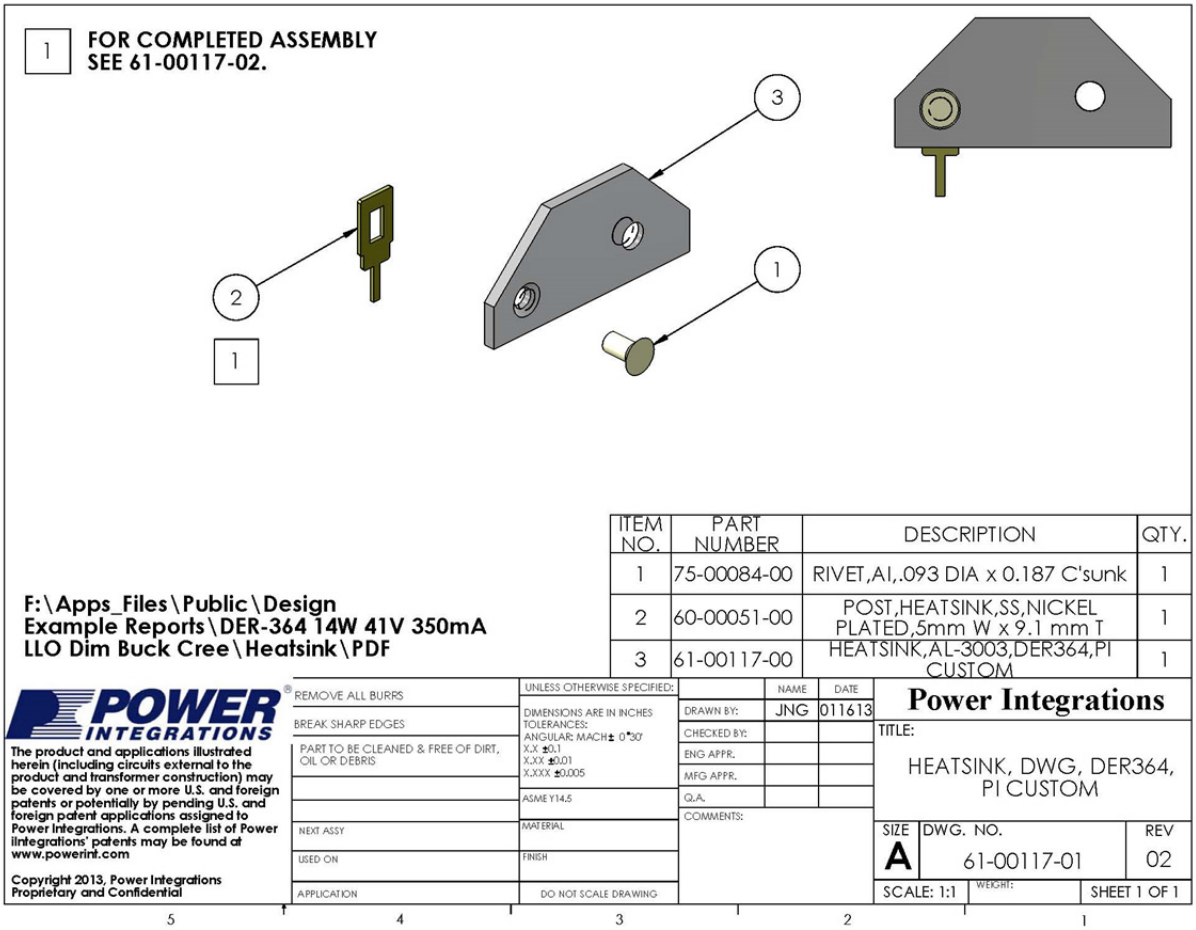
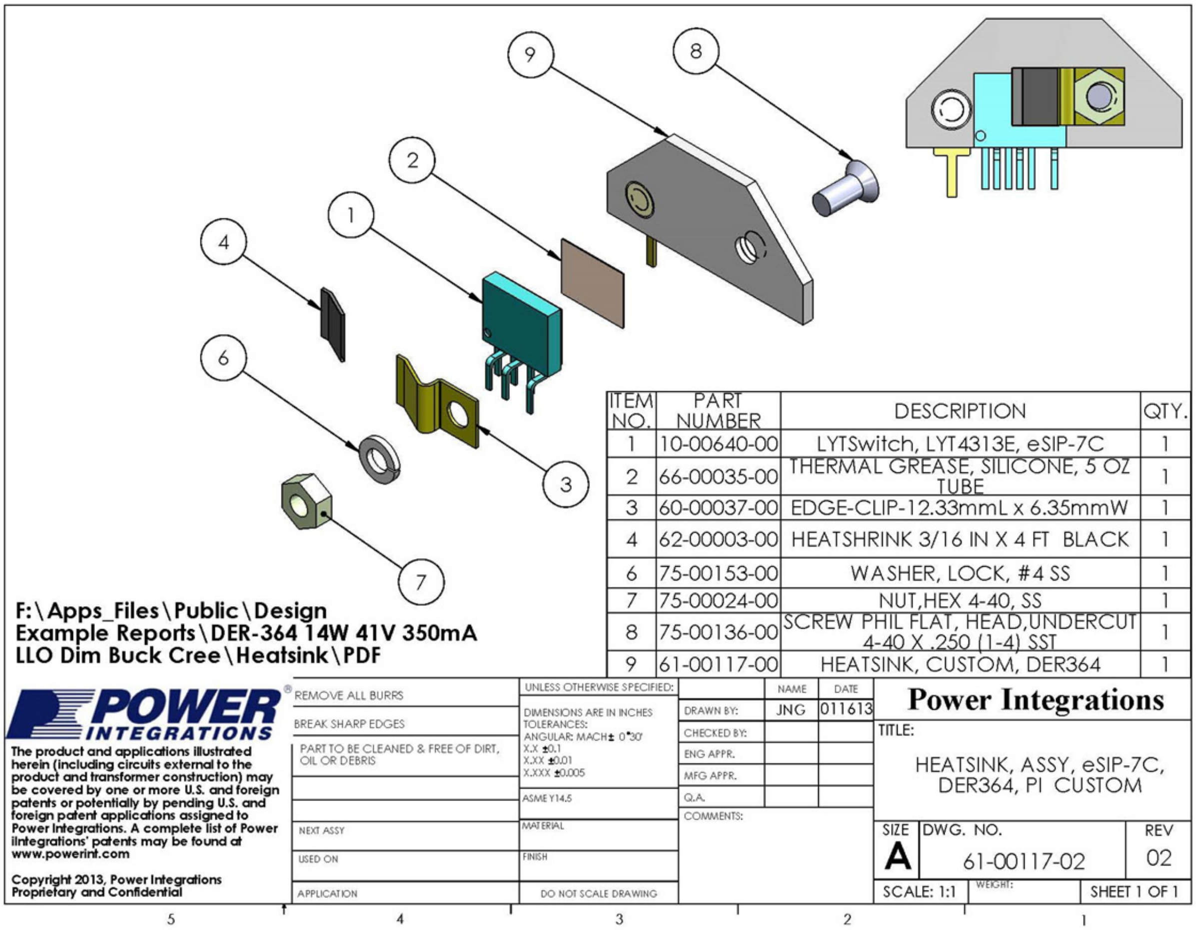


Figure 12 – U1 Heat Sink Assembly Drawing.

9.3 U1 and Heat Sink Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	10-00640-00	LYTSwitch, LYT4313E, eSIP-7C	1
2	66-00035-00	THERMAL GREASE, SILICONE, 5 OZ TUBE	1
3	60-00037-00	EDGE-CLIP-12.33mmL x 6.35mmW	1
4	62-00003-00	HEATSHRINK 3/16 IN X 4 FT BLACK	1
6	75-00153-00	WASHER, LOCK, #4 SS	1
7	75-00024-00	NUT,HEX 4-40, SS	1
8	75-00136-00	SCREW PHIL FLAT, HEAD,UNDERCUT 4-40 X .250 (1-4) SST	1
9	61-00117-00	HEATSINK, CUSTOM, DER364	1

Figure 13 – U1 and Heat Sink Assembly Drawing.

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10 Performance Data

All measurements performed at room temperature using an LED e-load. The table in Section 10.6 shows complete test data values.

10.1 Efficiency

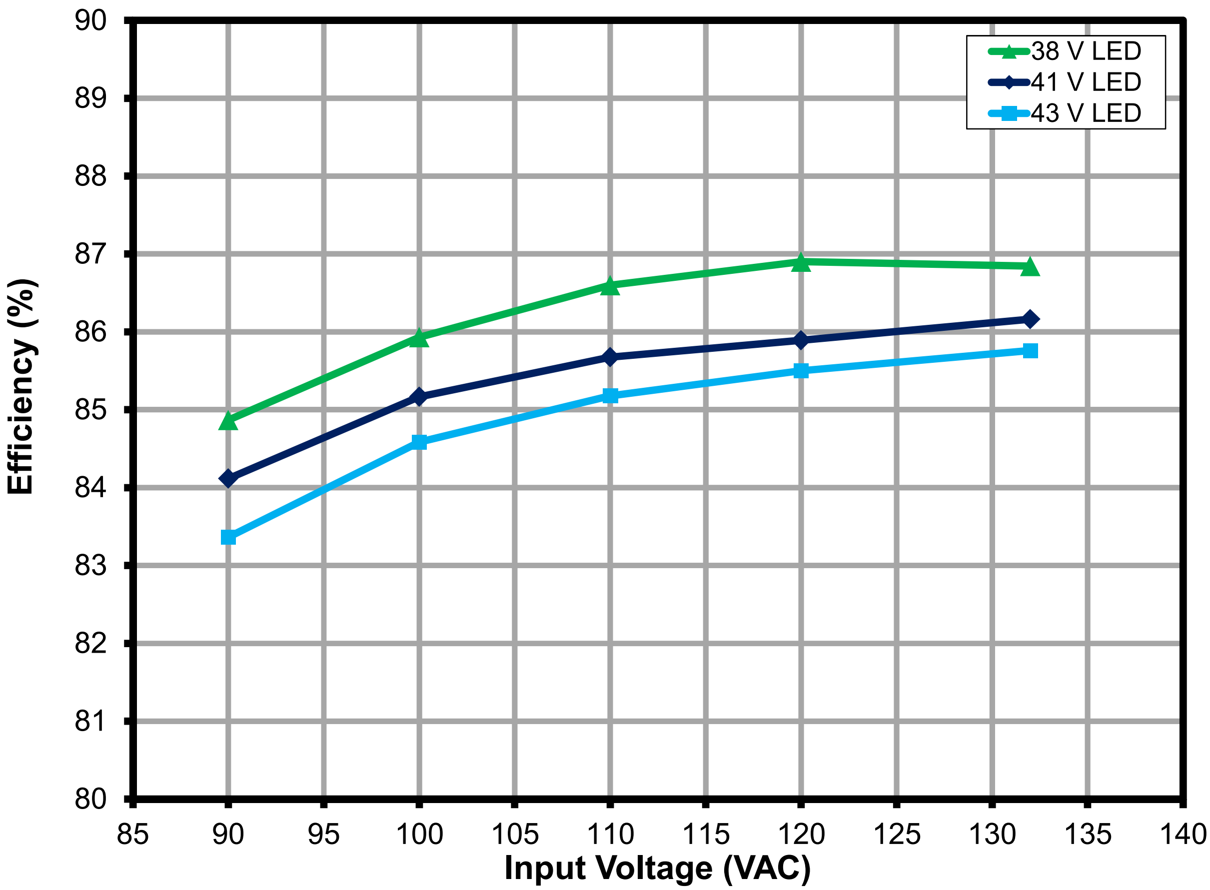

Figure 14 – Efficiency vs. Line.

10.2 Line and Load Regulation

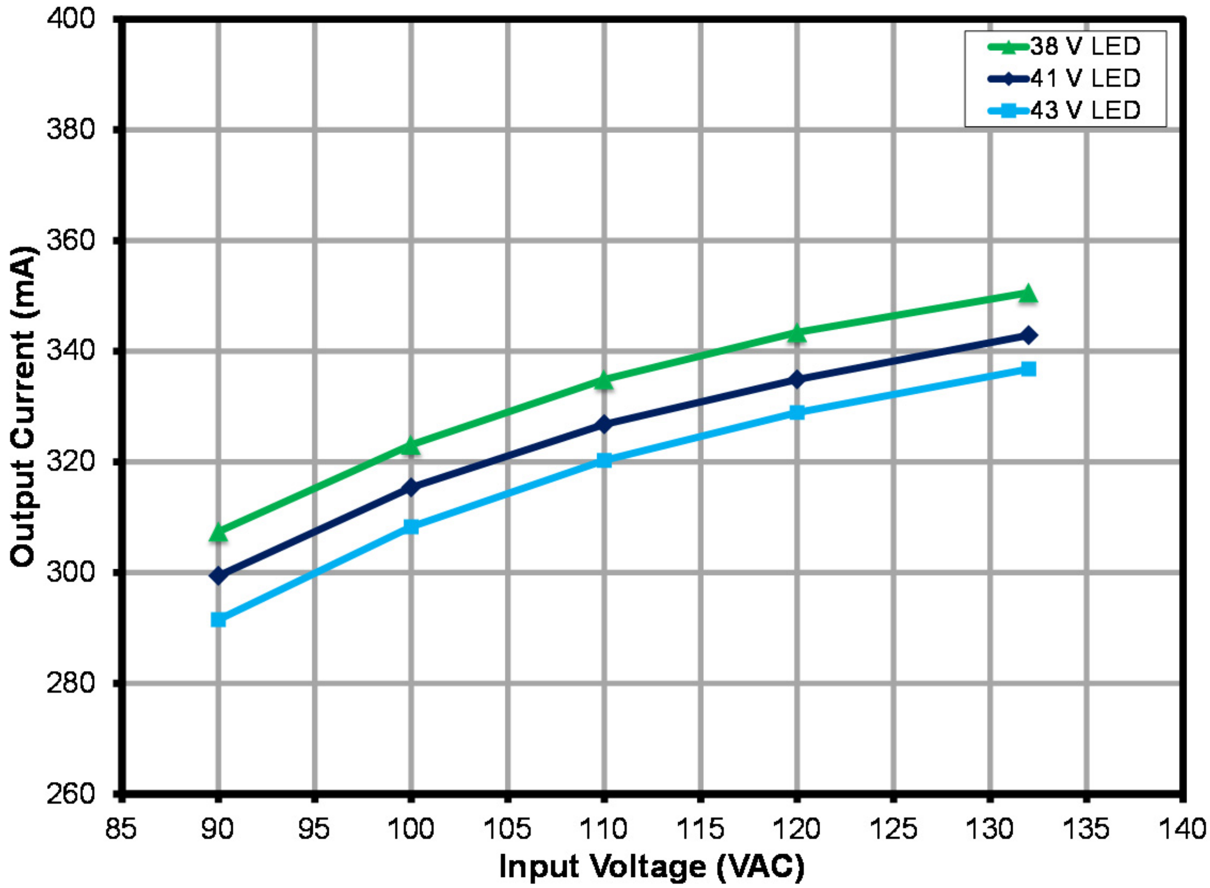

Figure 15 – Regulation vs. Line and Load.

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10.3 Power Factor

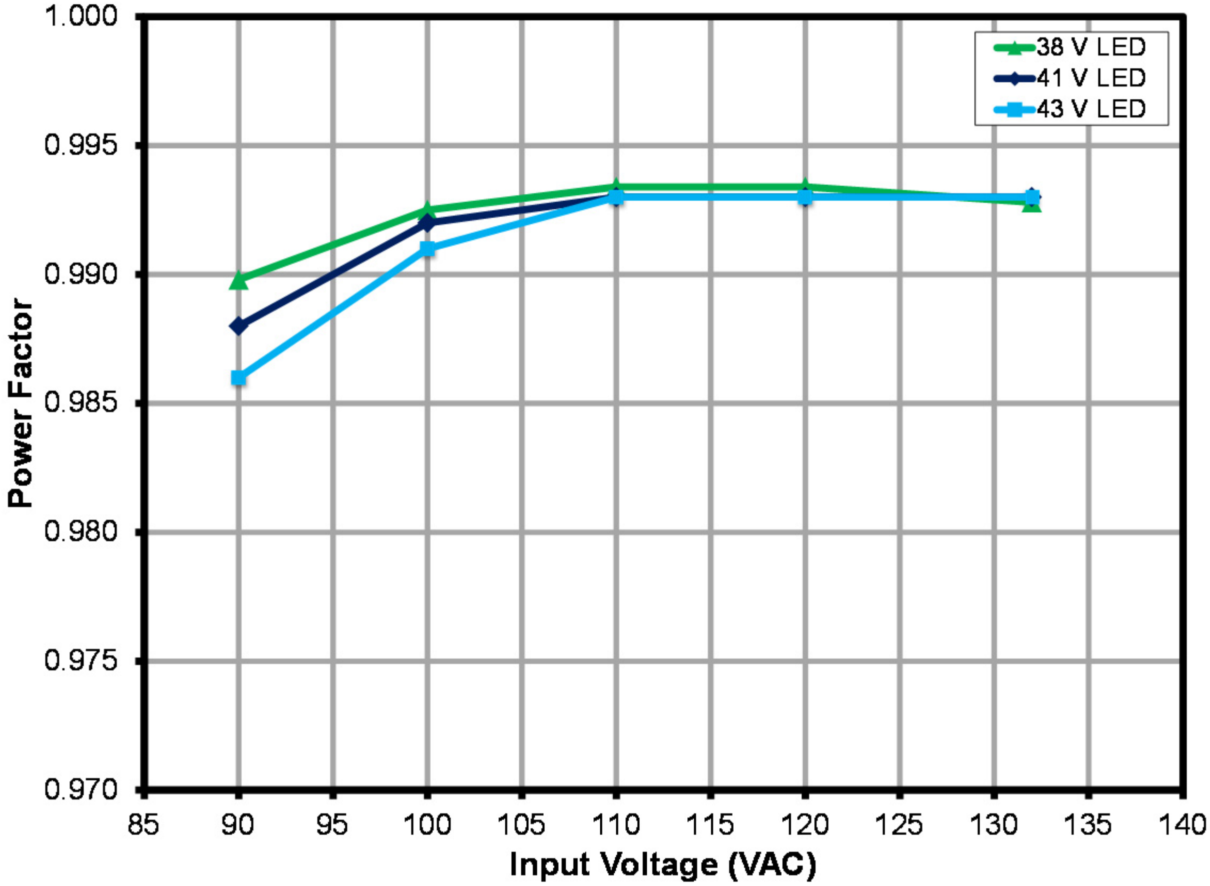

Figure 16 – Power Factor vs. Line and Load.

10.4 A-THD

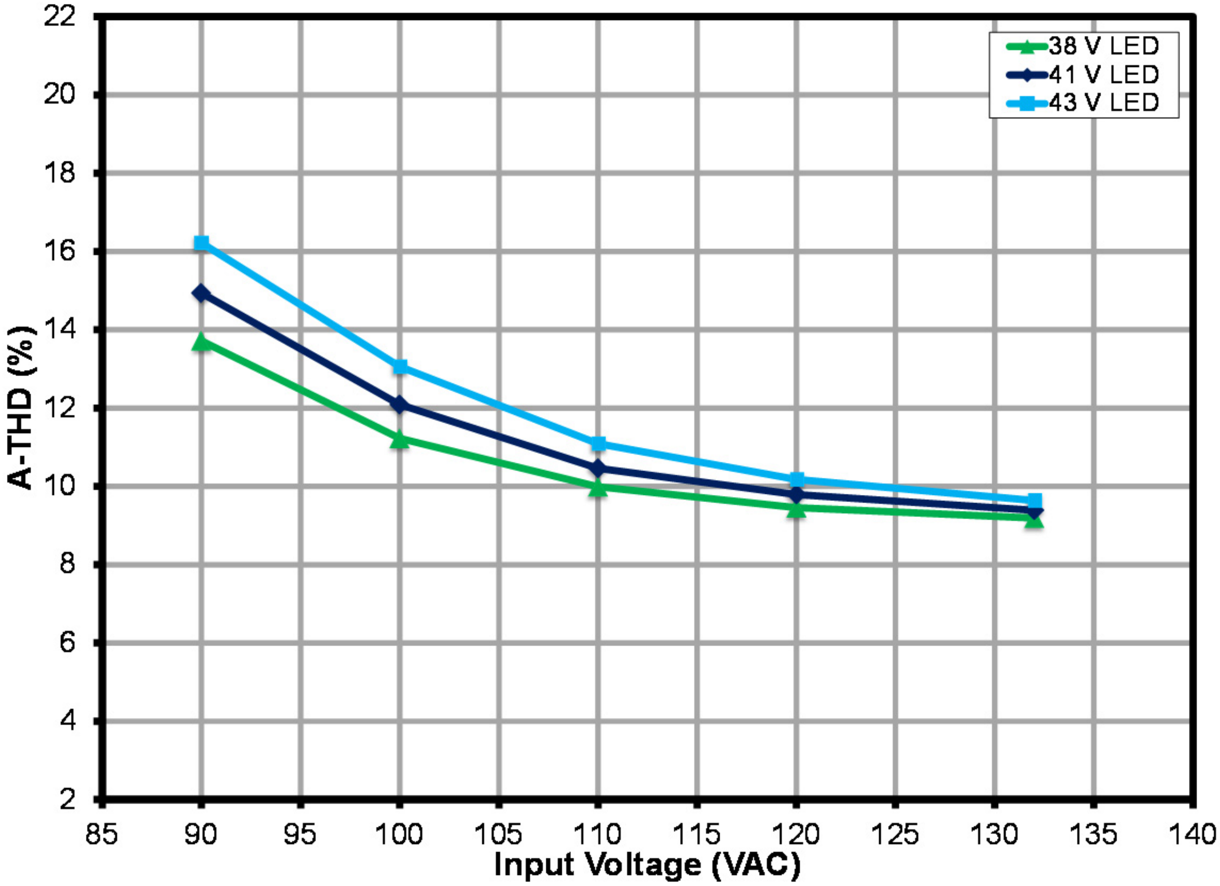

Figure 17 – A-THD vs. Line and Load.

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10.5 Harmonic Currents

The design met the IEC61000-3-2 Limits for Class C equipment (section 7.3-a) for an active input power of <25 W, which states that the harmonic currents shall not exceed the related limits given in Table 2 - Limits for Class C equipment.

10.5.1 38 V LED Load

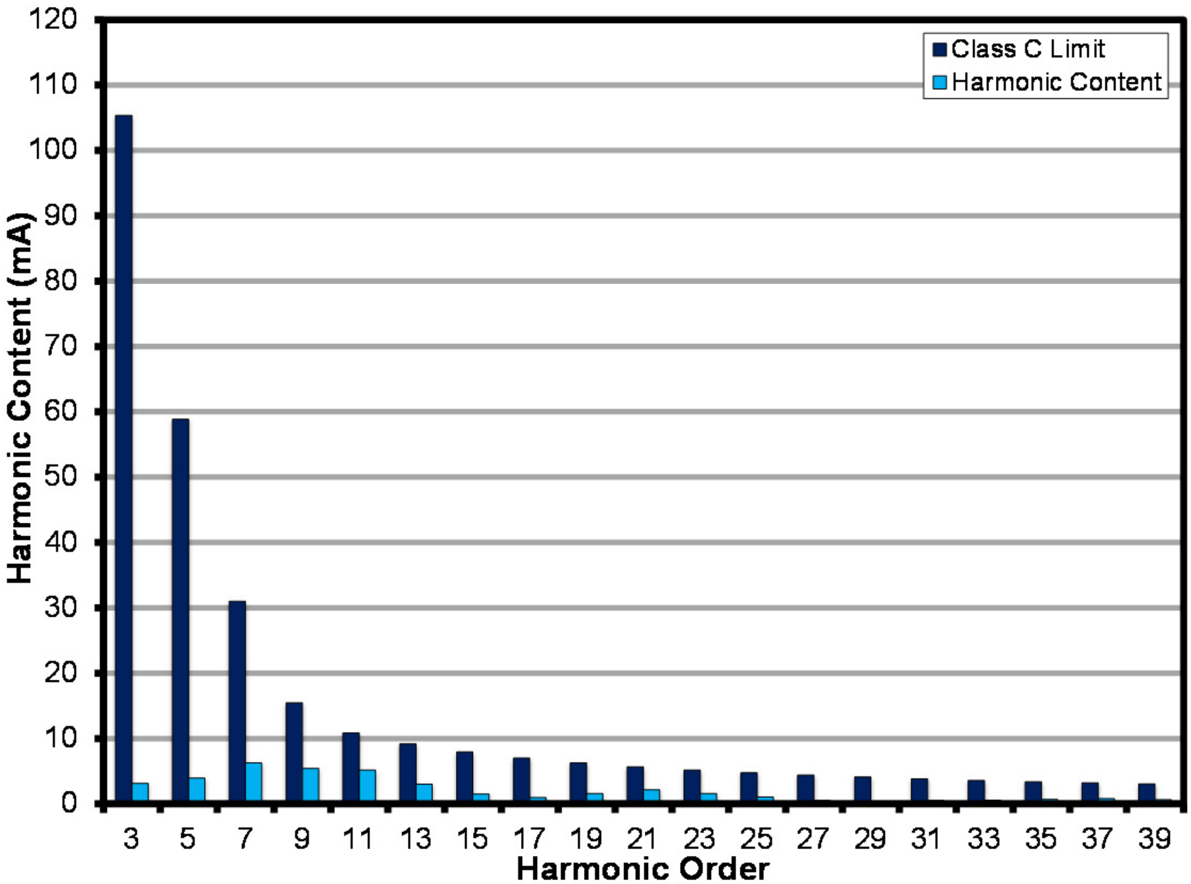

Figure 18 – 38 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

10.5.2 41 V LED Load

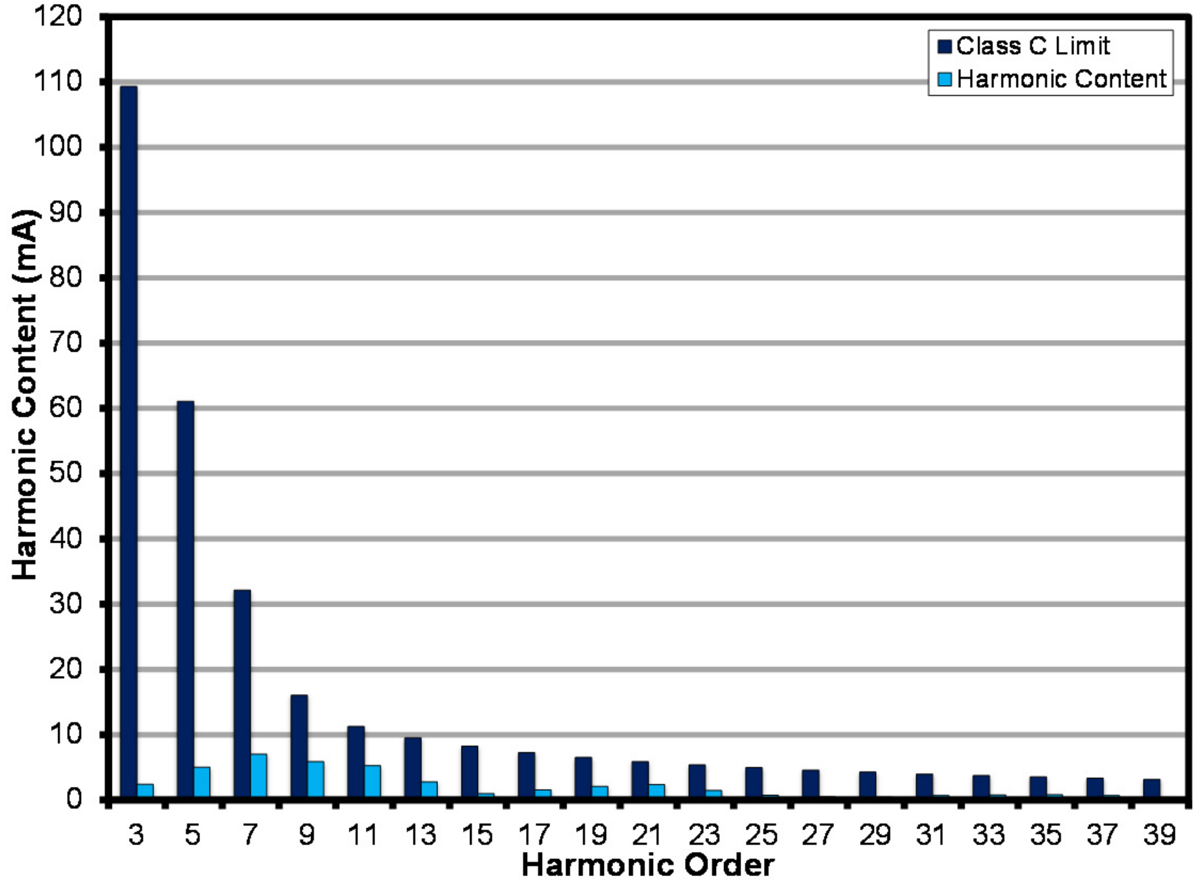

Figure 19 – 41 V LED Load Input Current Harmonics Case (IEC61000-3-2) at 120 VAC, 60 Hz.

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10.5.3 43 V LED Load

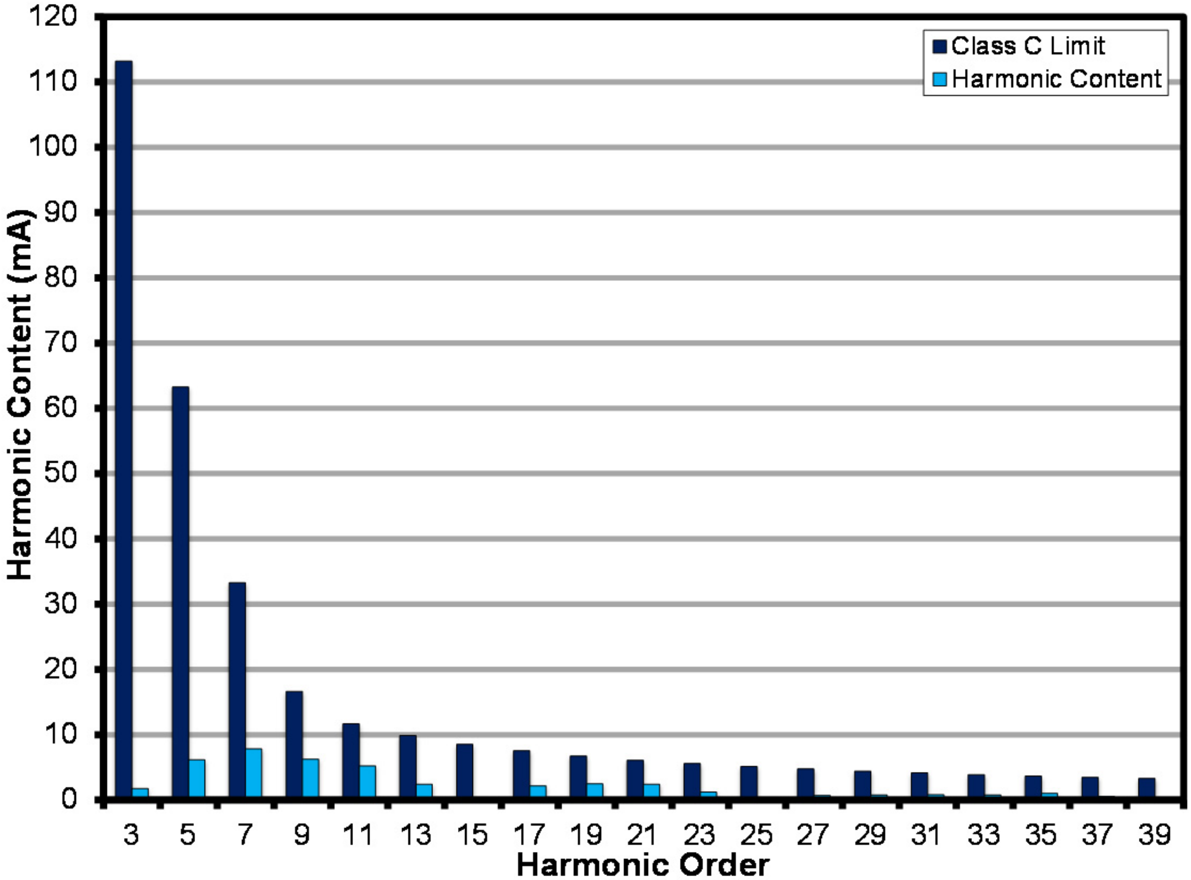

Figure 20 – 43 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

10.6 Test Data

All measurements were taken with the board at open frame, 25 °C ambient, and 60 Hz line frequency.

10.6.1 Test Data, 38 V LED Load

Input		Input Measurement					Load Measurement			
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)	Efficiency (%)
90	60	90.09	158.51	14.135	0.990	13.72	38.9740	307.400	11.996	84.87
100	60	100.12	147.98	14.705	0.993	11.23	39.0610	323.100	12.636	85.93
110	60	110.15	138.44	15.149	0.993	9.99	39.1250	334.900	13.119	86.60
120	60	120.15	129.84	15.497	0.993	9.46	39.1710	343.400	13.467	86.90
132	60	132.16	120.79	15.849	0.993	9.19	39.2130	350.600	13.764	86.84

10.6.2 Test Data, 41 V LED Load

Input		Input Measurement					Load Measurement			
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)	Efficiency (%)
90	60	90.09	164.06	14.605	0.988	14.94	40.9800	299.400	12.285	84.12
100	60	100.11	153.38	15.228	0.992	12.09	41.0720	315.400	12.969	85.17
110	60	110.15	143.63	15.712	0.993	10.46	41.1380	326.800	13.461	85.67
120	60	120.16	134.68	16.076	0.993	9.79	41.1870	334.900	13.808	85.89
132	60	132.19	125.16	16.427	0.993	9.39	41.2320	342.900	14.154	86.16

10.6.3 Test Data, 43 V LED Load

Input		Input Measurement					Load Measurement			
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)	Efficiency (%)
90	60	90.10	169.38	15.050	0.986	16.22	42.9910	291.500	12.546	83.36
100	60	100.11	158.57	15.725	0.991	13.06	43.0960	308.300	13.301	84.59
110	60	110.12	148.68	16.252	0.993	11.09	43.1690	320.300	13.843	85.18
120	60	120.15	139.52	16.647	0.993	10.18	43.2220	328.900	14.233	85.50
132	60	132.19	129.60	17.010	0.993	9.64	43.2700	336.800	14.588	85.76

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10.6.4 120 VAC 60 Hz, 33 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60	129.84	15.497	0.993	9.46
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	128.96				
2	0.03	0.02%		2.00%	
3	3.16	2.45%	105.3796	29.80%	Pass
5	3.96	3.07%	58.8886	10.00%	Pass
7	6.28	4.87%	30.9940	7.00%	Pass
9	5.43	4.21%	15.4970	5.00%	Pass
11	5.16	4.00%	10.8479	3.00%	Pass
13	3.04	2.36%	9.1790	3.00%	Pass
15	1.54	1.19%	7.9551	3.00%	Pass
17	0.99	0.77%	7.0192	3.00%	Pass
19	1.58	1.23%	6.2804	3.00%	Pass
21	2.18	1.69%	5.6822	3.00%	Pass
23	1.58	1.23%	5.1881	3.00%	Pass
25	1.04	0.81%	4.7731	3.00%	Pass
27	0.52	0.40%	4.4195	3.00%	Pass
29	0.20	0.16%	4.1147	3.00%	Pass
31	0.49	0.38%	3.8493	3.00%	Pass
33	0.59	0.46%	3.6160	3.00%	Pass
35	0.72	0.56%	3.4093	3.00%	Pass
37	0.81	0.63%	3.2251	3.00%	Pass
39	0.65	0.50%	3.0597	3.00%	Pass

10.6.5 120 VAC 60 Hz, 41 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60	134.68	16.0760	0.9933	9.79
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	133.75				
2	0.04	0.03%		2.00%	
3	2.42	1.81%	109.3168	29.80%	Pass
5	5.02	3.75%	61.0888	10.00%	Pass
7	7.05	5.27%	32.1520	7.00%	Pass
9	5.88	4.40%	16.0760	5.00%	Pass
11	5.28	3.95%	11.2532	3.00%	Pass
13	2.78	2.08%	9.5219	3.00%	Pass
15	0.99	0.74%	8.2523	3.00%	Pass
17	1.55	1.16%	7.2815	3.00%	Pass
19	2.07	1.55%	6.5150	3.00%	Pass
21	2.39	1.79%	5.8945	3.00%	Pass
23	1.47	1.10%	5.3820	3.00%	Pass
25	0.74	0.55%	4.9514	3.00%	Pass
27	0.46	0.34%	4.5846	3.00%	Pass
29	0.45	0.34%	4.2685	3.00%	Pass
31	0.70	0.52%	3.9931	3.00%	Pass
33	0.77	0.58%	3.7511	3.00%	Pass
35	0.81	0.61%	3.5367	3.00%	Pass
37	0.69	0.52%	3.3455	3.00%	Pass
39	0.34	0.25%	3.1740	3.00%	Pass

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10.6.6 120 VAC 60 Hz, 43 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60	139.52	16.6470	0.9931	10.18

nth Order	mA Content	% Content	Limit <25 W	Limit >25 W	Remarks
1	138.46				
2	0.03	0.02%		2.00%	
3	1.77	1.28%	113.1996	29.79%	Pass
5	6.17	4.46%	63.2586	10.00%	Pass
7	7.82	5.65%	33.2940	7.00%	Pass
9	6.27	4.53%	16.6470	5.00%	Pass
11	5.25	3.79%	11.6529	3.00%	Pass
13	2.41	1.74%	9.8601	3.00%	Pass
15	0.41	0.30%	8.5455	3.00%	Pass
17	2.16	1.56%	7.5401	3.00%	Pass
19	2.48	1.79%	6.7464	3.00%	Pass
21	2.40	1.73%	6.1039	3.00%	Pass
23	1.23	0.89%	5.5731	3.00%	Pass
25	0.36	0.26%	5.1273	3.00%	Pass
27	0.71	0.51%	4.7475	3.00%	Pass
29	0.77	0.56%	4.4201	3.00%	Pass
31	0.81	0.59%	4.1349	3.00%	Pass
33	0.77	0.56%	3.8843	3.00%	Pass
35	1.00	0.72%	3.6623	3.00%	Pass
37	0.55	0.40%	3.4644	3.00%	Pass
39	0.20	0.14%	3.2867	3.00%	Pass

11 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 120 VAC, 60 Hz line frequency, room temperature, and a nominal 41 V LED load.

The output current High Limit I_{OUT} (HL) and Low Limit I_{OUT} (LL) were incorporated based on the USA NEMA publication SSL6-2010 section 4 page 9 for dimming performance system requirements for reference. The standard however refers to 120 VAC operating input voltage and pertains to the limits as relative light output. The limits incorporated on the succeeding graphs assumes that 100% relative light output falls on the maximum operating output current of 360 mA and 0 mA as 0% light output, and input line of 120 VAC, 60 Hz.

11.1 Dimming Curve with Simulated (Using Agilent 6812B AC Source) Leading Edge Dimmer

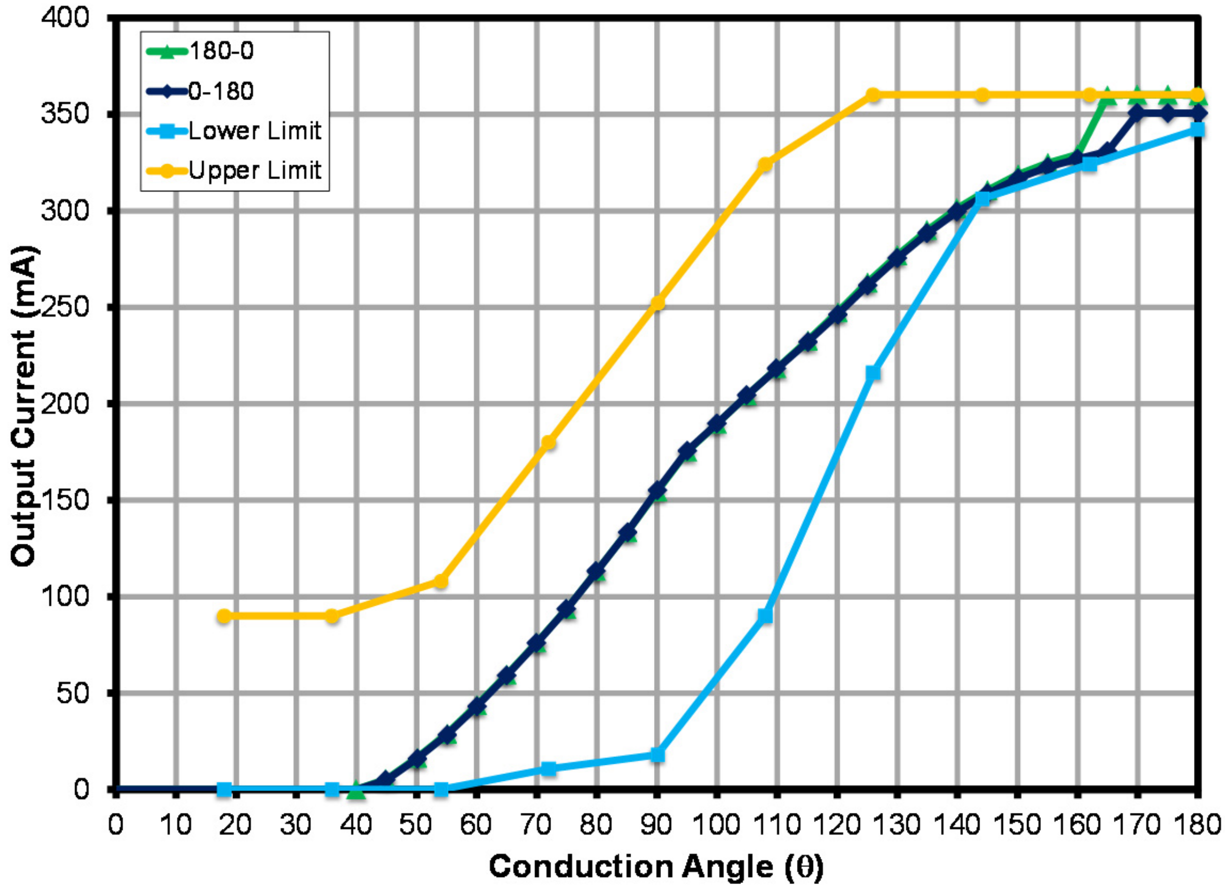

Figure 21 – Dimming Curve at 120 VAC, 60 Hz Input.

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11.2 *Fast Start-up (<200 ms) with TRIAC-Based Dimmer*

Using a TRIAC-based U.S. dimmer model NT-600 (Lutron) with thumb-wheel adjust set to minimum turn-on (i.e. <30 degrees) which guarantees the LED driver is off when it is switched to ON position. The test was made by turning/sliding the dimmer knob as quickly as possible from minimum to maximum position then measuring the time from the point the dimmer started conducting to the point the output current started rising.

Input voltage: 120 VAC / 60 Hz

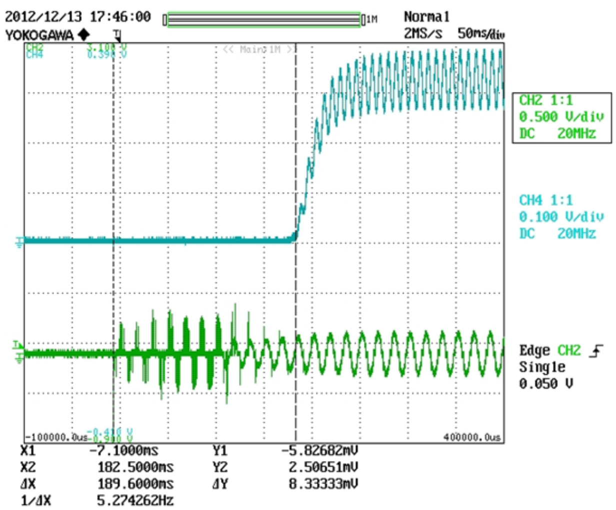

Figure 22 – Measured Start-up Time 189 ms.
Flicking the Switch ON, Dimmer at Full Conduction.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 500 mA, 50 ms / div.

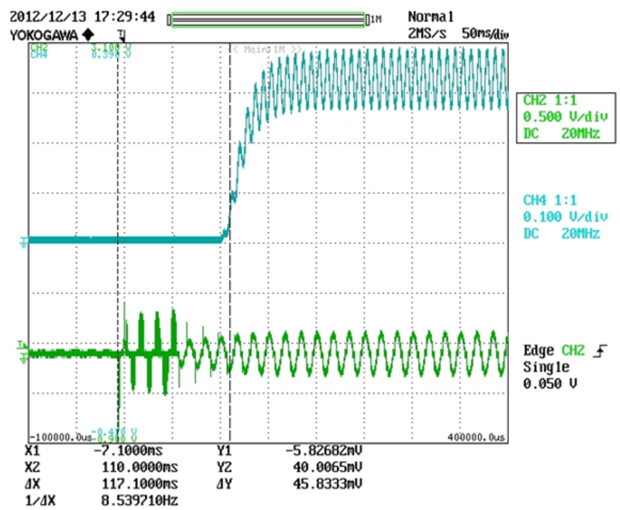

Figure 23 – Measured Start-up Time 117 ms.
Quickly Sliding the Knob from Minimum to Full Conduction.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 500 mA, 50 ms / div.

11.3 Pop-on Point with TRIAC-based Dimmer

Pop-on per NEMA SSL-6 definition is lowest dimmer setting above minimum at which the lamp transitions from off to dimmed.

This particular test was conducted using 120 V / 60 Hz TRIAC dimmer model NT-600 (LUTRON dimmer).

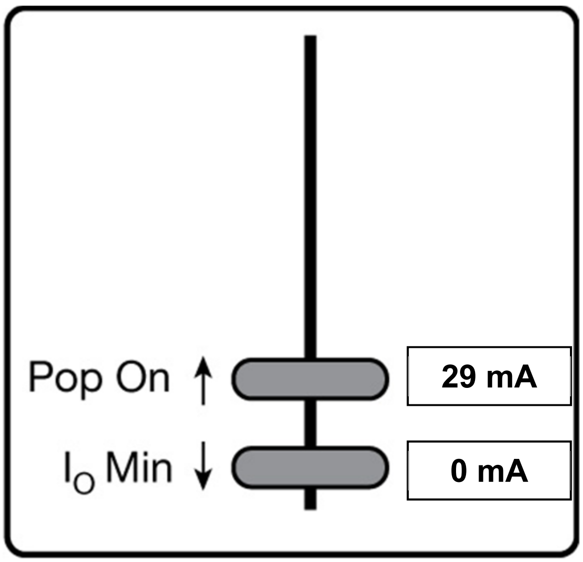

Figure 24 – 42º Conduction Angle was Measured at Pop-on Point.

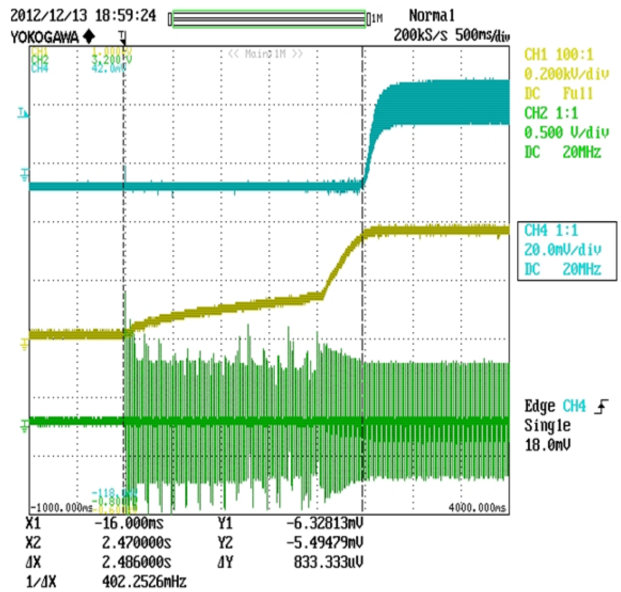

Figure 25 – 42º Conduction Angle at Pop-on Point.
Upper: I_{OUT}, 20 mA / div.
Middle: V_{OUT}, 200 V / div.
Lower: I_{IN}, 0.5 A / div., 500 ms / div.

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11.4 Output Current and Input Current Waveforms with Dimmer

Input: 120 VAC, 60 Hz Utility Line
Output: 41 V LED Load
Dimmer: LUTRON NT-600

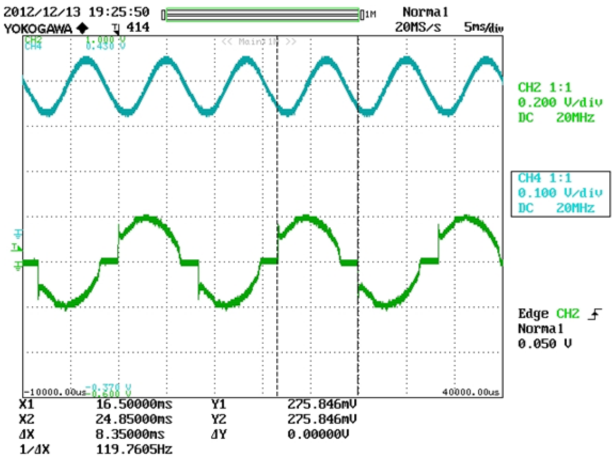

Figure 26 – 144º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

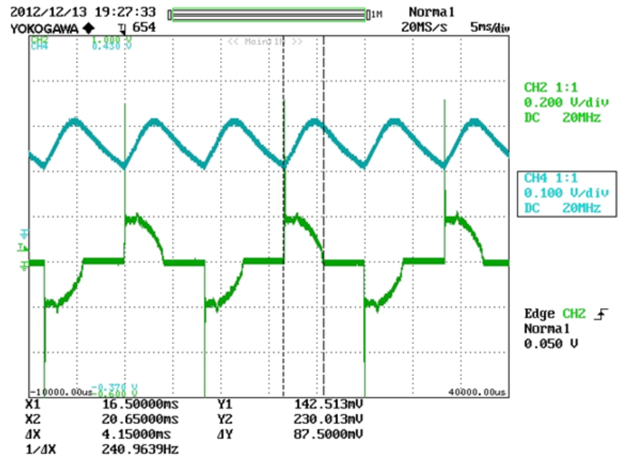

Figure 27 – 90º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

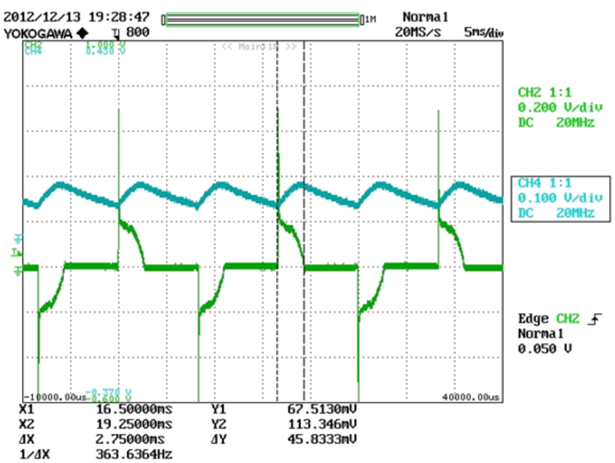

Figure 28 – 60º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

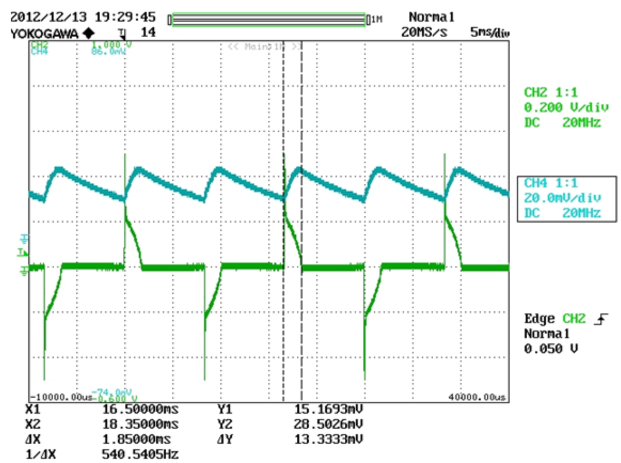

Figure 29 – 40º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

11.5 Compatibility List

The following U.S. TRIAC-based dimmers were tested with programmable AC source (120 VAC, 60 Hz) and 41 V LED load.

Dimmer Brand	Type	Remarks	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
LUTRON	L	Lutron 600-Watt Slide Dimmer LG-600PH-LA	600W	LG-600PH-WH	0.1	277	2700
LUTRON	L	Lutron Skylark Incandescent 600W 3-Way Preset Dimmer with On/Off	600W	S-603P-WH	0.1	293	2930
LUTRON	T	Lutron SLV-600P-WH 600-Watt Skylark Magnetic Low-Voltage Single-Pole Dimmer	600W	SLV600P-WH	0.1	291	2910
LUTRON	L	Slide-to-Off Single Pole Skylark Dimmer Switch (RFI suppression)	600W	S-600-WH	0.1	318	3180
LUTRON	L	Lutron Skylark 5-Amp White Gloss Dimmer	600W	S-600PH-WH	0.1	296	2960
LUTRON	L	Cfl&led Dimmer, Paddle/slide, 120V, 600W	600W	DVWCL-153-PLH-WH	14	302	21
LUTRON	L	600W Diva Dimmer, 3-Way - Ivory	600W	DV-603P-WH	0.1	278	2780
LUTRON	L	Lutron Diva DV-600P-WH Incand 600 Watt Single Pole Light Dimmer in White	600W	DV-600P-WH	0.1	278	2780
LUTRON	L	Ivry Toggle Dimmer 1p Preset	600W	TG-600PH-WH	0.1	287	2870
LUTRON	T	Lutron Ariadni AY-600P-WH Incand Preset 600 Watt Single Pole Light Dimmer in White	600W	AY-600P-WH	15	305	20
LUTRON	L	Glyder Incandescent Single Pole 600 Watts Preset Dimmer, White	600W	GL-600P-WH	0.1	290	2900
LEVITON	L	SureSlide 600W Incandescent Dimmer	600W	R62-06633-1LW	0.1	325	3250
LEVITON	L	SureSlide 600W Incandescent Slide Dimmer, Single-Pol	600W	R62-06631-1LW	0.1	310	3100
LEVITON	L	IllumaTech Incandescent Preset Slide Dimmer	600W	R60-IPI06-1LM	62	326	5
LEVITON	Electronic	I 500 W, 120 VAC, Decora Brand Style 4 Level Dimmer	500W	R52-06161-00W	41	312	8
LEVITON	L	IllumaTech Rotary Controls 120V AC 60Hz	600W	R52-RPI06-1LW	0.1	334	3340
LEVITON	L	A Push On and Push Off Dimmer	600W	R60-06681-0LW	0.1	269	2690
LEVITON	L	Leviton 600-Watt 3-Way Lighted White/Ivory Push Dimmer	600W	R60-06684-1LW	0.1	354	3540
LEVITON			600W	6683	0.1	354	3540
LEVITON	L	SURESLIDE" MAGNETIC LOW VOLTAGE DIMMER *600VA, 120V AC, 60Hz	450W	R02-06613-PLW	0.1	322	3220
COOPER				SLC03P-W-K-L	0.1	302	3020
LUTRON	L	Lutron 15-Amp White Slide Dimmer	600W	GL-600-WH	0.1	317	3170
LUTRON	L	Diva, Screw Base Compact Fluorescent Dimming with Philips® DIMMABLE Energy Saver CFL, Single Pole/3-Way, 200W, White	200W	DVPDC-203P-WH	148	322	2
LUTRON	L	Lyneo Lx Single Pole Dimmer 600W	500W	LX-600PL-wh	31	312	10
LUTRON	L	Single Pole - Incandescent - Push On/Off - 600 Watt - White	600W	D-600P-WH	0.1	292	2920
LUTRON			600W	CTCL-153PDH	9	301	34
LUTRON			600W	S-600P	0.1	294	2940
LUTRON				TGLV-600P	0.1	292	2920
LUTRON			450W	TGLV-600PR	0.1	288	2880
LUTRON	L	Lutron Diva Satin 5-Amp Desert Stone Preset Dimmer	300W	TT-300NLH-WH	0.1	316	3160

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LUTRON	L	Lutron Credenza 300-Watt White Lamp Dimmer	300W	TT-300H-WH	0.1	316	3160
LUTRON				S-600P	0.1	298	2980
LUTRON				S-600P	0.1	323	3230
COOPER				S106P	0.1	307	3070
LUTRON		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, 3-Way, 1000W, White	1000	S-103P-WH	55	315	5
LUTRON		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, Single Pole, 1000W, White	1000	S-10P-WH	35	312	9
LUTRON		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, Single Pole, 600W, White	600	S-600PNLH-WH	0.1	300	3000
LUTRON		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, 3-Way, 600W, White	600	S-603PNL-WH	0.1	300	3000
LUTRON		Skylark, Dimmers with On/Off Switch, Magnetic Low Voltage, 3-Way, 600VA, White	600	SLV-603P-WH	0.1	287	2870
LUTRON		Skylark, Slide-To-Off Dimmers, Incandescent/Halogen, Eco-Dim, Single Pole/3-Way, 600W, Clamshell Packing, White	600	S-603PGH-WH	0.1	225	2250
LUTRON		Ariadni, Dimmers, Magnetic Low Voltage, Single Pole, 600VA, White	600	AYLV-600P-WH	0.1	291	2910
LUTRON		Ariadni, Dimmers, Magnetic Low Voltage, 3-Way, 600VA, White	600	AYLV-603P-WH	0.1	280	2800
LUTRON		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, 3-Way, 1000W, White	1000	AY-103PNL-WH	32	310	9
LUTRON		Ariadni, Dimmers, Incandescent/Halogen, 3-Way, 1000W, White	1000	AY-103P-WH	30	310	10
LUTRON		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, Single Pole, 1000W, White	1000	AY-10PNL-WH	44	330	7
LUTRON		Ariadni, Dimmers, Incandescent/Halogen, Single Pole, 1000W, White	1000	AY-10P-WH	50	311	6
LUTRON		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, 3-Way, 600W, White	600	AY-603PNL-WH	0.1	268	2680
LUTRON		Ariadni, Dimmers, Incandescent/Halogen, Eco-dim, Single Pole/3-Way, 600W, White	600	AY-603PG-WH	0.1	194	1940
LUTRON		Ariadni, Dimmers, Incandescent/Halogen, 3-Way, 600W, White	600	AY-603P-WH	0.1	275	2750
LUTRON		Ariadni, Dimmers with Locator Light, Incandescent/Halogen, Single Pole, 600W, White	600	AY-600PNL-WH	0.1	283	2830
LUTRON		Diva, Dimmers with Locator Light, Magnetic Low Voltage, Single Pole, 1000VA, White	1000	DVLV-10P-WH	0.1	273	2730
LUTRON		Diva, Dimmers with Locator Light, Magnetic Low Voltage, 3-Way, 1000VA, White	1000	DVLV-103P-WH	0.1	277	2770
LUTRON		Diva, Dimmers with Locator Light, Magnetic Low Voltage, 3-Way, 600VA, White	600	DVLV-603P-WH	0.1	278	2780
LUTRON		Skylark, Slide-To-Off Dimmers,	1000	S-1000-WH	0.1	315	3150

		Incandescent/Halogen, Single Pole, 1000W, White					
LUTRON		Skylark, Dimmers with On/Off Switch, Incandescent/Halogen, Single Pole, 600W, White	600	S-600P-WH	0.1	290	2900
LUTRON		Skylark, Dimmers with On/Off Switch & Locator Light, Incandescent/Halogen, 3-Way,1000W, White	1000	S-103PNL-WH	52	317	6
LUTRON		Glyder, Slide-To-Off Dimmers, Magnetic Low Voltage, Single Pole, 600W, White	600	GLV-600-WH	0.1	313	3130

Figure 30 – U.S. TRIAC-Based Dimmers Compatibility List.

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12 Thermal Performance

12.1 IR Thermal Profile

Images captured after running for more than 2 hours (25 °C), open frame for the conditions specified.

Non-Dimming V_{IN} = 90 VAC, 60 Hz, 41 V LED Load.	Non-Dimming V_{IN} = 132 VAC, 60 Hz, 41 V LED Load.
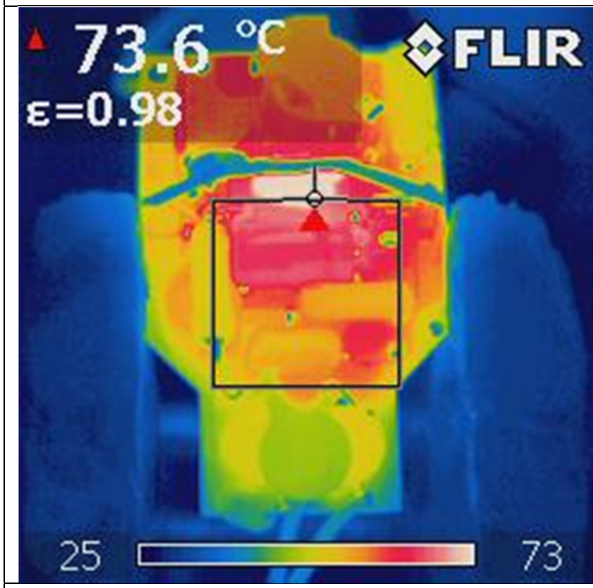	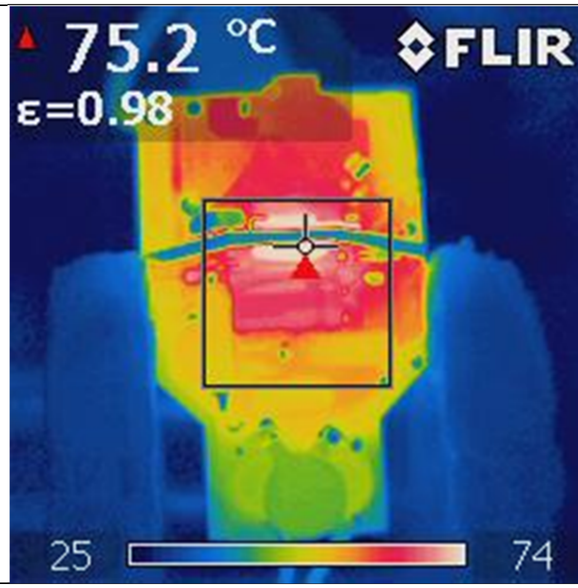
Figure 31 – U1 was Hottest Device.	**Figure 32 –** U1 was Hottest Device.

TRIAC Dimmer Connected V_{IN} = 120 VAC, 60 Hz, 41 V LED Load.

With TRIAC: V_{IN} = 120 VAC, 60 Hz, 41 V LED Load at Full Conduction.
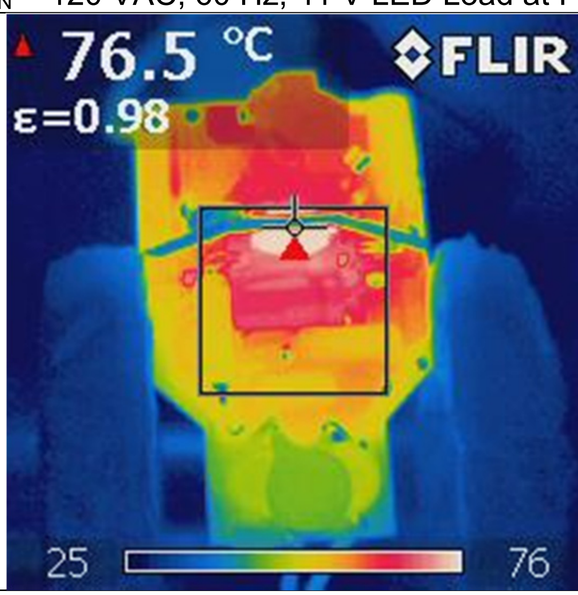
Figure 33 – U1 was Hottest Device.

12.2 Output Current and Output Voltage Waveform at Normal Operation

Input Condition	I_{OUT}, Mean (mA)	I_{OUT}, Peak to Peak (mA)	I_{OUT} Ripple (%)
90 VAC, 60 Hz	310	133	±21.4
120 VAC, 60 Hz	344	138	±20
132 VAC, 60 Hz	353	142	±20.1

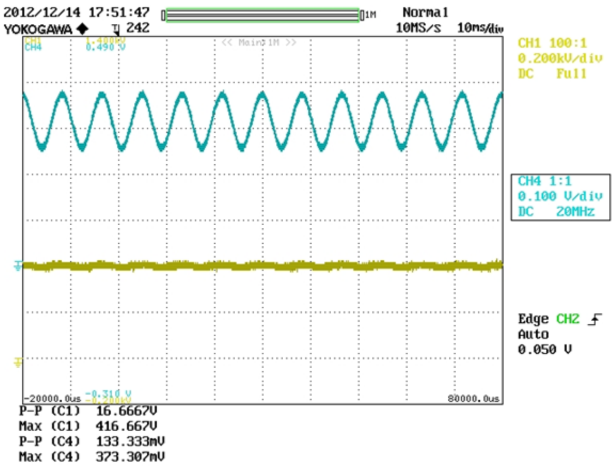

Figure 34 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 200 V, 10 ms / div.

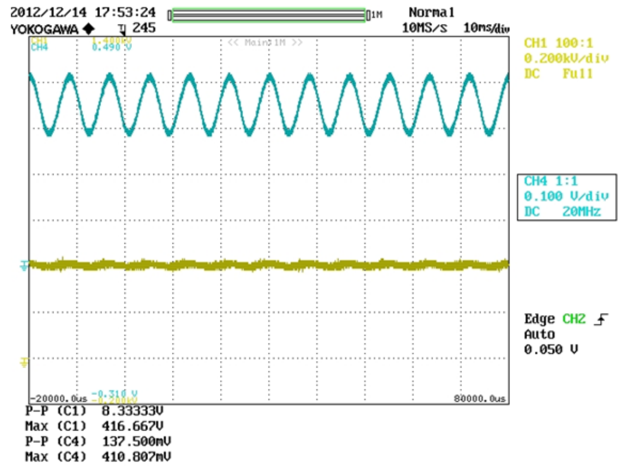

Figure 35 – 120 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 200 V, 10 ms / div.

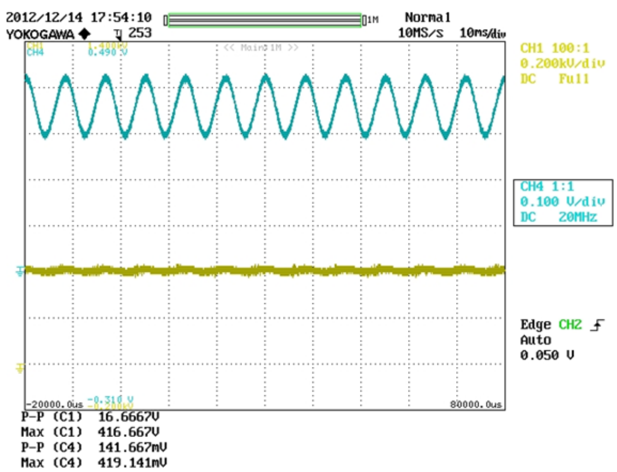

Figure 36 – 132 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 200 V, 10 ms / div.

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12.3 Output Voltage and Output Current Waveform at Start-up

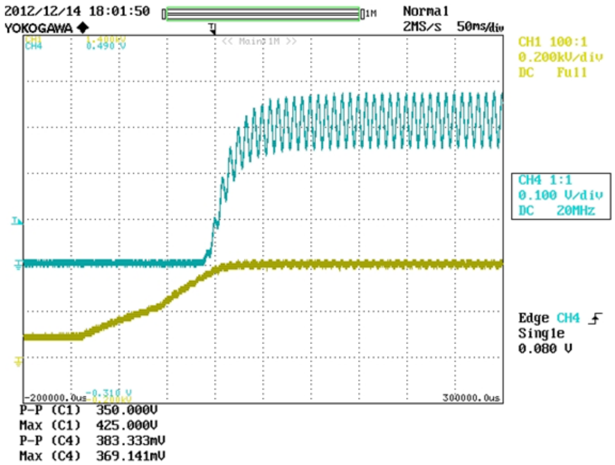

Figure 37 – 90 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 200 V, 50 ms / div.

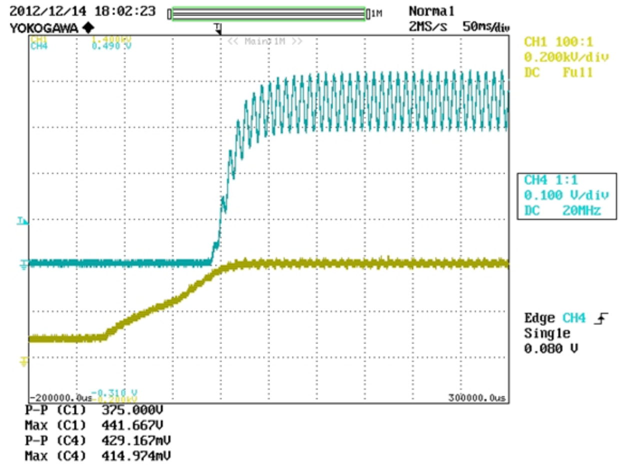

Figure 38 – 132 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 200 V, 50 ms / div.

12.4 Drain Voltage and Current at Normal Operation

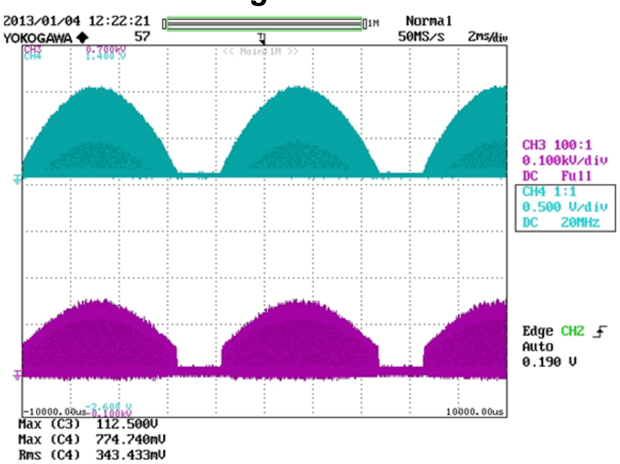

Figure 39 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

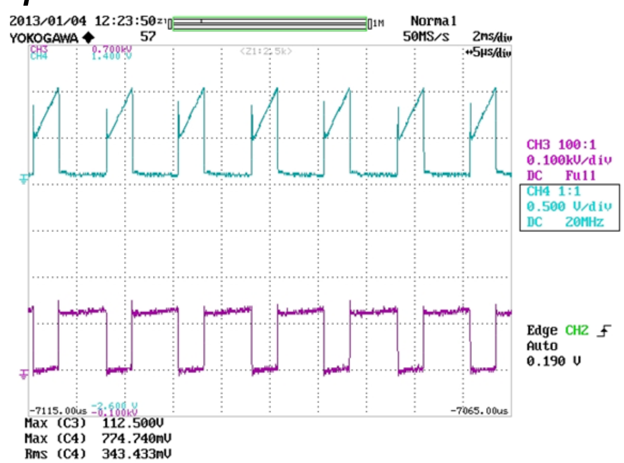

Figure 40 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

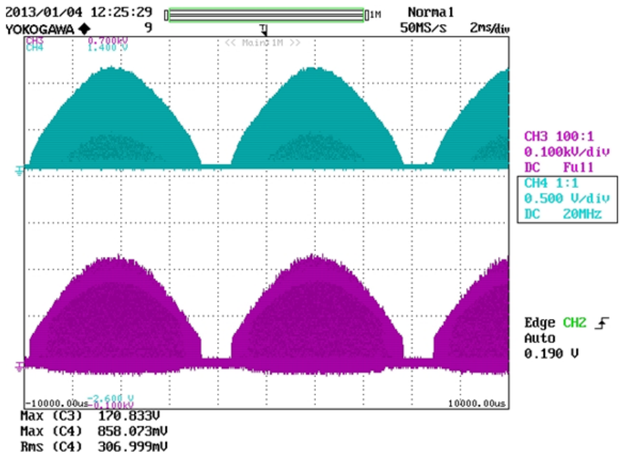

Figure 41 – 132 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

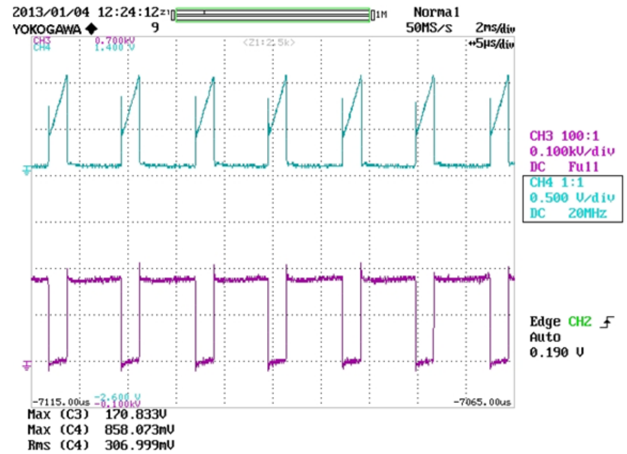

Figure 42 – 132 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

12.5 Drain Voltage and Current at Start-up

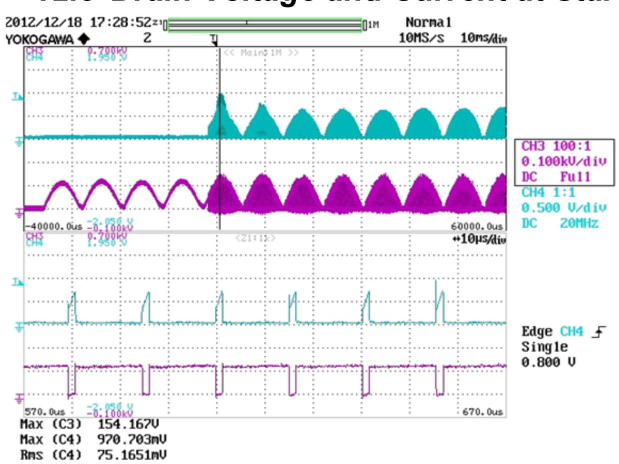

Figure 43 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V,10 ms / div.

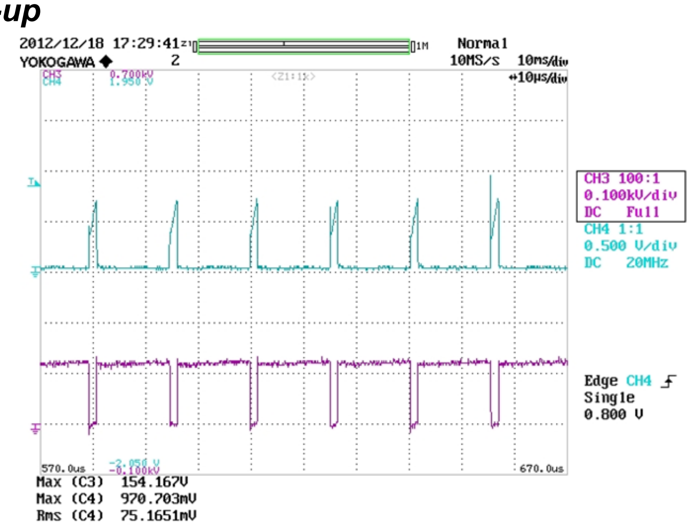

Figure 44 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

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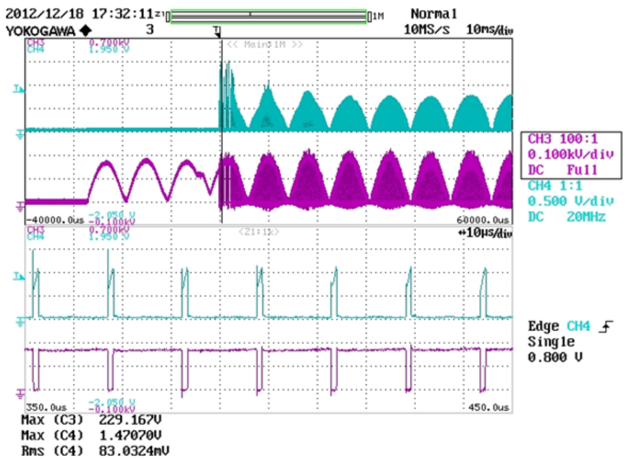

Figure 45 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

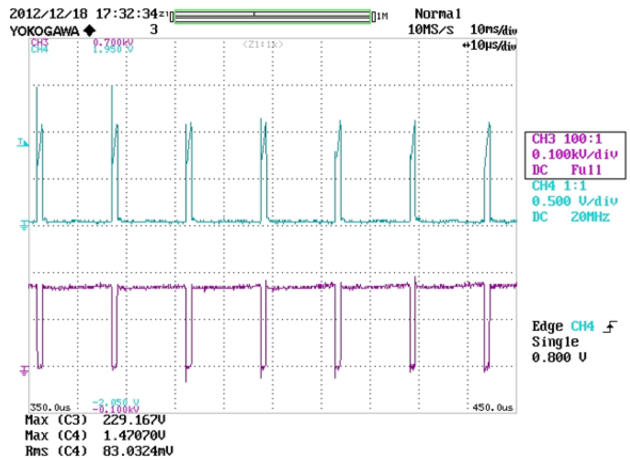

Figure 46 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

12.6 Drain Voltage and Current at Output Short Condition

During output short condition, the I_{FB} current falls below the $I_{FB(AR)}$ threshold and enters the auto-restart condition. During this condition, to minimize power dissipation on the power components, the auto-restart circuit turns the power supply on and off at an auto-restart duty cycle of typically DC_{AR} for as long as the fault condition persists.

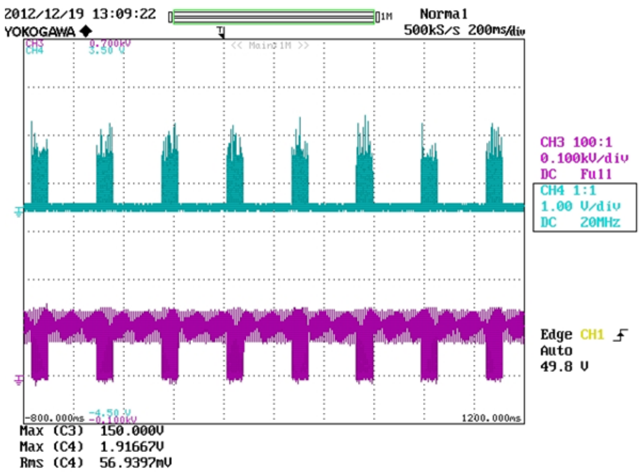

Figure 47 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

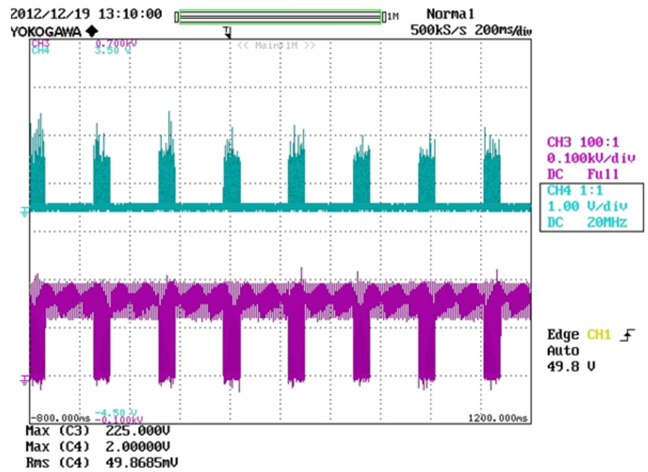

Figure 48 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

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12.7 Output Diode Voltage and Current Waveform at Normal Operation

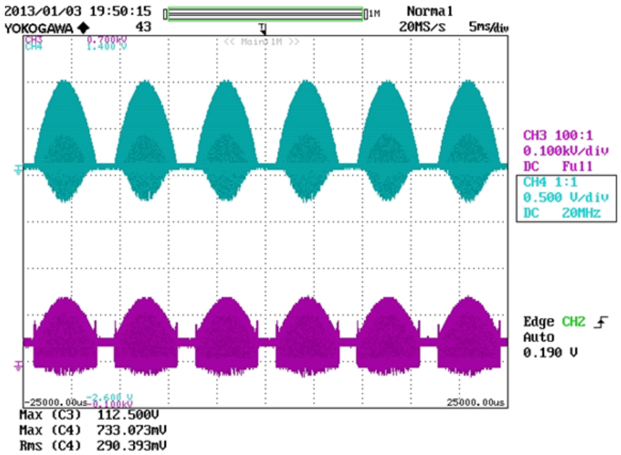

Figure 49 – 90 VAC, 60 Hz.
Upper: I_{D7}, 500 mA / div.
Lower: V_{D7}, 100 V, 5 ms / div.

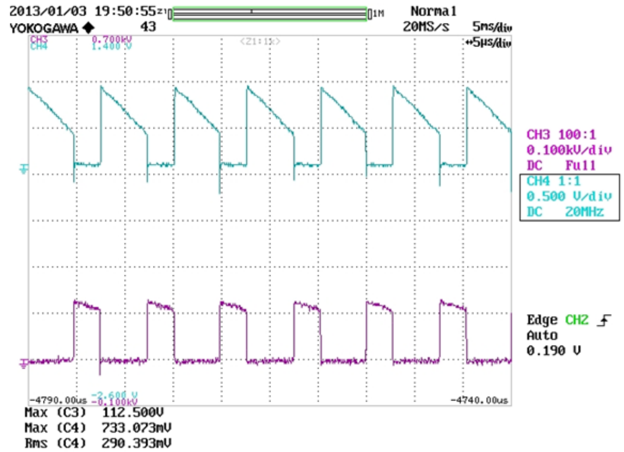

Figure 50 – 90 VAC, 60 Hz.
Upper: I_{D7}, 500 μA / div.
Lower: V_{D7}, 100 V, 5 μs / div

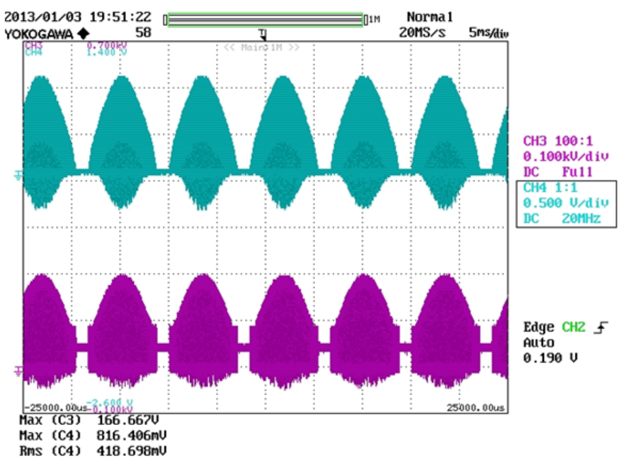

Figure 51 – 132 VAC, 60 Hz.
Upper: I_{D7}, 500 mA / div.
Lower: V_{D7}, 100 V, 5 ms / div

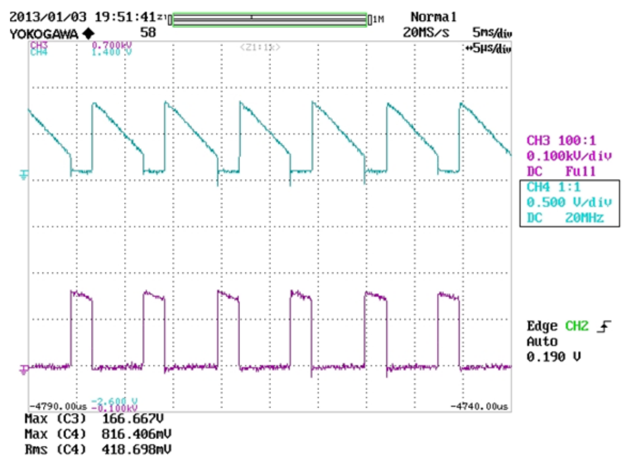

Figure 52 – 132 VAC, 60 Hz.
Upper: I_{D7}, 500 mA / div.
Lower: V_{D7}, 100 V, 5 μs / div.

12.8 Output Voltage and Current at Start-up Profile

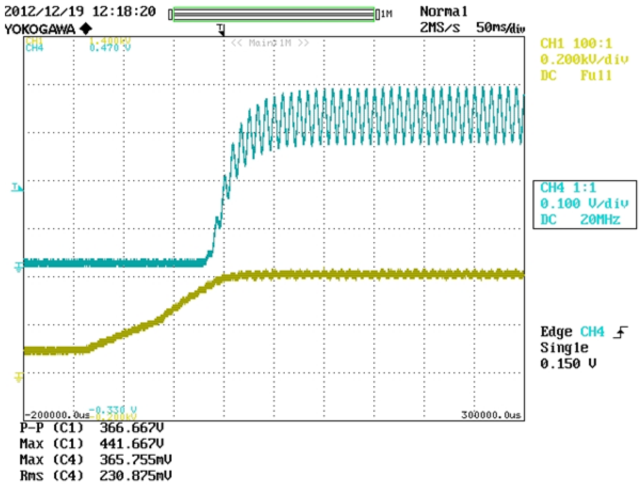

Figure 53 – 90 VAC, 60 Hz Start-up Condition.
Upper: I_{D5}, 0.1 A / div.
Lower: V_{D5}, 200 V, 50 ms / div.

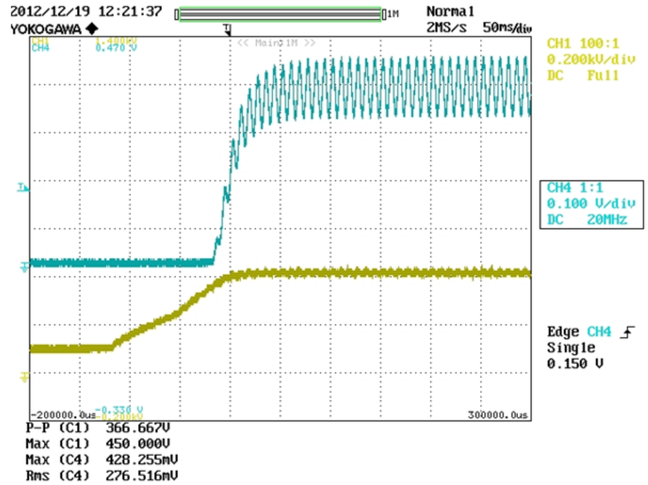

Figure 54 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{D5}, 0.1 A / div.
Lower: V_{D5}, 200 V, 50 ms / div.

13 Non-Dimming Waveforms

13.1 Output Current and Input Current Waveforms

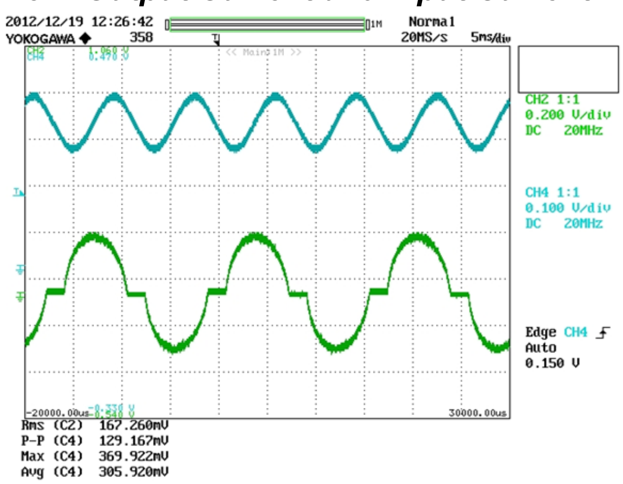

Figure 55 – 90 VAC, 41 V LED Load.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

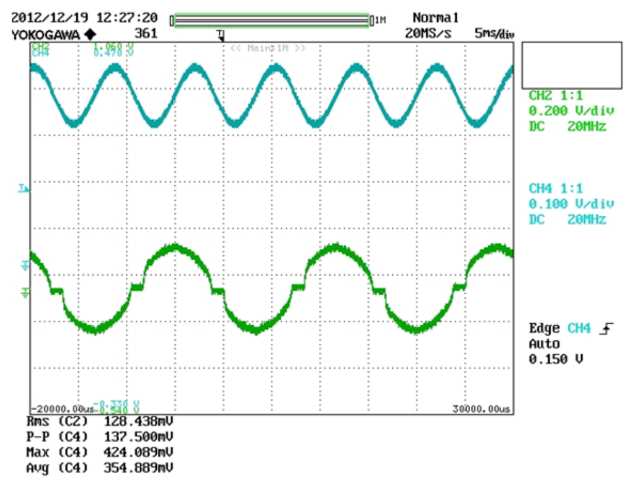

Figure 56 – 132 VAC, 41 V LED Load.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{IN}, 200 mA, 5 ms / div.

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14 Conducted EMI

The design met the limits for conducted electromagnetic emission (EMI) with frequency range of 9 kHz to 30 MHz as per described in the CISPR 15 / IEC: 2005 Standard.

14.1 Test Set-up

The unit was tested using 41 V LED load at input voltage of 120 VAC, 60 Hz at room temperature. The unit was placed inside a conical metal housing as shown in Figure 57.

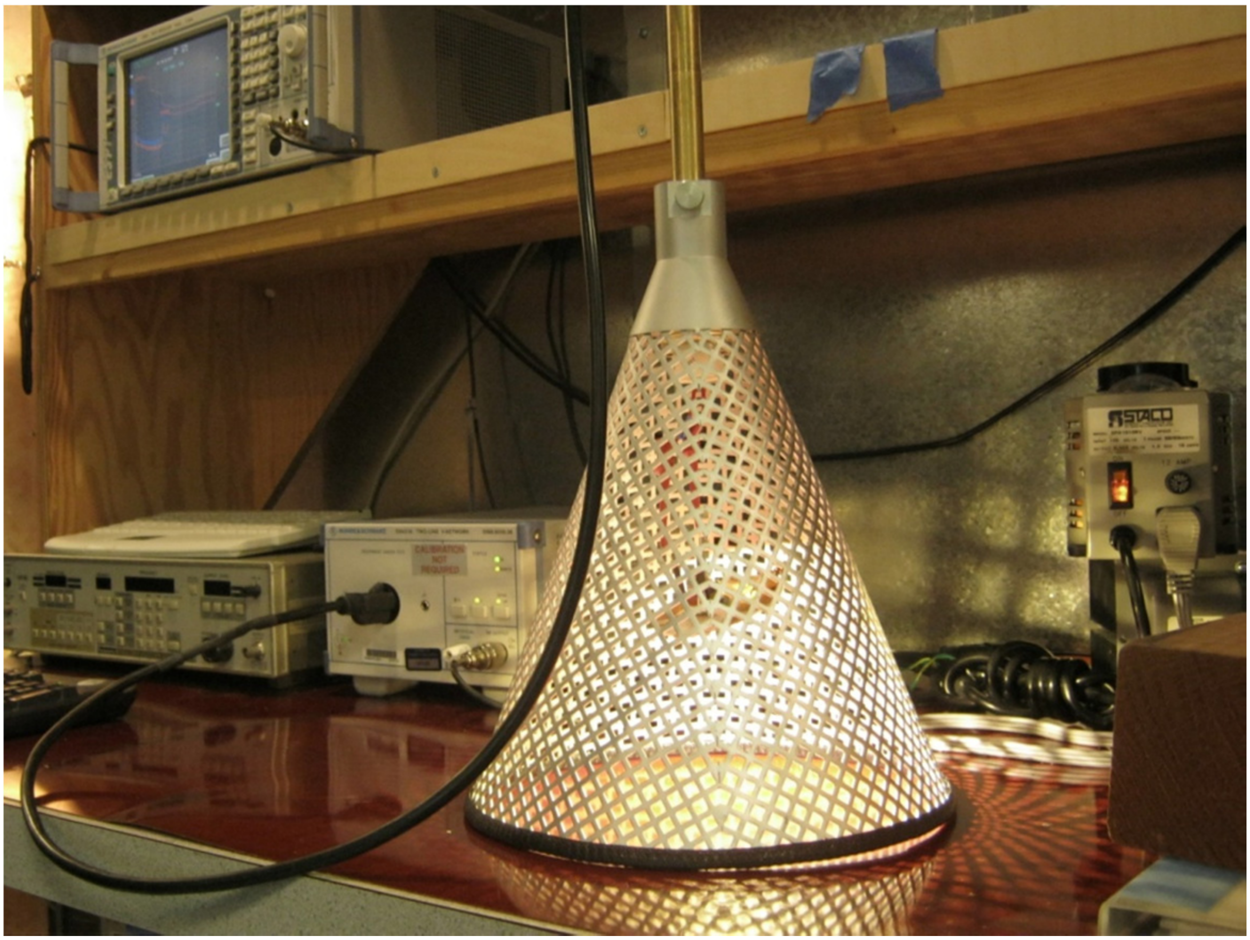
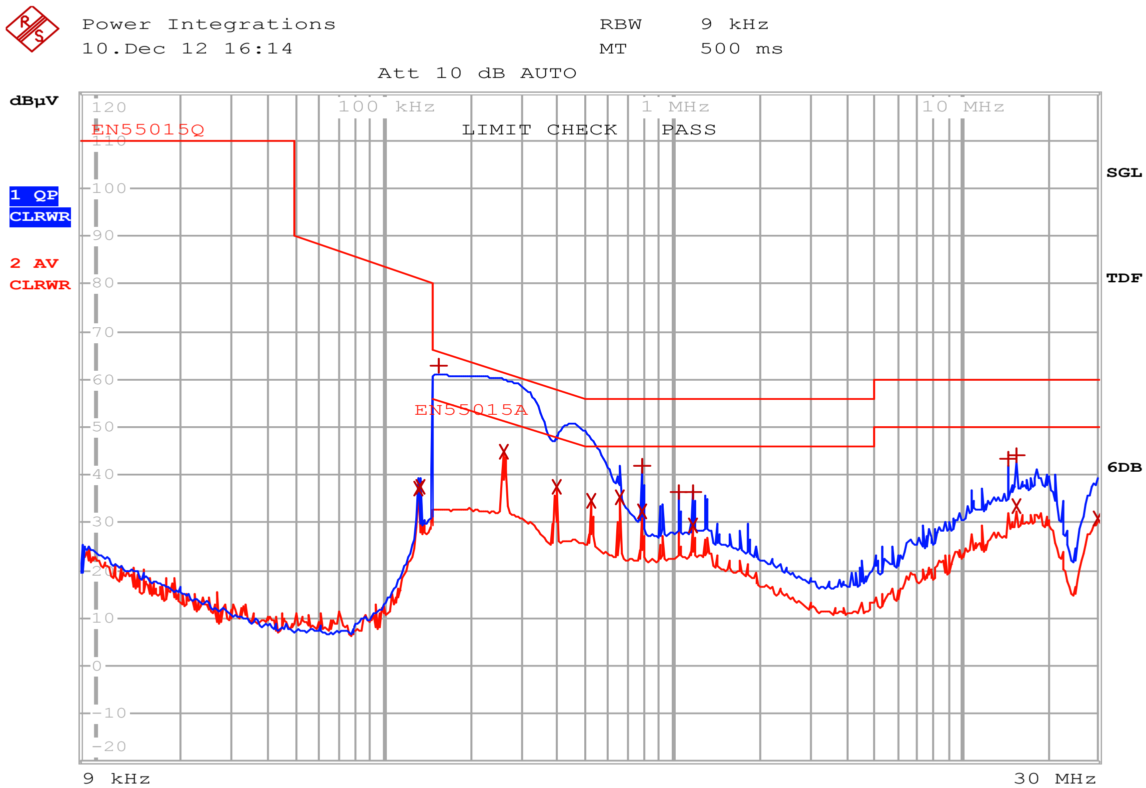


Figure 57 – EMI Test Set-up with the Unit and LED Load Placed Inside a Conical Metal Housing as Described in CISPR 15 / IEC: 2005 Standard.

14.2 Test Result



EDIT PEAK LIST (Final Measurement Results)				
Trace1:		EN55015Q		
Trace2:		EN55015A		
Trace3:		---		
	TRACE	FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2	Average	130.825395691 kHz	37.10 N gnd	
2	Average	133.454986145 kHz	37.53 N gnd	
1	Quasi Peak	154.54515 kHz	62.86 L1 gnd	-2.89
2	Average	261.871472881 kHz	45.01 L1 gnd	-6.35
2	Average	393.789848222 kHz	37.53 N gnd	-10.45
2	Average	525.514079005 kHz	34.65 L1 gnd	-11.34
2	Average	654.11570866 kHz	35.15 N gnd	-10.84
1	Quasi Peak	782.418853721 kHz	41.74 N gnd	-14.25
2	Average	782.418853721 kHz	32.34 N gnd	-13.65
1	Quasi Peak	1.04414099339 MHz	36.45 L1 gnd	-19.54
1	Quasi Peak	1.17656420634 MHz	36.51 L1 gnd	-19.48
2	Average	1.17656420634 MHz	29.34 L1 gnd	-16.65
1	Quasi Peak	14.4411515385 MHz	43.37 N gnd	-16.62
1	Quasi Peak	15.4828690896 MHz	44.08 N gnd	-15.91
2	Average	15.4828690896 MHz	33.47 N gnd	-16.52
2	Average	29.8580960942 MHz	31.03 N gnd	-18.96

Figure 58 – Conducted EMI, 41 V LED Load, 120 VAC, 60 Hz, and EN55015 B Limits**.**

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15 Line Surge

The unit was subjected to ±2500 V 100 kHz ring wave and ±500 V differential surge at 120 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

The unit tested passed both ±2500 V 100 kHz ring wave and ±500 V differential surge with and without MOV (see Figures 59 and 60). In both conditions unit passed.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+2500	120	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	120	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
+2500	120	L1, L2	90	100 kHz Ring Wave (500 A)	Pass
-2500	120	L1, L2	90	100 kHz Ring Wave (500 A)	Pass

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+500	120	L1, L2	0	Surge (2 Ω)	Pass
-500	120	L1, L2	0	Surge (2 Ω)	Pass
+500	120	L1, L2	90	Surge (2 Ω)	Pass
-500	120	L1, L2	90	Surge (2 Ω)	Pass

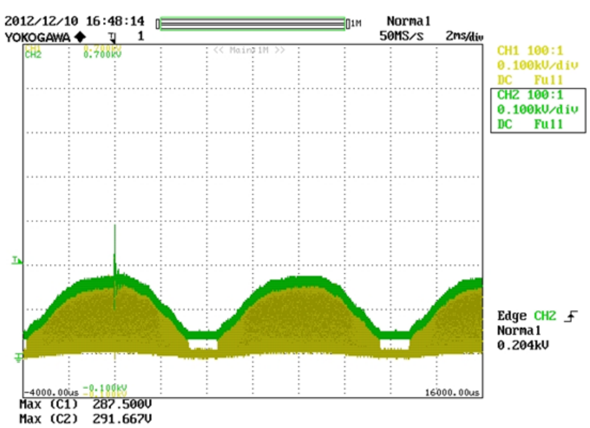

Figure 59 – +2500 V 100 kHz Differential Ring Wave.

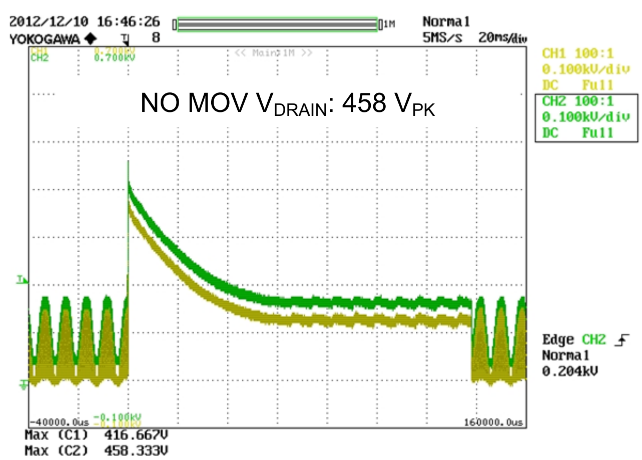

Figure 60 – No MOV +500 V 1.2 μs / 50 μs Differential Surge.

16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
04-Apr-13	RM	1.0	Initial release	Apps and Mktg

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