Design Example Report

Title	***14.5 W Power Factor Corrected (>0.98) TRIAC Dimmable Non-Isolated Buck A19 Lamp Replacement LED Driver Using LinkSwitch™-PH LNK407EG***
Specification	90 VAC – 132 VAC Input; 30 V_{TYP}, 480 mA Output or 40 V_{TYP}, 350 mA Output
Application	Dimmable LED Driver for A19 Lamp Replacement
Author	Applications Engineering Department
Document Number	DER-341
Date	September 14, 2012
Revision	2.0

Summary and Features

- Single-stage power factor corrected and accurate constant current (CC) output
- Low cost, low component count and small PCB footprint
- Highly energy efficient, >89% at 115 VAC input
- Fast start-up time (<100 ms) – no perceptible delay
- Integrated protection and reliability features
    - Short-circuit protected
    - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
    - No damage during brown-out or brown-in conditions
- PF >0.98 at 115 VAC
- %A-THD <15% at 115 VAC
- Meets IEC 2.5 kV ring wave, 500 V differential line surge and EN55015 conducted EMI

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5245 Hellyer Avenue, San Jose, CA 95138 USA.
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Important Note: Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

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1 Introduction

The document describes a non-isolated, high power factor (PF), TRIAC dimmable LED driver. The driver is designed to drive a nominal LED string voltage of 30 V at 480 mA from an input voltage range of 90 VAC to 132 VAC (60 Hz typical). The LED driver utilizes the LNK407EG from the LinkSwitch-PH family of ICs.

The topology used is a single-stage non-isolated buck that meets the high power factor, good current regulation, and dimming requirements for this design. LinkSwitch-PH based designs provide a high power factor (>0.9) meeting international requirements.

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

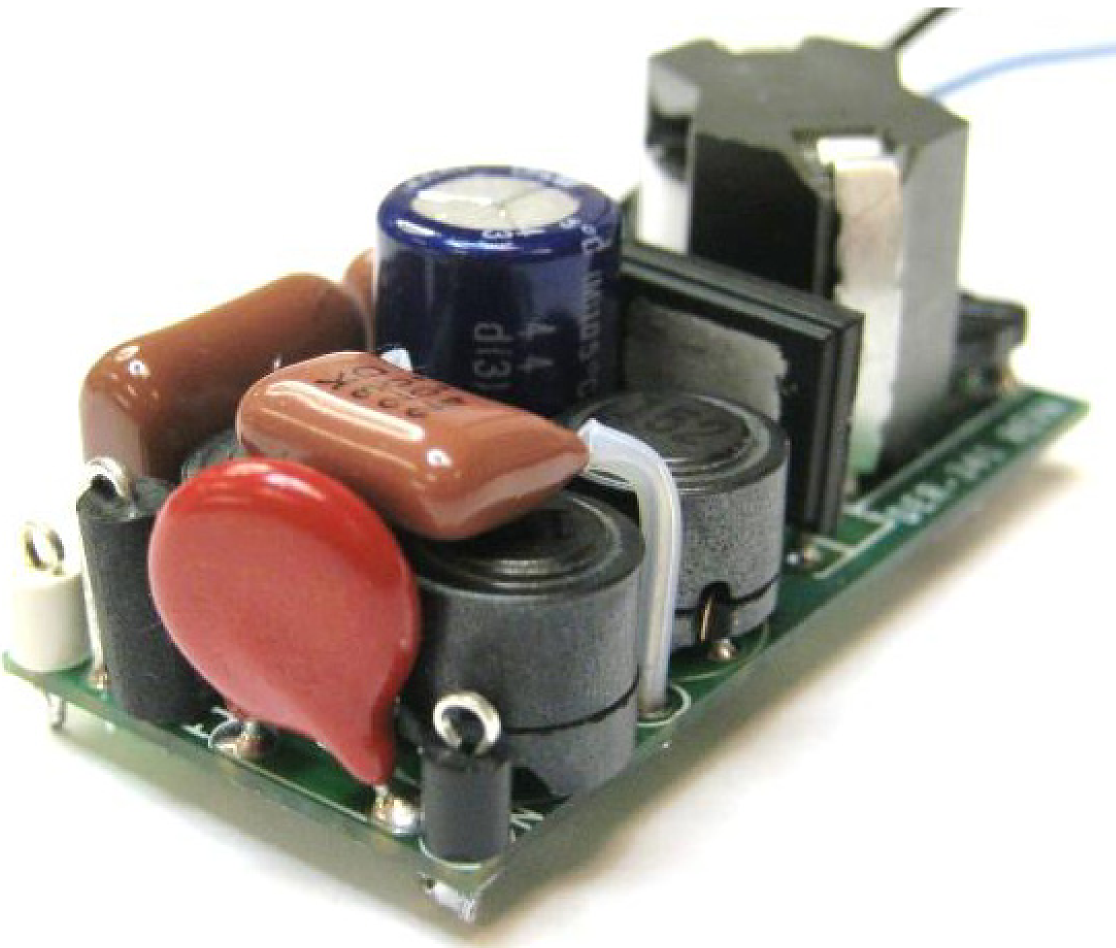

Figure 1 – Populated Circuit Board.

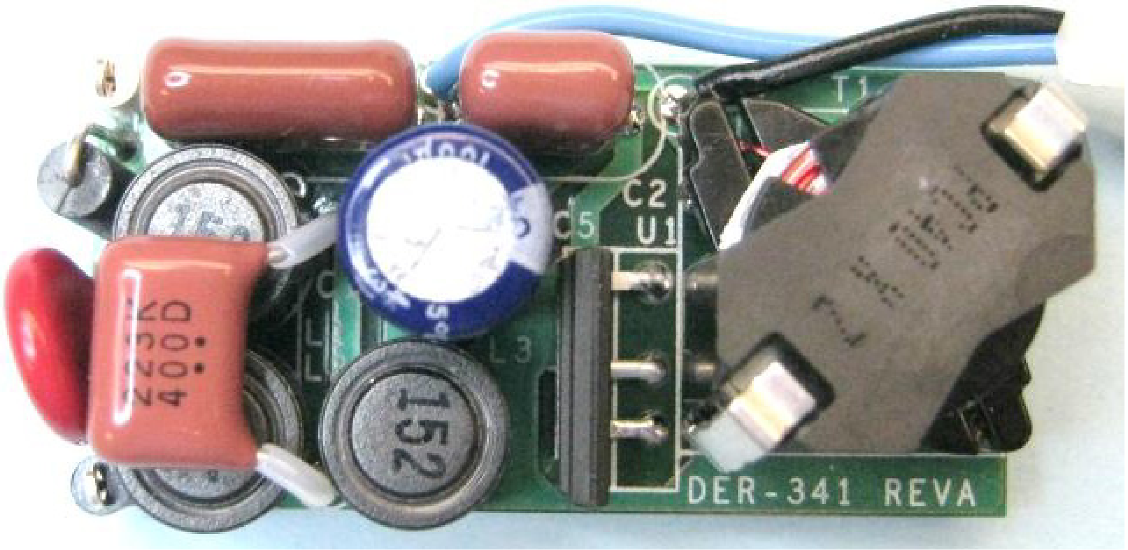

Figure 2 – Populated Circuit Board, Top View.

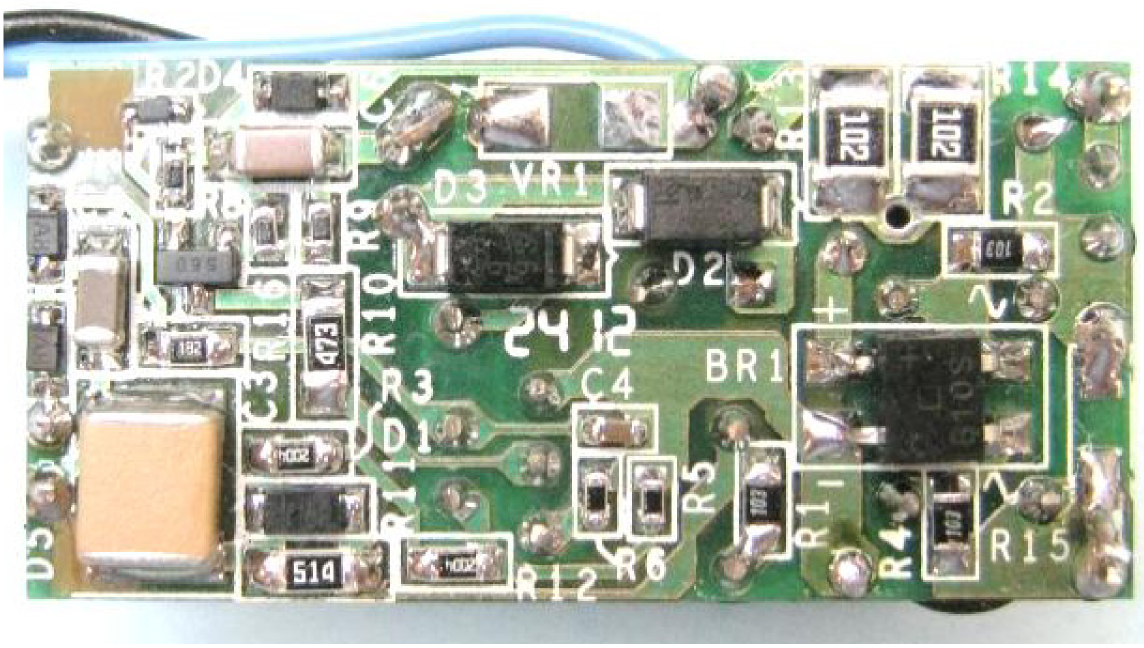

Figure 3 – Populated Circuit Board, Bottom View.

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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	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Output						
Output Voltage	V_{OUT}	29	30	31	V	
Output Current	I_{OUT}		480		mA	At 115 VAC
Total Output Power						
Continuous Output Power	P_{OUT}		14.5		W	
Efficiency						
Nominal	η	88	89		%	Measured at P_{OUT} 25 °C at 115 VAC
Environmental						
Conducted EMI		Meets CISPR22B / EN55015				
Line Surge Differential Mode (L1-L2)			500		V	1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω
Ring Wave (100 kHz) Differential Mode (L1-L2)			2.5		kV	2 Ω Short-Circuit Series Impedance
Power Factor		0.9	0.98			At 115 VAC
A-THD				15	%	At 115 VAC
Harmonic Currents		EN 61000-3-2 Class C				Class C Limits (For P_{IN} >25 W Limit)
Ambient Temperature	T_{AMB}		40		°C	Free convection, sea level

3 Schematic

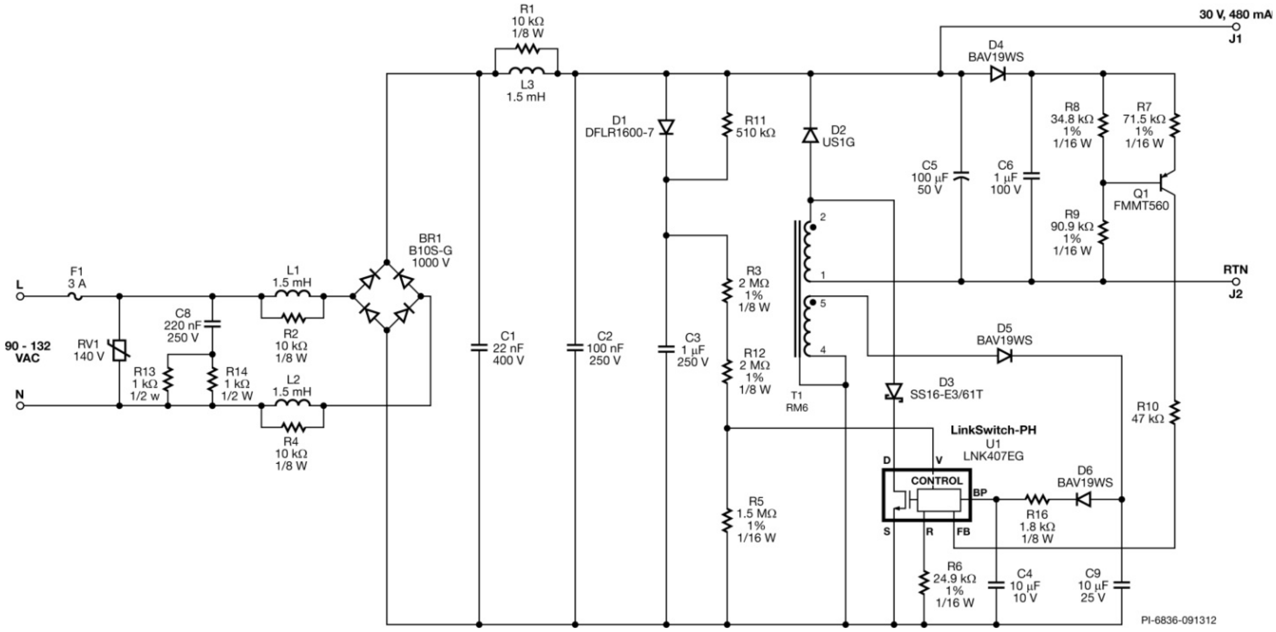

Figure 4 – Schematic Diagram for 30 V / 480 mA.

Notes for 40 V / 350 mA:

1. *Replace transformer T1 (620 µH inductance and bias winding of 22 turns). Refer to addendum section for more details.*
2. *Change R7 to 90.9 kΩ / 1%.*

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4 Circuit Description

The LinkSwitch-PH (U1) is a highly integrated primary side controller intended for use in LED driver applications. The LinkSwitch-PH provides high power factor in a single-stage conversion topology while regulating the output current. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET is incorporated into the device.

Capacitor C1, C2, and differential choke L1, L2, and L3 perform EMI filtering while maintaining high-power factor. This input filter network plus the frequency jittering feature of LinkSwitch-PH allows compliance to Class B emission limits. Resistor R1, R2 and R4 were used to damp the resonance of the inductor filters, preventing unwanted peaks in EMI measurements.

The buck power circuit with floating output connection is composed of U1 (power switch + control), D2 (free-wheeling diode), C5 (output capacitor), and T1 (output inductor). Diode D3 was used to prevent negative voltage appearing across drain-source of U1 especially near the zero-crossing of the input voltage. Diode D1 and C3 detect the peak AC line voltage. The voltage across C3 along with R3, R12, and R5 sets current fed into the V pin. This current is used by U1 to control line undervoltage (UV), overvoltage (OV), and provide feed-forward current which in conjunction with the FEEDBACK (FB) pin current provides constant current to the LED load.

A bias winding coupled to T1 is also employed to provide supply to the BYPASS (BP) pin of U1. This enables U1 to operate at deep dimming conditions when the input voltage is chopped heavily by the TRIAC dimmer. Diode D5 rectified the bias voltage and is filtered by capacitor C9. Resistor R16 limits the current supplied to the BYPASS pin and diode D5 provides isolation for C9 from C4 during start-up condition.

The FEEDBACK pin current used by U1 for output voltage feedback is provided by the voltage to current converter network formed by R7, R8, R9, R10, Q1, C6, and D4. Output voltage is converted to feedback current by the following relation:

$$I_{FB} \approx k \times V_{OUT}$$

Where:

$$k = \frac{1}{R7} * \frac{R8}{R8 + R9}$$

The voltage across R8 was chosen to be high enough to eliminate or minimize the effect of the temperature and V_{CE} dependence on the V_{BE} voltage of Q1.

4.1 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading edge and trailing edge phase dimmers introduced some trade-offs in the design.

Due to the much lower power consumed by LED based lighting, the current drawn by the overall lamp is below the holding current of the TRIAC in many dimmers. This causes undesirable behavior such as limited dim range and/or flickering when the TRIAC fires inconsistently. 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 to zero and turn off.

To overcome these issues, the passive bleeder comprising of capacitor C8 and resistors R13 and R14 were added at the input of the power supply.

4.2 Design Note

The output of the driver does not have overvoltage protection installed.
DO NOT POWER-UP THE UNIT WITHOUT AN LED LOAD.

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5 PCB Layout

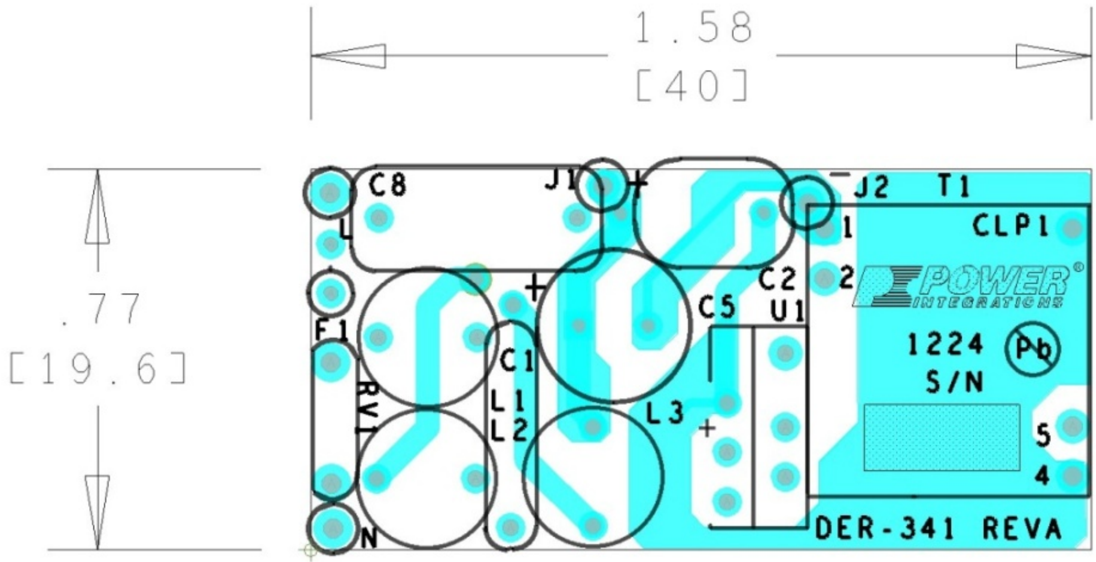

Figure 5 – Top Side.

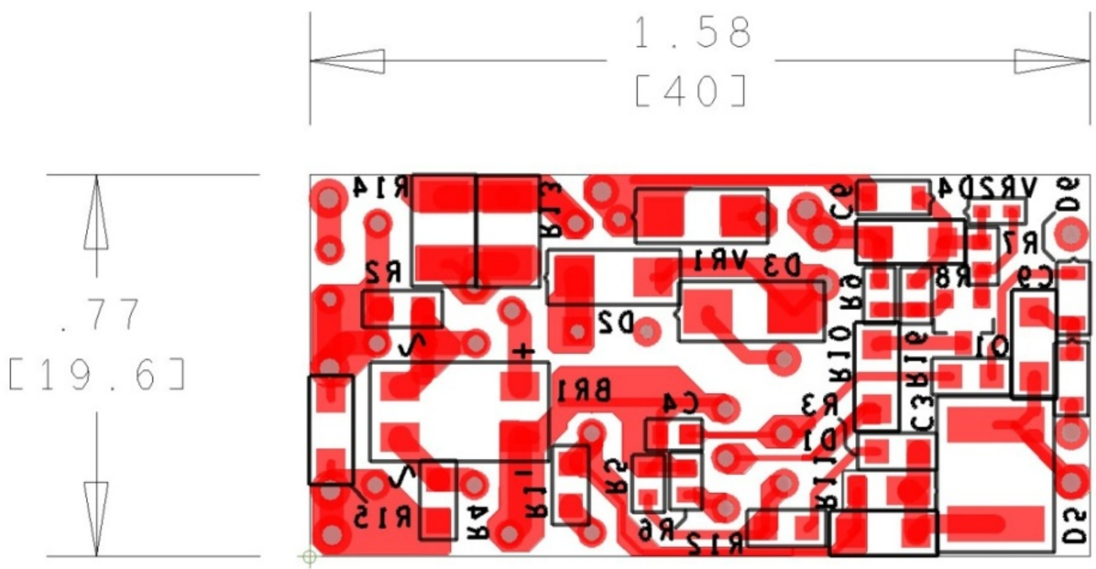

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Part Ref	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip Technology
2	1	C1	22 nF, 400 V, Film	ECQ-E4223KF	Panasonic
3	1	C2	100 nF, 250 V, Film	ECQ-E2104KB	Panasonic
4	1	C3	1.0 μF, 250 V, Ceramic, X7R, 2220	C5750X7R2E105K	TDK
5	1	C4	10 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A106M	TDK
6	1	C5	100 μF, 50 V, Electrolytic, Low ESR, 220 mΩ, (8 x 12)	ELXZ500ELL101MH12D	Nippon Chemi-Con
7	1	C6	1 μF, 100 V, Ceramic, X7R, 1206	C3216X7R2A105K	TDK
8	1	C8	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
9	1	C9	10 μF, 25 V, Ceramic, X5R, 1206	ECJ-3YB1E106M	Panasonic
10	1	D1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
11	1	D2	DIODE ULTRA FAST, GPP, 400 V, 1A SMA	US1G-13-F	Diodes, Inc.
12	1	D3	60 V, 1 A, Schottky, DO-214AC	SS16-E3/61T	Vishay
13	3	D4 D5 D6	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diode Inc.
14	1	F1	3 A, 125 V, Fast, Microfuse, Axial	MQ3	Bel Fuse
15	2	J1 J2	PCB Terminal Hole, 22 AWG	N/A	N/A
16	2	L N	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
17	3	L1 L2 L3	1.5 mH, 0.19 A, Ferrite Core	CTSCH875DF-152K	CT Parts
18	1	Q1	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
19	3	R1 R2 R4	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
20	2	R3 R12	2 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2004V	Panasonic
21	1	R5	1.50 MΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1504V	Panasonic
22	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
23	1	R7	71.5 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF7152V	Panasonic
24	1	R8	34.8 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3482V	Panasonic
25	1	R9	90.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9092V	Panasonic
26	1	R10	47 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ473V	Panasonic
27	1	R11	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
28	2	R13 R14	1 kΩ, 5%, 1/2 W, Thick Film, 1210	ERJ-14YJ102U	Panasonic
29	1	R16	1.8 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ182V	Panasonic
30	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
31	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
32	1	U1	LinkSwitch-PH, eSIP	LNK407EG	Power Integrations

Note for 40V/350mA version:

23	1	R7	90.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9092V	Panasonic
31	1	T1	Bobbin, RM6, Vertical, 6 pins	Custom for 40V/350mA	Epcos

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7 Inductor Specification

7.1 Electrical Diagram

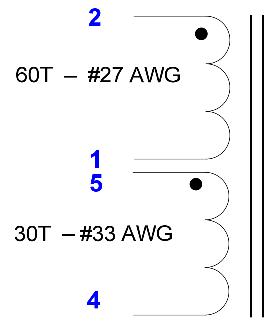

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 1-2 all other windings open, measured at 66 kHz, 0.4 V_{RMS}	470 µH ±7%
Resonant Frequency	Pins 1-2, all other windings open	1.8 MHz (Min.)

7.3 Materials

Item	Description
[1]	Core: RM6S PC40 or equivalent.
[2]	Bobbin: B-RM6-V 6pins 3/3.
[3]	Magnet Wire, #27 AWG, solderable double coated.
[4]	Magnet Wire, #33 AWG, solderable double coated.

7.4 Inductor Build Diagram

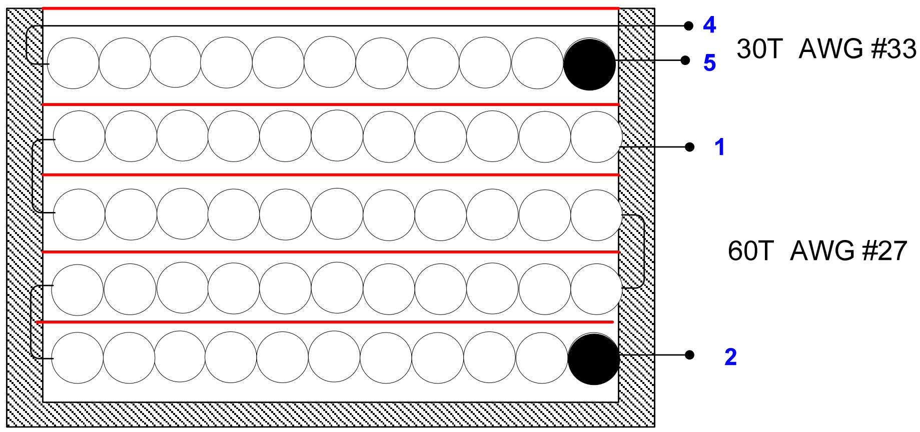

Figure 8 – Inductor Build Diagram.

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 right.
WD1	Start at pin 2. Wind 60 turns of item [3] as shown in Figure 2. Terminate at pin 1.
WD2	Start at pin 5. Wind 30 turns of item [4] and terminate the other end at pin 4.
Finish	Grind the core to get the specified inductance. Place the clip to secure both cores. Cut pins 3 and 6.

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8 Inductor Design Spreadsheet

ACDC_LNK-PH_Buck_032811; Rev.1.0; Copyright Power Integrations 2011	INPUT	OUTPUT	UNIT	LNK-PH_032811: LinkSwitch-PH Buck Design Spreadsheet
ENTER APPLICATION VARIABLES				
Dimming required	YES			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	69	69	Hz	AC Mains Frequency
VO	30.00		V	Typical output voltage of LED string at full load
VO_MAX		37.50	V	Maximum LED string Voltage. Ensure that the maximum LED string voltage is below VO_MAX
VO_MIN		23.68	V	Minimum LED string Voltage. Ensure that the minimum LED string voltage is above VO_MIN
V_OVP		41.25	V	Over-voltage setpoint
IO	0.48			Typical full load LED current
PO		14.4	Watts	Output Power
n	0.90	0.90		Estimated efficiency of operation
ENTER LinkSwitch-PH VARIABLES				
LNK-PH	LNK407			Selected Linkswitch-PH device. If Dimming is required, select device from LNK40X family, Otherwise select device from LNK41X family
Current Limit Mode	RED			Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN		1.420	A	Minimum current limit
ILIMITMAX		1.660	A	Maximum current limit
fS		66000	Hz	Switching Frequency
fSmin		62000	Hz	Minimum Switching Frequency
fSmax		70000	Hz	Maximum Switching Frequency
IV		39.91	uA	V pin current
Rv		4	M-ohms	Upper V pin resistor
RV2		1.402	M-ohms	Lower V pin resistor
IFB	95.00	95.00	uA	!!! Warning. IFB is too low. Use larger device
R7		88.42	k-ohms	IFB setting resistor (See RDR254 schematic)
R8		35.35	k-ohms	Upper resistor in base divider (See RDR254 schematic)
R9		90.90	k-ohms	Lower resistor in base divider (See RDR254 schematic)
VDS		10	V	LinkSwitch-PH on-state Drain to Source Voltage
VD	0.60		V	Output Winding Diode Forward Voltage Drop
VDB	0.70		V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters				
KP	0.75	0.75		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
LP		470	uH	Primary Inductance
KP Expected		0.62		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
Expected IO (average)		0.48	A	Expected Average Output Current
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES				
Core Type	RM6			Selected Core for inductor
Core			*P/N:*	*
Bobbin			*P/N:*	CSV-RM6/R-1S-4P
AE		0.32	cm^2	Core Effective Cross Sectional Area
LE		2.56	cm	Core Effective Path Length
AL		1420	nH/T^2	Ungapped Core Effective Inductance
BW		6.4	mm	Bobbin Physical Winding Width
M		0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	4.00	4		Number of Primary Layers

DC INPUT VOLTAGE PARAMETERS				
VMIN		127	V	Peak input voltage at VACMIN
VMAX		187	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS				
DMAX		0.24		Minimum duty cycle at peak of VACMIN
IAVG		0.48	A	Average Primary Current
IP		1.18	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS		0.48	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS				
LP		470	uH	Primary Inductance
NP		60		Primary Winding Number of Turns
ALG		131	nH/T^2	Gapped Core Effective Inductance
BM		2899	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP		3987	Gauss	Peak Flux Density (BP<4200)
BAC		1081	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur		904		Relative Permeability of Ungapped Core
LG		0.28	mm	Gap Length (Lg > 0.1 mm)
BWE		25.6	mm	Effective Bobbin Width
OD		0.43	mm	Maximum Primary Wire Diameter including insulation
INS		0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA		0.37	mm	Bare conductor diameter
AWG		27	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM		203	Cmils	Bare conductor effective area in circular mils
CMA		420	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)

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9 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 29 V to 31 V. Refer to the table on Section 9.6 for complete test data.

9.1 Efficiency

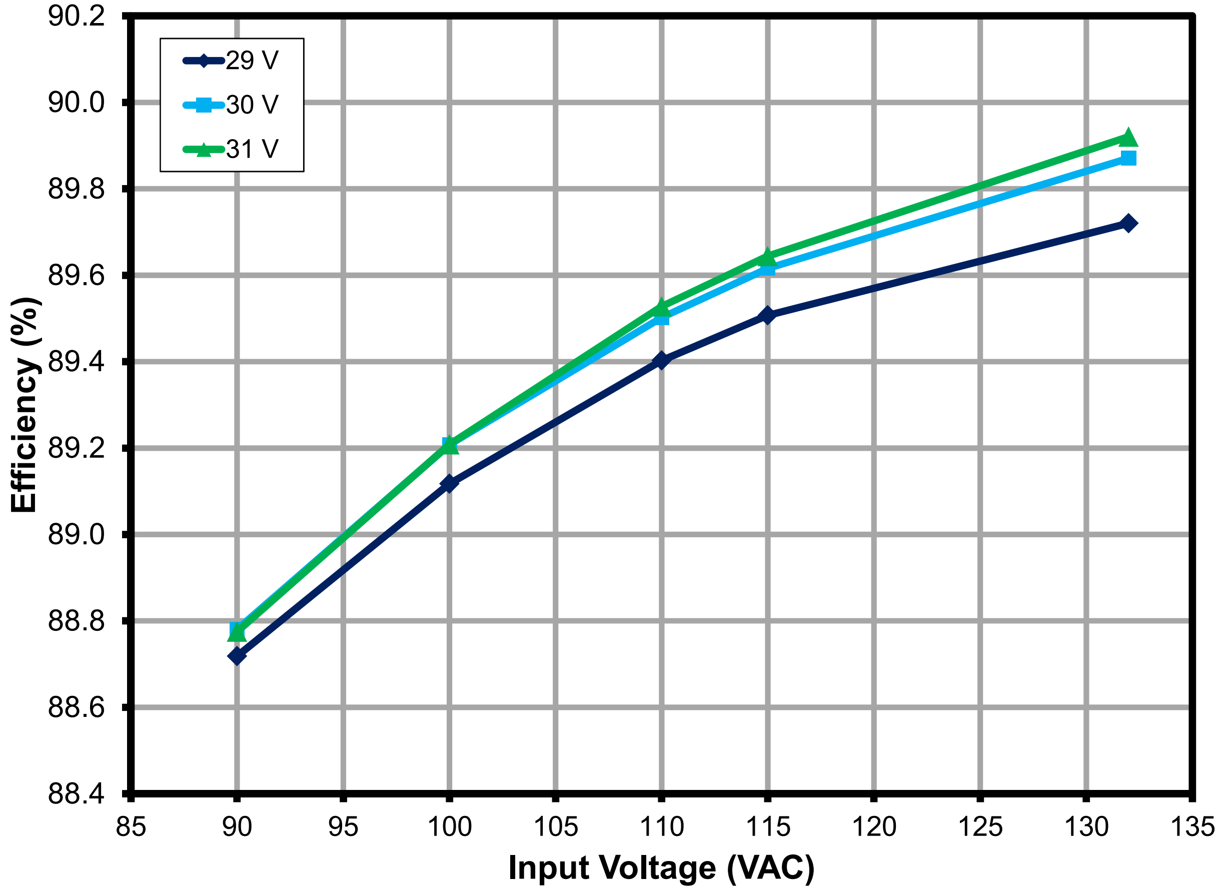

Figure 9 – Efficiency vs. Line and Load.

9.2 Line and Load Regulation

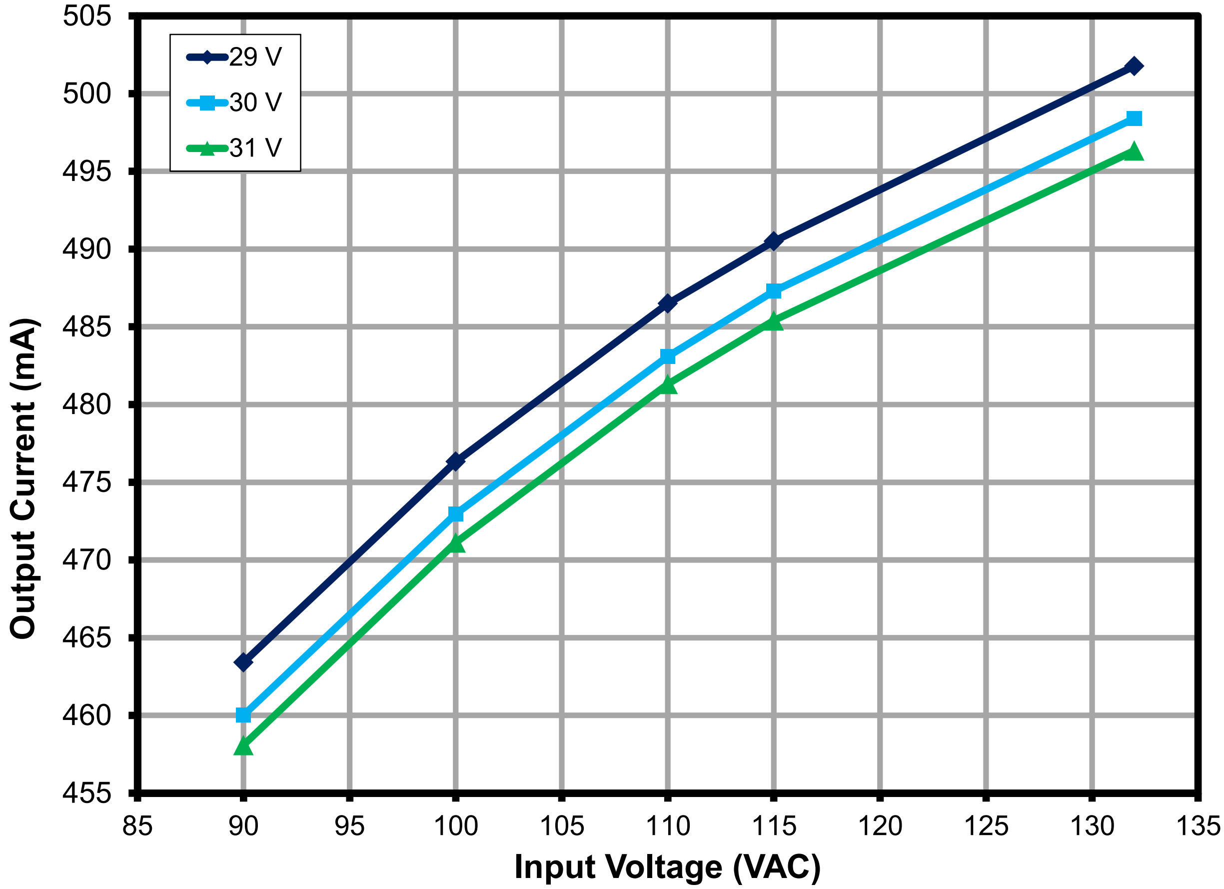

Figure 10 – Regulation vs. Line and Load.

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9.3 Power Factor

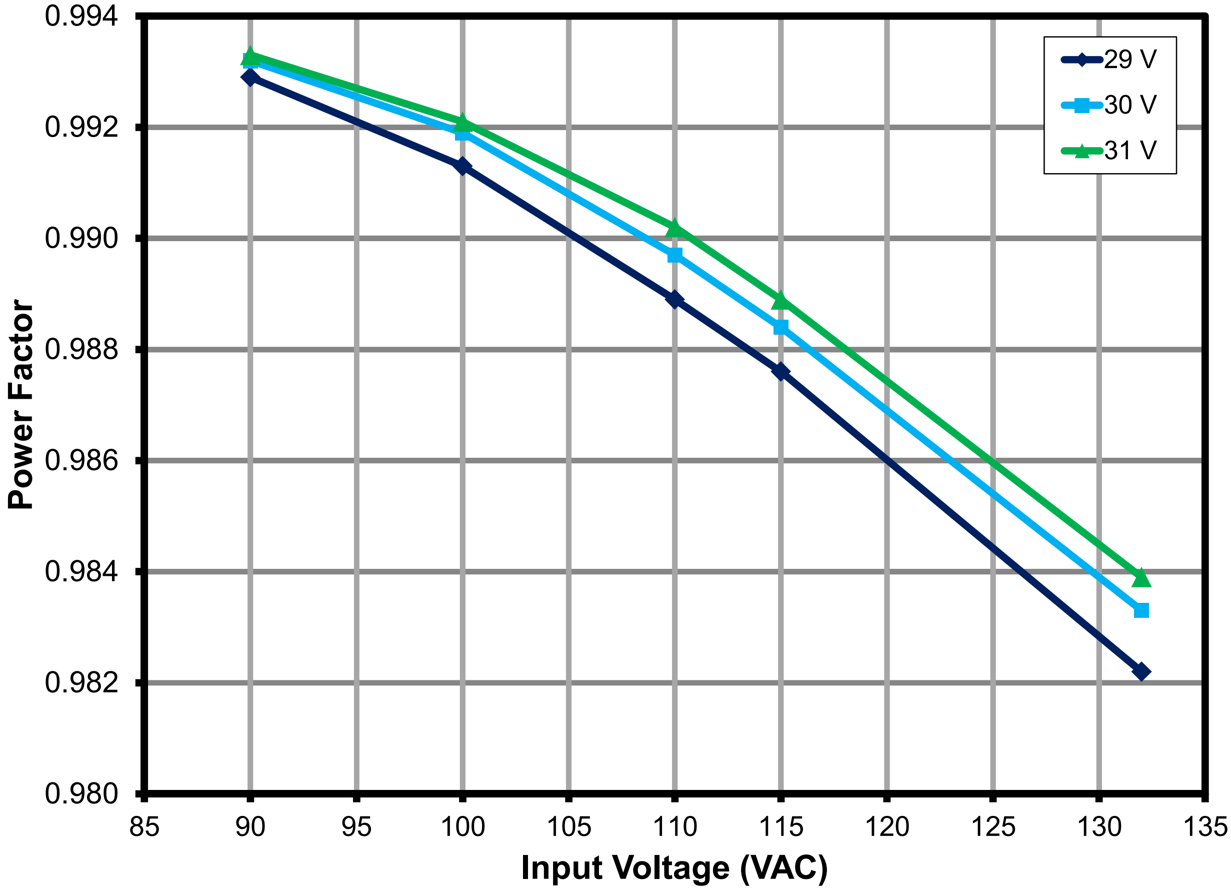

Figure 11 – Power Factor vs. Line and Load.

9.4 A-THD

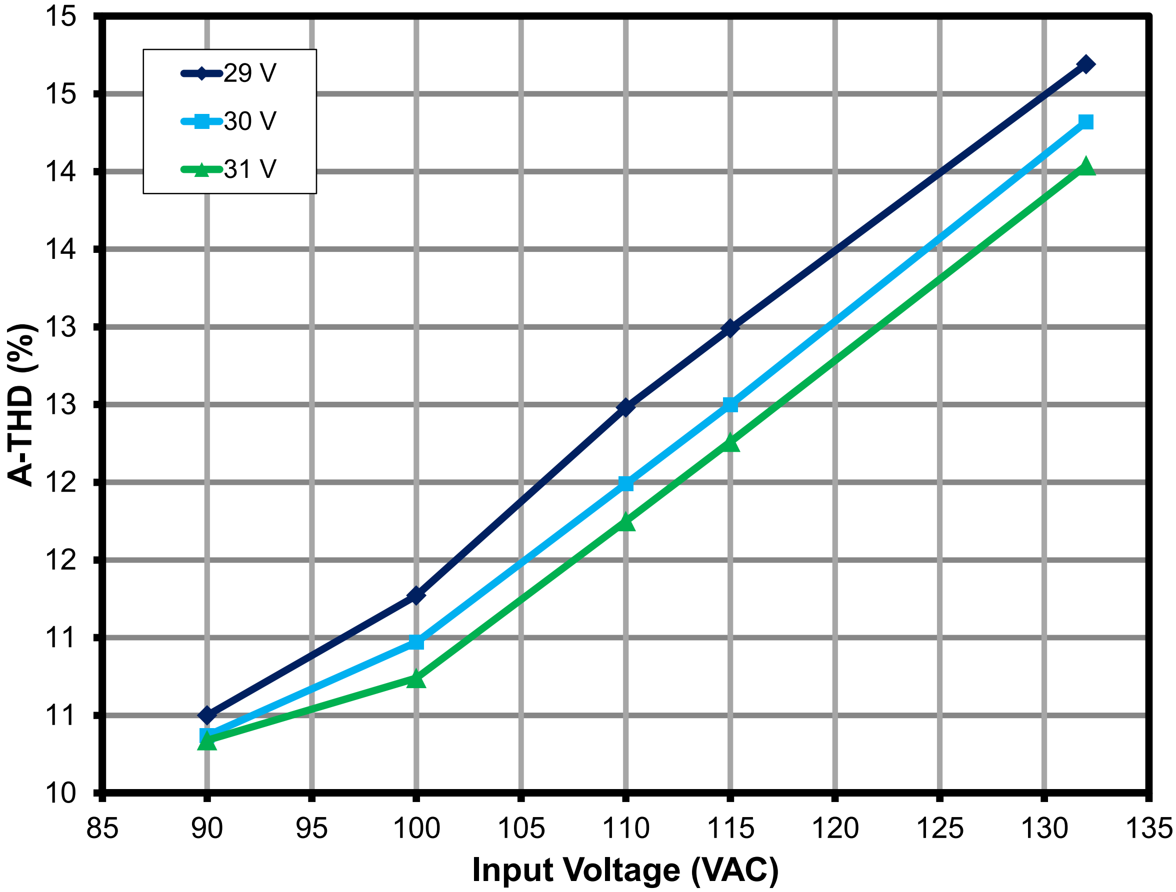

Figure 12 – A-THD vs. Line and Load.

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9.5 Harmonics

9.5.1 29 V LED Load

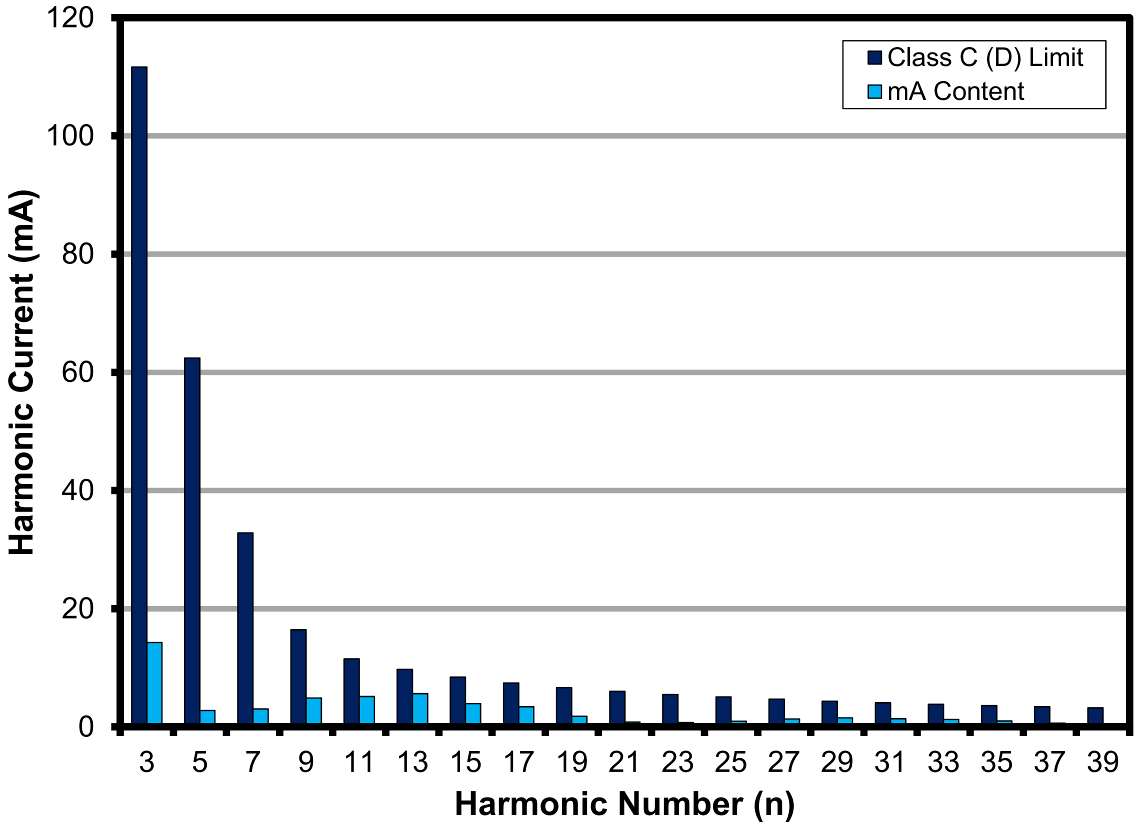

Figure 13 – 29 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

9.5.2 30 V LED Load

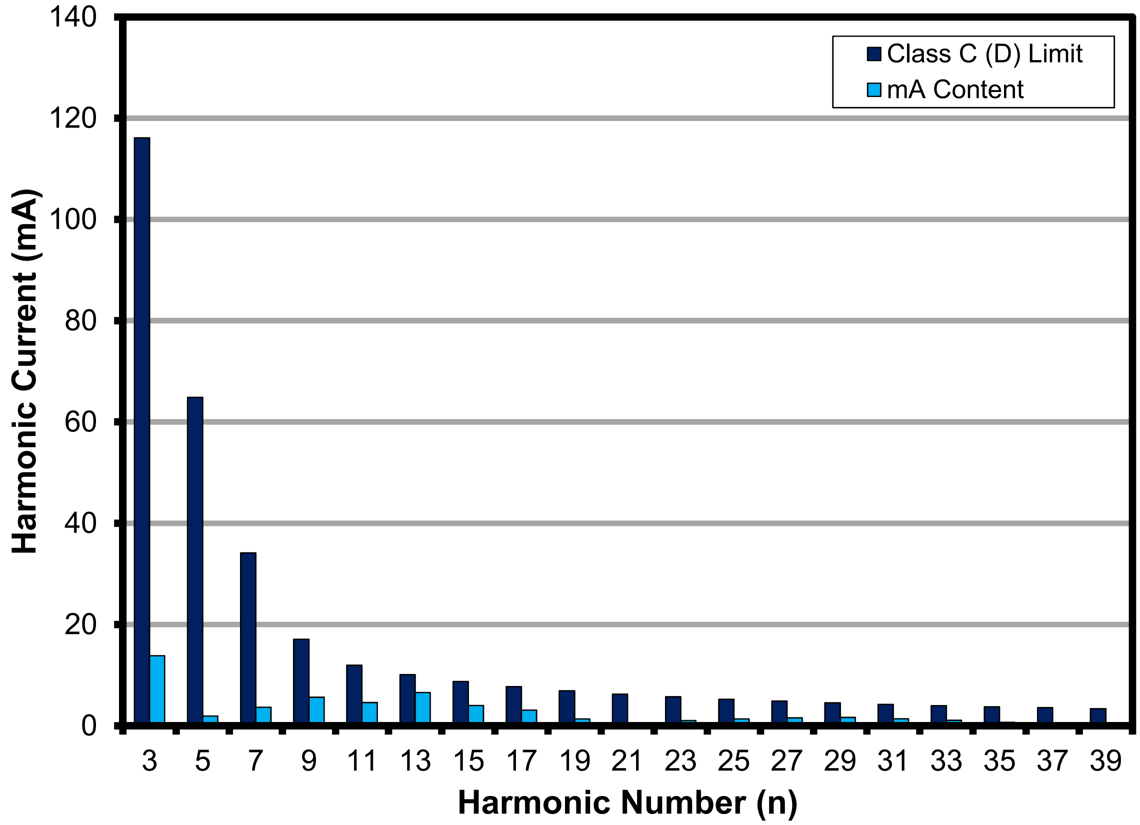

Figure 14 – 30 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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9.5.3 31 V LED Load

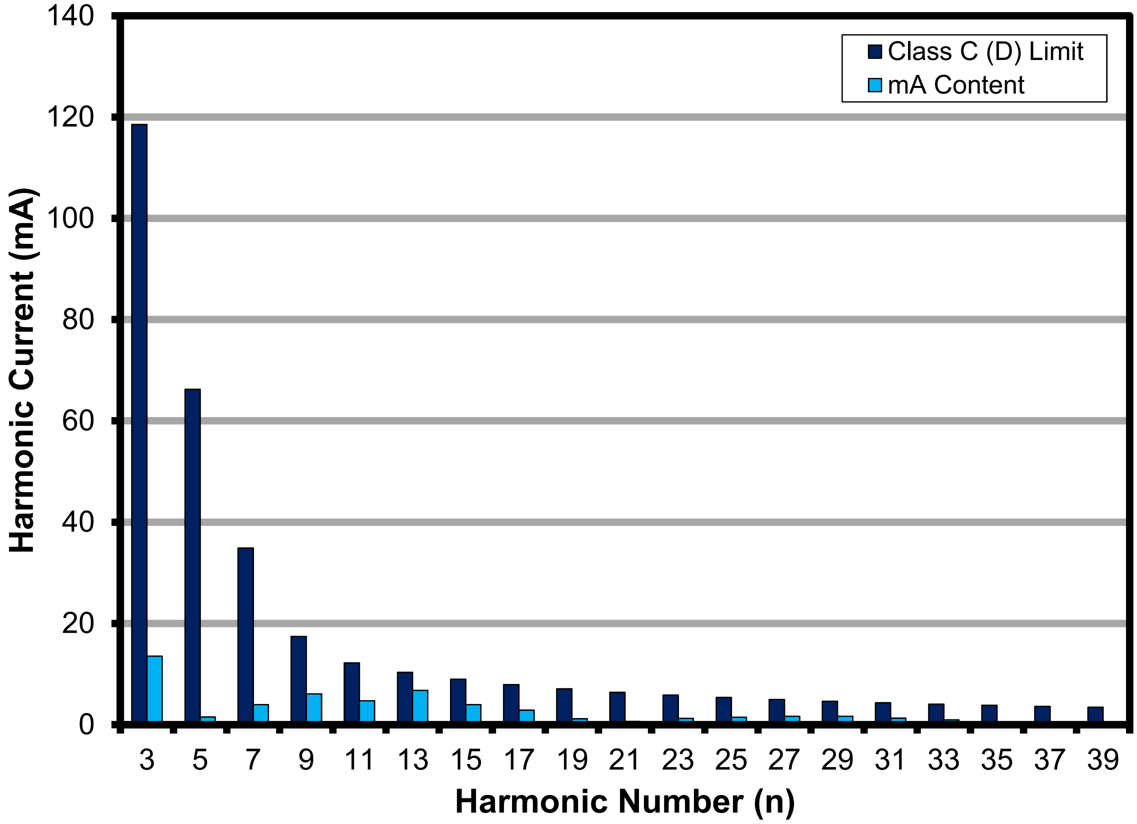

Figure 15 – 31 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

9.6 Test Data

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

9.6.1 Test Data, 29 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
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)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	89.99	174.90	15.627	0.993	10.50	28.93	463.41	13.86	13.41	88.72	1.76
100	60	99.95	161.55	16.007	0.991	11.27	29.00	476.32	14.27	13.81	89.12	1.74
110	60	110.01	149.88	16.306	0.989	12.48	29.05	486.50	14.58	14.13	89.40	1.73
115	60	114.99	144.60	16.421	0.988	12.99	29.06	490.50	14.70	14.25	89.51	1.72
132	60	132.01	129.36	16.771	0.982	14.69	29.11	501.77	15.05	14.61	89.72	1.72

9.6.2 Test Data, 30 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
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)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	90.00	181.68	16.239	0.993	10.37	30.31	460.02	14.42	13.94	88.78	1.82
100	60	99.97	167.76	16.633	0.992	10.97	30.39	472.96	14.84	14.37	89.21	1.80
110	60	110.02	155.62	16.946	0.990	11.99	30.44	483.09	15.17	14.71	89.50	1.78
115	60	115.00	150.20	17.074	0.988	12.5	30.46	487.29	15.30	14.84	89.62	1.77
132	60	132.02	134.23	17.425	0.983	14.32	30.52	498.41	15.66	15.21	89.87	1.77

9.6.3 Test Data, 31 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
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)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90	60	90.00	185.45	16.579	0.993	10.34	31.08	458.08	14.72	14.24	88.77	1.86
100	60	99.97	171.26	16.986	0.992	10.74	31.16	471.12	15.15	14.68	89.21	1.83
110	60	110.03	158.83	17.303	0.990	11.75	31.21	481.31	15.49	15.02	89.53	1.81
115	60	115.01	153.25	17.430	0.989	12.26	31.23	485.41	15.63	15.16	89.64	1.81
132	60	132.02	136.87	17.779	0.984	14.04	31.29	496.34	15.99	15.53	89.92	1.79

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10 Dimming Performance Data

TRIAC dimming results were taken with input voltage of 120 VAC, 60 Hz line frequency, room temperature, and nominal 30 V LED load.

10.1 Typical Dimming Curve with Leading Edge Type Dimmer

Data taken using programmable AC source (Agilent 6812B) providing leading edge chopped AC input.

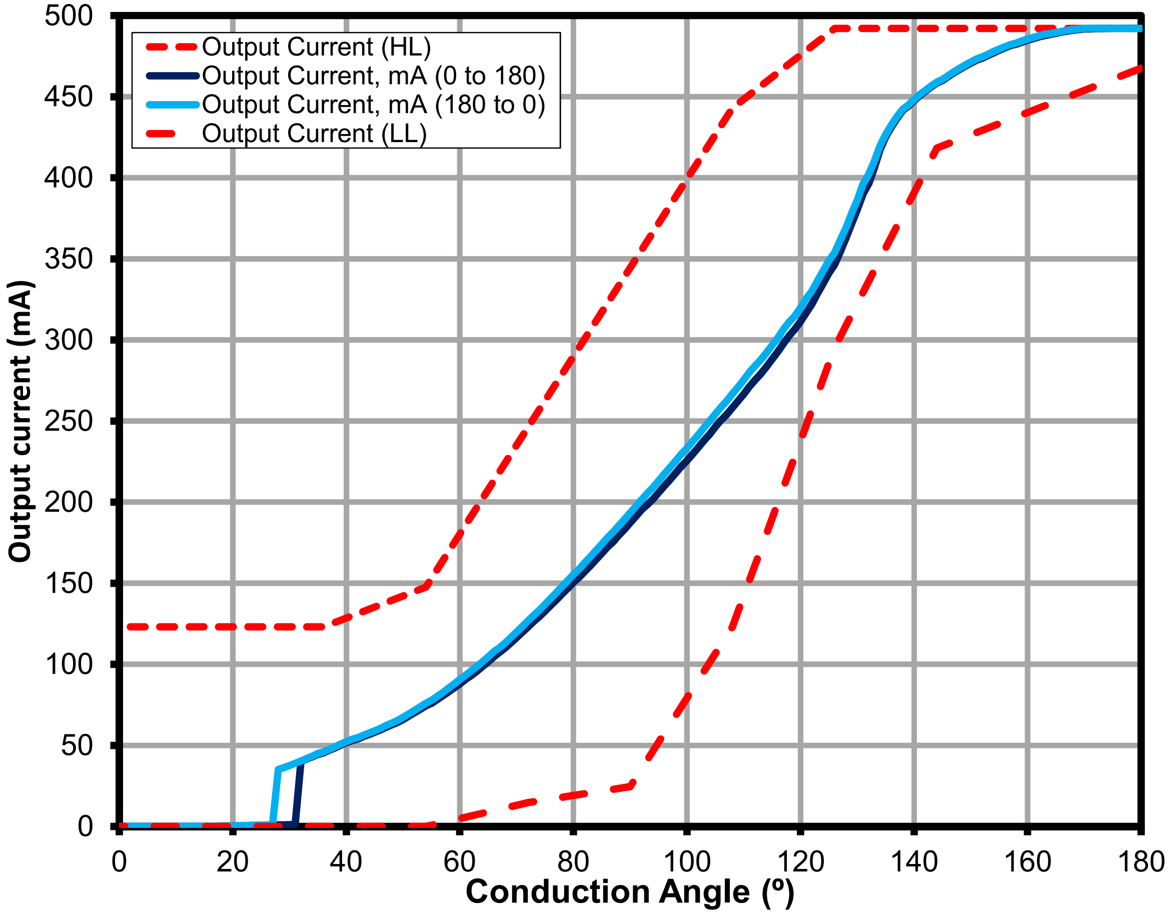

Figure 16 – Leading Edge Dimming Characteristics.

10.2 Dimmer Compatibility List

The unit was tested with the following high-line dimmers at 120 VAC, 60 Hz (direct from utility line) input and 30 V LED load.

	List of Dimmers	Type	Part Number	Max Iout, mA	Min Iout, mA	Dim Ratio
1	LUTRON LG600PH-LA	L	LG-600PH-WH	436	1.07	407
2	LUTRON S603P	L	S-603P-WH	457	1.05	435
3	LUTRON SLV600P	L	SLV600P-WH	453	1.1	412
4	LUTRON S600	L	S-600-WH	485	1.05	462
5	LUTRON S-600PH-WH	L	S-600PH-WH	458	1.05	436
6	LUTRON DVCL153P	L	DVWCL-153-PLH-WH	461	46	10
7	LUTRON DV603P	L	DV-603P-WH	436	1.1	396
8	LUTRON DV600P	L	DV-600P-WH	435	1.1	395
9	LUTRON TG600PH-IV	L	TG-600PH-WH	450	1.07	421
10	LUTRON AY600P	L	AY-600P-WH	448	1.1	407
11	LUTRON GL600P-WH	L	GL-600P-WH	457	1.05	435
12	LEVITON 6633PLI	L	R62-06633-1LW	496	1.03	482
13	LEVITON 6631-LI	L	R62-06631-1LW	473	1.06	446
14	LEVITON IPI06	L	R60-IPI06-1LM	493	83	6
15	LEVITON RP106	L	R52-RPI06-1LW	499	1	499
16	LEVITON 6681	L	R60-06681-0IW	499	35	14
17	LEVITON 6684	L	R60-06684-1IW	499	1	499
18	LEVITON 6613	L	R02-06613-PLW	492	1.11	443
19	COOPER SLC03		SLC03P-W-K-L	469	127	4
20	LUTRON GL600-WH	L	GL-600-WH	484	1.05	461
21	LUTRON DVPDC-203P-WH	L	DVPDC-203P-WH	487	139	4
22	LUTRON LX600PL	L	LX-600PL-wh	480	66	7
23	LUTRON S-600P	L	S-600P	460	1.05	438
24	LUTRON TGLV-600P	L	TGLV-600P	463	1.1	421
25	LUTRON TGLV-600PR	L	TGLV-600PR	445	1.11	401
26	LUTRON TT-300NLH-WH	L	TT-300NLH-WH	488	1.01	483
27	LUTRON TT-300H-WH	L	TT-300H-WH	488	1	488
28	LUTRON NLV-1000-WH	L	NLV-1000-WH	468	40	12

Figure 17 – TRIAC Dimmer Compatibility Table.

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11 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), open frame for the conditions specified.

11.1 Non-Dimming V_{IN} = 90 VAC, 60 Hz, 30 V LED Load

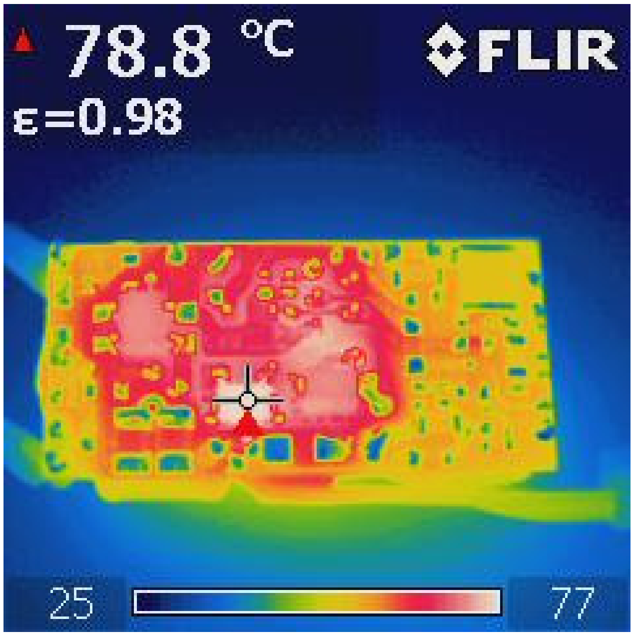

Figure 18 – Bottom Side.
D2-US1G: 78.8 ºC

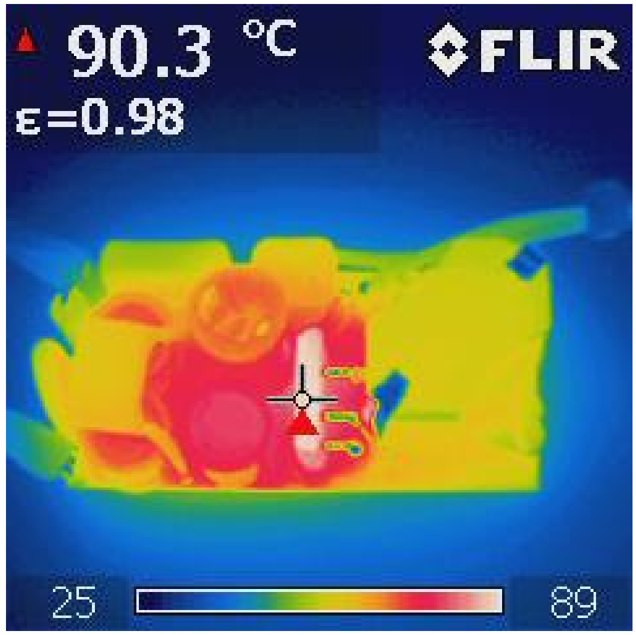

Figure 19 – Top Side.
U1-LNK407EG: 90.3 ºC

11.2 Non-Dimming V_{IN} = 132 VAC, 60 Hz, 30 V LED Load

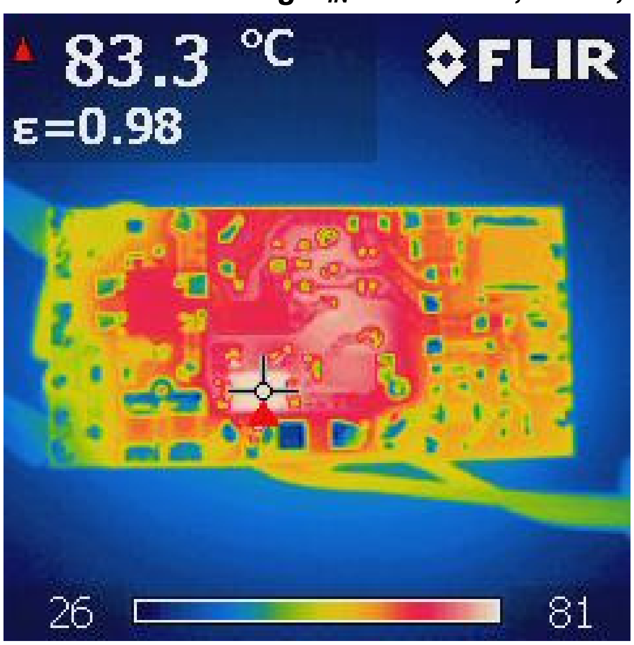

Figure 20 – Bottom Side.
D2-US1G: 83.3ºC

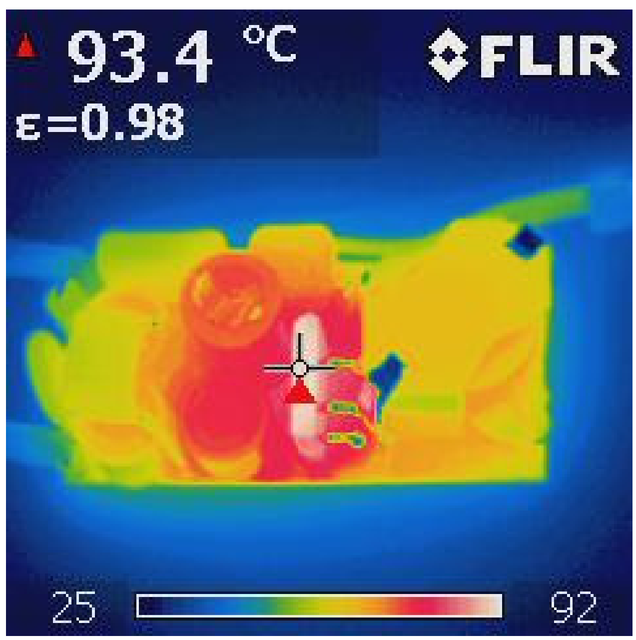

Figure 21 – Top Side.
U1-LNK407EG: 93.4 ºC

11.3 Dimming V_{IN} = 120 VAC 60 Hz, 90º Conduction Angle, 30 V LED Load

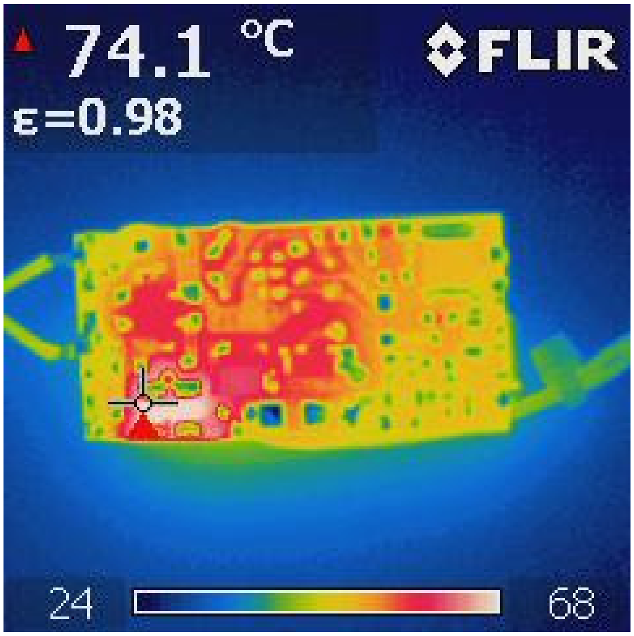

Figure 22 – Bottom Side.
R14-Bleeder Resistor: 74.1 ºC

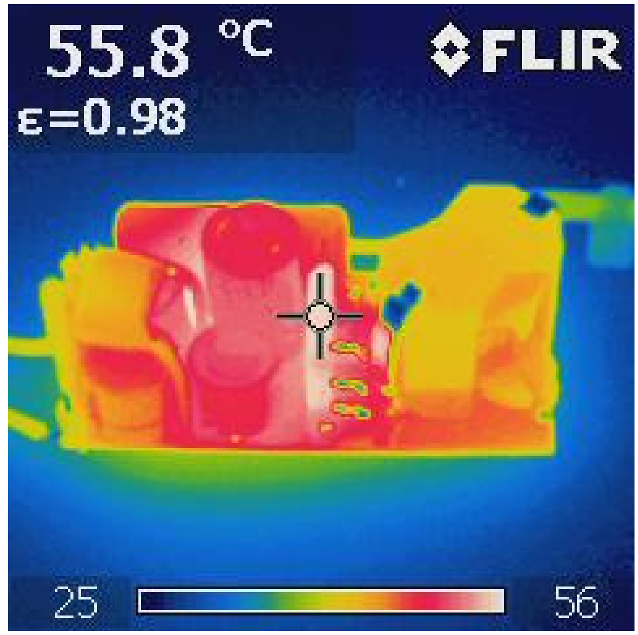

Figure 23 – Top Side.
U1-LNK407EG: 55.8 ºC

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12 Non-Dimming Waveforms

12.1 Input Voltage and Input Current Waveforms

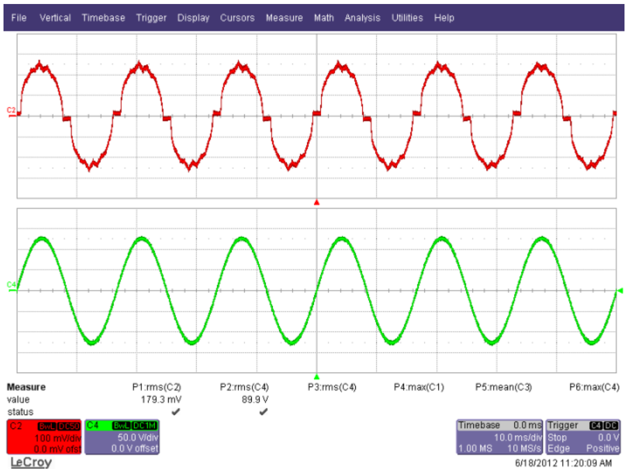

Figure 24 – 90 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

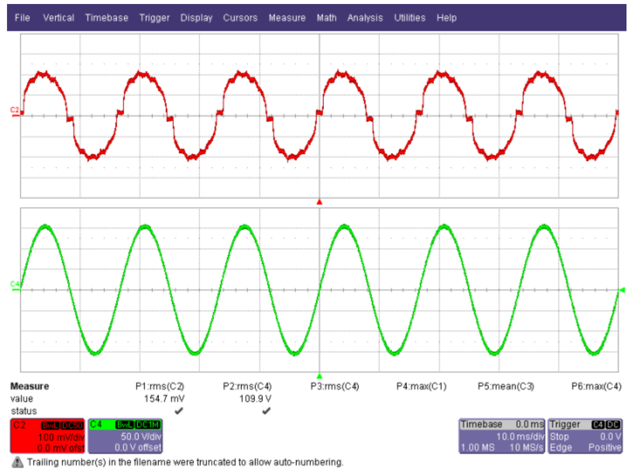

Figure 25 – 110 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

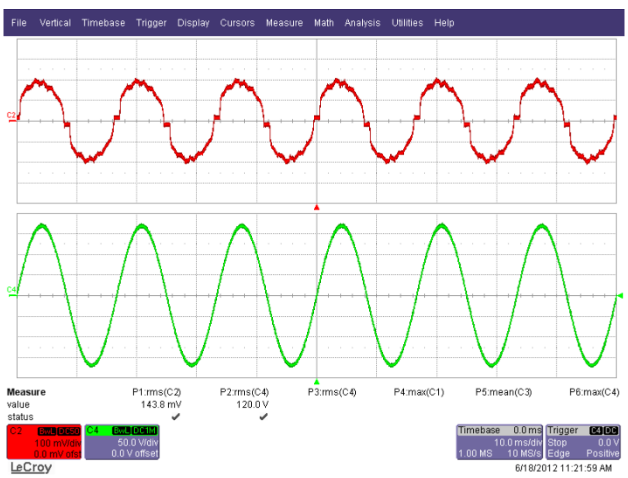

Figure 26 – 120 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

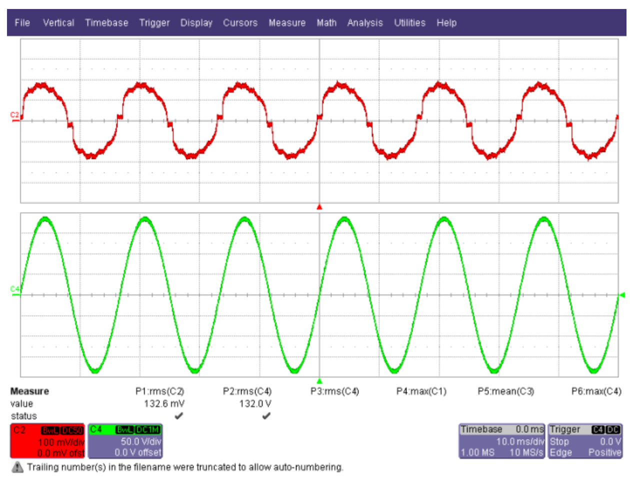

Figure 27 – 132 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

12.2 Output Current and Output Voltage at Normal Operation

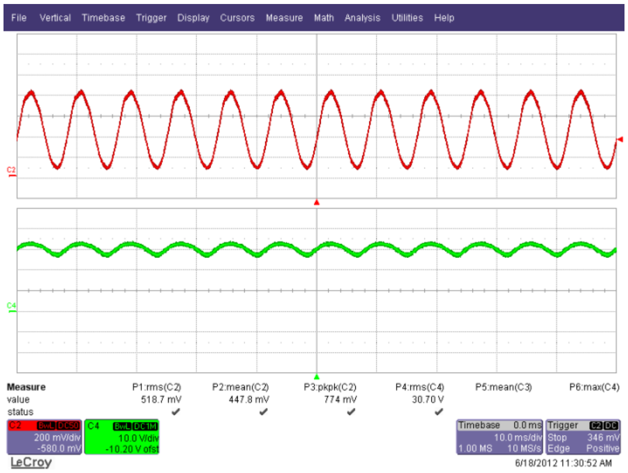

Figure 28 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

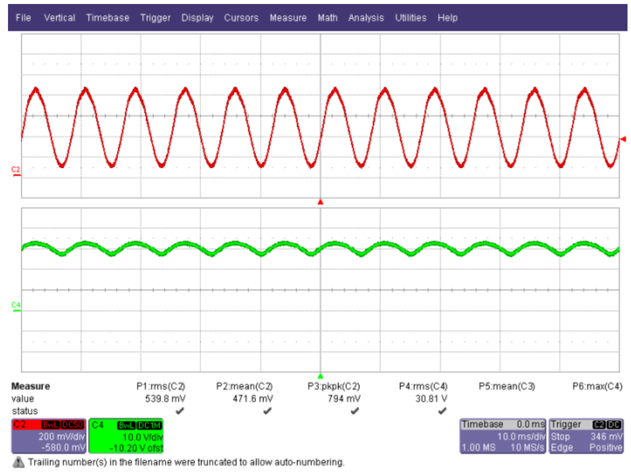

Figure 29 – 110 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

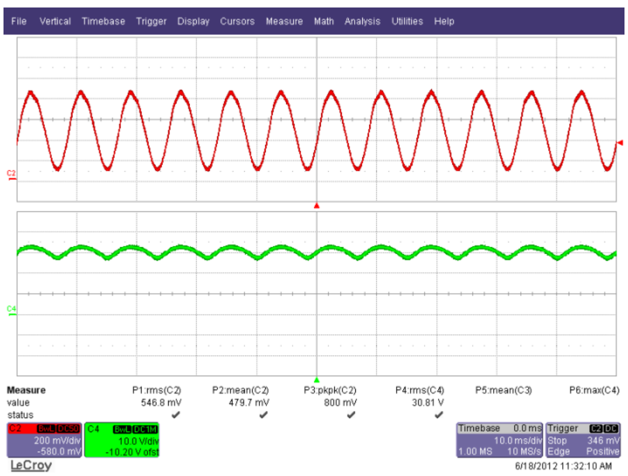

Figure 30 – 120 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

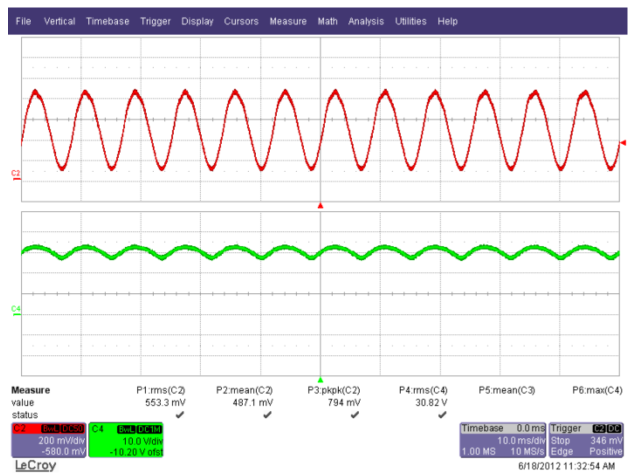

Figure 31 – 132 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

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12.3 Output Current/Voltage Rise and Fall

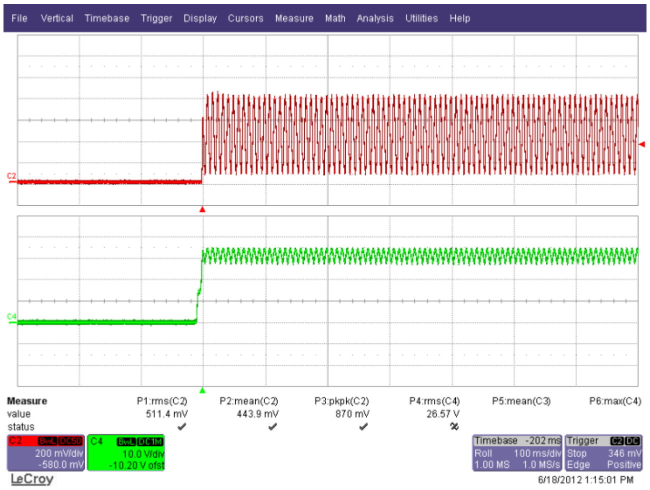

Figure 32 –90 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

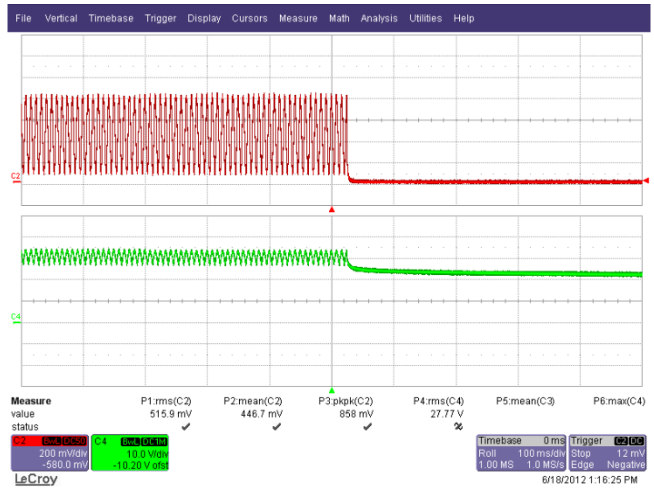

Figure 33 – 90 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

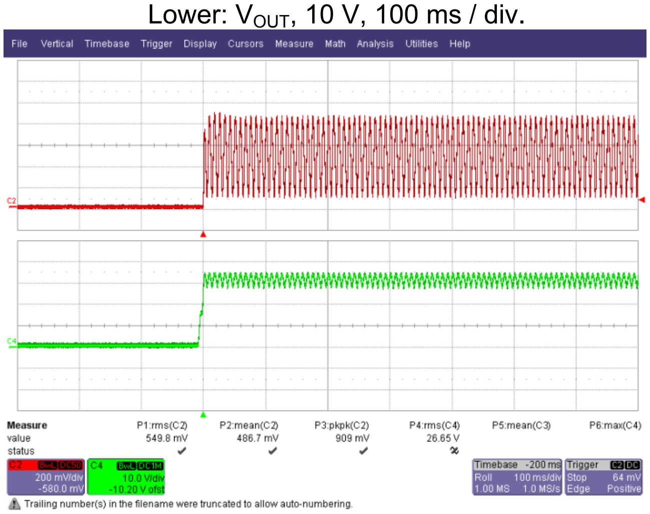

Figure 34 – 132 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

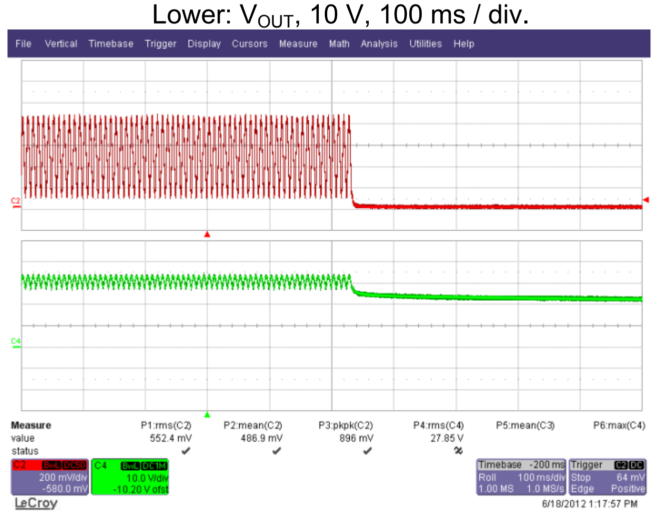

Figure 35 – 132 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

12.4 Input Voltage and Output Current Waveform at Start-up

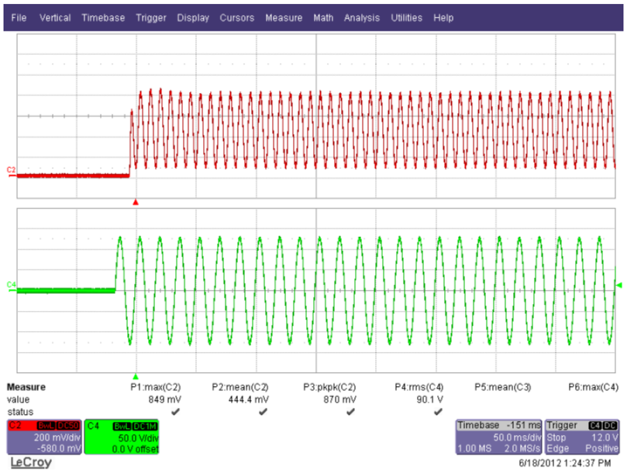

Figure 36 – 90 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 50 ms / div.

Figure 37 – 110 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 50 ms / div.

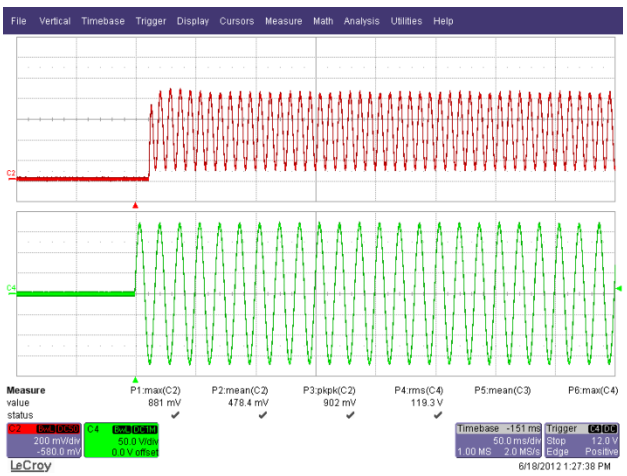

Figure 38 – 120 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 50 ms / div.

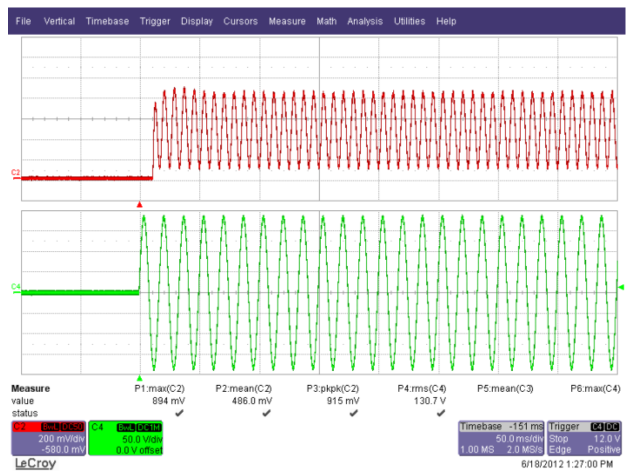

Figure 39 – 132 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 50 ms / div.

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12.5 Drain Voltage and Drain Current at Normal Operation

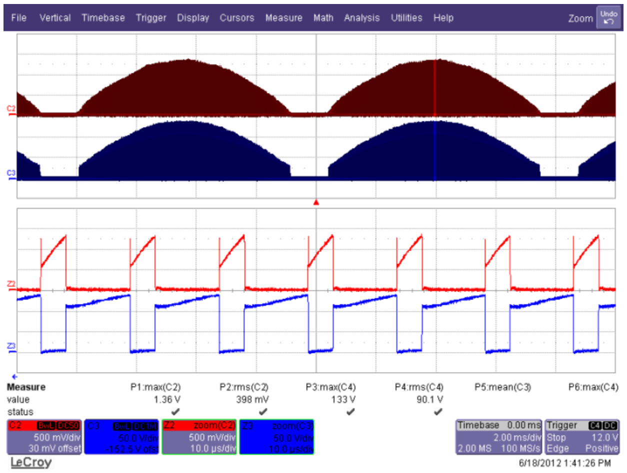

Figure 40 – 90 VAC, 60 Hz.
C2: I_{DRAIN}, 0.5 A, 2 ms / div.
C3: V_{DRAIN}, 50 V, 2 ms / div.
Z2: I_{DRAIN}, 0.5 A, 10 µs / div.
Z3: V_{DRAIN}, 50 V, 10 µs / div.

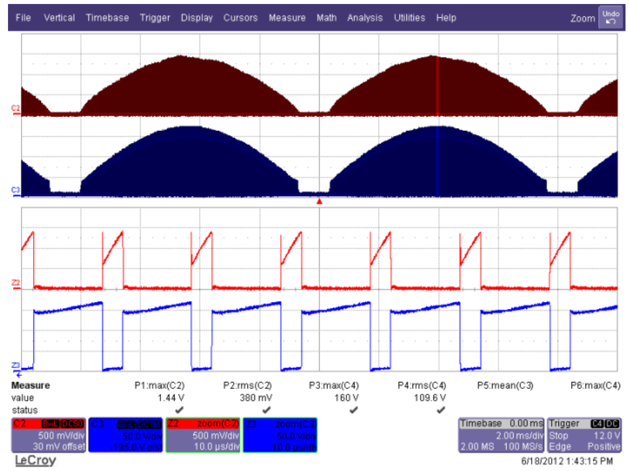

Figure 41 – 110 VAC, 60 Hz.
C2: I_{DRAIN}, 0.5 A, 2 ms / div.
C3: V_{DRAIN}, 50 V, 2 ms / div.
Z2: I_{DRAIN}, 0.5 A, 10 µs / div.
Z3: V_{DRAIN}, 50 V, 10 µs / div.

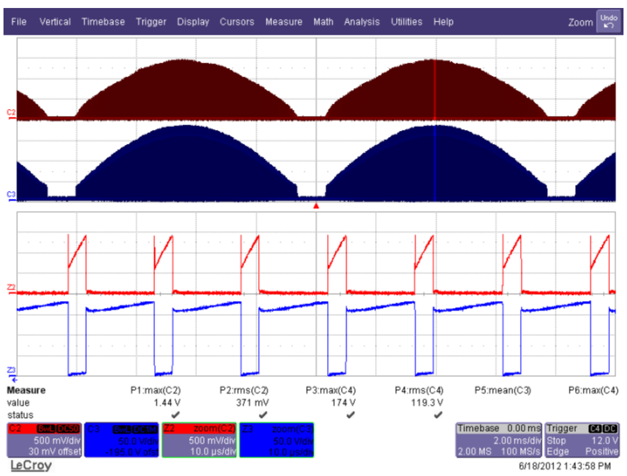

Figure 42 – 120 VAC, 60 Hz.
C2: I_{DRAIN}, 0.5 A, 2 ms / div.
C3: V_{DRAIN}, 50 V, 2 ms / div.
Z2: I_{DRAIN}, 0.5 A, 10 µs / div.
Z3: V_{DRAIN}, 50 V, 10 µs / div.

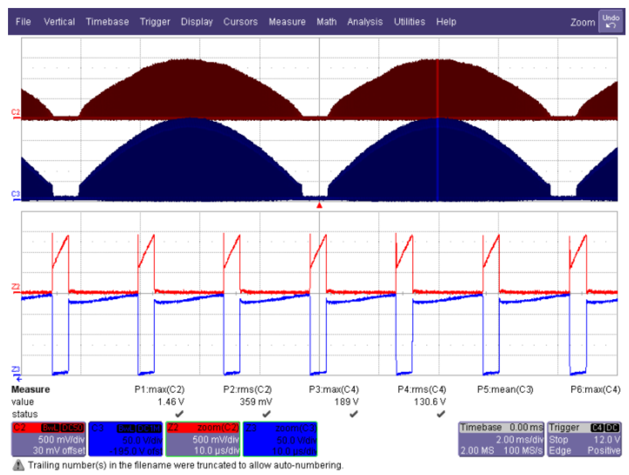

Figure 43 – 132 VAC, 60 Hz.
C2: I_{DRAIN}, 0.5 A, 2 ms / div.
C3: V_{DRAIN}, 50 V, 2 ms / div.
Z2: I_{DRAIN}, 0.5 A, 10 µs / div.
Z3: V_{DRAIN}, 50 V, 10 µs / div.

12.6 Start-up Drain Voltage and Current

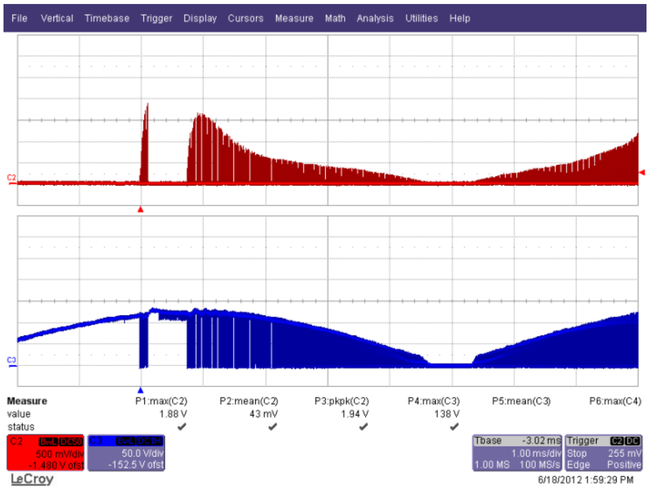

Figure 44 – 90 VAC, 60 Hz Start-up
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 1 ms / div.

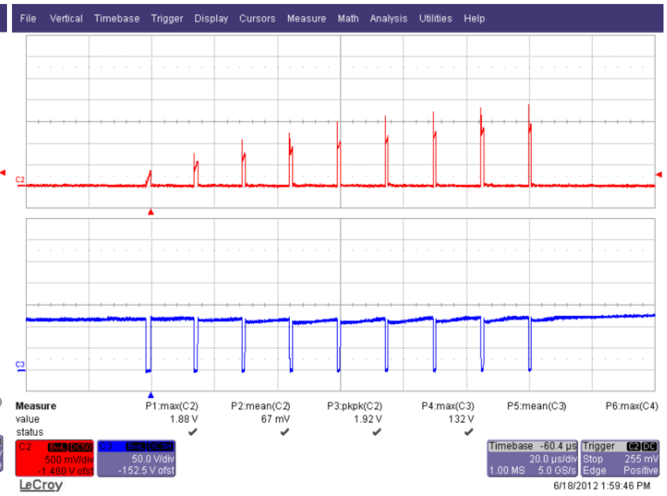

Figure 45 – 90 VAC, 60 Hz Start-up
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 20 µs / div.

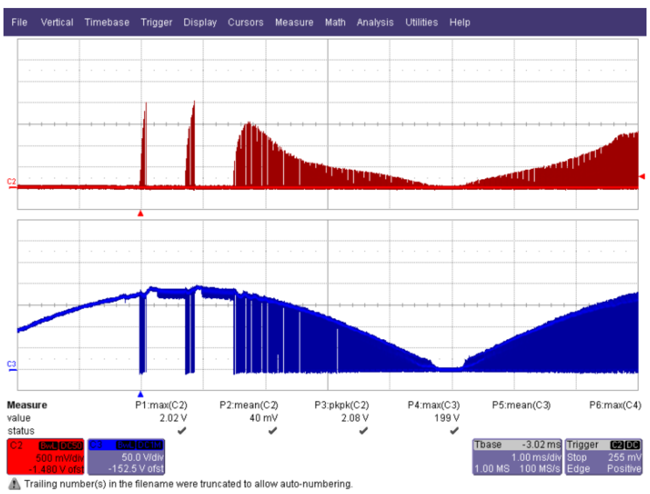

Figure 46 – 132 VAC, 60 Hz Start-up
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 1 ms / div.

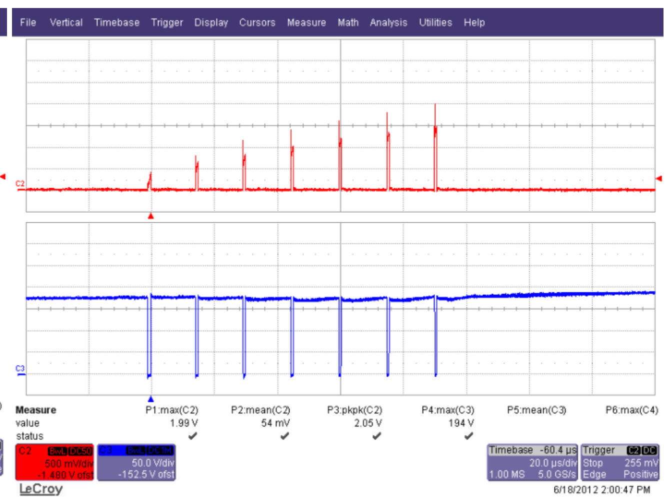

Figure 47 – 132 VAC, 60 Hz Start-up
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 20 µs / div.

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12.7 Drain Current and Drain Voltage During Output Short Condition

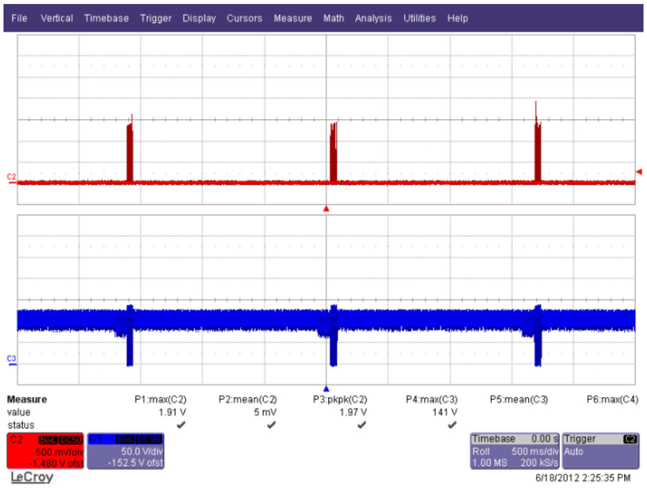

Figure 48 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 500 ms / div.

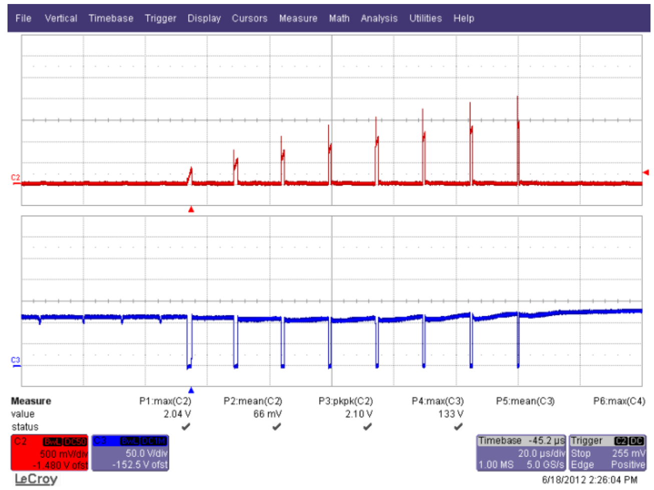

Figure 49 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 20 µs / div.

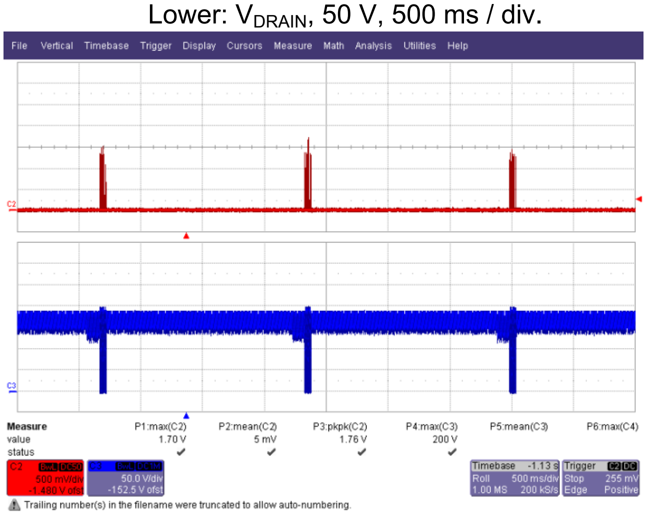

Figure 50 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 500 ms / div.

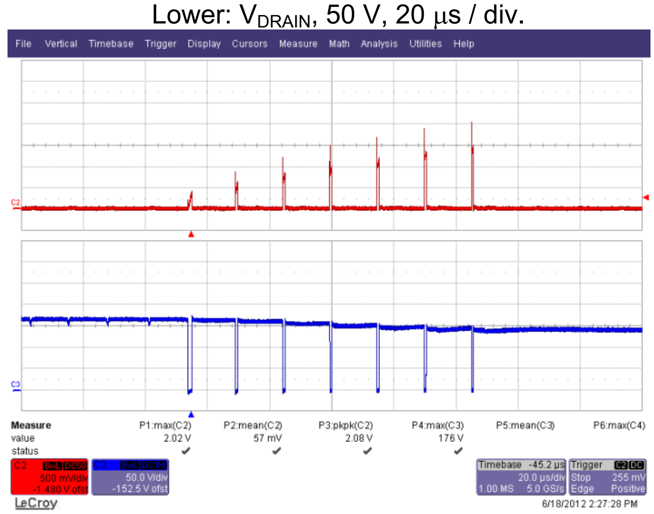

Figure 51 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 20 µs / div.

13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms

Input: 120 VAC, 60 Hz
Output: 30 V LED Load
Dimmer: LUTRON LG-600PH-WH

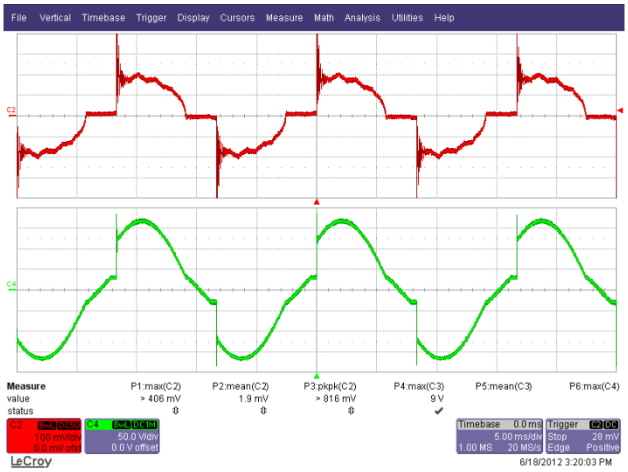

Figure 52 – 125º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

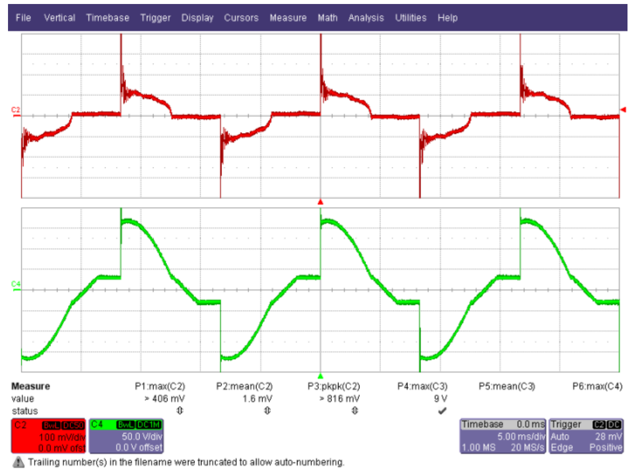

Figure 53 – 92º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

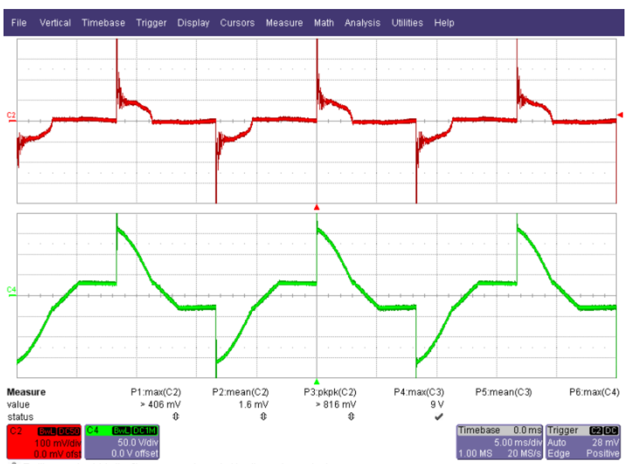

Figure 54 – 65º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

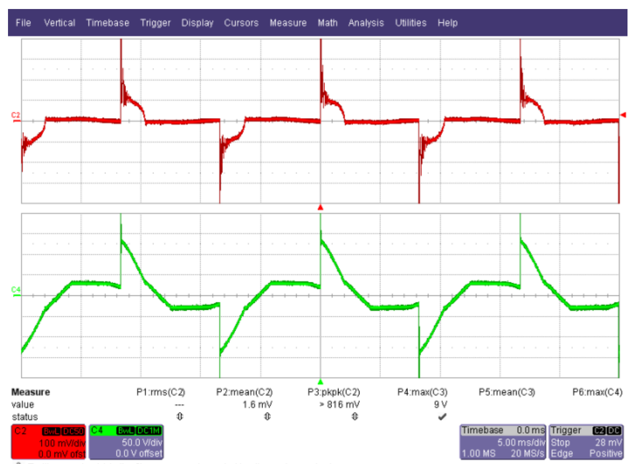

Figure 55 – 45º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

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13.2 Output Current Waveforms

Input: 120 VAC, 60 Hz
Output: 30 V LED Load
Dimmer: LUTRON LG-600PH-WH

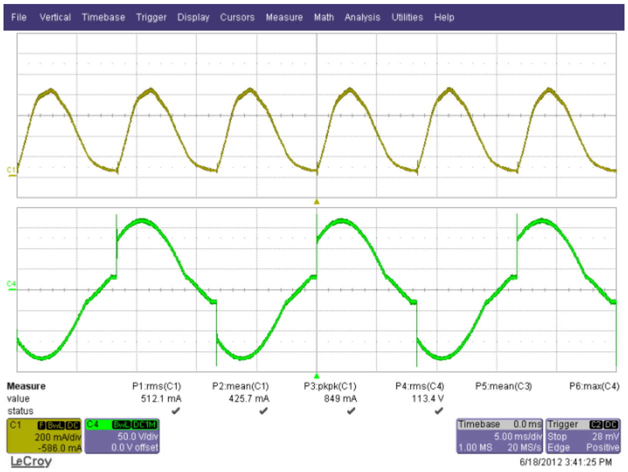

Figure 56 – 125º Conduction Angle.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

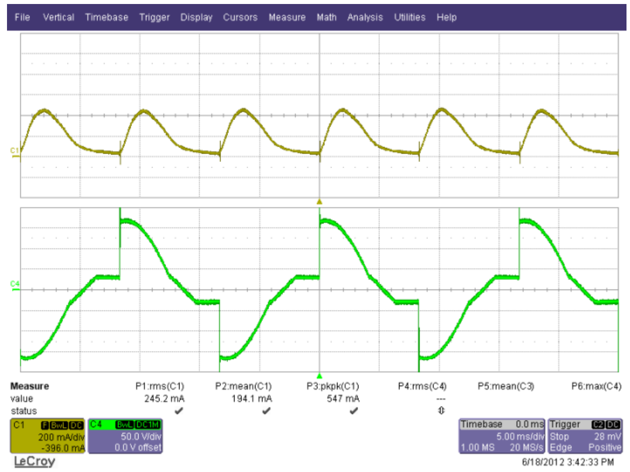

Figure 57 – 92º Conduction Angle.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

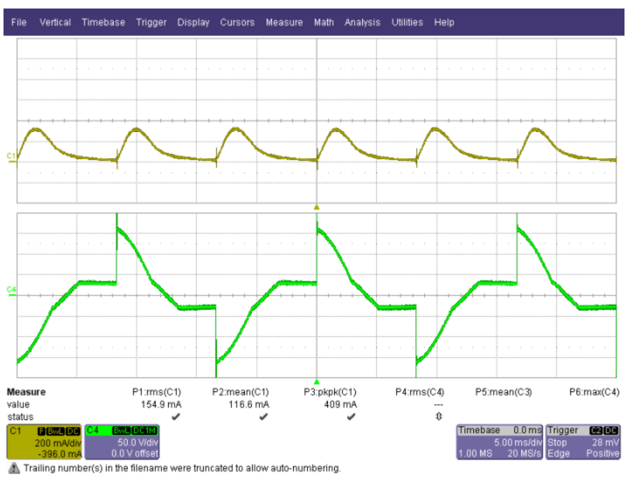

Figure 58 – 65º Conduction Angle.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

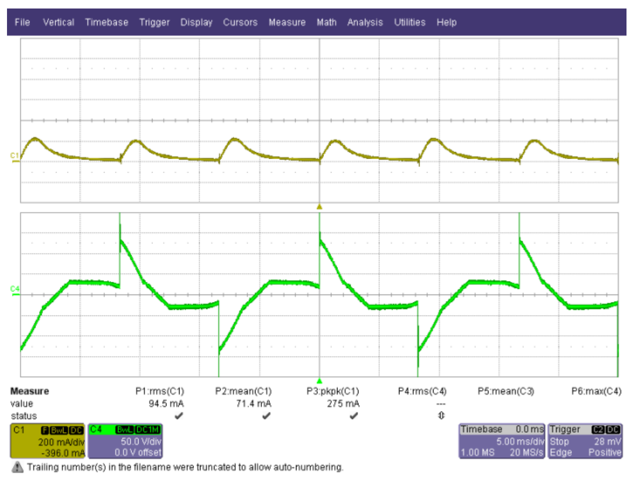

Figure 59 – 45º Conduction Angle.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

14 Conducted EMI

14.1 Test Set-up

The unit was tested using LED load (~30 V V_{OUT}) with input voltage of 115 VAC, 60 Hz at room temperature.

Figure 60 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.

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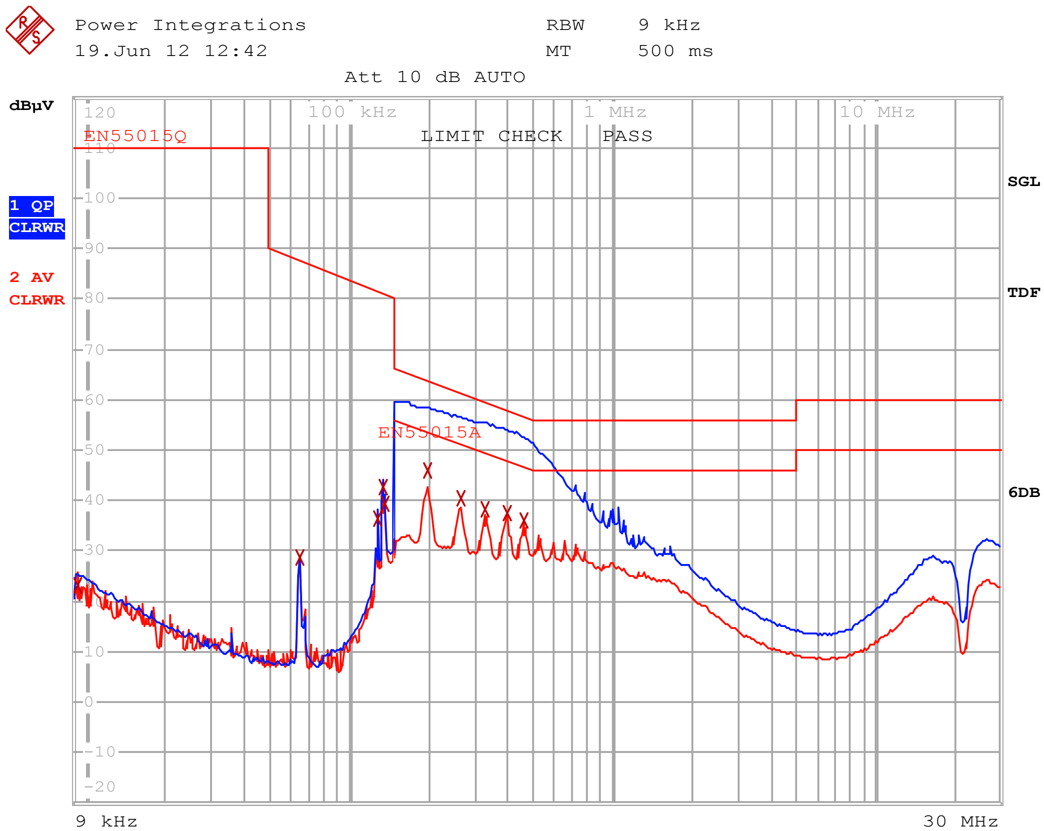
14.2 Test Result



EDIT PEAK LIST (Final Measurement Results)				
Trace1:		EN55015Q		
Trace2:		EN55015A		
Trace3:		---		
TRACE		FREQUENCY	LEVEL dBµV	DELTA LIMIT dB
2	Average	9.272709 kHz	23.09 N gnd	
2	Average	64.5467705779 kHz	28.77 L1 gnd	
2	Average	126.977840157 kHz	36.54 N gnd	
2	Average	133.454986145 kHz	42.75 N gnd	
2	Average	136.137431366 kHz	39.51 N gnd	
2	Average	198.193645035 kHz	45.85 N gnd	-7.82
2	Average	264.49018761 kHz	40.32 N gnd	-10.96
2	Average	329.215131266 kHz	38.16 N gnd	-11.30
2	Average	397.727746704 kHz	37.62 N gnd	-10.27
2	Average	461.749566613 kHz	36.08 N gnd	-10.57

Figure 61 – Conducted EMI, 30 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

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.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+2500	120	L1, L2	0	100kHz Ring Wave (200 A)	Pass
-2500	120	L1, L2	0	100kHz Ring Wave (200 A)	Pass
+2500	120	L1, L2	90	100kHz Ring Wave (200 A)	Pass
-2500	120	L1, L2	90	100kHz Ring Wave (200 A)	Pass

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

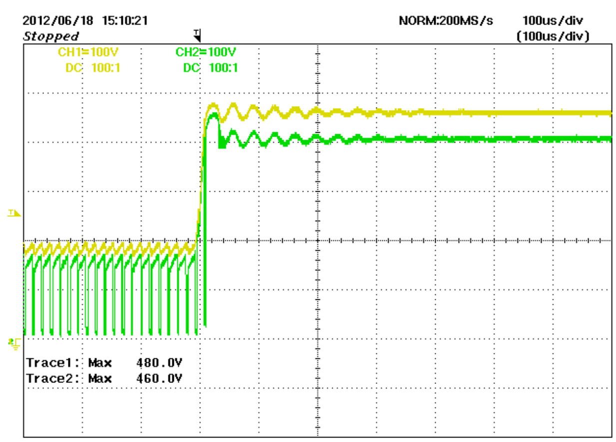


Figure 62 – +500 V (90º Injection Phase) Differential Surge VDS Waveforms.
C1: Input Rectified Voltage (Voltage Across C2)
C2: U1 Drain Voltage Reference to Source.

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16 Addendum for 40 V / 350 mA Output Design

16.1 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section. Compliance characteristic is same as the original version.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	120	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Output						
Output Voltage	V_{OUT}	39	40	41	V	
Output Current	I_{OUT}		350		mA	At 115 VAC
Total Output Power						
Continuous Output Power	P_{OUT}		14.0		W	
Efficiency						
Nominal	η	87	90		%	Measured at P_{OUT} 25 °C at 115 VAC
Power Factor		0.9	0.98			At 115 VAC
A-THD				15	%	At 115 VAC
Harmonic Currents		EN 61000-3-2 Class C				Class C Limits

Note:

Refer to the schematic section 3 for the component updates for 40 V / 350 mA version.

16.2 Inductor Specification (40 V / 350 mA)

16.2.1 Electrical Diagram

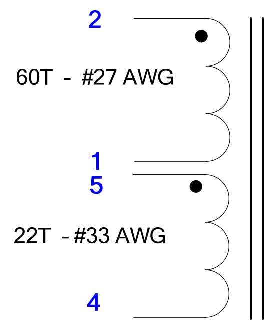

Figure 63 – Inductor Electrical Diagram.

16.2.2 Electrical Specifications

Primary Inductance	Pins 1-2 all other windings open, measured at 66 kHz, 0.4 $V_{RMS.}$	620 μH ±7%
Resonant Frequency	Pins 1-2, all other windings open.	1.8 MHz (Min.)

16.2.3 Materials

Item	Description
[1]	Core: RM6S PC40 or equivalent.
[2]	Bobbin: B-RM6-V 6pins 3/3.
[3]	Magnet Wire, #27 AWG, solderable double coated.
[4]	Magnet Wire, #33 AWG, solderable double coated.

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16.2.4 Inductor Build Diagram

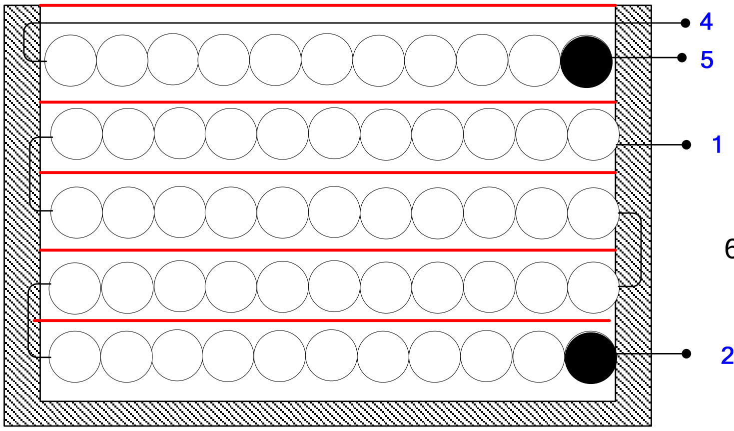

Figure 64 – Inductor Build Diagram.

16.2.5 Inductor Construction

General Note	For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the right.
WD1	Start at pin 2. Wind 60 turns of item [3] as shown in Figure 2. Terminate at pin 1.
WD2	Start at pin 5. Wind 22 turns of item [4] and terminate the other end at pin 4.
Finish	Grind the core to get the specified inductance. Place the clip to secure both cores. Cut pins 3 and 6.

16.3 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 38 V to 42 V output voltage.

16.4 Dimmer Compatibility List

The unit was tested with the following U.S. dimmers at 120 VAC, 60 Hz (supplied from programmable AC source) input and 40 V LED load.

List of Dimmers	Type	Remarks	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
LUTRON LG600PH-LA	L	Lutron 600-Watt Slide Dimmer LG-600PH-LA	600W	LG-600PH-WH	26	283	11
LUTRON S603P	L	Lutron Skylark Incandescent 600W 3-Way Preset Dimmer with On/Off	600W	S-603P-WH	23	291	13
LUTRON SLV600P	T	Lutron SLV-600P-WH 600-Watt Skylark Magnetic Low-Voltage Single-Pole Dimmer	600W	SLV600P-WH	35	288	8
LUTRON S600	L	Slide-to-Off Single Pole Skylark Dimmer Switch (RFI suppression)	600W	S-600-WH	28	305	11
LUTRON S-600PH-WH	L	Lutron Skylark 5-Amp White Gloss Dimmer	600W	S-600PH-WH	25	291	12
LUTRON DVCL153P	L	Cfl&led Dimmer, Paddle/slide, 120V, 600W	600W	DVWCL-153-PLH-WH	38	291	8
LUTRON DV603P	L	600W Diva Dimmer, 3-Way - Ivory	600W	DV-603P-WH	26	282	11
LUTRON DV600P	L	Lutron Diva DV-600P-WH Incand 600 Watt Single Pole Light Dimmer in White	600W	DV-600P-WH	26	282	11
LUTRON TG600PH-IV	L	Ivry Toggle Dimmer 1p Preset	600W	TG-600PH-WH	25	288	12
LUTRON AY600P	T	Lutron Ariadni AY-600P-WH Incand Preset 600 Watt Single Pole Light Dimmer in White	600W	AY-600P-WH	23	284	12
LUTRON GL600P-WH	L	Glyder Incandescent Single Pole 600 Watts Preset Dimmer, White	600W	GL-600P-WH	26	290	11
LEVITON 6633PLI	L	SureSlide 600W Incandescent Dimmer	600W	R62-06633-1LW	26	308	12
LEVITON 6631-LI	L	SureSlide 600W Incandescent Slide Dimmer, Single-Pol	600W	R62-06631-1LW	21	297	14
LEVITON IPI06	L	IllumaTech Incandescent Preset Slide Dimmer	600W	R60-IPI06-1LM	62	307	5
LEVITON RP106	L	IllumaTech Rotary Controls 120V AC 60Hz	600W	R52-RPI06-1LW	28	307	11
LEVITON 6681	L	A Push On and Push Off Dimmer	600W	R60-06681-0IW	25	298	12
LEVITON 6684	L	Leviton 600-Watt 3-Way Lighted White/Ivory Push Dimmer	600W	R60-06684-1IW	26	307	12
LEVITON 6683			600W	6683	40	308	8
LEVITON 6613	L	SURESLIDE" MAGNETIC LOW VOLTAGE DIMMER *600VA, 120V AC, 60Hz	450W	R02-06613-PLW	26	307	12
COOPER SLC03				SLC03P-W-K-L	39	295	8
LUTRON GL600-WH	L	Lutron 15-Amp White Slide Dimmer	600W	GL-600-WH	2	303	152
LUTRON DVPDC-203P-WH	L	Diva, Screw Base Compact Fluorescent Dimming with Philips® DIMMABLE Energy Saver CFL, Single Pole/3-Way, 200W, White	200W	DVPDC-203P-WH	98	304	3
LUTRON LX600PL	L	Lyneo Lx Single Pole Dimmer 600W	500W	LX-600PL-wh	52	301	6
LUTRON D600P	L	Single Pole - Incandescent - Push On/Off - 600 Watt - White	600W	D-600P-WH	29	288	10
LUTRON CTCL-153PDH			600W		38	292	8
LUTRON S-600P			600W	S-600P	25	291	12
LUTRON TGLV-600P				TGLV-600P	28	292	10
LUTRON TGLV-600PR			450W	TGLV-600PR	31	287	9
LUTRON TT-300NLH-WH	L	Lutron Diva Satin 5-Amp Desert Stone Preset Dimmer	300W	TT-300NLH-WH	31	306	10
LUTRON TT-300H-WH	L	Lutron Credenza 300-Watt White Lamp Dimmer	300W	TT-300H-WH	25	306	12
Lutron		S-600P			24	288	12
Lutron		S-600P			26	303	12
Cooper		S106P			288	297	1
Lutron		S-103P-WH			57	290	5

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Lutron		S1-10P-WH			42	295	7
Lutron		S-600PNLH-WH			25	293	12
Lutron		S-603PNL-WH			28	292	10
Lutron		SLV-603P-WH			26	285	11
Lutron		S-603PGH-WH			27	198	7

16.4.1 Efficiency

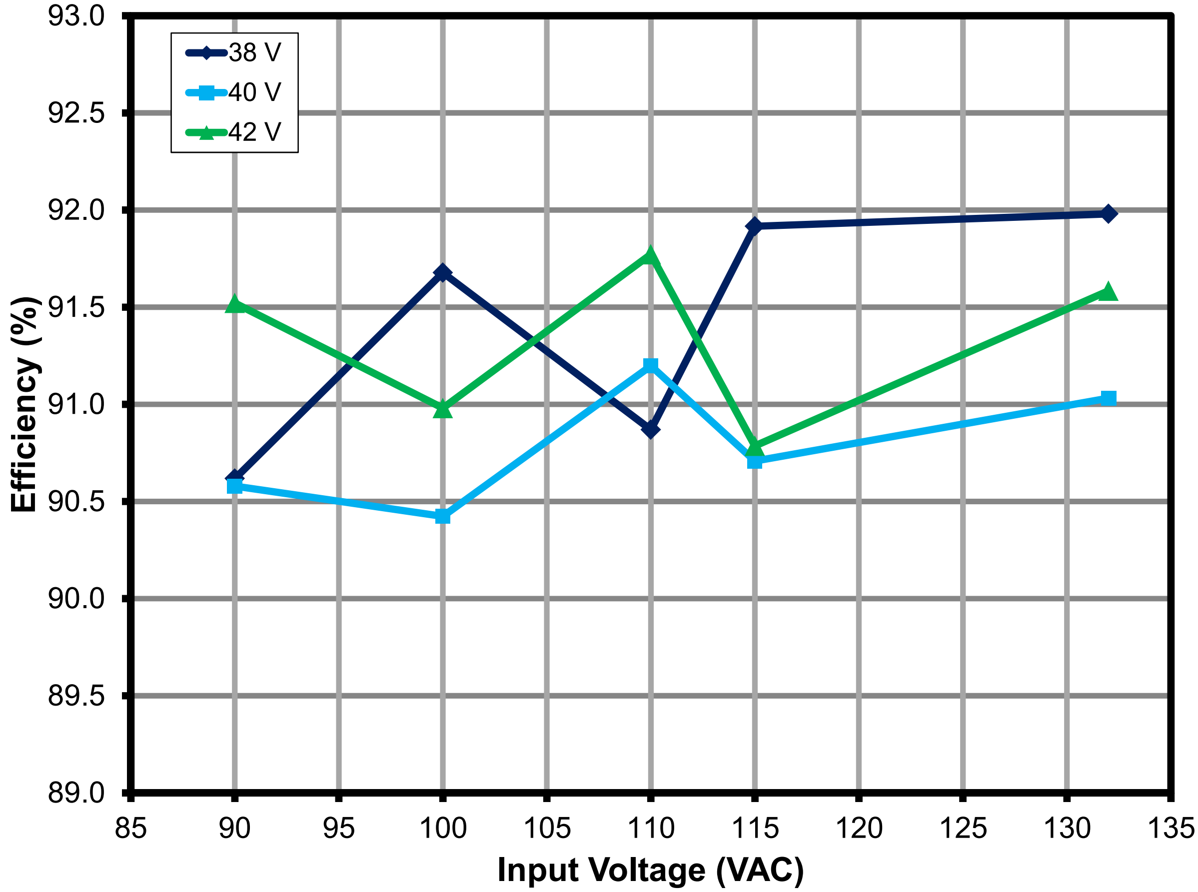

Figure 65 – Efficiency vs. Line and Load. 40 V / 350 mA.

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16.4.2 Line and Load Regulation

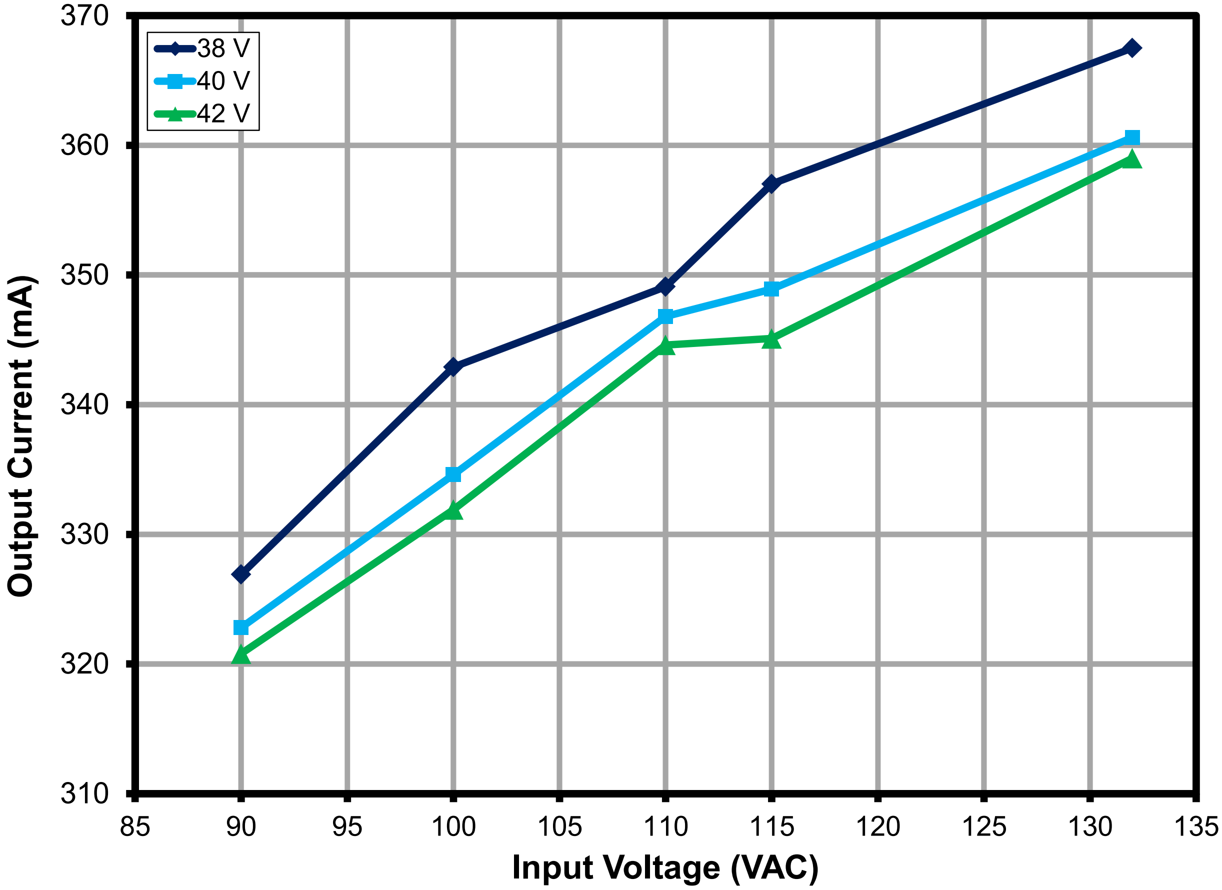

Figure 66 – Regulation vs. Line and Load.

16.4.3 Power Factor

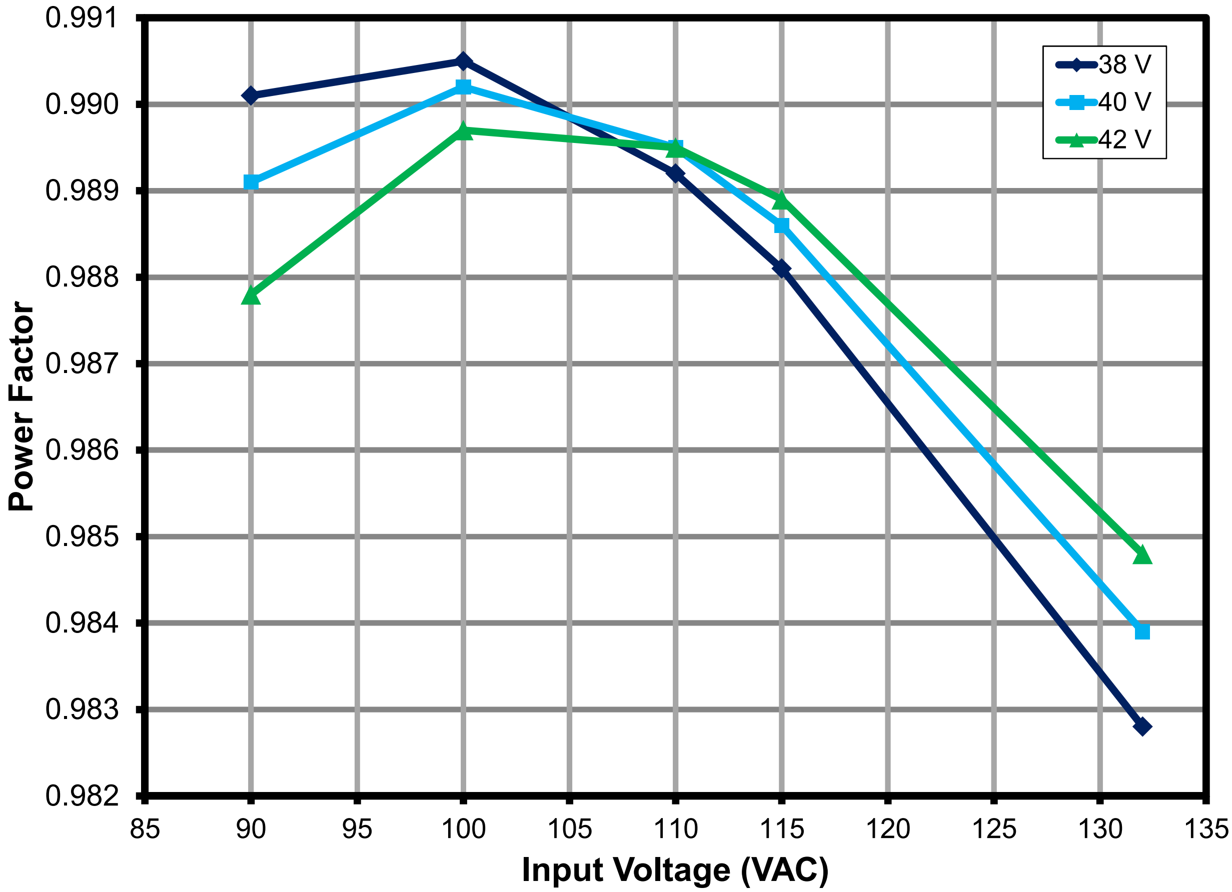

Figure 67 – Power Factor vs. Line and Load.

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16.4.4 A-THD

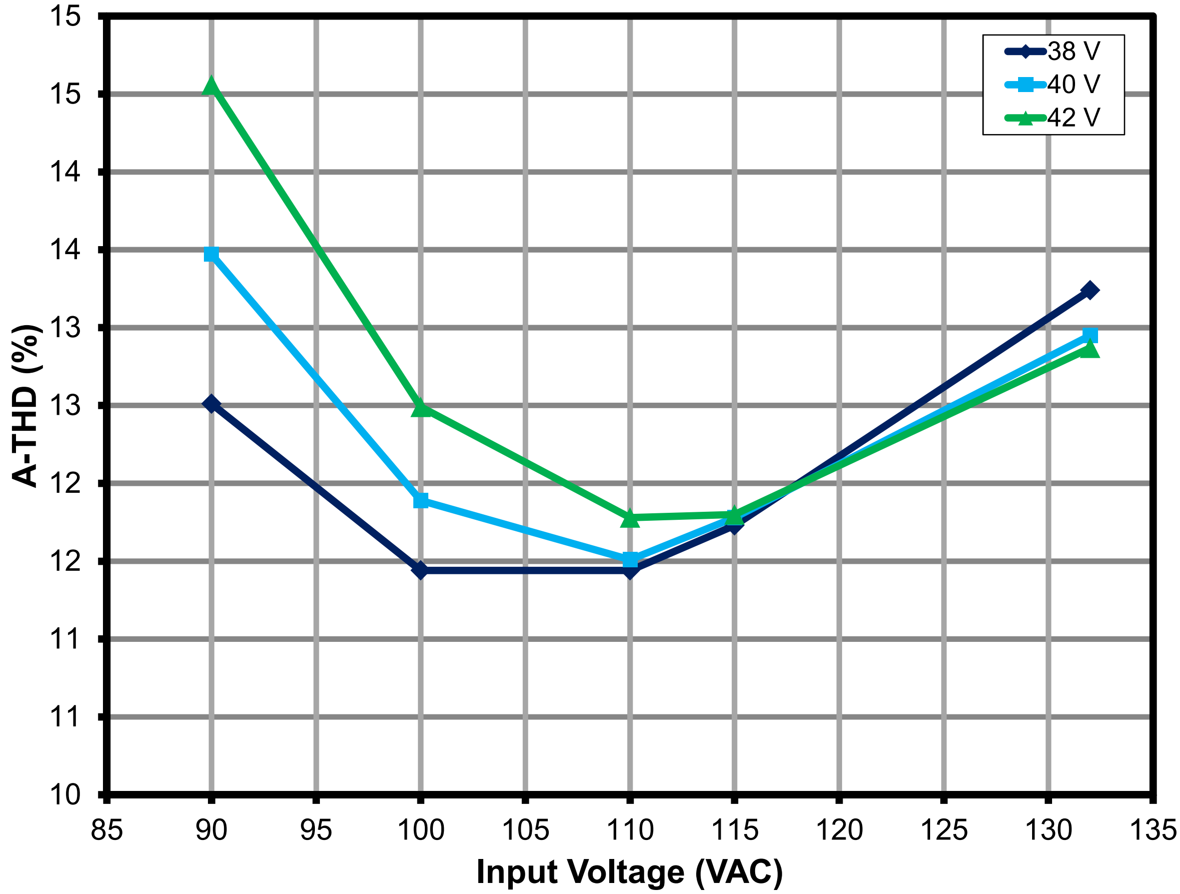

Figure 68 – A-THD vs. Line and Load.

16.4.5 40 V Harmonics

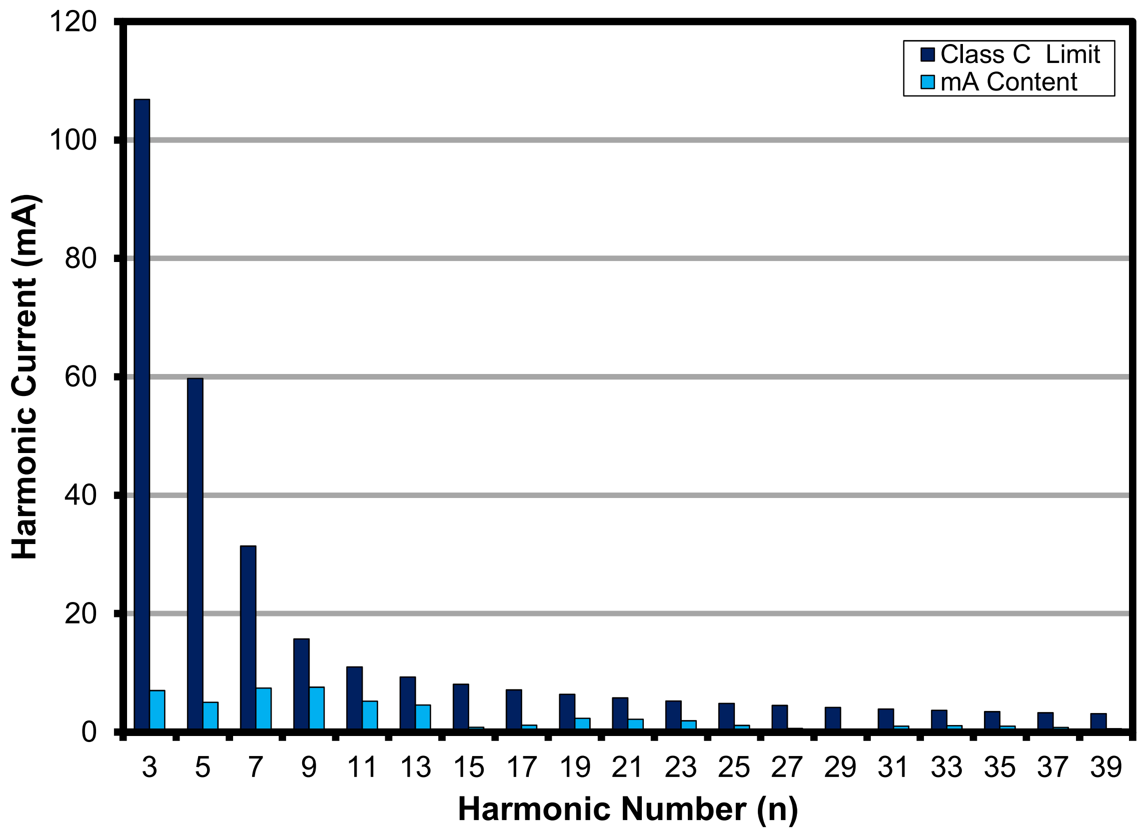

Figure 69 – 40 V / 350 mA LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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16.4.6 Conducted EMI Test Result

The unit was tested using LED load (~40 V V_{OUT}) with input voltage of 115 VAC, 60 Hz at room temperature. Refer to section 14.1 for test set-up.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.84316745416 kHz	22.15	L1 gnd	
2	Average	63.9076936414 kHz	19.47	N gnd	
2	Average	69.2028746009 kHz	19.74	L1 gnd	
2	Average	130.825395691 kHz	35.05	N gnd	
2	Average	137.49880568 kHz	35.69	N gnd	
1	Quasi Peak	159.22802259 kHz	58.24	N gnd	-7.25
2	Average	198.193645035 kHz	40.22	N gnd	-13.46
2	Average	267.135089486 kHz	37.13	N gnd	-14.06
2	Average	332.507282579 kHz	35.99	N gnd	-13.39
2	Average	2.05405734435 MHz	19.34	L1 gnd	-26.65
2	Average	25.4636191981 MHz	20.92	L1 gnd	-29.07

Figure 70 – Conducted EMI, 40 V/350mA LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
17-Aug-12	CA	1.0	Initial Release	Apps & Mktg
14-Sep-12	JDC	2.0	Added simple modification to convert to 40 V / 350 mA version	

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Customer Service:
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e-mail: usasales@powerint.com

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

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

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 114, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail: taiwansales@powerint.com

CHINA (SHANGHAI)
Rm 1601/1610, Tower 1
Kerry Everbright City
No. 218 Tianmu Road West
Shanghai, P.R.C. 200070
Phone: +86-021-6354-6323
Fax: +86-021-6354-6325
e-mail: chinasales@powerint.com

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

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

EUROPE HQ
1st Floor, St. James's House
East Street, Farnham
Surrey GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
e-mail: eurosales@powerint.com

CHINA (SHENZHEN)
3rd Floor, Block A, Zhongtou
International Business Center, No.
1061, Xiang Mei Road, FuTian District,
ShenZhen, China, 518040
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
e-mail: chinasales@powerint.com

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

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

APPLICATIONS HOTLINE
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