Design Example Report

Title	***9.5 W, Isolated Flyback, TRIAC Dimmable, Power Factor Corrected (>0.96) LED Driver Using LYTSwitch™ LYT4314E***
Specification	90 VAC – 132 VAC Input; 18 V, 530 mA Output
Application	Track Light LED Driver
Author	Applications Engineering Department
Document Number	DER-353
Date	November 13, 2012
Revision	1.0

Summary and Features

- High efficiency, ≥81% at 120 VAC
- PF >0.96 easily meeting EN 61000-3-2 Class D (C)
- THD <15%
- Two TRIAC dimmable configurations presented
  - With active pre-load - widest dimmer model compatibility and wide dimming range
  - Lowest cost without active pre-load - wide dimmer compatibility for 600 W dimmers
- Low system cost
  - Single-stage converter
  - Single-sided PCB
  - Low component count
- Enhanced user experience
  - Flicker-free, fast monotonic start-up (<200 ms) – no perceptible delay
  - No pop-on or dead travel
  - Broad dimmer compatibility
- Integrated protection and reliability features
  - Output open circuit / output short-circuit protected with auto-recovery
  - Fast acting Line input overvoltage shutdown extends voltage withstand during line faults
    - Easily meets ±2500 V ring wave and ±500 V differential surge

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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>.

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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 an isolated high power factor (PF) TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 21 V at 530 mA from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT4314E from the LYTSwitch family of ICs.

The topology used is a single-stage power factor corrected flyback that delivers high efficiency, high power factor, low THD, isolation, low component count, and delivers excellent TRIAC dimming.

High power factor and low THD is achieved by employing the LYTSwitch IC which also provides a sophisticated range of protection features including auto-restart for open control loop and output short-circuit conditions. Line overvoltage protection 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.

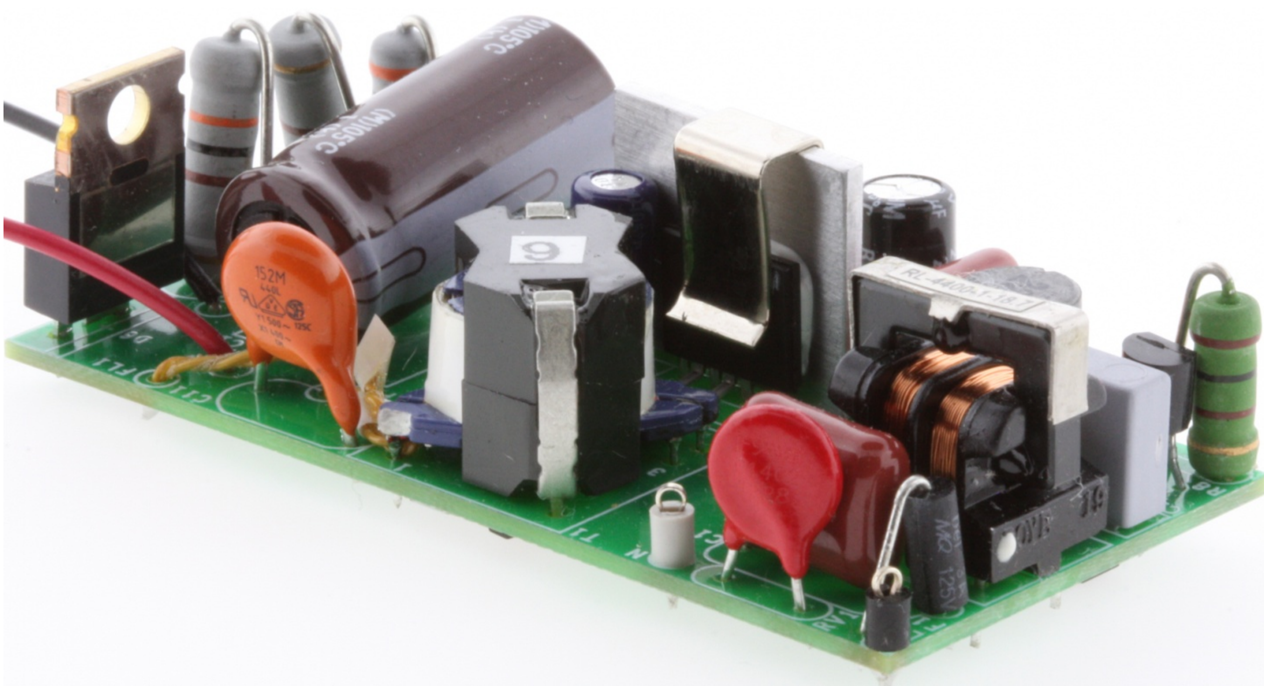

Figure 1 – Populated Circuit Board Photograph

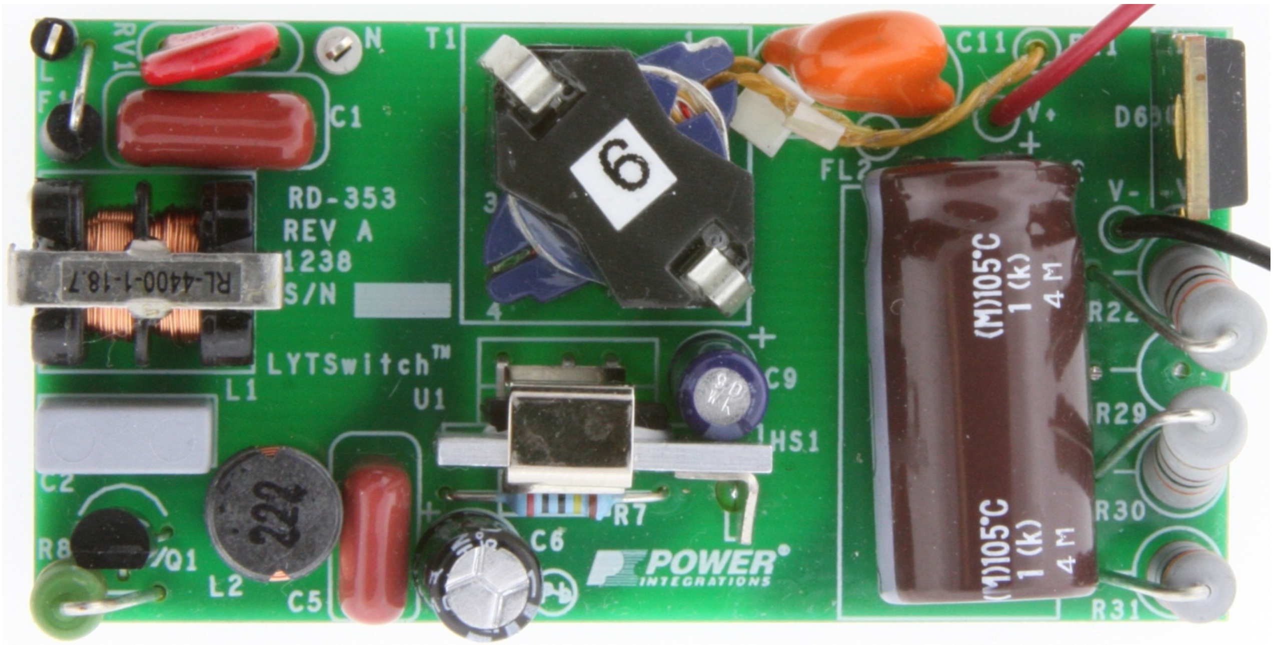

Figure 2 – Populated Circuit Board Photograph (Top View).

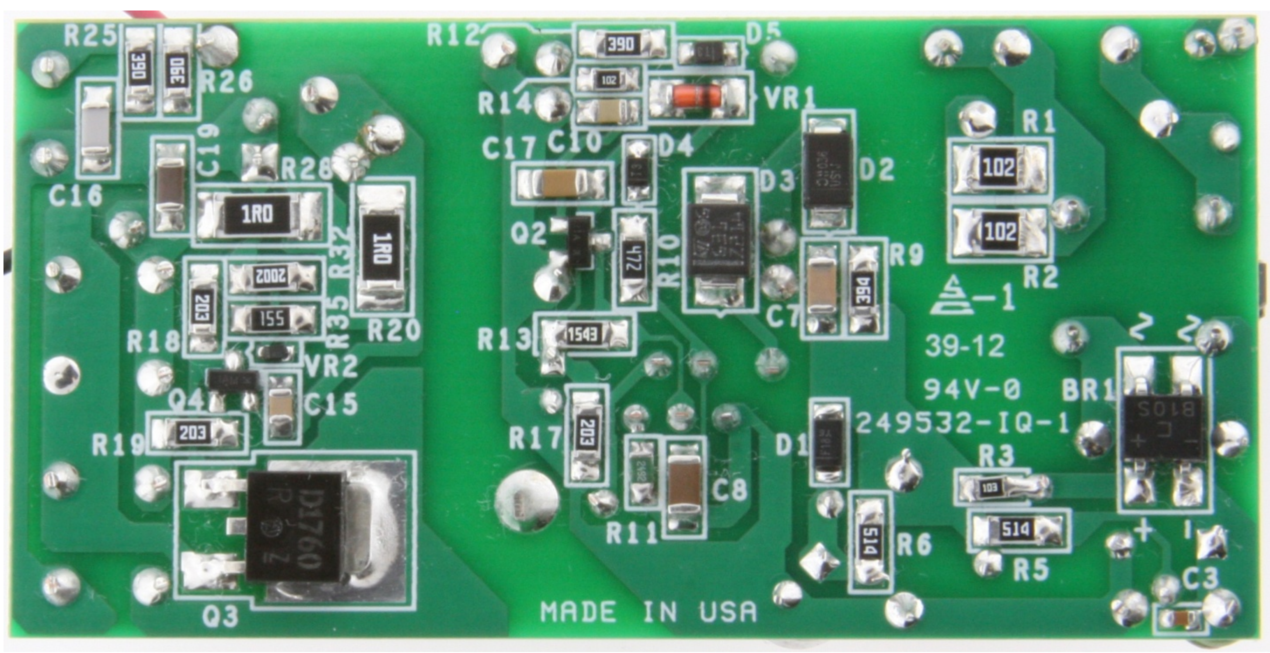

Figure 3 – Populated Circuit Board Photograph (Bottom View).

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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	
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}	15	18	21	V	
Output Current	I_{OUT}		530		mA	V_{OUT} = 21, V_{IN} = 120 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		9.5		W	
Efficiency						
Full Load	η		82		%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Common mode (L1/L2-PE)						
Differential Surge (1.2 / 50 µs)			500		V	
Power Factor			0.96			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}		50		°C	Free convection, sea level

3 Schematic

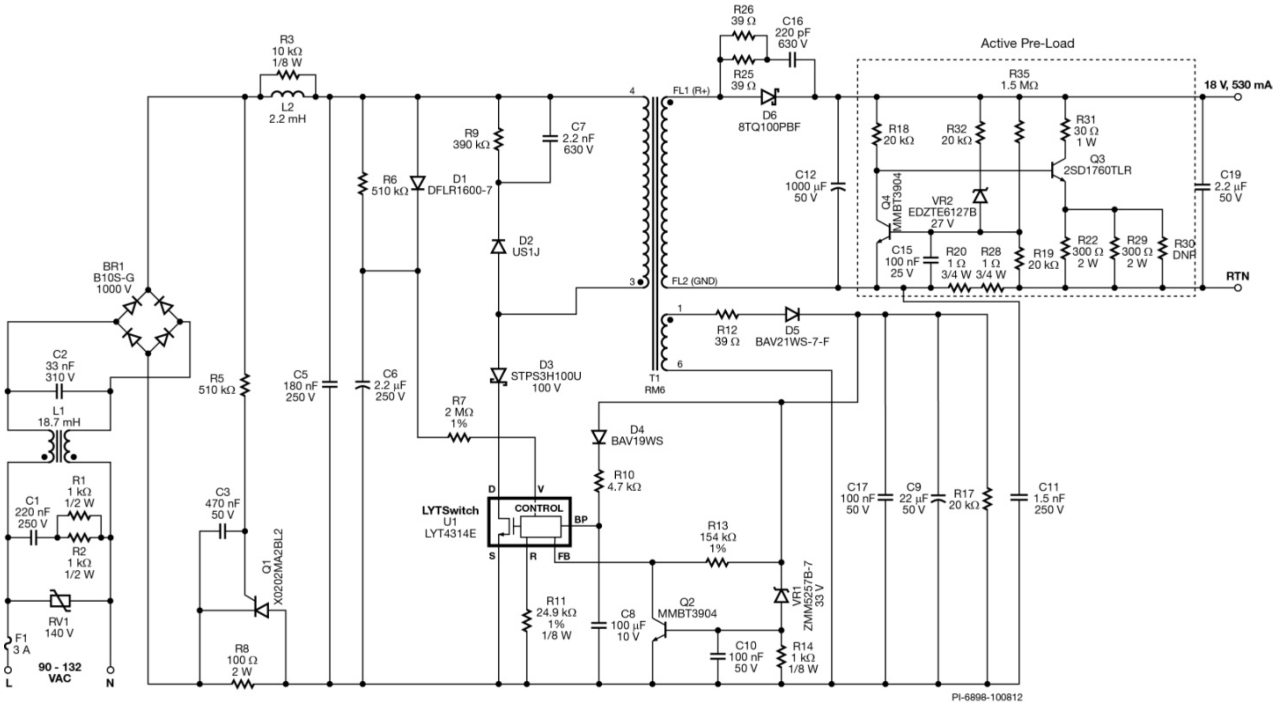

Figure 4 – Schematic with Optional Active Pre-load.

Notes:

1. R30 is not fitted as it is an optional resistor for adjusting dimming curve.
2. Blocking diode D3 can be replaced by fast rectifier i.e. ES2D for cost sensitive applications where ~0.2% drop in efficiency is acceptable.
3. RV1 is not required for differential line surge levels ≤500 V.

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4 Circuit Description

The LYTSwitch device is a controller with an integrated 650 V power MOSFET for use in LED driver applications. The LYTSwitch is configured for use in a single-stage flyback 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. The fast acting line overvoltage detection of LYTSwitch in conjunction with D1 and C6 peak detector capacitor provides a clamp to limit the maximum voltage stress across the integrated power MOSFET. Optional MOV (Metal Oxide Varistor) RV1 can be used for >500 V differential line surge requirement. Varistor RV1 provides a clamp to limit the maximum voltage during differential line surges. A 140 VAC rated part is recommended, being slightly above the maximum specified operating voltage of 132 VAC. Diode bridge BR1 rectifies the AC line voltage with capacitor C5 providing a low impedance path (decoupling) for the primary switching current.

EMI filtering is provided by inductors L1, L2, and capacitors C2, and C5. Resistor R3 across L2 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

One side of the transformer (T1) is connected to the DC bus and the other to the DRAIN (D) pin of the LYTSwitch device via blocking diode D3. During the on-time of the power MOSFET, current ramps through the primary, storing energy which is then delivered to the output during the power MOSFET off-time. An RM6S/I core size was selected to meet the power processing requirements of the design.

To provide peak line voltage information to U1 the incoming rectified AC peak charges C6 via D1. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R7. Resistor R6 provides a discharge path for C6 with a time constant much longer than that of the rectified AC to prevent the V pin current being modulated at the line frequency (which would degrade power factor).

The line overvoltage shutdown function extends the rectified line voltage withstand (during surges and line swells) to the 650 BV_{DSS} rating of the internal power MOSFET. Line overvoltage shutdown is triggered when the V pin current exceeds 112 μA or approximately 158 VAC.

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. For improved line and load regulation, a 24.9 kΩ resistor is used on the REFERENCE (R) pin (R11) and 2 MΩ (R7) on the V pin to provide a linear relationship between input voltage and the output current.

During the power MOSFET off-time, D2, R9, and C7 clamp the drain voltage to a safe level due to the effects of leakage inductance. Diode D3 is necessary to prevent reverse current from flowing through U1 while the voltage across C5 (rectified input AC) falls to below the reflected output voltage (parameter V_{OR} in the design spreadsheet). For lower cost an ultrafast type may be selected (ES2D) with a slight (0.3%) reduction in efficiency.

Diode D5, C9, R12 and R17 generate a primary bias supply from an auxiliary winding on the transformer. Resistor R12 provides filtering so that the bias voltage tracks the output voltage closely and maintains a constant output current with changes in LED voltage. Resistor R17 prevents C9 peak charging during output short circuit condition, ensuring the driver safely enters auto-restart.

Capacitor C8 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C8 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN (D) pin. Once charged U1 starts switching at which point the operating supply current is provided from the bias supply via R10.

The use of an external bias supply (via D4 and R10) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming conditions.

Capacitor C8 also selects the output power mode, 100 μF was selected (reduced power mode) to minimize the device dissipation and minimize heat sinking requirements.

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 secondary windings). Resistor R13 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.

4.4 Output Rectification

The transformer secondary winding is rectified by D6 and filtered by capacitors C12, and C19. Capacitor C19 should be replaced by a 20 kΩ 1206 smd resistor if the active pre-load is not required.

For designs where higher ripple is acceptable, the output capacitance value can be reduced.

4.5 Disconnected and Shorted Load Protection

The part enters auto-restart whenever the FB current falls below the $I_{FB(AR)}$ threshold for longer than the ~76 ms.

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In case of open (disconnected) load fault, Zener diode VR1 will conduct turning on transistor Q2. Transistor Q2 then pulls down the FB pin to force the IC into auto-restart mode.

During an output short circuit the output voltage and therefore bias voltage collapses. This causes the current into the FB pin to drop below $I_{FB(AR)}$.

Once in auto-restart dissipation is limited to ~25% of the rated output power, providing a safe condition. Once the fault is removed the driver returns to normal operation at the completion of the current auto-restart cycle off period (~225 ms).

4.6 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 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 passive bleeder circuits were added. 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 active damper consists of components R5, Q1, C3 and R8. This circuit limits the inrush current that flows to charge C5 when the TRIAC turns on by placing R8 in series for the first 1 ms of the conduction period. After approximately 1 m, Q1 turns on and shorts R8. This keeps the power dissipation on R8 low and allows a larger value to be used for more effective current limiting. Resistor R5 and C3 provide the 1 ms delay after the TRIAC conducts. The SCR selected for Q1 is a low current, low cost device in a TO-92 package. Resistor R36 (typical value 10 – 22 Ω) in series with R8 is optional placement for additional damping for TRIAC, rated at 1000 W.

The passive bleeder circuit is comprised of C1 and parallel combination of R1, and R2. This keeps the input current above the TRIAC holding current while the driver input current increases during each AC half-cycle preventing the TRIAC switch from oscillating at the start (and end) of each conduction angle period.

4.6.1 Active Pre-Load Circuit

The active pre-load circuit is added to extend dimming range capability and provide additional loading during TRIAC dimming, which increases the number of compatible dimmer models.

Resistors R20 and R28 senses the output current. If the output current valley falls below ~200 mA, transistor Q4 turns-off and transistor Q3 turns-on decreasing the output current flowing into the LED. This arrangement provides output current of ~1% (of full load) at 30 V_{RMS} input (chopped input voltage) to the LED driver. At a minimum output current (valley of the ripple) of 200 mA, the active pre-load circuit disengages to prevent reducing efficiency. Resistors R22, R29, and R31 set the maximum current flowing into the pre-load circuit and thus can be used to adjust the desired dimming curve. Zener diode VR2 and R32 are also employed to disable the active pre-load during an open load condition. The temperature rise of resistors R22, R29 and R31 can be significant and should be verified in the final product. They may also be mounted to the LED heat sink as dissipation only occurs at <50% of full LED current.

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5 PCB Layout

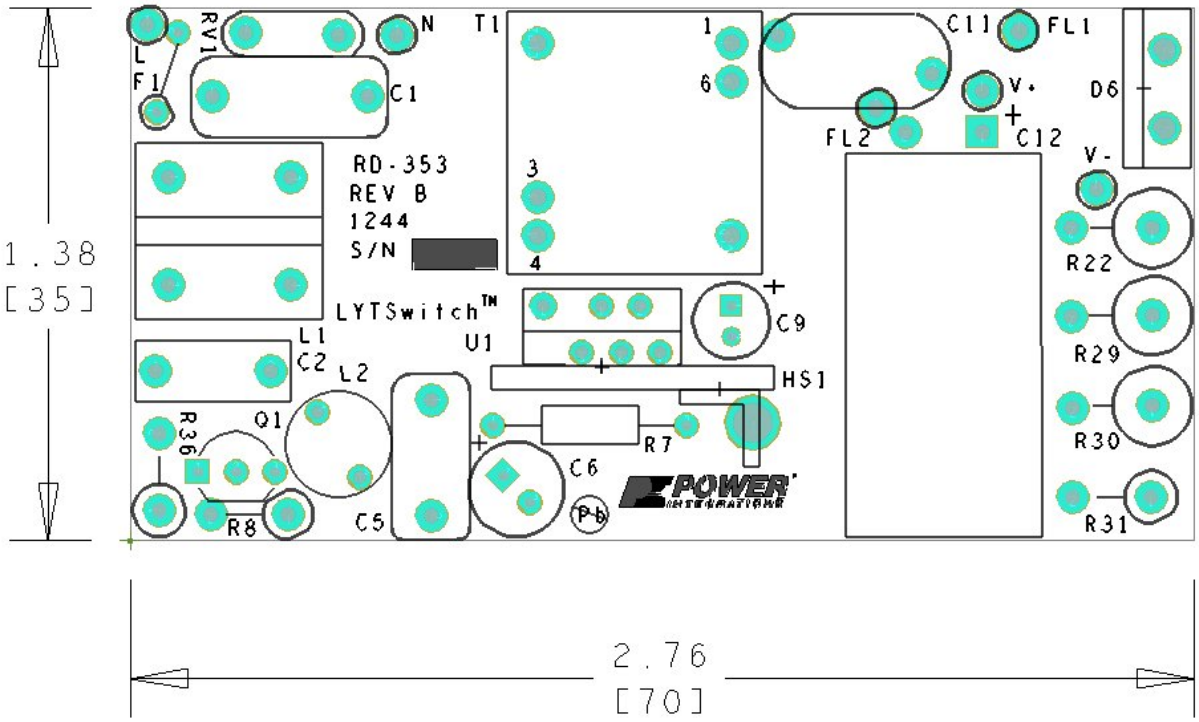

Figure 5 – Top Side.

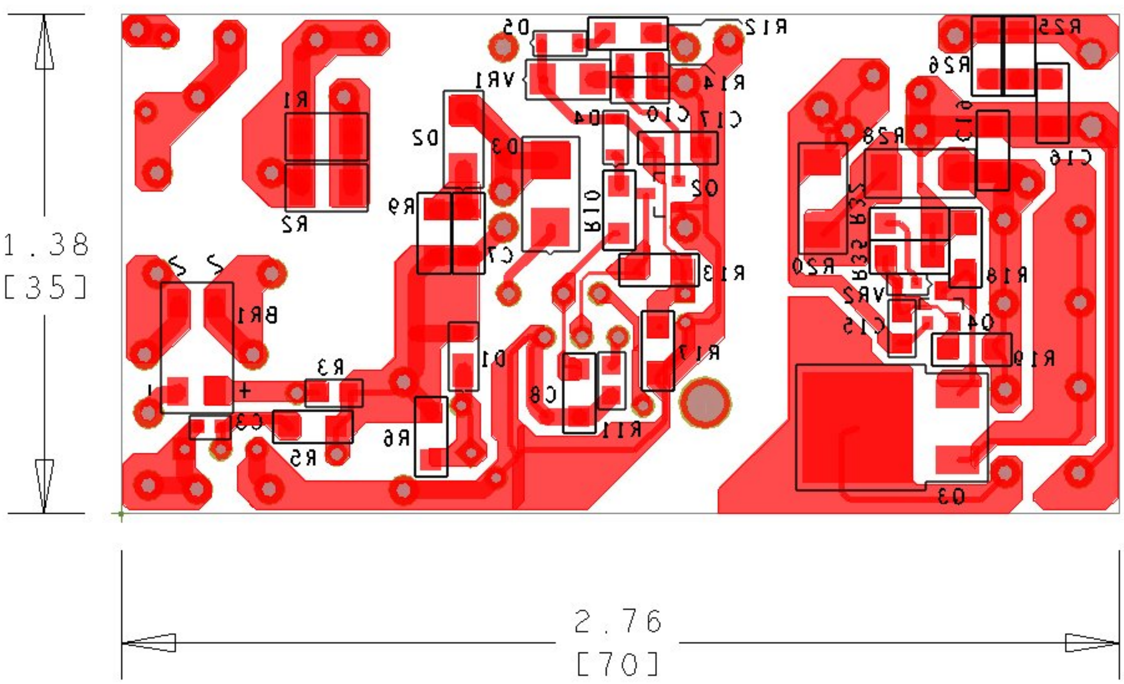

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
3	1	C2	33 nF, 310 VAC, Polyester Film, X2	BFC233920333	Vishay
4	1	C3	470 nF, 50 V, Ceramic, Y5G, 0603	C1608Y5V1H474Z	TDK
5	1	C5	180 nF, 250 V, Film	ECQ-E2184KB	Panasonic
6	1	C6	2.2 μF, 250 V, Electrolytic, (6.3 x 11)	225CKH250M	Illinois Capacitor
7	1	C7	2.2 nF, 630 V, Ceramic, X7R, 1206	ECJ-3FBJ222K	Panasonic
8	1	C8	100 μF, 10 V, X5R, 1206	C3216X5R1A107M	TDK
9	1	C9	22 μF, 50 V, Electrolytic, Low ESR, 900 mΩ, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
10	1	C10	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
11	1	C11	1.5 nF, Ceramic, Y1	440LD15-R	Vishay
12	1	C12	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	Nippon Chemi-Con
13	1	C15	100 nF, 25 V, Ceramic, X7R, 0805	08053C104KAT2A	AVX
14	1	C16	220 pF, 630 V, Ceramic, NPO, 1206	C3216C0G2J221J	TDK
15	1	C17	100 nF, 50 V, Ceramic, X7R, 1206	GRM319R71H104KA01D	Murata
16	1	C19	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
17	1	D1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
18	1	D2	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
19	1	D3	100 V, 3 A, Schottky, DO-214AA	STPS3H100U	ST Micro
20	1	D4	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
21	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
22	1	D6	100 V, 8 A, Schottky, TO-220AC	8TQ100PBF	Vishay
23	1	F1	3 A, 125 V, Fast, Microfuse, Axial	MQ3	BelFuse
24	1	L1	18.7 mH, 0.22 A, Common Mode Choke	RL-4400-1-18.7	Renco
25	1	L2	2.2 mH, 0.19 A, Ferrite Core	CTCH895F-222K	CT Parts
26	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
27	2	Q2 Q4	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semir
28	1	Q3	NPN, Power BJT, 400 V, 2 A, SOT-428	2SD1760TLR	Rohm Semi
29	2	R1 R2	1 kΩ, 5%, 1/2 W, Thick Film, 1210	ERJ-14YJ102U	Panasonic
30	1	R3	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
31	2	R5 R6	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
32	1	R7	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole
33	1	R8	100 Ω, 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
34	1	R9	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
35	1	R10	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
36	1	R11	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	Panasonic
37	3	R12 R25 R26	39 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ390V	Panasonic
38	1	R13	154 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1543V	Panasonic
39	1	R14	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
40	4	R17 R18 R19 R32	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
41	2	R20 R28	1 Ω, 5%, 3/4 W, Thick Film, 2010	ERJ-12ZYJ1R0U	Panasonic
42	2	R22 R29	300 Ω, 5%, 2 W, Metal Oxide	RSF200JB-300R	Yageo
43	1	R31	30 Ω, 5%, 1 W, Metal Oxide	RSF100JB-30R	Yageo
44	1	R35	1.5 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ155V	Panasonic
45	1	R36	0 Ω, 1/4 W, Metal Oxide	Z0R-25-R-52-0R	Yageo

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46	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
47	1	T1	Bobbin, RM6, Vertical, 6 pins Transformer	B65808-N1006-D1 SNX-R1662	Epcos Santronics USA
48	1	U1	LYTSwitch, eSIP-7C	LYT4314E	Power Integrations
49	1	VR1	33 V, 5%, 500 mW, DO-213AA (MiniMELF)	ZMM5257BDICT-ND	Diodes, Inc.
50	1	VR2	27 V, 5%, 150 mW, SOD 523	EDZTE6127B	Rohm Semi

7 Transformer Specification

7.1 Electrical Diagram

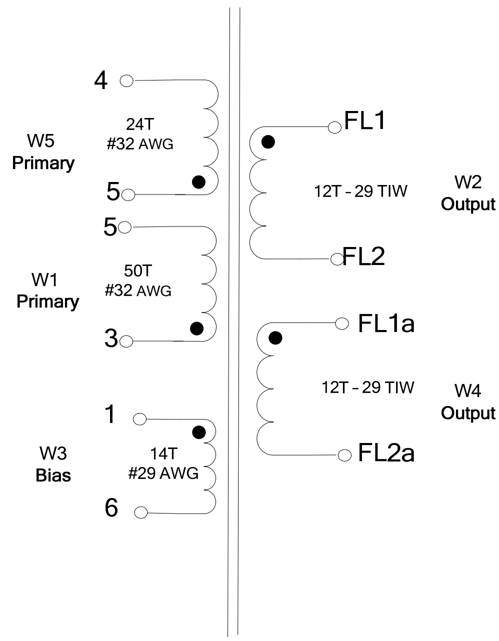

Figure 7 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 3, 4, 6 to FL1, FL2.	3000 VAC
Primary Inductance	Pins 3-4, all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	1.4 mH ±5%
Resonant Frequency	Pins 3-4, all other windings open.	1000 kHz (Min.)
Primary Leakage Inductance	Pins 3-4, with FL1-FL2 shorted, measured at 100 kHz, 0.4 V_{RMS}.	15 μH max

7.3 Materials

Item	Description
[1]	Core: RM6S/I 3F3.
[2]	B-RM6-V 6 pins (3/3) or equivalent. With mounting clip, CLI/P-RM6.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 6.4 mm wide.
[4]	Wire: Magnet, #32 AWG, solderable double coated.
[5]	Wire: Magnet, #29 AWG, solderable double coated.
[6]	Wire, Triple Insulated, Furukawa TEX-E or Equivalent, #29 TIW.
[7]	Transformer Varnish, Dolph BC-359 or equivalent.

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7.4 Transformer Build Diagram

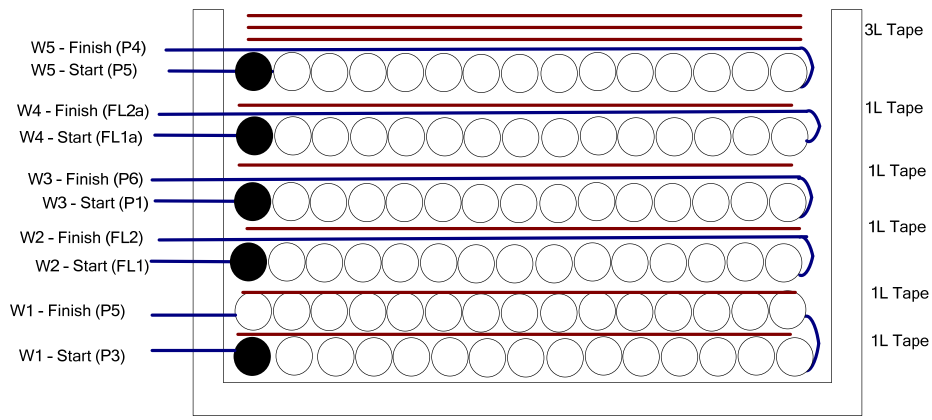

Figure 8 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel such that pin side on the left side. Winding direction is the clockwise direction.
WDG 1 (Primary)	Starting at pin 3, wind 50 turns of wire item [4] in two layers. Apply one layer of tape item [3] between 1st and 2nd layer. Finish at pin 5.
Insulation	Apply one layer of tape item [3].
WDG 2 (Secondary)	Starting at pin 1 side of the bobbin, leave about 1” of wire item [6], use small tape to mark as FL1, wind 12 turns in one layer. At the last turn exit the same slot, leave about 0.75”, and mark as FL2.
Insulation	Apply one layer of tape item [3].
WDG 3 (Bias)	Starting at pin 1, wind 14 turns of wire item [5], spreading the wire, and finish at pin 6.
Insulation	Apply one layer of tape item [3].
WDG 2 (Secondary)	Starting at pin 1 side of the bobbin, leave about 1” of wire item [6], use small tape to mark as FL1a, wind 12 turns in one layer. At the last turn exit the same slot, leave about 0.75”, and mark as FL2a. Twist FL1a with FL1 and FL2a with FL2.
WDG 3 (Primary)	Starting at pin 5, wind 24 turns of wire item [4] in one layer. Finish at pin 4.
Finish Wrap	Apply three layers of tape item [3] for finish wrap.
Final Assembly	Cut pin 2 and pin 5. Grind core to get 1.4 mH inductance. Assemble and secure core halves. Dip impregnate using varnish item [7].

8 U1 Heat Sink

8.1 U1 Heat Sink Fabrication Drawing

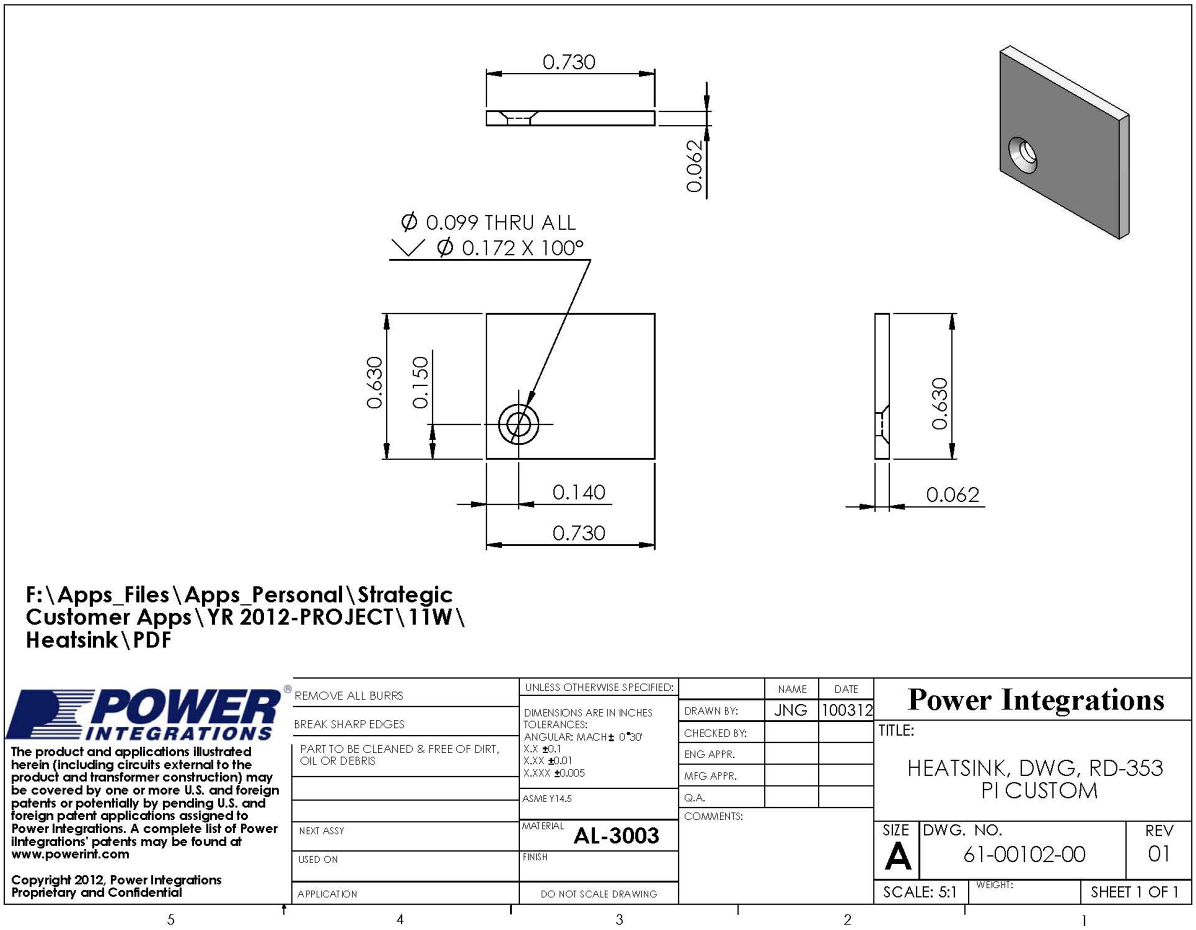

Figure 9 – Heat Sink Dimensions.

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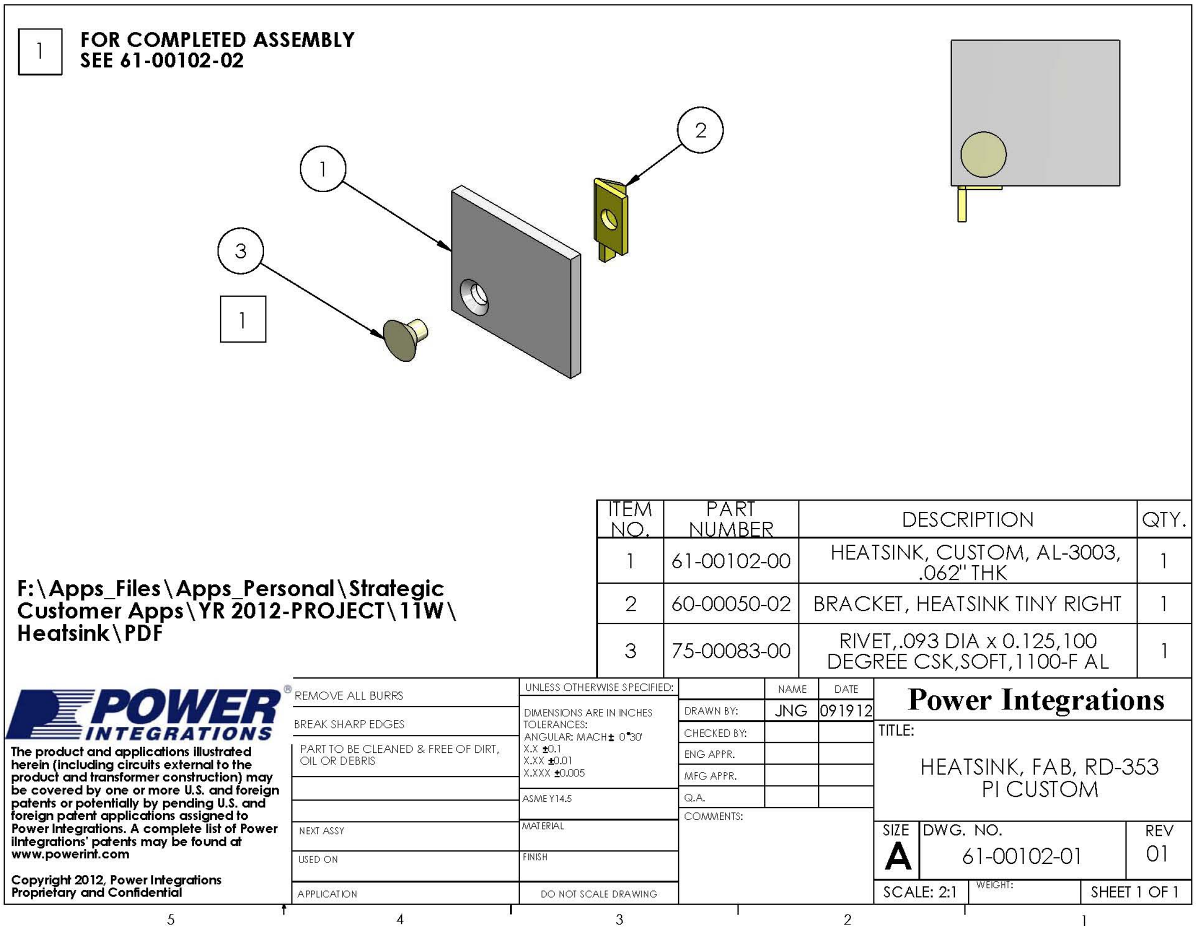
8.2 U1 Heat Sink Assembly Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	61-00102-00	HEATSINK, CUSTOM, AL-3003, .062" THK	1
2	60-00050-02	BRACKET, HEATSINK TINY RIGHT	1
3	75-00083-00	RIVET,.093 DIA x 0.125,100 DEGREE CSK,SOFT,1100-F AL	1

Figure 9a – U1 Heat Sink Assembly Drawing**.**

8.3 U1 and Heat Sink Assembly Drawing

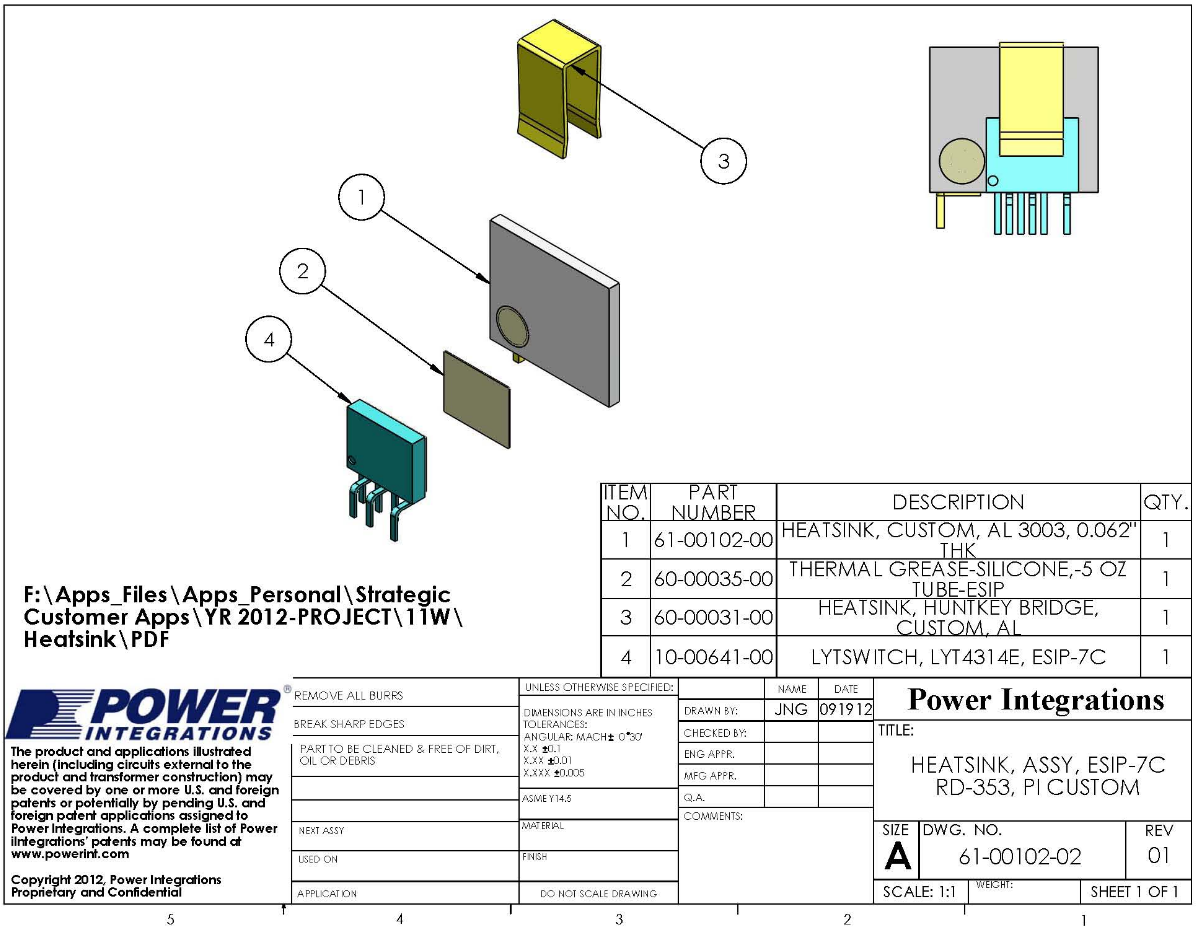


Figure 10 – U1 and Heat Sink Assembly Drawing.

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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 a voltage of 15 V ~ 21 V. The table in Section 9.6 shows complete test data values.

9.1 Efficiency

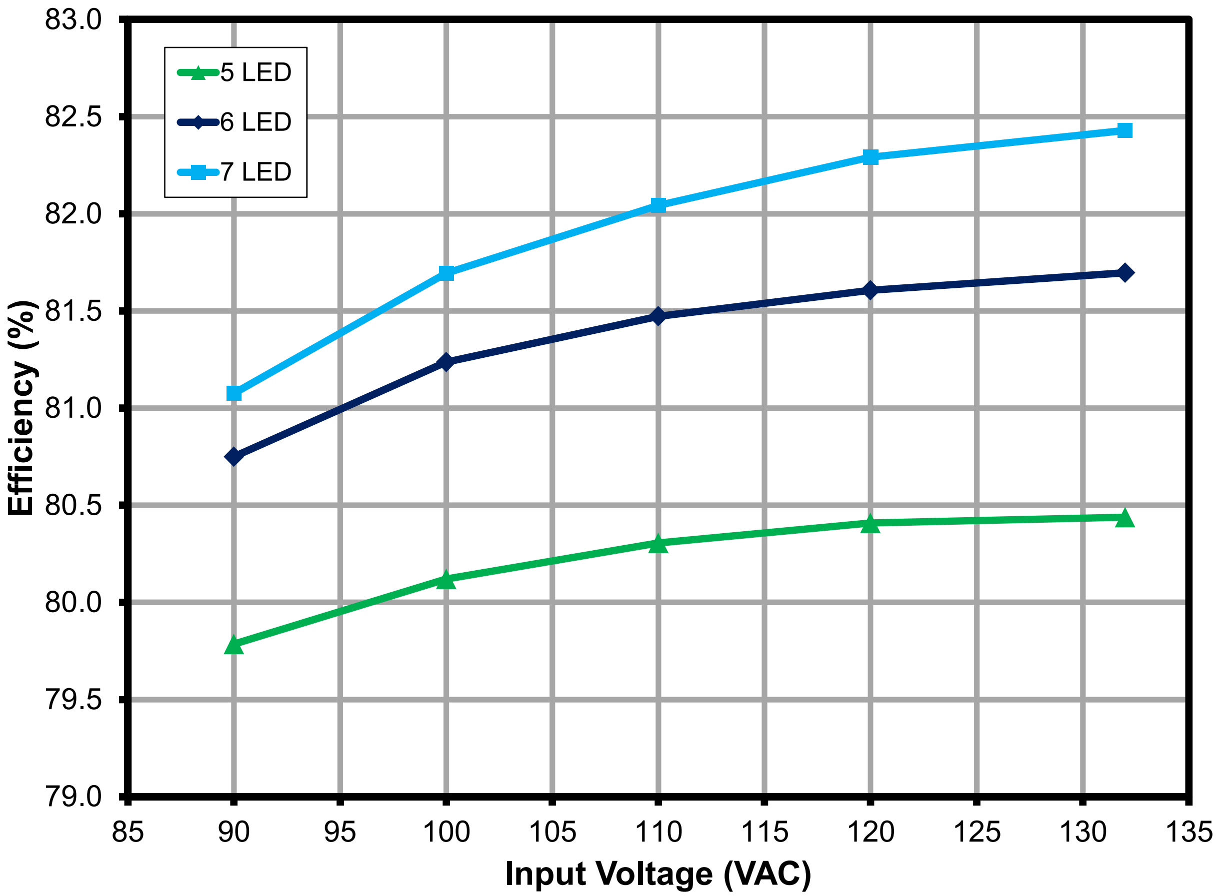

Figure 11 – Efficiency vs. Line and Load.

9.2 Line and Load Regulation

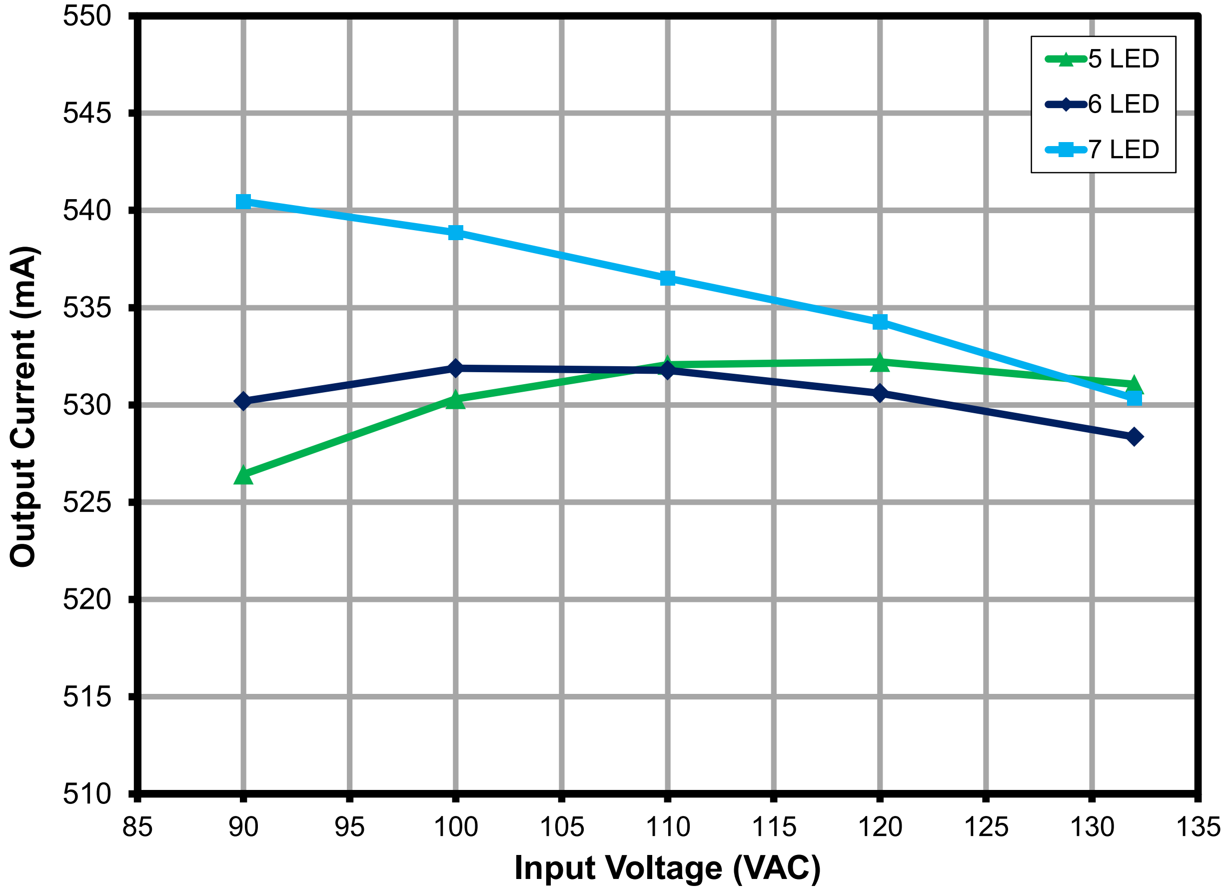

Figure 12 – Regulation vs. Line and Load.

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9.3 Power Factor

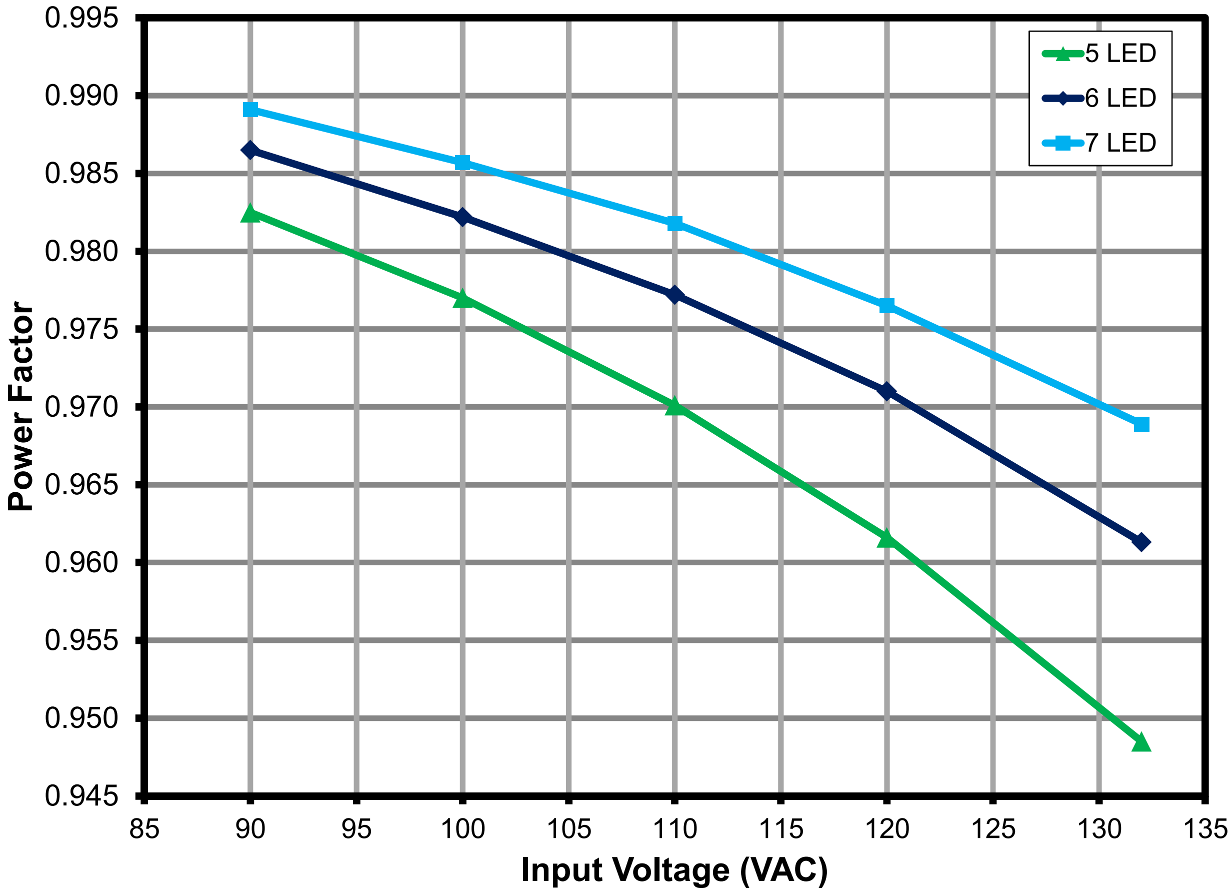

Figure 13 – Power Factor vs. Line and Load.

9.4 A-THD

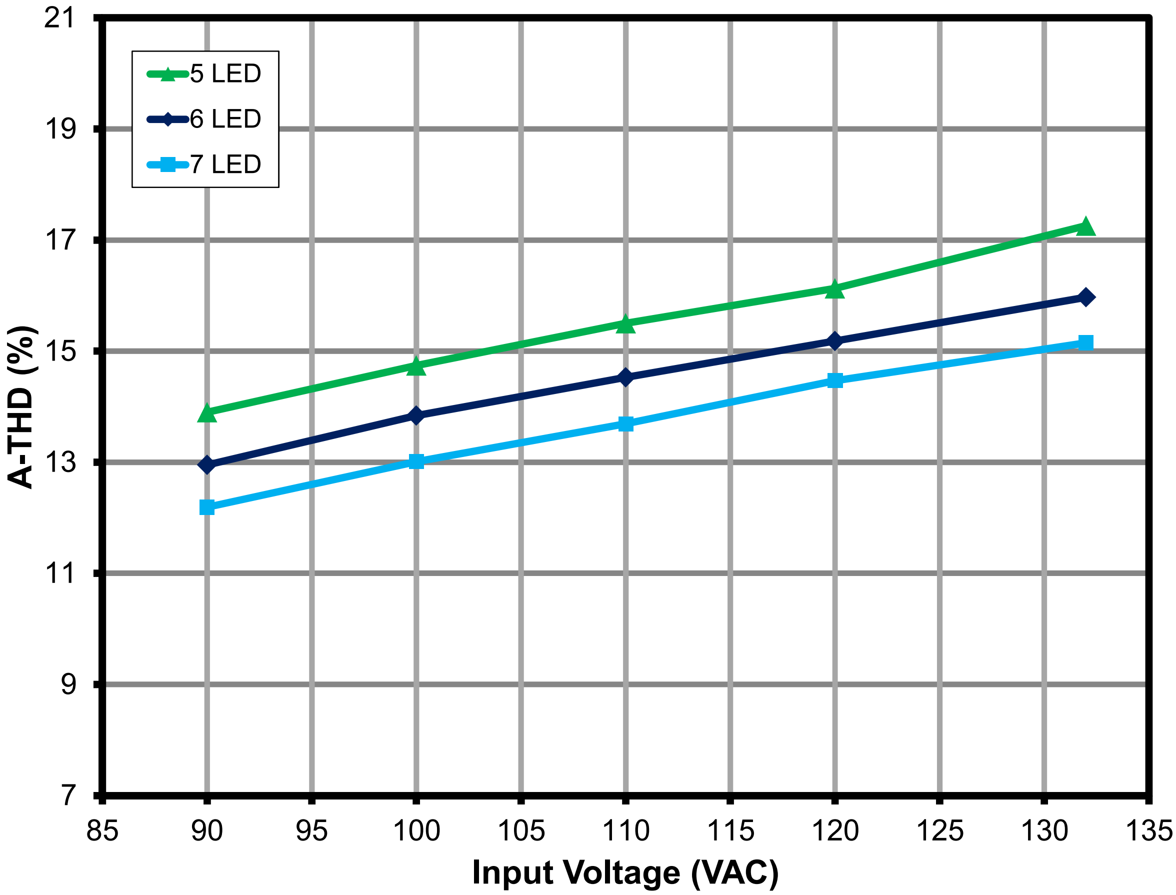

Figure 14 – A-THD vs. Line and Load.

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9.5 Harmonic Currents

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment[1]. Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

9.5.1 15 V LED Load

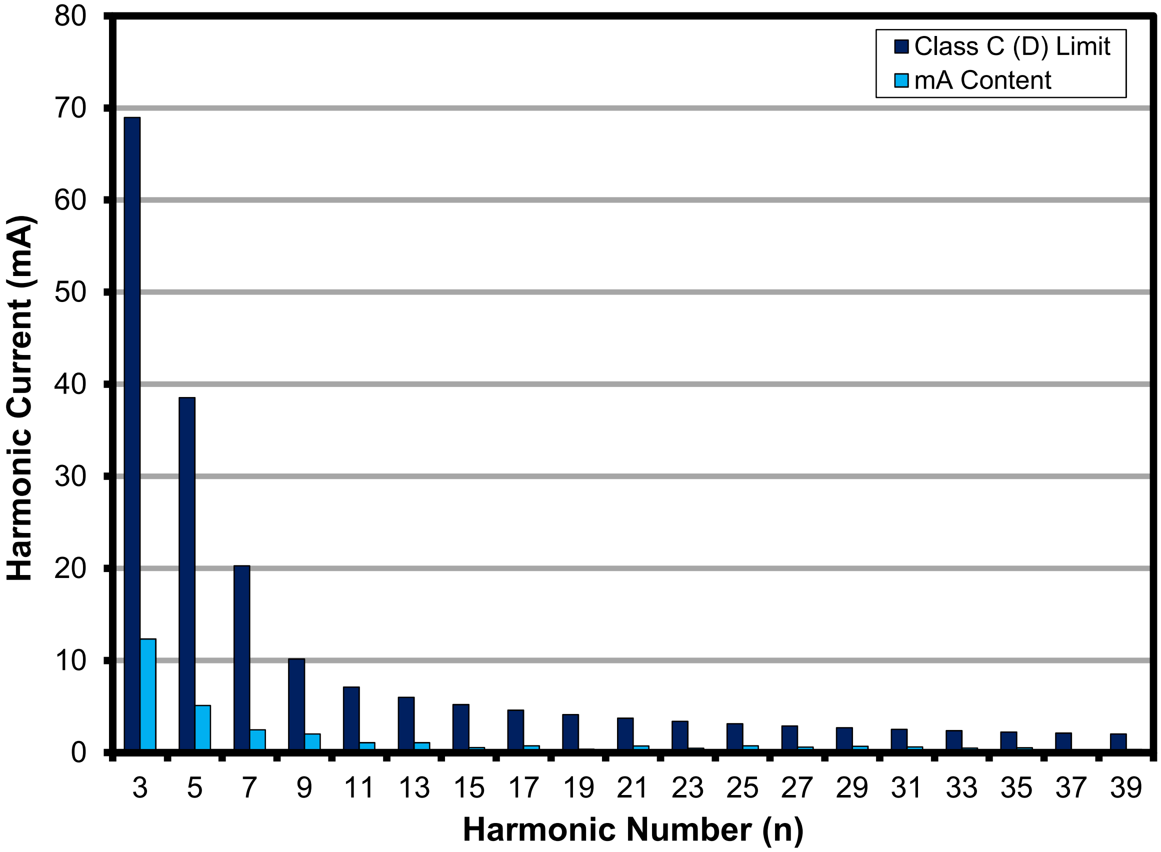

Figure 15 – 15 V LED Load Input Current Harmonics case (IEC61000-3-2) at 120 VAC, 60 Hz.

[1] IEC6000-3-2 Section 7.3, table 2, column 2.

9.5.3 18 V LED Load

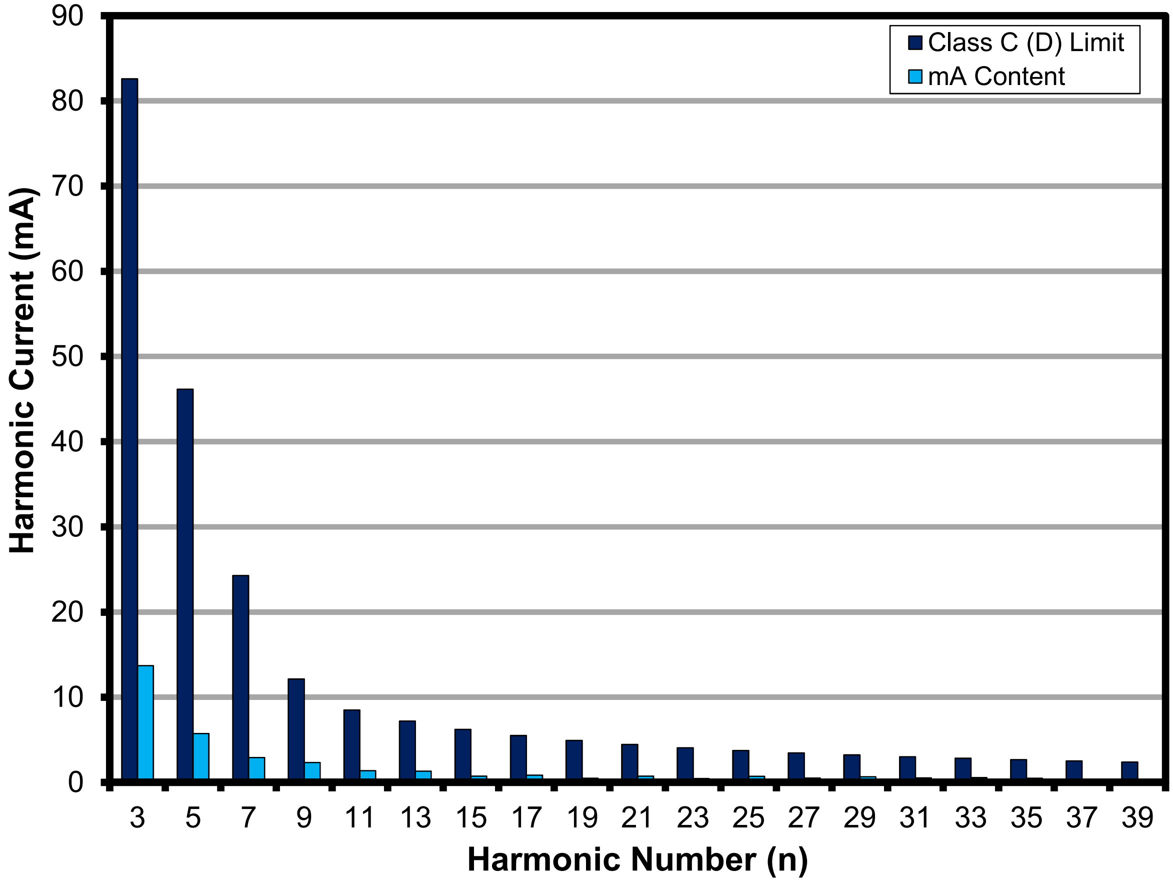

Figure 16 – 18 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

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9.5.4 21 V LED Load

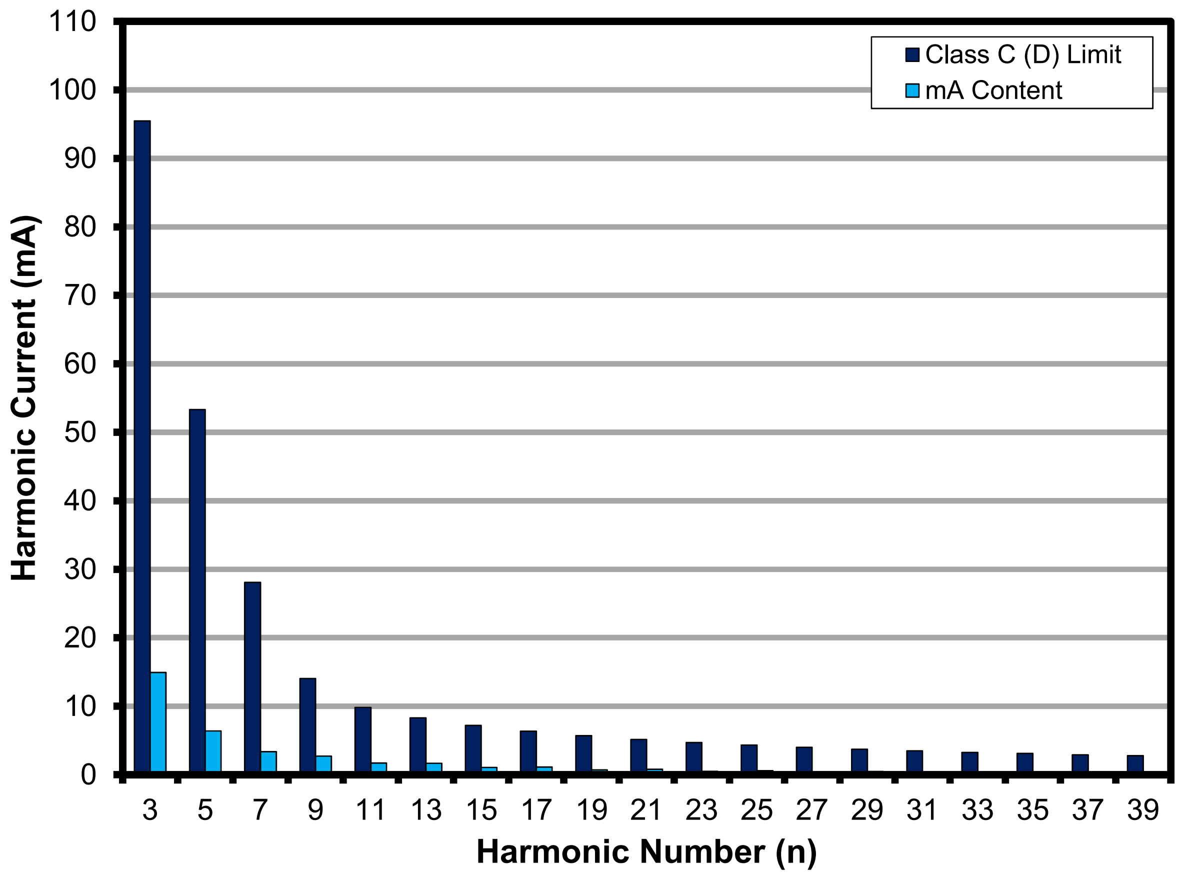

Figure 17 – 21 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

9.6 Test Data

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

9.6.1 Test Data, 15 V V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.05	114.25	10.109	0.983	13.90	15.27	526.43	8.07	8.04	79.79	2.04
100.02	103.80	10.144	0.977	14.74	15.28	530.30	8.13	8.10	80.12	2.02
110.08	95.09	10.155	0.970	15.5	15.28	532.07	8.16	8.13	80.31	2.00
120.05	87.86	10.143	0.962	16.13	15.28	532.21	8.16	8.13	80.41	1.99
132.08	80.73	10.114	0.949	17.26	15.28	531.06	8.14	8.11	80.44	1.98

9.6.2 Test Data, 18 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.05	138.29	12.285	0.987	12.95	18.66	530.19	9.92	9.90	80.75	2.36
100.02	124.65	12.245	0.982	13.84	18.66	531.88	9.95	9.92	81.24	2.30
110.07	113.40	12.199	0.977	14.53	18.65	531.78	9.94	9.92	81.47	2.26
120.05	104.18	12.144	0.971	15.18	18.63	530.60	9.91	9.89	81.61	2.23
132.08	95.06	12.070	0.961	15.97	18.62	528.36	9.86	9.84	81.70	2.21

9.6.3 Test Data, 21 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.04	162.22	14.447	0.989	12.19	21.63	540.45	11.71	11.69	81.08	2.73
100.01	144.90	14.285	0.986	13.01	21.61	538.86	11.67	11.65	81.69	2.62
110.07	130.95	14.151	0.982	13.69	21.60	536.52	11.61	11.59	82.04	2.54
120.04	119.76	14.038	0.977	14.47	21.58	534.26	11.55	11.53	82.29	2.49
132.07	108.61	13.898	0.969	15.15	21.56	530.34	11.46	11.43	82.43	2.44

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9.6.4 120 VAC 60 Hz, 15 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	87.86	10.1430	0.9616	16.13
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	86.63				
2	0.02	0.02%		2.00%	
3	12.32	14.22%	68.9724	28.85%	Pass
5	5.11	5.90%	38.5434	10.00%	Pass
7	2.46	2.84%	20.2860	7.00%	Pass
9	2.00	2.31%	10.1430	5.00%	Pass
11	1.08	1.25%	7.1001	3.00%	Pass
13	1.08	1.25%	6.0078	3.00%	Pass
15	0.54	0.62%	5.2067	3.00%	Pass
17	0.73	0.84%	4.5942	3.00%	Pass
19	0.38	0.44%	4.1106	3.00%	Pass
21	0.71	0.82%	3.7191	3.00%	Pass
23	0.47	0.54%	3.3957	3.00%	Pass
25	0.74	0.85%	3.1240	3.00%	Pass
27	0.58	0.67%	2.8926	3.00%	Pass
29	0.68	0.78%	2.6931	3.00%	Pass
31	0.61	0.70%	2.5194	3.00%	Pass
33	0.49	0.57%	2.3667	3.00%	Pass
35	0.51	0.59%	2.2315	3.00%	Pass
37	0.25	0.29%	2.1108	3.00%	Pass
39	0.31	0.36%	2.0026	3.00%	Pass
41	0.09	0.10%			
43	0.13	0.15%			
45	0.16	0.18%			
47	0.20	0.23%			
49	0.26	0.30%			

9.6.5 120 VAC 60 Hz, 18 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	104.18	12.1440	0.9710	15.18
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	102.92				
2	0.04	0.04%		2.00%	
3	13.71	13.32%	82.5792	29.13%	Pass
5	5.73	5.57%	46.1472	10.00%	Pass
7	2.90	2.82%	24.2880	7.00%	Pass
9	2.34	2.27%	12.1440	5.00%	Pass
11	1.37	1.33%	8.5008	3.00%	Pass
13	1.32	1.28%	7.1930	3.00%	Pass
15	0.73	0.71%	6.2339	3.00%	Pass
17	0.86	0.84%	5.5005	3.00%	Pass
19	0.47	0.46%	4.9215	3.00%	Pass
21	0.73	0.71%	4.4528	3.00%	Pass
23	0.45	0.44%	4.0656	3.00%	Pass
25	0.72	0.70%	3.7404	3.00%	Pass
27	0.51	0.50%	3.4633	3.00%	Pass
29	0.67	0.65%	3.2244	3.00%	Pass
31	0.54	0.52%	3.0164	3.00%	Pass
33	0.55	0.53%	2.8336	3.00%	Pass
35	0.49	0.48%	2.6717	3.00%	Pass
37	0.34	0.33%	2.5273	3.00%	Pass
39	0.38	0.37%	2.3977	3.00%	Pass
41	0.18	0.17%			
43	0.24	0.23%			
45	0.11	0.11%			
47	0.13	0.13%			
49	0.13	0.13%			

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9.6.6 120 VAC 60 Hz, 21 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	119.76	14.0380	0.9765	14.47
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	118.44				
2	0.04	0.03%		2.00%	
3	14.93	12.61%	95.4584	29.30%	Pass
5	6.39	5.40%	53.3444	10.00%	Pass
7	3.38	2.85%	28.0760	7.00%	Pass
9	2.72	2.30%	14.0380	5.00%	Pass
11	1.71	1.44%	9.8266	3.00%	Pass
13	1.67	1.41%	8.3148	3.00%	Pass
15	1.05	0.89%	7.2062	3.00%	Pass
17	1.12	0.95%	6.3584	3.00%	Pass
19	0.70	0.59%	5.6891	3.00%	Pass
21	0.79	0.67%	5.1473	3.00%	Pass
23	0.49	0.41%	4.6997	3.00%	Pass
25	0.59	0.50%	4.3237	3.00%	Pass
27	0.37	0.31%	4.0034	3.00%	Pass
29	0.48	0.41%	3.7273	3.00%	Pass
31	0.30	0.25%	3.4869	3.00%	Pass
33	0.40	0.34%	3.2755	3.00%	Pass
35	0.34	0.29%	3.0884	3.00%	Pass
37	0.39	0.33%	2.9214	3.00%	Pass
39	0.26	0.22%	2.7716	3.00%	Pass
41	0.32	0.27%			
43	0.23	0.19%			
45	0.26	0.22%			
47	0.23	0.19%			
49	0.20	0.17%			

10 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 120 VAC, 60 Hz line frequency, room temperature, and 21 V LED load.

The output current high limit I_{OUT} (HL) and low limit I_{OUT} (LL) were incorporated based on the NEMA SSL6-2010 (section 4, page 9). The limits incorporated on the succeeding graphs assumes that 100% relative light output falls on the maximum operating output current of 530 mA and 0 mA is 0% light output, and input line of 120 VAC, 60 Hz.

10.1 Dimming Curve with Simulated TRIAC

Agilent 6812B AC Source programmed as perfect leading edge dimmer

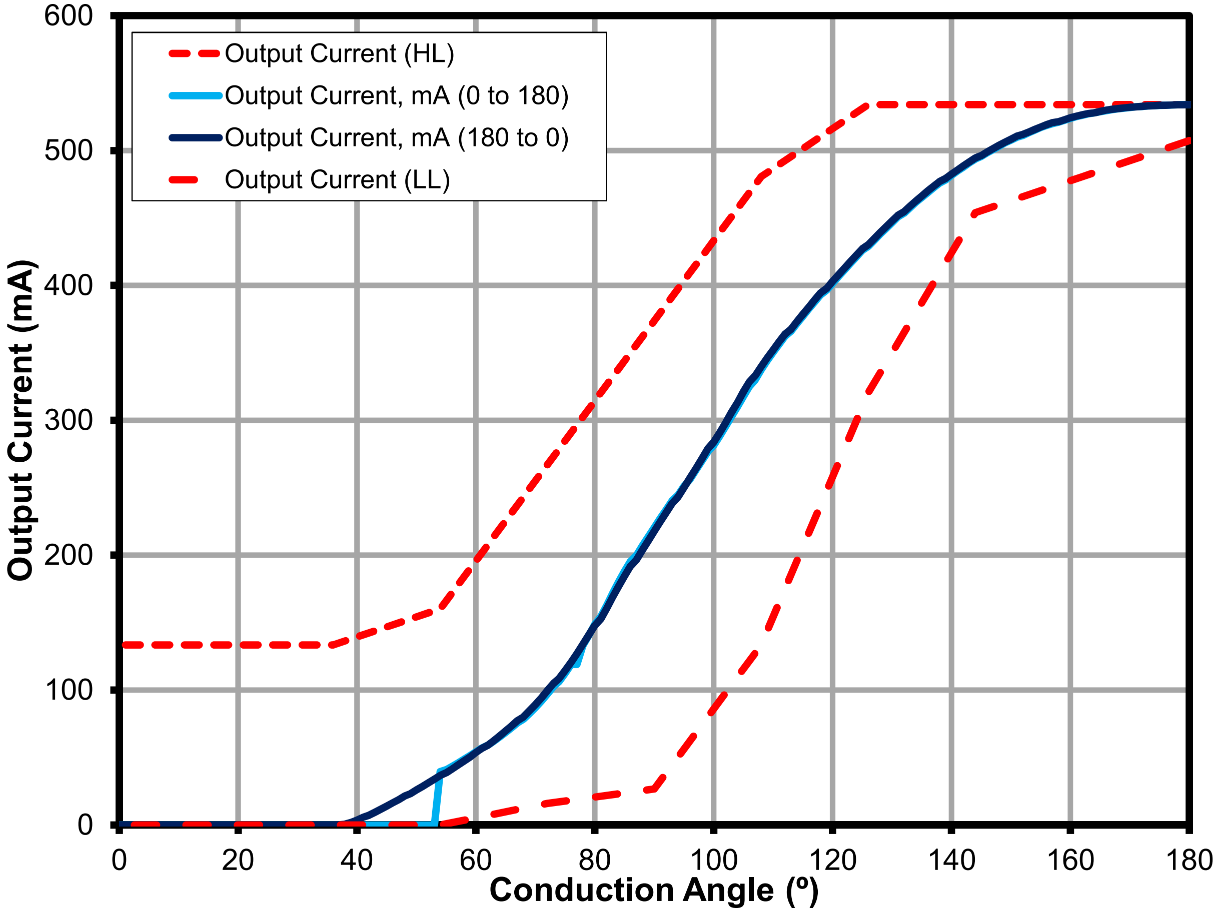

Figure 18 – Dimming Curve at 120 VAC, 60 Hz Input, 21 V LED Load.

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10.2 Performance with Actual Dimmers

The following data were taken by measuring the RMS input voltage to the driver as a result of TRIAC chopping the AC input. A leading and trailing edge TRIAC dimmer was used on the data below using 21 V LED load and 120 V, 60 Hz AC input.

10.2.1 Dimming Curve

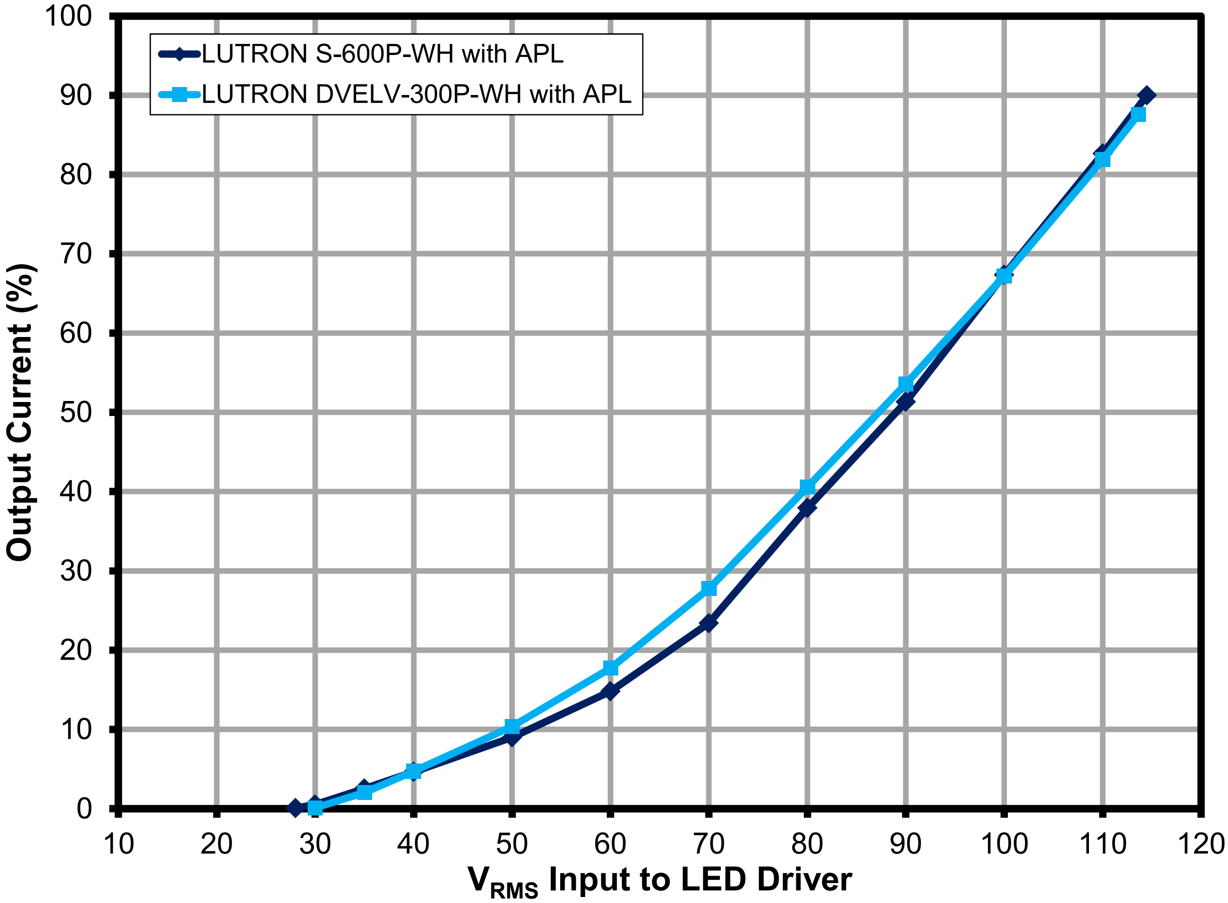

Figure 19 – Dimming Curve as a function of Input Voltage to the Driver.

10.2.2 Typical Leading Edge Dimmer Performance Data

Dimmer: LUTRON S-600P-WH
Input: 120 VAC, 60 Hz

$V_{IN(RMS)}$ (V)	I_{OUT} (mA)	I_{OUT} (%)	V_{OUT} (V)	P_{OUT} (W)	P_{IN} (W)	Efficiency (%)	P_{LOSS} (W)	Start-upTime (ms)
114.5	477	90.00	21.4	10.25	14	73.2	3.75	137
110	438	82.64	21.22	9.33	13.1	71.2	3.77	149
100	357	67.36	20.92	7.5	11.12	67.4	3.62	167
90	272	51.32	20.58	5.63	9.2	61.2	3.57	197
80	201	37.92	20.23	4.11	7.8	52.7	3.69	228
70	124	23.40	19.81	2.49	6.67	37.3	4.18	274
60	78.5	14.81	19.4	1.53	5.79	26.4	4.26	335
50	47.6	8.98	19.05	0.91	4.95	18.4	4.04	506
40	24.6	4.64	18.66	0.46	4.26	10.8	3.8	1250
35	13.5	2.55	18.37	0.25	3.9	6.4	3.65	
30	2.8	0.53	17.83	0.05	3.51	1.4	3.46	
28	0.43	0.08	17.3	0.007	3.34	0.2	3.333	

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10.2.3 Typical Trailing Edge Dimmer Performance Data

Dimmer: LUTRON DVELV-300P-WH
Input: 120 VAC, 60 Hz

$V_{IN(RMS)}$ (V)	I_{OUT} (mA)	I_{OUT} (%)	V_{OUT} (V)	P_{OUT} (W)	P_{IN} (W)	Efficiency (%)	P_{LOSS} (W)	Start-upTime (ms)
113.6	464	87.55	21.42	9.97	13.37	74.6	3.4	133
110	434	81.89	21.24	9.25	12.48	74.1	3.23	133
100	356	67.17	20.95	7.5	10.38	72.3	2.88	140
90	284	53.58	20.64	5.88	8.58	68.5	2.7	151
80	215	40.57	20.3	4.39	7.19	61.1	2.8	176
70	147	27.74	19.97	2.97	6.13	48.5	3.16	189
60	94	17.74	19.55	1.86	5.26	35.4	3.4	226
50	55	10.38	19.1	1.05	4.45	23.6	3.4	296
40	25	4.72	18.63	0.466	3.7	12.6	3.234	468
35	10.85	2.05	18.26	0.198	3.3	6.0	3.102	727
30	0.47	0.09	17.28	0.008	2.9	0.3	2.892	1520

10.2.4 Dimmer Compatibility List

Item	List of Dimmers	Part Number	$V_{RMS(MIN)}$	I_{MIN} (mA)	$V_{RMS(MAX)}$	I_{MAX} (mA)	Dim Ratio
1	LUTRON LG600PH-LA	LG-600PH-WH	26	0.16	114.4	475	2969
2	LUTRON S603P	S-603P-WH	27.27	0.24	115.0	478	1992
3	LUTRON SLV600P	SLV600P-WH	28.3	0.96	115.4	485	505
4	LUTRON S600	S-600-WH	27	0.17	117.5	508	2988
5	LUTRON S-600PH-WH	S-600PH-WH	27	0.24	114.8	479	1996
6	LUTRON DVCL153P	DVWCL-153-PLH-WH	27	0.27	113.3	464	1719
7	LUTRON DV603P	DV-603P-WH	27	0.25	114.4	477	1908
8	LUTRON DV600P	DV-600P-WH	26.9	0.18	114.6	477	2650
9	LUTRON TG600PH-IV	TG-600PH-WH	35	12.00	115.6	488	41
10	LUTRON AY600P	AY-600P-WH	36	14.30	115.1	483	34
11	LUTRON GL600P-WH	GL-600P-WH	27.6	0.48	114.7	479	998
12	LEVITON 6633PLI	R62-06633-1LW	27	0.70	118.4	521	744
13	LEVITON 6631-LI	R62-06631-1LW	28	0.22	116.4	495	2250
14	LEVITON IPI06	R60-IPI06-1LM	38	22.00	118.1	516	23
15	LEVITON 6161-I	R52-06161-00W	33	0.65	115.0	482	742
16	LEVITON RP106	R52-RPI06-1LW	36	0.68	119.0	526	774
17	LEVITON 6681	R60-06681-0IW	27.4	0.20	112.0	450	2250
18	LEVITON TGM10-1LW	TGM10-1LW	30	2.60	113.2	463	178
19	LEVITON 6684	R60-06684-1IW	28.7	0.12	118.9	527	4392
20	LEVITON 6683	6683	30	0.22	119.0	527	2395
21	LEVITON 6613	R02-06613-PLW	27	0.30	118.6	522	1740
22	COOPER SLC03	SLC03P-W-K-L	27.4	0.36	116.0	492	1367
23	LUTRON GL600-WH	GL-600-WH	27	0.37	117.1	505	1365
24	LUTRON DVPDC-203P-WH	DVPDC-203P-WH	60	80.00	117.0	500	6
25	LUTRON LX600PL	LX-600PL-wh	27	0.21	116.6	497	2367
26	LUTRON D600P	D-600P-WH	28	0.50	113.1	462	924
27	LUTRON CTCL-153PDH		28	0.10	113.6	467	4670
28	LUTRON S-600P	S-600P	27	0.30	114.8	479	1597

29	LUTRON TGLV-600P	TGLV-600P	32	9.30	116.0	491	53
30	LUTRON TGLV-600PR	TGLV-600PR	34	11.00	115.3	485	44
31	LUTRON TT-300NLH-WH	TT-300NLH-WH	27	0.35	117.8	513	1466
32	LUTRON TT-300H-WH	TT-300H-WH	28	0.60	117.8	513	855
33	LUTRON NLV-1000-WH	NLV-1000-WH	26	0.10	116.1	493	4930
34	Lutron	MAELV -600	33.8	9.40	115.1	478	51
35	Lutron	S-600P	26.2	0.12	114.4	475	3958
36	Lutron	MAW-600	27	0.37	117.3	506	1368
37	Cooper	MIR-600	30.1	5.10	117.1	503	99
38	Lutron	S-600P	29.8	4.10	115.0	480	117
39	Lutron	S106P	27.8	0.20	114.0	469	2345
40	Lutron	S-600PNLH-WH	26.7	0.19	115.4	485	2553
41	Lutron	S-603PNL-WH	27.8	0.49	115.3	484	988
42	Lutron	SLV-603P-WH	33.44	10.40	115.1	482	46
43	Lutron	S-603PGH-WH	27.2	0.33	105.6	397	1203
44	Lutron	AYLV-600P-WH	32.2	8.80	115.2	485	55
45	Lutron	AYLV-603P-WH	34	12.00	114.4	477	40
46	Lutron	AY-103PNL-WH	29.5	1.50	116.4	496	331
47	Lutron	AY-10PNL-WH	28.8	0.90	118.5	520	578
48	Lutron	AY-10P-WH	26	0.10	116.8	501	5010
49	Lutron	AY-603PNL-WH	30.4	3.20	112.6	459	143
50	Lutron	AY-603PG-WH	32.3	6.70	102.4	372	56
51	Lutron	AY-603P-WH	36.5	14.30	112.7	460	32
52	Lutron	AY-600PNL-WH	31.2	3.70	115.1	483	131
53	Lutron	DVELV-300P-WH	29.87	0.41	113.8	467	1139
54	Lutron	DVLV-10P-WH	33.37	10.65	114.3	474	45
55	Lutron	DVLV-103P-WH	31.74	7.00	114.6	477	68
56	Lutron	DVLV-603P-WH	30.67	4.70	114.8	479	102
57	Lutron	S-1000-WH	28.3	0.75	117.4	507	676
58	Lutron	SELV-300P-WH	28.3	0.06	112.4	455	7583
59	Lutron	S-600P-WH	27	0.18	114.6	476	2644
60	Lutron	S-103PNL-WH	31	0.59	114.3	474	803
61	Lutron	GLV-600-WH	27.5	0.58	117.3	507	874

Figure 20 – Dimmer Compatibility List.

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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, 21 V LED Load

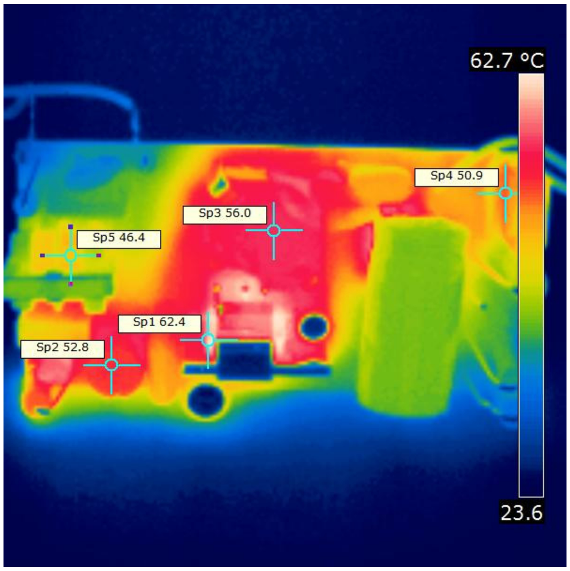

Figure 21 – Top Side. U1 = 62.4 ºC.

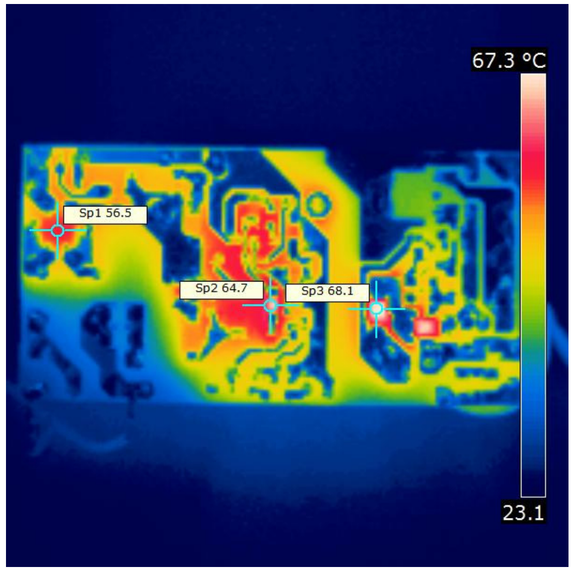

Figure 22 – Bottom Side. R20 = 68.1 ºC.

11.2 Non-Dimming V_{IN} = 132 VAC, 60 Hz, 21 V LED Load

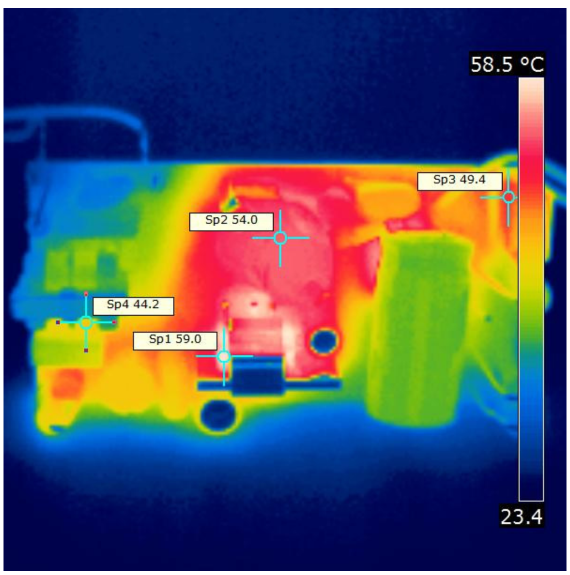

Figure 23 – Top Side. U1 = 59 ºC.

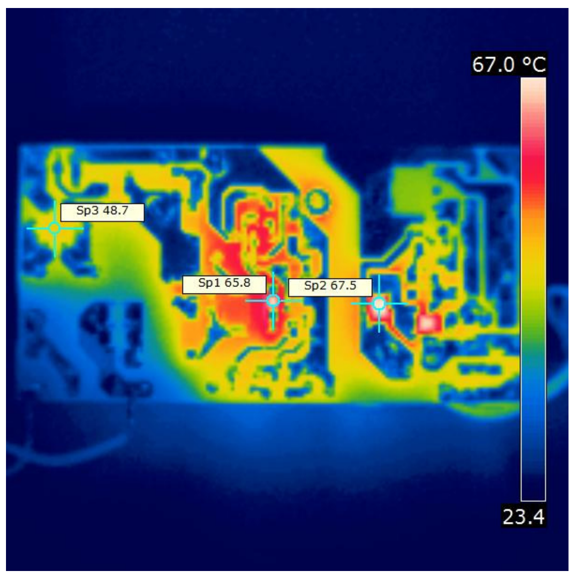

Figure 24 – Bottom Side. R20 = 67.3 ºC.

11.3 Dimming V_{IN} = 120 VAC, 60 Hz, 90º Conduction Angle, 21 V LED Load

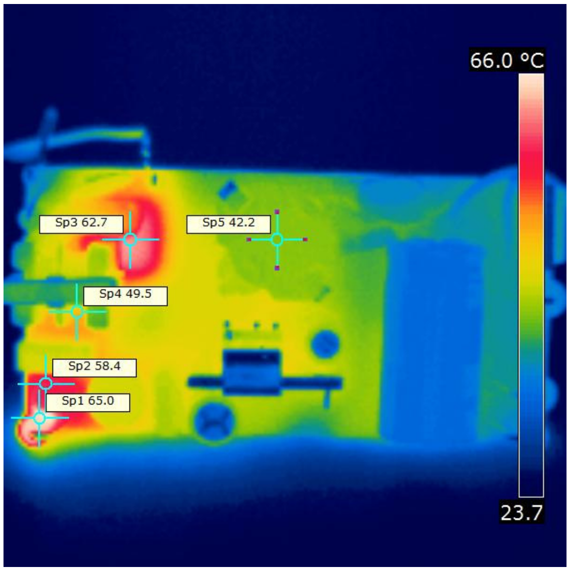

Figure 25 – Top Side. R8 = 65 ºC.

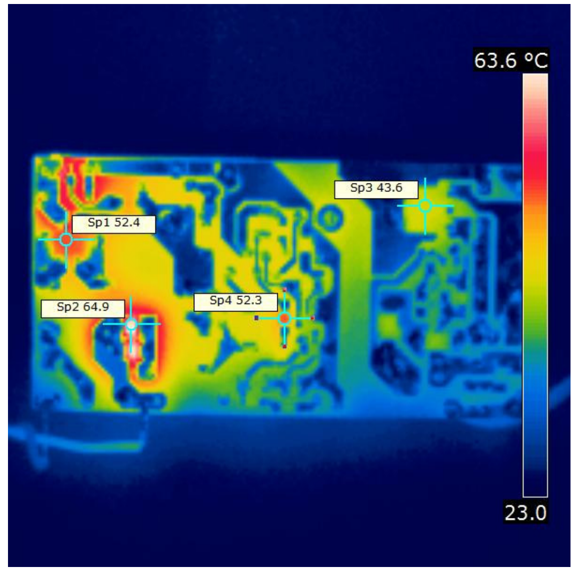

Figure 26 – Bottom Side. R2=64.9 ºC.

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12 Non- Dimming Waveforms

12.1 Input Voltage and Input Current Waveforms

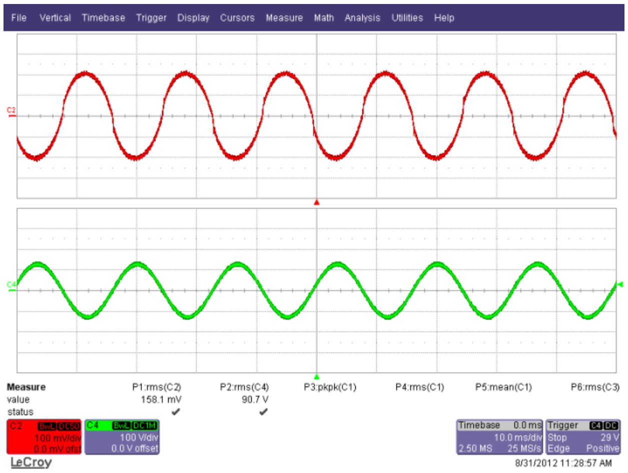

Figure 27 – 90 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

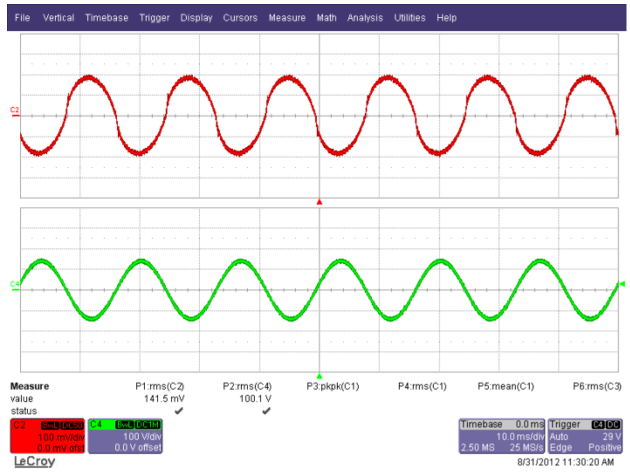

Figure 28 – 100 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

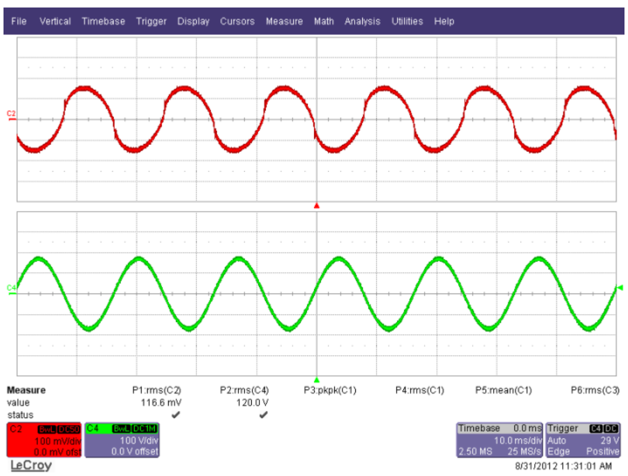

Figure 29 – 120 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

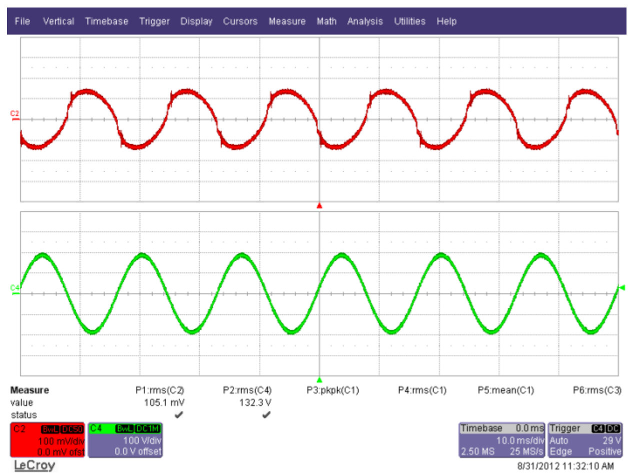

Figure 30 – 132 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

12.2 Output Current and Output Voltage at Normal Operation

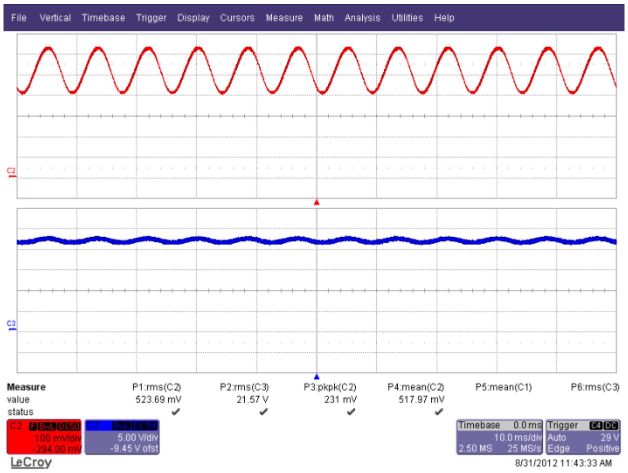

Figure 31 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 10 ms / div.

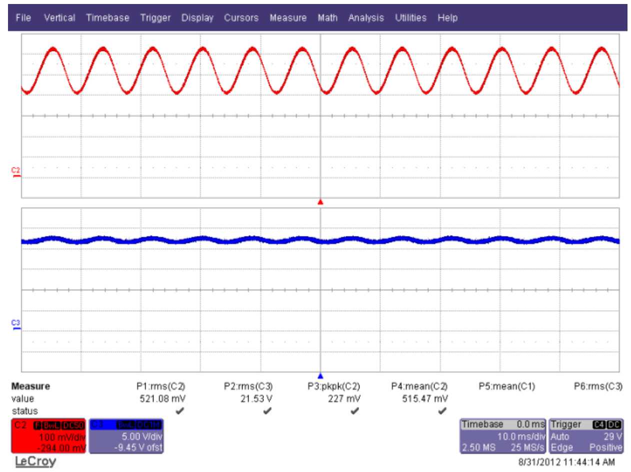

Figure 32 – 100 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 10 ms / div.

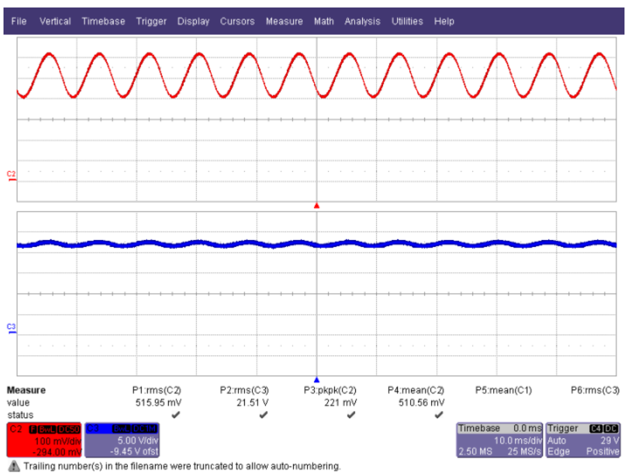

Figure 33 – 120 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 10 ms / div.

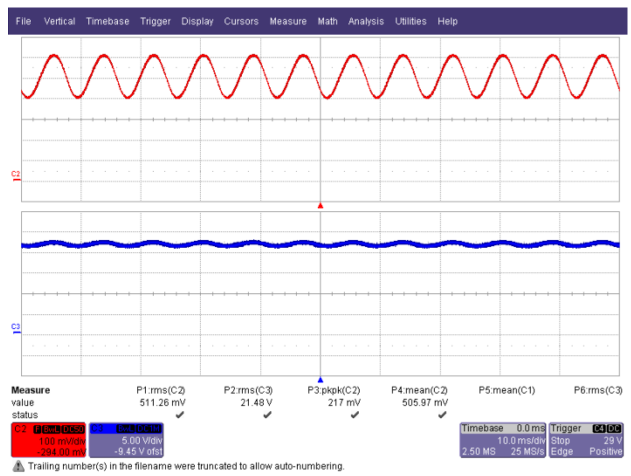

Figure 34 – 132 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 10 ms / div.

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12.3 Input Voltage and Output Current Waveform at Start-up

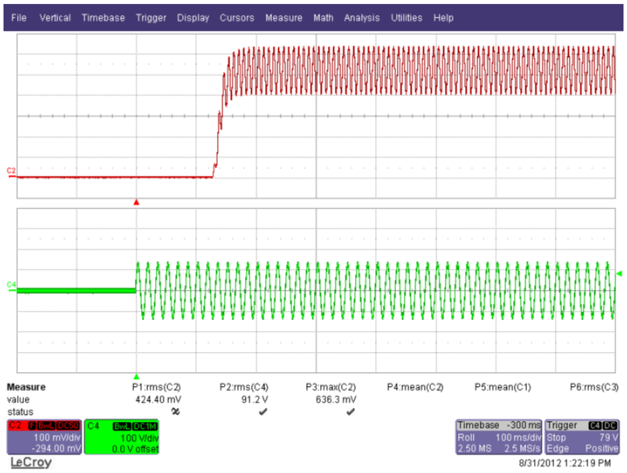

Figure 35 – 90 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

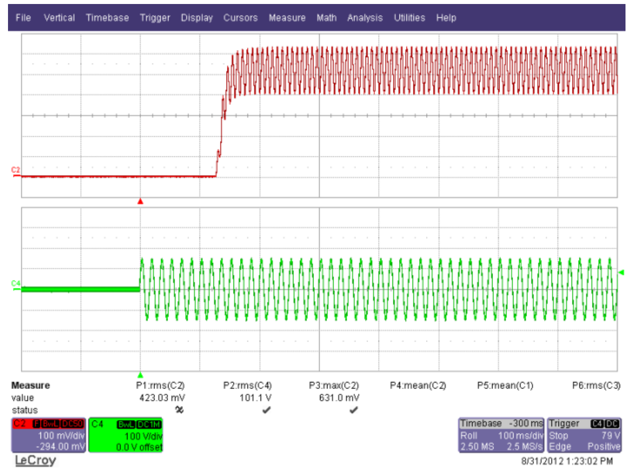

Figure 36 – 100 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

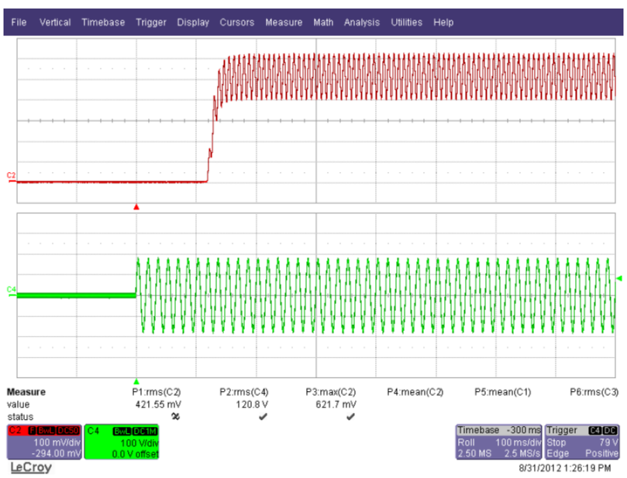

Figure 37 – 120 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

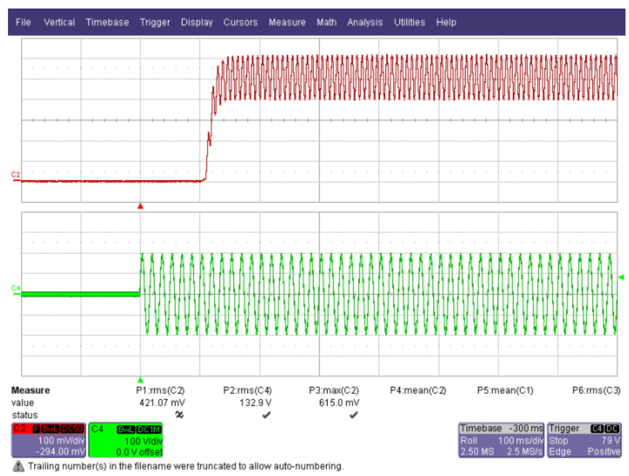

Figure 38 – 132 VAC, 60 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

12.4 Drain Voltage and Current at Normal Operation

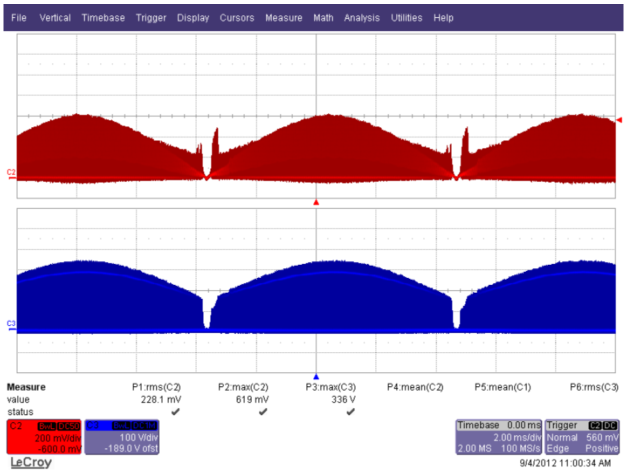

Figure 39 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

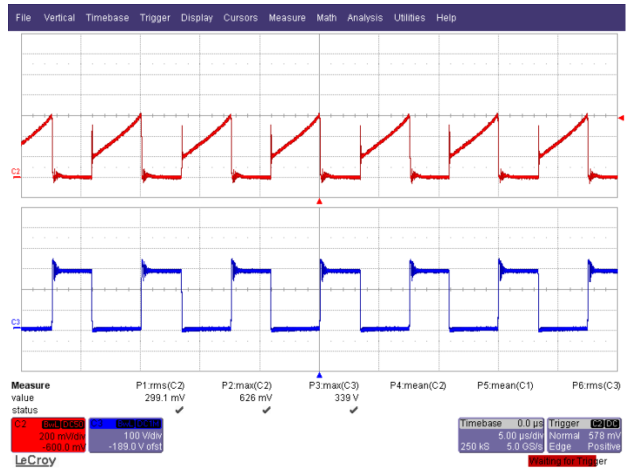

Figure 40 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

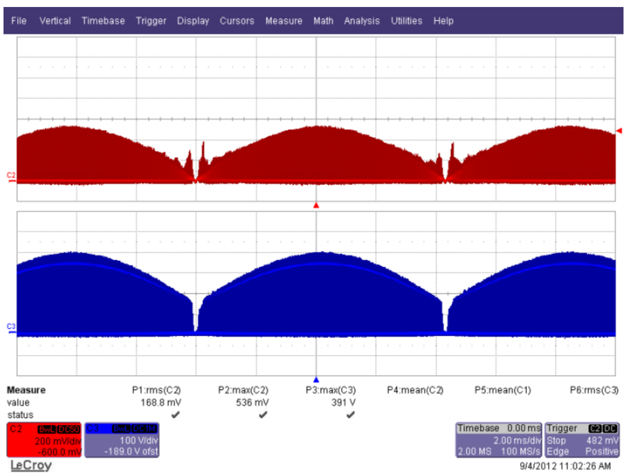

Figure 41 – 132 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

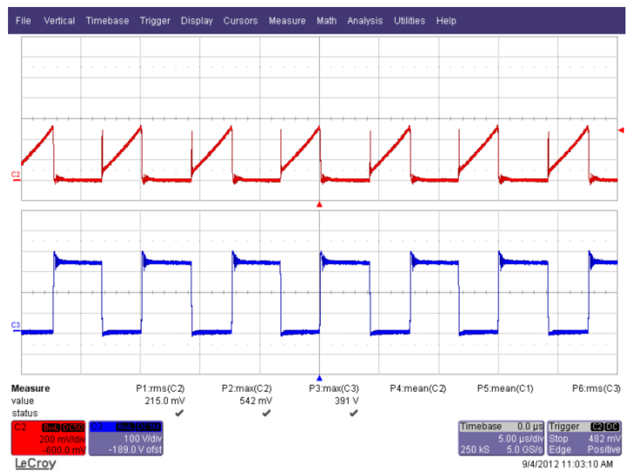

Figure 42 – 132 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

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12.5 Drain Voltage and Current at Start-up

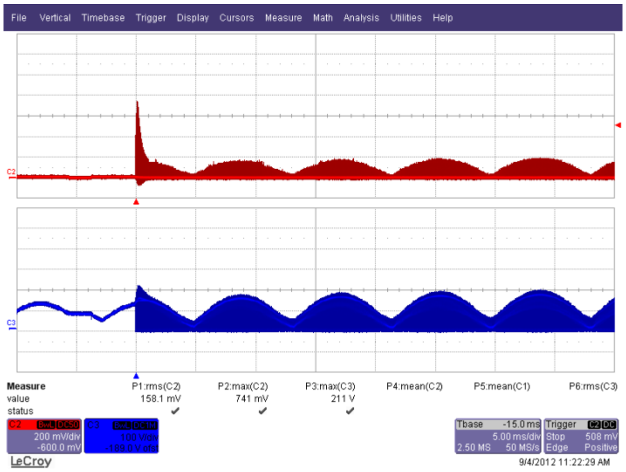

Figure 43 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

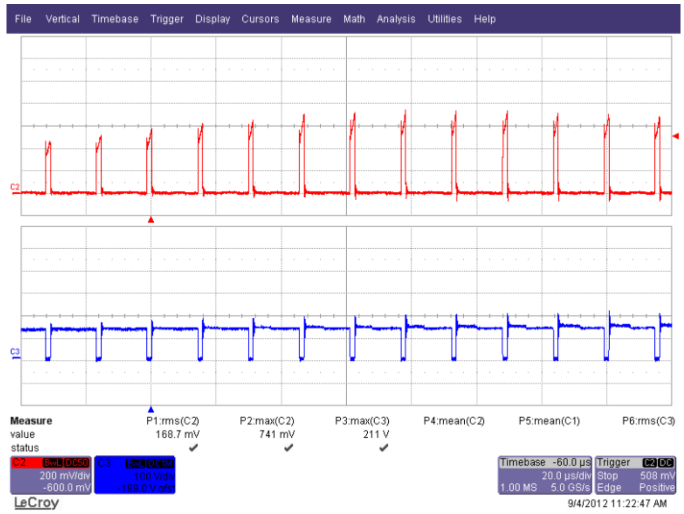

Figure 44 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 20 µs / div.

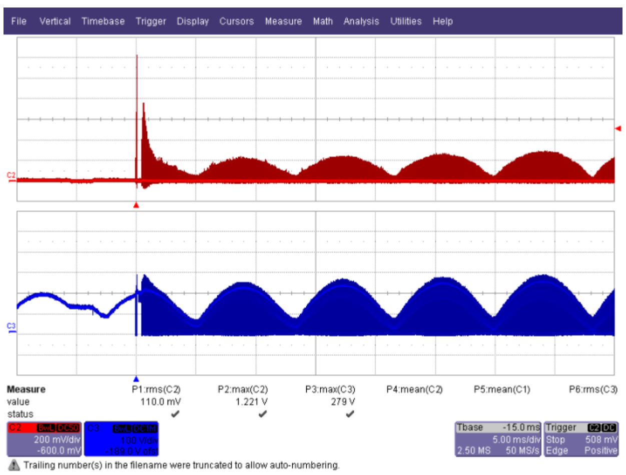

Figure 45 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

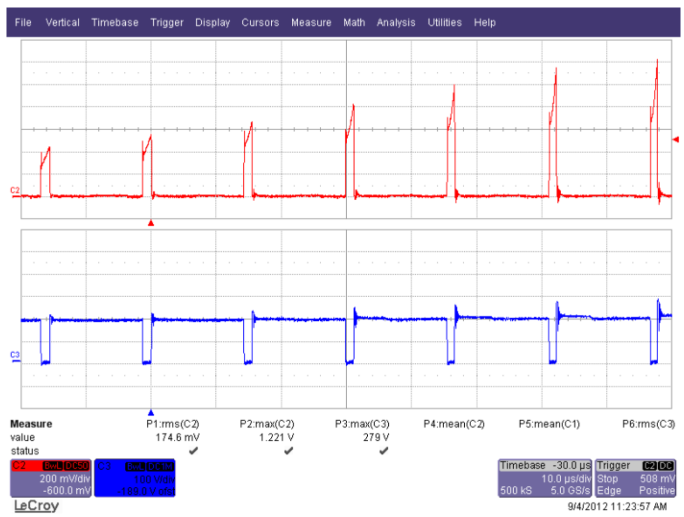

Figure 46 – 132 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

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.

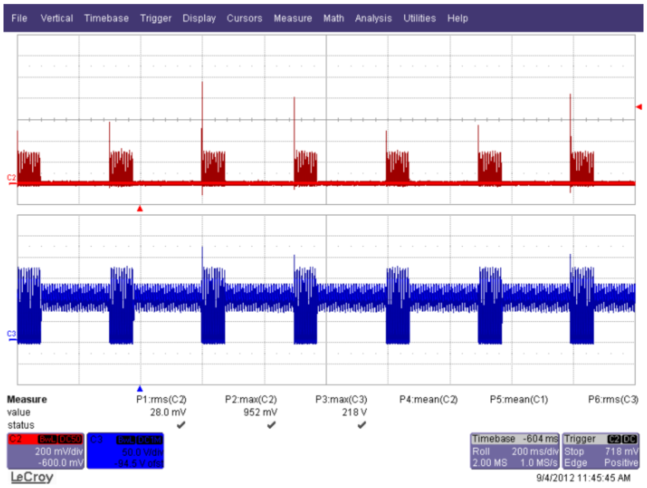

Figure 47 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V, 200 ms / div.

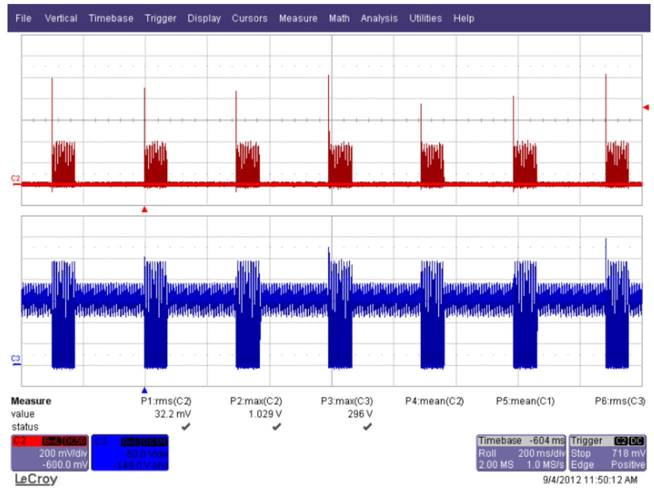

Figure 48 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 50 V, 200 ms / div.

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12.7 Output Diode Voltage and Current at Normal Operation

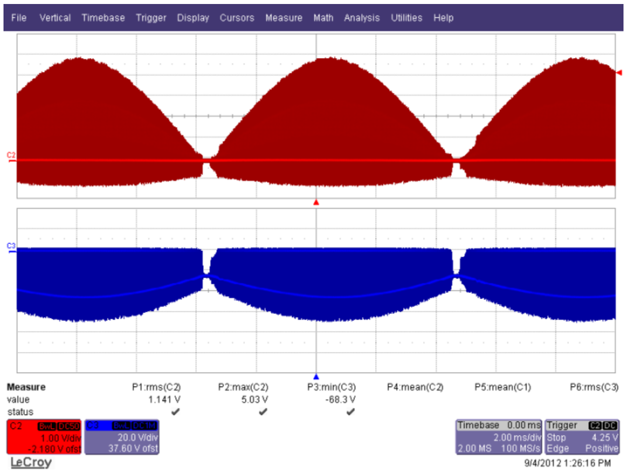

Figure 49 – 90 VAC, 60 Hz.
Upper: I_{D6}, 1 A / div.
Lower: V_{D6}, 20 V, 2 ms / div.

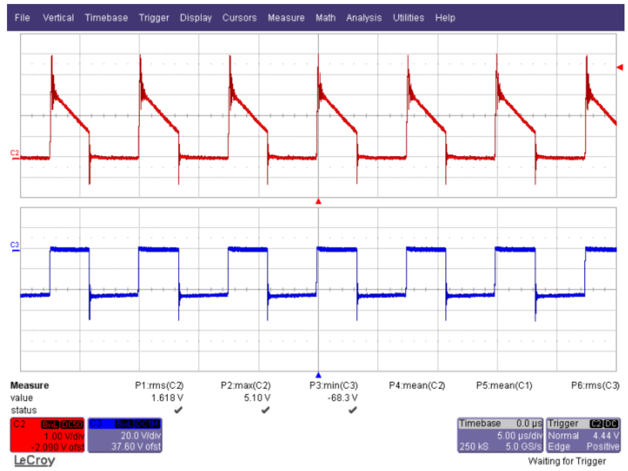

Figure 50 – 90 VAC, 60 Hz.
Upper: I_{D6}, 1 A / div.
Lower: V_{D6}, 20 V / div., 5 μs / div.

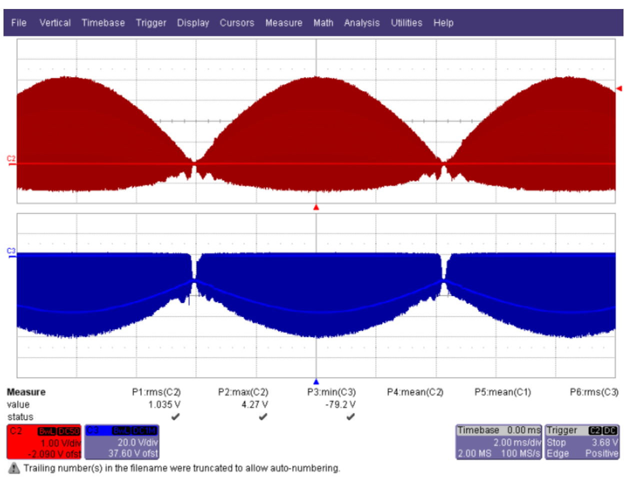

Figure 51 – 132 VAC, 60 Hz.
Upper: I_{D6}, 1 A / div.
Lower: V_{D6}, 20 V, 2 ms / div.

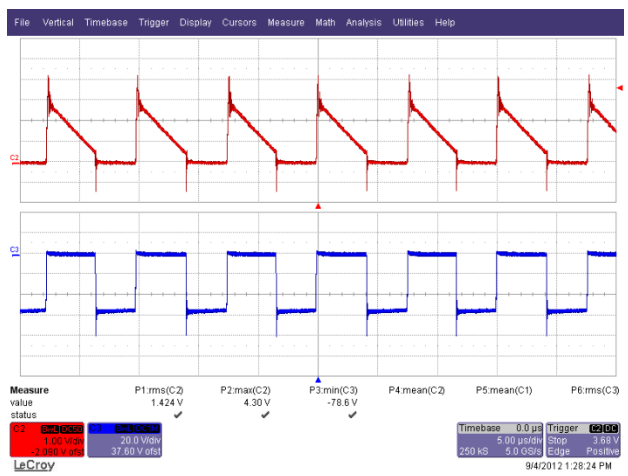

Figure 52 – 132 VAC, 60 Hz.
Upper: I_{D6}, 1 A / div.
Lower: V_{D6}, 20 V / div., 5 μs / div.

12.8 Output Diode Voltage and Current at Start-up and Output Short Condition

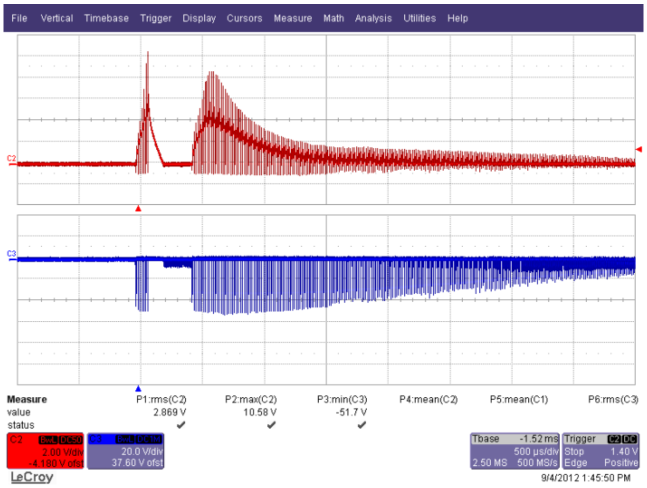

Figure 53 – 132 VAC, 60 Hz Start-up Condition.
Upper: I_{D6}, 2 A / div.
Lower: V_{D6}, 20 V, 0.5 ms / div.

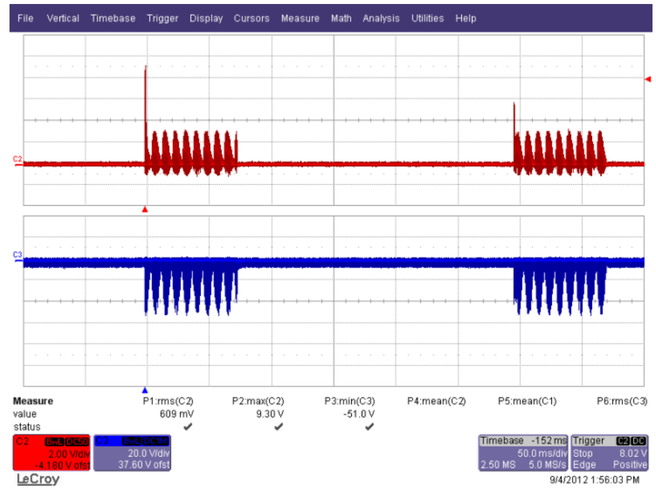

Figure 54 – 132 VAC, 60 Hz Output Short Condition.
Upper: I_{D6}, 2 A / div.
Lower: V_{D6}, 20 V, 50 ms / div.

12.9 Output Voltage during Open Load Condition

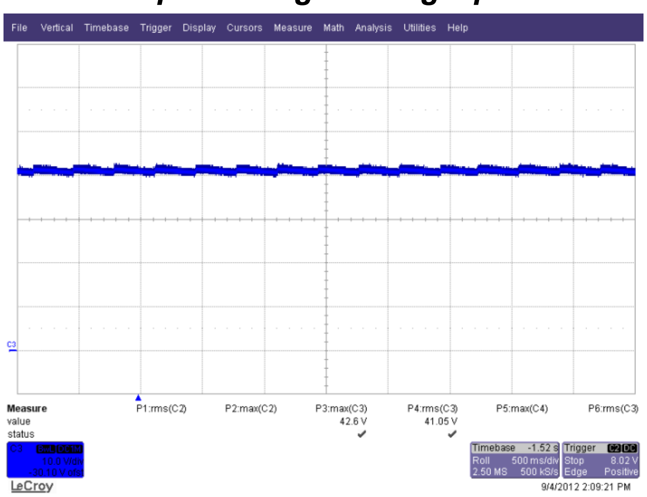

Figure 55 – 90 VAC, 60 Hz Open Load Condition.
V_{OUT}, 10 V / div.

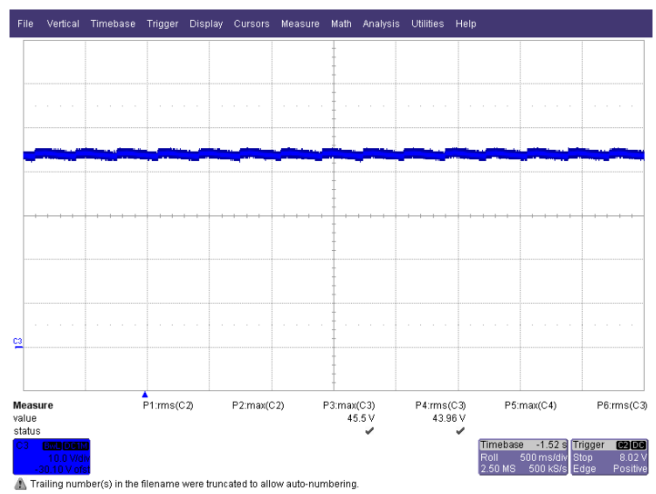

Figure 56 – 132 VAC, 60 Hz Open Load Condition.
V_{OUT}, 10 V / div.

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13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms

Input: 120 VAC, 60 Hz Utility Line
Output: 22.5 V LED Load
Dimmer: LUTRON S-600P-WH

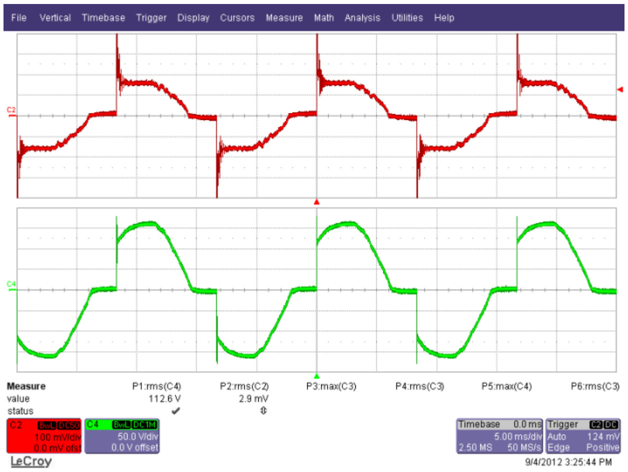

Figure 57 – 132º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

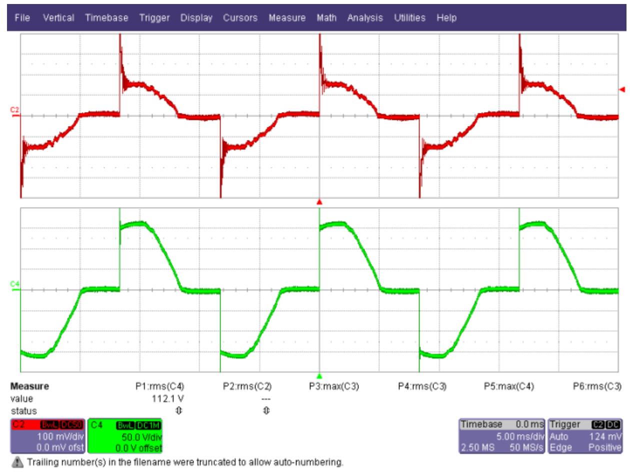

Figure 58 – 108º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

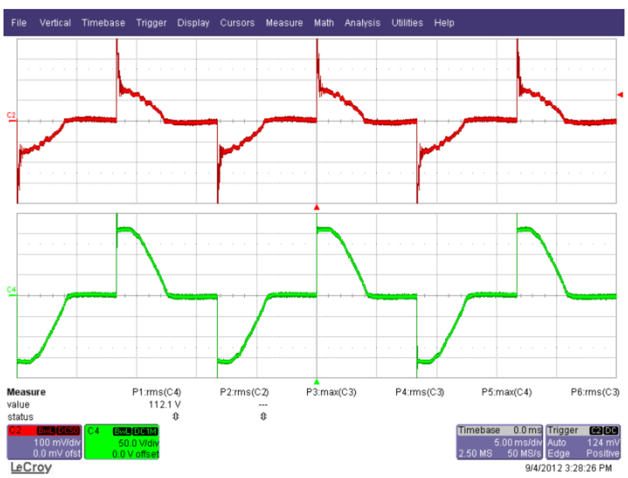

Figure 59 – 86º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

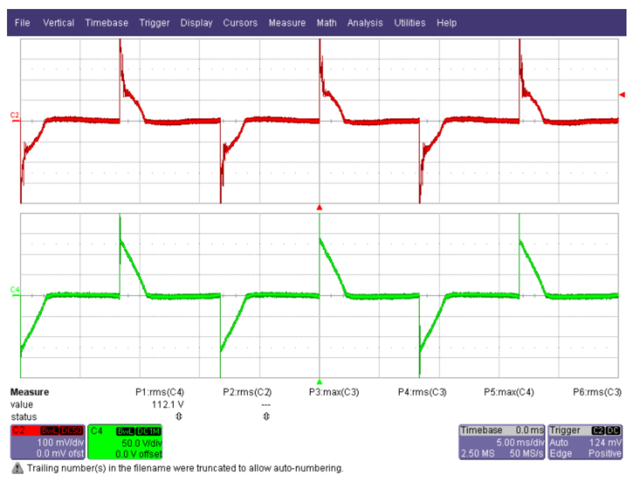

Figure 60 – 45º Conduction Angle.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

13.2 Output Current Waveforms

Input: 120 VAC, 60 Hz Utility Line
Output: 22.5 V LED Load
Dimmer: LUTRON S-600P-WH

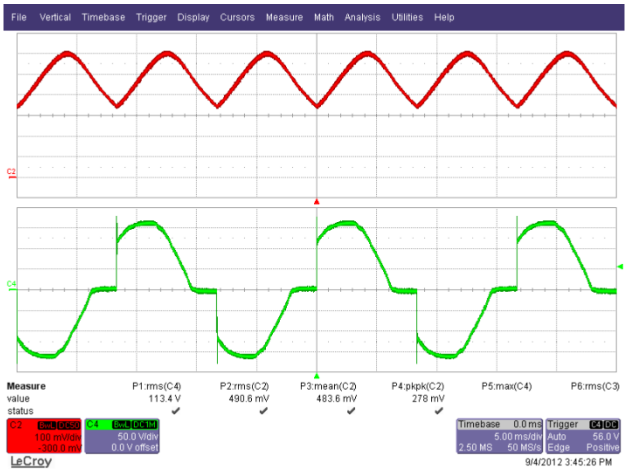

Figure 61 – 132º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

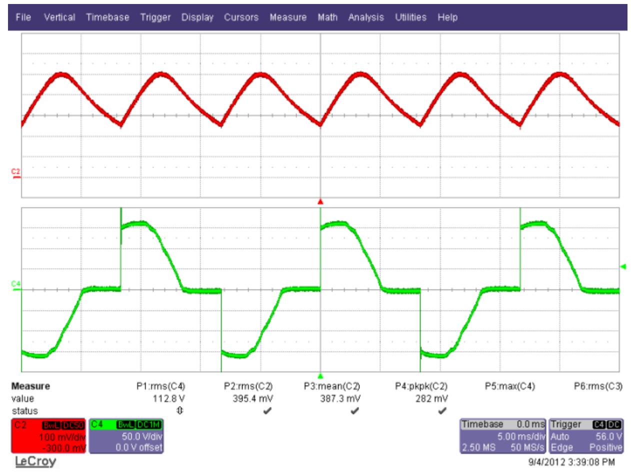

Figure 62 – 108º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

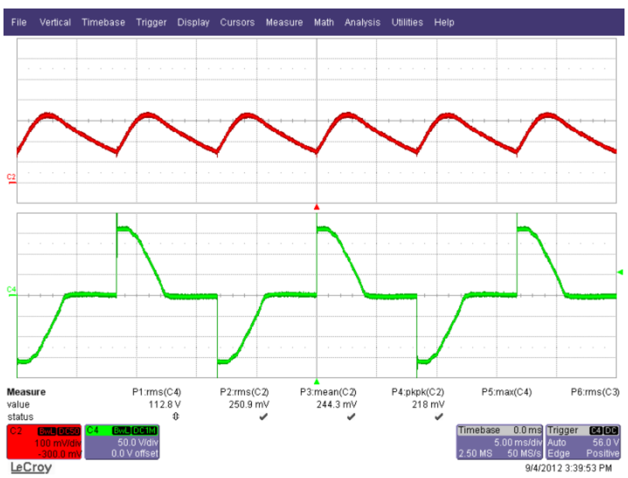

Figure 63 – 86º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

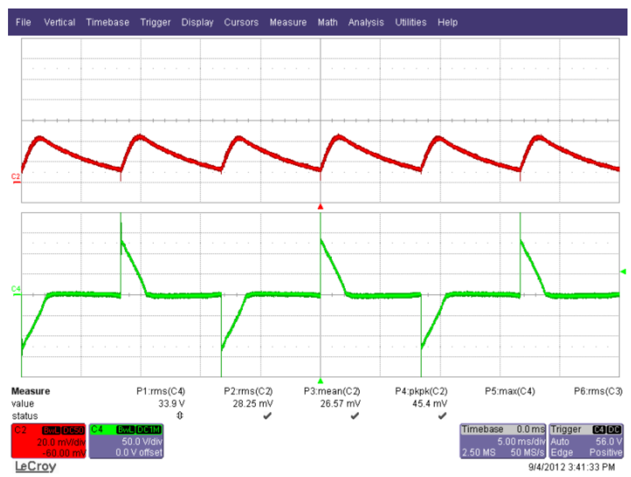

Figure 64 – 45º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 50 V, 5 ms / div.

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13.3 Input Voltage and Output Current Waveform at Start-up

Input: 120 VAC, 60 Hz Utility Line
Output: 22.5 V LED Load
Dimmer: LUTRON S-600P-WH

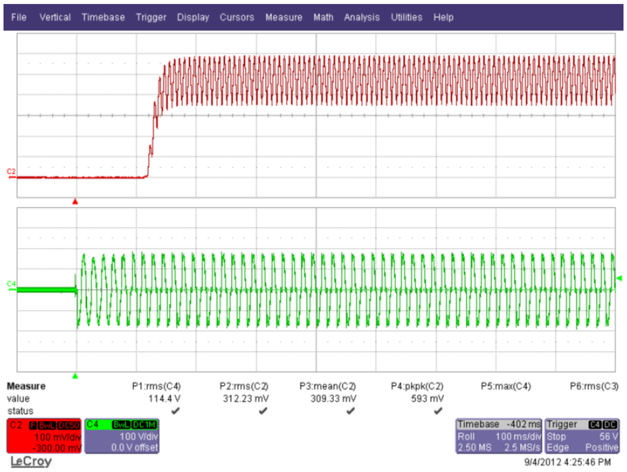

Figure 65 – 120 VAC, 60 Hz, 132 ºConduction Angle Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

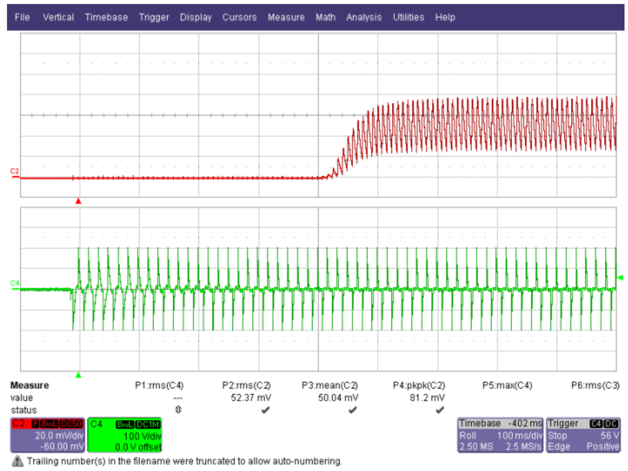

Figure 66 – 120 VAC, 60 Hz 10% I_{OUT} Start-up.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

14 Conducted EMI

14.1 Test Set-up

The unit was tested using LED load (21 V V_{OUT}) with input voltage of 120 VAC, 60 Hz at room temperature and with the unit place inside a grounded cone.

Figure 67 – EMI Test Set-up.

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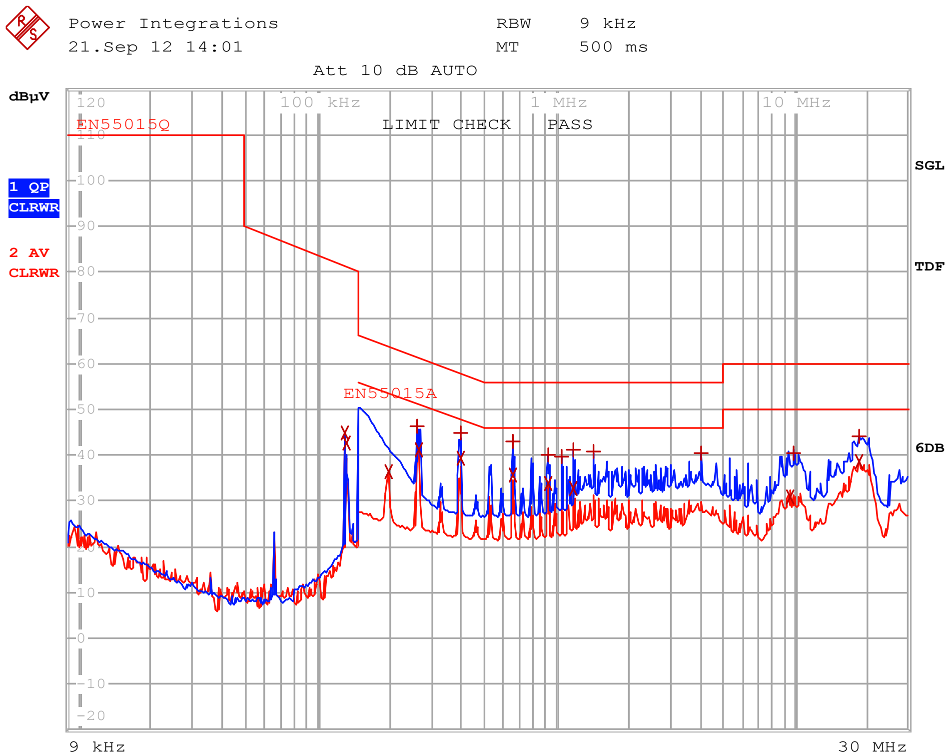
14.2 Test Result



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	44.77	N gnd	
2	Average	132.133649648 kHz	42.78	N gnd	
2	Average	198.193645035 kHz	36.40	L1 gnd	-17.27
1	Quasi Peak	261.871472881 kHz	46.17	L1 gnd	-15.19
2	Average	264.49018761 kHz	41.30	L1 gnd	-9.98
2	Average	393.789848222 kHz	39.17	N gnd	-8.80
1	Quasi Peak	397.727746704 kHz	44.74	N gnd	-13.15
1	Quasi Peak	654.11570866 kHz	42.94	N gnd	-13.06
2	Average	654.11570866 kHz	35.60	N gnd	-10.39
1	Quasi Peak	917.447639259 kHz	40.02	L1 gnd	-15.97
2	Average	917.447639259 kHz	33.82	L1 gnd	-12.17
1	Quasi Peak	1.04414099339 MHz	39.67	L1 gnd	-16.33
1	Quasi Peak	1.17656420634 MHz	41.21	L1 gnd	-14.78
2	Average	1.17656420634 MHz	32.71	L1 gnd	-13.28
1	Quasi Peak	1.43563192593 MHz	40.67	L1 gnd	-15.32
1	Quasi Peak	4.04078721227 MHz	40.45	L1 gnd	-15.54
2	Average	9.60341065306 MHz	30.94	L1 gnd	-19.05
1	Quasi Peak	9.89440359926 MHz	40.43	L1 gnd	-19.56
1	Quasi Peak	18.7049927256 MHz	44.12	L1 gnd	-15.87
2	Average	18.7049927256 MHz	38.65	N gnd	-11.34

Figure 68 – Conducted EMI, 21 V LED Load, 120 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	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

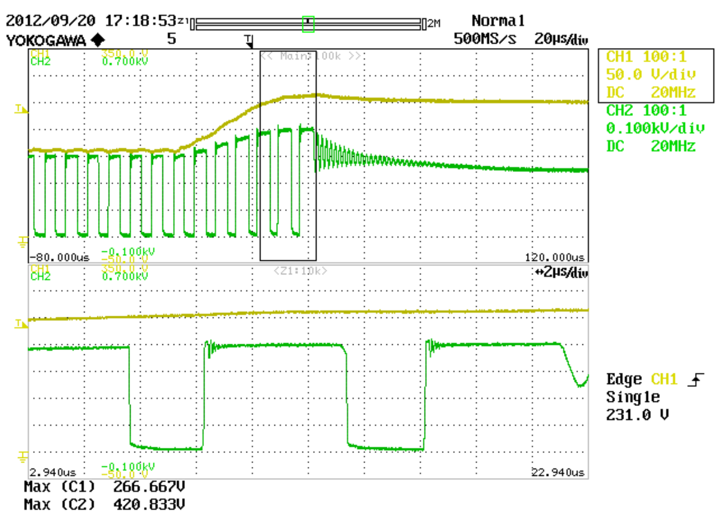


Figure 69 – 500 V Differential Line Surge at 90˚ Injection Phase.
CH1: Input Rectified Voltage; CH3: VDS_{U1}.

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The unit was also tested with RV1 removed and C6 replaced by a 400 V rated 2.2 μF, electrolytic capacitor. U1 drain voltage measured was 458 V when a 500 V differential surge was applied.

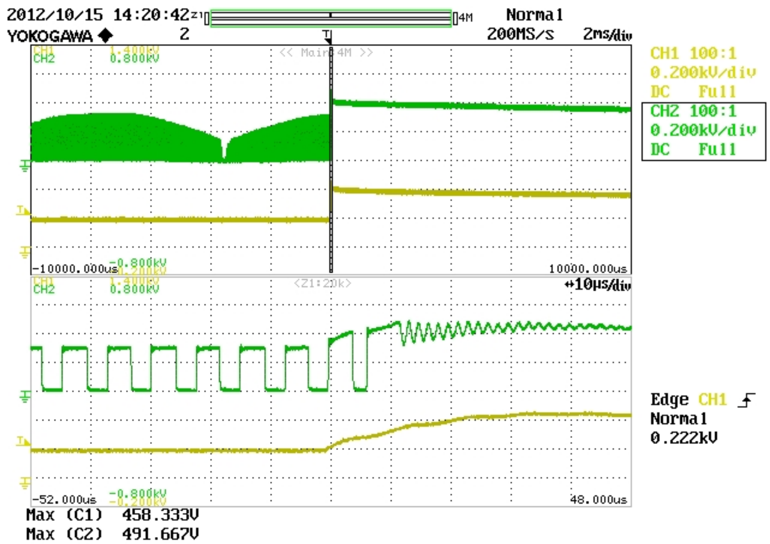

Figure 70 500 V Differential Line Surge at 90˚ Injection Phase with RV1 removed.
CH1: Voltage across C6 (peak detector capacitor); CH2: $VDS_{U1.}$

16 No Active Pre-Load Option

The active pre-load can be removed for improve efficiency performance. The trade-off is limited dim ratio for TRIAC dimmers with a higher minimum conduction angle.

16.1 Schematic

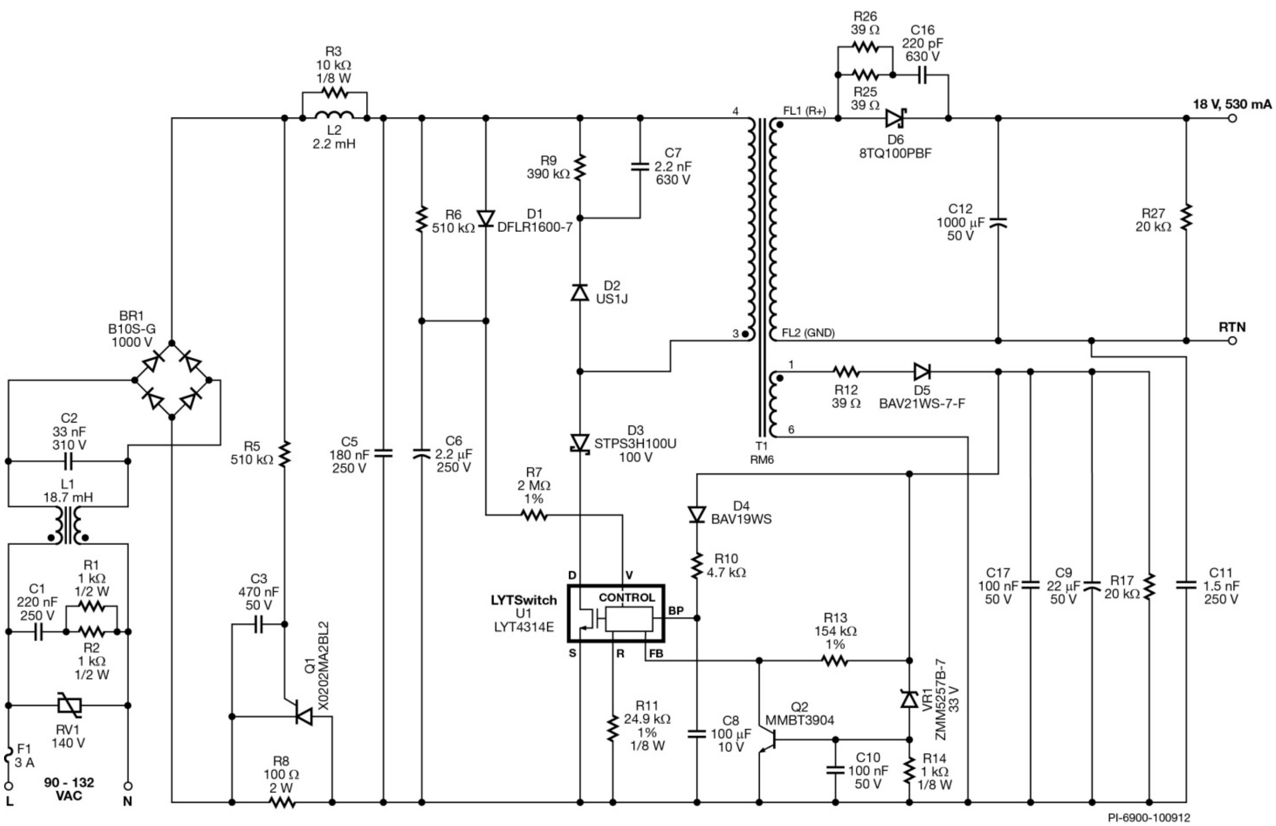

Figure 71 – No Active Pre-Load Schematic.

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16.2 No APL Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
3	1	C2	33 nF, 310 VAC, Polyester Film, X2	BFC233920333	Vishay
4	1	C3	470 nF, 50 V, Ceramic, Y5G, 0603	C1608Y5V1H474Z	TDK
5	1	C5	180 nF, 250 V, Film	ECQ-E2184KB	Panasonic
6	1	C6	2.2 μF, 250 V, Electrolytic, (6.3 x 11)	225CKH250M	Illinois Capacitor
7	1	C7	2.2 nF, 630 V, Ceramic, X7R, 1206	ECJ-3FBJ222K	Panasonic
8	1	C8	100 μF, 10 V, X5R, 1206	C3216X5R1A107M	TDK
9	1	C9	22 μF, 50 V, Electrolytic, Low ESR, 900 mΩ, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
10	1	C10	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
11	1	C11	1.5 nF, Ceramic, Y1	440LD15-R	Vishay
12	1	C12	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	Nippon Chemi-Con
13	1	C16	220 pF, 630 V, Ceramic, NPO, 1206	C3216C0G2J221J	TDK
14	1	C17	100 nF, 50 V, Ceramic, X7R, 1206	GRM319R71H104KA01D	Murata
15	1	D1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
16	1	D2	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
17	1	D3	100 V, 3 A, Schottky, DO-214AA	STPS3H100U	ST Micro
18	1	D4	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
19	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
20	1	D6	100 V, 8 A, Schottky, TO-220AC	8TQ100PBF	Vishay
21	1	F1	3 A, 125V, Fast, Microfuse, Axial	MQ3	BelFuse
22	1	L1	18.7 mH, 0.22 A, Common Mode Choke	RL-4400-1-18.7	Renco
23	1	L2	2.2 mH, 0.19 A, Ferrite Core	CTCH895F-222K	CT Parts
24	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
25	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
26	2	R1 R2	1 kΩ, 5%, 1/2 W, Thick Film, 1210	ERJ-14YJ102U	Panasonic
27	1	R3	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
28	2	R5 R6	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
29	1	R7	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackple
30	1	R8	100 Ω, 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
31	1	R9	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
32	1	R10	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
33	1	R11	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	Panasonic
34	3	R12 R25 R26	39 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ390V	Panasonic
35	1	R13	154 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1543V	Panasonic
36	1	R14	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
37	2	R17 R27	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
38	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
39	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
40	1	U1	LYTSwitch, eSIP-7C	LYT4314E	Power Integrations
41	1	VR1	33 V, 5%, 500 mW, DO-213AA (MiniMELF)	ZMM5257BDICT-ND	Diodes, Inc.

16.3 No APL Efficiency

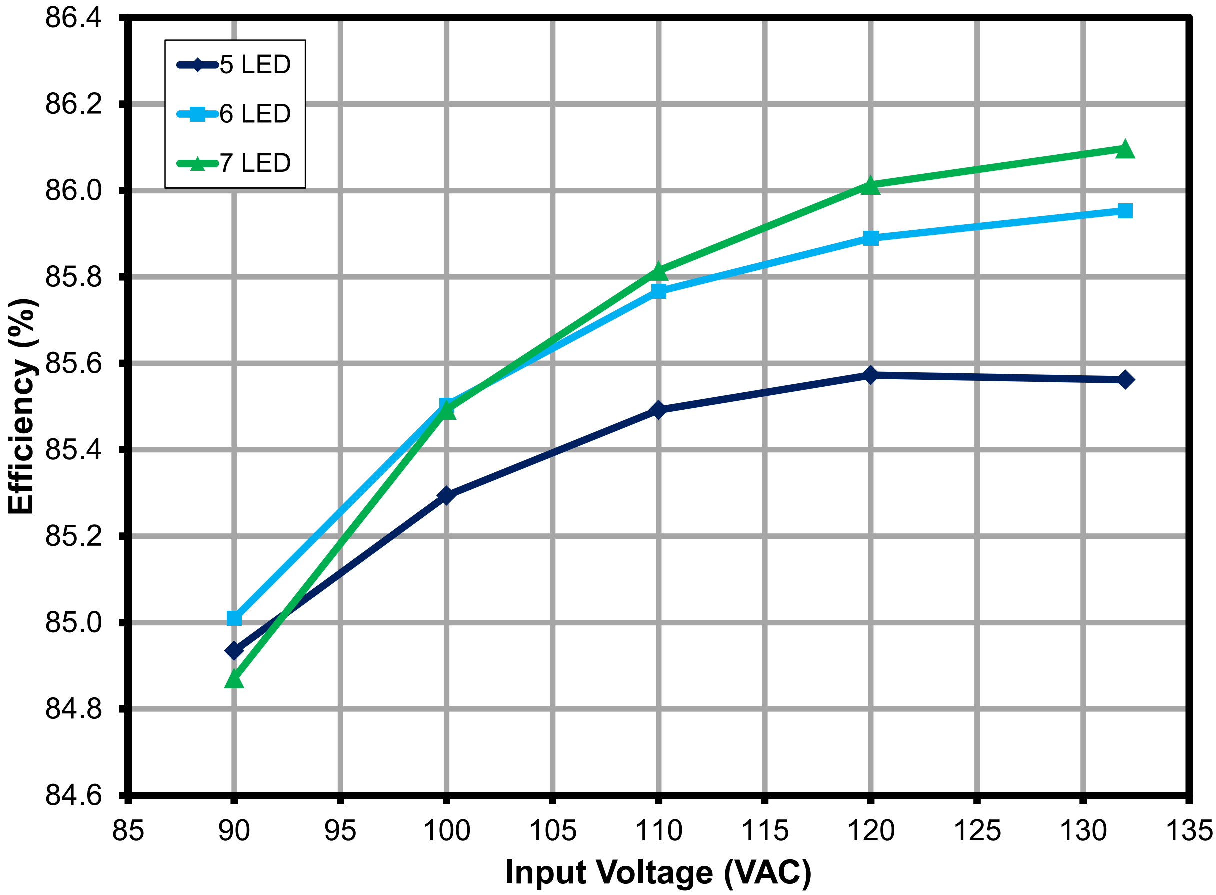

Figure 72 – Efficiency vs. Line and Load.

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16.4 No APL Line and Load Regulation

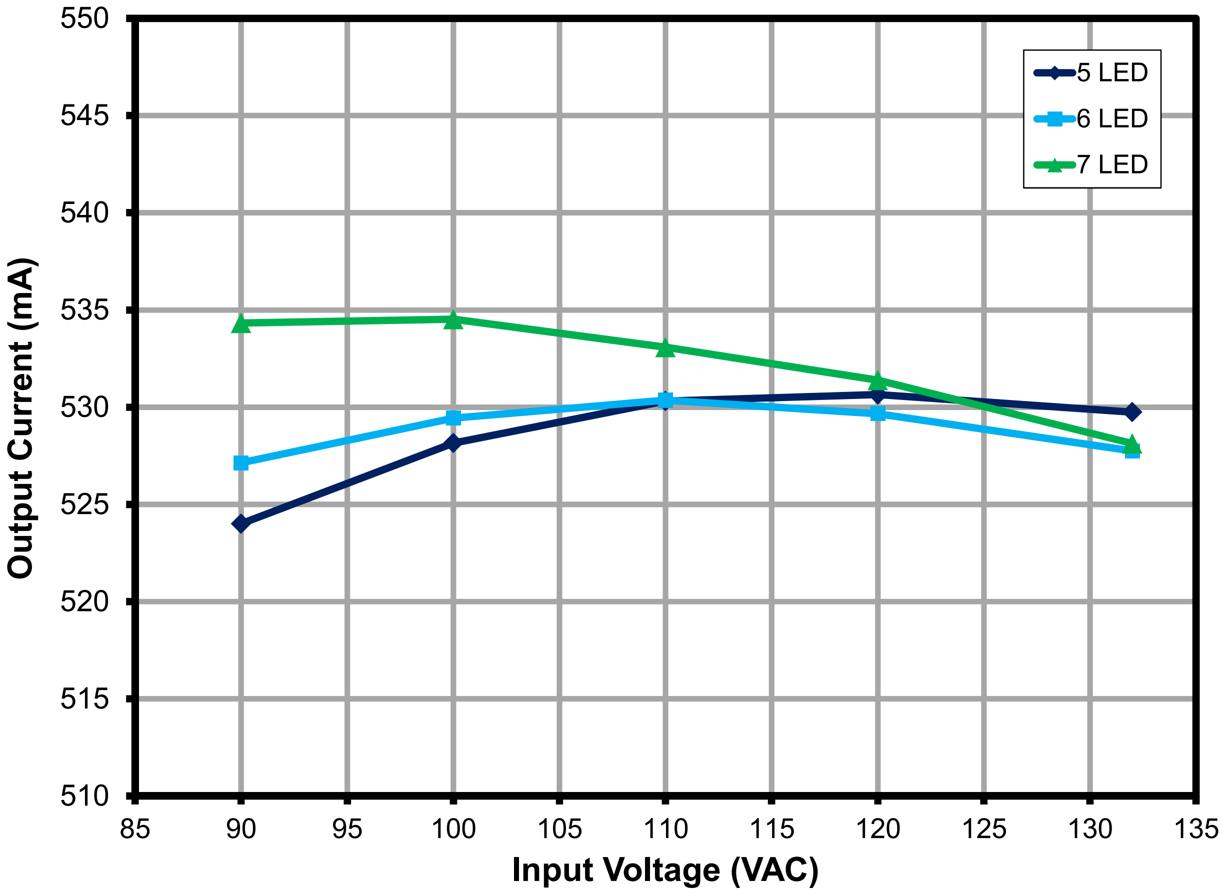

Figure 73 – Regulation vs. Line and Load.

16.5 No APL Power Factor

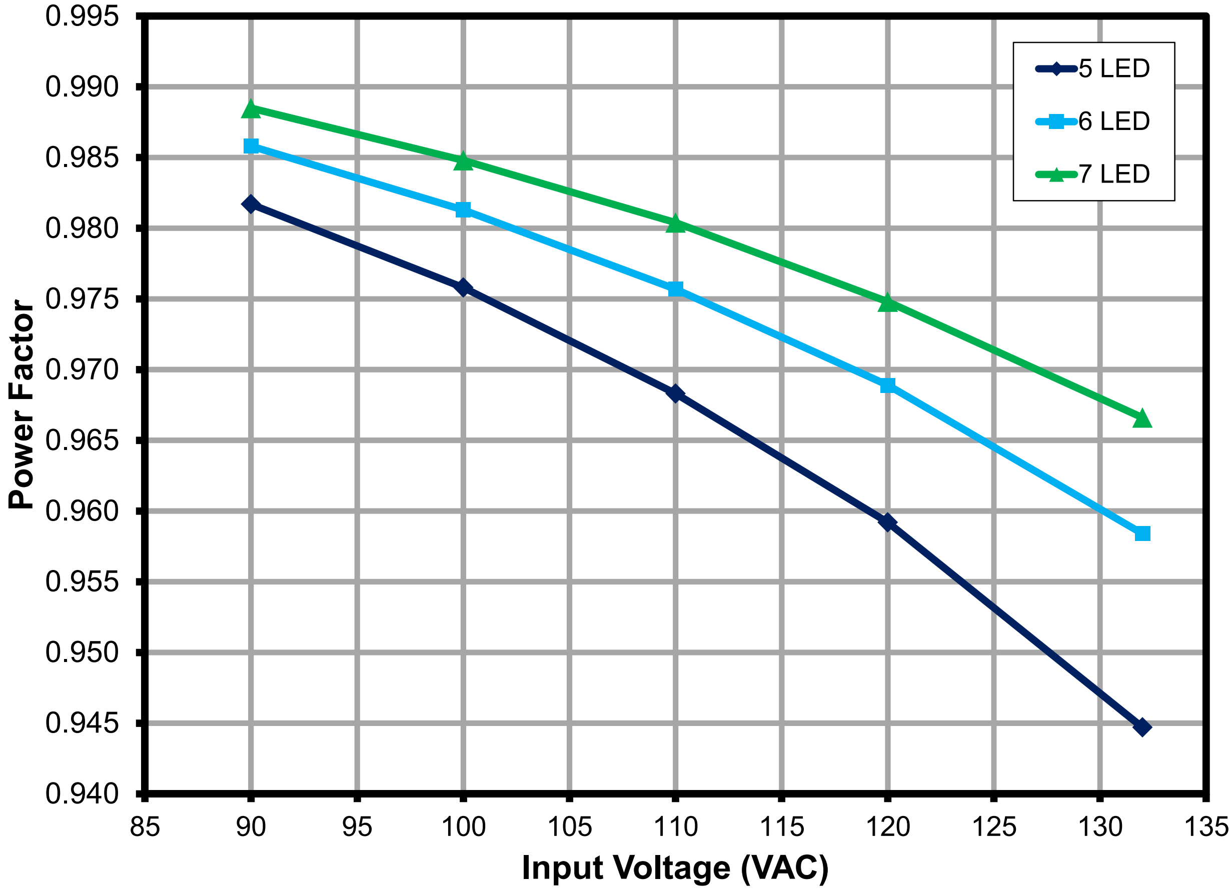

Figure 74 – Power Factor vs. Line and Load.

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16.6 No APL A-THD

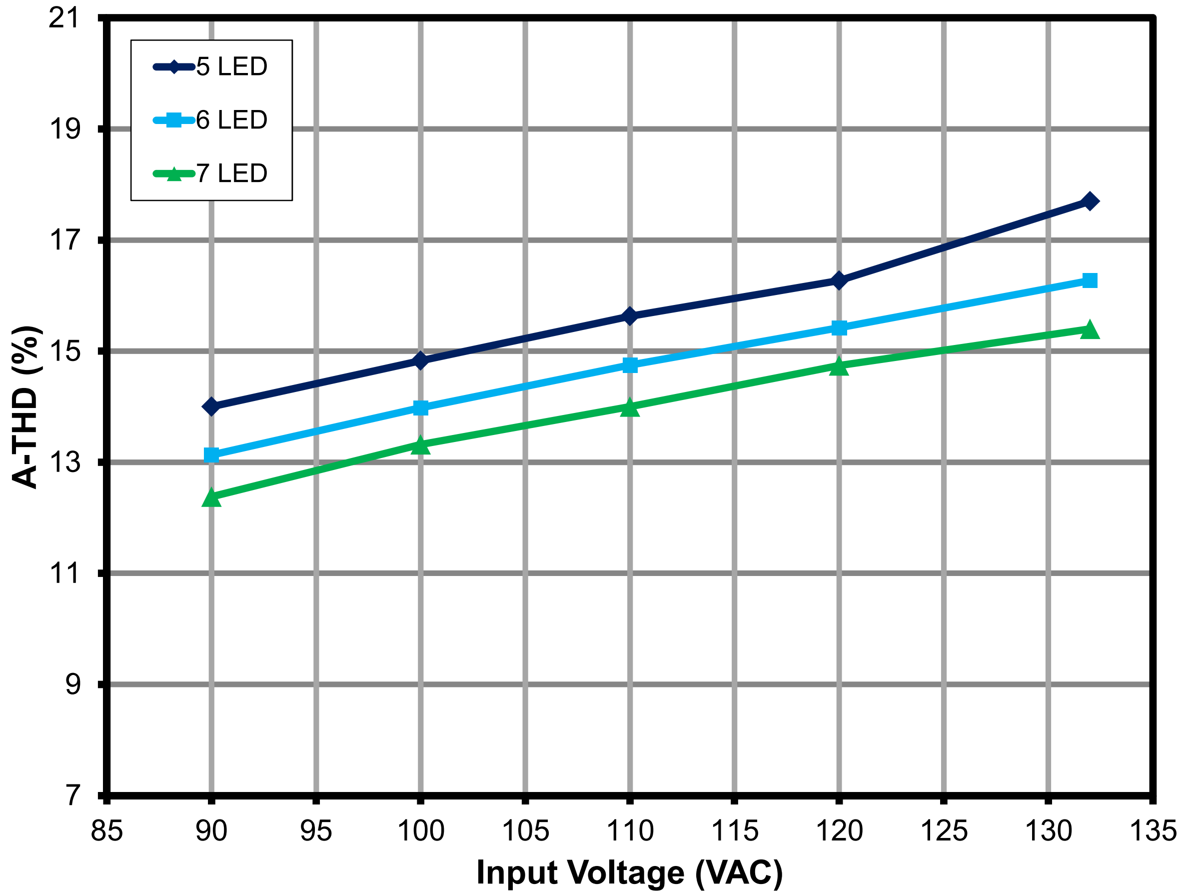

Figure 75 – A-THD vs. Line and Load.

16.7 No APL Harmonic Currents

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment[2]. Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

16.7.1 15 V LED Load

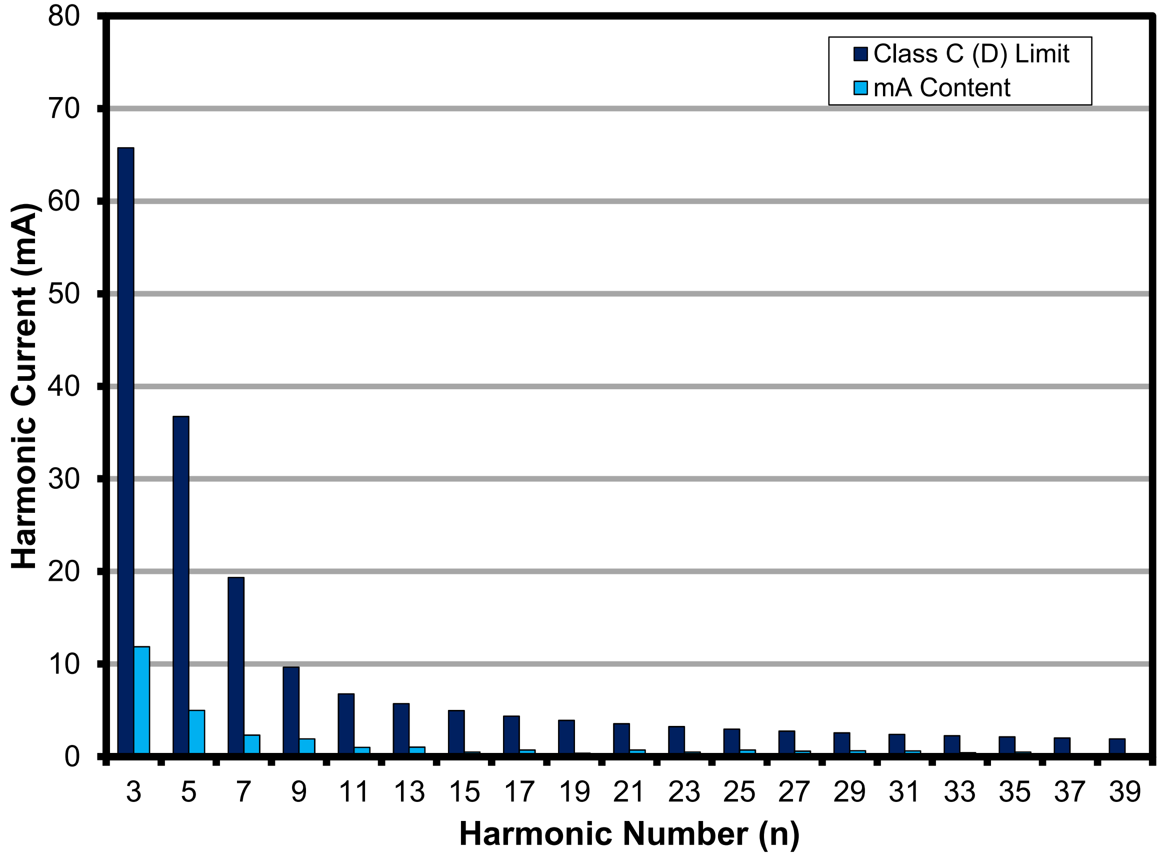

Figure 76 – 15 V LED Load Input Current Harmonics case (IEC61000-3-2) at 120 VAC, 60 Hz.

[2] IEC6000-3-2 Section 7.3, table 2, column 2.

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16.7.3 18 V LED Load

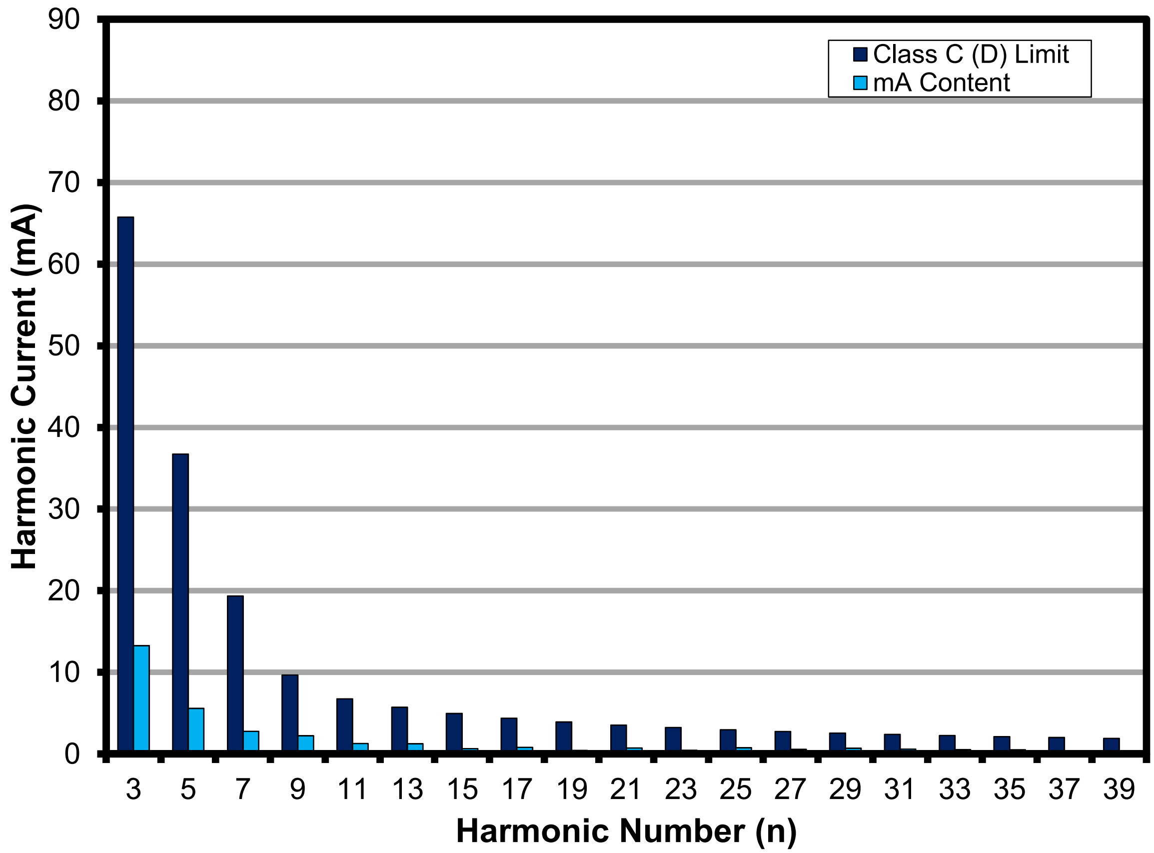

Figure 77 – 18 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

16.7.4 21 V LED Load

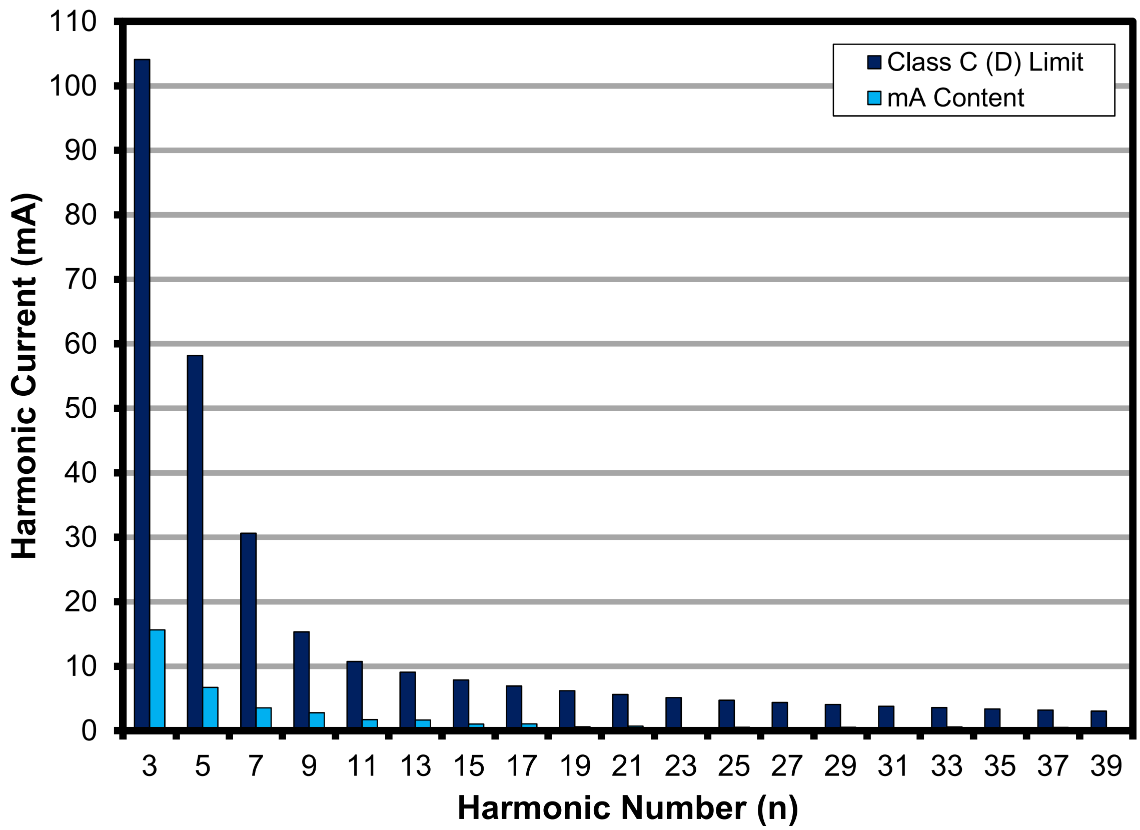

Figure 78 – 21 V LED Load Input Current Harmonics (IEC61000-3-2) at 120 VAC, 60 Hz.

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16.8 No APL Test Data

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

16.8.1 Test Data, 15 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.01	108.92	9.624	0.982	14.00	15.50	524.00	8.17	8.12	84.93	1.45
99.97	99.04	9.661	0.976	14.83	15.50	528.16	8.24	8.19	85.29	1.42
110.02	90.82	9.676	0.968	15.63	15.50	530.32	8.27	8.22	85.49	1.40
119.99	84.00	9.669	0.959	16.27	15.49	530.65	8.27	8.22	85.57	1.40
132.01	77.36	9.648	0.945	17.7	15.49	529.75	8.26	8.20	85.56	1.39

16.8.2 Test Data, 18 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.00	130.67	11.594	0.986	13.13	18.60	527.14	9.86	9.81	85.01	1.74
99.97	118.18	11.593	0.981	13.98	18.63	529.44	9.91	9.86	85.50	1.68
110.03	107.77	11.570	0.976	14.75	18.62	530.36	9.92	9.87	85.77	1.65
119.99	99.19	11.532	0.969	15.42	18.61	529.66	9.90	9.86	85.89	1.63
132.02	90.72	11.479	0.958	16.27	18.61	527.76	9.87	9.82	85.95	1.61

16.8.3 Test Data, 21 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
90.00	152.60	13.577	0.989	12.38	21.47	534.33	11.52	11.47	84.87	2.05
99.97	136.89	13.476	0.985	13.32	21.46	534.52	11.52	11.47	85.49	1.96
110.03	124.04	13.380	0.980	14	21.45	533.09	11.48	11.43	85.81	1.90
120.00	113.68	13.298	0.975	14.74	21.44	531.39	11.44	11.39	86.01	1.86
132.02	103.37	13.192	0.967	15.4	21.42	528.13	11.36	11.31	86.10	1.83

16.8.4 120 VAC 60 Hz, 15 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	84.00	9.6690	0.9592	16.27
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	82.79				
2	0.02	0.02%		2.00%	
3	11.88	14.35%	65.7492	28.78%	Pass
5	4.99	6.03%	36.7422	10.00%	Pass
7	2.34	2.83%	19.3380	7.00%	Pass
9	1.92	2.32%	9.6690	5.00%	Pass
11	1.01	1.22%	6.7683	3.00%	Pass
13	1.03	1.24%	5.7270	3.00%	Pass
15	0.51	0.62%	4.9634	3.00%	Pass
17	0.71	0.86%	4.3795	3.00%	Pass
19	0.39	0.47%	3.9185	3.00%	Pass
21	0.72	0.87%	3.5453	3.00%	Pass
23	0.49	0.59%	3.2370	3.00%	Pass
25	0.73	0.88%	2.9781	3.00%	Pass
27	0.60	0.72%	2.7575	3.00%	Pass
29	0.64	0.77%	2.5673	3.00%	Pass
31	0.61	0.74%	2.4017	3.00%	Pass
33	0.44	0.53%	2.2561	3.00%	Pass
35	0.49	0.59%	2.1272	3.00%	Pass
37	0.24	0.29%	2.0122	3.00%	Pass
39	0.28	0.34%	1.9090	3.00%	Pass
41	0.09	0.11%			
43	0.13	0.16%			
45	0.20	0.24%			
47	0.27	0.33%			
49	0.28	0.34%			

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16.8.5 120 VAC 60 Hz, 18 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	99.19	11.5320	0.9689	15.42
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	97.97				
2	0.03	0.03%		2.00%	
3	13.27	13.54%	78.4176	29.07%	Pass
5	5.57	5.69%	43.8216	10.00%	Pass
7	2.77	2.83%	23.0640	7.00%	Pass
9	2.23	2.28%	11.5320	5.00%	Pass
11	1.27	1.30%	8.0724	3.00%	Pass
13	1.24	1.27%	6.8305	3.00%	Pass
15	0.65	0.66%	5.9198	3.00%	Pass
17	0.81	0.83%	5.2233	3.00%	Pass
19	0.43	0.44%	4.6735	3.00%	Pass
21	0.74	0.76%	4.2284	3.00%	Pass
23	0.47	0.48%	3.8607	3.00%	Pass
25	0.77	0.79%	3.5519	3.00%	Pass
27	0.57	0.58%	3.2888	3.00%	Pass
29	0.71	0.72%	3.0619	3.00%	Pass
31	0.59	0.60%	2.8644	3.00%	Pass
33	0.54	0.55%	2.6908	3.00%	Pass
35	0.51	0.52%	2.5370	3.00%	Pass
37	0.34	0.35%	2.3999	3.00%	Pass
39	0.38	0.39%	2.2768	3.00%	Pass
41	0.13	0.13%			
43	0.18	0.18%			
45	0.11	0.11%			
47	0.12	0.12%			
49	0.17	0.17%			

16.8.7 120 VAC 60 Hz, 21 V LED Load Harmonics Data

Current Harmonics Limits for IEC61000-3-2

V	Freq	I (mA)	P	PF	%THD
120	60.00	113.68	13.2980	0.9748	14.74
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	112.41				
2	0.07	0.06%		2.00%	
3	14.43	12.84%	90.4264	29.24%	Pass
5	6.18	5.50%	50.5324	10.00%	Pass
7	3.20	2.85%	26.5960	7.00%	Pass
9	2.62	2.33%	13.2980	5.00%	Pass
11	1.62	1.44%	9.3086	3.00%	Pass
13	1.58	1.41%	7.8765	3.00%	Pass
15	0.96	0.85%	6.8263	3.00%	Pass
17	1.04	0.93%	6.0232	3.00%	Pass
19	0.64	0.57%	5.3892	3.00%	Pass
21	0.76	0.68%	4.8759	3.00%	Pass
23	0.48	0.43%	4.4519	3.00%	Pass
25	0.63	0.56%	4.0958	3.00%	Pass
27	0.43	0.38%	3.7924	3.00%	Pass
29	0.55	0.49%	3.5308	3.00%	Pass
31	0.40	0.36%	3.3031	3.00%	Pass
33	0.44	0.39%	3.1029	3.00%	Pass
35	0.36	0.32%	2.9256	3.00%	Pass
37	0.39	0.35%	2.7674	3.00%	Pass
39	0.32	0.28%	2.6255	3.00%	Pass
41	0.25	0.22%			
43	0.25	0.22%			
45	0.15	0.13%			
47	0.17	0.15%			
49	0.13	0.12%			

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16.9 No APL Dimming Curve with Simulated TRIAC

Using Agilent 6812B AC Source programmed as perfect leading edge dimmer

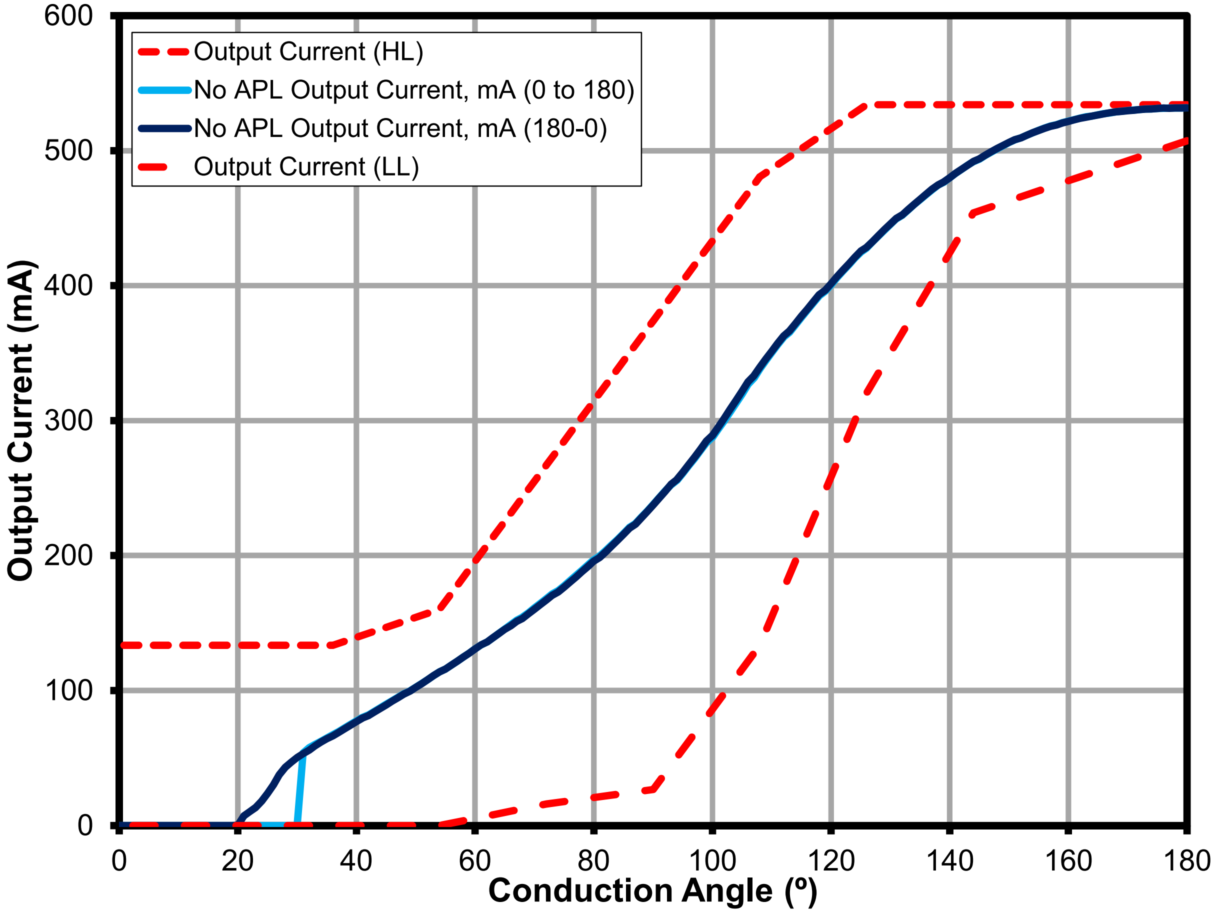

Figure 79 – Dimming Curve at 120 VAC, 60 Hz Input.

16.10 No APL Performance with Actual Dimmers

The following data were taken by measuring the RMS input voltage to the driver as a result of TRIAC chopping the AC input. A leading and trailing edge TRIAC dimmer was used on the data below using 21 V LED load and 120 V, 60 Hz AC input.

16.10.1 Dimming Curve

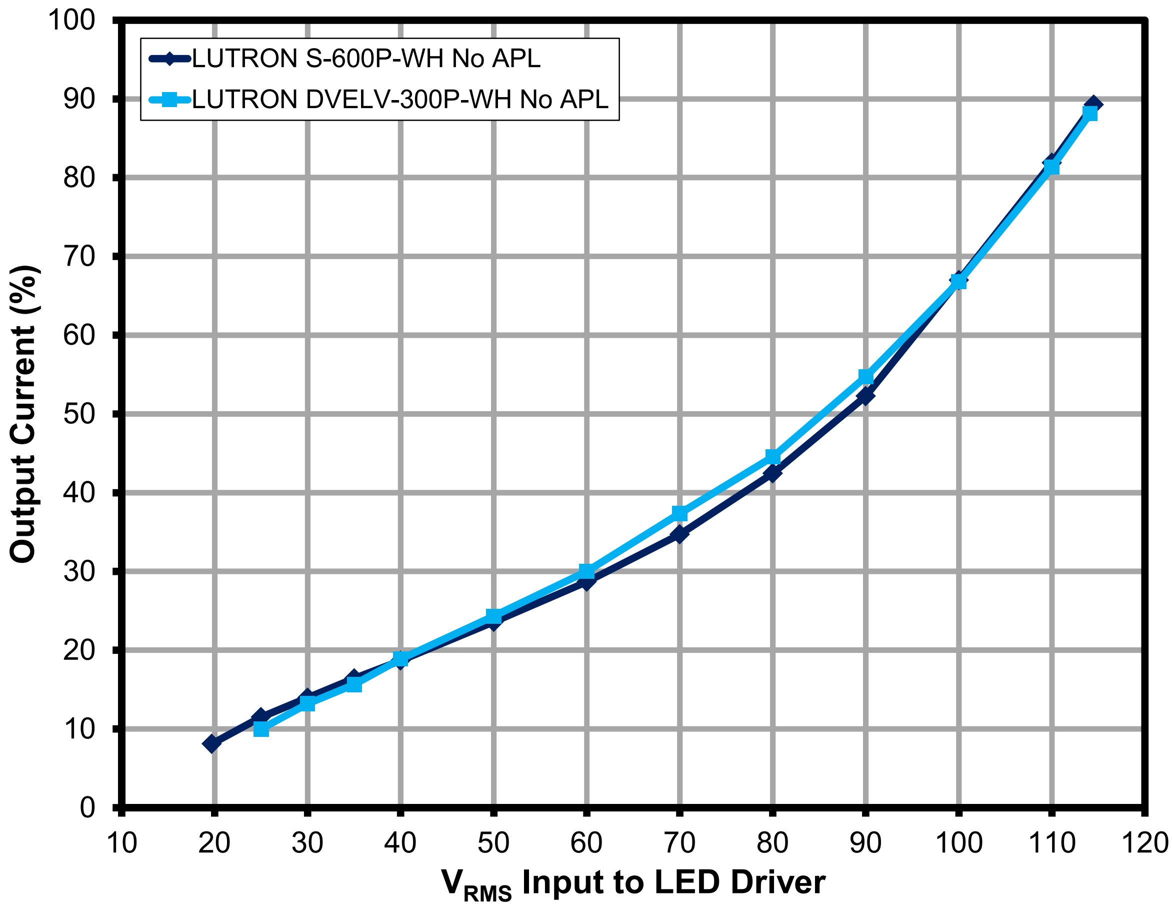

Figure 80 – Dimming Curve as a Function of Input Voltage to the Driver.

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16.10.2 Typical Leading Edge Dimmer Performance Data

Dimmer: LUTRON S-600P-WH
Input: 120 VAC, 60 Hz

$V_{IN(RMS)}$ (V)	I_{OUT} (mA)	I_{OUT} (%)	V_{OUT} (V)	P_{OUT} (W)	P_{IN} (W)	Efficiency (%)	P_{LOSS} (W)	Start-upTime (ms)
114.5	473	89.25	21.25	10.11	13.47	75.1	3.36	128
110	434	81.89	21.14	9.21	12.65	72.8	3.44	128
100	355	66.98	20.82	7.43	10.9	68.2	3.47	153
90	277	52.26	20.51	5.7	9.1	62.6	3.4	164
80	225	42.45	20.3	4.58	7.84	58.4	3.26	186
70	184	34.72	20.2	3.73	6.82	54.7	3.09	204
60	152	28.68	20	3.05	5.98	51.0	2.93	251
50	125	23.58	19.81	2.48	5.19	47.8	2.71	318
40	99	18.68	19.6	1.95	4.5	43.3	2.55	412
35	87	16.42	19.5	1.7	4.1	41.5	2.4	550
30	74	13.96	19.37	1.44	3.78	38.1	2.34	1800
25	61	11.51	19.22	1.16	3.5	33.1	2.34	
19.7	43	8.11	19	0.82	3.1	26.5	2.28	

16.10.3 Typical Trailing Edge Dimmer Performance Data

Dimmer: LUTRON DVELV-300P-WH
Input: 120 VAC, 60 Hz

$V_{IN(RMS)}$ (V)	I_{OUT} (mA)	I_{OUT} (%)	V_{OUT} (V)	P_{OUT} (W)	P_{IN} (W)	Efficiency (%)	P_{LOSS} (W)	Start-upTime (ms)
114.1	467	88.11	21.14	9.96	12.97	76.8	3.01	110
110	431	81.32	21	9.12	12.05	75.7	2.93	118
100	354	66.79	20.75	7.4	10.1	73.3	2.7	122
90	290	54.72	20.5	6	8.53	70.3	2.53	123
80	236	44.53	20.3	4.83	7.2	67.1	2.37	128
70	198	37.36	20.2	4.03	6.28	64.2	2.25	147
60	159	30.00	20	3.2	5.35	59.8	2.15	187
50	129	24.34	19.81	2.6	4.62	56.3	2.02	212
40	100	18.87	19.58	1.96	3.93	49.9	1.97	254
35	83	15.66	19.5	1.62	3.54	45.8	1.92	307
30	70	13.21	19.3	1.36	3.24	42.0	1.88	355
25	53	10.00	19.12	1	2.86	35.0	1.86	520

16.10.4 Dimmer Compatibility List

Item	List of Dimmers	Part Number	$V_{RMS(MIN)}$	I_{MIN} (mA)	$V_{RMS(MAX)}$	I_{MAX} (mA)	Dim Ratio
1	LUTRON LG600PH-LA	LG-600PH-WH	21	53	114.6	474	9
2	LUTRON S603P	S-603P-WH	21	48	115.0	476	10
3	LUTRON SLV600P	SLV600P-WH	28	70	115.5	482	7
4	LUTRON S600	S-600-WH	24	58	117.6	505	9
5	LUTRON S-600PH-WH	S-600PH-WH	19	41	115.0	477	12
6	LUTRON DVCL153P	DVWCL-153-PLH-WH	15.3	22	113.3	462	21
7	LUTRON DV603P	DV-603P-WH	23	56	114.6	473	8

8	LUTRON DV600P	DV-600P-WH	21.7	53	114.7	474	9
9	LUTRON TG600PH-IV	TG-600PH-WH	35	85	115.6	484	6
10	LUTRON AY600P	AY-600P-WH	36	87	115.2	480	6
11	LUTRON GL600P-WH	GL-600P-WH	25	62	114.8	476	8
12	LEVITON 6633PLI	R62-06633-1LW	20	51	118.7	518	10
13	LEVITON 6631-LI	R62-06631-1LW	12	5	116.5	493	105
14	LEVITON IPI06	R60-IPI06-1LM	34	87	118.3	513	6
15	LEVITON 6161-I	R52-06161-00W	33	68	115.2	480	7
16	LEVITON RP106	R52-RPI06-1LW	32	56	119.0	523	9
17	LEVITON 6681	R60-06681-0IW	12	6	115.5	484	82
18	LEVITON TGM10-1LW	TGM10-1LW	16.5	34	113.2	459	14
19	LEVITON 6684	R60-06684-1IW	14	17	119.0	524	31
20	LEVITON 6683	6683	17	25	119.0	524	21
21	LEVITON 6613	R02-06613-PLW	19	42	118.7	519	12
22	COOPER SLC03	SLC03P-W-K-L	16	25	116.0	490	20
23	LUTRON GL600-WH	GL-600-WH	26.67	68	117.4	502	7
24	LUTRON DVPDC-203P-WH	DVPDC-203P-WH	60	152	117.0	497	3
25	LUTRON LX600PL	LX-600PL-wh	27	65	116.7	495	8
26	LUTRON D600P	D-600P-WH	15	27	113.2	460	17
27	LUTRON CTCL-153PDH		15.5	26	113.7	465	18
28	LUTRON S-600P	S-600P	18	41	115.0	477	12
29	LUTRON TGLV-600P	TGLV-600P	32.7	81	116.0	489	6
30	LUTRON TGLV-600PR	TGLV-600PR	34	83	115.0	482	6
31	LUTRON TT-300NLH-WH	TT-300NLH-WH	24	59	118.0	510	9
32	LUTRON TT-300H-WH	TT-300H-WH	12	7	118.0	510	73
33	LUTRON NLV-1000-WH	NLV-1000-WH	24	61	116.2	490	8
34	Lutron	MAELV -600	31	72	115.3	477	7
35	Lutron	S-600P	23	57	114.5	473	8
36	Lutron	S-600P	18.7	41	117.5	503	12
37	Cooper	S106P	29.9	76	117.0	500	7
38	Lutron	S-103P-WH	29.9	75	115.0	477	6
39	Lutron	S-10P-WH	25.6	59	114.0	467	8
40	Lutron	S-600PNLH-WH	25.4	63	115.5	483	8
41	Lutron	S-603PNL-WH	28	68	115.4	482	7
42	Lutron	SLV-603P-WH	33.33	83	115.2	480	6
43	Lutron	S-603PGH-WH	21	50	106.0	395	8
44	Lutron	AYLV-600P-WH	32.2	81	114.8	475	6
45	Lutron	AYLV-603P-WH	33.8	85	114.8	475	6
46	Lutron	AY-103PNL-WH	29.4	71	116.5	493	7
47	Lutron	AY-103P-WH	29.2	65	116.9	497	8
48	Lutron	AY-10PNL-WH	26	65	118.6	518	8
49	Lutron	AY-10P-WH	23	57	117.0	497	9
50	Lutron	AY-603PNL-WH	30	73	112.7	455	6
51	Lutron	AY-603PG-WH	32.6	78	103.6	380	5
52	Lutron	AY-603P-WH	36	87	114.3	470	5
53	Lutron	AY-600PNL-WH	31	74	115.4	482	7
54	Lutron	DVELV-300P-WH	24.8	50	114.0	462	9
55	Lutron	DVLV-10P-WH	33.3	84	114.4	470	6
56	Lutron	DVLV-103P-WH	31.6	79	114.7	474	6

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57	Lutron	DVLV-603P-WH	30.6	76	114.9	476	6
58	Lutron	S-1000-WH	28	69	117.5	503	7
59	Lutron	SELV-300P-WH	24.5	50	112.6	452	9
60	Lutron	S-600P-WH	19.5	42	114.6	474	11
61	Lutron	S-103PNL-WH	30.8	69	114.4	472	7
62	Lutron	GLV-600-WH	22.8	58	117.5	503	9

Figure 81 – Dimmer Compatibility List.

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
13-Nov-12	CA	1.0	Initial Release	Apps & Mktg

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