Design Example Report

Title	***30 W Isolated Flyback, 1 – 10 V Analog Dimming LED Driver Using LYTSwitch™-4 LYT4315E***
Specification	90 VAC – 132 VAC Input; 30 V – 60 V, 0.50 A_{TYP} Output
Application	DC T8 Tube
Author	Applications Engineering Department
Document Number	DER-442
Date	September 24, 2015
Revision	1.0

Summary and Features

- Wide output voltage range (30 V to 60 V) with accurate constant current (CC) regulation
- Single-stage power factor correction , PF >0.95
- 1 V to 10 V analog dimming
- Consistent dimming performance across output and input voltage range
- Energy efficient at 115 V, >85% at 115 VAC input
- Constant voltage open load protection
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis
  - No damage during brown-out conditions
- PF >0.95 at 115 VAC
- A-THD <20% at 115 VAC
- Meets IEC 2.5 kV ring wave, 1 kV differential surge and EN55015 conducted EMI

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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

This document is an engineering report describing a wide output voltage range and 1 V to 10 V dimmable isolated flyback LED driver (power supply) utilizing a LYT4315E from the LYTSwitch-4 family of devices.

The design provides a constant output current of 500 mA from 30 V to 60 V output with the input range of 90 VAC to 132 VAC.

The key design goals were to achieve high efficiency, 1 V to 10 V dimming and constant current regulation across the output range.

The LYTSwitch-4 driver IC, combines the PFC function which both meet power factor and harmonics requirements.

The topology used is an isolated flyback operating in continuous conduction mode. Constant current and dimming regulation are achieved through a secondary feedback control circuit utilizing a quad operational amplifier. The internal controller adjusts the power MOSFET duty cycle to maintain a sinusoidal input current providing high power factor and low harmonic currents.

The LYT4315E also provides several protection features including auto-restart for open control loop and output short-circuit conditions, line overvoltage protection and over temperature protection. Line overvoltage provides extended line fault and surge withstand, output overvoltage protects the supply should the load be disconnected and accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet and performance data.

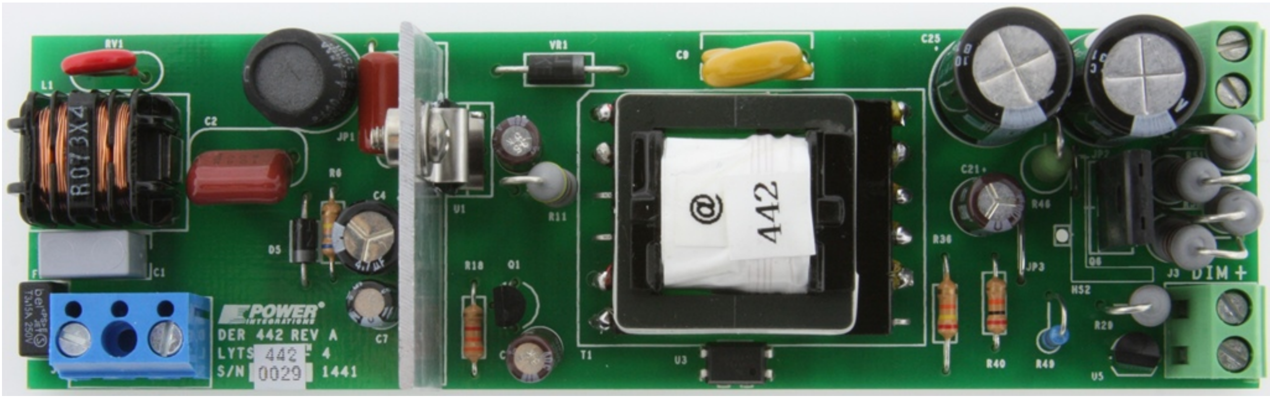

Figure 1 – Populated Circuit Board, Top View.

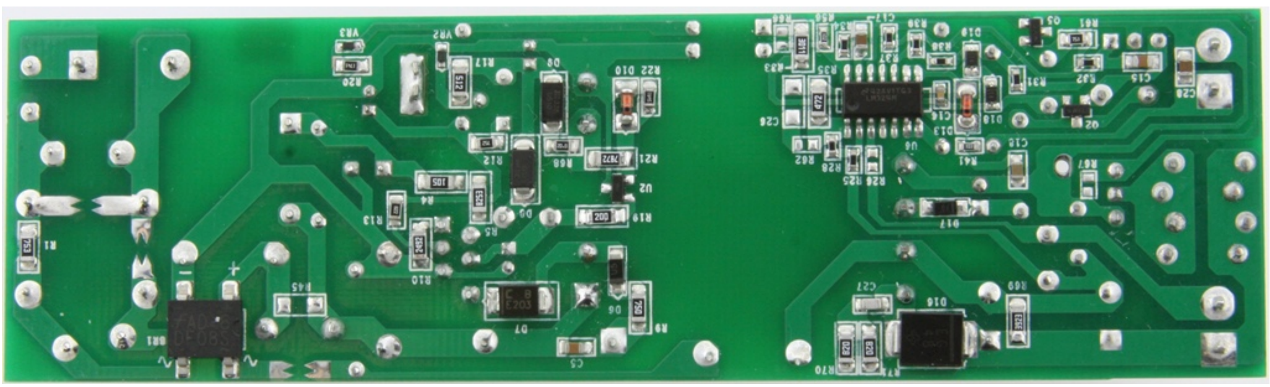

Figure 2 – Populated Circuit Board, Bottom View.

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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	115	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	30	45	60	V	
Output Current	I_{OUT}	0.45	0.50	0.55	A	
Total Output Power						
Continuous Output Power	P_{OUT}	15	22.5	30	W	
Efficiency						
Full Load	η		85		%	Measured at Po= 30 W, 25 ˚C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			1.0		kV	
Power Factor			0.95			Measured at 115 VAC, 60 Hz
Ambient Temperature	T_{AMB}			40	°C	Free convection, sea level

3 Schematic

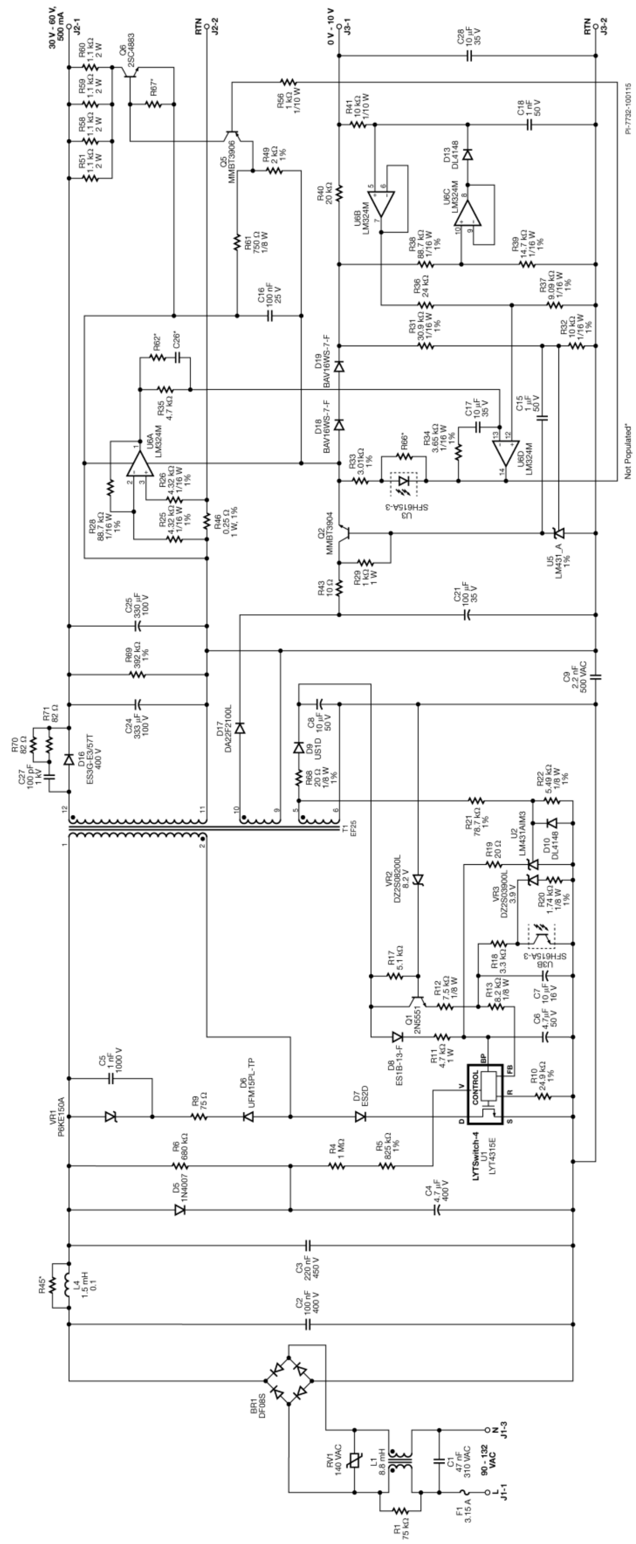

Figure 3 – Schematic.

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4 Circuit Description

The LYTSwitch-4 device (U1 - LYT4315E) integrates the 725 V power MOSFET, controller and start-up functions into a single package, reducing the component count versus typical implementations. Configured as part of a 30 W, wide output voltage range (30 V to 60 V) isolated continuous conduction mode flyback converter, U1 provides high power factor via its internal control algorithm together with the small input capacitance of the design. The LYT4315E device is selected from the LYTSwitch-4 power table to provide optimized I_{FB} current realizing a good dimming regulation performance throughout the input and output voltage ranges. Continuous conduction mode operation results in reduced primary peak and RMS current. This both reduces EMI noise, allowing smaller EMI filtering components and improves efficiency. Output current regulations and 1 V to 10 V dimming capability throughout the ranges are maintained by a closed loop feedback circuit using a quad-operational amplifier.

4.1 Input Stage

Fuse F1 provides protection against component failure. Varistor RV1 works as a clamp to limit the maximum voltage spike at the primary side during differential line surge events. A 140 VAC rated part was selected, being slightly above the maximum specified operating voltage (132 VAC). A fast acting line overvoltage detection of the LYTSwitch-4 IC in conjunction with D5 and C4 peak detector capacitor provides a clamp to limit the maximum voltage stress across the power MOSFET of the IC.

The AC input is full wave rectified by BR1 to achieve good power factor and low THD.

Differential choke L4, together with the input filter capacitor C2 and C3 work as a first stage π EMI filter. Capacitor C1 and commode mode choke L1 form a second-stage EMI filter network after the bridge diode BR1. Y capacitor C9 provides a common mode noise path from secondary to primary input EMI filter networks. These EMI filters, together with the LYTSwitch-4 frequency jittering feature allow compliance to the Class B emission limit.

4.2 LYTSwitch-4 Primary

The primary winding finish terminal (no dot end) of the transformer (T1) is connected to the DC bus and the start (dotted end) terminal to the DRAIN (D) pin of the LYTSwitch-4 IC via blocking diode D7. During the on-time of the power MOSFET, current ramps through the primary winding, storing energy which is then delivered to the output during the power MOSFET off-time.

To provide peak line voltage information to U1 the incoming rectified AC peak charges C4 via D5. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R4 and R5. 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 725 BV_{DSS} rating of the internal power MOSFET.

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. A 24.9 kΩ resistor is used on the REFERENCE (R) pin (R10) and 4.2 MΩ (R4 and R5) on the V pin to provide a linear relationship between input voltage and the output current.

During the power MOSFET off-time, D6, VR1, R9, and C5 clamp the drain voltage to a safe level. Diode D7 is necessary to prevent reverse current from flowing through U1 while the voltage across C3 (rectified input AC) falls to below the reflected output voltage (parameter VOR in the design spreadsheet). Diode D9 and C8 generate a primary bias supply for U1 from an auxiliary winding on the transformer. Resistor R20 provides voltage spike filtering to obtain an accurate bias voltage output with respect to the output voltage.

Capacitor C6 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the internal controller. During start-up, C6 is charged to ~6 V from an internal high-voltage current source connected to the D pin.

The use of an external bias supply (via D8 and R11) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming condition.

Capacitor C6 also selects the output power mode, for the LYT4315E device, a 4.7 μF capacitor was selected to obtain its maximum power output capability.

Since I_{FB} is controlled by a closed loop feedback circuit, a linear regulator comprising of Q1, R17, VR2, R12 and C7 is used to provide a constant bias supply voltage to U3 throughout the output voltage ranges.

4.3 Feedback Circuit

Output current regulation and 1 V to 10 V dimming performance is maintained by controlling the I_{FB} current through a secondary feedback circuit. The secondary feedback circuit drives the optocoupler U3 to control the I_{FB} current at the primary side. An increase in optocoupler current results in reduced I_{FB} current, hence reducing the output LED current.

The feedback circuit bias supply is a forward type converter rectified by D17 and filtered by C21. The supply output voltage is proportional to the input AC voltage. A linear regulator using U5, Q2, C11, R29 and C16 provides constant supply on the secondary feedback circuit to ensure stability throughout the ranges. Shunt regulator U5 has an accurate 2.5 V internal voltage reference, and with sampling resistors R31 and R32, sets the secondary bias supply voltage to 11.2 V. Capacitor C15 provides feedback compensation to the shunt regulator U5.

The forward voltage drops of D18 and D19 provide 1.2 V offset voltage between U6 bias supply and the input of the buffer amplifier U6B (pin 5). Offset voltage allows the buffer amplifier output (pin 7) to accurately follow the input dim signal on pin 5.

The LED Load current flowing in the output power rail is sensed and converted to small voltage signal (V_{SENSE}) using 1 W wire wound resistor R46. The sense resistor must be large enough to withstand inrush current during accidental output short-circuit. The voltage signal from the current sense resistor is then amplified by a differential amplifier U6A with a voltage gain defined by R28 and R25 ($V_{PIN1} = V_{SENSE}XR25/R28$). The amplified signal from current sense resistor is then fed to the inverting input (V-) (pin 13) of the comparator U6D through R35. The inverting (V-) input signal is directly proportional to the LED load current which is basically a sinusoidal waveform due to high output ripple current.

The non-inverting input voltage (V+) (pin 12) to the comparator (U6D) is supplied by the buffer amplifier U6B, having a high input impedance to prevent affecting the input dim signal. During no dim input signal, the default 10 V DC input dim signal to pin 5 of the buffer amplifier U6B comes from the bias supply through R40. The output (pin 7) of the buffer amplifier U6B follows the 10 V input signals setting up a non-inverting input to the comparator U6D through sampling resistors R36 and R37. The non-inverting input voltage signal to pin 12 of the comparator U6D is directly proportional to the input dim voltage signals. Lower voltage dim signal corresponds to lower non-inverting input voltage.

With optimized value of feedback loop compensation R34 and C17, the comparator U6D generates sinusoidal output voltage waveforms on pin 14 with an average voltage value inversely proportional to the output LED load current and directly proportional to the dimming input voltage. The output of the comparator U6D in pin 14 drives optocoupler U3 to provide a feedback signal to the primary side and control the I_{FB}. During dimming, a decrease of input dim voltage results in a decreased of comparator output at pin 14 increasing the optocoupler LED current and therefore pulling down the I_{FB} current at the secondary side. Buffer amplifier circuit using U6C, D13, C18 and sampling resistors R38 and R9, supplies the 1.0 V dimming signals during 0 V or short-circuited dim input.

Resistor R33 limits the DC gain of the optocoupler to ensure constant current regulation throughout the ranges. Zener diode VR3 and R20 limit the I_{FB} current during transient operation at maximum output LED voltage to prevent flicker and output current overshoot.

4.4 No-Load Protection

In the event of no-load operation, the output voltage is regulated at 67 V. The output voltage is detected on the primary bias winding through the turns ratio of secondary and the bias winding. Shunt regulator U2 will force the BP pin in auto-restart to regulate the output voltage. Divider R21 and R22 sets the overvoltage protection (OVP) threshold. Diode D10 protects U2 from a reverse current when the voltage reverses on bias winding during turn on.

4.5 Shorted Load and Overload Protection

During short-circuit operation, the bias voltage decreases forcing the device to enter in auto-restart mode whenever the FB current falls below the $I_{FB(AR)}$ threshold for longer than the ~76 ms. The load is protected against overload and short-circuits via a primary current limit. During a short, primary current will build-up until it reaches current limit. Refer to short-circuit waveforms for more information.

4.6 Output Rectification

The transformer secondary winding is rectified by D16 and filtered by capacitors C24 and C25. For designs where lower ripple is required, the output capacitance value can be increased.

During the output diode D16 Off time, RC snubber C27, R70 and R71 reduces the reverse voltage stress and leakage inductance ringing that will help reduce conducted EMI.

4.7 Active Pre-load

The active pre-load circuit is added to extend dimming range capability and provide additional output loading during 0 V to 3 V input dim voltage. Voltage divider resistors R49 and R61 set the pre-load activation threshold starting from 3 V to 0 V dim input. The base pin of the PNP transistor Q5 detects the comparator U6D output at pin 14 through its base resistor R56 then drive the pre-load switch Q6 when its base voltage is lower by 0.7 V from the its emitter pin voltage. At dim input voltage of 4 V to 10 V the active pre-load disengages to prevent reducing the efficiency. Resistor R51, R58, R59 and R60 set the maximum current flowing into the pre-load circuit. The temperature rise of resistors R51, R58, R59 and R60 can be significant and should be verified in the final product.

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5 PCB Layout

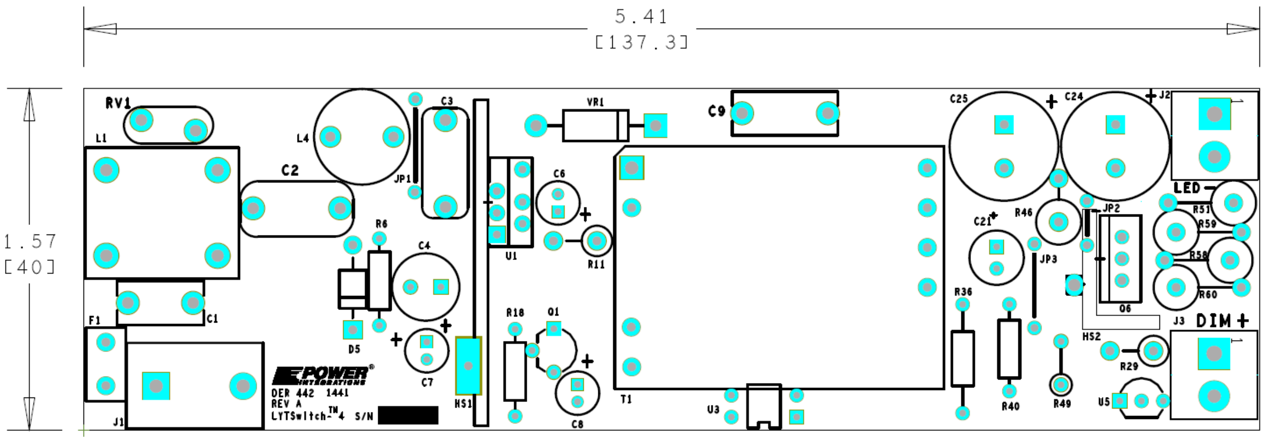

Figure 4 – Top Side.

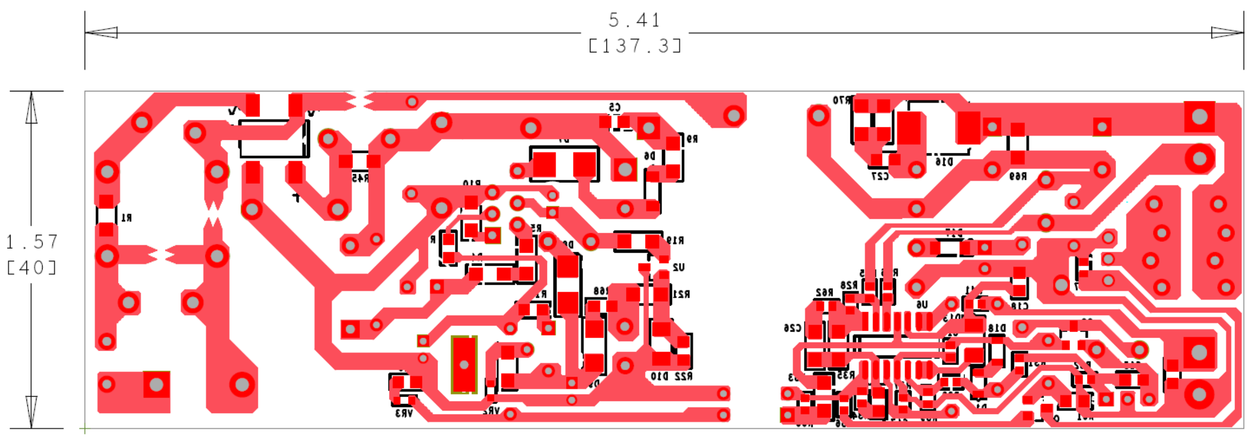

Figure 5 – Bottom Side.

6 Bill of Materials

Item	QTY	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	800 V, 1 A, Bridge Rectifier, SMD, DFS	DF08S	Diodes, Inc.
2	1	C1	47 nF, 310 VAC, Polyester Film, X2	BFC233920473	Vishay
3	1	C2	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
4	1	C3	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
5	1	C4	4.7 µF, 400 V, Electrolytic, (8 x 11.5)	SHD400WV 4.7uF	Sam Young
6	1	C5	1 nF, 1000 V, Ceramic, X7R, 0805	C0805C102KDRACTU	Kemet
7	1	C6	4.7 µF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG500ELL4R7ME11D	Nippon Chemi-Con
8	1	C7	10 µF, 16 V, Electrolytic, Gen. Purpose, (5 x 11)	UVR1C100MDD	Nichicon
9	1	C8	10 µF, 50 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG500ELL100ME11D	Nippon Chemi-Con
10	1	C9	CAP Ceramic 2.2 nF 500 VAC	VY1222M47Y5UQ63V0	Vishay
11	1	C15	1 µF, 50 V, Ceramic, X7R, 0805	C2012X7R1H105M	TDK Corp
12	1	C16	100 nF, 25 V, Ceramic, X7R, 0603	VJ0603Y104KNXAO	Vishay
13	1	C17	10 µF, 35 V, Ceramic, X5R, 0805	C2012X5R1V106K085AC	TDK
14	1	C18	1 nF, 50 V, Ceramic, X7R, 0805	08055C102KAT2A	AVX
15	1	C21	100 µF, 35 V, Electrolytic, Gen. Purpose, (6.3 x 11)	EKMG350ELL101MF11D	Nippon Chemi-Con
16	1	C24	330 µF, 100 V, Electrolytic, (12.5 x 25)	UVZ2A331MHD	Nichicon
17	1	C25	330 µF, 100 V, Electrolytic, (12.5 x 25)	UVZ2A331MHD	Nichicon
18	1	C26	No Component-Unstuffed	Unstuffed	Unstuffed
19	1	C27	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
20	1	C28	10 µF, 35 V, Ceramic, X5R, 0805	C2012X5R1V106K085AC	TDK
21	1	D5	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
22	1	D6	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	Micro Commercial
23	1	D7	200 V, 2 A, Ultrafast Recovery, 20 ns, DO-214AA	ES2D	Diodes, Inc.
24	1	D8	100 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC	ES1B-13-F	Diodes, Inc.
25	1	D9	Diode Ultrafast, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
26	1	D10	75 V, 0.15 A, Fast Switching, 4 ns, MELF, SOD80C	DL4148-TP	Micro Commercial
27	1	D13	75 V, 0.15 A, Fast Switching, 4 ns, MELF, SOD80C	DL4148-TP	Micro Commercial
28	1	D16	Diode Ultrafast 400 V 3 A, DO-214AB	ES3G-E3/57T	Vishay
29	1	D17	200 V, 1 A, MINI2	DA22F2100L	Panasonic
30	1	D18	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
31	1	D19	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
32	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
33	1	HS1	SHTM, Heat Sink, eSIP, DER-442		Custom
34	1	HS_POST1	Optional Compoent- Do not mount	Optional	Optional
35	1	J1	CONN TERM BLOCK 5.08 MM 3 Pos	ED120/3DS	On Shore Tech
36	1	J2	2 Pos (1 x 2) header, 5 mm (0.196) pitch, Vertical	1715022	Phoenix Contact
37	1	J3	2 Pos (1 x 2) header, 5 mm (0.196) pitch, Vertical	1715022	Phoenix Contact
38	1	JP1	Wire Jumper, Insulated, TFE, #22 AWG, 0.4 in	C2004-12-02	AlphaWires
39	1	JP2	Wire Jumper, Insulated, TFE, #22 AWG, 0.2 in	C2004-12-02	AlphaWires
40	1	JP3	Wire Jumper, Insulated, TFE, #22 AWG, 0.4 in	C2004-12-02	AlphaWires
41	1	L1	8.8 mH, 0.7 mA, AC Filter T/H CMC	SU10VFC-R07088	Kemet
42	1	L4	1.5 mH, 0.8 A, 20%	RL-5480-4-1500	Renco
43	1	Q1	NPN, Small Signal BJT, 160 V, 0.6 A, TO-92	2N5551RLRAG	On Semi
44	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
45	1	Q5	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
46	1	Q6	NPN, Power BJT, 150 V, 2 A, TO-220F	2SC4883	Sanken
47	1	R1	75 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ753V	Panasonic
48	1	R4	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
49	1	R5	825 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF8253V	Panasonic
50	1	R6	680 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-680K	Yageo
51	1	R9	75 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ750V	Panasonic
52	1	R10	24.9 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2492V	Panasonic
53	1	R11	4.7 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-4K7	Yageo

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54	1	R12	7.5 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ752V	Panasonic
55	1	R13	8.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ822V	Panasonic
56	1	R17	5.1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ512V	Panasonic
57	1	R18	3.3 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-3K3	Yageo
58	1	R19	20 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ200V	Panasonic
59	1	R20	1.74 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1741V	Panasonic
60	1	R21	78.7 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7872V	Panasonic
61	1	R22	5.49 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5491V	Panasonic
62	1	R25	4.32 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4321V	Panasonic
63	1	R26	4.32 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4321V	Panasonic
64	1	R28	88.7 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF8872V	Panasonic
65	1	R29	1 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-1K0	Yageo
66	1	R31	30.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3092V	Panasonic
67	1	R32	10 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1002V	Panasonic
68	1	R33	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
69	1	R34	3.65 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3651V	Panasonic
70	1	R35	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
71	1	R36	24 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-24K	Yageo
72	1	R37	9.09 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9091V	Panasonic
73	1	R38	88.7 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF8872V	Panasonic
74	1	R39	14.7 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1472V	Panasonic
75	1	R40	20 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-20K	Yageo
76	1	R41	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
77	1	R45	No Component-Unstuffed	Unstuffed	Unstuffed
78	1	R46	0.25 Ω, 1%, 1 W	2306 327 52507	Phoenix
79	1	R49	2 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-2K00	Yageo
80	1	R51	1.1 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K1	Yageo
81	1	R56	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
82	1	R58	1.1 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K1	Yageo
83	1	R59	1.1 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K1	Yageo
84	1	R60	1.1 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K1	Yageo
85	1	R61	750 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ751V	Panasonic
86	1	R62	No Component-Unstuffed	Unstuffed	Unstuffed
87	1	R66	No Component-Unstuffed	Unstuffed	Unstuffed
88	1	R67	No Component-Unstuffed	Unstuffed	Unstuffed
89	1	R68	20 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF20R0V	Panasonic
90	1	R69	392 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3923V	Panasonic
91	1	R70	82 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ820V	Panasonic
92	1	R71	82 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ820V	Panasonic
93	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
94	1	T1	Bobbin, EF25, Horizontal, 12 pins Transformer	YC2504 SNX-R1778-X1	Ying Chin Santronics
95	1	U1	LYTSwitch-4, eSIP-7C	LYT4315E	Power Integrations
96	1	U2	IC, REG Zener Shunt ADJ SOT-23	LM431AIM3/NOPB	National Semi
97	1	U3	Optocoupler, 70 V, CTR 100-200%, 4-DIP	SFH615A-3	
98	1	U5	2.495 V Shunt Regulator IC, 2%, 0 to 70C, TO92	LM431ACZ	National Semi
99	1	U6	IC, OP AMP QUAD LOW POWER, SOIC-14	LM324MX/NOPB	Texas Instruments
100	1	VR1	150 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE150A	LittleFuse
101	1	VR2	8.2 V, 5%, 150 mW, SSMINI-2	DZ2S08200L	Panasonic
102	1	VR3	3.9 V, 5%, 150 mW, SSMINI-2	DZ2S03900L	Panasonic

7 Transformer Specification

7.1 Electrical Diagram

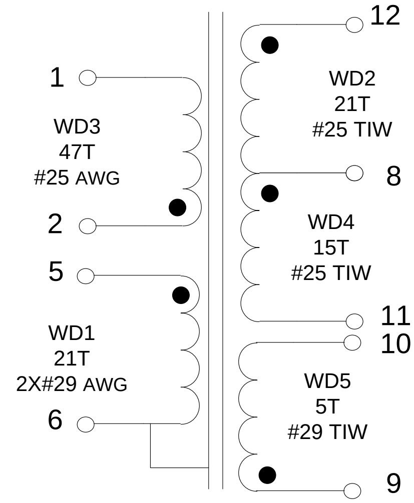

Figure 6 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V pk-pk, 100 kHz switching frequency, between pin 1 and pin 2, with all other windings open.	396 μH
Tolerance	Tolerance of primary inductance.	±5%
Primary Leakage Inductance	Measured between pin 1 to pin 2, with all other windings shorted.	10 μH Max.

7.3 Materials

Item	Description
[1]	Core: EF25; PC44.
[2]	Bobbin, EF25, Horizontal, 12 pins, Part no. 25-00882-00.
[3]	Magnet Wire: AWG #25.
[4]	Magnet Wire: AWG #29.
[5]	Triple Insulated Wire: AWG #25.
[6]	Triple Insulated Wire: AWG #29.
[7]	Transformer Tape: 15.5 mm.
[8]	Transformer Tape: 7.2 mm.
[9]	Non-insulated Wire: AWG #30.

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7.4 Transformer Build Diagram

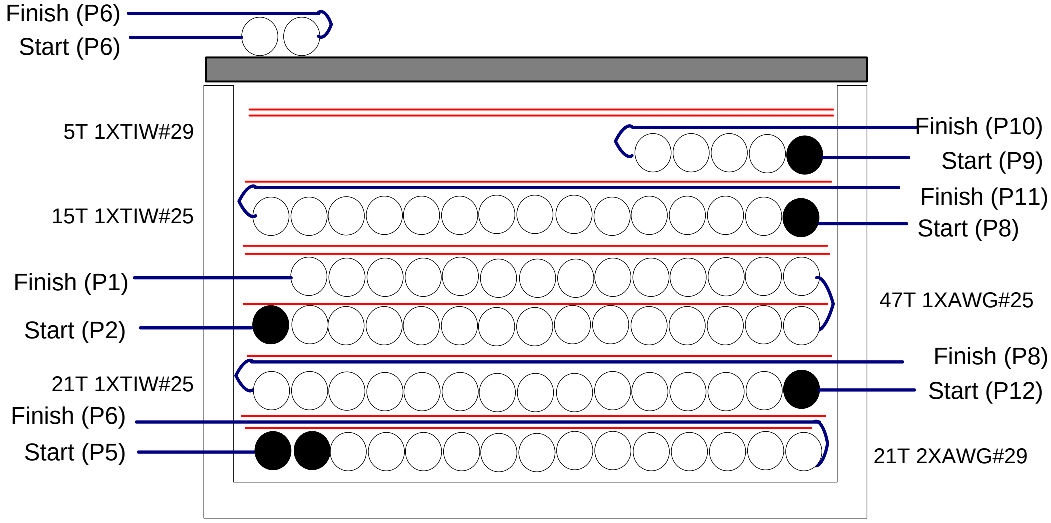

Figure 7 – Transformer Electrical Diagram.

7.5 Transformer Construction

Winding Directions	Bobbin is oriented on winder such that pin 1 side is on the left side. All Winding directions are clockwise looking at pin 1 of the bobbin.
WDG1-Bias (Primary)	Start on pin 5 and wind 21 turns (bifilar) of item (4) evenly from left to the right. Start to add ¼ turn of the insulation tape (item 7) before terminating the finish terminal of WDG1 back to the left at pin 6.See below
Insulation	Start to add ¼ turn of the insulation tape (item 7) before terminating the finish terminal of WDG1 back to the left at pin 6. Wrap the remaining ¾ turn tape insulation after terminating the finish of WDG1 on pin 6.
WDG2-Secondary	Start on Pin 12 and wind 21 turns of item (5) evenly from right to left, then terminate the finish back to the right at pin 8.
Insulation	Add 1 layer of tape, item [7], for insulation.
WDG3-Primary	Start on pin 2 and wind 47 turns of item (3) from left to right and right to left in 2 layers and finish this winding on pin 1.
Insulation	Add 2 layer of tape, item [7], for insulation.
WDG4-Secondary	Start on pin 8 and wind 15 turns of item (5) on the first layer from right to left then finish the winding to Pin 11
Insulation	Add 1 layer of tape, item [7], for insulation.
WDG5-Bias (Secondary)	Start on P9 and wind 5 turns of item (4) from right to left then finish the winding at pin 10
Insulation	Add 2 layer of tape, item [7], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal primary inductance of 396uH
Assemble Core	Assemble the 2 cores on the bobbin
Flux Wire Band	Wrap a 2 shorted turns of item (9) around the outside of the windings and core halves with tight tensions. Terminate to pin 6 with this wire and wrap the 2 cores with 2 layer of tape, Item (8).
Pins	Pull-out terminal pin number 3, 4 and 7. Cut pin 8 by 4mm
Finish	Dip the transformer assembly in varnish.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_101813; Rev.1.3; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_101813: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**YES**		**YES**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			90	V	Minimum AC Input Voltage
VACMAX			132	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	45.00		45	V	Typical output voltage of LED string at full load
VO_MAX	60.00		60.00	V	Maximum expected LED string Voltage.
VO_MIN	30.00		30.00	V	Minimum expected LED string Voltage.
V_OVP			61.76	V	Over-voltage protection setpoint
IO	0.50		0.50	A	Typical full load LED current
PO			22.5	W	Output Power
n	0.87		0.87		Estimated efficiency of operation
VB			20	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch-4	**LYT4315**		**LYT4315**		Selected LYTSwitch-4
Current Limit Mode	**FULL**		**FULL**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.76	A	Minimum current limit
ILIMITMAX			2.06	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			79.8	uA	V pin current
RV	2.00		2.0	M-ohms	Upper V pin resistor
RV2			1.E+12	M-ohms	Lower V pin resistor
IFB	153.00		153.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			143.8	k-ohms	FB pin resistor
VDS			10	V	LYTSwitch on-state Drain to Source Voltage
VD			0.50	V	Output Winding Diode Forward Voltage Drop (0.5 V for Schottky and 0.8 V for PN diode)
VDB			0.70	V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP	0.60		0.60		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			396	uH	Primary Inductance
VOR	60.00		60	V	Reflected Output Voltage.
Expected IO (average)			0.50	A	Expected Average Output Current
KP_VACMAX			0.69		Expected ripple current ratio at VACMAX
TON_MIN			1.84	us	Minimum on time at maximum AC input voltage
PCLAMP			0.21	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EF25**		**EF25**		Core Size
Custom Core					Enter custom core part number
AE			0.52	cm^2	Core Effective Cross Sectional Area
LE			5.8	cm	Core Effective Path Length
AL			2000	nH/T^2	Ungapped Core Effective Inductance
BW			15.6	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)

L			3		Number of Primary Layers
NS			35		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			127	V	Peak input voltage at VACMIN
VMAX			187	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.34		Minimum duty cycle at peak of VACMIN
IAVG			0.28	A	Average Primary Current
IP			1.52	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.49	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			396	uH	Primary Inductance
LP_TOL	10		10		Tolerance of primary inductance
NP			46		Primary Winding Number of Turns
NB			20		Bias Winding Number of Turns
ALG			186	nH/T^2	Gapped Core Effective Inductance
BM			2511	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3410	Gauss	Peak Flux Density (BP<3700)
BAC			753	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1776		Relative Permeability of Ungapped Core
LG			0.32	mm	Gap Length (Lg > 0.1 mm)
BWE			46.8	mm	Effective Bobbin Width
OD			1.01	mm	Maximum Primary Wire Diameter including insulation
INS			0.08	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.93	mm	Bare conductor diameter
AWG			19	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			1290	Cmils	Bare conductor effective area in circular mils
CMA		Info	2608	Cmils/Amp	!!! Info. Decrease CMA (200 < CMA < 600) Decrease L(primary layers),increase NS,smaller Core
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			2.00	A	Peak Secondary Current
ISRMS			0.86	A	Secondary RMS Current
IRIPPLE			0.70	A	Output Capacitor RMS Ripple Current
CMS			172	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			27	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.36	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.45	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			342	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			203	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			114	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)					

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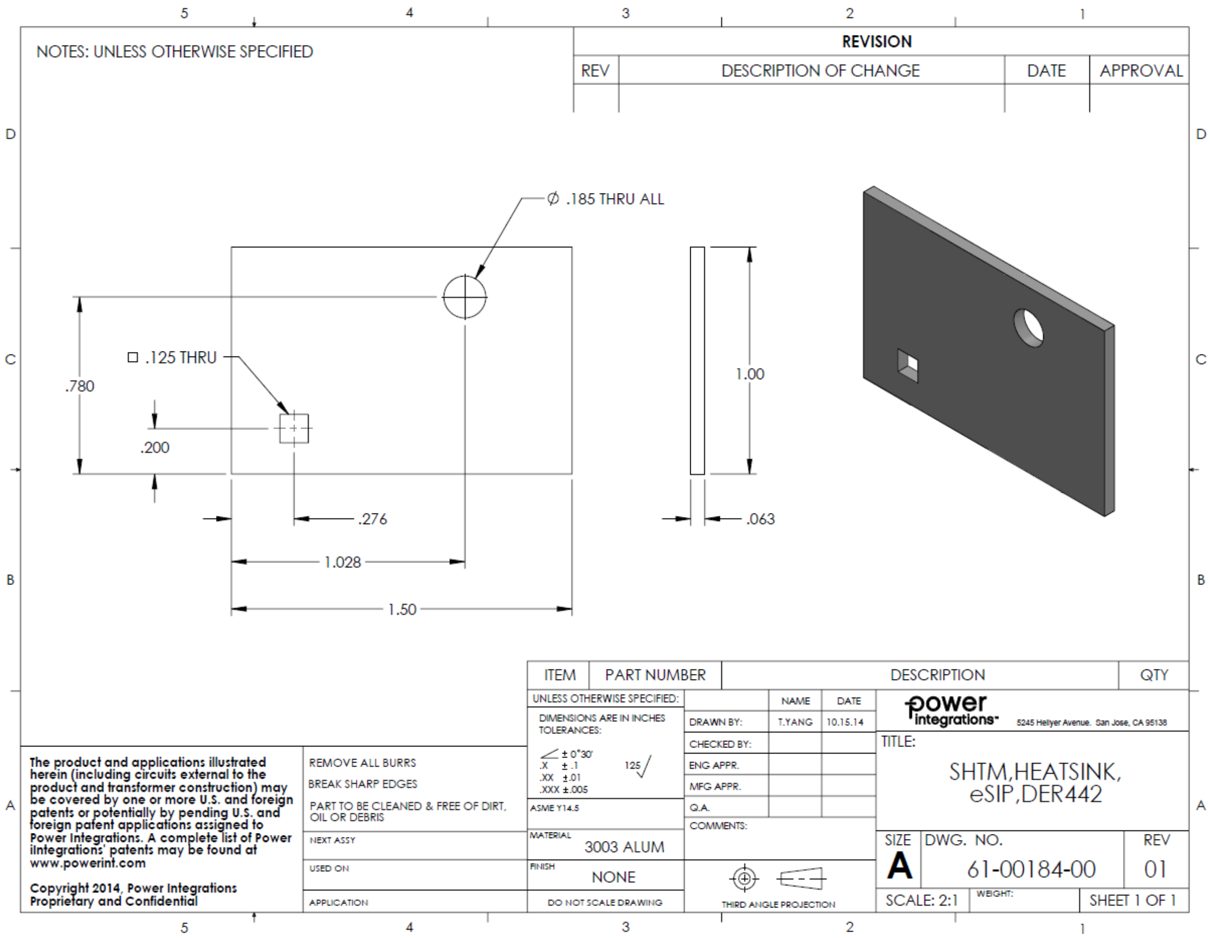
V pin Resistor Fine Tuning					
RV1			2.00	M-ohms	Upper V Pin Resistor Value
RV2			1.E+12	M-ohms	Lower V Pin Resistor Value
VAC1			115.0	V	Test Input Voltage Condition1
VAC2			230.0	V	Test Input Voltage Condition2
IO_VAC1			0.50	A	Measured Output Current at VAC1
IO_VAC2			0.50	A	Measured Output Current at VAC2
RV1 (new)			2.00	M-ohms	New RV1
RV2 (new)			10455.82	M-ohms	New RV2
V_OV			161.1	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			34.5	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			144	k-ohms	Upper FB Pin Resistor Value
RFB2			1.E+12	k-ohms	Lower FB Pin Resistor Value
VB1			16.5	V	Test Bias Voltage Condition1
VB2			33.5	V	Test Bias Voltage Condition2
IO1			0.50	A	Measured Output Current at Vb1
IO2			0.50	A	Measured Output Current at Vb2
RFB1 (new)			143.8	k-ohms	New RFB1
RFB2(new)			1.0000E+12	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic		Max Current	Limit		
1st Harmonic		237	N/A	mA	
3rd Harmonic		18	N/A	%	N/A
5th Harmonic		7	N/A	%	N/A
7th Harmonic		3	N/A	%	N/A
9th Harmonic		2	N/A	%	N/A
11th Harmonic		1	N/A	%	N/A
13th Harmonic		1	N/A	%	N/A

9 Heat Sink Assembly

9.1 eSIP Heat Sink Fabrication Drawing



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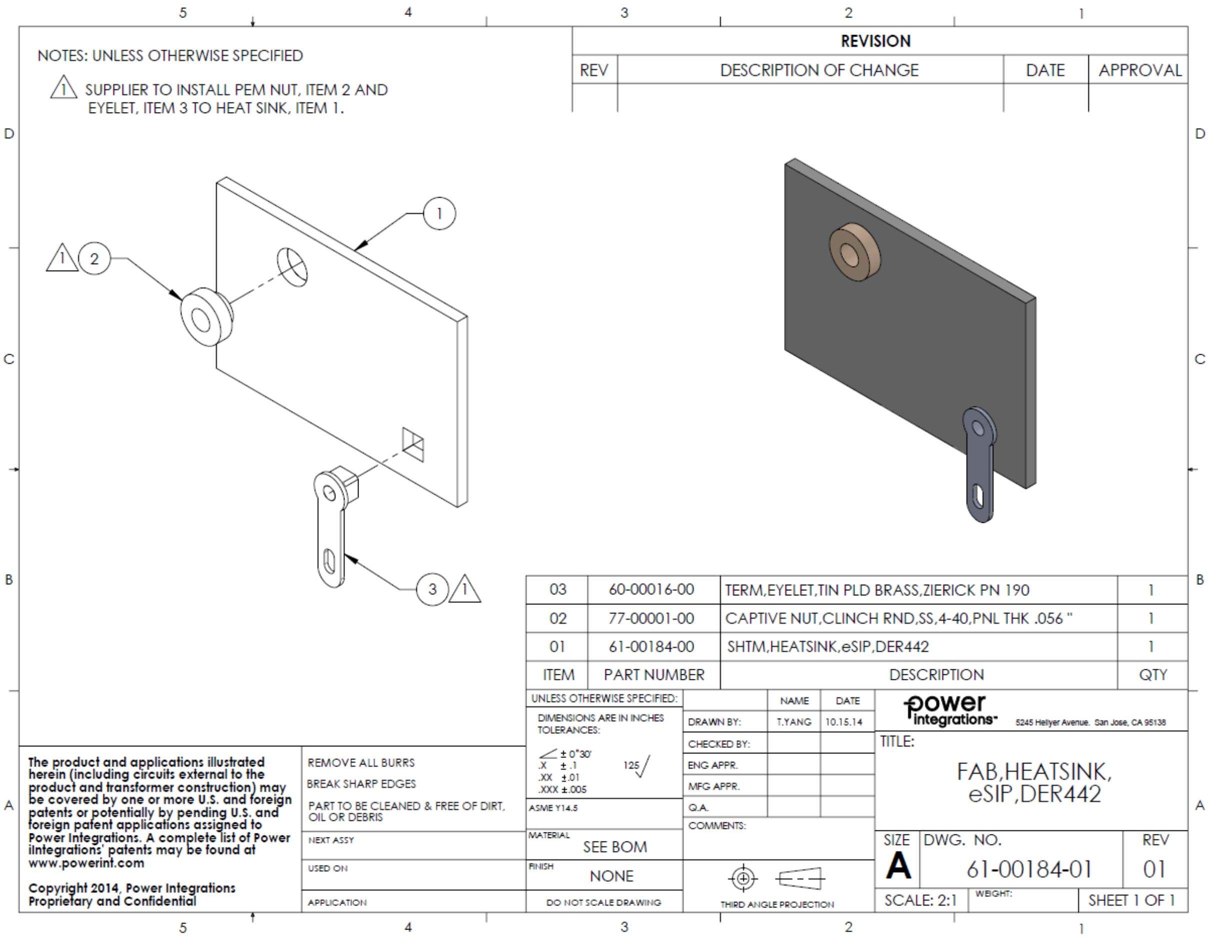
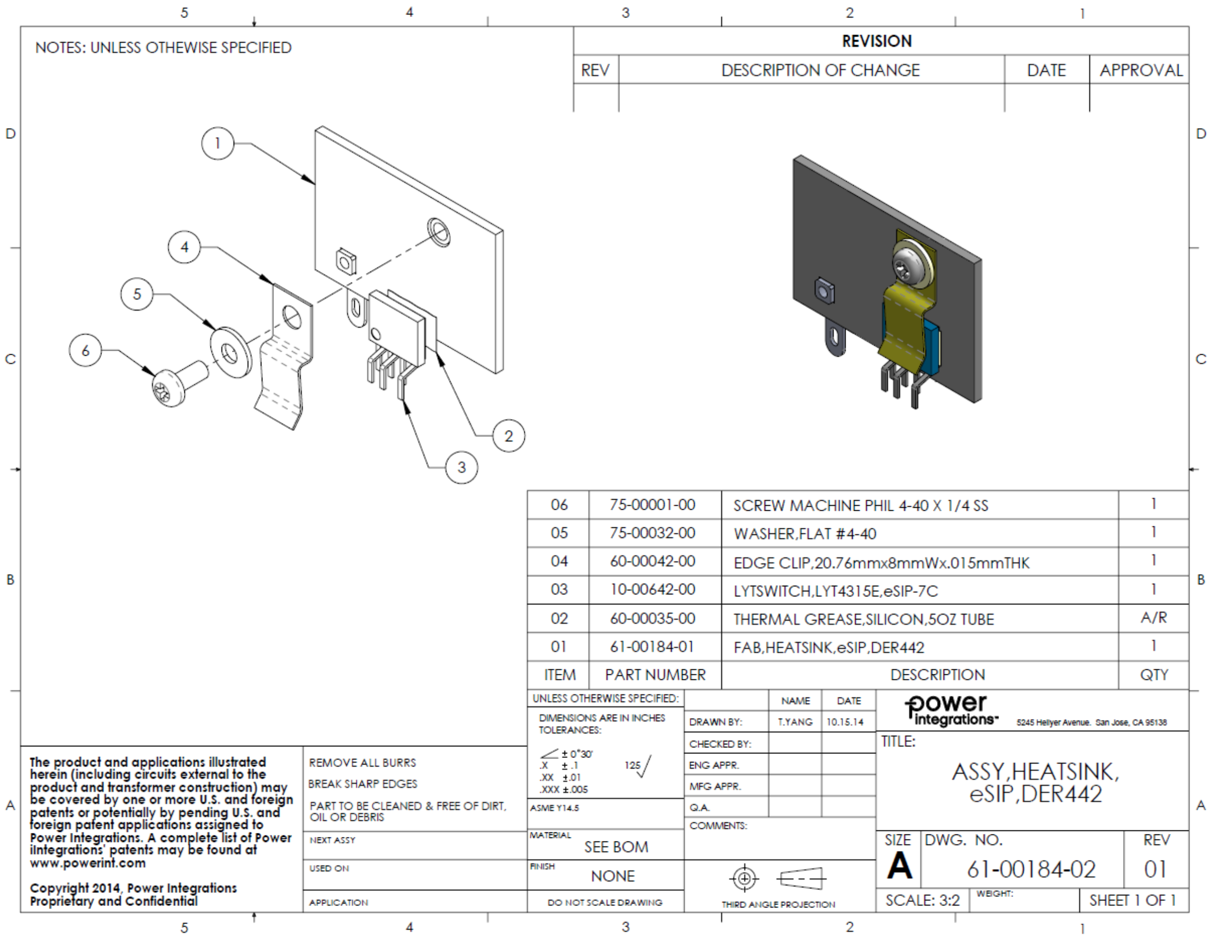
9.2 eSIP Heat Sink Assembly Drawing



9.3 eSIP and Heat Sink and Assembly Drawing



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10 Performance Data

All measurements were performed at room temperature using a 30 V, 45 V and 60 V LED string. Refer to the table below for the complete set of test data and graphs.

10.1 Efficiency

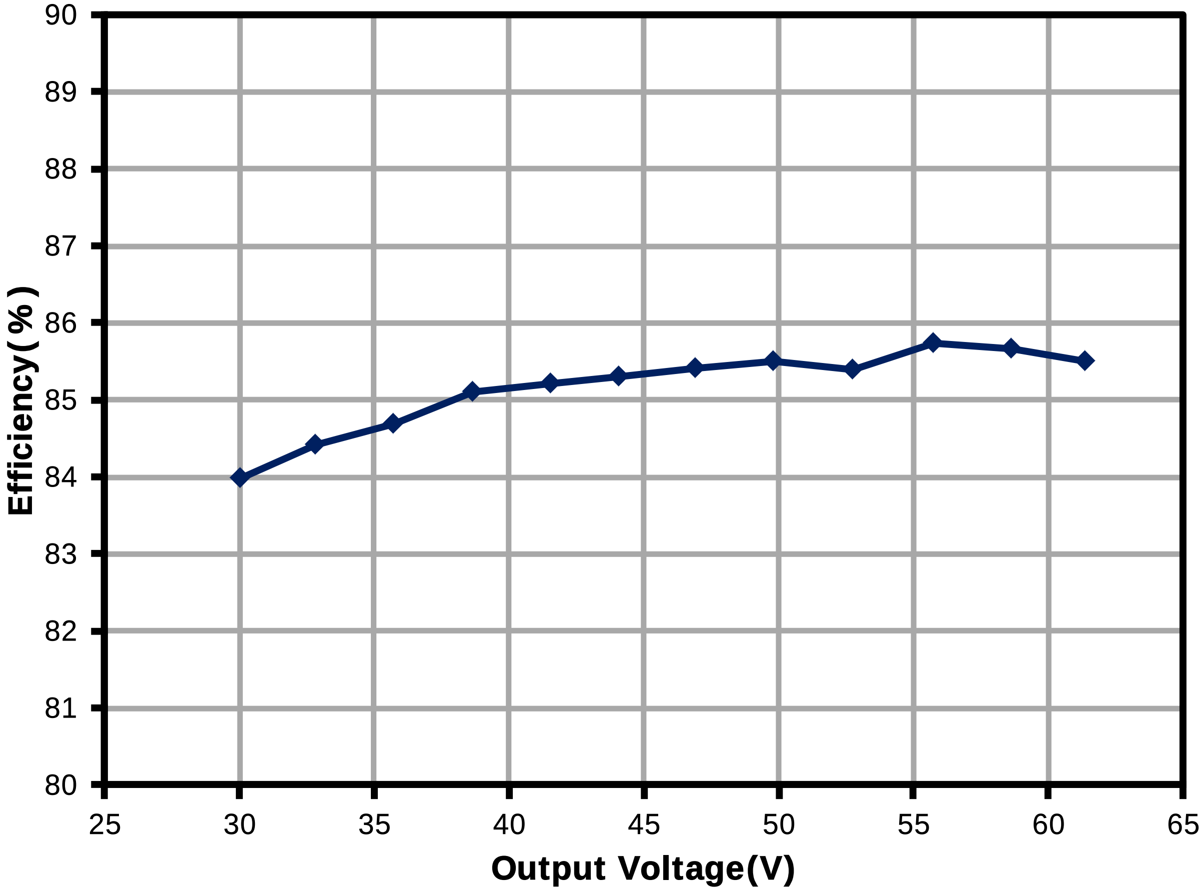

Figure 8 – Efficiency vs. LED Load Strings at 115 V.

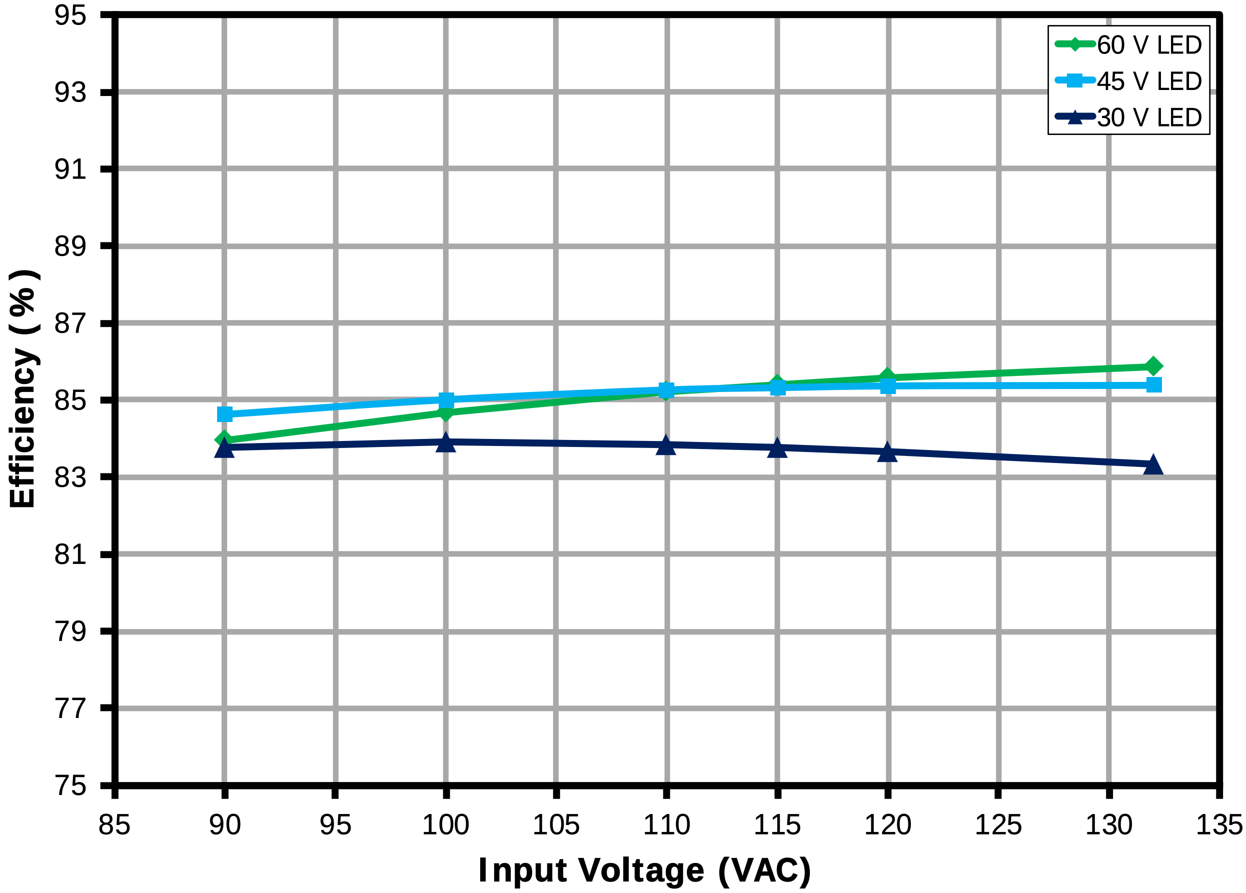

Figure 9 – Efficiency vs. Line and LED Load.

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10.2 Line Regulation

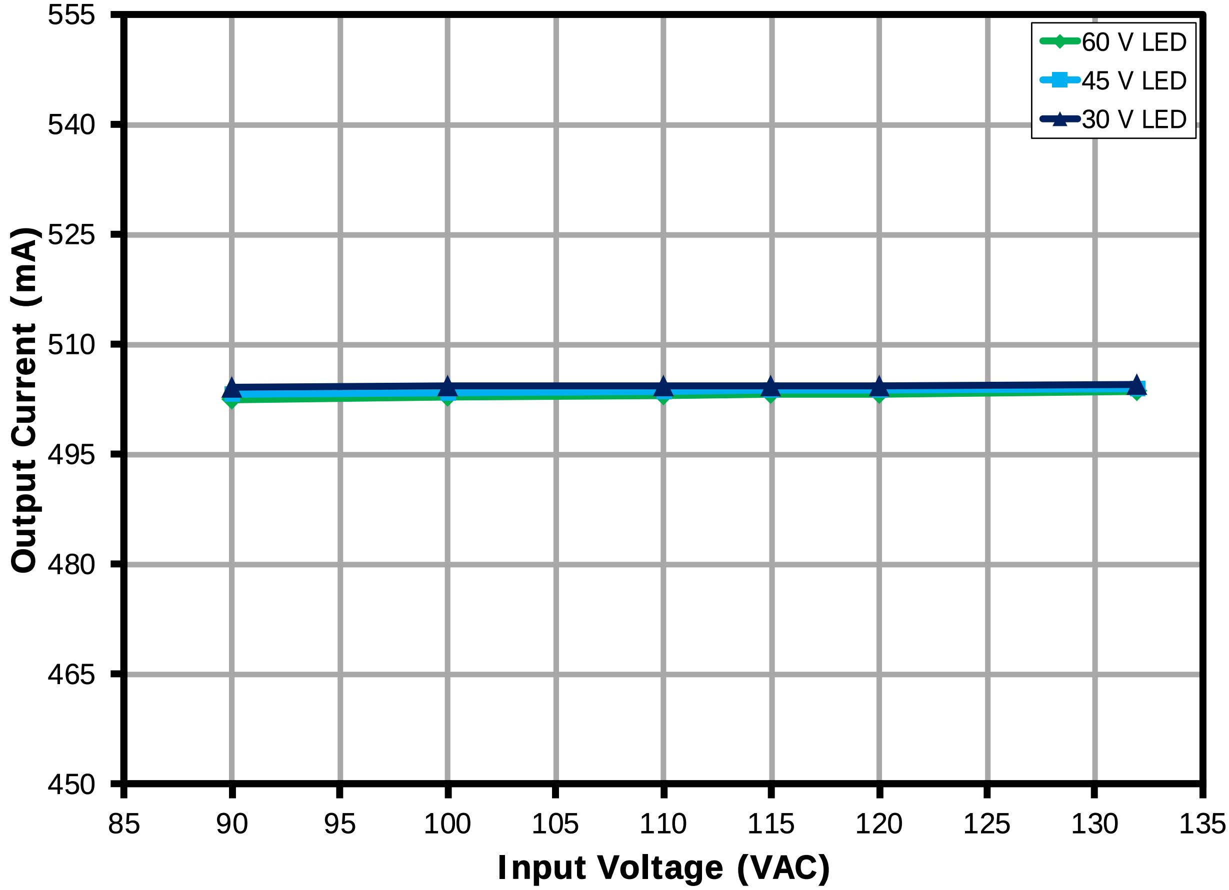

Figure 10 – Regulation vs. Line and LED Load.

10.3 Output Voltage Regulation at No-Load

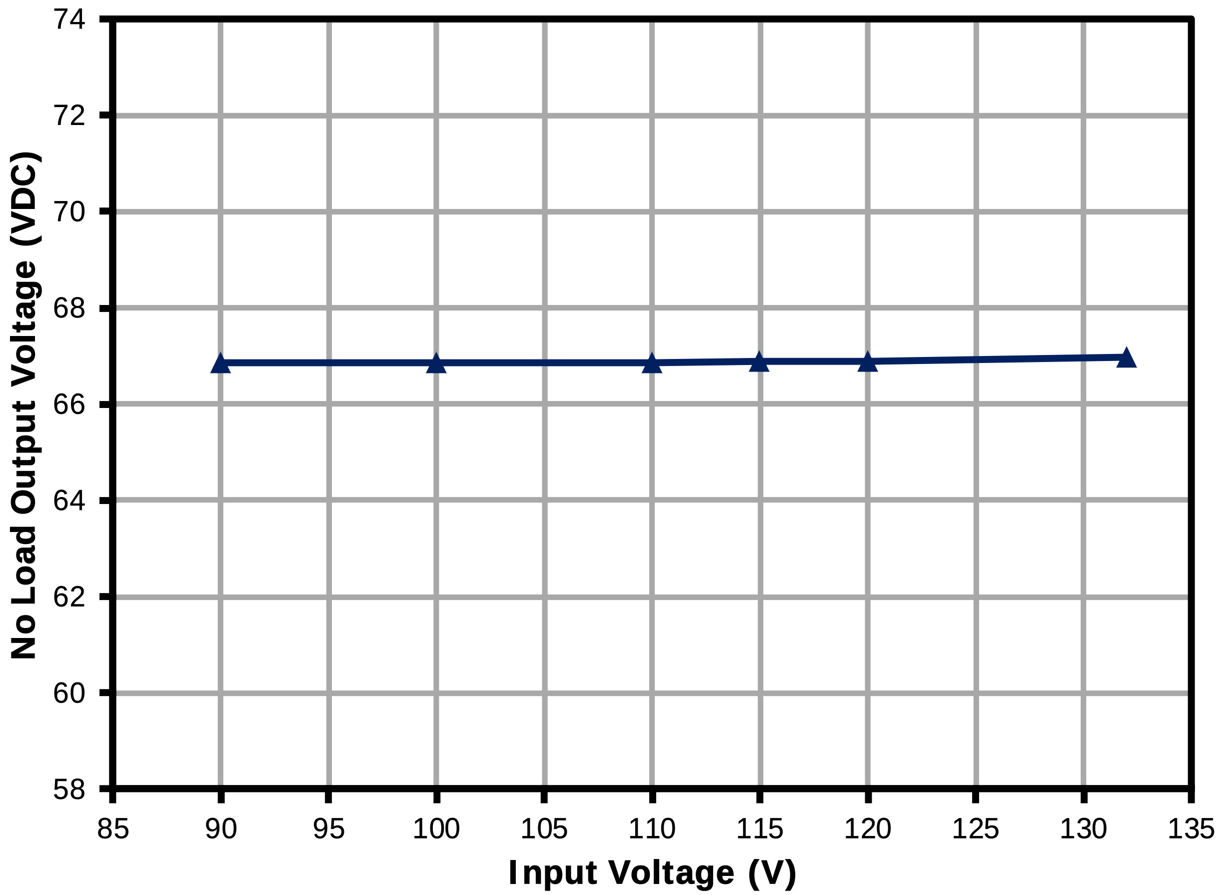

Figure 11 – Output Voltage Regulation (No-Load) vs. Line.

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10.4 Power Factor

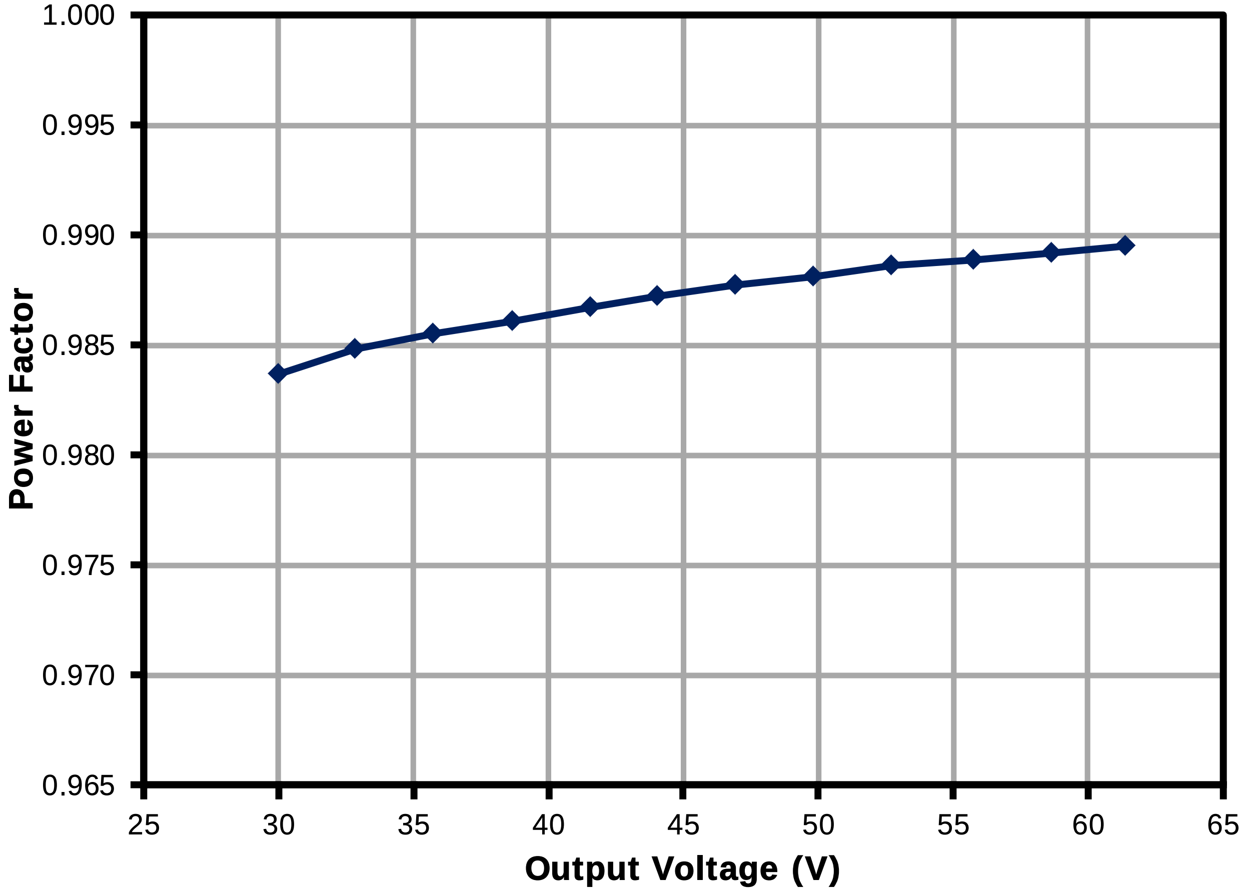

Figure 12 – Power Factor vs. LED Load at 115 V.

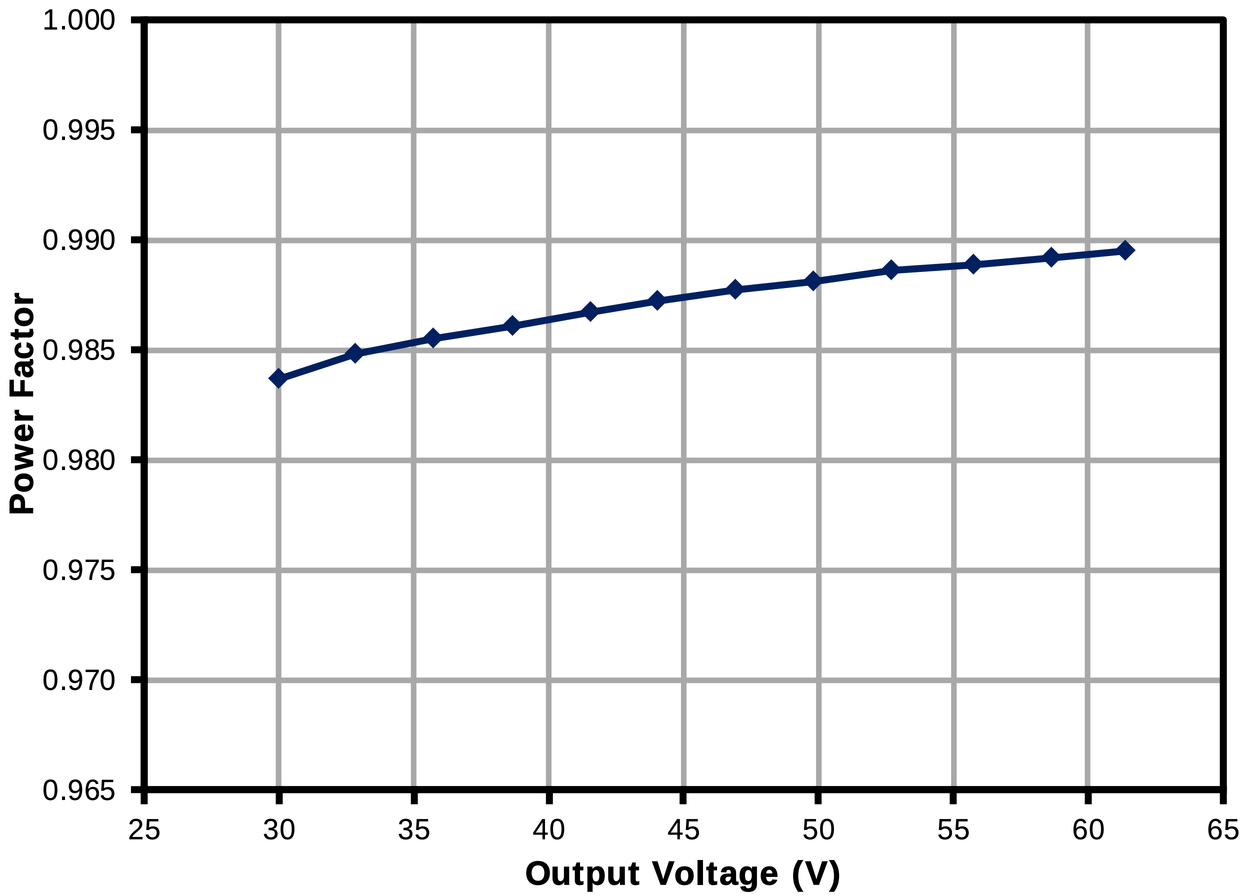

Figure 13 – Power Factor vs. Line and LED Load.

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10.5 A-THD

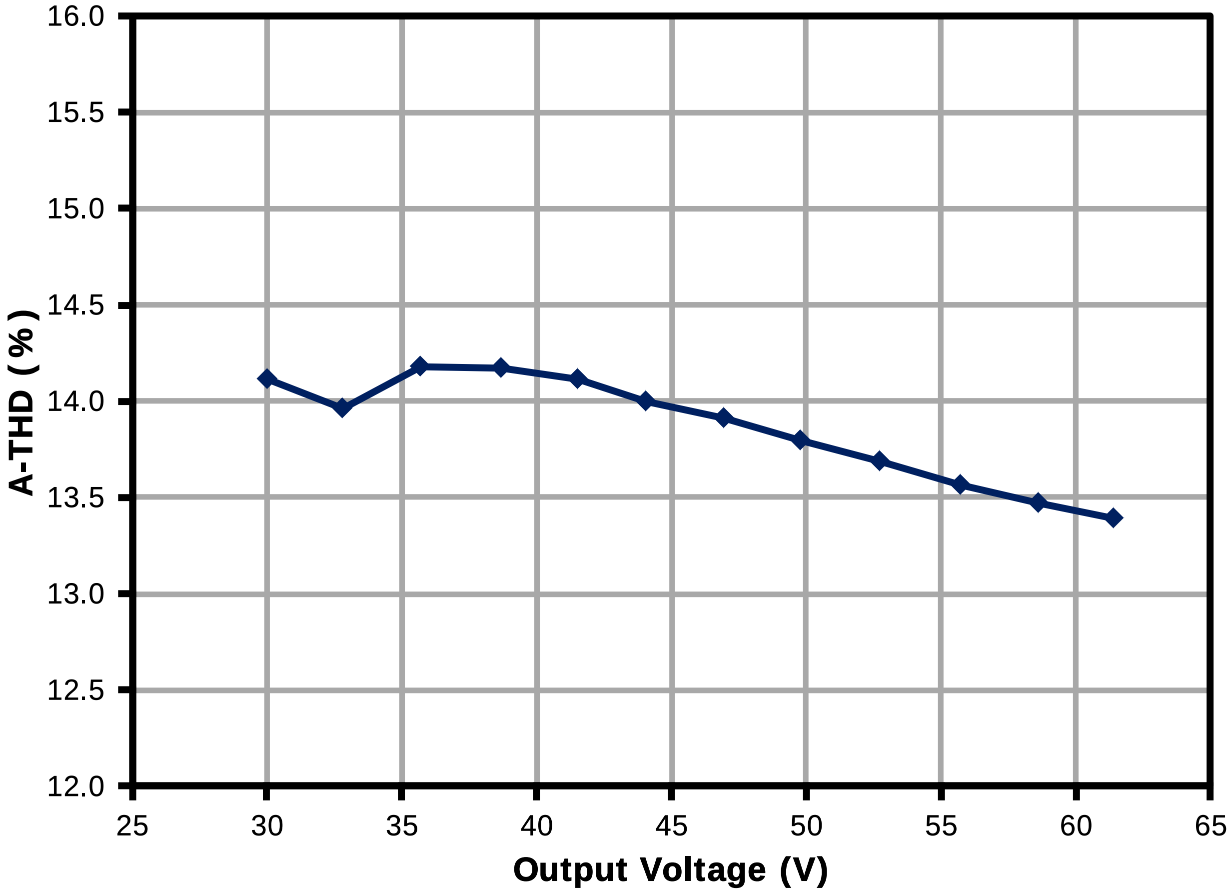

Figure 14 – %A-THD vs. LED Load at 115 V.

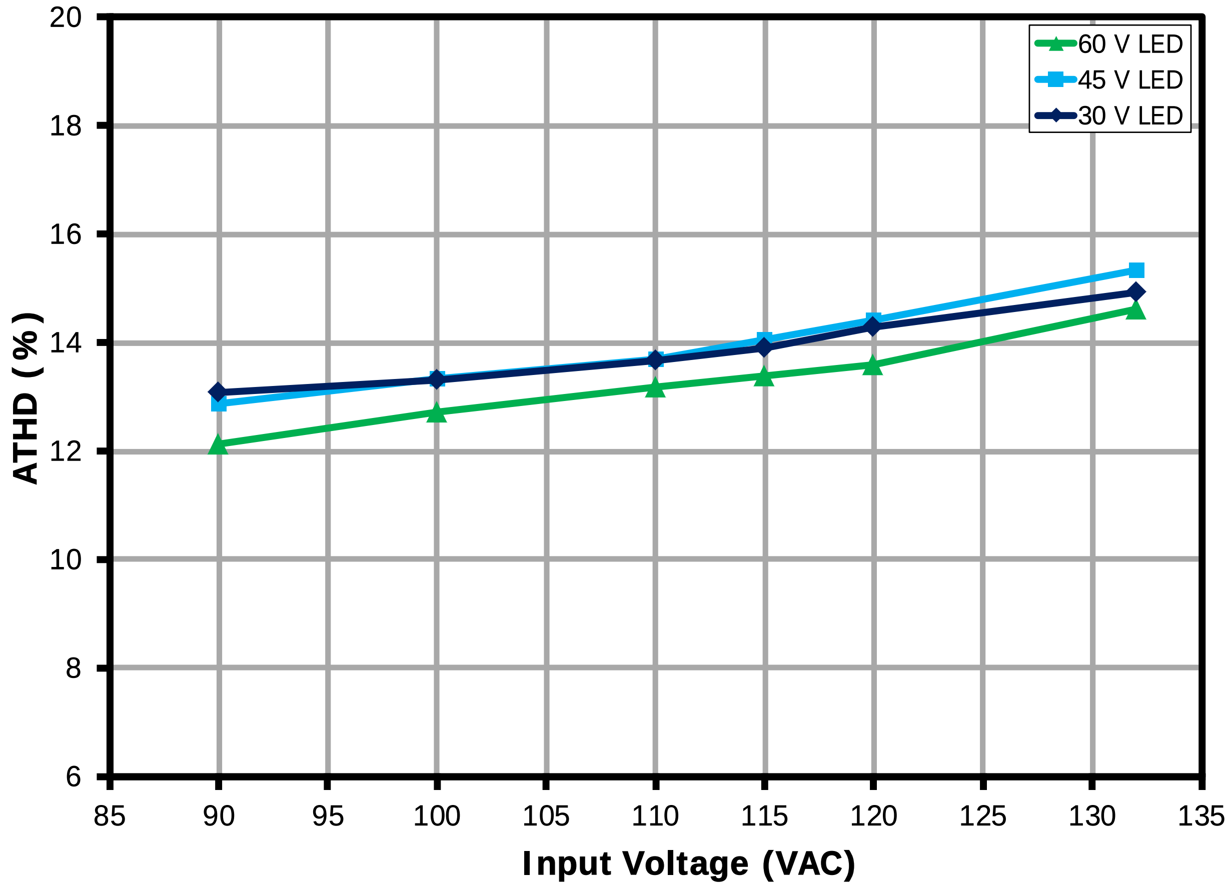

Figure 15 – %ATHD vs. Line and LED Load.

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10.6 Harmonics

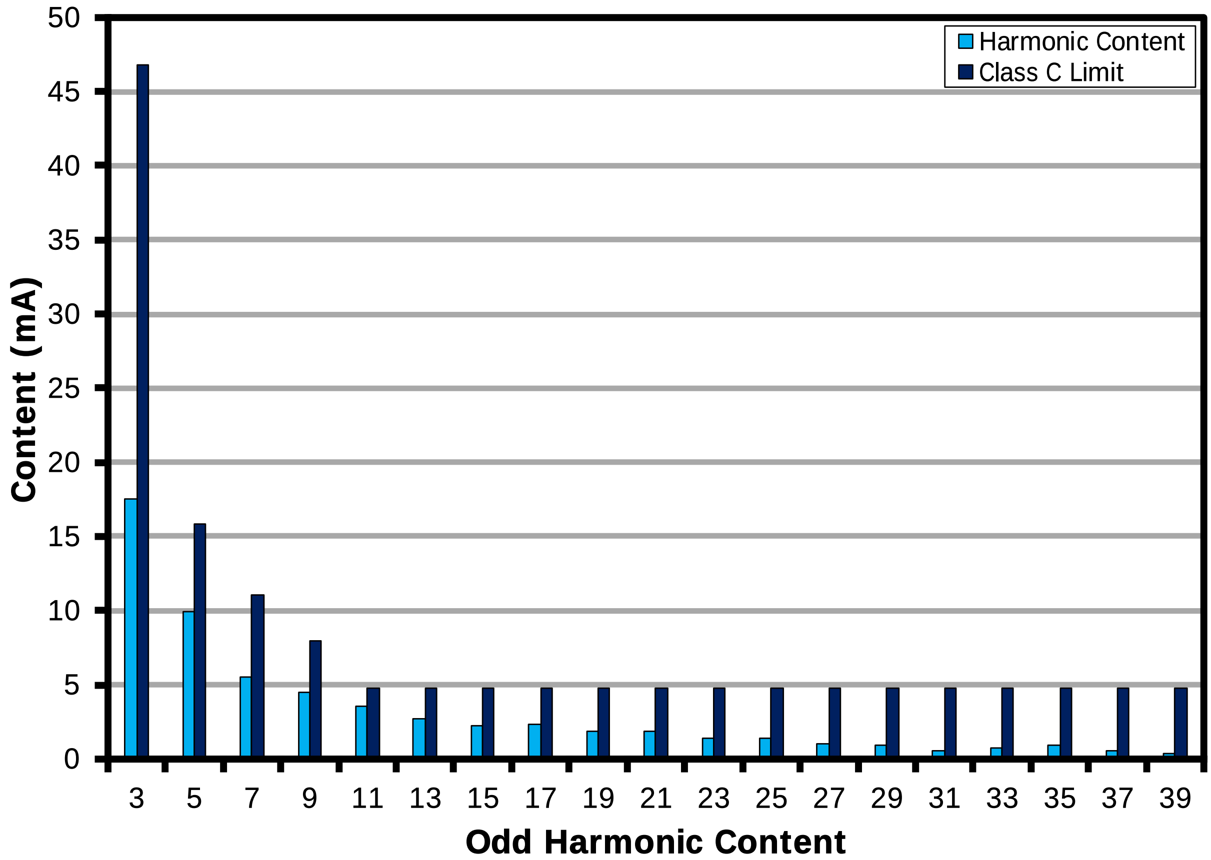

Figure 16 – 30 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

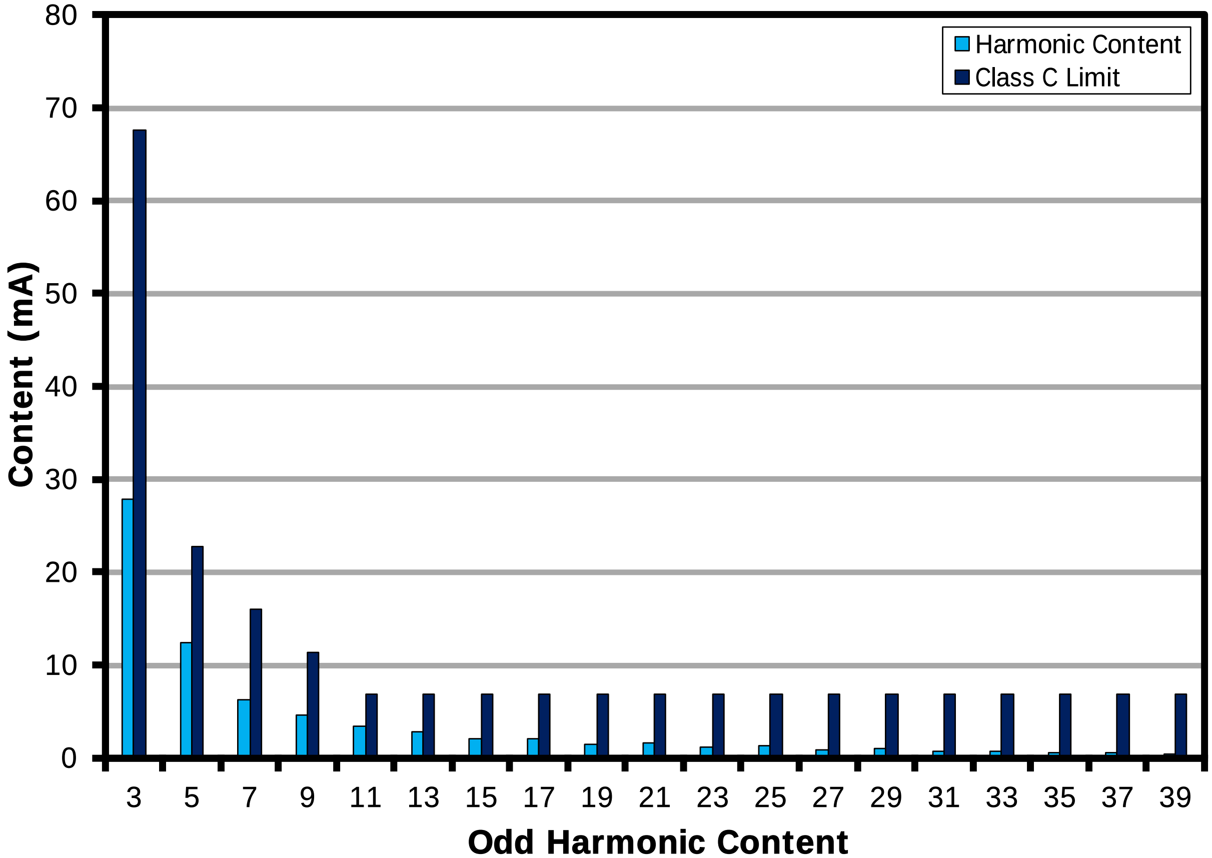

Figure 17 – 45 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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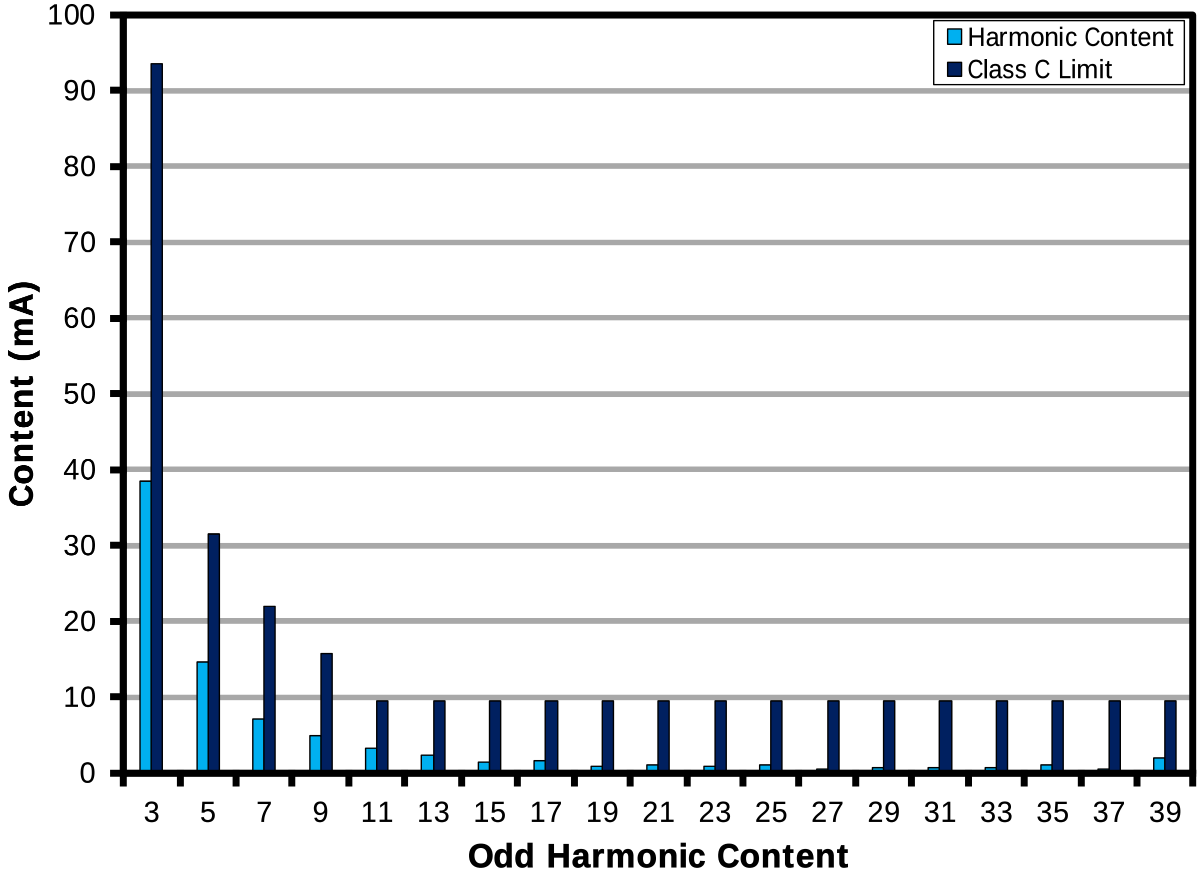

Figure 18 – 60 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

10.7 Dimming Characteristic Curve

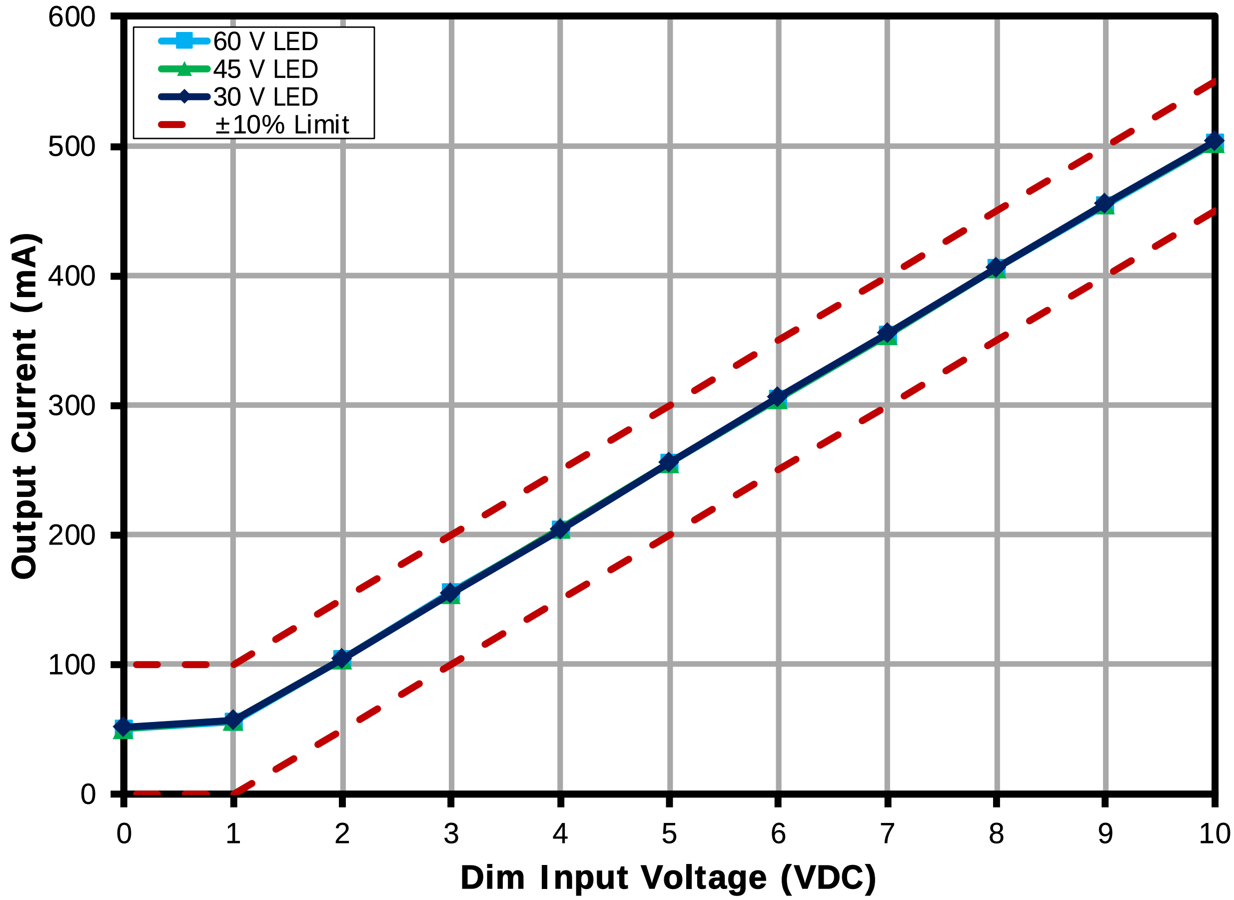

Figure 19 – Dimming Curve Characteristic at V_{IN} = 115 VAC, 60 Hz.

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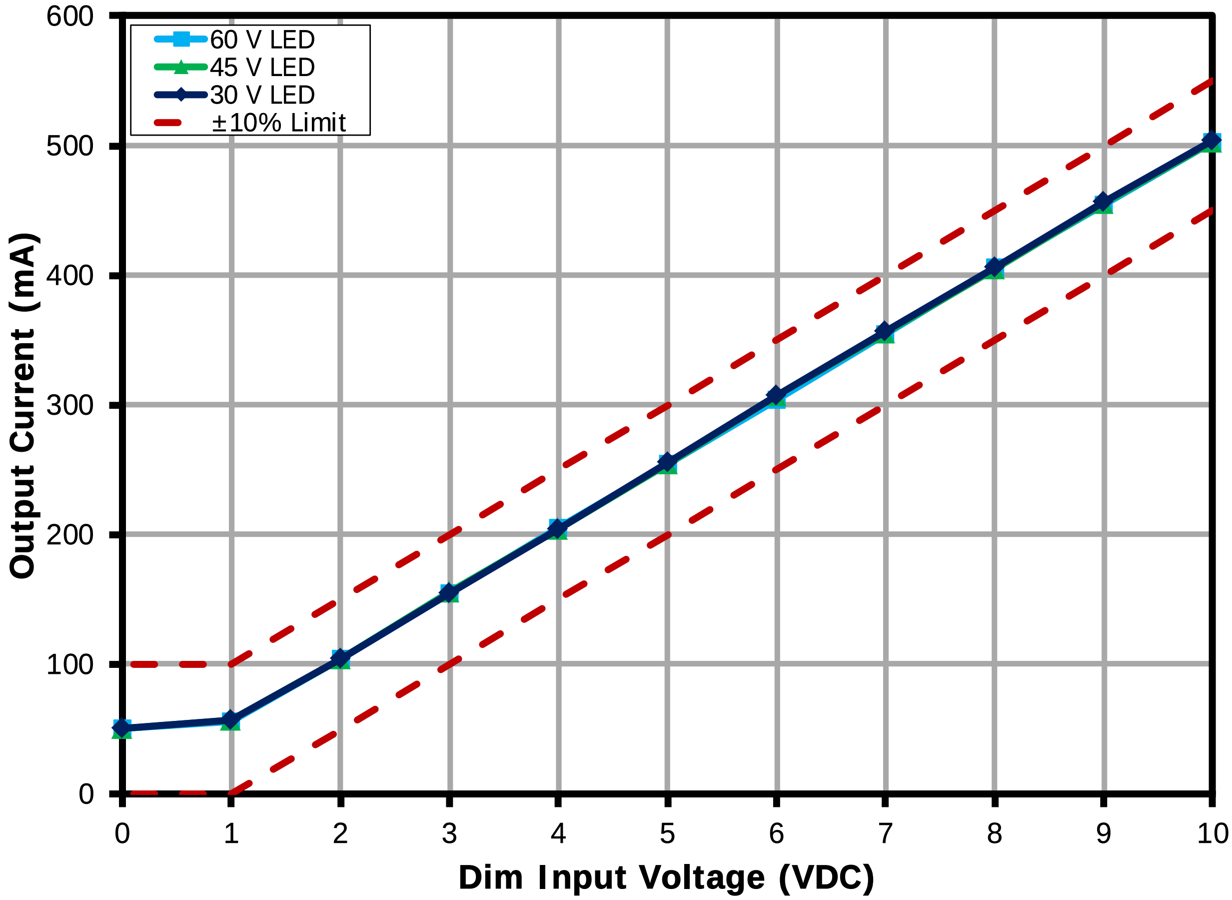

Figure 20 – Dimming Curve Characteristic at V_{IN} = 100 VAC, 60 Hz.

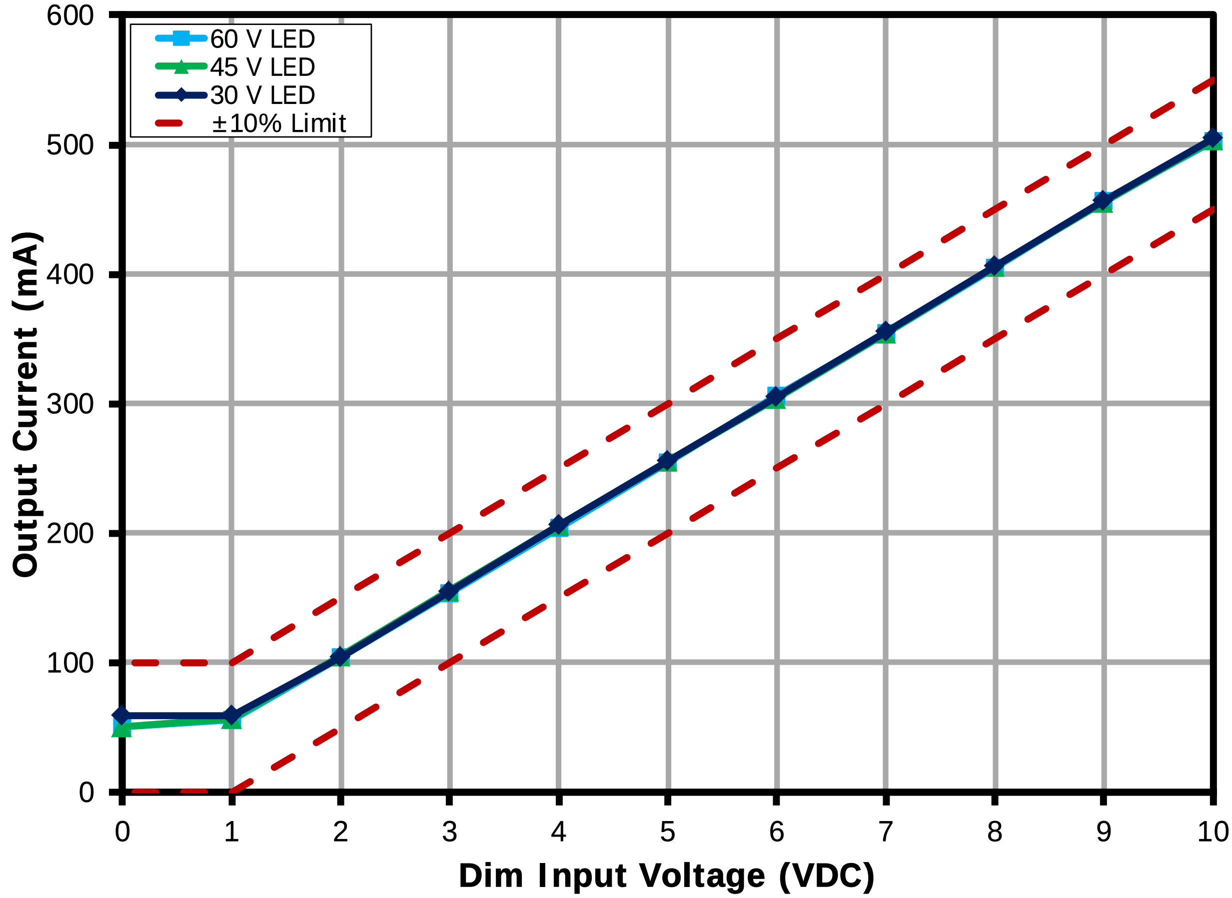

Figure 21 – Dimming Curve Characteristic at V_{IN} = 120 VAC, 60 Hz

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10.8 Dimming Efficiency

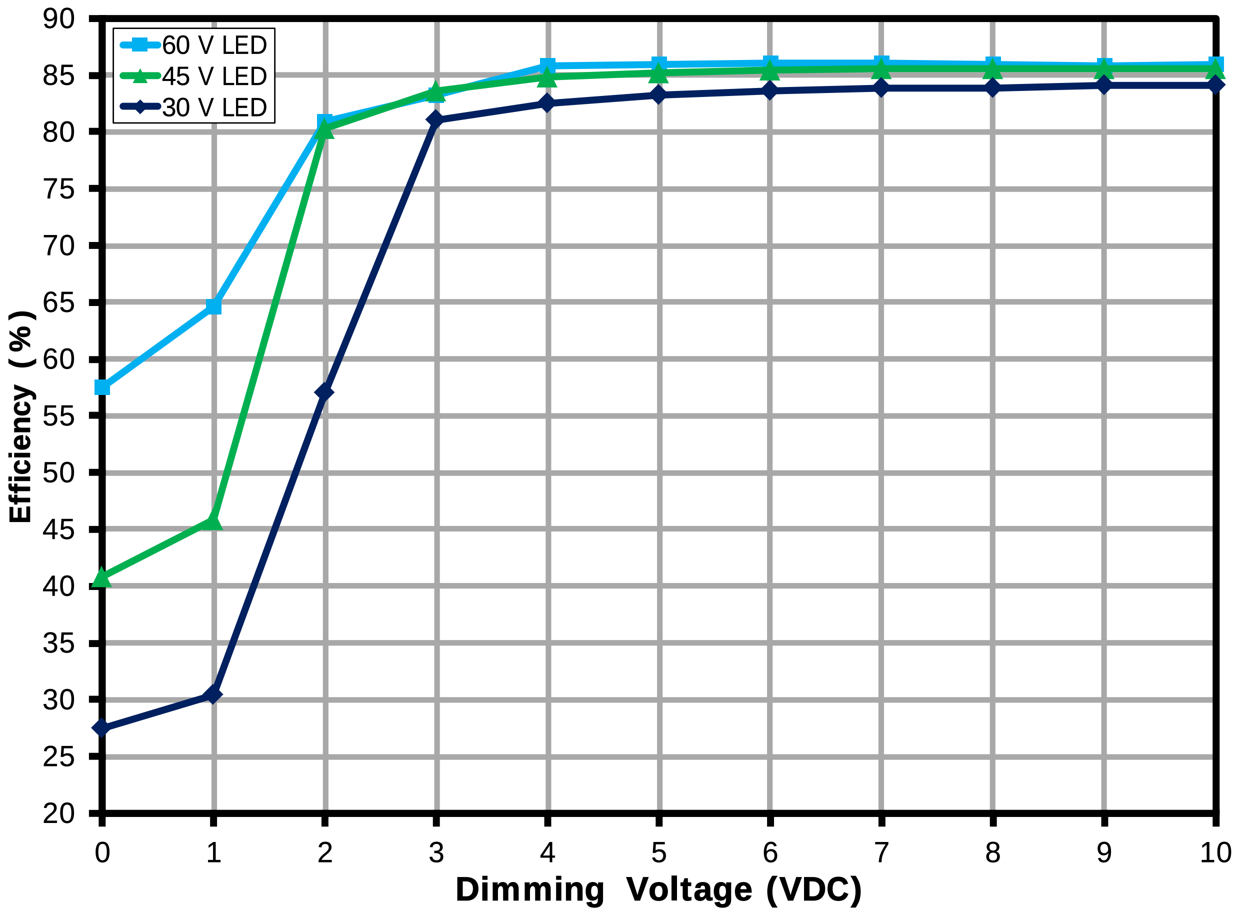

Figure 22 – Dimming Efficiency at V_{IN} = 115 VAC, 60 Hz

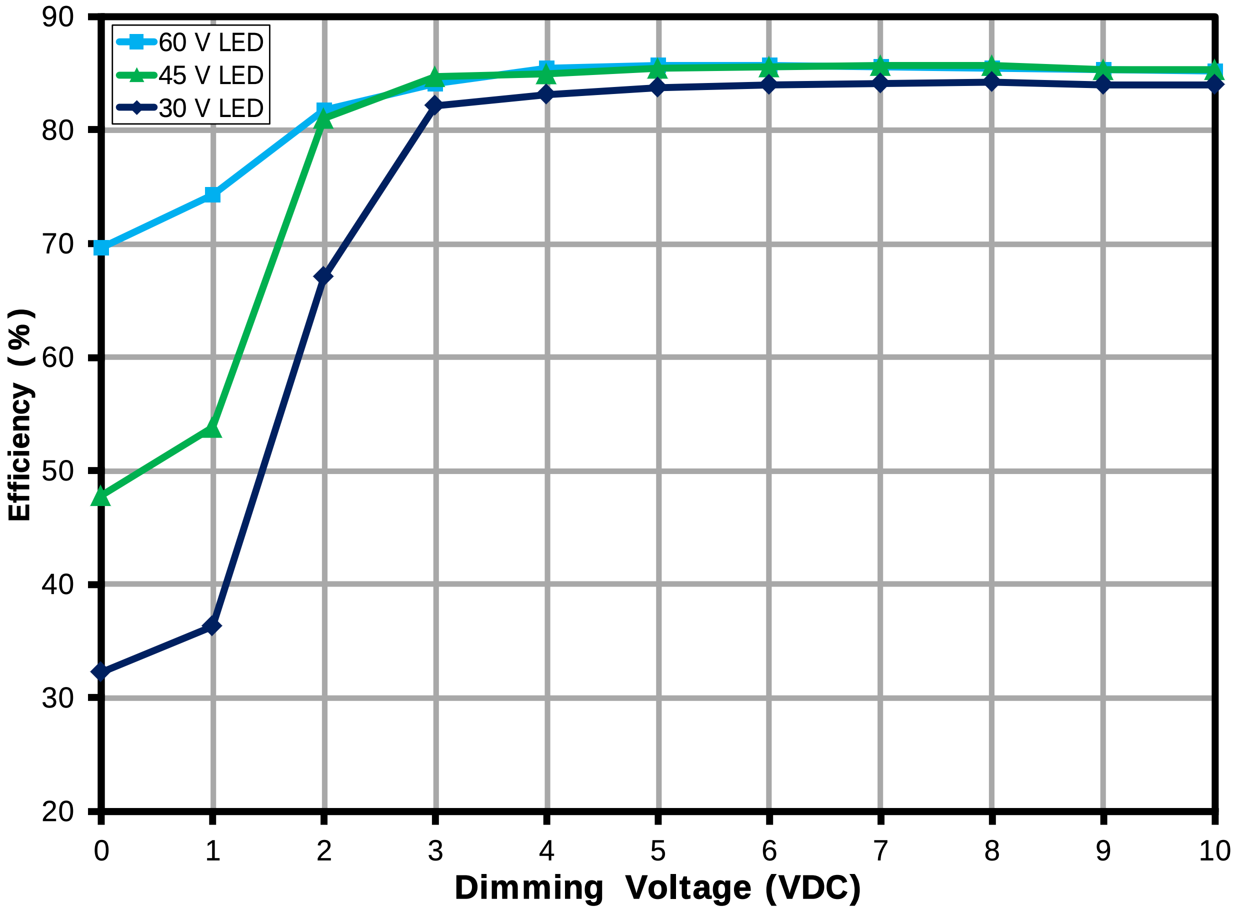

Figure 23 – Dimming Efficiency at V_{IN} = 100 VAC, 60 Hz.

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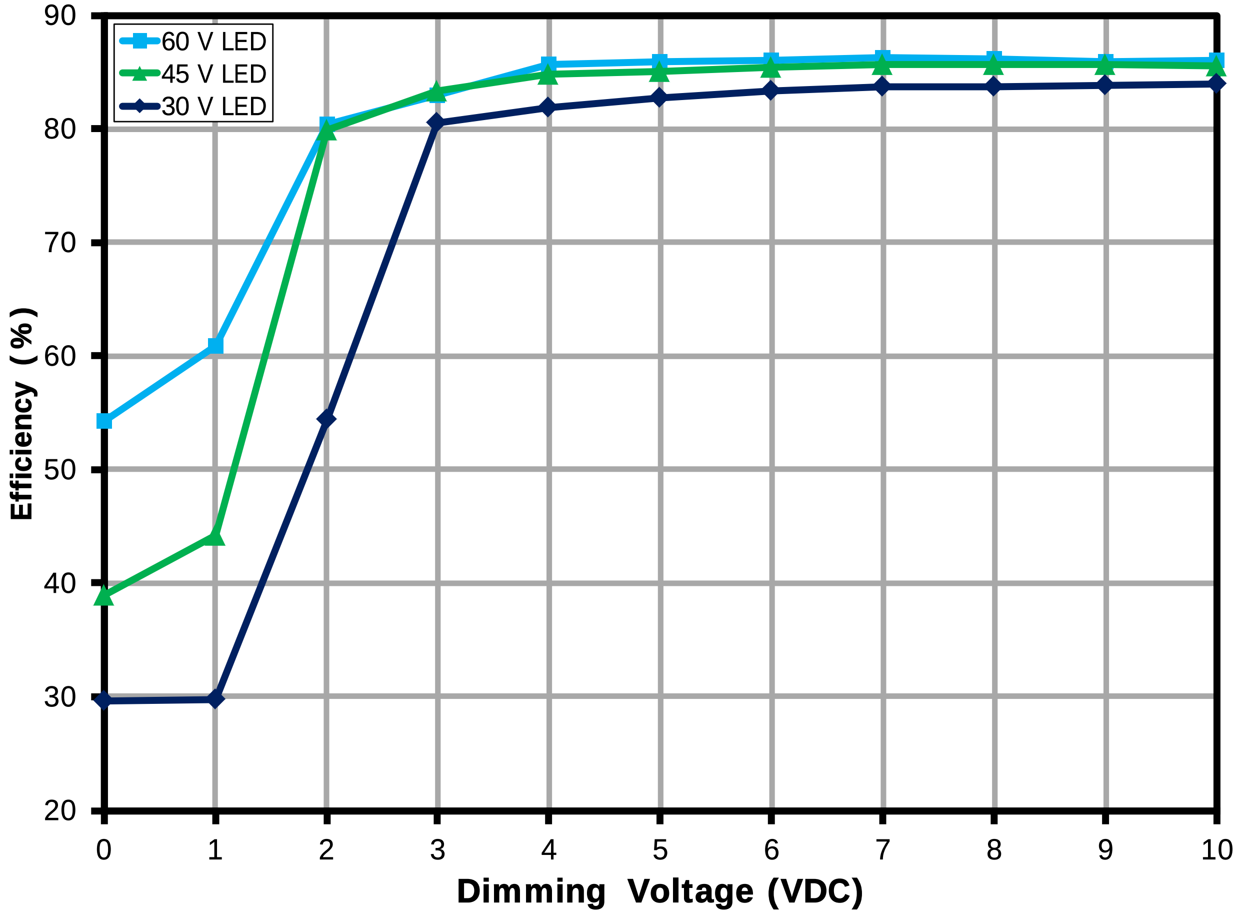

Figure 24 – Dimming Curve Efficiency at V_{IN} = 120 VAC, 60 Hz.

11 Test Data

11.1 Test Data at 115 VAC, 60 Hz

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
115	60	114.83	160.30	18.11	0.984	14.11	30.03	504.11	15.21	83.98
115	60	114.82	174.03	19.68	0.985	13.96	32.83	503.91	16.61	84.41
115	60	114.81	188.40	21.32	0.986	14.18	35.72	503.70	18.05	84.69
115	60	114.90	202.72	22.97	0.986	14.17	38.68	503.74	19.55	85.10
115	60	114.79	217.43	24.63	0.987	14.11	41.55	503.70	20.99	85.22
115	60	114.78	230.28	26.09	0.987	14.00	44.08	503.67	22.26	85.30
115	60	114.77	244.68	27.74	0.988	13.91	46.94	503.60	23.69	85.41
115	60	114.89	259.01	29.40	0.988	13.80	49.82	503.55	25.14	85.50
115	60	114.88	274.35	31.16	0.989	13.69	52.74	503.47	26.61	85.39
115	60	114.88	288.64	32.79	0.989	13.56	55.76	503.37	28.11	85.74
115	60	114.88	303.81	34.53	0.989	13.47	58.65	503.42	29.57	85.66
115	60	114.87	318.40	36.19	0.990	13.39	61.40	503.24	30.94	85.50

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11.2 Test Data, 30 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
90	60	89.89	202.91	18.031	0.989	13.08	29.81	504.18	15.10	83.76
100	60	99.92	182.66	18.014	0.987	13.31	29.83	504.31	15.11	83.90
110	60	109.94	166.31	18.011	0.985	13.67	29.80	504.41	15.10	83.85
115	60	114.91	159.12	17.989	0.984	13.89	29.73	504.42	15.07	83.76
120	60	119.96	153.07	18.036	0.982	14.29	29.77	504.42	15.09	83.67
132	60	131.95	140.18	18.098	0.978	14.91	29.76	504.46	15.08	83.34

11.3 Test Data, 45 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
90	60	89.87	296.98	26.435	0.990	12.87	44.34	503.28	22.37	84.63
100	60	99.90	266.17	26.305	0.989	13.33	44.31	503.46	22.36	85.01
110	60	109.92	241.50	26.229	0.988	13.70	44.30	503.64	22.36	85.26
115	60	114.89	231.38	26.243	0.987	14.06	44.35	503.68	22.39	85.32
120	60	119.95	221.79	26.237	0.986	14.41	44.35	503.80	22.40	85.37
132	60	131.93	202.37	26.256	0.983	15.35	44.37	503.98	22.42	85.38

11.4 Test Data, 60 V LED Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
90	60	89.84	415.17	37.005	0.992	12.13	61.73	502.49	31.07	83.95
100	60	99.87	370.35	36.657	0.991	12.72	61.65	502.82	31.04	84.68
110	60	109.90	335.16	36.468	0.990	13.17	61.68	503.06	31.07	85.21
115	60	114.87	319.91	36.364	0.990	13.39	61.63	503.16	31.06	85.40
120	60	119.93	306.03	36.297	0.989	13.59	61.63	503.28	31.06	85.57
132	60	131.92	277.90	36.178	0.987	14.61	61.59	503.63	31.06	85.86

11.5 Test Data, No-Load Output Voltage and Input Power

Input		Input Measurement			Output
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	V_{OUT} (VDC)
90	60	89.94	17.50	0.216	66.86
100	60	99.96	16.67	0.241	66.86
110	60	109.98	15.80	0.269	66.86
115	60	114.94	15.20	0.280	66.88
120	60	119.99	15.05	0.286	66.90
132	60	131.98	16.24	0.305	66.98

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11.6 Test Data, Harmonic Content at 30 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	PF		%THD
115	60	0.98	0.984		13.693
nth Order	**mA Content**	**% Content**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	158.54				
2	0.08	0.05%	2.00%		
3	17.56	11.08%	29.51%	46.79	Pass
5	9.97	6.29%	10.00%	15.85	Pass
7	5.55	3.50%	7.00%	11.10	Pass
9	4.49	2.83%	5.00%	7.93	Pass
11	3.59	2.26%	3.00%	4.76	Pass
13	2.70	1.70%	3.00%	4.76	Pass
15	2.24	1.41%	3.00%	4.76	Pass
17	2.31	1.46%	3.00%	4.76	Pass
19	1.84	1.16%	3.00%	4.76	Pass
21	1.89	1.19%	3.00%	4.76	Pass
23	1.40	0.88%	3.00%	4.76	Pass
25	1.39	0.88%	3.00%	4.76	Pass
27	1.00	0.63%	3.00%	4.76	Pass
29	0.95	0.60%	3.00%	4.76	Pass
31	0.58	0.37%	3.00%	4.76	Pass
33	0.76	0.48%	3.00%	4.76	Pass
35	0.91	0.57%	3.00%	4.76	Pass
37	0.51	0.32%	3.00%	4.76	Pass
39	0.33	0.21%	3.00%	4.76	Pass

11.7 Test Data, Harmonic Content at 45 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	PF		%THD
114.78	231.91	230.28	0.987		14.001
nth Order	**mA Content**	**% Content**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	228.21				
2	0.07	0.03%	2.00%		Pass
3	27.88	12.22%	29.62%	67.59	Pass
5	12.47	5.46%	10.00%	22.82	Pass
7	6.26	2.74%	7.00%	15.97	Pass
9	4.68	2.05%	5.00%	11.41	Pass
11	3.45	1.51%	3.00%	6.85	Pass
13	2.84	1.24%	3.00%	6.85	Pass
15	2.01	0.88%	3.00%	6.85	Pass
17	2.13	0.93%	3.00%	6.85	Pass
19	1.45	0.64%	3.00%	6.85	Pass
21	1.63	0.71%	3.00%	6.85	Pass
23	1.21	0.53%	3.00%	6.85	Pass
25	1.30	0.57%	3.00%	6.85	Pass
27	0.85	0.37%	3.00%	6.85	Pass
29	0.98	0.43%	3.00%	6.85	Pass
31	0.68	0.30%	3.00%	6.85	Pass
33	0.68	0.30%	3.00%	6.85	Pass
35	0.58	0.25%	3.00%	6.85	Pass
37	0.56	0.25%	3.00%	6.85	Pass
39	0.39	0.17%	3.00%	6.85	Pass

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11.8 Test Data, Harmonic Content at 60 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	PF		%THD
115	60	318.40	0.990		13.389
nth Order	**mA Content**	**% Content**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	315.29				
2	0.09	0.03%	2.00%		Pass
3	38.52	12.22%	29.69%	93.59	Pass
5	14.67	4.65%	10.00%	31.53	Pass
7	7.03	2.23%	7.00%	22.07	Pass
9	4.92	1.56%	5.00%	15.76	Pass
11	3.21	1.02%	3.00%	9.46	Pass
13	2.40	0.76%	3.00%	9.46	Pass
15	1.50	0.48%	3.00%	9.46	Pass
17	1.60	0.51%	3.00%	9.46	Pass
19	0.90	0.29%	3.00%	9.46	Pass
21	1.06	0.34%	3.00%	9.46	Pass
23	0.89	0.28%	3.00%	9.46	Pass
25	0.98	0.31%	3.00%	9.46	Pass
27	0.51	0.16%	3.00%	9.46	Pass
29	0.67	0.21%	3.00%	9.46	Pass
31	0.74	0.23%	3.00%	9.46	Pass
33	0.64	0.20%	3.00%	9.46	Pass
35	1.03	0.33%	3.00%	9.46	Pass
37	0.48	0.15%	3.00%	9.46	Pass
39	1.91	0.61%	3.00%	9.46	Pass

11.9 Test Data, Dimming at V_{IN} = 100 VAC, 60 Hz

30 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
99.92	180.34	17.78	0.987	13.17	29.44	504.20	14.92	83.93	10
99.92	161.96	15.95	0.986	13.50	29.23	456.13	13.40	84.02	9
99.93	143.31	14.08	0.983	14.59	29.08	406.22	11.87	84.27	8
99.87	124.40	12.26	0.987	9.86	28.85	356.13	10.32	84.16	7
99.88	106.51	10.49	0.986	7.96	28.63	306.79	8.82	84.03	6
99.89	88.74	8.71	0.983	8.16	28.39	256.03	7.29	83.70	5
99.91	71.23	6.94	0.975	9.27	28.12	204.59	5.77	83.08	4
99.92	54.81	5.26	0.961	10.91	27.90	154.75	4.32	82.12	3
99.93	45.08	4.27	0.947	11.43	27.51	103.82	2.86	67.04	2
99.93	45.00	4.26	0.946	11.77	27.01	57.15	1.55	36.33	1
99.92	45.01	4.26	0.946	11.63	26.94	50.93	1.37	32.28	0
45 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
99.90	264.37	26.13	0.989	13.29	44.19	503.04	22.30	85.33	10
99.79	237.63	23.45	0.989	13.25	43.82	455.46	20.01	85.34	9
99.80	210.48	20.75	0.988	13.83	43.78	405.25	17.78	85.70	8
99.82	183.16	18.01	0.985	15.07	43.33	355.45	15.43	85.66	7
99.92	157.48	15.42	0.980	17.55	42.97	306.80	13.20	85.61	6
99.86	131.25	12.74	0.972	20.75	42.69	254.64	10.88	85.40	5
99.88	104.32	10.14	0.973	18.82	42.15	204.17	8.61	84.98	4
99.90	79.21	7.68	0.971	16.18	41.78	155.60	6.51	84.67	3
99.91	55.00	5.27	0.960	12.73	41.18	103.77	4.28	81.06	2
99.92	45.06	4.27	0.949	11.69	40.45	56.86	2.30	53.86	1
99.92	45.03	4.27	0.949	11.98	40.35	50.52	2.04	47.77	0
60 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
99.87	369.08	36.54	0.991	12.54	61.89	502.52	31.15	85.25	10
99.88	330.64	32.73	0.991	12.56	61.32	454.69	27.92	85.31	9
99.89	292.62	28.96	0.991	12.62	60.81	406.52	24.75	85.48	8
99.90	253.02	25.01	0.989	13.29	60.30	354.70	21.41	85.62	7
99.80	215.41	21.19	0.986	15.45	59.78	303.50	18.16	85.69	6
99.82	181.25	17.68	0.977	19.76	59.42	254.76	15.15	85.67	5
99.85	146.41	14.11	0.965	24.42	58.85	204.79	12.06	85.46	4
99.88	110.20	10.68	0.970	20.55	58.12	154.41	8.98	84.06	3
99.90	75.34	7.30	0.969	16.19	57.42	103.93	5.97	81.82	2
99.92	45.33	4.28	0.946	13.89	56.43	56.39	3.18	74.28	1
99.92	43.35	4.08	0.942	13.84	56.30	50.51	2.84	69.69	0

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11.10 Test Data, Dimming at V_{IN} = 115 VAC, 60 Hz

30 V LED

Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
114.91	159.27	18.00	0.984	14.05	29.89	504.16	15.14	84.09	10
114.91	143.52	16.18	0.981	14.96	29.77	455.10	13.60	84.06	9
114.85	127.48	14.32	0.978	15.97	29.51	405.74	12.01	83.90	8
114.86	110.26	12.42	0.981	11.73	29.23	355.25	10.41	83.82	7
114.88	95.13	10.70	0.979	9.95	29.15	306.18	8.95	83.61	6
114.89	79.82	8.94	0.974	9.47	29.05	255.51	7.44	83.25	5
114.90	64.28	7.11	0.963	11.07	28.66	204.32	5.87	82.46	4
114.91	49.36	5.34	0.941	12.95	27.92	154.60	4.32	80.98	3
114.91	46.74	5.03	0.936	13.15	27.50	104.07	2.87	57.01	2
114.91	46.99	5.06	0.937	13.88	26.99	56.78	1.54	30.36	1
114.91	47.08	5.07	0.937	13.17	26.93	51.57	1.39	27.46	0

45 V LED

Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
114.89	229.48	26.03	0.987	14.05	44.11	503.10	22.26	85.52	10
114.79	206.14	23.33	0.986	14.61	43.71	455.37	19.95	85.54	9
114.81	182.78	20.63	0.983	15.77	43.39	406.15	17.66	85.60	8
114.83	159.03	17.87	0.978	17.82	43.05	354.57	15.29	85.59	7
114.85	136.77	15.28	0.973	19.95	42.73	305.13	13.06	85.47	6
114.86	115.31	12.79	0.965	21.98	42.52	256.08	10.90	85.24	5
114.88	92.19	10.19	0.962	21.22	42.10	205.12	8.64	84.84	4
114.89	69.35	7.68	0.964	13.86	41.63	154.20	6.42	83.67	3
114.91	49.13	5.31	0.941	14.46	41.07	103.78	4.26	80.28	2
114.91	46.39	4.99	0.937	13.98	40.36	56.78	2.29	45.91	1
114.91	46.37	4.99	0.937	13.50	40.27	50.55	2.04	40.79	0

60 V LED

Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
114.87	318.27	36.18	0.990	13.32	61.74	502.78	31.09	85.93	10
114.88	285.12	32.40	0.989	13.49	61.15	454.30	27.82	85.88	9
114.89	252.54	28.65	0.987	14.40	60.62	405.91	24.64	86.00	8
114.79	219.62	24.80	0.984	16.34	60.15	354.53	21.35	86.06	7
114.81	188.89	21.18	0.977	19.72	59.70	305.05	18.23	86.05	6
114.91	158.79	17.65	0.968	23.16	59.34	255.52	15.17	85.93	5
114.91	127.27	14.05	0.961	24.78	59.02	204.12	12.05	85.79	4
114.92	99.06	10.90	0.958	23.76	58.35	155.64	9.08	83.30	3
114.93	67.19	7.41	0.960	14.69	57.51	104.23	6.00	80.91	2
114.91	45.69	4.91	0.935	14.67	56.50	56.09	3.17	64.59	1
114.91	45.72	4.91	0.935	14.50	56.36	50.08	2.82	57.49	0

11.11 Test Data, Dimming at V_{IN} = 120 VAC, 60 Hz

45 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
119.88	151.45	17.83	0.982	14.24	29.49	504.52	14.96	83.91	10
119.89	137.20	16.11	0.979	15.12	29.46	456.62	13.51	83.86	9
119.90	121.53	14.22	0.976	16.34	29.23	405.87	11.91	83.74	8
119.92	105.40	12.37	0.979	11.46	28.95	356.07	10.35	83.68	7
119.93	90.04	10.54	0.976	9.46	28.71	304.75	8.78	83.28	6
119.94	75.85	8.83	0.970	9.80	28.46	255.71	7.30	82.70	5
119.95	62.29	7.16	0.958	11.04	28.29	206.74	5.86	81.89	4
119.96	47.96	5.37	0.934	13.63	27.94	154.71	4.33	80.57	3
119.96	47.40	5.30	0.933	13.71	27.54	104.69	2.89	54.42	2
119.96	47.89	5.37	0.934	13.17	27.04	58.87	1.60	29.72	1
119.96	47.90	5.37	0.934	13.21	27.05	58.68	1.59	29.63	0
70 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
119.83	221.88	26.22	0.986	14.55	44.41	503.39	22.41	85.49	10
119.85	198.83	23.46	0.984	15.23	44.03	455.19	20.09	85.64	9
119.95	176.42	20.76	0.981	16.64	43.72	405.90	17.78	85.64	8
119.88	154.09	18.03	0.976	18.58	43.52	354.69	15.46	85.71	7
119.90	132.09	15.37	0.970	20.35	43.08	304.40	13.13	85.43	6
119.91	111.91	12.92	0.963	22.38	42.90	256.09	11.00	85.10	5
119.93	90.10	10.35	0.958	22.07	42.51	206.29	8.77	84.81	4
119.94	67.90	7.82	0.960	13.96	41.80	155.66	6.51	83.29	3
119.96	48.22	5.41	0.935	14.84	41.18	104.94	4.32	79.94	2
119.96	46.83	5.24	0.933	14.77	40.43	57.21	2.31	44.17	1
119.96	46.81	5.24	0.933	14.11	40.32	50.56	2.04	38.94	0
95 V LED									
Input Measurement					LED Load Measurement			Efficiency (%)	Dim Voltage (V_{DC})
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	% ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
119.92	305.68	36.26	0.989	13.59	61.92	502.82	31.18	85.99	10
119.93	275.37	32.63	0.988	14.05	61.32	456.47	28.03	85.90	9
119.82	242.69	28.67	0.986	15.16	60.91	404.99	24.70	86.14	8
119.84	212.05	24.94	0.981	17.47	60.60	354.58	21.51	86.23	7
119.86	183.30	21.40	0.974	20.76	60.14	306.04	18.42	86.06	6
119.89	152.63	17.66	0.965	23.72	59.61	254.36	15.17	85.89	5
119.91	122.65	14.12	0.960	24.48	59.10	204.52	12.09	85.63	4
119.93	94.08	10.78	0.955	24.01	58.21	153.61	8.94	83.01	3
119.95	64.78	7.43	0.956	14.59	57.43	104.02	5.98	80.44	2
119.96	46.57	5.21	0.933	15.06	56.41	56.24	3.17	60.90	1
119.96	46.58	5.21	0.933	14.55	56.29	50.28	2.83	54.31	0

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12 Thermal Performance

Thermal measurements were done with the UUT operated at room temperature (25 ºC) with 60 V LED load. Test time is at least 1 hour.

12.1 Thermal Performance at 132 VAC with 60 V LED Load.

Figure 25 – 132 V VAC, Full load
Spot 1: LYT4315E (U1): 73.2 ºC.

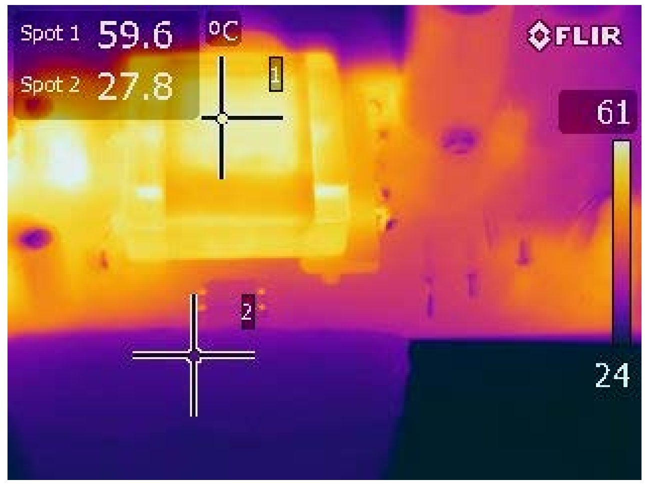

Figure 26 – 132 V VAC, Full Load.
Spot 1: Transformer (T1): 59.6 ºC.

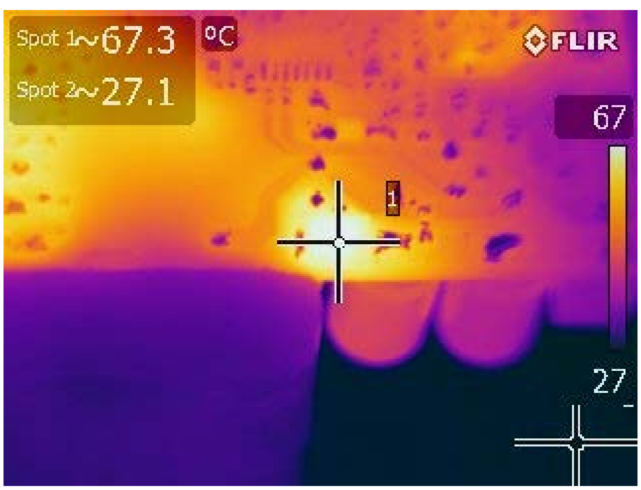

Figure 27 – 132 V VAC, Full Load.
Spot 1: Output Diode (D16): 67.2 ºC.

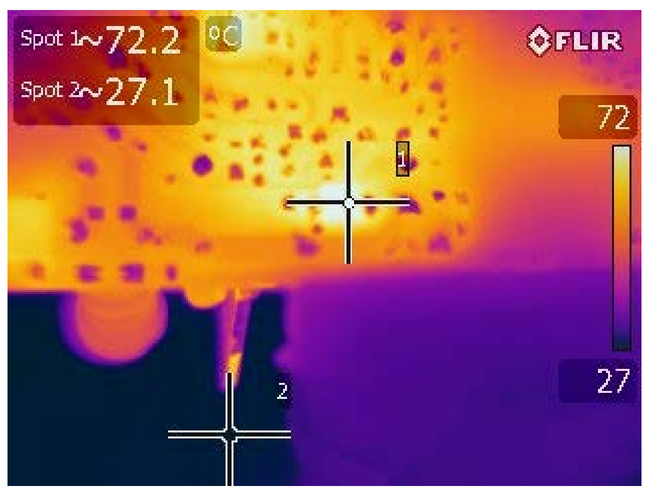

Figure 28 – 132 V VAC, Full Load.
Spot 1: Blocking Diode (D7): 72.2 ºC.

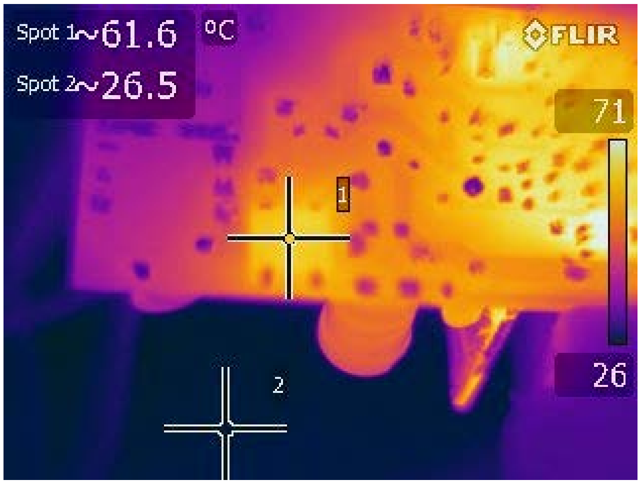

Figure 29 – 132 V VAC, Full Load.
Spot 1: Bridge Diode (BR1): 61.6 °C.

12.2 Thermal Performance at 115 VAC with 60 V LED Load

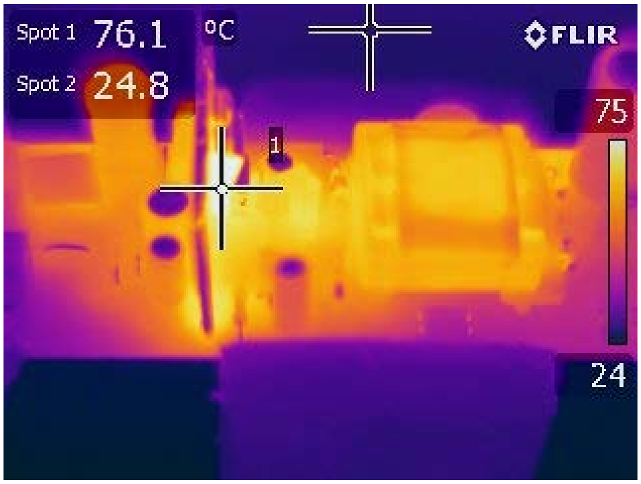

Figure 30 – 115 V VAC, Full Load.
Spot 1: LYT4315E (U1): 76.1 ºC.

Figure 31 – 115 V VAC, Full Load.
Spot 1: Transformer (T1): 59.3 ºC.

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Figure 32 – 115 V VAC, Full Load.
Spot 1: Output Diode (D16): 66.7 °C.

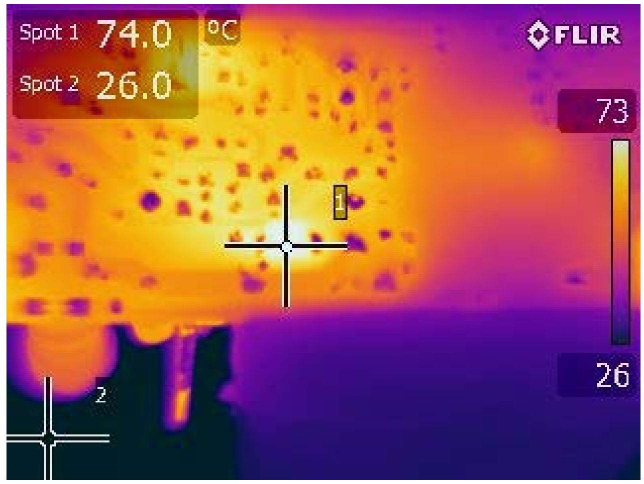

Figure 33 – 115 V VAC, Full Load.
Spot 1: Blocking Diode (D7): 74 °C.

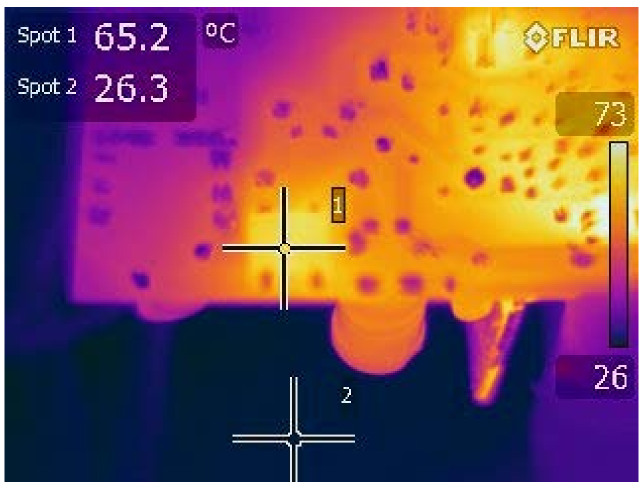

Figure 34 – 115 V VAC, Full Load.
Spot 1: Bridge Diode (BR1): 65.2 °C.

12.3 Thermal Performance at 90 VAC with 60 V LED Load

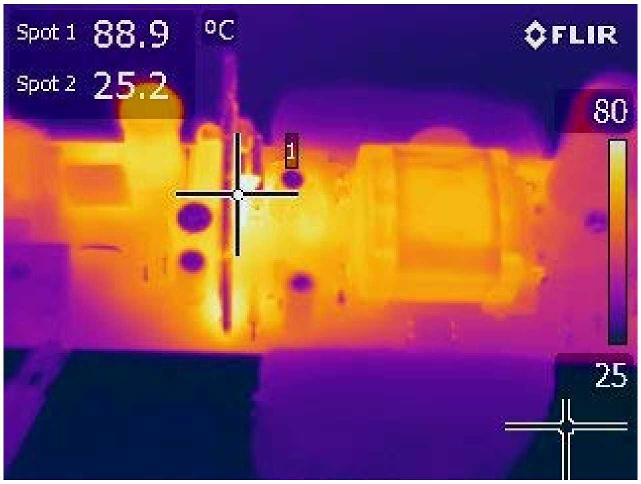

Figure 35 – 90 V VAC, Full Load.
Spot 1: LYT4315E (U1): 88.9 ^{o}C.

Figure 36 – 90 V VAC, Full Load.
Spot 1: Transformer (T1): 62.4 ^{o}C.

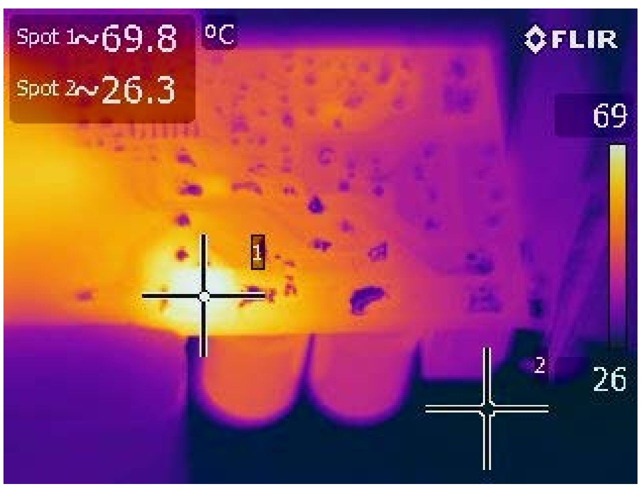

Figure 37 – 90 V VAC, Full Load.
Spot 1: Output Diode (D16): 69.8 ^{o}C.

Figure 38 – 90 V VAC, Full Load.
Spot 1: Blocking Diode (D7): 84.3 ^{o}C.

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Figure 39 – 90 V VAC, Full Load.
Spot 1: Bridge Diode (BR1): 77 °C.

12.4 Thermal Performance of the Active Pre-Load at 0 V Dimming

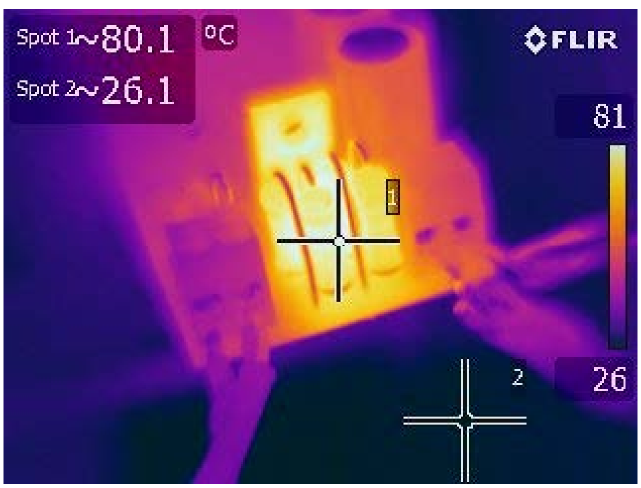

Figure 40 – 90 V VAC, 30 V LED Load, 0 V Dim.
Spot 1: Pre-Load Resistors (R51-R60): 80.1 °C.

Figure 41 – 90 V VAC, 30 V LED Load, 0 V Dim.
Spot 1: Pre-Load Switch (Q6): 77.4 °C.

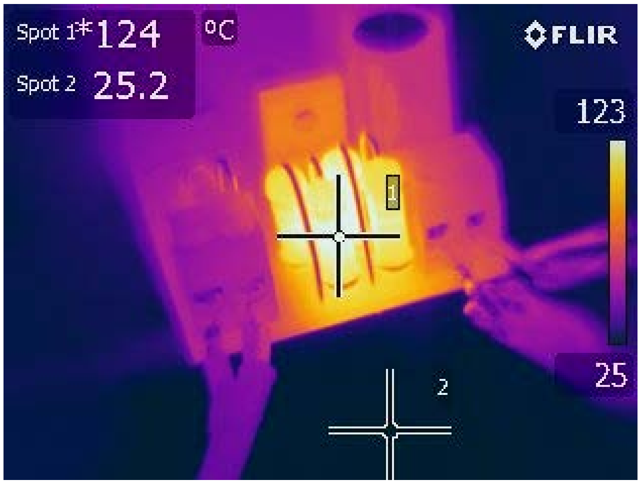

Figure 42 – 115 V VAC, 30 V LED Load, 0 V dim.
Spot 1: Pre-Load Resistors (R51-60): 124 °C.

Figure 43 – 115 V VAC, 30 V LED Load, 0 V Dim.
Spot 1: Pre-Load Switch (Q6): 77 °C.

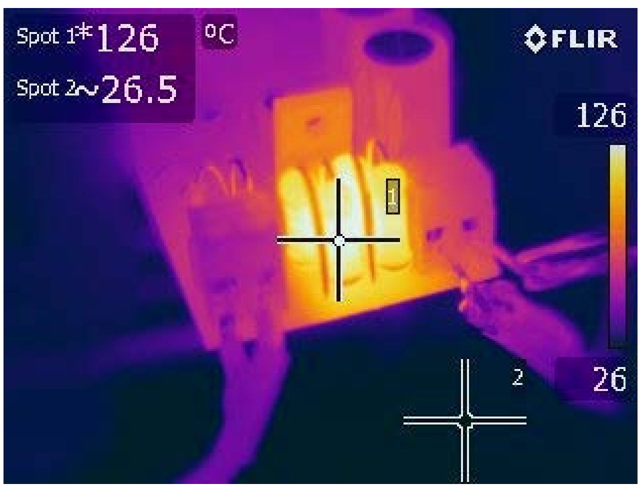

Figure 44 – 132 V VAC, 30 V LED Load, 0 V Dim.
Spot 1: Pre-Load Resistors (R51-R60): 126 °C.

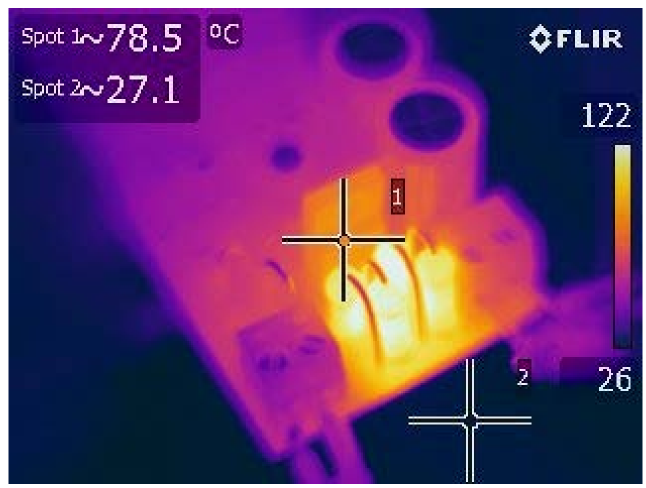

Figure 45 – 132 V VAC, 30 V LED Load, 0 V Dim.
Spot 1: Pre-Load Switch (Q6): 78.5 °C.

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13 Waveforms

13.1 Input Voltage and Input Current Waveforms

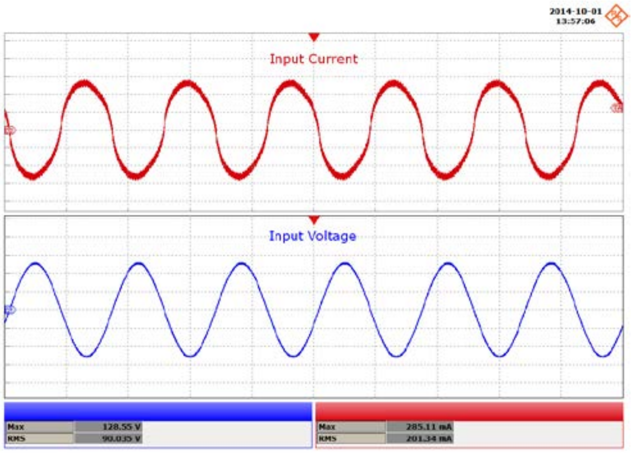

Figure 46 – 90 VAC, 30 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.
Peak I_{IN}: 285.11 mA.
Peak V_{IN}: 128.55 V.

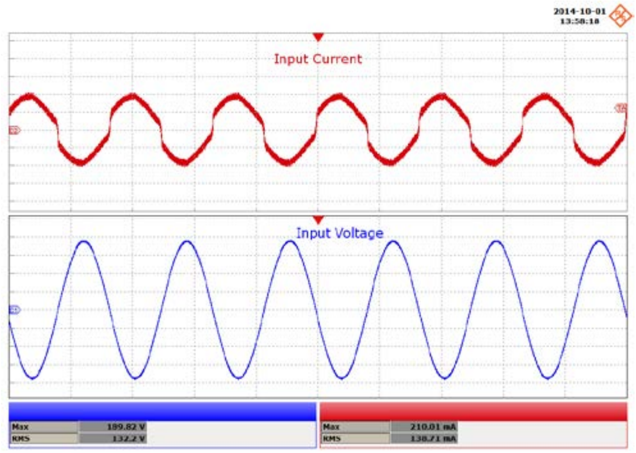

Figure 47 – 132 VAC, 30 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.
Peak I_{IN}: 210.0 mA.
Peak V_{IN}: 189.8 V.

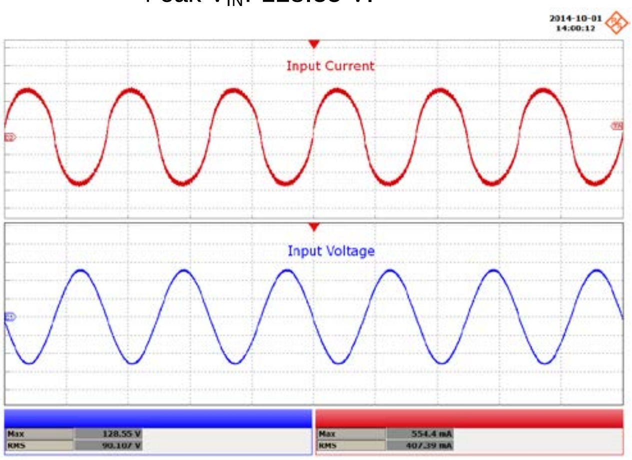

Figure 48 – 132 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.
Peak I_{IN}: 554.4 mA.
Peak V_{IN}: 128.55 V.

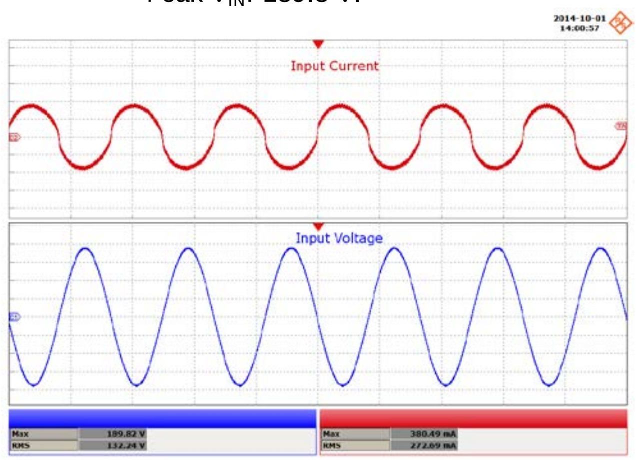

Figure 49 – 132 VAC, 60 V LED Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.
Peak I_{IN}: 380.49 mA.
Peak V_{IN}: 189.82 V.

13.2 Output Current Rise and Fall

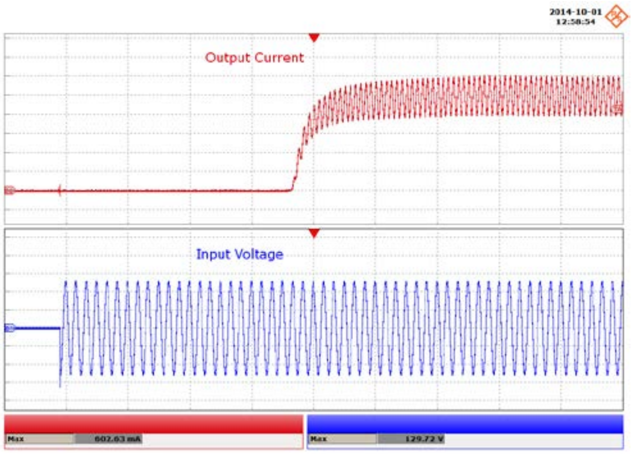

Figure 50 – 90 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 602.63 mA.
Peak V_{IN}: 129.72 V.

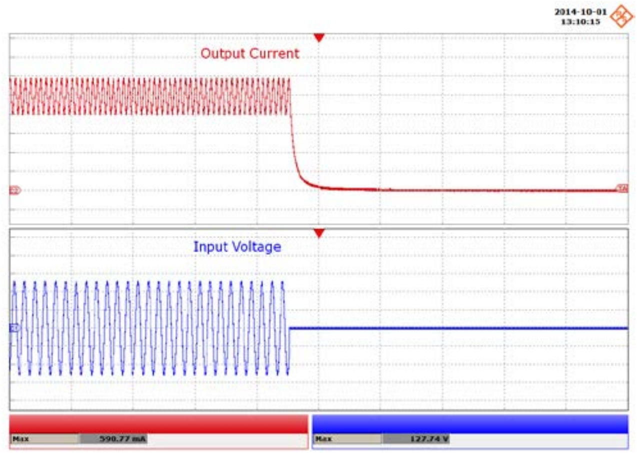

Figure 51 – 90 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 590.77 mA.
Peak V_{IN}: 127.74 V.

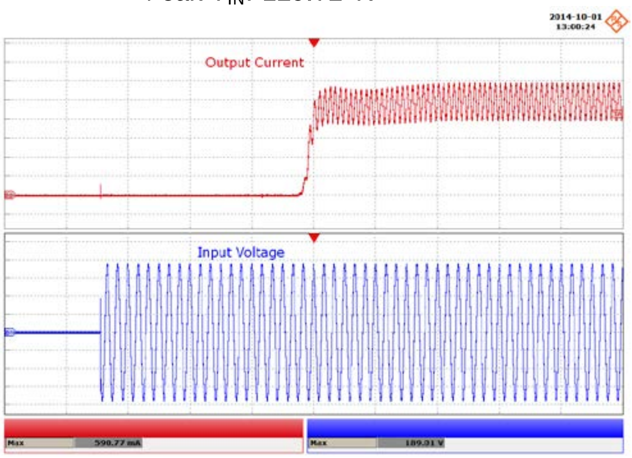

Figure 52 – 132 VAC, 60 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{OUT}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 590.77 mA
Peak I_{OUT}: 433.54 V

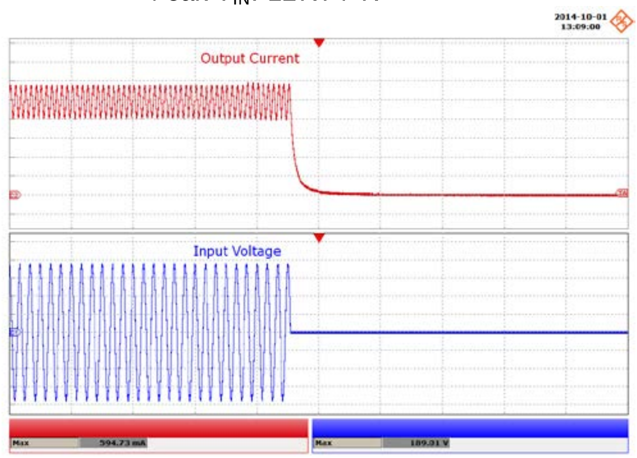

Figure 53 – 132 VAC, 60 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 594.73 mA.
Peak I_{OUT}: 189.01 V.

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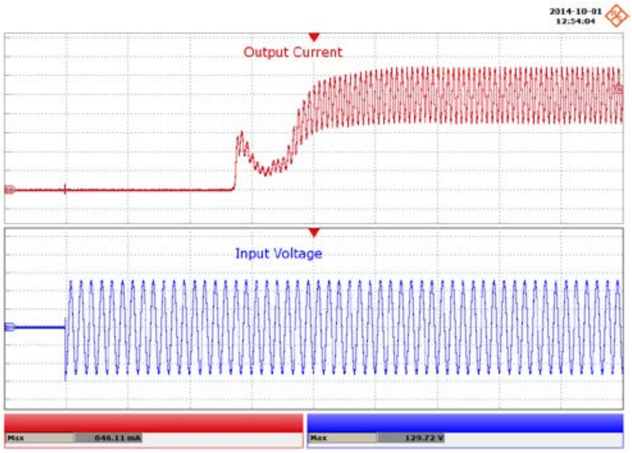

Figure 54 – 90 VAC, 30 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50V / div., 100 ms / div.
Peak I_{OUT}: 646.11 mA.
Peak V_{IN}: 129.72 V.

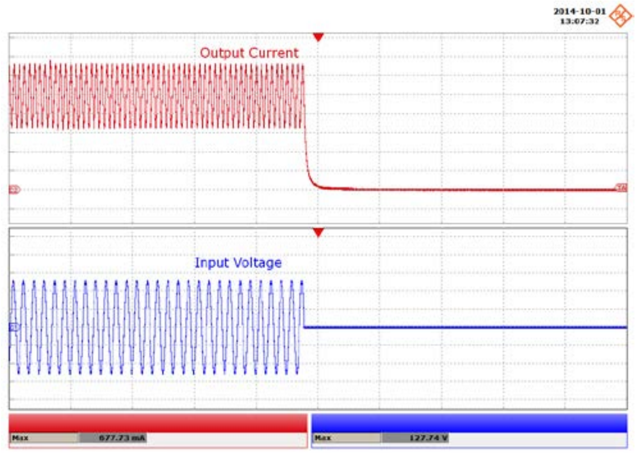

Figure 55 – 90 VAC, 30 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 677.73 mA.
Peak V_{IN}: 127.74 V.

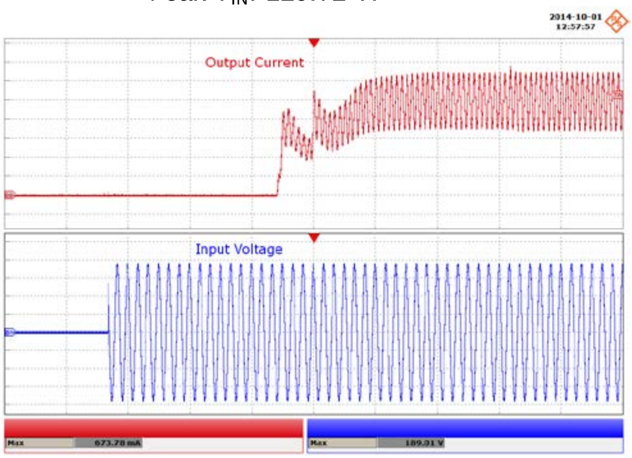

Figure 56 – 132 VAC, 30 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 673.78 mA.
Peak V_{IN}: 189.01 V.

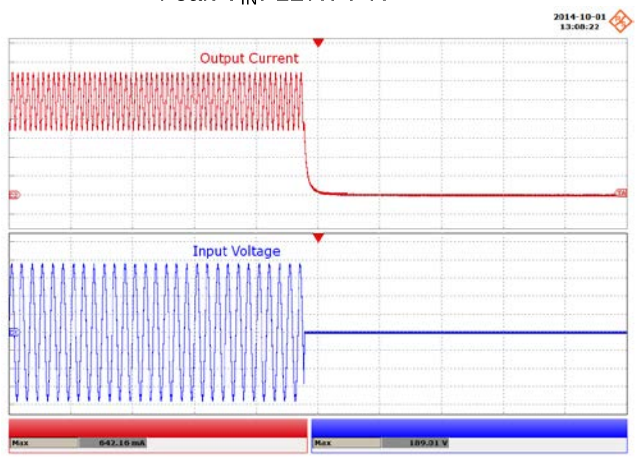

Figure 57 – 132 VAC, 30 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.
Peak I_{OUT}: 642.16 mA.
Peak V_{IN}: 189.01 V.

13.3 Output Current and Voltage at Power Up, Power Down

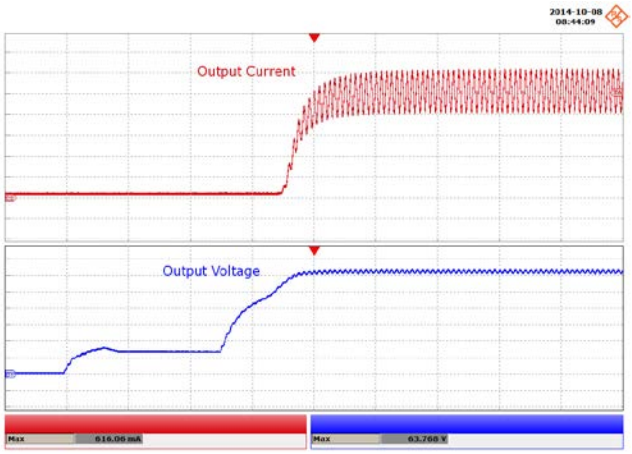

Figure 58 – 90 VAC, 60 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div, 100 ms / div.
Peak I_{OUT}: 516.06 mA.
Peak V_{OUT}: 63.77V.

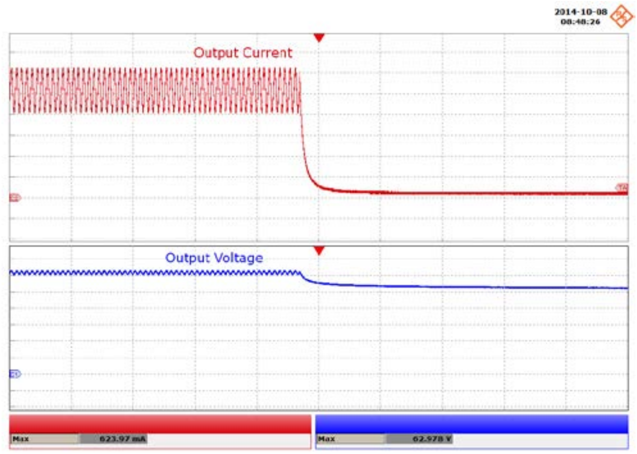

Figure 59 – 90 VAC, 60 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div, 100 ms / div.
Peak I_{OUT}: 623.9 mA.
Peak V_{OUT}: 62.9 V.

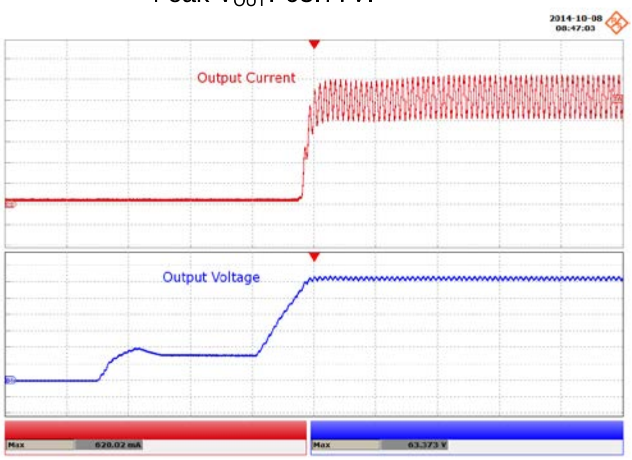

Figure 60 – 132 VAC, 60 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 620 mA.
Peak V_{OUT}: 63.37 V.

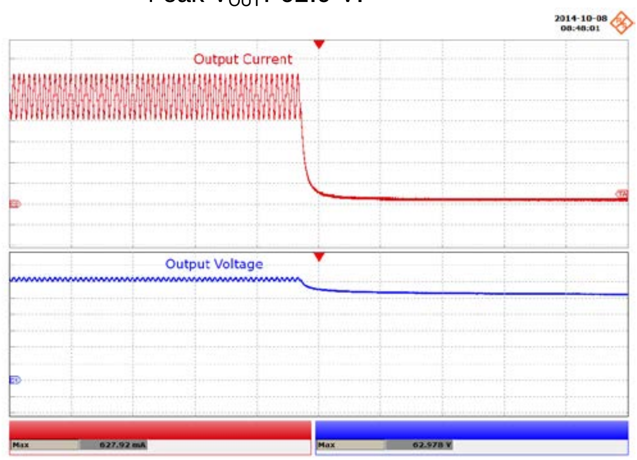

Figure 61 – 132 VAC, 60 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 627.9 mA.
Peak V_{OUT}: 62.97 V.

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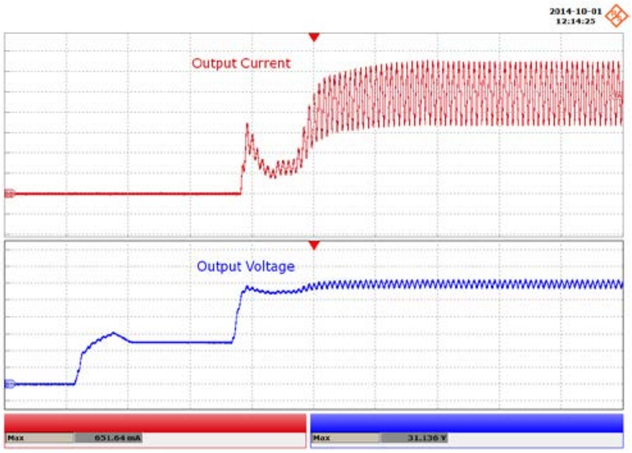

Figure 62 – 90 VAC, 30 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V / div., 100 ms / div.
Peak I_{OUT}: 651.6 mA.
Peak V_{OUT}: 31.1 V.

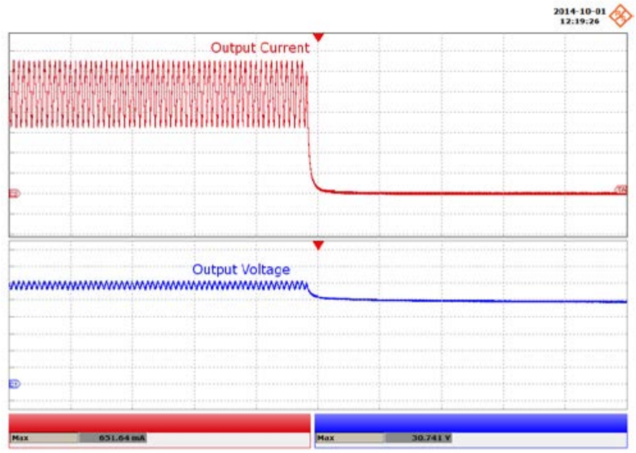

Figure 63 – 90 VAC, 30 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V / div., 100 ms / div.
Peak I_{OUT}: 651.64 mA.
Peak V_{OUT}: 30.74 V.

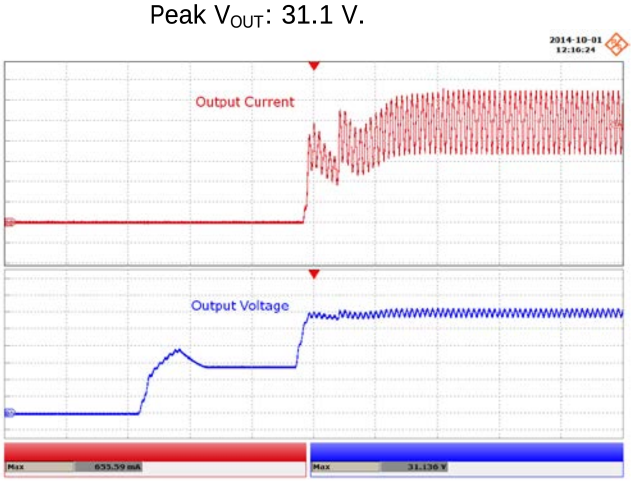

Figure 64 – 132 VAC, 30 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V / div., 100 ms / div.
Peak I_{OUT}: 655.69 mA.
Peak V_{OUT}: 31.14 V.

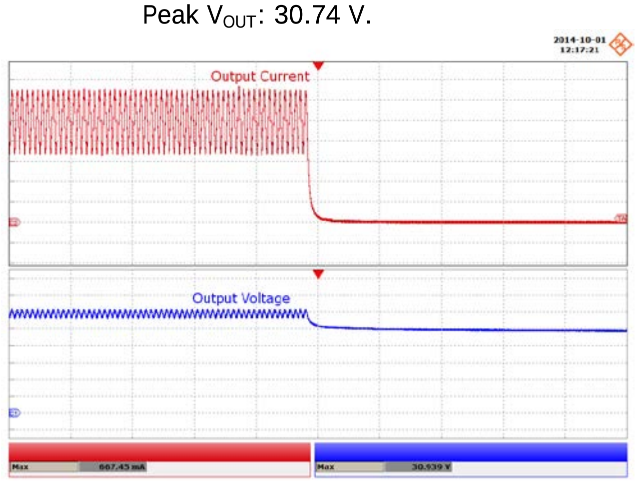

Figure 65 – 132 V VAC, 30 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V / div., 100 ms / div.
Peak I_{OUT}: 667.45 mA.
Peak V_{OUT}: 30.94 V.

13.4 Drain Voltage and Current at Normal Operation

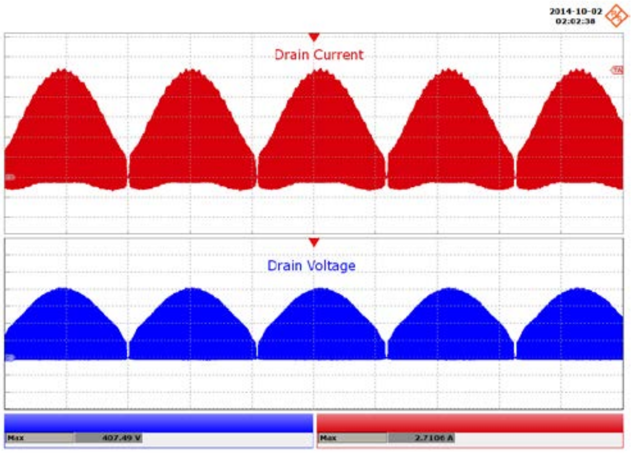

Figure 66 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.71 A.
Peak V_{DRAIN}: 407.49 V.

Figure 67 – 90 VAC, 60 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 2.71 A.
Peak V_{DRAIN}: 407.5 V.

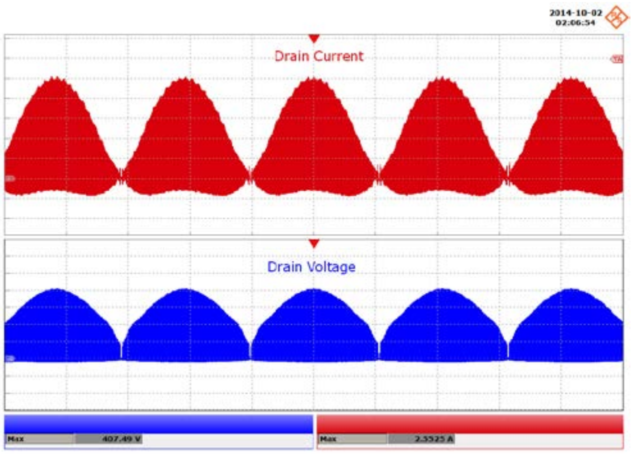

Figure 68 – 132 VAC, 60 V LED Load
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.55 A.
Peak V_{DRAIN}: 407.49 V.

Figure 69 – 132 VAC, 60 V LED Load
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 2.55 A.
Peak V_{DRAIN}: 407.49 V.

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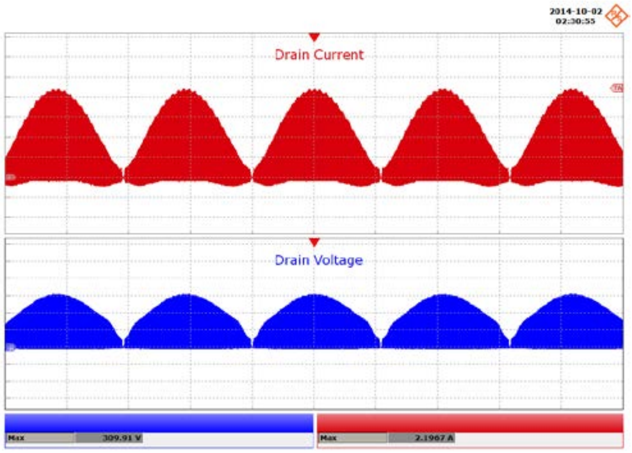

Figure 70 – 90 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.2 A.
Peak V_{DRAIN}: 309.9 V.

Figure 71 – 90 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 2.2 A.
Peak V_{DRAIN}: 309.9 V.

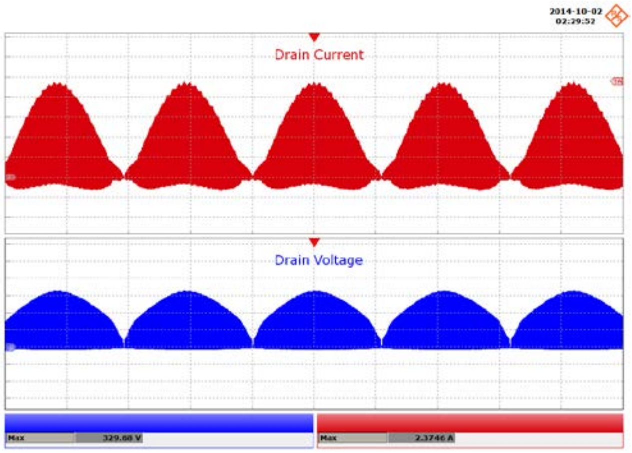

Figure 72 – 132 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: I_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.37 A.
Peak I_{DRAIN}: 329.7 V.

Figure 73 – 132 VAC, 30 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 2.37 A.
Peak I_{DRAIN}: 329.7 V.

13.5 Drain Voltage and Current Start-up Profile

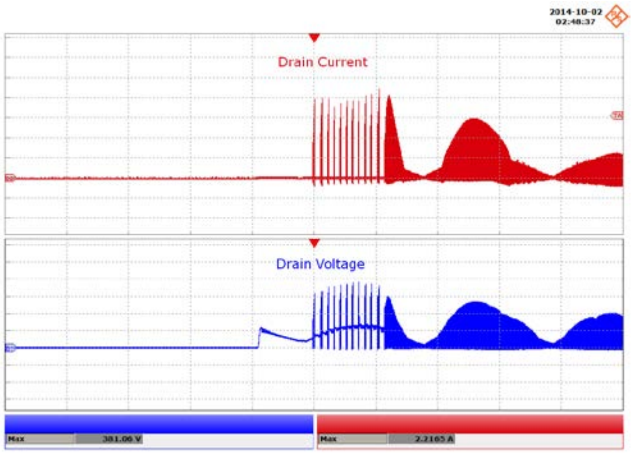

Figure 74 – 90 VAC, 60 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.22 A.
Peak V_{DRAIN}: 381.06 V.

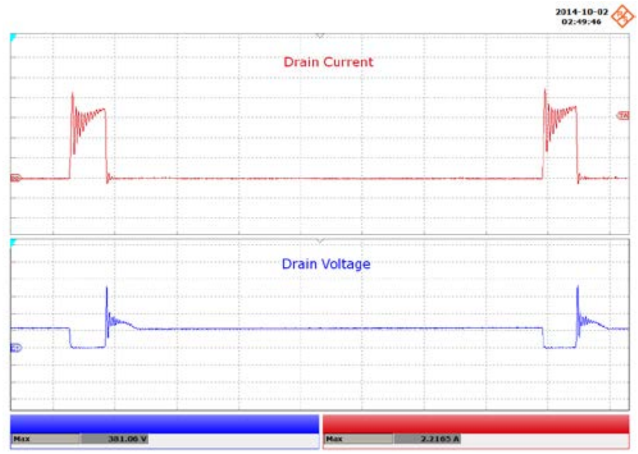

Figure 75 – 90 VAC, 60 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 2.22 A.
Peak V_{DRAIN}: 381.06 V.

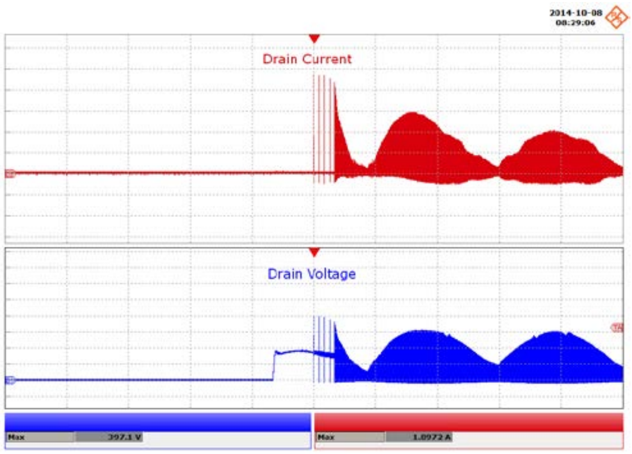

Figure 76 – 132 VAC, 60 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.89 A.
Peak V_{DRAIN}: 397.1 V.

Figure 77 – 132 VAC, 60 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 1.89 A.
Peak V_{DRAIN}: 397.1 V.

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13.6 Drain Voltage and Current during Output Short Condition

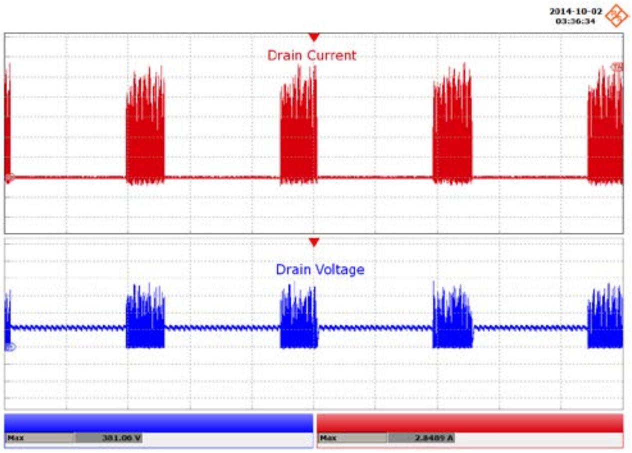

Figure 78 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.
Peak I_{DRAIN}: 2.85 A.
Peak V_{DRAIN}: 381.1 V.

Figure 79 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 400 ns / div.
Peak I_{DRAIN}: 2.89 A.
Peak V_{DRAIN}: 365.25 V.

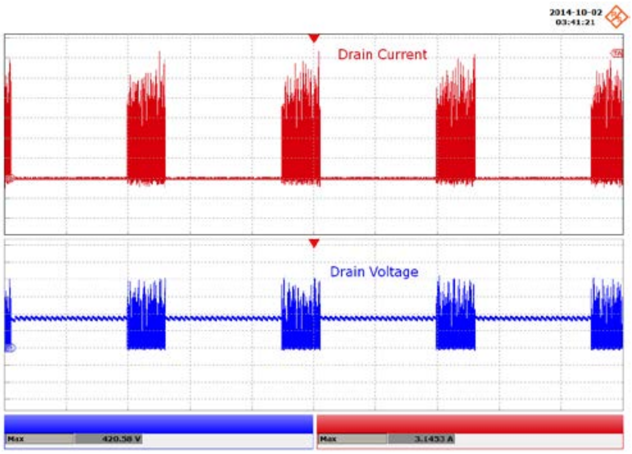

Figure 80 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.
Peak I_{DRAIN}: 3.15 A.
Peak V_{DRAIN}: 420.58 .V

Figure 81 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 400 ns / div.
Peak I_{DRAIN}: 3.13 A.
Peak V_{DRAIN}: 408.7 V.

Input		Input Measurement During Output Short		
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)
170	50	169.99	17.17	0.67
230	50	230.01	16.95	0.82
265	50	265.04	17.53	0.96
300	50	299.98	16.34	1.07

13.7 Output Diode Voltage and Current at Normal Operation

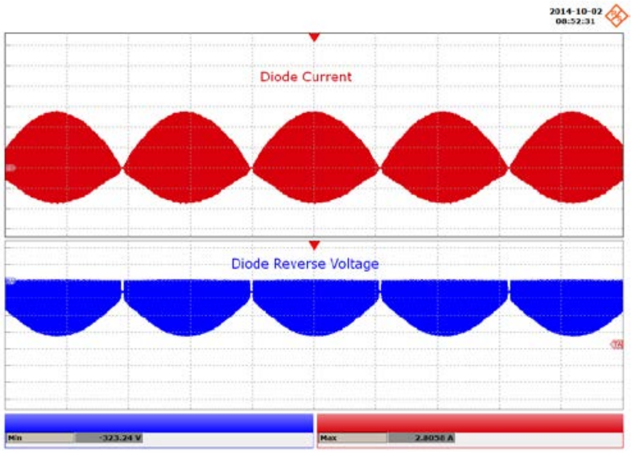

Figure 82 – 90 VAC, 60 V LED Load, Normal.
Upper: I_{DIODE}, 1 A / div.
Lower: V_{DIODE}, 100 V / div., 4 ms / div.
Peak I_{DIODE}: 2.81 A.
Peak Diode Reverse Voltage: 323.24 V.

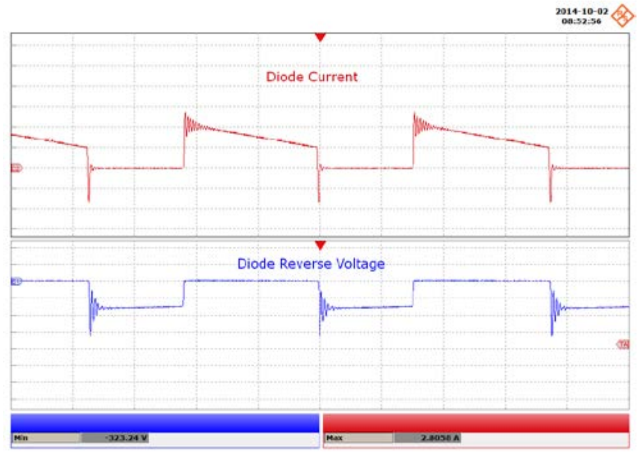

Figure 83 – 90 VAC, 60 V LED Load, Normal.
Upper: I_{DIODE}, 1 A / div.
Lower: V_{DIODE}, 100 V / div, 2 µs / div.
Peak I_{DIODE}: 2.81 A.
Peak Diode Reverse Voltage: 323.24 V.

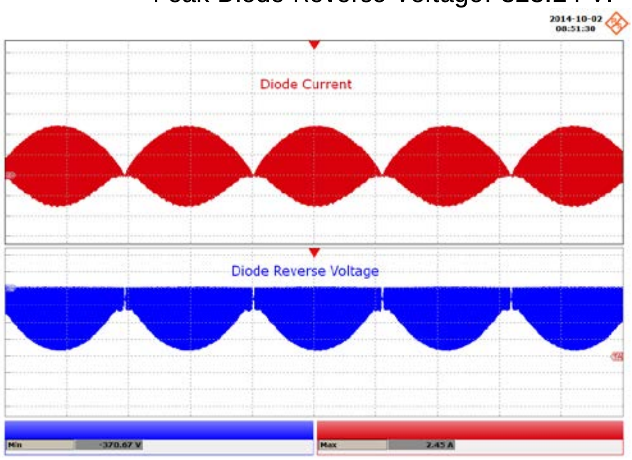

Figure 84 – 132 VAC, 60 VvLED Load, Normal.
Upper: I_{DIODE}, 1 A / div.
Lower: V_{DIODE}, 100 V / div., 4 ms / div.
Peak I_{DIODE}: 2.45 A.
Peak Diode Reverse Voltage: 370.67 V.

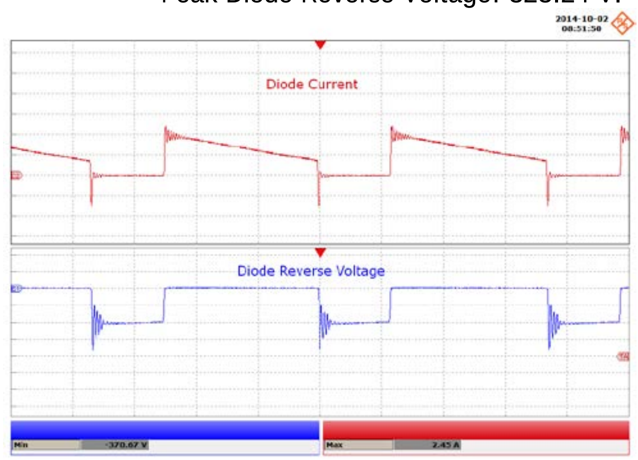

Figure 85 – 132 VAC, 60 V LED Load, Normal.
Upper: I_{DIODE}, 1 A / div.
Lower: V_{DIODE}, 100 V / div., 2 µs / div.
Peak I_{DIODE}: 2.45 A.
Peak Diode Reverse Voltage: 370.67 V.

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13.8 No-Load Characteristic

13.8.1 Drain Current Profile at No-Load

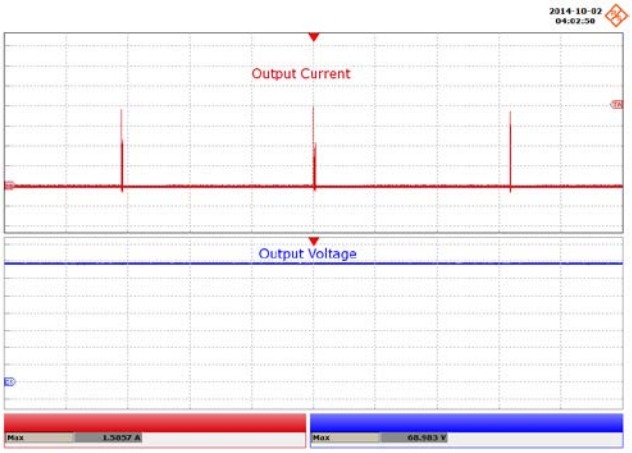

Figure 86 – 90 VAC, No LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{OUT}, 10 V / div., 40 ms / div.
Peak I_{DRAIN}: 1.587 A.
Peak V_{OUT}: 68.98 V.

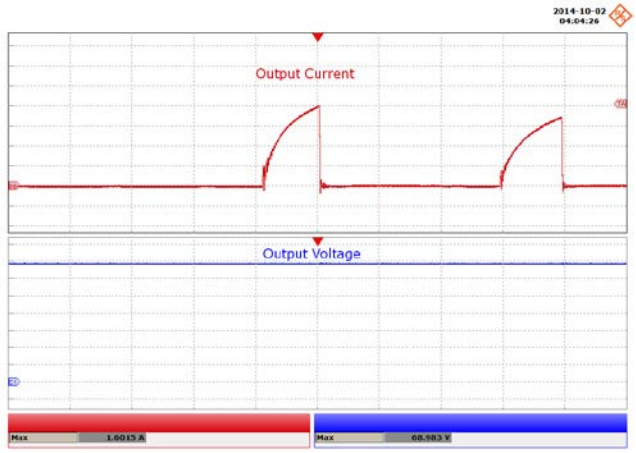

Figure 87 – 90 VAC, No LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{OUT}, 10 V / div., 4 μs / div.
Peak I_{DRAIN}: 1.6 A.
Peak V_{OUT}: 68.98 V.

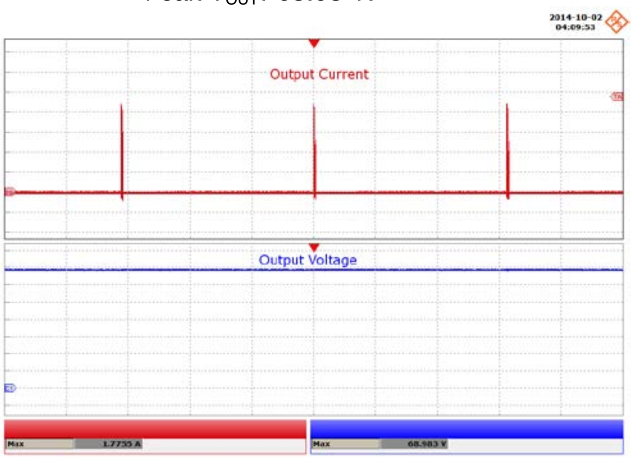

Figure 88 – 132 VAC, No LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{OUT}, 10 V / div., 40 ms / div.
Peak I_{DRAIN}: 1.78 A.
Peak V_{OUT}: 68.98 V.

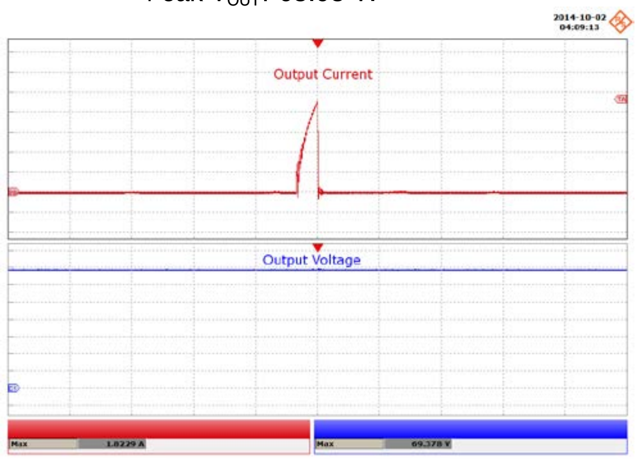

Figure 89 – 132 VAC, No LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{OUT}, 10 V / div., 4 μs / div.
Peak I_{DRAIN}: 1.82 A.
Peak V_{OUT}: 69.28 V.

13.8.2 Output Voltage and Current at Open LED Load

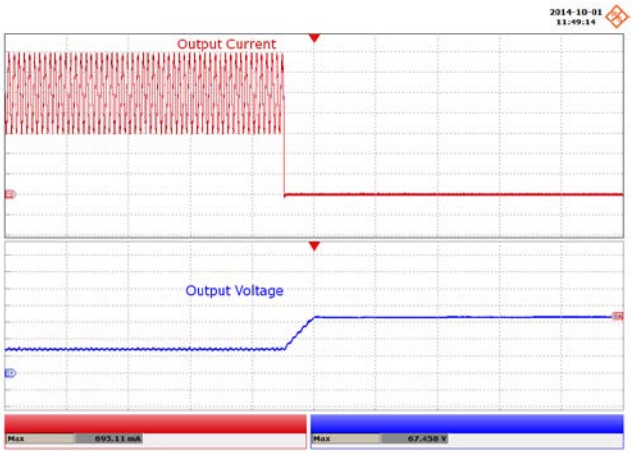

Figure 90 – 90 VAC, 30 V LED Load,
Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 695.11 mA.
Peak V_{OUT}: 67.46 V.

Figure 91 – 132 VAC, 30 V LED Load,
Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 706.97 mA.
Peak V_{OUT}: 67.46 V.

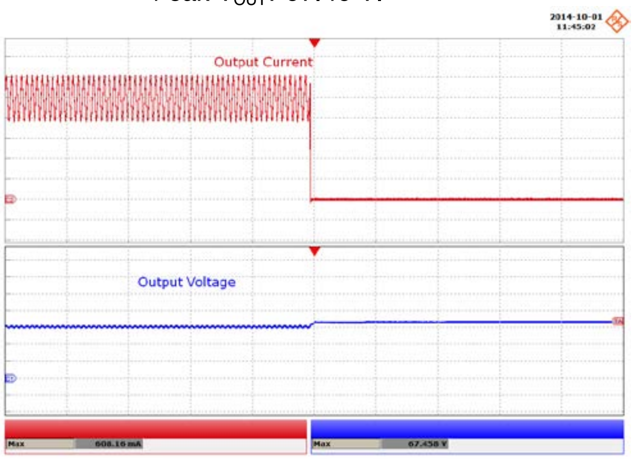

Figure 92 – 90 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 608.16 mA.
Peak V_{OUT}: 67.46 V.

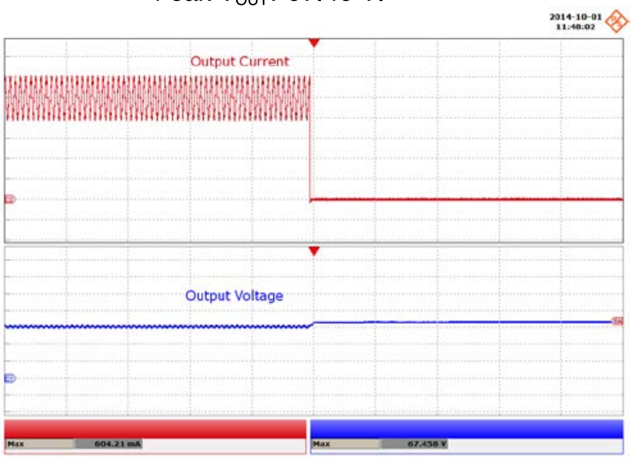

Figure 93 – 132 VAC, 60 V LED Load,
Running Open Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 604.2 mA.
Peak V_{OUT}: 67.46 V.

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13.8.3 Output Voltage and Current at Open Load Start-up

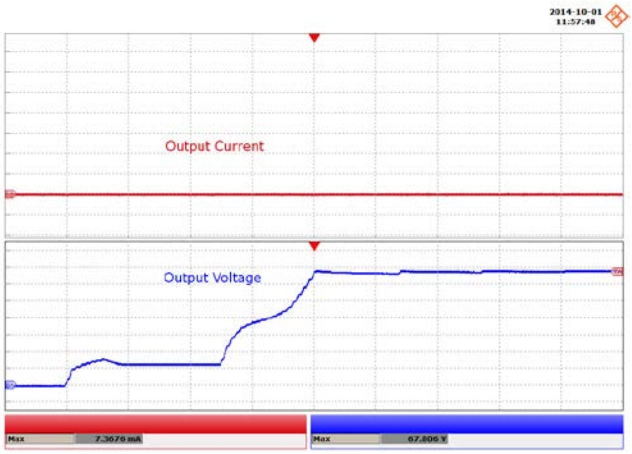

Figure 94 – 90 VAC, 60 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 67.81 V.

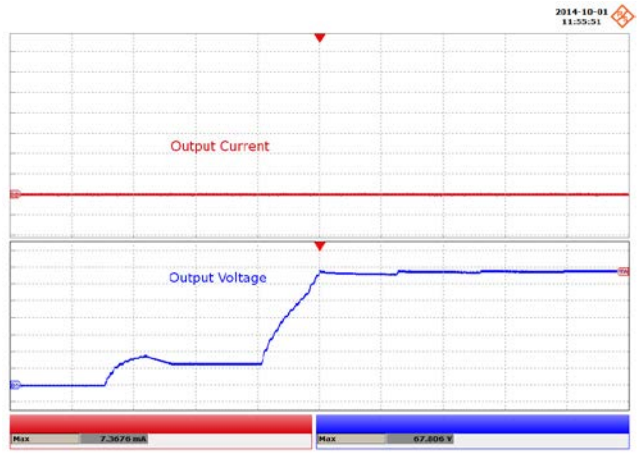

Figure 95 – 115 VAC, 60 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 67.81 V.

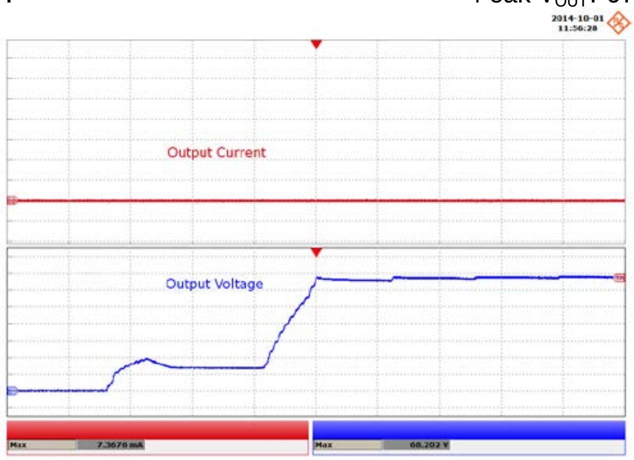

Figure 96 – 132 VAC, 60 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 68.2 V.

13.9 Output Ripple Current

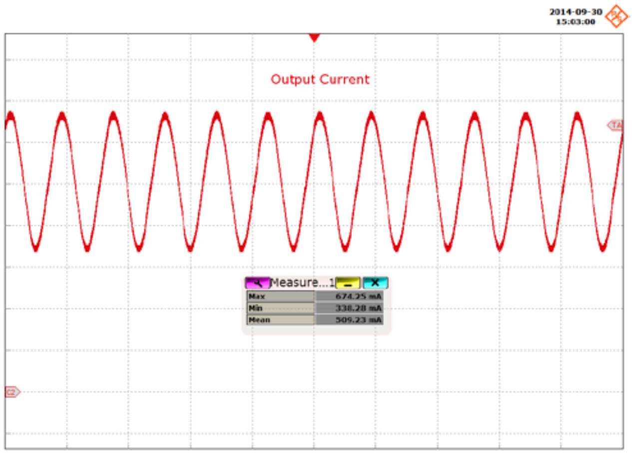

Figure 97 – 100 VAC, 60 Hz, 30 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

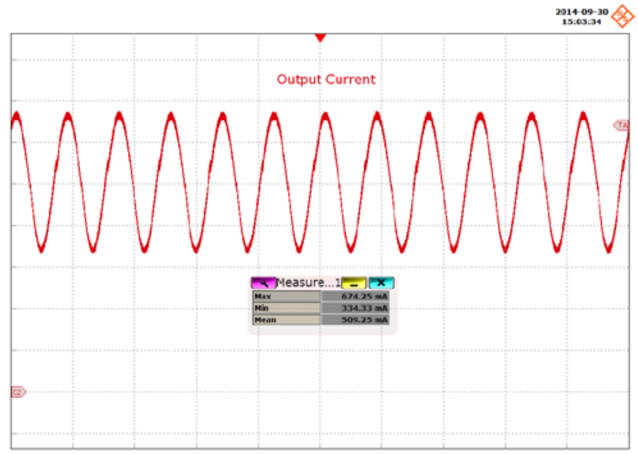

Figure 98 – 120 VAC, 60 Hz, 30 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

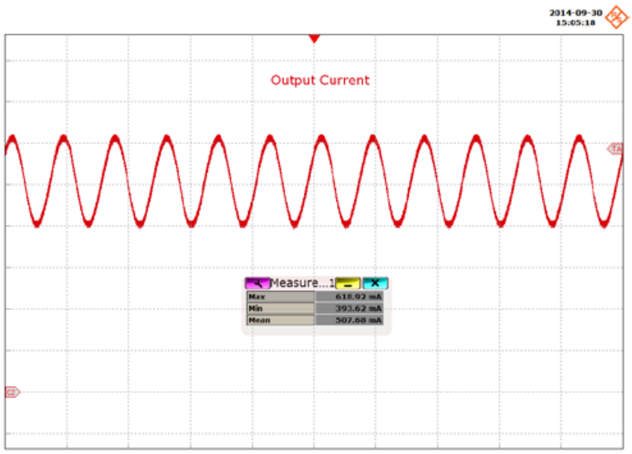

Figure 99 – 100 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 100 mA / div, 10 ms / div.

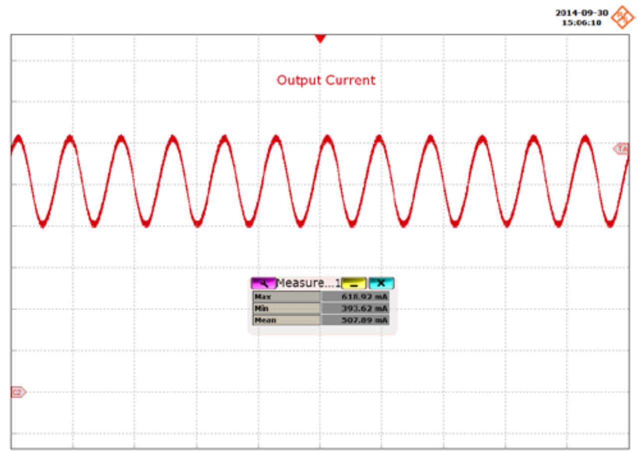

Figure 100 – 120 VAC, 60 Hz, 60 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

V_{IN}	$I_{OUT(MAX)}$ (mA)		$I_{OUT(MIN)}$ (mA)		I_{MEAN}		Ripple Ratio (I_{RP-P} / I_{MEAN})		% Flicker 100 x (I_{RP-P}) / ($I_{OUT(MAX)}$ + $I_{OUT(MIN)}$)	
	30 V	**60 V**	**30 V**	**60 V**	**30 V**	**60 V**	**30 V**	**60 V**	**30 V**	**60 V**
100 V, 60 Hz	682.16	618.92	326.23	393.62	509.53	507.68	0.70	0.44	35.30	22.25
120 V, 60 Hz	674.25	618.92	334.33	393.62	509.25	507.89	0.67	0.44	33.70	22.25

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14 AC Cycling Test

No output current overshoot was observed during on and off cycle.

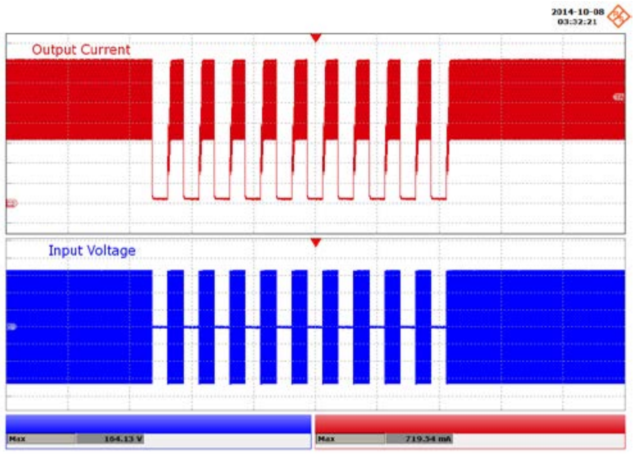

Figure 101 – 115 VAC, 30 V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 719.54 mA.
Peak V_{IN}: 164.13 V.

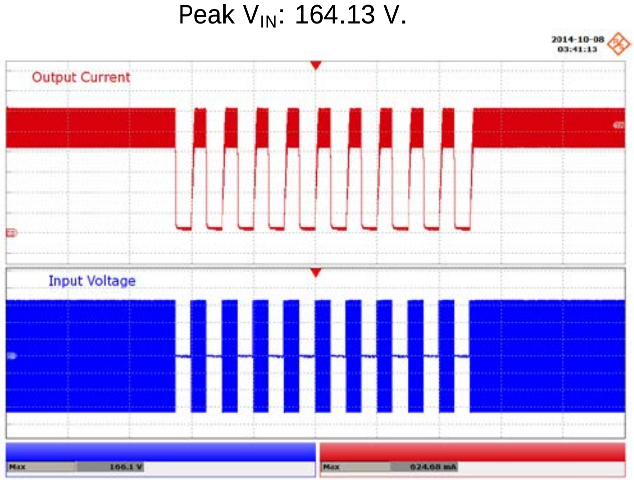

Figure 102 – 115 VAC, 60 V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 628.68 mA.
Peak V_{IN}: 166.1 V.

15 Conducted EMI

15.1 Test Set-up

EQUIPMENT AND LOAD USED:

1. ROHDE & SCHWARZ ENV216 TWO LINE V-NETWORK
2. ROHDE & SCHWARZ ESRP EMI TEST RECEIVER
3. HIOKI 3322 POWER HiTESTER
4. CHROMA MEASUREMENT TEST FIXTURE
5. 45 V, 70 V AND 60 V LED LOAD WITH INPUT VOLTAGE SET AT 115 VAC.

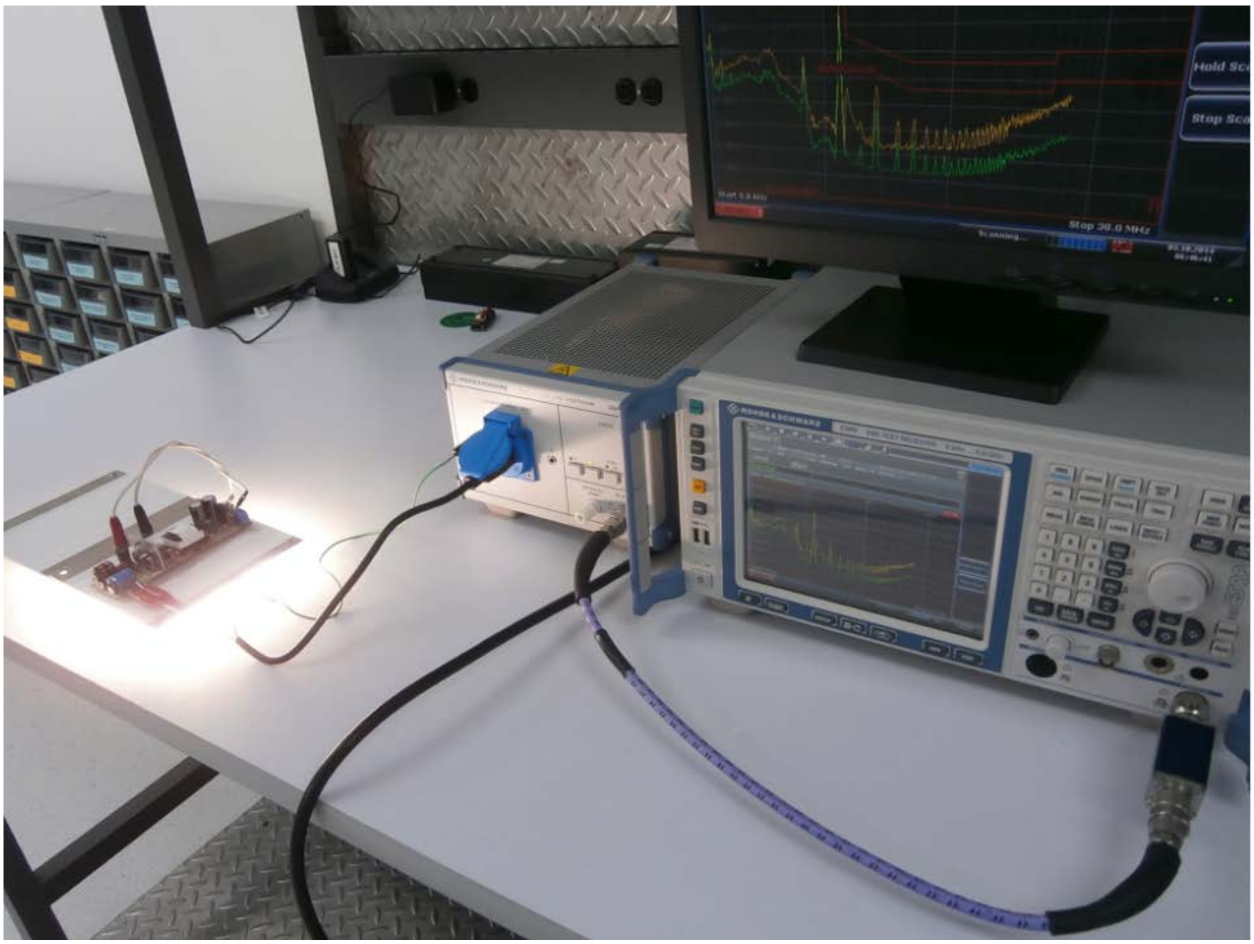

Figure 103 – Conducted EMI Test Set-up.

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15.2 EMI Test Result

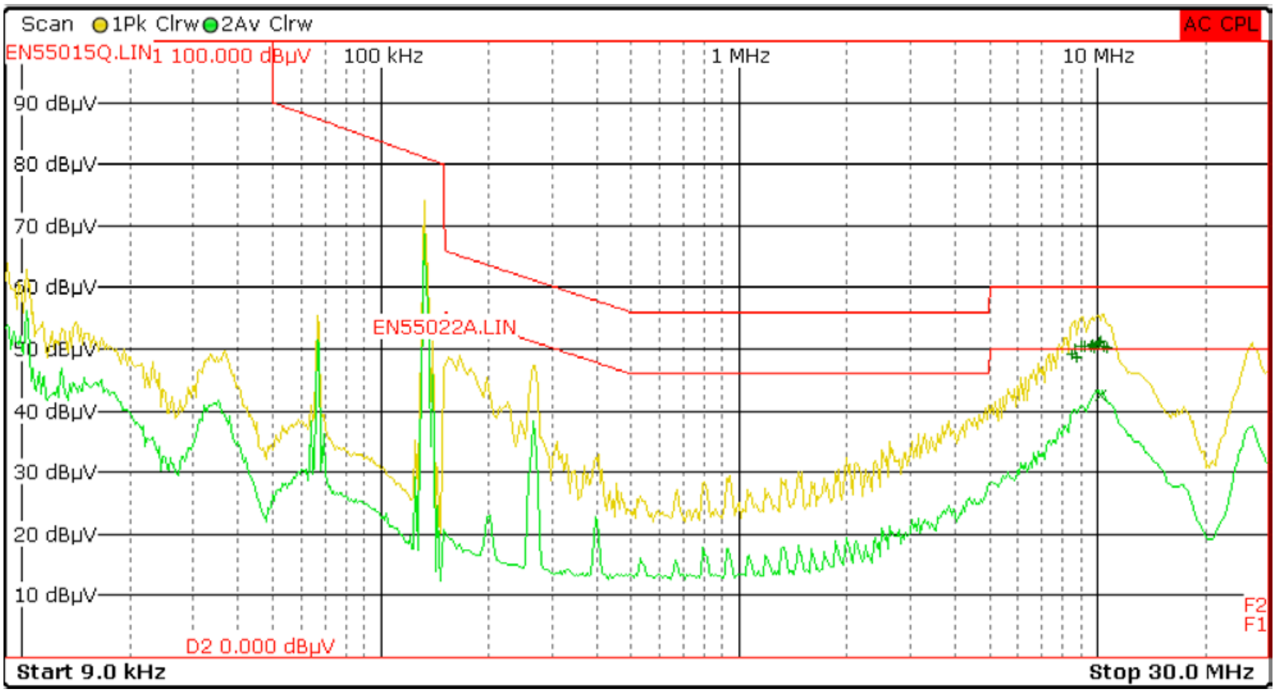

Figure 104 – Conducted EMI, 30 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBμV	DeltaLimit
1 Quasi Peak	8.5260 MHz	49.13 L1	-10.87 dB
1 Quasi Peak	8.6580 MHz	50.00 L1	-10.00 dB
1 Quasi Peak	8.7900 MHz	48.71 L1	-11.29 dB
1 Quasi Peak	9.0540 MHz	50.64 L1	-9.36 dB
1 Quasi Peak	9.1860 MHz	50.57 L1	-9.43 dB
1 Quasi Peak	9.5820 MHz	50.47 L1	-9.53 dB
1 Quasi Peak	9.7140 MHz	50.82 L1	-9.18 dB
1 Quasi Peak	9.8460 MHz	50.34 L1	-9.66 dB
1 Quasi Peak	10.1100 MHz	51.00 L1	-9.00 dB
1 Quasi Peak	10.2420 MHz	51.30 L1	-8.70 dB
2 Average	10.2420 MHz	42.41 N	-7.59 dB
1 Quasi Peak	10.3780 MHz	50.52 L1	-9.48 dB
1 Quasi Peak	10.6380 MHz	50.24 L1	-9.76 dB

Figure 105 – Conducted EMI, 30 V LED Load, Final Measurement Results at Line and Neutral.

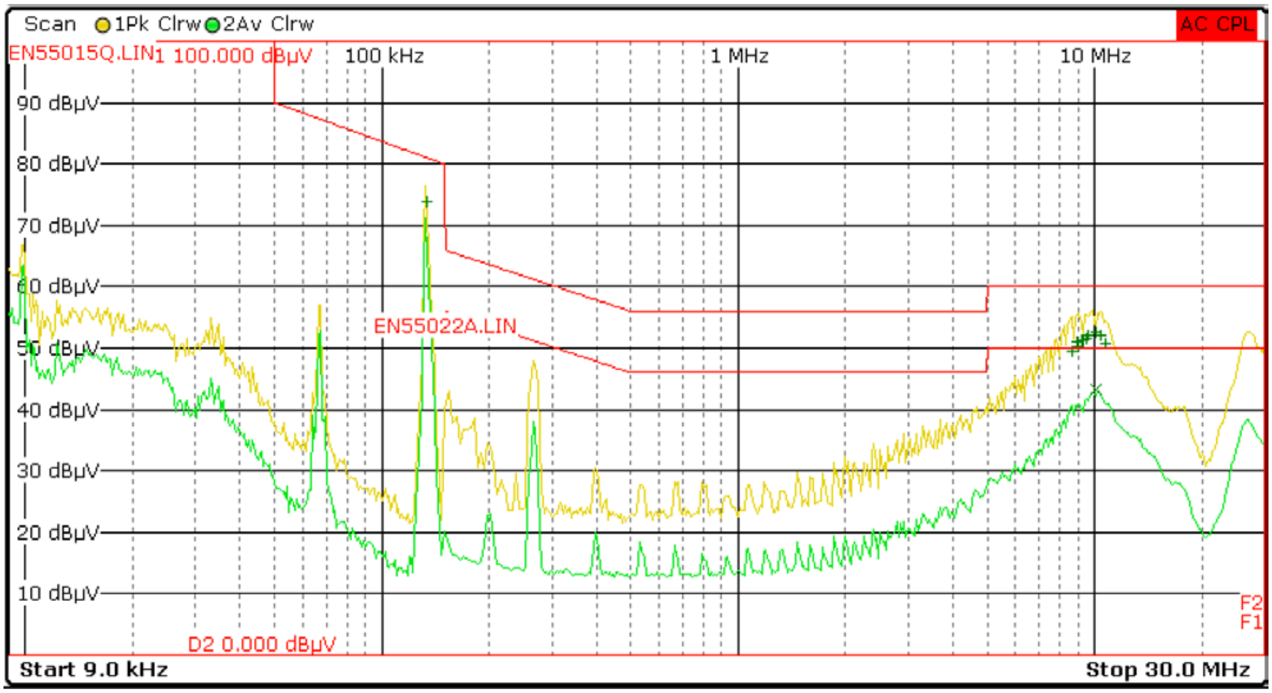

Figure 106 – Conducted EMI, 45 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	133.5600 kHz	73.72 L1	-7.34 dB
1 Quasi Peak	8.6660 MHz	49.44 L1	-10.56 dB
1 Quasi Peak	8.9260 MHz	51.02 L1	-8.98 dB
1 Quasi Peak	9.0620 MHz	50.13 L1	-9.87 dB
1 Quasi Peak	9.1940 MHz	51.30 N	-8.70 dB
1 Quasi Peak	9.3220 MHz	51.23 L1	-8.77 dB
1 Quasi Peak	9.4540 MHz	51.58 L1	-8.42 dB
1 Quasi Peak	9.5860 MHz	52.12 L1	-7.88 dB
2 Average	10.1140 MHz	43.34 L1	-6.66 dB
1 Quasi Peak	10.1180 MHz	52.57 L1	-7.43 dB
1 Quasi Peak	10.3820 MHz	52.10 L1	-7.90 dB
1 Quasi Peak	10.7780 MHz	50.81 L1	-9.19 dB

Figure 107 – Conducted EMI, 45 V LED Load, Final Measurement Results at Line and Neutral.

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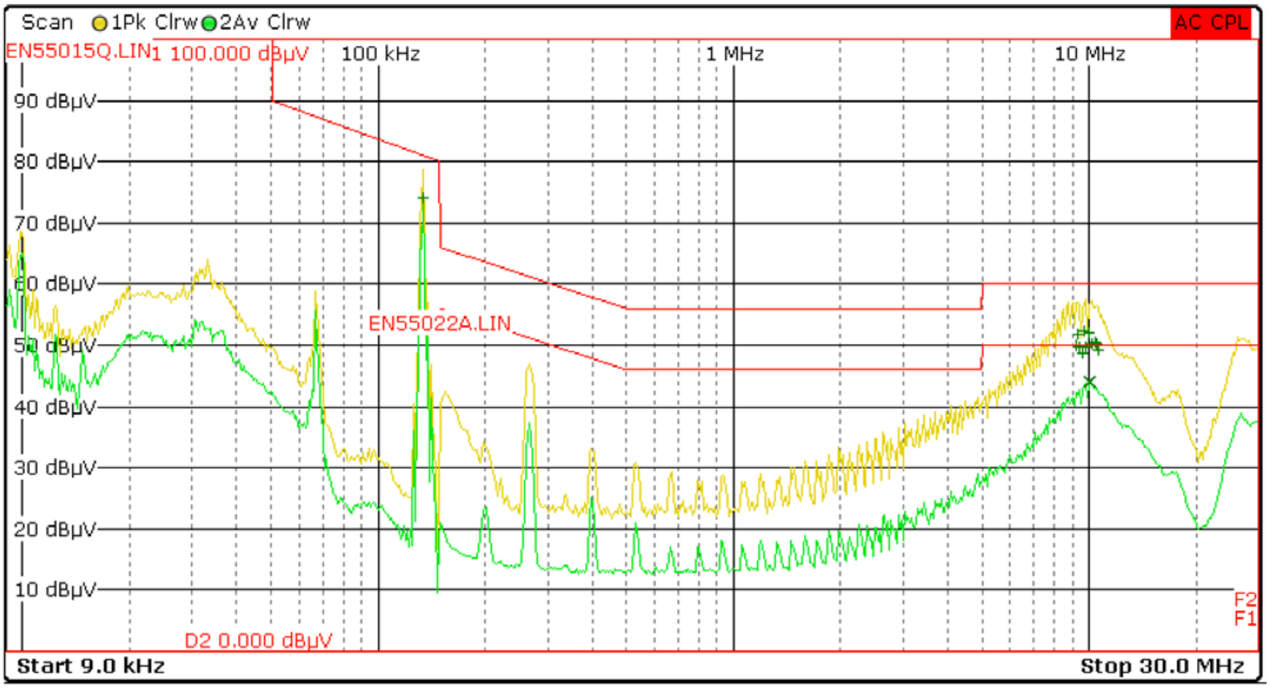

Figure 108 – Conducted EMI, 60 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	133.4000 kHz	74.17 L1	-6.90 dB
1 Quasi Peak	9.1780 MHz	50.10 N	-9.90 dB
1 Quasi Peak	9.3060 MHz	51.78 L1	-8.22 dB
1 Quasi Peak	9.4420 MHz	49.75 L1	-10.25 dB
1 Quasi Peak	9.5740 MHz	48.73 L1	-11.27 dB
1 Quasi Peak	9.7020 MHz	52.39 L1	-7.61 dB
1 Quasi Peak	9.8380 MHz	49.85 N	-10.15 dB
1 Quasi Peak	9.9660 MHz	52.20 L1	-7.80 dB
2 Average	9.9660 MHz	43.94 L1	-6.06 dB
2 Average	10.0980 MHz	43.92 L1	-6.08 dB
1 Quasi Peak	10.2340 MHz	50.23 L1	-9.77 dB
1 Quasi Peak	10.3660 MHz	50.58 L1	-9.42 dB
1 Quasi Peak	10.4980 MHz	50.19 L1	-9.81 dB
1 Quasi Peak	10.6300 MHz	49.32 L1	-10.68 dB

Figure 109 – Conducted EMI, 60 V LED Load, Final Measurement Results at Line and Neutral.

16 Line Surge

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring repair or recycling of input voltage.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass

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

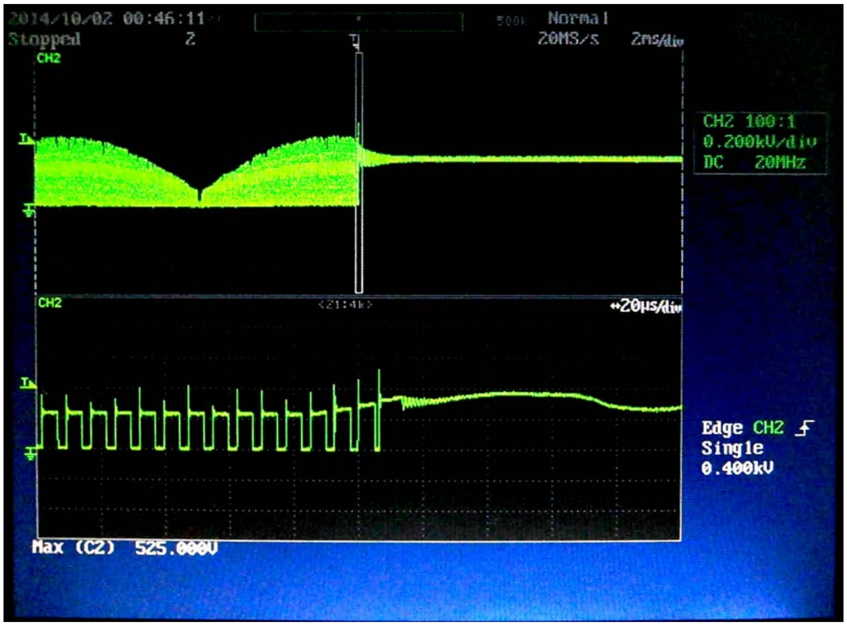

Figure 110 – +1000 kV Differential Surge, 90 °C Phase.
Lower: V_{DRAIN}, 200 V / div., 20 μs / div.
Peak V_{DRAIN}: 525 V.

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17 Brown in/Brown-out Test

No failure of any component during brownout test of 1 V / sec AC cut-in and cut-off.

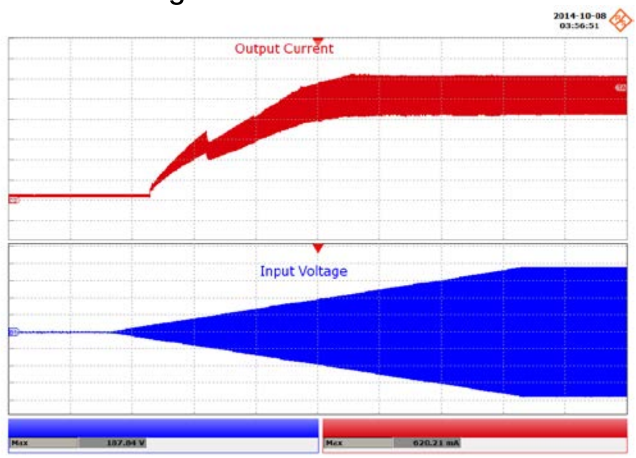

Figure 111 – 0 - 132 VAC, 60 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 20 s / div.
Peak I_{OUT}: 620.21 mA.
Peak V_{IN}: 187.84 V.

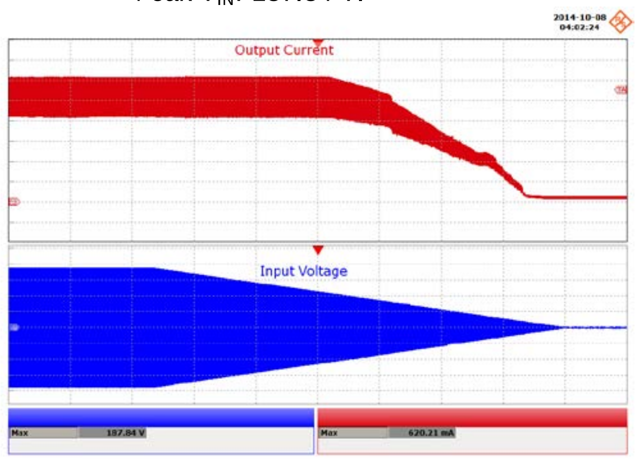

Figure 112 – 132 – 0 VAC, 60 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 20 s / div.
Peak I_{OUT}: 620.21 mA.
Peak V_{IN}: 187.84 V.

18 Revision History

Date	Author	Revision	Description and Changes	Reviewed
24-Sep-15	MGM	1.0	Initial release	Apps & Mktg

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