Design Example Report

Title	***33 W Isolated Flyback, JEL-801 Compatible, 0 – 10 V Analog Dimming LED Driver Using LYTSwitch™-4 LYT4325E***
Specification	170 VAC – 300 VAC Input; 45 V – 95 V, 0.35 A_{TYP} Output
Application	T8 Tube
Author	Applications Engineering Department
Document Number	DER-427
Date	February 6, 2015
Revision	1.0

Summary and Features

- Meets JEL 801 requirements
- Wide output voltage range (45 V – 95 V) with accurate constant current (CC) regulation
- Single-stage power factor correction , PF >0.9
- 0-10 V analog dimming
- Consistent dimming performance across input and output voltage ranges
- Highly energy efficient, >85% at 230 VAC
- Constant voltage disconnected load protection
- Integrated protection features
  - Output short-circuit protection with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis
- No damage during brown-out conditions
- PF >0.9 at 230 VAC
- A-THD <20% at 230 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.

1 Introduction

This engineering report describes a wide output voltage range, isolated flyback LED driver utilizing a LYT4325E from the LYTSwitch-4 family of devices.

DER-427 provides a constant output current of 350 mA across an output voltage range of 45 V to 95 V and supports an input range of 170 VAC to 300 VAC. The power supply meets JEL 801 requirements and offers 0 V to 10 V analog dimming for T8 tube applications.

The LYTSwitch-4 driver IC, combines the PFC function (which meets both power factor and harmonics requirements) and a constant current driver into a single conversion stage.

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 LYTSwitch-4 controller adjusts the power MOSFET duty-cycle to maintain a sinusoidal input current providing high power factor and low harmonic currents.

The LYT4325E also provides comprehensive protection features including auto-restart to protect in the event of an open control-loop and output short-circuit fault conditions, plus line overvoltage 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 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.

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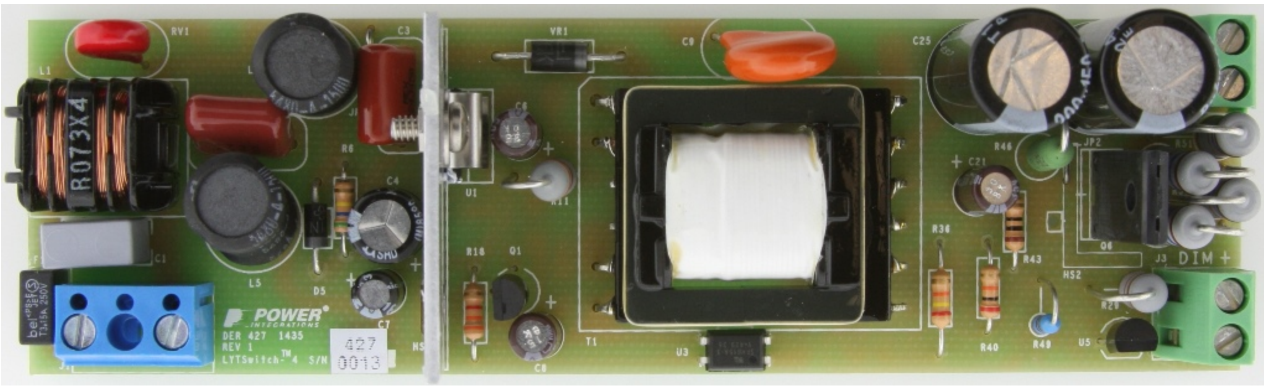

Figure 1 – Populated Circuit Board, Top View.

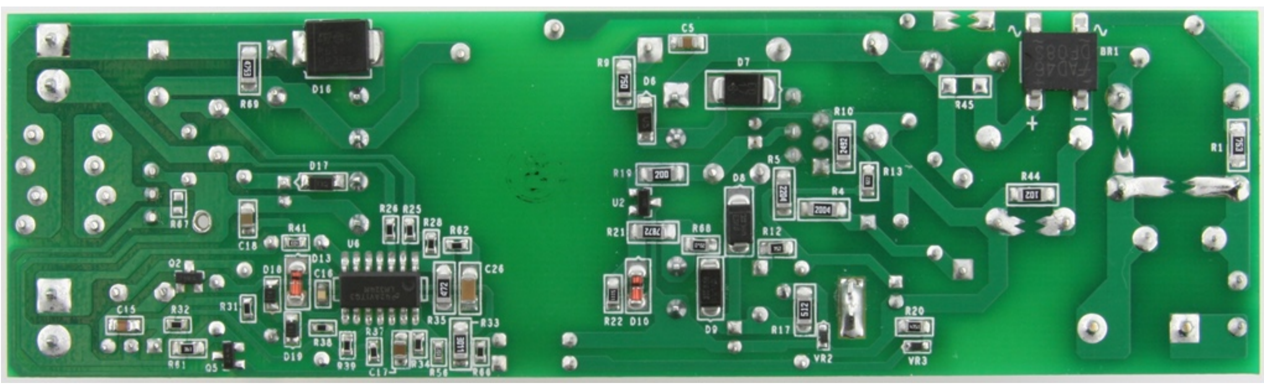

Figure 2 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	170	230	300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	45	70	95	V	
Output Current	I_{OUT}	0.32	0.35	0.39	A	
Total Output Power						
Continuous Output Power	P_{OUT}	15.8	24.5	33.3	W	
Efficiency						
Full Load	η		85		%	Measured at Po= 33.25W, 25 ^{o}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			0.9			Measured at 230 VAC, 50 Hz
Ambient Temperature	T_{AMB}			40	^{o}C	Free convection, sea level

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3 Schematic

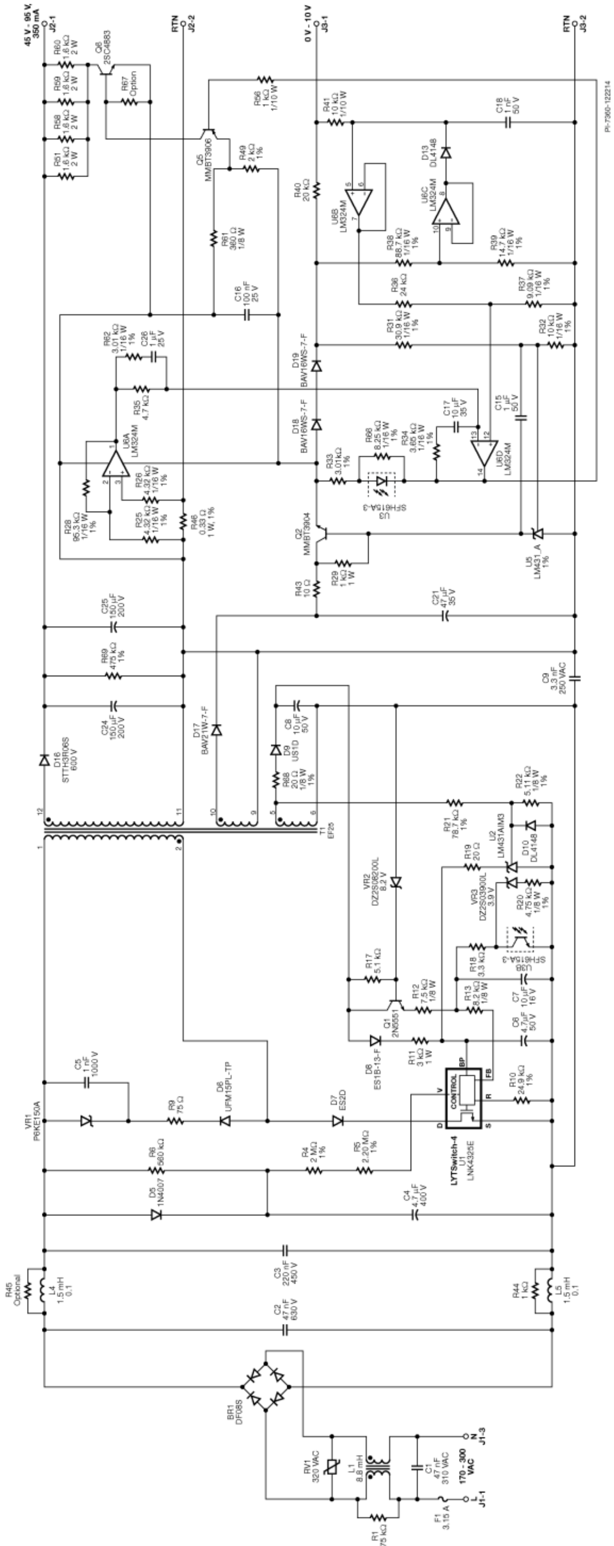

Figure 3 – Schematic.

4 Circuit Description

The LYTSwitch-4 device (U1 - LYT4325E) integrates the 725 V power MOSFET, controller and start-up functionality into a single package. This reduces the component count compared to a typical 2-stage implementations. Configured as a 33 W, wide output voltage range (45 V – 95 V) isolated continuous conduction mode flyback converter, U1 provides high power factor via its internal control.

The LYT4325E device is selected from the LYTSwitch-4 power table to provide optimized I_{FB} current, realizing good dimming regulation performance throughout the input and output voltage ranges. Continuous conduction mode operation results in reduced primary peak and RMS currents, which both reduces EMI, allowing smaller EMI filtering components and improves efficiency. Output current regulation and 0 V to 10 V analog dimming capability is achieved by a closed-loop feedback circuit using a quad operational amplifier.

4.1 Input Stage

Fuse F1 provides protection against component failure. Varistor RV1 acts as a clamp to limit the maximum voltage spike on the primary during differential line surge events. A 320 VAC rated part was selected, being slightly above the maximum specified operating voltage (300 VAC). The fast-acting line overvoltage detector in the LYTSwitch-4 IC works in conjunction with D5 and C4 (peak detector capacitor) to provide a clamp that limits the maximum voltage stress across the integrated power MOSFET.

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

Differential choke L4 and L5 together with the input filter capacitor C2 and C3 work as the first stage of an EMI π filter. Capacitor C1 and commode mode choke L1 form the second-stage of the EMI filter after the bridge BR1. Y capacitor C9 provides a common mode noise path from secondary-to-primary. These EMI filters, together with the LYTSwitch-4 frequency jittering feature ensures compliance with the EN55015 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 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

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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 feature extends the 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 analog of the output voltage.

Capacitor C6 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the IC. 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 LYT4325E device, a 4.7 μF capacitor was selected to enable maximum output power.

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 across the output voltage range.

4.3 Feedback Circuit

Output current regulation and 0 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 and controls the I_{FB} current on the primary side. An increase in optocoupler current results in reduced I_{FB} current, reducing the output LED current.

The feedback circuit bias supply comprising D17, C21 and R43 has a separate winding to minimize loss. A linear regulator using U5, Q2, C11, R29 and C16 provides a constant voltage to the secondary feedback circuit across all operating conditions. The 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.

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

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

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

Resistor R34 and C17 provide frequency compensation to the comparator U6D to optimize the output current regulation across the input range. Comparator U6D drives the forward current of the optocoupler U3 to provide a feedback control signal to the primary side. During dimming, a decrease of input dimming voltage decreases the output of comparator (U6D) at pin 14 increasing the optocoupler forward current. These will therefore pull down the device (LYT4325E) I_{FB} current on the secondary side lowering the output current. During 0 V dimming (or shorted dimming input terminal), the buffer amplifier U6C and sampling resistors R38 and R39 provide a 1 V dimming input voltage to maintain the output current closely same with 1 V dimming.

Resistor R62 and C26 form a phase boost circuit to improve phase margin and prevent LED flickering cause by oscillations during dimming. Resistor R33 and R66 limit the DC gain of the optocoupler to ensure constant current regulation. Zener diode VR3 and R20 limit the I_{FB} current during transient operation at maximum LED output voltage.

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4.4 No-Load Protection

In the event of a no-load condition, the output voltage is limited to 112 V. The output voltage is detected on the primary 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 the 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 auto-restart mode. Auto-restart is triggered whenever the FB current falls below the $I_{FB(AR)}$ threshold for longer than ~76 ms. The circuit is protected against overload and shorts by a primary-side current limit. During a short, primary current will increase until it reaches current the limit. Refer to the 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.

4.7 Active Pre-load

The active pre-load circuit is added to extend dimming range capability and provide additional output loading when a 0 V to 1 V input dim voltage is asserted. Voltage divider resistors R49 and R61 sets the pre-load activation threshold at 0 V to 1 V dim. The base pin of the PNP transistor Q5 detects the comparator (U6D) output from pin 14 through resistor R56 and drives the pre-load switch Q6 when its base voltage is 0.7 V lower from the emitter voltage. At a dim input voltage of 2 V to 10 V the active pre-load disengages to improve efficiency. Resistor R51, R58, R59 and R60 set the maximum current flowing into the pre-load. The temperature rise of resistors R51, R58, R59 and R60 can be significant and should be verified in the final product.

5 PCB Layout

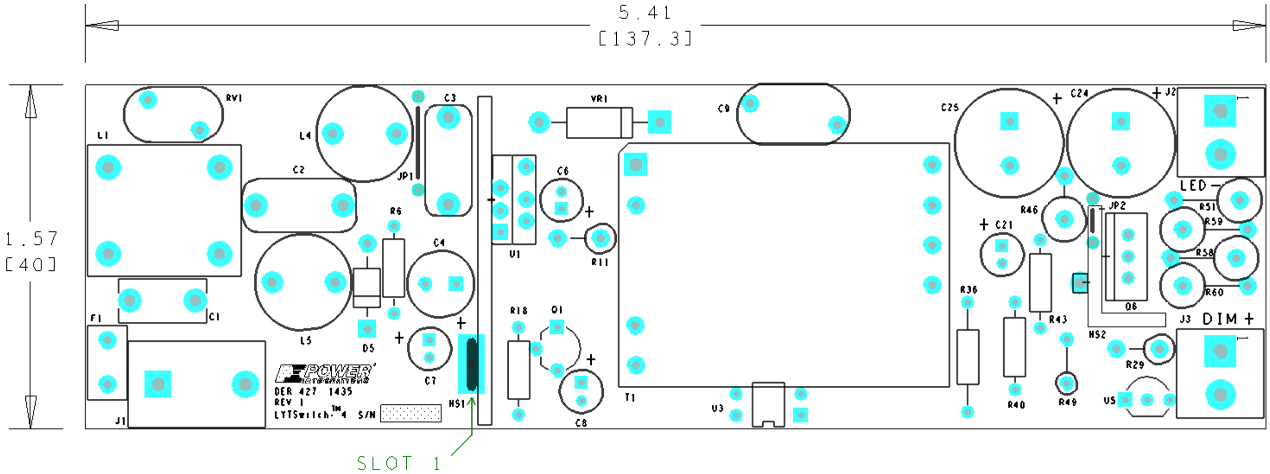

Figure 4 – Top Side.

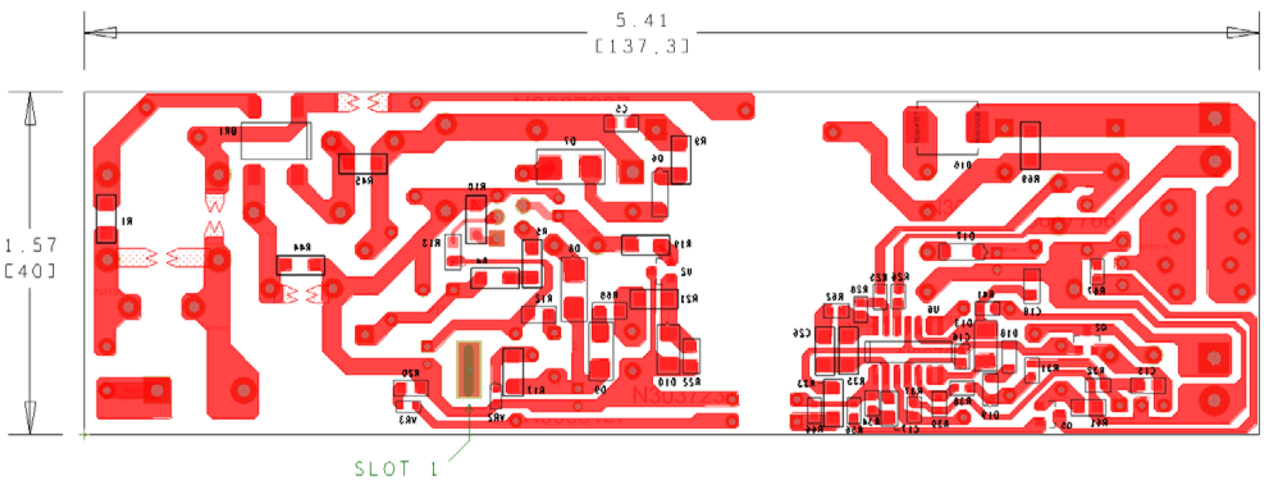

Figure 5 – Bottom Side.

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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	47 nF, 630 V, Film	ECQ-E6473KF	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	3.3 nF, Ceramic, Y1	440LD33-R	Vishay
11	1	C15	1 μF, 50 V, Ceramic, X7R, 0805	C2012X7R1H105M	TDK
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	47 μF, 35 V, Electrolytic, Gen. Purpose, (5 x 11)	EKMG350ELL470ME11D	Nippon Chemi-Con
16	1	C24	150 μF, 200 V, Electrolytic, (12.5 x 30)	200KXW150MEFC12.5X30	Rubycon
17	1	C25	150 μF, 200 V, Electrolytic, (12.5 x 30)	200KXW150MEFC12.5X30	Rubycon
18	1	C26	1 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK
19	1	D5	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
20	1	D6	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	Micro Commercial
21	1	D7	200 V, 2 A, Ultrafast Recovery, 20 ns, DO-214AA	ES2D-E3/52T	Diodes, Inc.
22	1	D8	100 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC	ES1B-13-F	Diodes, Inc.
23	1	D9	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
24	1	D10	75 V, 0.15 A, Fast Switching, 4 ns, Mini MELF	DL4148-TP	Diodes, Inc.
25	1	D13	75 V, 0.15 A, Fast Switching, 4 ns, Mini MELF	DL4148-TP	Diodes, Inc.
26	1	D16	600 V, 3 A, SMC, DO-214AB	STTH3R06S	ST Micro
27	1	D17	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
28	2	D18 D19	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
29	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
30	1	HS1	FAB, Heat Sink, DC TUBE-T8, DER-427	61-00163-01	Custom
31	1	HS_POST1	No Component-Unstuffed	Unstuff	Unstuff
32	1	J1	CONN TERM BLOCK 5.08 mm 3POS	ED120/3DS	On Shore Tech
33	2	J2 J3	2 Position (1 x 2) header, 5 mm (0.196) pitch, Vertical	1715022	Phoenix Contact
34	1	JP1	Wire Jumper, Insulated, TFE, 22 AWG, 0.4 in	C2004-12-02	AlphaWire
35	1	JP2	Wire Jumper, Insulated, TFE, 22 AWG, 0.2 in	C2004-12-02	AlphaWire
36	1	L1	8.8 mH, 0.7 mA, AC Filter T/H Common Mode Choke	SU10VFC-R07088	Kemet
37	1	L4	1.5 mH, 0.8 A, 20%	RL-5480-4-1500	Renco
38	1	L5	1.5 mH, 0.8 A, 20%	RL-5480-4-1500	Renco
39	1	Q1	NPN, Small Signal BJT, 160 V, 0.6 A, TO-92	2N5551RLRAG	On Semi
40	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
41	1	Q5	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
42	1	Q6	NPN, Power BJT, 150 V, 2 A, TO-220F	2SC4883	Sanken
43	1	R1	75 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ753V	Panasonic
44	1	R4	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
45	1	R5	2.20 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2204V	Panasonic
46	1	R6	560 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-560K	Yageo
47	1	R9	75 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ750V	Panasonic
48	1	R10	24.9 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2492V	Panasonic

49	1	R11	3 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-3K0	Yageo
50	1	R12	7.5 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ752V	Panasonic
51	1	R13	8.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ822V	Panasonic
52	1	R17	5.1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ512V	Panasonic
53	1	R18	3.3 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-3K3	Yageo
54	1	R19	20 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ200V	Panasonic
55	1	R20	4.75 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4751V	Panasonic
56	1	R21	78.7 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7872V	Panasonic
57	1	R22	5.11 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5111V	Panasonic
58	1	R25	4.32 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4321V	Panasonic
59	1	R26	4.32 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4321V	Panasonic
60	1	R28	95.3 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9532V	Panasonic
61	1	R29	1 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-1K0	Yageo
62	1	R31	30.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3092V	Panasonic
63	1	R32	10 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1002V	Panasonic
64	1	R33	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
65	1	R34	3.65 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3651V	Panasonic
66	1	R35	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
67	1	R36	24 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-24K	Yageo
68	1	R37	9.09 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9091V	Panasonic
69	1	R38	88.7 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF8872V	Panasonic
70	1	R39	14.7 k, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1472V	Panasonic
71	1	R40	20 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-20K	Yageo
72	1	R41	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
73	1	R43	10 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-10R	Yageo
74	1	R44	1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ102V	Panasonic
75	1	R45	Optional	NA	NA
76	1	R46	0.33 Ω, 1%, 1 W	2306 327 53307	Phoenix
77	1	R49	2 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-2K00	Yageo
78	1	R51	1.6 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K6	Yageo
79	1	R56	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
80	1	R58	1.6 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K6	Yageo
81	1	R59	1.6 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K6	Yageo
82	1	R60	1.6 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K6	Yageo
83	1	R61	360 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ361V	Panasonic
84	1	R62	3.01 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3011V	Panasonic
85	1	R66	8.25 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF8251V	Panasonic
86	1	R67	Optional	NA	NA
87	1	R68	20 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF20R0V	Panasonic
88	1	R69	475 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4753V	Panasonic
89	1	RV1	320 V, 26 J, 7 mm, RADIAL	V320LA7P	Littlefuse
90	1	T1	Bobbin, EF25, Horizontal, 12 pins	YC2504	Ying Chin
91	1	U1	LYTSwitch-4, eSIP-7C	LYT4325E	Power Integrations
92	1	U2	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semi
93	1	U3	Optocoupler, 70 V, CTR 100-200%, 4-DIP	SFH615A-3	Isocom Components
94	1	U5	2.495 V Shunt Regulator IC, 2%, 0 to 70C, TO92	LM431ACZ	National Semi
95	1	U6	IC, OP AMP QUAD LOW POWER, SOIC-14	LM324MX/NOPB	Texas Instruments
96	1	VR1	150 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE150A	LittleFuse
97	1	VR2	8.2 V, 5%, 150 mW, SSMINI-2	DZ2S08200L	Panasonic
98	1	VR3	3.9 V, 5%, 150 mW, SSMINI-2	DZ2S03900L	Panasonic

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7 Inductor Specification

7.1 Electrical Diagram

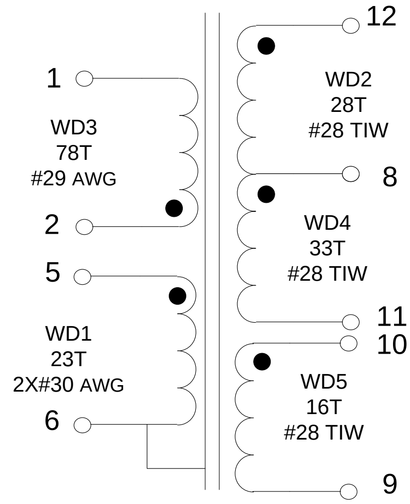

Figure 6 – Inductor Electrical Diagram.

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.	912 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: #29 AWG.
[4]	Magnet Wire: #30 AWG.
[5]	Triple Insulated Wire: #28 AWG.
[6]	Transformer tape: 15.5 mm.
[7]	Transformer tape: 7.2 mm.
[8]	Non-insulated wire: #30 AWG.

7.4 Transformer Build Diagram

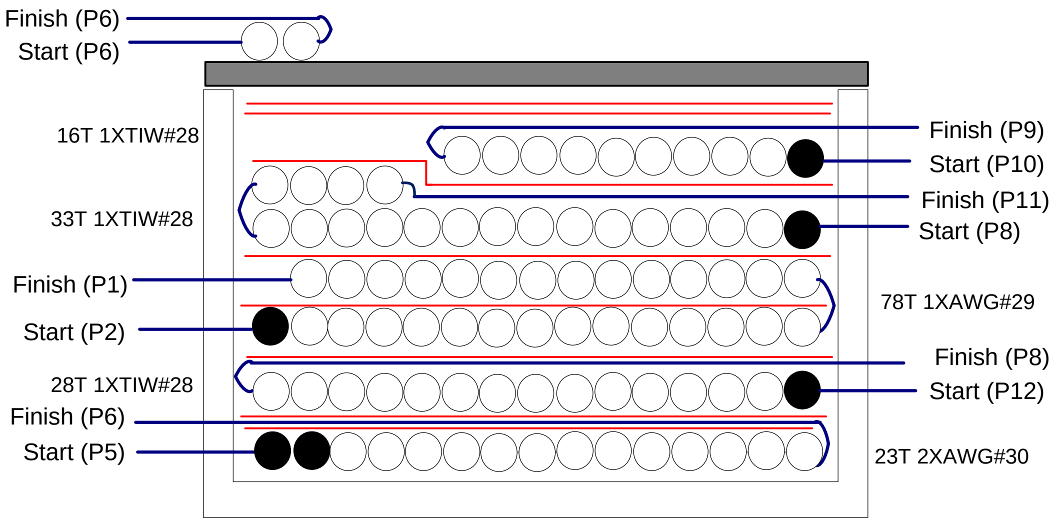

Figure 7 – Transformer Build Diagram.

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7.5 Inductor 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 23 turns (bifilar) of item (4) evenly from left to the right. Start to add ¼ turn of the insulation tape (item 6) 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 6) 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 28 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 [6], for insulation.
WDG3 - Primary	Start on pin 2 and wind 78 turns of item (3) from left to right and right to left in 2 layers and finish this winding on pin 1.
Insulation	Add 1 layer of tape, item [6], for insulation.
WDG4 - Secondary	Start on pin 8 and wind 28 turns of item (5) on the first layer from right to left then continue to wind 5 turns at the second layer from left to right and finish this winding on pin 11.
Insulation	Add 1 layer of tape, item [6], for insulation.
WDG5 - Bias (Secondary)	Start on pin 10 and wind 16 turns of item (5) from right to left then finish the winding at pin 9.
Insulation	Add 2 layer of tape, item [6], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal primary inductance of 912 μH.
Assemble Core	Assemble the 2 cores on the bobbin.
Flux Wire Band	Wrap a 2 shorted turns of item (8) 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 (7).
Pins	Pull-out terminal pin number 3, 4 and 7. Cut pin 8 by 4 mm.
Finish	Dip the transformer assembly in varnish.

8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_HL_102113; Rev.1.1; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_HL_102113: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**YES**		**YES**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN	170.00	INFO	170	V	The specified input voltage may cause wider line regulation. Set VACMIN to 180 or higher
VACMAX	300.00		300	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	70.00		70	V	Typical output voltage of LED string at full load
VO_MAX	95.00		95.00	V	Maximum expected LED string Voltage.
VO_MIN	45.00		45.00	V	Minimum expected LED string Voltage.
V_OVP	104.50	Warning	104.50	V	!!! Warning. Over-voltage setpoint is too high. Device will automatically set output to 90.74 V
IO	0.35		0.35	A	Typical full load LED current
PO			24.5	W	Output Power
n	0.86		0.86		Estimated efficiency of operation
VB			25	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	**LYT4325**		**LYT4325**		Selected LYTSwitch
Current Limit Mode	**RED**		**RED**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.14	A	Minimum current limit
ILIMITMAX			1.33	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			76.7	uA	V pin current
RV	4.20		4.2	M-ohms	Upper V pin resistor
RV2			1.E+12	M-ohms	Lower V pin resistor
IFB	162.00		162.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			135.8	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	0.68		0.68		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			912	uH	Primary Inductance
VOR	90.00		90	V	Reflected Output Voltage.
Expected IO (average)			0.33	A	Expected Average Output Current
KP_VNOM			0.65		Expected ripple current ratio at VACNOM
TON_MIN			1.33	us	Minimum on time at maximum AC input voltage
PCLAMP			0.18	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EE25**		**EE25**		Select Core Size
Custom Core					Enter Custom core part number (if applicable)
AE			0.41	cm^2	Core Effective Cross Sectional Area
LE			4.7	cm	Core Effective Path Length
AL			2140	nH/T^2	Ungapped Core Effective Inductance
BW			9.8	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary

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					Creepage Distance)
L			3		Number of Primary Layers
NS	61.00		61		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			240	V	Peak input voltage at VACMIN
VMAX			424	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.28		Minimum duty cycle at peak of VACMIN
IAVG			0.14	A	Average Primary Current
IP			0.92	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.27	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			912	uH	Primary Inductance
LP_TOL			10		Tolerance of primary inductance
NP			78		Primary Winding Number of Turns
NB			22		Bias Winding Number of Turns
ALG			150	nH/T^2	Gapped Core Effective Inductance
BM			2631	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP		**Warning**	3800	Gauss	!!! REDUCE BP<3700 (increase NS, smaller LYTSwitch, larger Core,increase KP)
BAC			895	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1952		Relative Permeability of Ungapped Core
LG			0.32	mm	Gap Length (Lg > 0.1 mm)
BWE			29.4	mm	Effective Bobbin Width
OD			0.38	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.32	mm	Bare conductor diameter
AWG			29	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			128	Cmils	Bare conductor effective area in circular mils
CMA			477	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			1.18	A	Peak Secondary Current
ISRMS			0.50	A	Secondary RMS Current
IRIPPLE			0.38	A	Output Capacitor RMS Ripple Current (based on Expected IO)
CMS			101	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			30	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.26	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.16	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			652	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			437	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			158	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)					
V pin Resistor Fine Tuning					
RV1			4.20	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			0.35	A	Measured Output Current at VAC1
IO_VAC2			0.35	A	Measured Output Current at VAC2
RV1 (new)			4.20	M-ohms	New RV1
RV2 (new)			21957.21	M-ohms	New RV2
V_OV			335.4	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			69.5	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			136	k-ohms	Upper FB Pin Resistor Value
RFB2			1.E+12	k-ohms	Lower FB Pin Resistor Value
VB1			15.9	V	Test Bias Voltage Condition1
VB2			34.1	V	Test Bias Voltage Condition2
IO1			0.35	A	Measured Output Current at Vb1
IO2			0.35	A	Measured Output Current at Vb2
RFB1 (new)			135.8	k-ohms	New RFB1
RFB2(new)			1.0000E+12	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic			% of Fund	Limit (%)	
1st Harmonic			110.37	N/A	Fundamental (mA)
3rd Harmonic			20.88	27.00	PASS. Percentage of 3rd Harmonic is lower than the limit
5th Harmonic			9.3	10.00	PASS. Percentage of 5th Harmonic is lower than the limit
7th Harmonic			5.6	7.00	PASS. Percentage of 7th Harmonic is lower than the limit
9th Harmonic			3.94	5.00	PASS. Percentage of 9th Harmonic is lower than the limit
11th Harmonic			3.00	3.00	FAIL. %age of 11th Harmonic exceeds the limit
13th Harmonic			2.34	3.00	PASS. Percentage of 13th Harmonic is lower than the limit
15th Harmonic			1.82	3.00	PASS. Percentage of 15th Harmonic is lower than the limit
THD			23.6	%	Estimated total Harmonic Distortion (THD)

Notes:

1. VACMIN – Info about "The specified input voltage may cause wider line regulation. Set VACMIN to 180 or higher" can be ignored since output current is controlled by a closed loop feedback circuit. The design meets specification at 170 V
2. V_OVP – Warning on V_OVP can be ignored because the spreadsheet calculates V_OVP based on IFB. The design uses a linear regulator circuit to provide constant supply voltage on the Ifb across the output voltage range.
3. Warning on the BP exceeding recommended BP value can be ignored. The transformer was heated to 100 ^{o}C and no saturation was observed.

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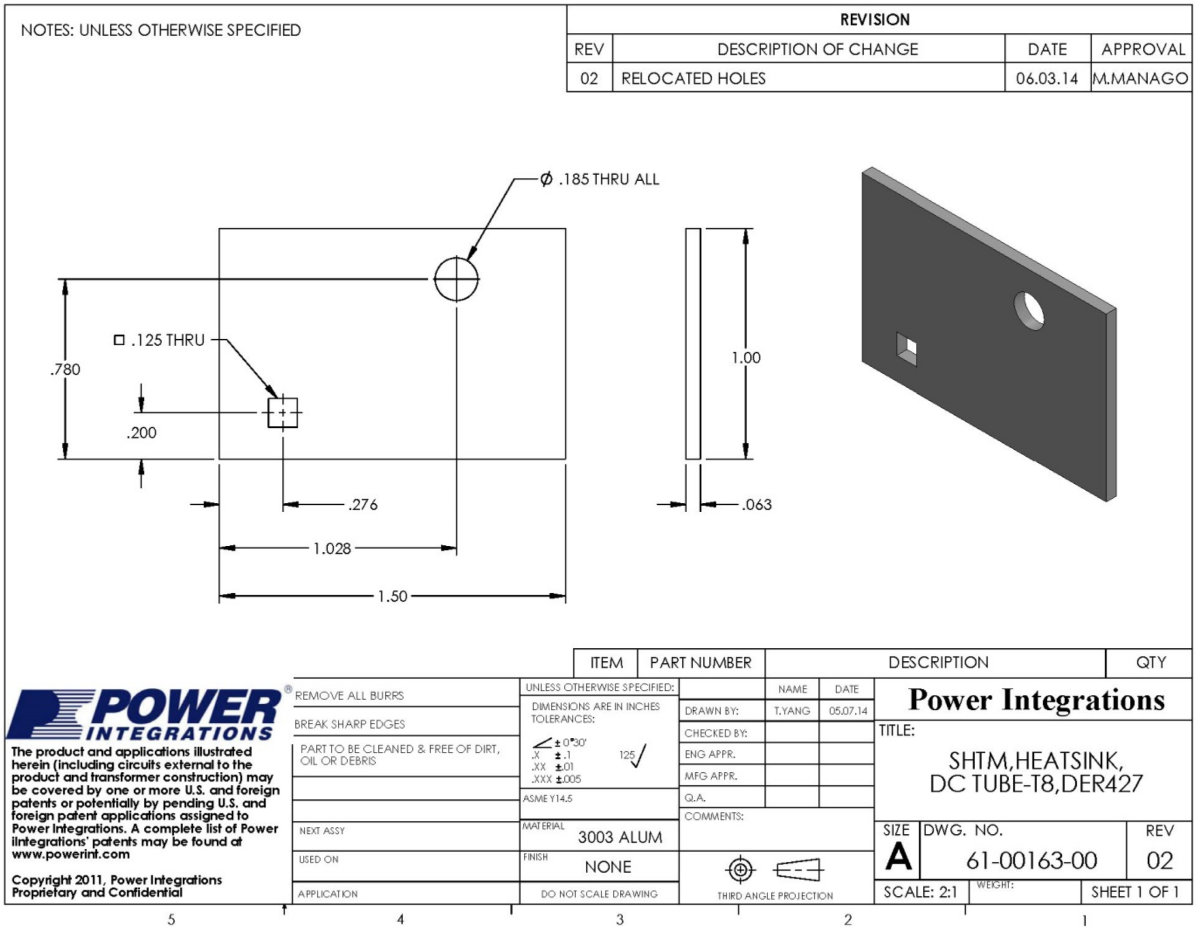
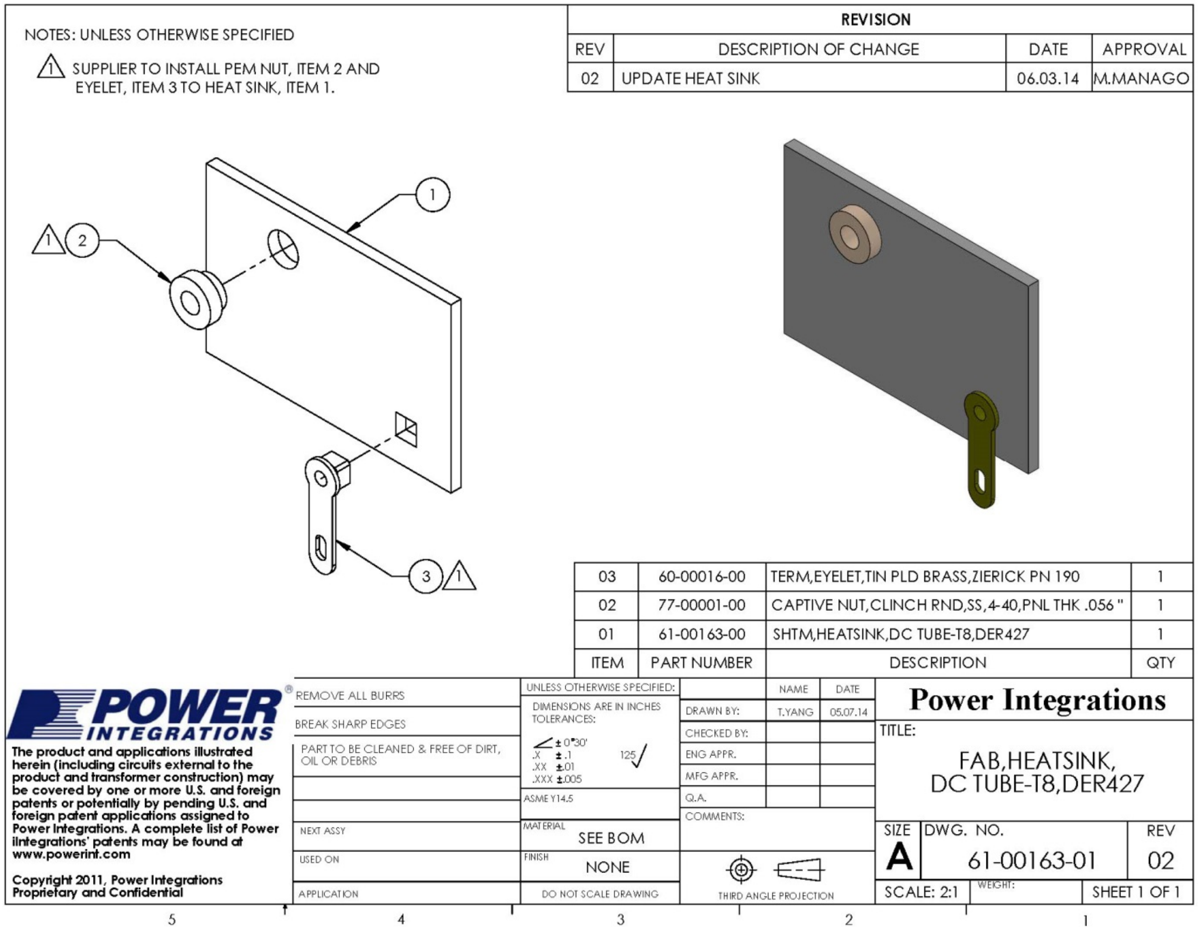
9 Heat Sink Assembly

9.1 eSIP Heat Sink Fabrication Drawing



9.2 eSIP Heat Sink Assembly Drawing



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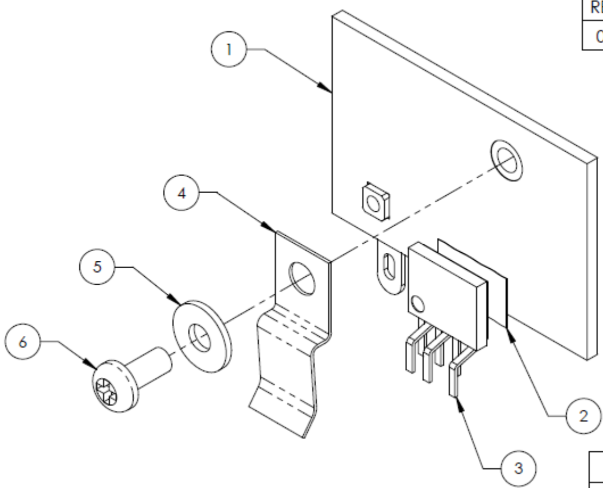
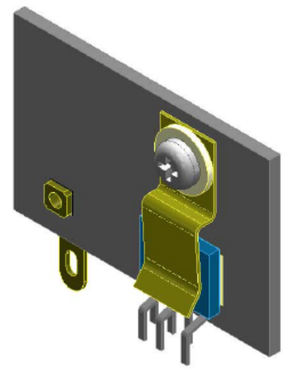
9.2.1 eSIP and Heat Sink and Assembly Drawing

NOTES: UNLESS OTHEWISE SPECIFIED

REVISION			
REV	DESCRIPTION OF CHANGE	DATE	APPROVAL
02	UPDATED HEAT SINK & CHG P/N OF ITEM 3	06.18.14	M.MANAGO





ITEM	PART NUMBER	DESCRIPTION	QTY
06	75-00001-00	SCREW MACHINE PHIL 4-40 X 1/4 SS	1
05	75-00032-00	WASHER,FLAT #4-40	1
04	60-00042-00	EDGE CLIP,20.76mmx8mmWx.015mmTHK	1
03	10-00733-00	LYTSWITCH,LYT4325E,eSIP-7C	1
02	60-00035-00	THERMAL GREASE,SILICON,5OZ TUBE	A/R
01	61-00163-01	FAB,HEATSINK,DC TUBE-T8,DER427	1

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The product and applications illustrated herein (including circuits external to the product and transformer construction) 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 iIntegrations' patents may be found at www.powerint.com

REMOVE ALL BURRS
BREAK SHARP EDGES
PART TO BE CLEANED & FREE OF DIRT, OIL OR DEBRIS
NEXT ASSY
USED ON
APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
∠ ± 0°30'
.X ± .1
.XX ± .01
.XXX ± .005
125 √
ASME Y14.5
MATERIAL SEE BOM
FINISH NONE
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN BY:	T.YANG	05.08.14
CHECKED BY:		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
THIRD ANGLE PROJECTION

Power Integrations

TITLE: ASSY,HEATSINK, DC TUBE-T8,DER427

SIZE A | DWG. NO. 61-00163-02 | REV 02
SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

10 Performance Data

All measurements were performed at room temperature using 45 V, 70 V and 95 V LED loads. Refer to Section 11 for the complete set of test results.

10.1 Efficiency

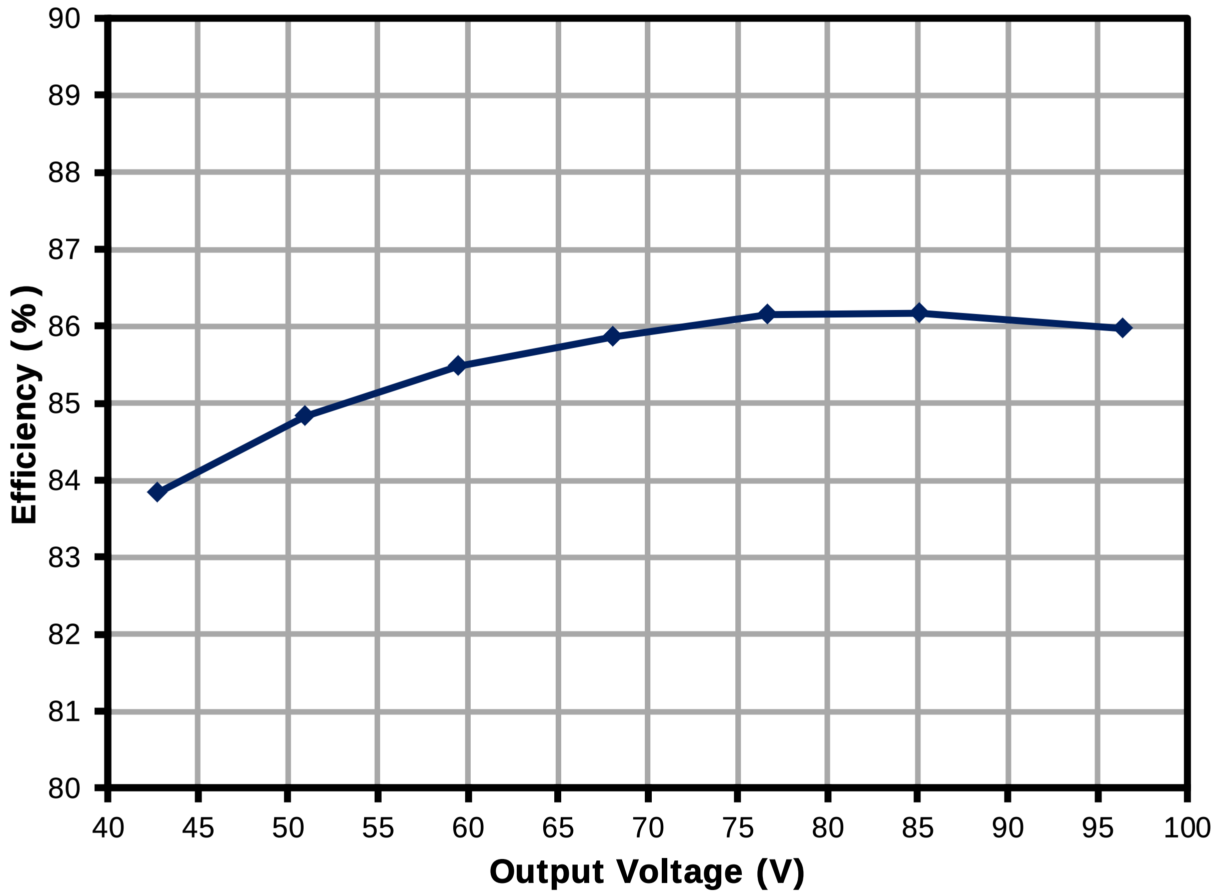

Figure 8 – Efficiency vs. LED Load Strings at 230 V.

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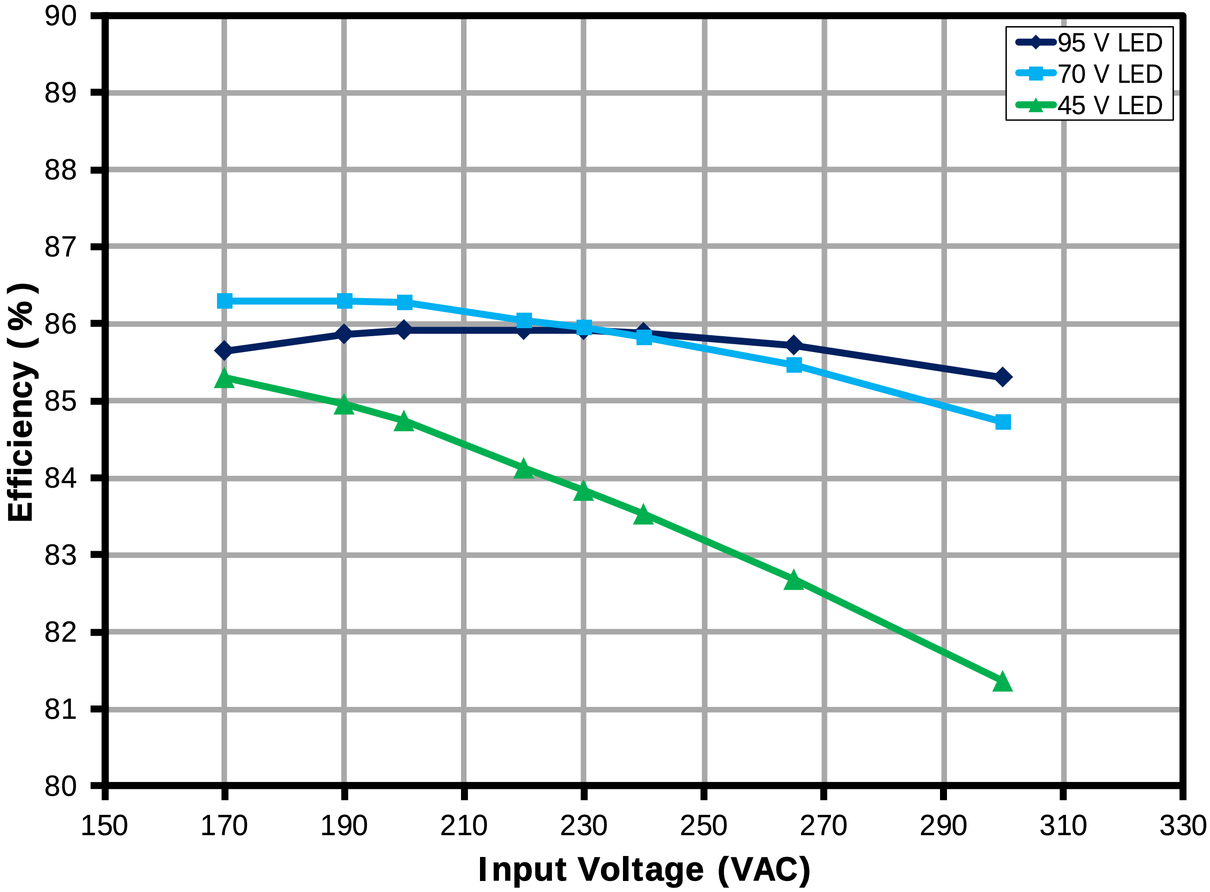

Figure 9 – Efficiency vs. Line and LED Load.

10.2 Line Regulation

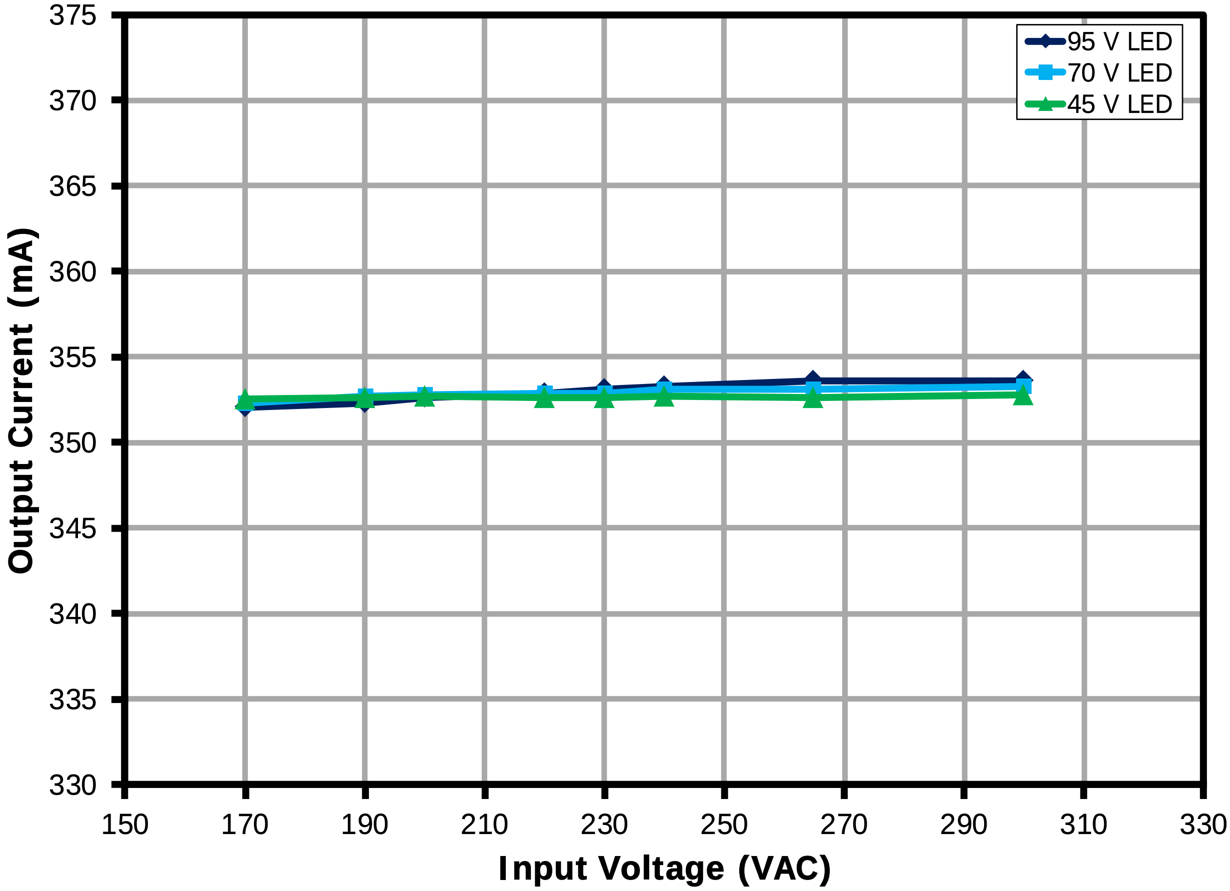

Figure 10 – Regulation vs. Line and LED Load.

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10.3 Output Voltage Regulation at No-Load

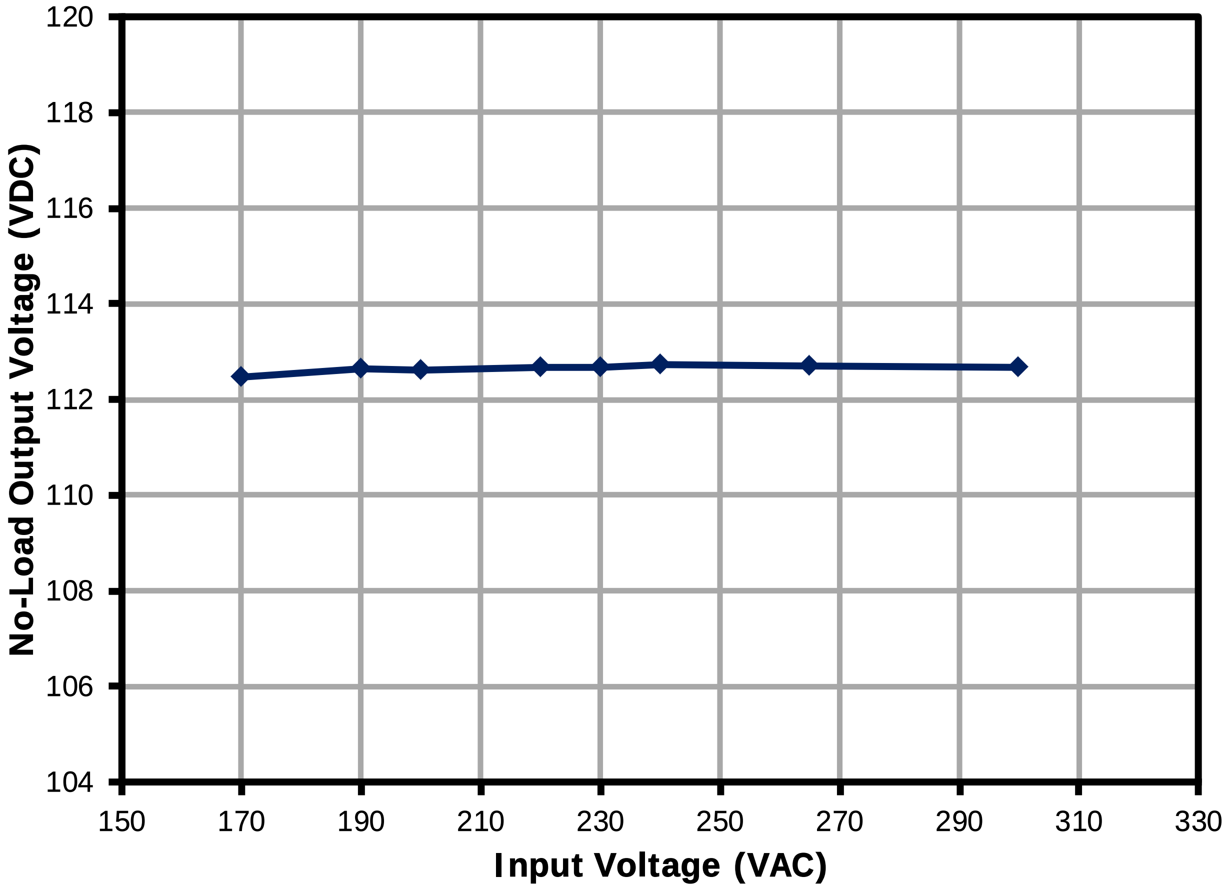

Figure 11 – Output Voltage Regulation (No-Load) vs. Line.

10.4 Power Factor

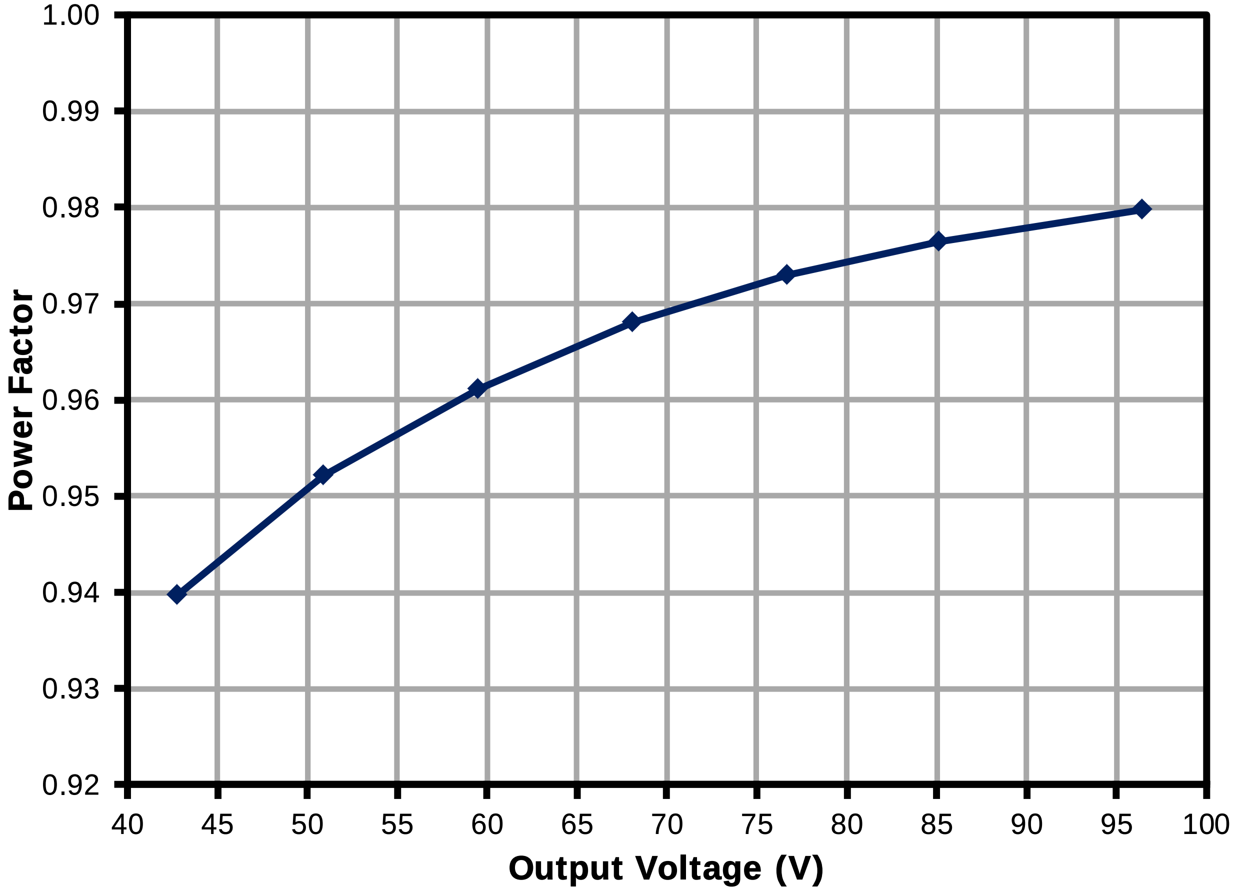

Figure 12 – Power Factor vs. LED Load at 230 V.

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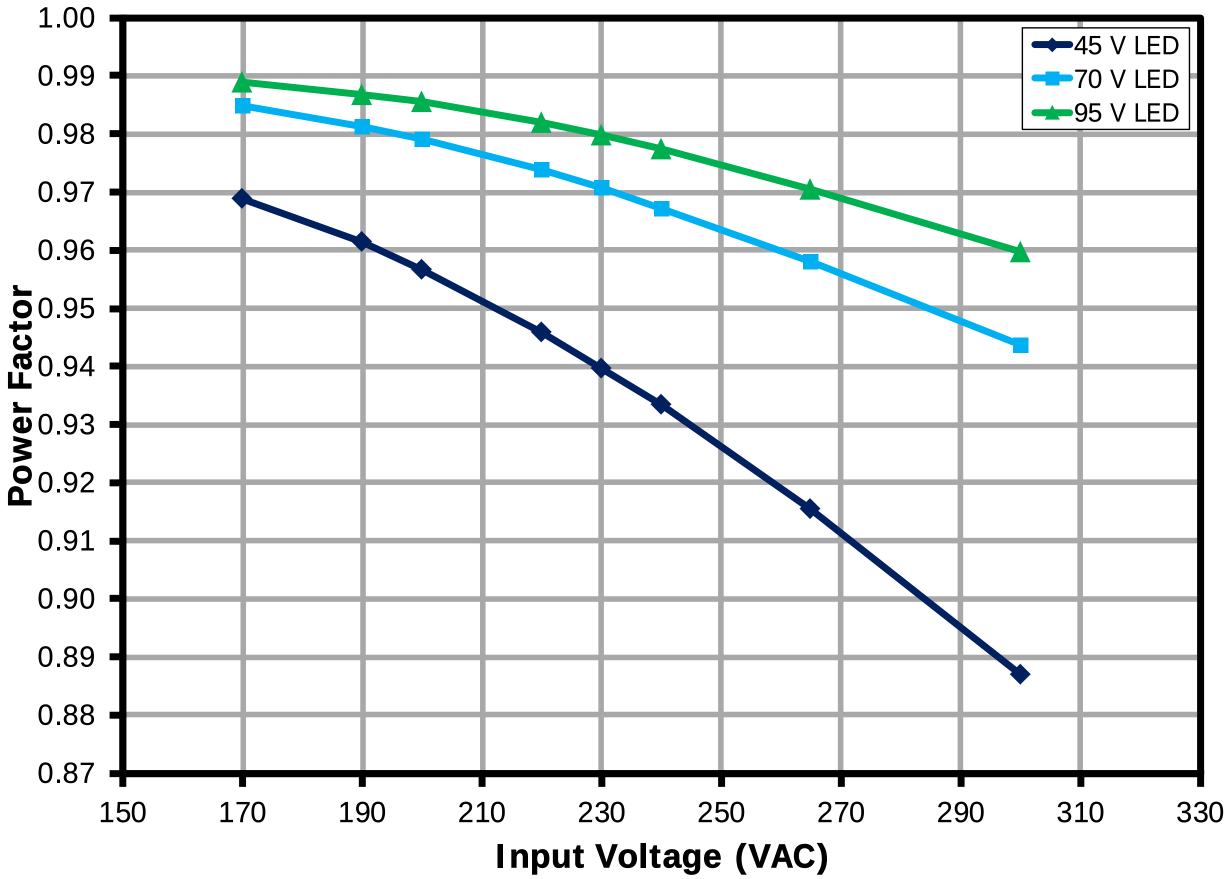

Figure 13 – Power Factor vs. Line and LED Load.

10.5 % ATHD

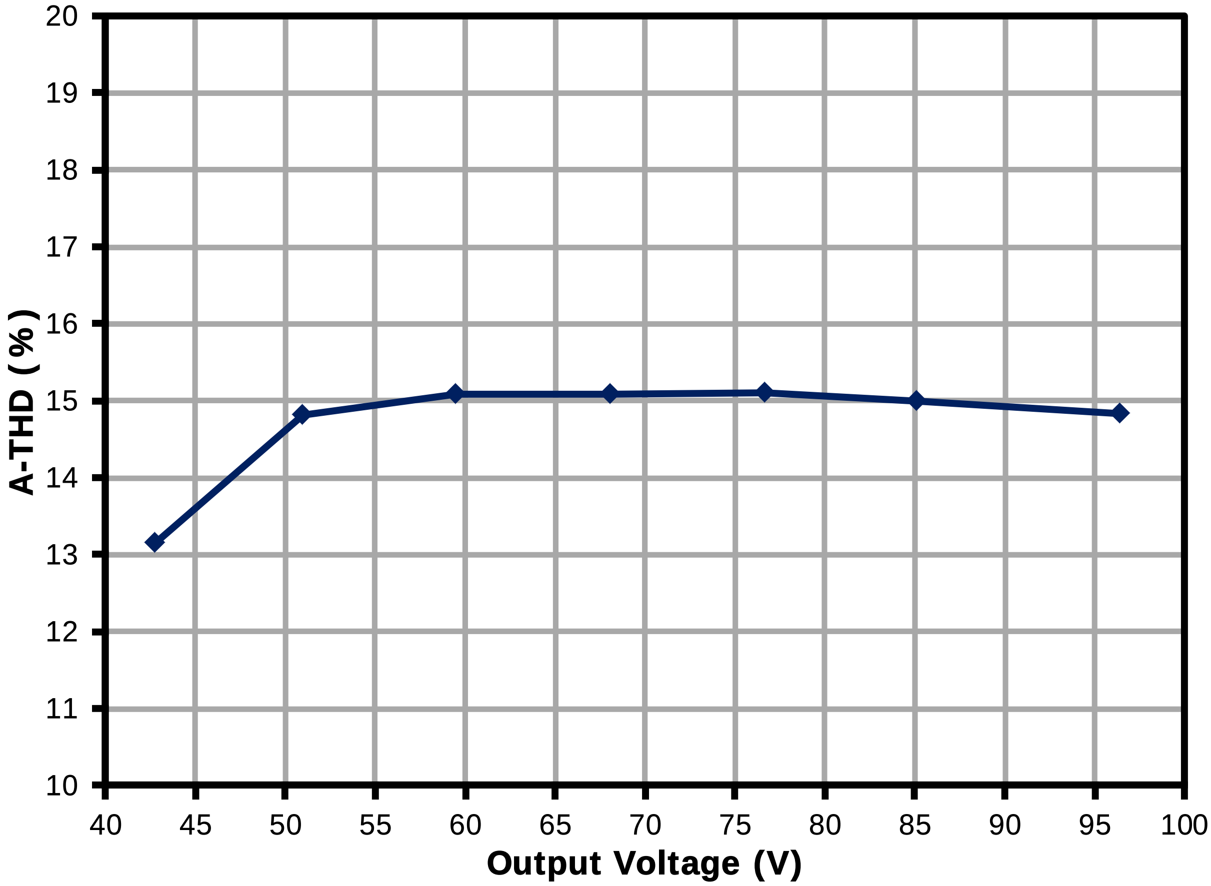

Figure 14 – %ATHD vs. LED Load at 230 V.

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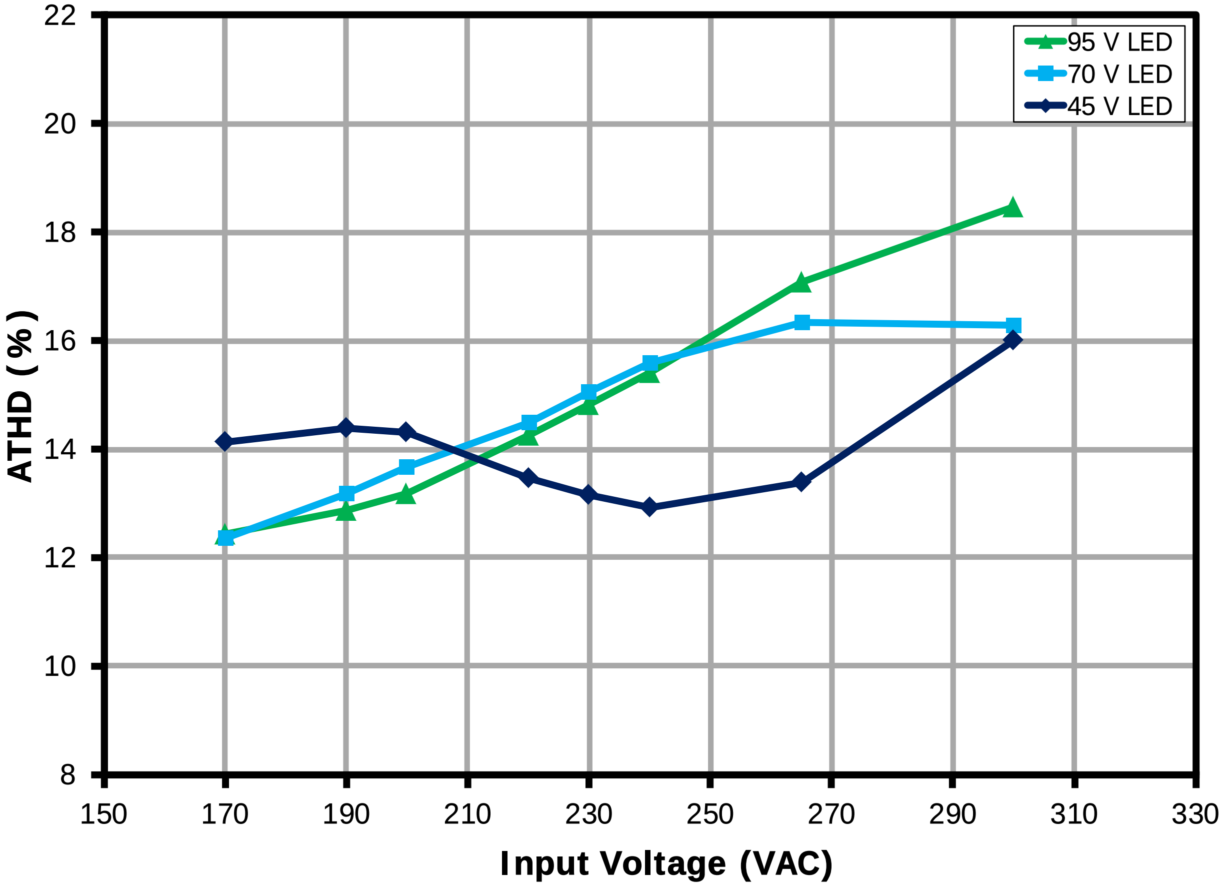

Figure 15 – %ATHD vs. Line and LED Load.

10.6 Harmonics

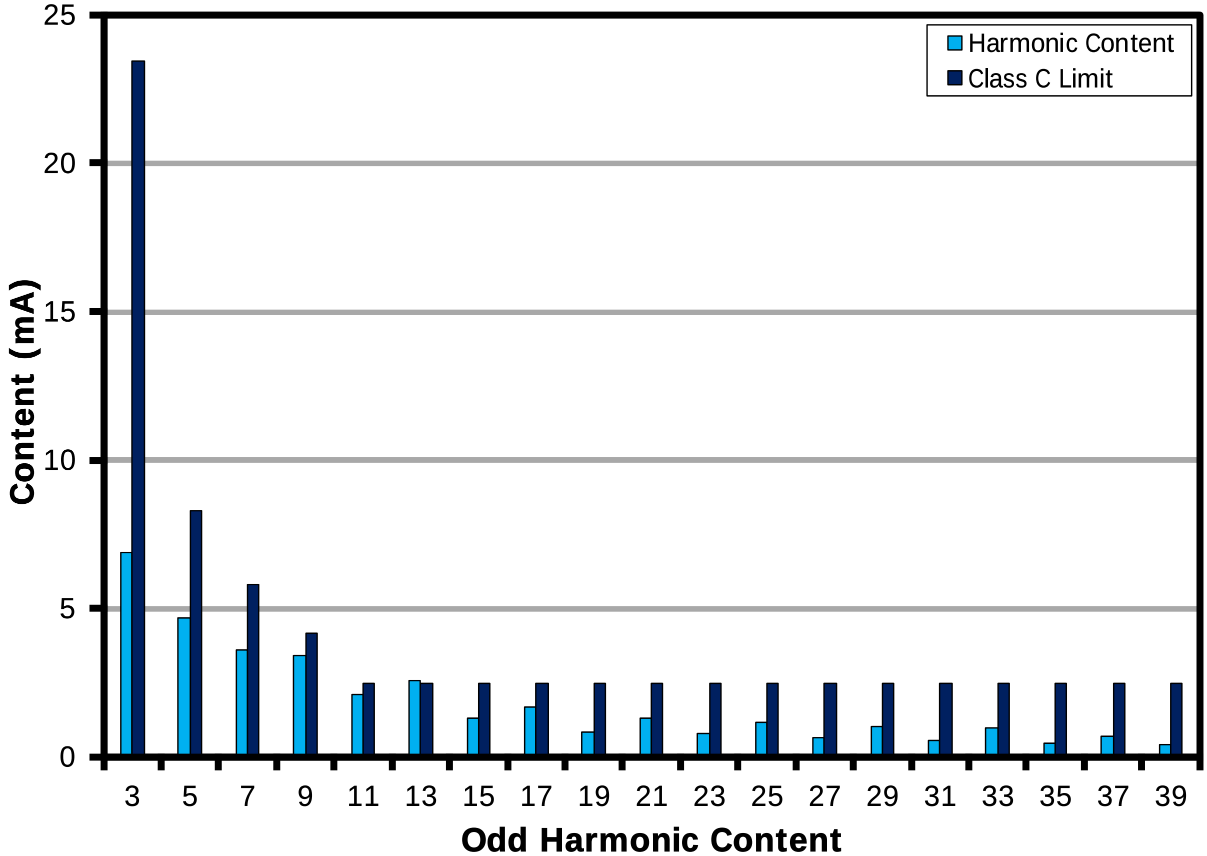

Figure 16 – 45 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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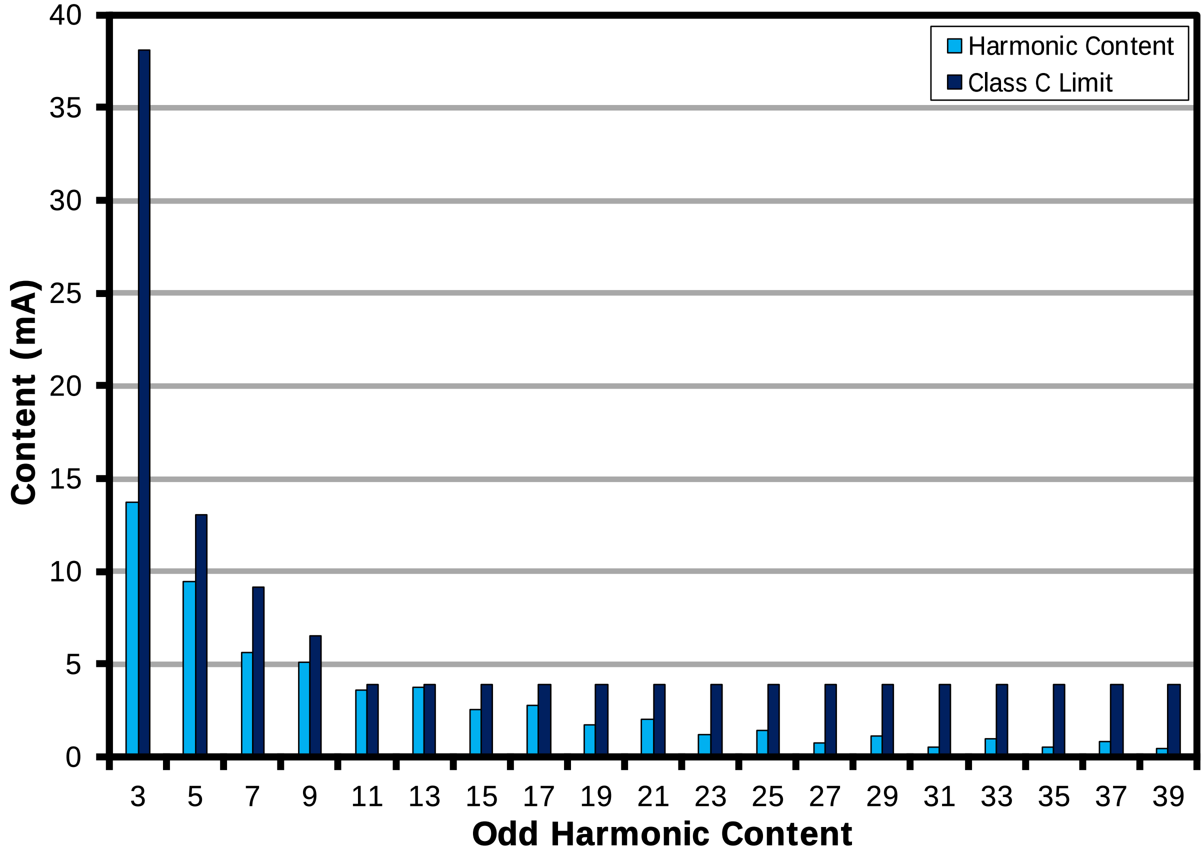

Figure 17 – 70 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

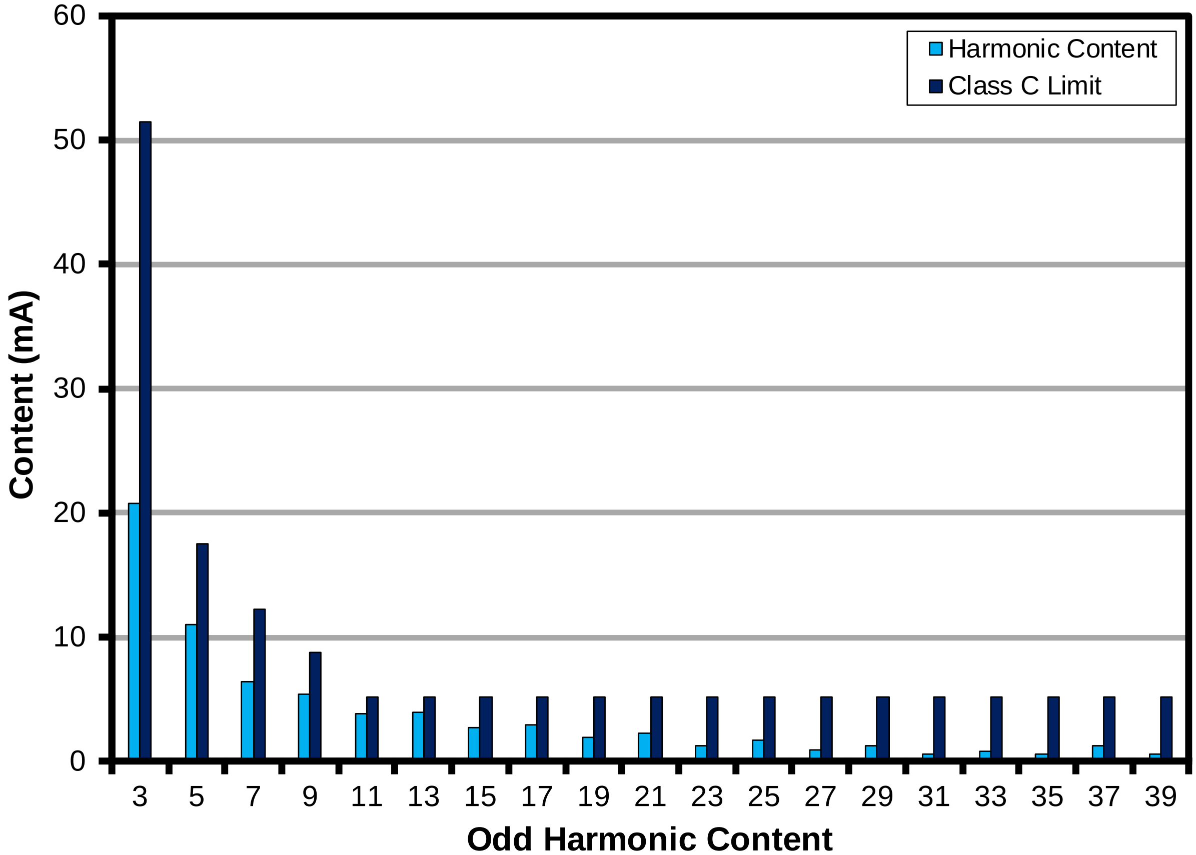

Figure 18 – 95 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10.7 0 V To 10 V Dimming Curve

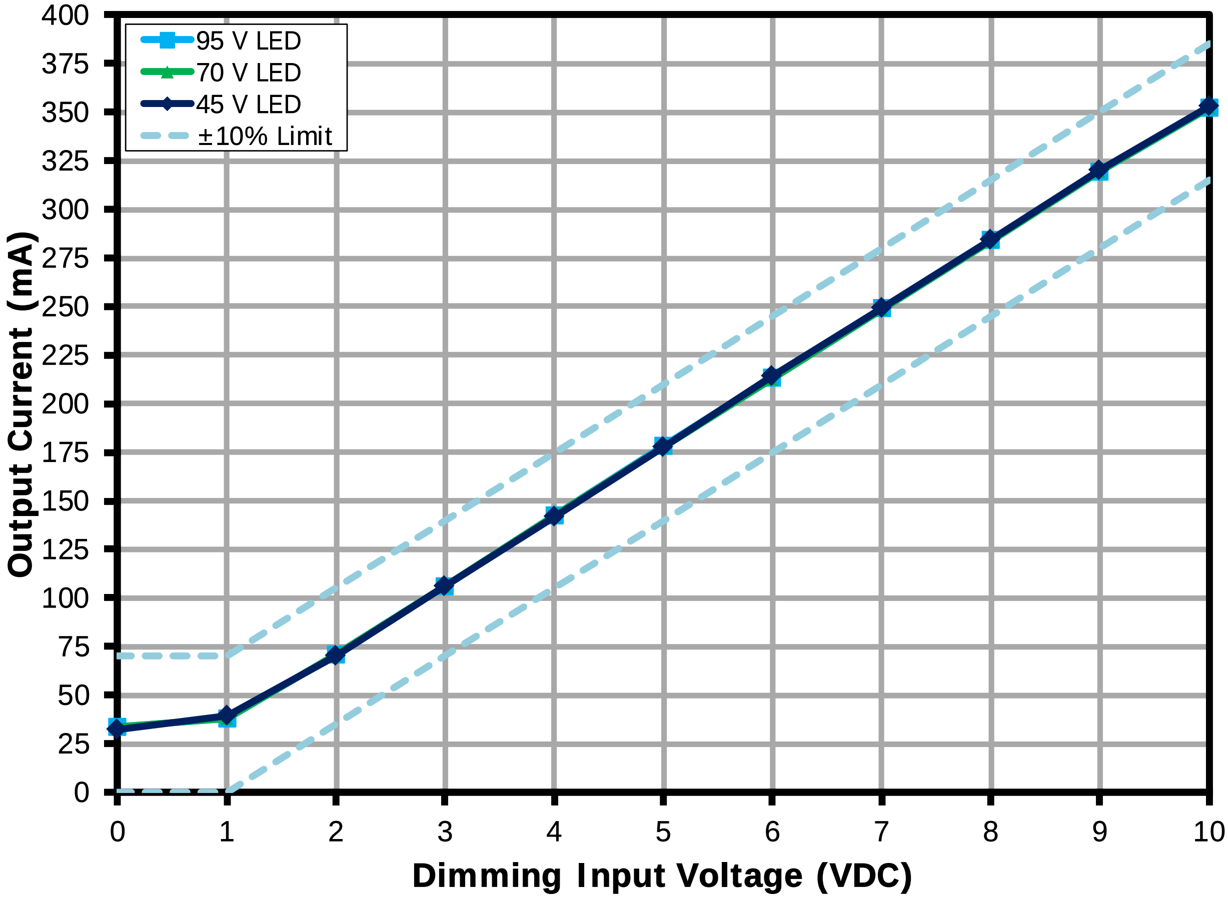

Figure 19 – Dimming Curve Characteristic at V_{IN} = 230 VAC, 50 Hz.

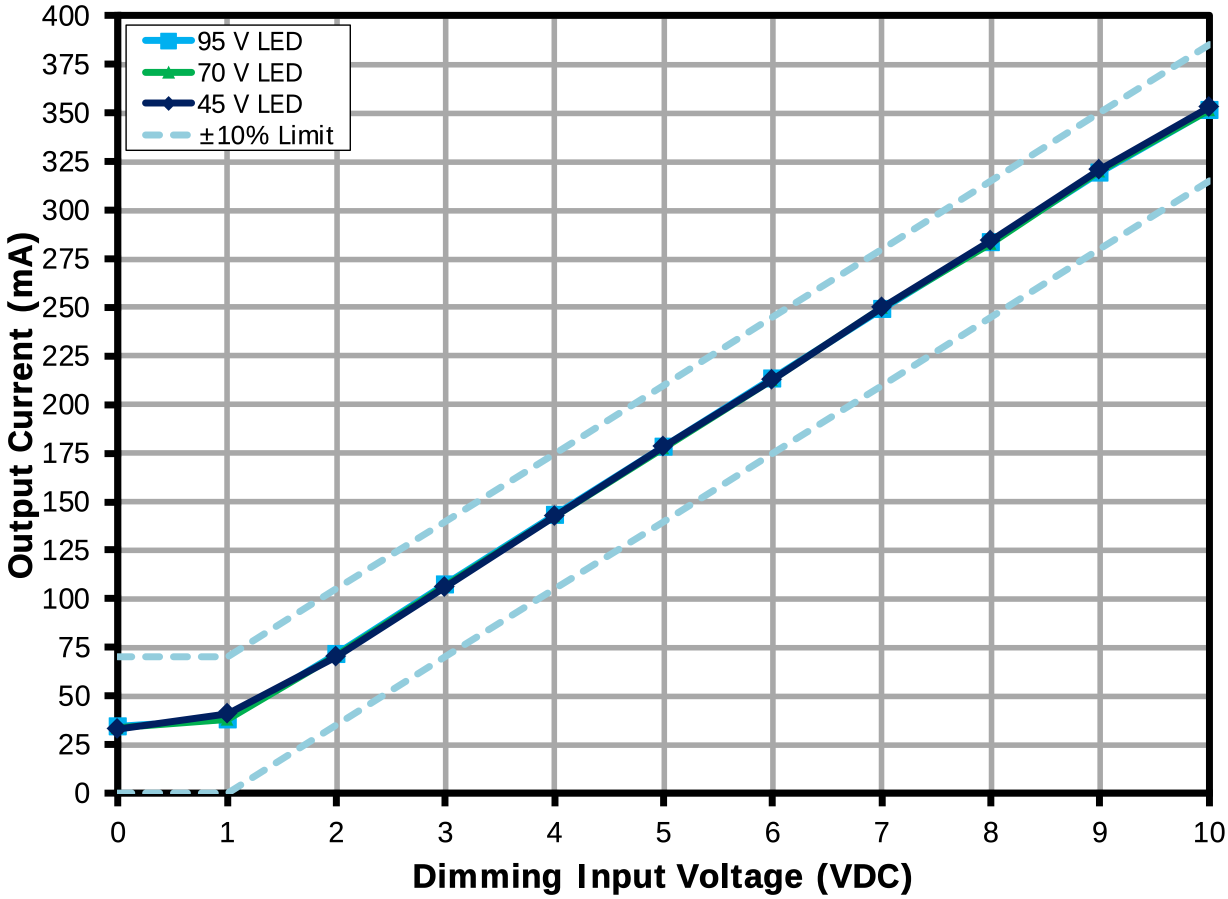

Figure 20 – Dimming Curve Characteristic at V_{IN} = 190 VAC, 50 Hz.

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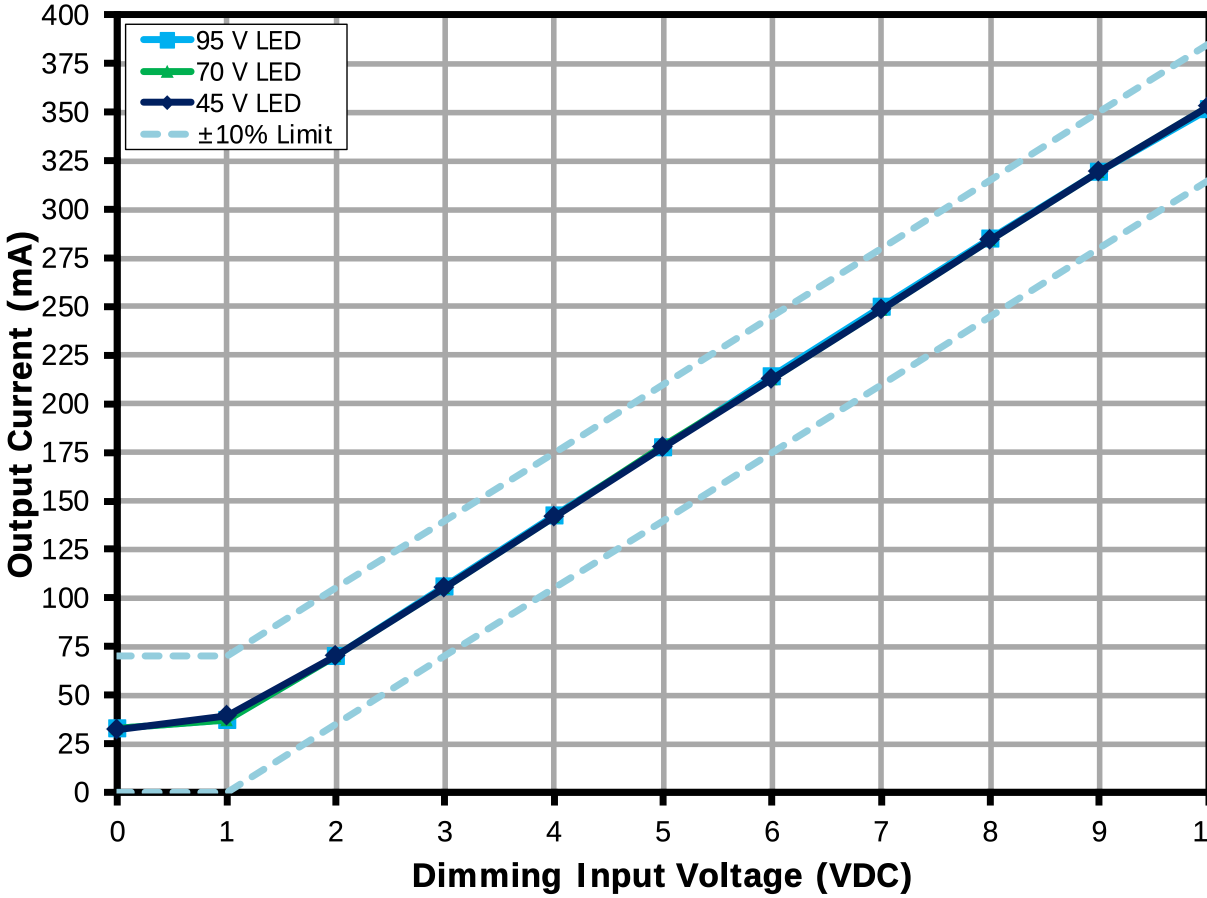

Figure 21 – Dimming Curve Characteristic at V_{IN} = 265 VAC, 50 Hz

10.8 Dimming Efficiency

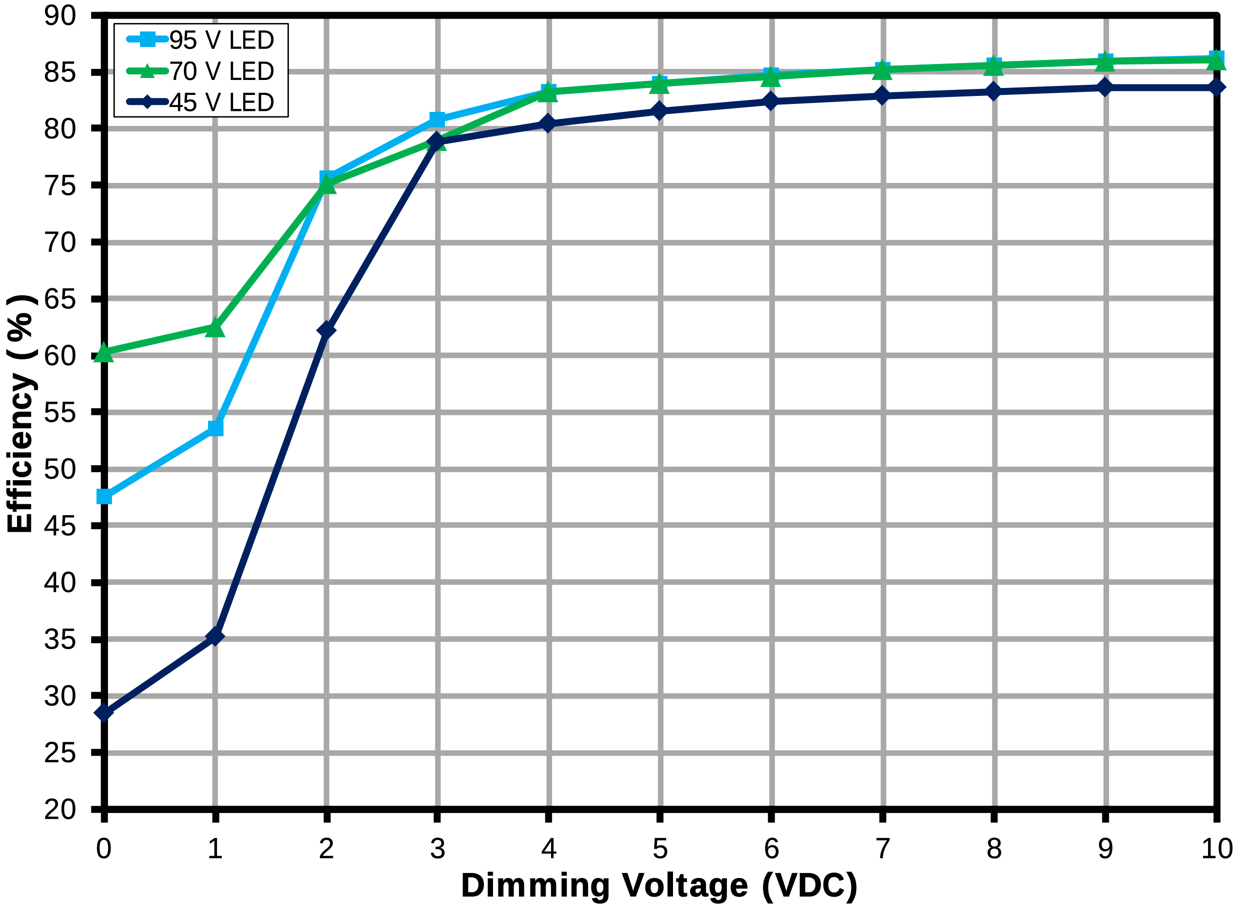

Figure 22 – Dimming Efficiency at V_{IN} = 230 VAC, 50 Hz

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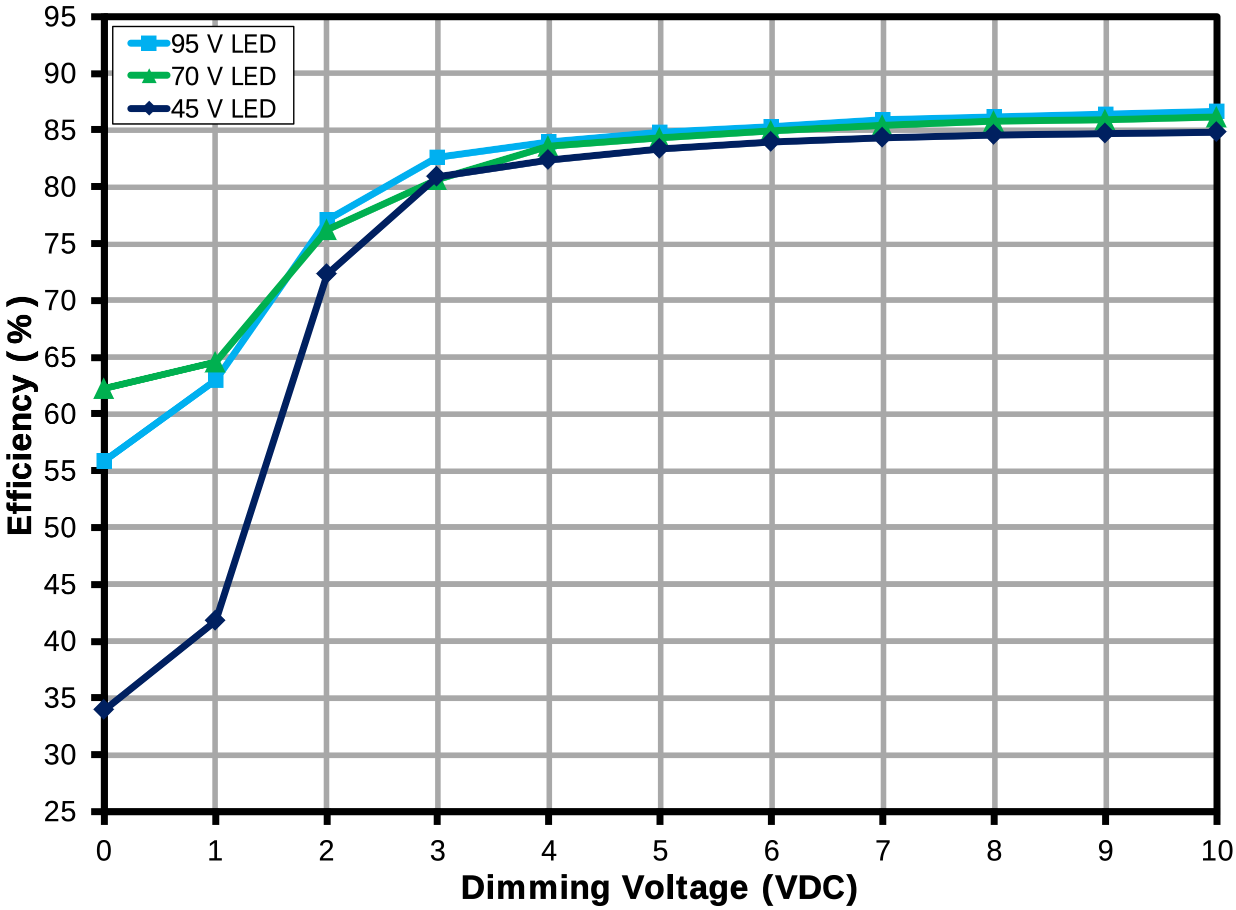

Figure 23 – Dimming Efficiency at V_{IN} = 190 VAC, 50 Hz.

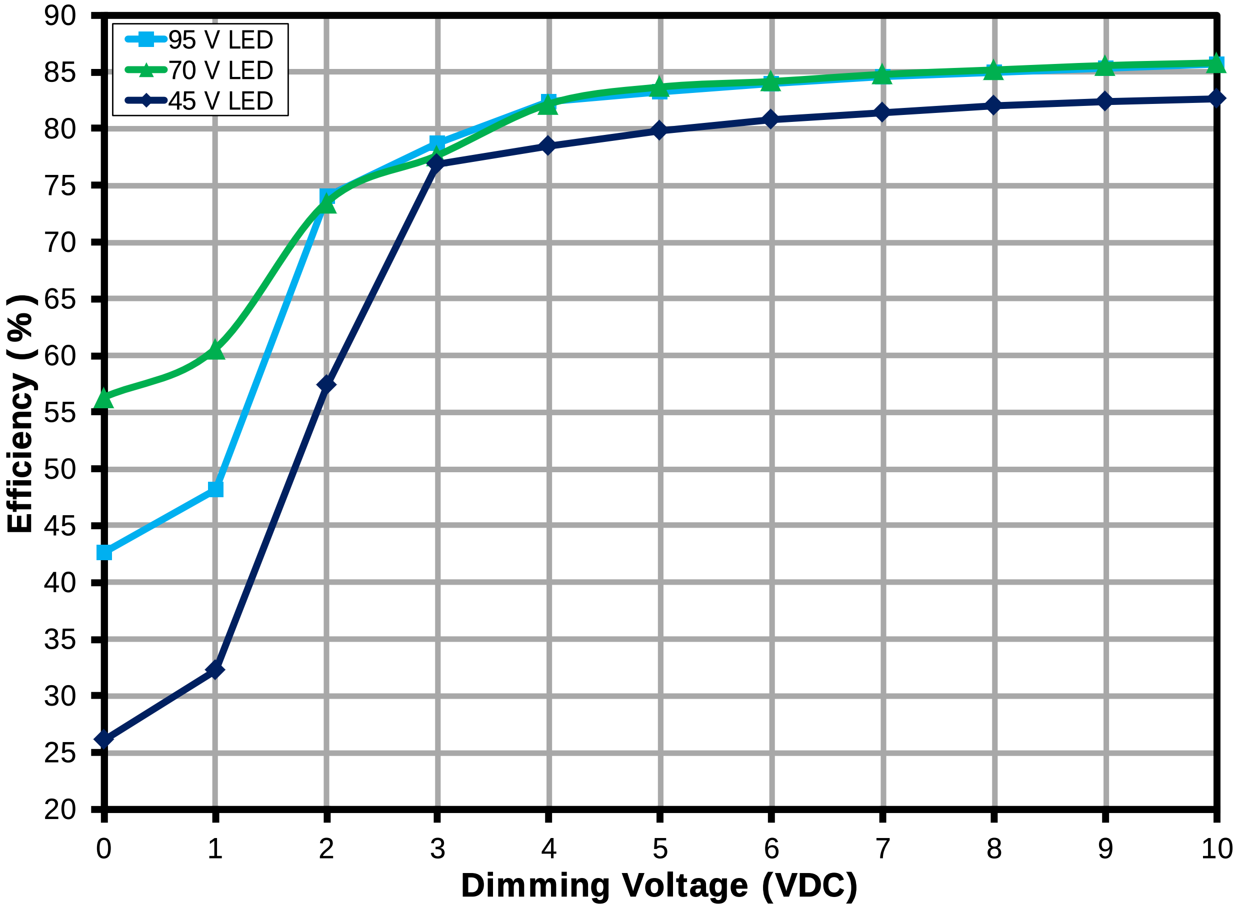

Figure 24 – Dimming Curve Efficiency at V_{IN} = 265 VAC, 50 Hz.

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11 Test Data

11.1 Test Data at 230 VAC, 50 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)	
230	50	230.0	84.1	18.2	0.94	13.2	42.8	353	15.2	83.8
230	50	230.0	97.6	21.4	0.95	14.8	51.0	353	18.1	84.8
230	50	229.9	112.0	24.8	0.96	15.1	59.5	353	21.2	85.5
230	50	229.9	126.4	28.1	0.97	15.1	68.1	353	24.2	85.9
230	50	229.9	141.1	31.6	0.97	15.1	76.7	353	27.2	86.2
230	50	229.9	155.9	35.0	0.98	15.0	85.1	353	30.2	86.2
230	50	229.9	175.8	39.6	0.98	14.8	96.4	352	34.1	86.0

11.2 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)	
170	50	169.9	108.6	17.9	0.97	14.1	42.9	353	15.3	85.3
190	50	189.9	98.3	17.9	0.96	14.4	42.8	353	15.2	85.0
200	50	199.9	94.0	18.0	0.96	14.3	42.8	353	15.2	84.8
220	50	219.9	87.0	18.1	0.95	13.5	42.8	353	15.2	84.1
230	50	230.0	84.1	18.2	0.94	13.2	42.8	353	15.2	83.8
240	50	240.0	81.4	18.2	0.93	12.9	42.8	353	15.2	83.5
265	50	265.0	75.9	18.4	0.92	13.4	42.7	353	15.2	82.7
300	50	300.0	70.4	18.7	0.89	16.0	42.7	353	15.2	81.4

11.3 Test Data, 70 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)	
170	50	170.0	175.1	29.3	0.99	12.4	71.5	352	25.3	86.3
190	50	189.9	157.4	29.3	0.98	13.2	71.5	353	25.3	86.3
200	50	199.9	150.3	29.4	0.98	13.7	71.6	353	25.4	86.3
220	50	220.0	137.7	29.5	0.97	14.5	71.6	353	25.4	86.0
230	50	230.0	132.0	29.5	0.97	15.1	71.5	353	25.3	86.0
240	50	240.0	127.1	29.5	0.97	15.6	71.4	353	25.3	85.8
265	50	265.0	116.7	29.6	0.96	16.3	71.4	353	25.3	85.5
300	50	300.0	105.7	29.9	0.94	16.3	71.5	353	25.4	84.7

11.4 Test Data, 95 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)	
170	50	170.0	237.1	39.8	0.99	12.4	96.7	352	34.1	85.6
190	50	189.9	212.1	39.7	0.99	12.9	96.6	352	34.1	85.9
200	50	199.9	201.5	39.7	0.99	13.2	96.5	353	34.1	85.9
220	50	220.0	184.1	39.8	0.98	14.3	96.5	353	34.2	85.9
230	50	230.0	176.5	39.8	0.98	14.8	96.5	353	34.2	85.9
240	50	240.0	169.7	39.8	0.98	15.4	96.5	353	34.2	85.9
265	50	265.0	155.1	39.9	0.97	17.1	96.5	354	34.2	85.7
300	50	300.0	139.2	40.1	0.96	18.5	96.5	354	34.2	85.3

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} (V_{DC})
170	50	169.99	20.68	0.49	112.48
190	50	189.93	19.00	0.52	112.65
200	50	199.95	17.72	0.53	112.61
220	50	219.99	15.83	0.53	112.68
230	50	230.00	15.76	0.57	112.68
240	50	240.02	15.63	0.60	112.73
265	50	265.04	14.40	0.58	112.69
300	50	299.98	14.34	0.70	112.67

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11.6 Test Data, Harmonic Content at 45 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	PF		%THD
230	50	84.00	0.940		13.064
nth Order	**mA Content**	**% Content**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	83.12				
2	0.03	0.04%	2.00%		
3	6.87	8.27%	28.20%	23.44	Pass
5	4.68	5.63%	10.00%	8.31	Pass
7	3.59	4.32%	7.00%	5.82	Pass
9	3.44	4.14%	5.00%	4.16	Pass
11	2.11	2.54%	3.00%	2.49	Pass
13	2.55	3.07%	3.00%	2.49	Pass
15	1.30	1.56%	3.00%	2.49	Pass
17	1.70	2.05%	3.00%	2.49	Pass
19	0.83	1.00%	3.00%	2.49	Pass
21	1.31	1.58%	3.00%	2.49	Pass
23	0.79	0.95%	3.00%	2.49	Pass
25	1.15	1.38%	3.00%	2.49	Pass
27	0.66	0.79%	3.00%	2.49	Pass
29	1.02	1.23%	3.00%	2.49	Pass
31	0.55	0.66%	3.00%	2.49	Pass
33	0.99	1.19%	3.00%	2.49	Pass
35	0.46	0.55%	3.00%	2.49	Pass
37	0.70	0.84%	3.00%	2.49	Pass
39	0.43	0.52%	3.00%	2.49	Pass

11.7 Test Data, Harmonic Content at 70 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF		%THD
230	50	132.35	29.539	0.971		15.073
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	130.78					
2	0.05	0.04%		2.00%		Pass
3	13.75	10.51%	100.43	29.12%	38.08	Pass
5	9.49	7.26%	56.12	10.00%	13.08	Pass
7	5.60	4.28%	29.54	7.00%	9.15	Pass
9	5.14	3.93%	14.77	5.00%	6.54	Pass
11	3.59	2.75%	10.34	3.00%	3.92	Pass
13	3.76	2.88%	8.75	3.00%	3.92	Pass
15	2.57	1.97%	7.58	3.00%	3.92	Pass
17	2.77	2.12%	6.69	3.00%	3.92	Pass
19	1.74	1.33%	5.99	3.00%	3.92	Pass
21	2.03	1.55%	5.42	3.00%	3.92	Pass
23	1.20	0.92%	4.94	3.00%	3.92	Pass
25	1.43	1.09%	4.55	3.00%	3.92	Pass
27	0.79	0.60%	4.21	3.00%	3.92	Pass
29	1.12	0.86%	3.92	3.00%	3.92	Pass
31	0.53	0.41%	3.67	3.00%	3.92	Pass
33	1.02	0.78%	3.45	3.00%	3.92	Pass
35	0.53	0.41%	3.25	3.00%	3.92	Pass
37	0.86	0.66%	3.07	3.00%	3.92	Pass
39	0.50	0.38%	2.92	3.00%	3.92	Pass

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11.8 Test Data, Harmonic Content at 95 V LED Load

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	PF		%THD
230	50	176.93	0.980		14.906
nth Order	**mA Content**	**% Content**	**% Limit >25 W**	**mA Limit >25 W**	**Remarks**
1	174.91				
2	0.04	0.02%	2.00%		Pass
3	20.72	11.85%	29.40%	51.42	Pass
5	11.08	6.33%	10.00%	17.49	Pass
7	6.45	3.69%	7.00%	12.24	Pass
9	5.47	3.13%	5.00%	8.75	Pass
11	3.85	2.20%	3.00%	5.25	Pass
13	3.95	2.26%	3.00%	5.25	Pass
15	2.72	1.56%	3.00%	5.25	Pass
17	2.96	1.69%	3.00%	5.25	Pass
19	1.93	1.10%	3.00%	5.25	Pass
21	2.24	1.28%	3.00%	5.25	Pass
23	1.34	0.77%	3.00%	5.25	Pass
25	1.71	0.98%	3.00%	5.25	Pass
27	1.00	0.57%	3.00%	5.25	Pass
29	1.31	0.75%	3.00%	5.25	Pass
31	0.66	0.38%	3.00%	5.25	Pass
33	0.88	0.50%	3.00%	5.25	Pass
35	0.57	0.33%	3.00%	5.25	Pass
37	1.24	0.71%	3.00%	5.25	Pass
39	0.58	0.33%	3.00%	5.25	Pass

11.9 Test Data, Dimming at V_{IN} = 190 VAC, 50 Hz

45 V LED LOAD									
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)		
189.9	98.0	17.9	0.96	14.3	42.6	353	15.2	84.9	10
189.9	89.3	16.2	0.95	13.0	42.4	321	13.7	84.8	9
189.9	79.7	14.3	0.94	12.6	42.2	284	12.1	84.6	8
189.9	70.1	12.5	0.94	11.8	41.9	250	10.5	84.3	7
189.9	60.3	10.7	0.93	11.9	41.8	213	9.0	84.0	6
189.9	51.3	8.9	0.92	13.6	41.5	178	7.5	83.3	5
189.9	42.2	7.2	0.89	16.6	41.2	142	5.9	82.3	4
189.9	33.3	5.4	0.85	21.5	40.8	106	4.3	80.9	3
189.9	26.2	3.9	0.79	28.5	40.4	70	2.8	72.3	2
189.9	26.0	3.9	0.78	28.1	39.9	41	1.6	41.8	1
189.9	26.0	3.9	0.78	28.8	39.7	33	1.3	33.9	0

70 V LED LOAD									
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)		
189.8	157.6	29.3	0.98	13.4	72.0	351	25.4	86.6	10
189.8	143.1	26.6	0.98	14.0	71.5	320	23.0	86.5	9
189.9	126.6	23.4	0.97	15.4	71.0	283	20.2	86.2	8
189.9	112.0	20.6	0.97	17.3	70.6	250	17.7	85.9	7
189.9	96.1	17.5	0.96	19.2	70.0	213	14.9	85.4	6
189.9	81.2	14.6	0.95	20.8	69.5	178	12.4	84.8	5
189.9	66.0	11.8	0.94	18.6	69.0	143	9.9	83.9	4
189.9	50.9	8.8	0.91	19.2	68.3	107	7.3	82.7	3
189.9	37.4	6.2	0.87	20.0	67.5	71	4.8	77.1	2
189.9	26.8	4.0	0.79	26.5	66.5	38	2.5	63.0	1
189.9	26.8	4.0	0.79	26.3	66.4	34	2.3	55.9	0

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95 V LED LOAD									
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)		
189.8	213.6	40.0	0.99	13.0	97.8	352	34.5	86.2	10
189.8	193.3	36.2	0.99	13.2	96.9	320	31.1	85.9	9
189.9	171.2	32.0	0.98	14.3	96.4	284	27.4	85.8	8
189.8	150.8	28.0	0.98	16.3	96.0	249	23.9	85.4	7
189.9	130.5	24.0	0.97	19.6	95.4	214	20.4	84.9	6
189.9	110.2	20.1	0.96	22.8	94.9	178	16.9	84.3	5
189.9	89.5	16.1	0.95	24.6	94.1	143	13.5	83.6	4
189.9	69.4	12.4	0.94	20.5	93.3	107	10.0	80.6	3
189.9	50.0	8.6	0.91	21.3	92.1	72	6.6	76.2	2
189.9	33.4	5.4	0.85	19.7	91.0	38	3.5	64.6	1
189.9	31.6	5.0	0.83	21.4	90.8	34	3.1	62.3	0

11.10 Test Data, Dimming at V_{IN} = 230 VAC, 50 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)		
230.0	83.6	18.1	0.94	12.9	42.4	353	15.1	83.7	10
230.0	76.4	16.3	0.93	13.0	42.2	320	13.6	83.6	9
230.0	68.4	14.5	0.92	13.2	42.0	284	12.0	83.2	8
230.0	60.6	12.7	0.91	13.8	41.8	249	10.5	82.9	7
230.0	53.1	10.9	0.89	15.6	41.7	214	9.0	82.4	6
230.0	45.4	9.1	0.87	18.4	41.4	178	7.4	81.6	5
230.0	38.0	7.3	0.83	22.7	41.1	142	5.9	80.4	4
230.0	30.8	5.5	0.78	29.3	40.8	106	4.3	78.9	3
230.0	26.8	4.5	0.74	34.3	40.3	70	2.8	62.1	2
230.0	26.5	4.5	0.74	34.4	39.8	40	1.6	35.2	1
230.0	26.5	4.5	0.73	34.4	39.6	32	1.3	28.5	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)		
229.9	132.0	29.4	0.97	15.1	71.6	353	25.4	86.2	10
229.9	119.6	26.6	0.97	16.2	71.1	319	22.8	85.9	9
229.9	106.7	23.5	0.96	17.3	70.7	284	20.1	85.6	8
230.0	93.9	20.5	0.95	18.2	70.2	248	17.5	85.2	7
230.0	81.5	17.6	0.94	19.4	69.9	213	14.9	84.7	6
230.0	69.3	14.7	0.92	20.6	69.4	178	12.4	84.0	5
230.0	57.3	11.8	0.90	20.3	68.8	143	9.8	83.3	4
230.0	45.1	9.0	0.87	20.4	68.1	106	7.3	80.8	3
230.0	34.2	6.3	0.81	26.3	67.4	71	4.8	75.6	2
230.0	27.3	4.7	0.75	33.0	66.4	38	2.5	53.6	1
230.0	27.2	4.7	0.75	33.0	66.2	34	2.2	47.5	0

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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)		
230.0	177.1	39.9	0.98	15.0	97.4	352	34.4	86.1	10
229.9	160.9	36.1	0.98	16.1	96.9	320	31.0	85.9	9
229.9	143.8	32.1	0.97	18.1	96.4	284	27.5	85.6	8
229.9	126.7	28.1	0.96	20.3	95.8	249	23.9	85.3	7
229.9	109.6	24.0	0.95	22.0	95.2	214	20.4	84.7	6
230.0	92.5	20.1	0.94	23.4	94.3	178	16.8	84.0	5
230.0	75.7	16.2	0.93	23.1	94.3	143	13.5	83.3	4
230.0	60.0	12.5	0.91	22.0	93.1	106	9.9	79.0	3
230.0	44.1	8.7	0.86	22.5	92.5	71	6.6	75.2	2
230.0	30.8	5.5	0.78	28.7	90.4	38	3.4	62.5	1
230.0	29.4	5.1	0.76	30.5	90.7	34	3.1	60.3	0

11.11 Test Data, Dimming at V_{IN} = 265 VAC, 50 Hz

45 V LED LOAD									
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)		
265.0	75.7	18.4	0.92	13.4	42.5	353	15.2	82.6	10
265.0	69.3	16.6	0.90	14.4	42.3	319	13.6	82.4	9
265.0	62.4	14.7	0.89	15.5	42.1	284	12.1	82.0	8
265.0	55.5	12.9	0.88	17.6	41.9	249	10.5	81.5	7
265.0	48.8	11.1	0.86	20.3	41.8	213	8.9	80.8	6
265.0	42.4	9.3	0.83	23.6	41.5	178	7.4	79.8	5
265.0	36.0	7.5	0.78	28.6	41.2	142	5.9	78.4	4
265.0	29.4	5.6	0.72	36.0	41.0	105	4.3	76.9	3
265.0	26.5	4.9	0.70	39.6	40.5	70	2.8	57.4	2
265.0	26.4	4.9	0.70	40.0	40.0	40	1.6	32.3	1
265.0	26.5	4.9	0.70	39.7	39.8	32	1.3	26.1	0

70 V LED LOAD									
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)		
265.0	117.2	29.8	0.96	16.4	72.0	353	26	85.7	10
265.0	106.5	26.8	0.95	16.9	71.5	319	23	85.4	9
265.0	95.3	23.8	0.94	17.6	71.0	284	20	85.0	8
265.0	84.3	20.8	0.93	18.4	70.6	248	18	84.6	7
265.0	73.5	17.8	0.92	19.3	70.1	213	15	83.9	6
265.0	63.3	15.0	0.89	21.1	69.6	179	12	83.2	5
265.0	52.4	11.9	0.86	21.6	69.0	142	10	82.4	4
265.0	42.2	9.2	0.82	24.2	68.3	106	7	78.7	3
265.0	32.3	6.4	0.75	33.0	67.5	70	5	74.1	2
265.0	27.3	5.2	0.72	38.1	66.5	37	2	48.1	1
265.0	27.3	5.2	0.72	38.6	66.4	33	2	42.6	0

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95 V LED LOAD									
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)**		
265.0	156.4	40.2	0.97	17.4	97.8	352	34.5	85.8	10
264.9	142.2	36.4	0.97	18.6	97.1	320	31.1	85.6	9
264.9	127.2	32.3	0.96	20.0	96.5	285	27.5	85.2	8
265.0	112.4	28.3	0.95	21.1	95.9	250	24.0	84.8	7
265.0	97.8	24.3	0.94	22.2	95.5	214	20.5	84.2	6
265.0	82.3	20.2	0.92	22.9	94.9	178	16.9	83.7	5
265.0	68.5	16.4	0.90	23.3	94.2	143	13.5	82.2	4
265.0	55.5	12.8	0.87	21.8	93.5	106	9.9	77.7	3
265.0	40.6	8.7	0.81	25.5	91.9	70	6.4	73.5	2
265.0	29.2	5.6	0.73	35.8	90.4	38	3.4	60.6	1
265.0	28.2	5.3	0.71	37.5	90.2	33	3.0	56.3	0

12 Thermal Performance

Thermal measurements were performed with the power supply operating at room temperature (25 ºC) with a 95 V LED load. Steady-state conditions were achieved after operating 1 hour.

12.1 Thermal Performance at 300 VAC with a 95 V LED Load.

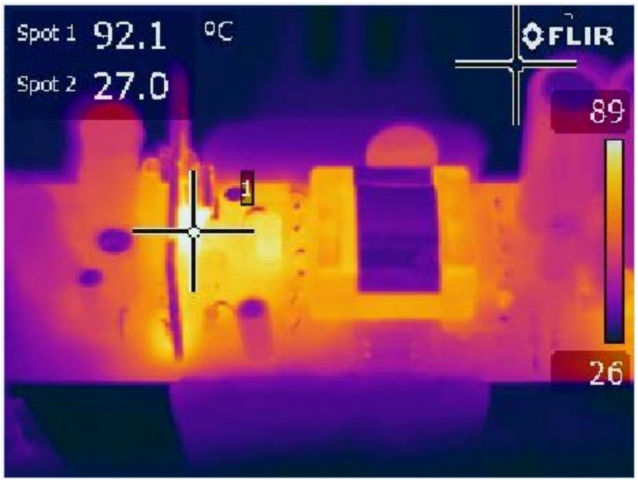

Figure 25 – 300 V VAC, Full load
Spot 1: LYT4325E (U1): 92.1 ^{o}C.

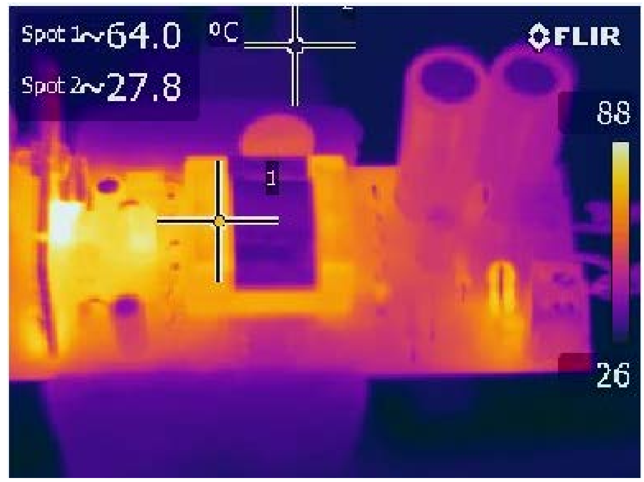

Figure 26 – 300 V VAC, Full Load.
Spot 1: Transformer (T1): 64 ^{o}C.

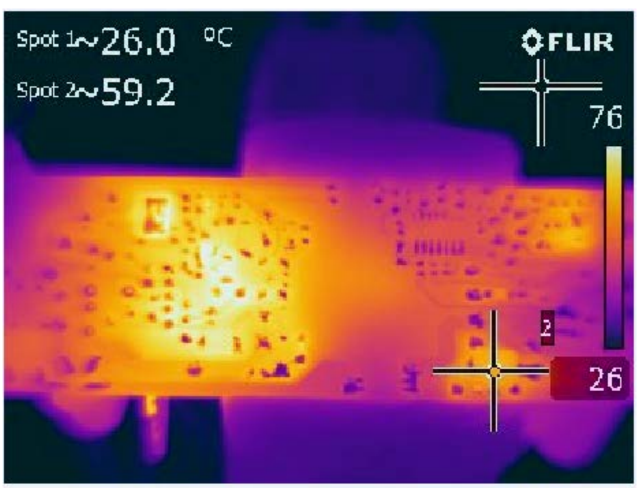

Figure 27 – 300 V VAC, Full Load.
Spot 2: Output Diode (D16): 59.2 ^{o}C.

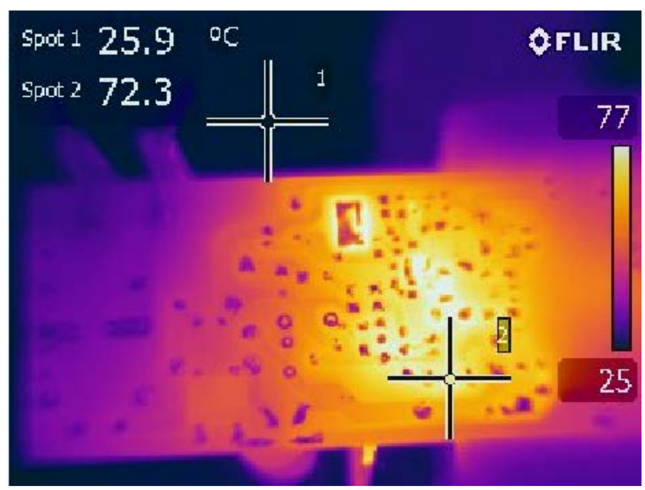

Figure 28 – 300 V VAC, Full Load.
Spot 2: Blocking Diode (D7): 72.3 ^{o}C.

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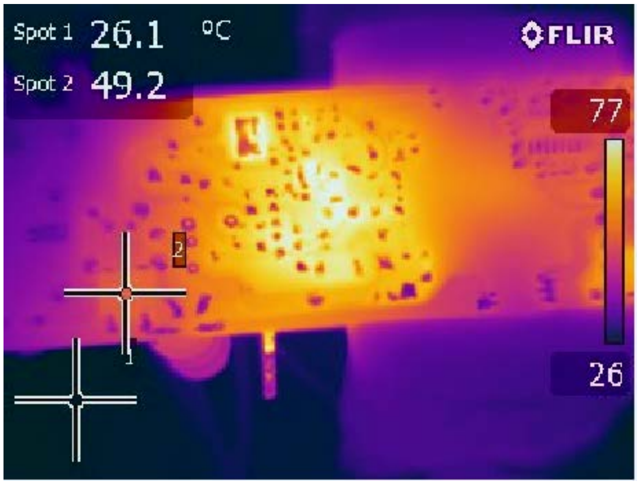

Figure 29 – 300 V VAC, Full Load.
Spot 2: Bridge Diode (BR1): 49.2 ^{o}C.

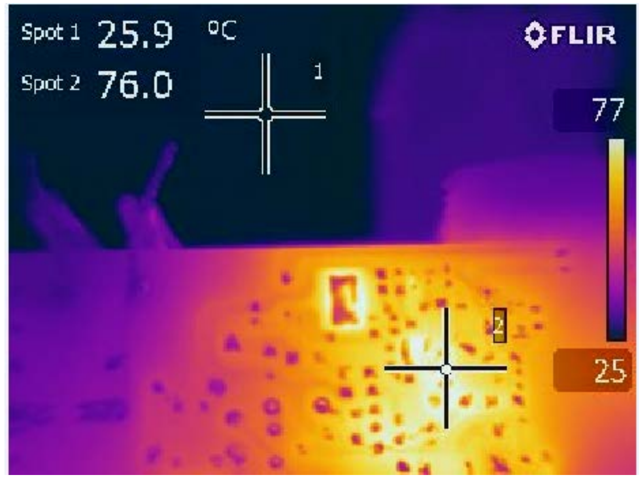

Figure 30 – 300 V VAC, Full Load.
Spot 2: Blocking Diode (D8) : 76 ^{o}C.

12.2 Thermal Performance at 230 VAC with a 95 V LED Load

Figure 31 – 230 V VAC, Full Load.
Spot 1: LYT4325E (U1): 85 ºC.

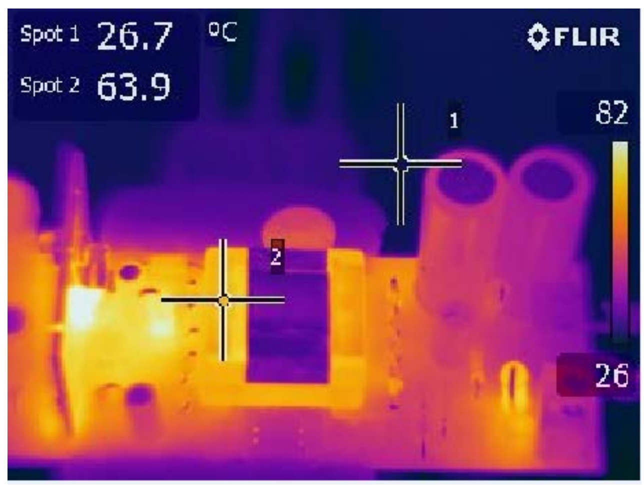

Figure 32 – 230 V VAC, Full Load.
Spot 2: Transformer (T1): 63.9 ºC.

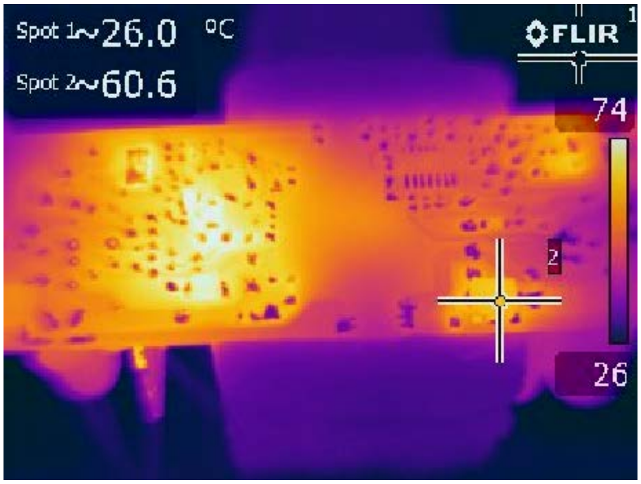

Figure 33 – 230 V VAC, Full Load.
Spot 2: Output Diode (D16): 60.6 °C.

Figure 34 – 230 V VAC, Full Load.
Spot 2: Blocking Diode (D7): 72.7 °C.

Figure 35 – 230 V VAC, Full Load.
Spot 2: Bridge Diode (BR1): 51.9 °C.

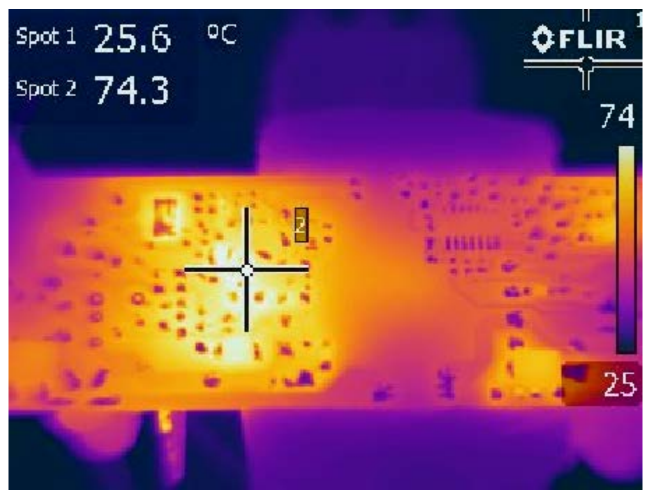

Figure 36 – 230 V VAC, Full Load.
Spot 2: Blocking Diode (D8): 74.3 °C.

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12.3 Thermal Performance at 170 VAC with a 95 V LED Load

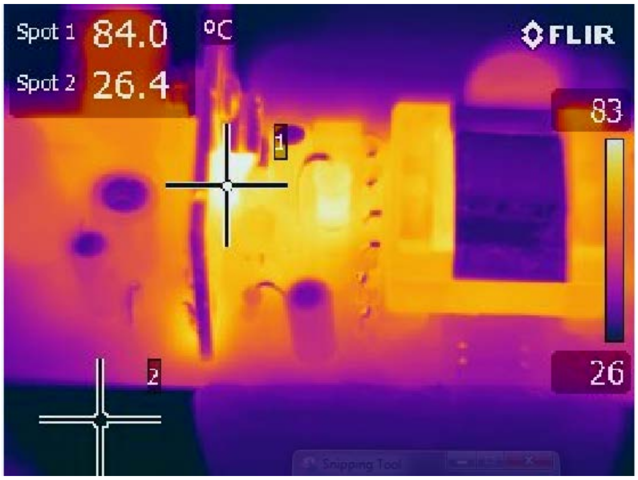

Figure 37 – 170 V VAC, Full Load.
Spot 1: LYT4325E (U1): 84 °C.

Figure 38 – 170 V VAC, Full Load.
Spot 1: Transformer (T1): 70 °C.

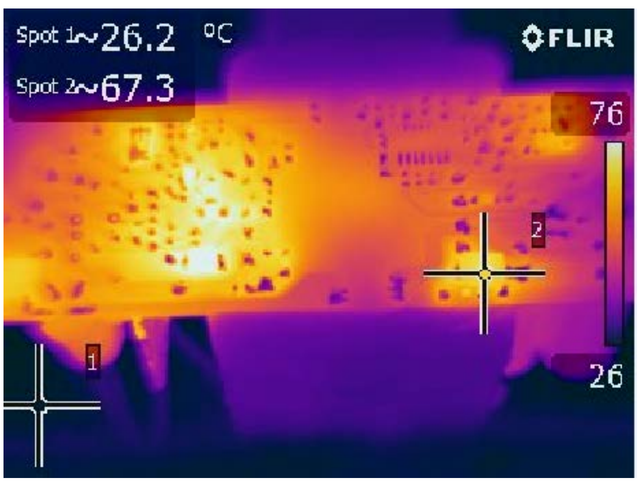

Figure 39 – 170 V VAC, Full Load.
Spot 2: Output Diode (D16): 67.3 °C.

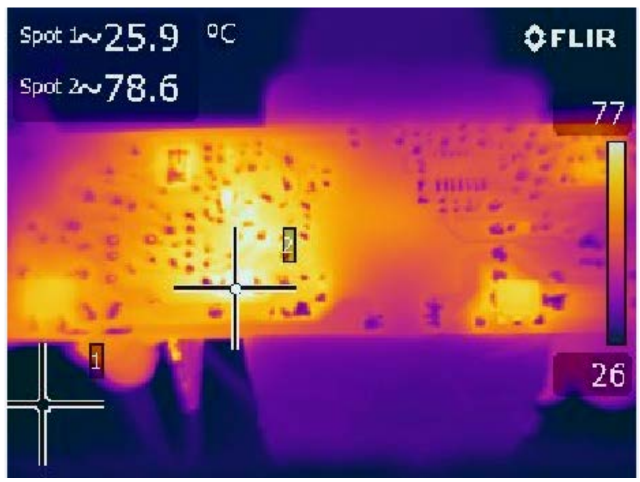

Figure 40 – 170 V VAC, Full Load.
Spot 2: Blocking Diode (D7): 78.6 °C.

Figure 41 – 170 V VAC, Full Load.
Spot 2: Blocking Diode (D8): 73.5 °C.

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13 Waveforms

13.1 Input Voltage and Input Current Waveforms

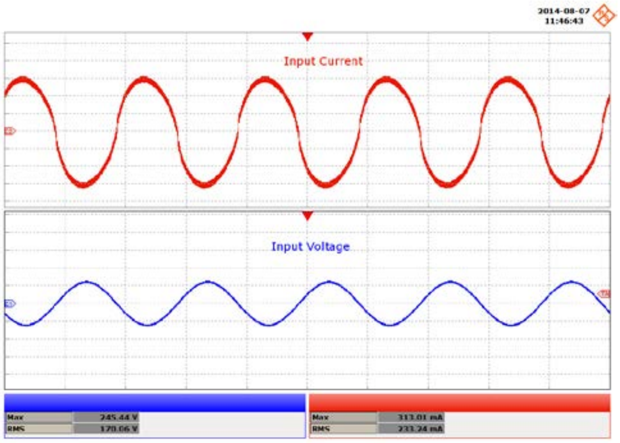

Figure 42 – 170 VAC, 95 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 313.01 mA.
Peak V_{IN}: 245.44 V.

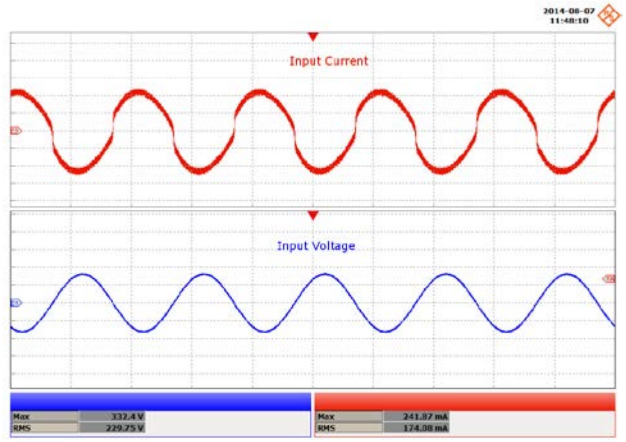

Figure 43 – 230 VAC, 95 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.
Peak I_{IN}: 241.87 mA.
Peak V_{IN}: 332.4 V.

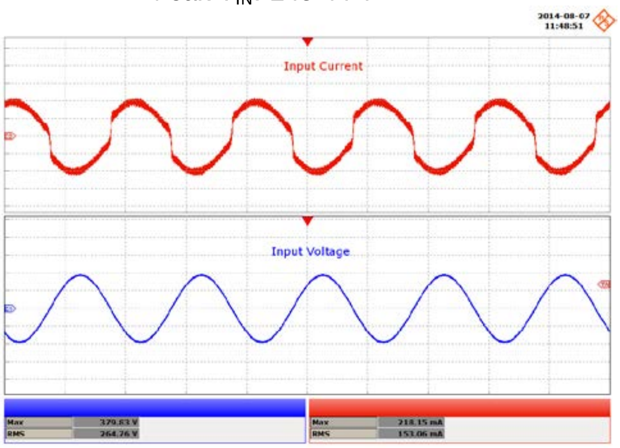

Figure 44 – 265 VAC, 95 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 218.15 mA.
Peak V_{IN}: 379.83 V.

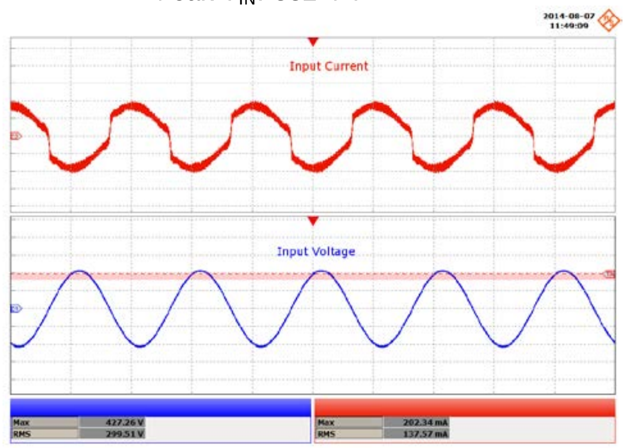

Figure 45 – 300 VAC, 95 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 202.34 mA.
Peak V_{IN}: 427.26 V.

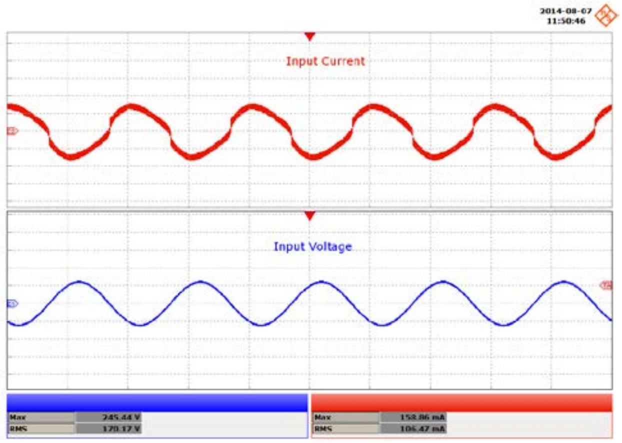

Figure 46 – 170 VAC, 45 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 158.86 mA.
Peak V_{IN}: 245.44 V.

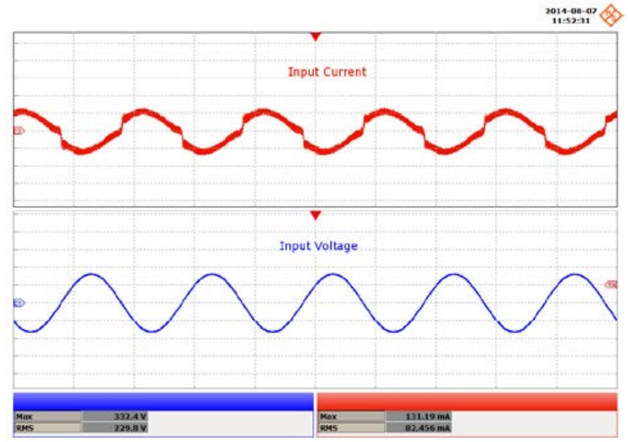

Figure 47 – 230 VAC, 45 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 131.19 mA.
Peak V_{IN}: 332.4 V.

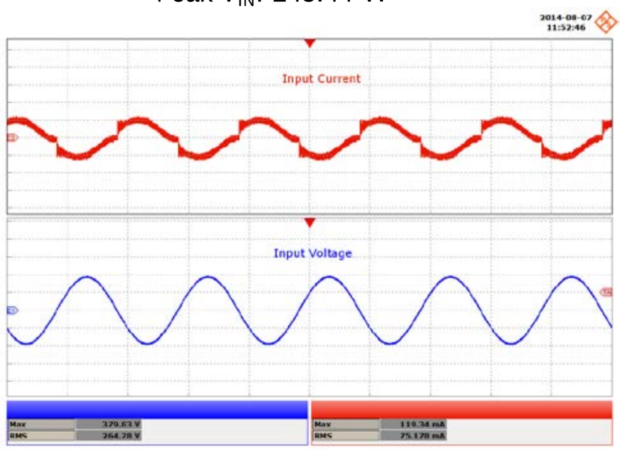

Figure 48 – 265 VAC, 45 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 119.34 mA.
Peak V_{IN}: 379.83 V.

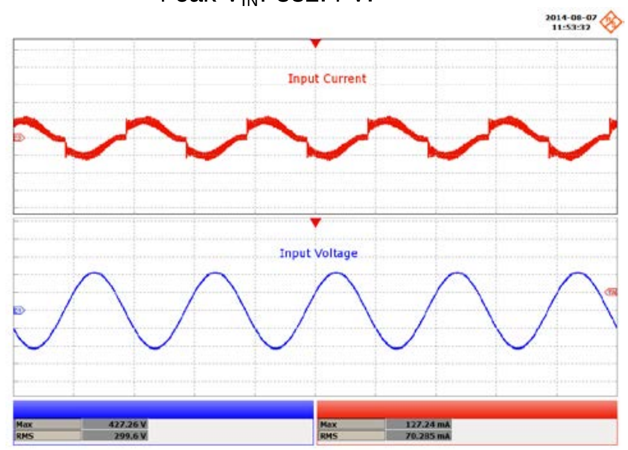

Figure 49 – 300 VAC, 45 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.
Peak I_{IN}: 127.24 mA.
Peak V_{IN}: 427.26 V.

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13.2 Output Current Rise and Fall

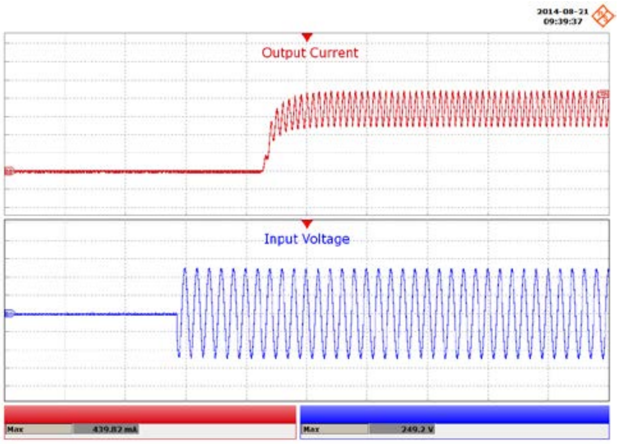

Figure 50 – 170 VAC, 95 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 439.82 mA.
Peak V_{IN}: 249.20 V.

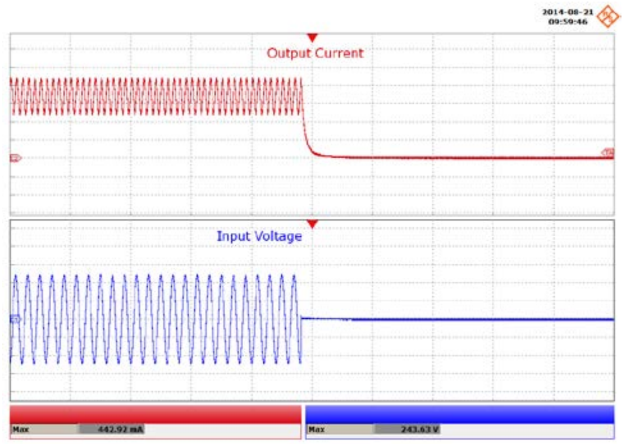

Figure 51 – 170 VAC, 95 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 442.92 mA.
Peak V_{IN}: 243.63 V.

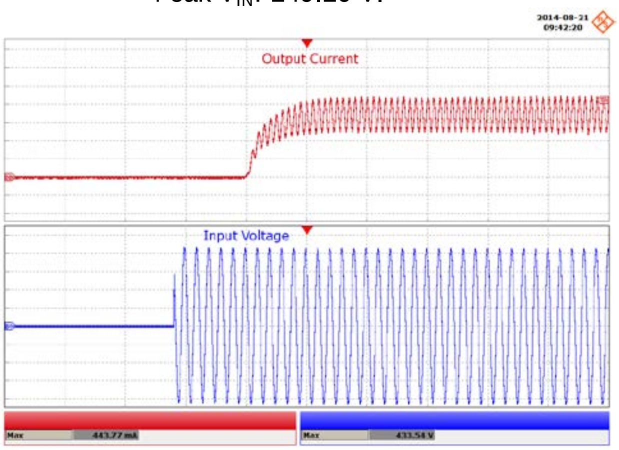

Figure 52 – 300 VAC, 95 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: I_{OUT}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 443.77 mA.
Peak I_{OUT}: 433.54 V.

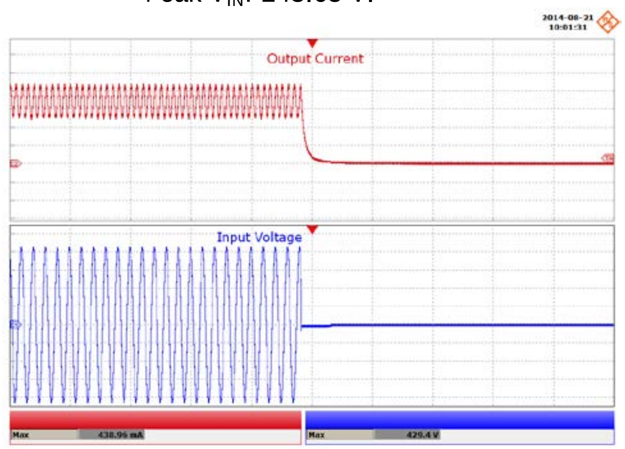

Figure 53 – 300 VAC, 95 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 438.96 mA.
Peak I_{OUT}: 429.4 V.

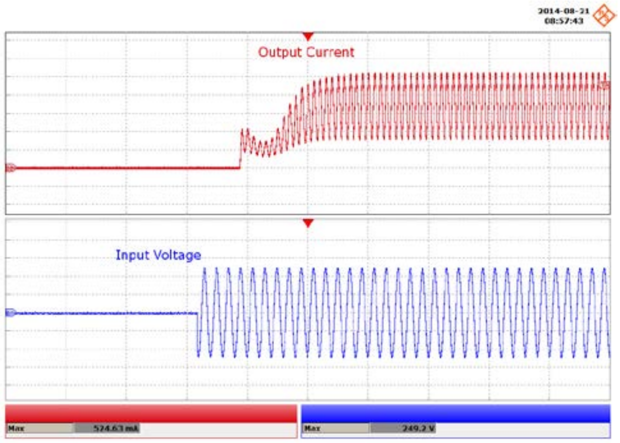

Figure 54 – 170 VAC, 45 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 524.63 mA.
Peak V_{IN}: 249.20 V.

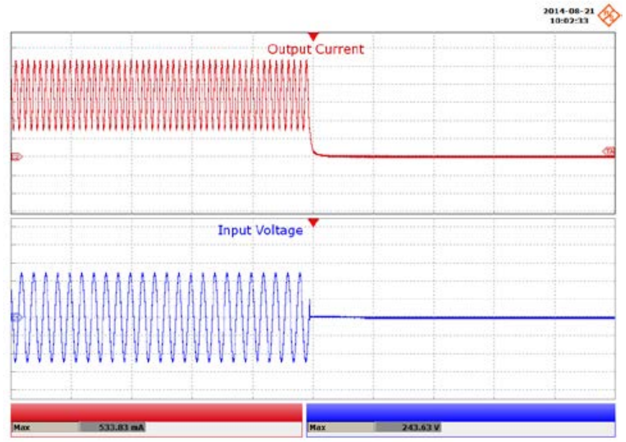

Figure 55 – 170 VAC, 45 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 533.83 mA.
Peak V_{IN}: 243.63 V.

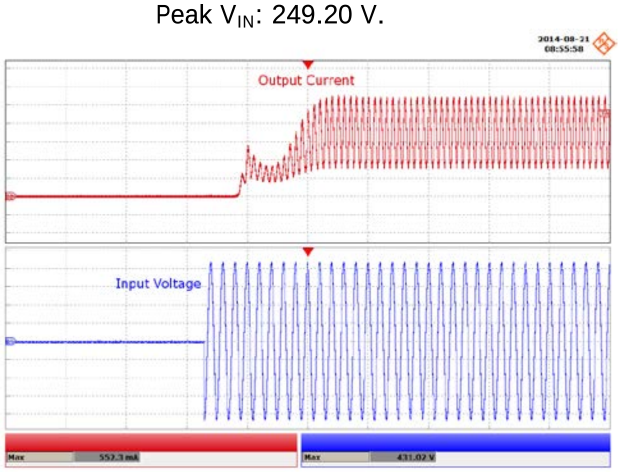

Figure 56 – 300 VAC, 45 V LED Load, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 552.30 mA.
Peak V_{IN}: 431.02 V.

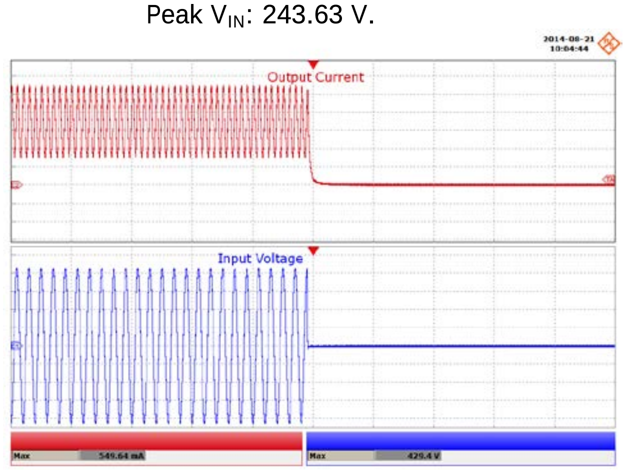

Figure 57 – 300 VAC, 45 V LED Load, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.
Peak I_{OUT}: 549.64 mA.
Peak V_{IN}: 429.4 V.

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13.3 Output Current and Voltage at Power Up, Power Down

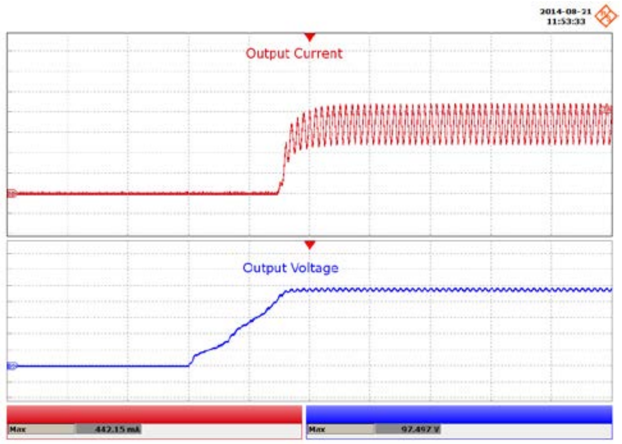

Figure 58 – 170 VAC, 95 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div, 100 ms / div.
Peak I_{OUT}: 442.15 mA.
Peak V_{OUT}: 97.497 V.

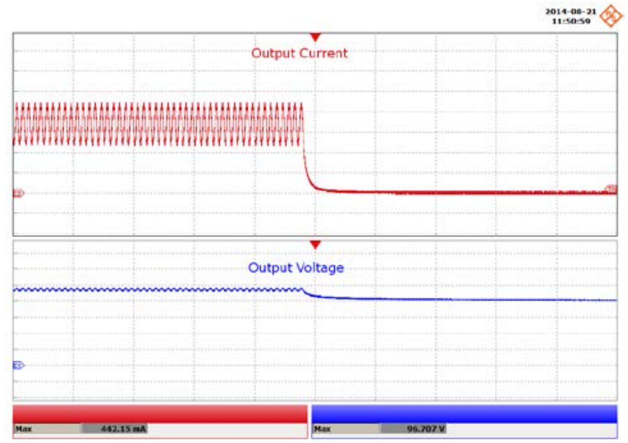

Figure 59 – 170 VAC, 95 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div, 100 ms / div.
Peak I_{OUT}: 442.15 mA.
Peak V_{OUT}: 96.707 V.

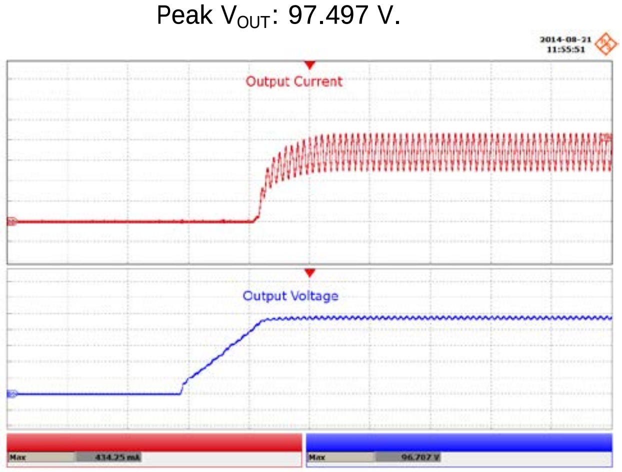

Figure 60 – 300 VAC, 95 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 434.25 mA.
Peak V_{OUT}: 96.707 V.

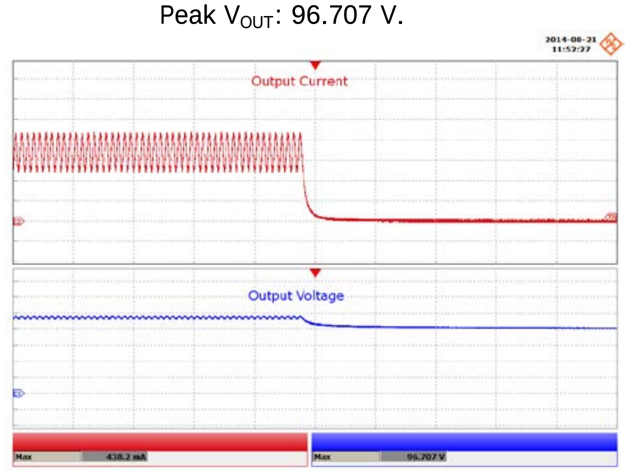

Figure 61 – 300 VAC, 95 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak I_{OUT}: 438.20 mA.
Peak V_{OUT}: 96.707 V.

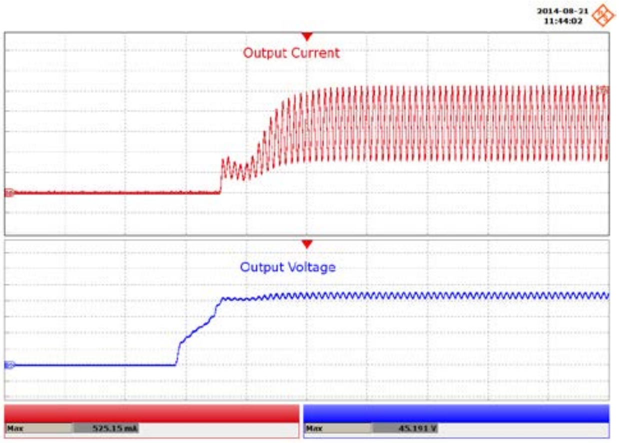

Figure 62 – 170 VAC, 45 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 525.15 mA.
Peak V_{OUT}: 45.191 V.

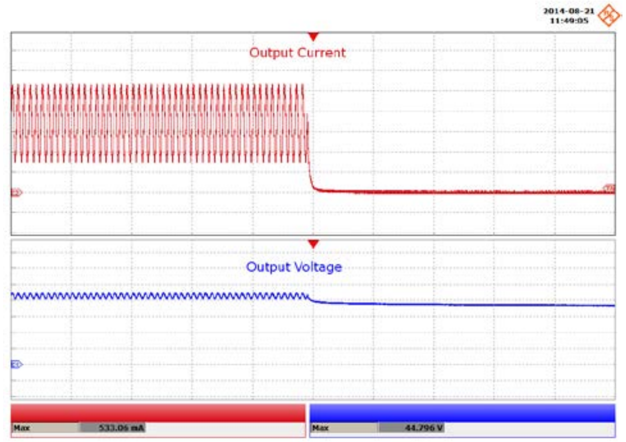

Figure 63 – 170 VAC, 45 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 533.06 mA.
Peak V_{OUT}: 44.796 V.

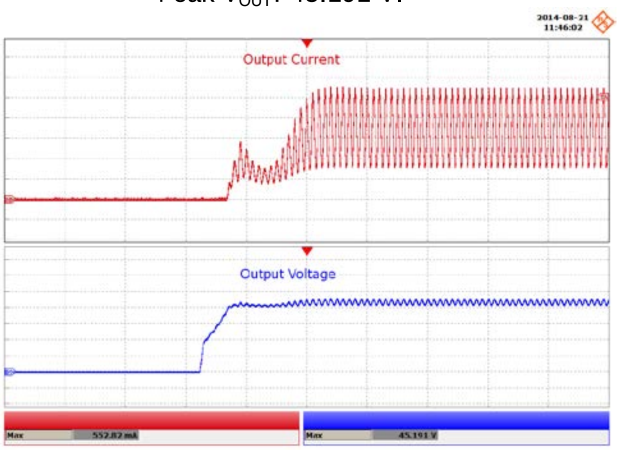

Figure 64 – 300 VAC, 45 V LED Load, Power Up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 552.82 mA.
Peak V_{OUT}: 45.191 V.

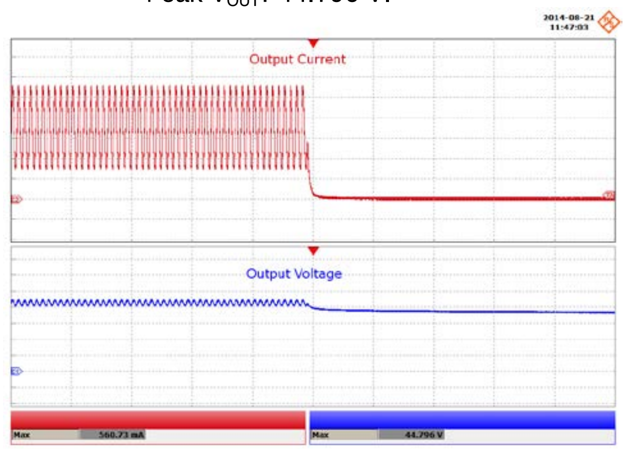

Figure 65 – 300 V VAC, 45 V LED Load, Power Down.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V / div., 100 ms / div.
Peak I_{OUT}: 560.73 mA.
Peak V_{OUT}: 44.796 V.

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13.4 Drain Voltage and Current in Normal Operation

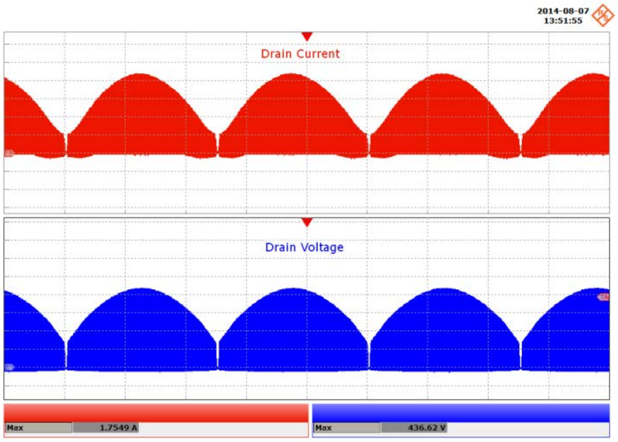

Figure 66 – 170 VAC, 95 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.75 A.
Peak V_{DRAIN}: 436.62 V.

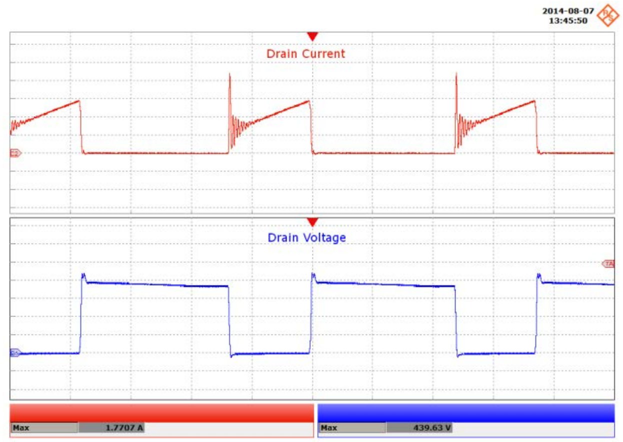

Figure 67 – 170 VAC, 95 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 1.77 A.
Peak V_{DRAIN}: 439.63 V.

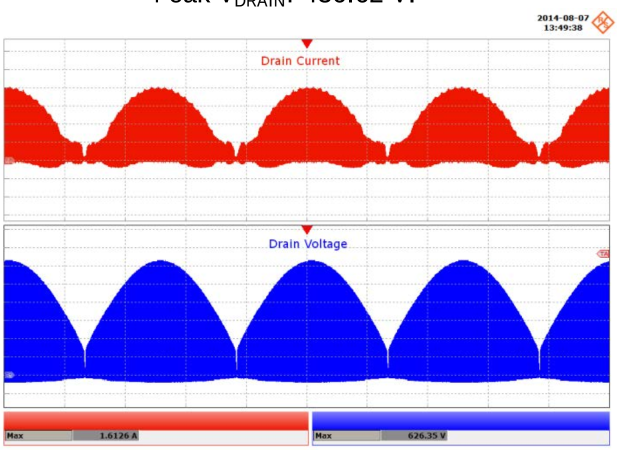

Figure 68 – 300 VAC, 95 V LED Load
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.61 A.
Peak V_{DRAIN}: 626.35 V.

Figure 69 – 300 VAC, 95 V LED Load
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 1.581 A.
Peak V_{DRAIN}: 626.35 V.

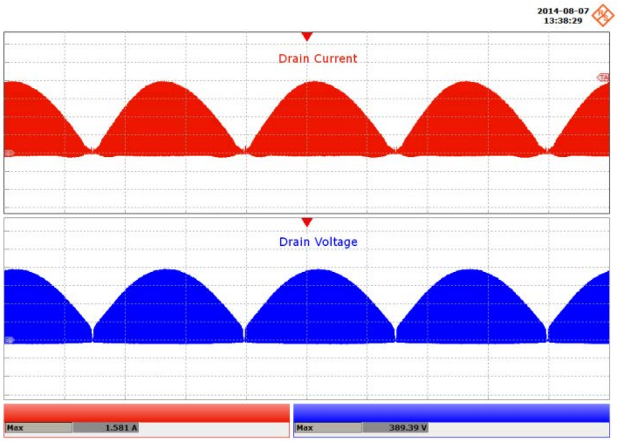

Figure 70 – 170 VAC, 45 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.581 A.
Peak V_{DRAIN}: 389.39 V.

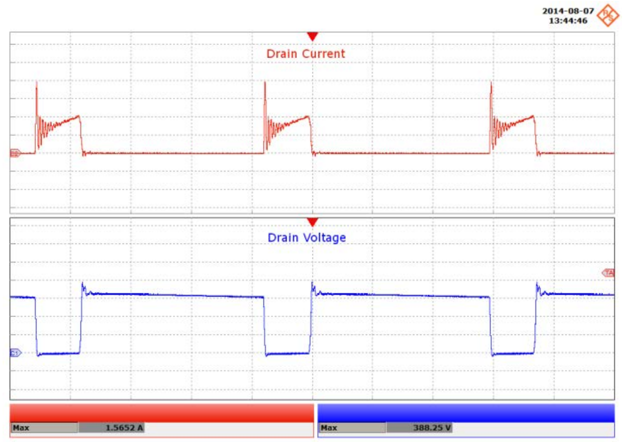

Figure 71 – 170 VAC, 45 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 1.565 A.
Peak V_{DRAIN}: 388.25 V.

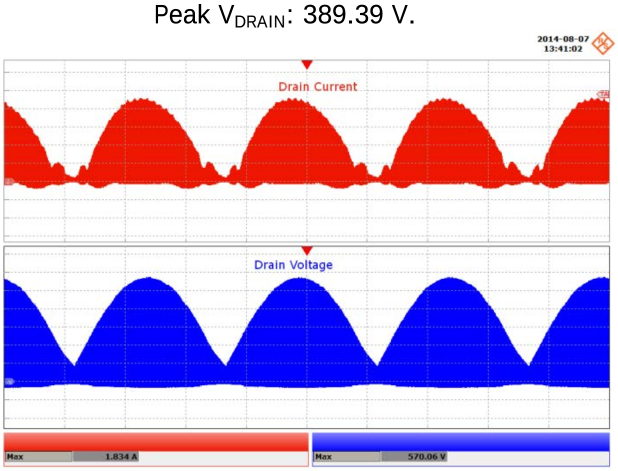

Figure 72 – 300 VAC, 45 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: I_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 1.834 A.
Peak I_{DRAIN}: 570.06 V.

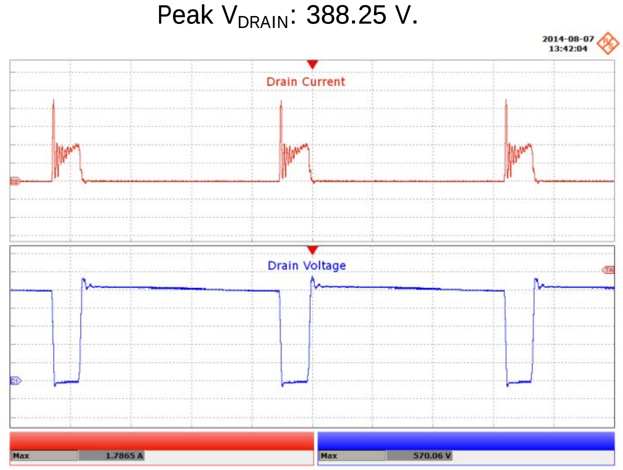

Figure 73 – 300 VAC, 45 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 μs / div.
Peak I_{DRAIN}: 1.786 A.
Peak I_{DRAIN}: 570.06 V.

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13.5 Drain Voltage and Current Start-up Profile

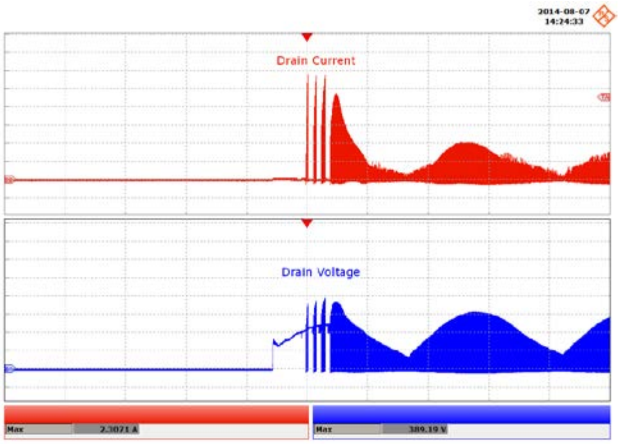

Figure 74 – 170 VAC, 95 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.307 A.
Peak V_{DRAIN}: 389.19 V.

Figure 75 – 170 VAC, 95 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 2.307 A.
Peak V_{DRAIN}: 389.19 V.

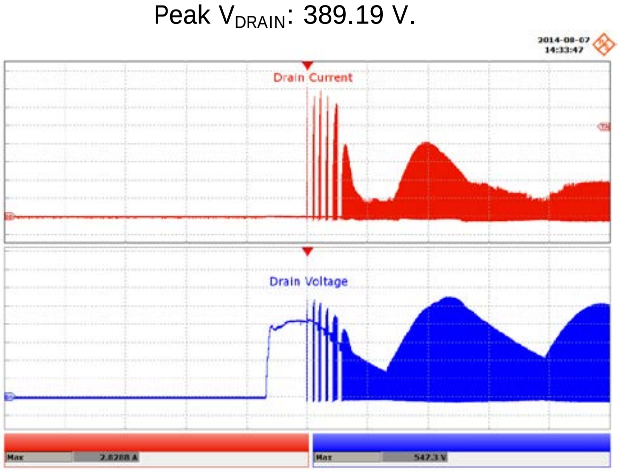

Figure 76 – 300 VAC, 95 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 4 ms / div.
Peak I_{DRAIN}: 2.829 A.
Peak V_{DRAIN}: 547.3 V.

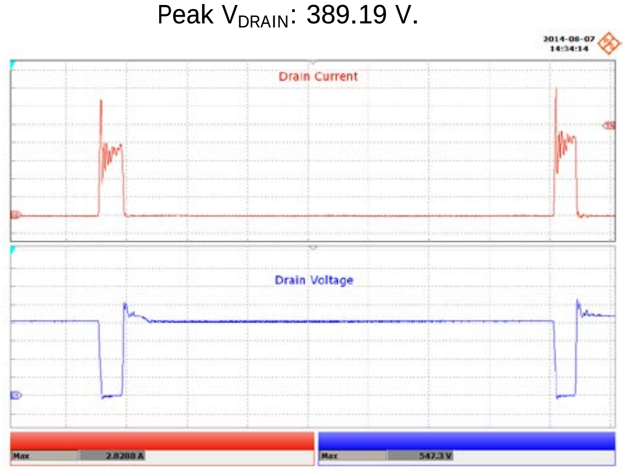

Figure 77 – 300 VAC, 95 V LED Load, Start-up.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 2 µs / div.
Peak I_{DRAIN}: 2.829 A.
Peak V_{DRAIN}: 547.3 V.

13.6 Drain Voltage and Current during Output Short-Circuit Condition

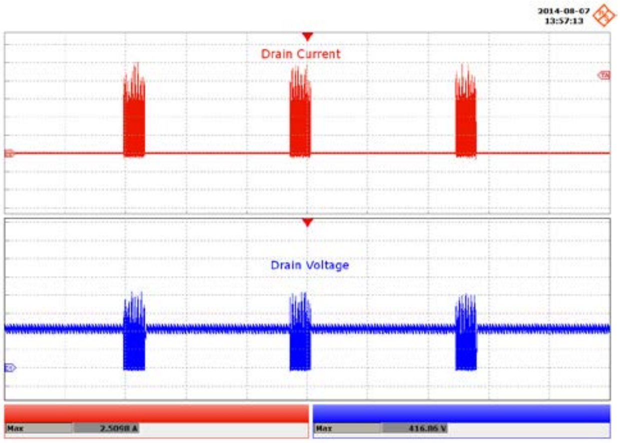

Figure 78 – 170 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 200 ms / div.
Peak I_{DRAIN}: 2.509 A.
Peak V_{DRAIN}: 416.86 V.

Figure 79 – 170 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 400 ns / div.
Peak I_{DRAIN}: 2.528 A.
Peak V_{DRAIN}: 412.91 V.

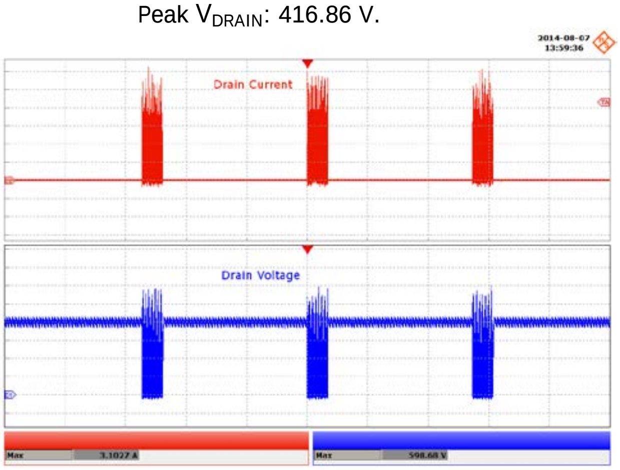

Figure 80 – 300 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 200 ms / div.
Peak I_{DRAIN}: 3.103 A.
Peak V_{DRAIN}: 598.68 .V

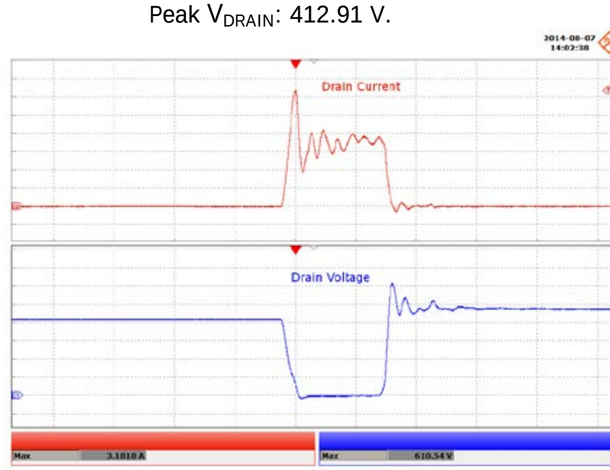

Figure 81 – 300 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 400 ns / div.
Peak I_{DRAIN}: 3.182 A.
Peak V_{DRAIN}: 610.54 V.

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	0.670
230	50	230.01	16.95	0.819
265	50	265.04	17.53	0.963
300	50	299.98	16.34	1.068

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13.7 Output Diode Voltage and Current in Normal Operation

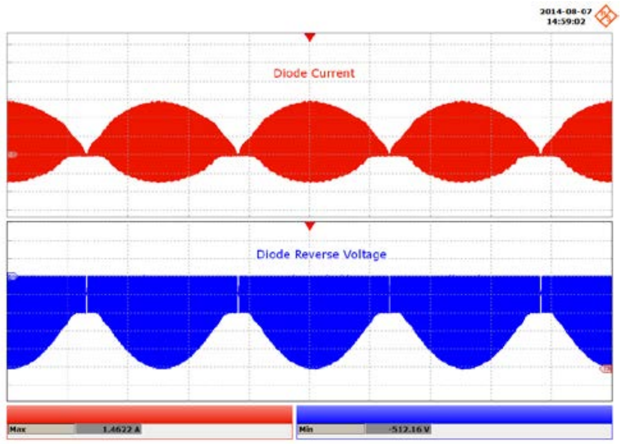

Figure 82 – 265 VAC, 95 V LED Load, Normal.
Upper: I_{DIODE}, 500 mA / div.
Lower: V_{DIODE}, 100 V / div., 4 ms / div.
Peak I_{DIODE}: 1.462 A.
Peak Diode Reverse Voltage: 512.16 V.

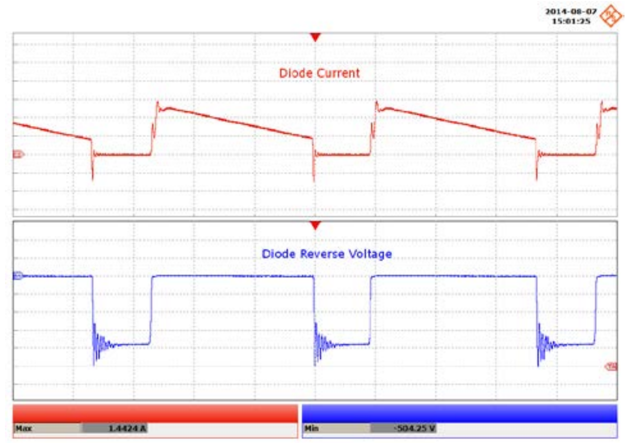

Figure 83 – 265 VAC, 95 V LED Load, Normal.
Upper: I_{DIODE}, 500 mA / div.
Lower: V_{DIODE}, 100 V / div, 2 µs / div.
Peak I_{DIODE}: 1.442 A.
Peak Diode Reverse Voltage: 504.25 V.

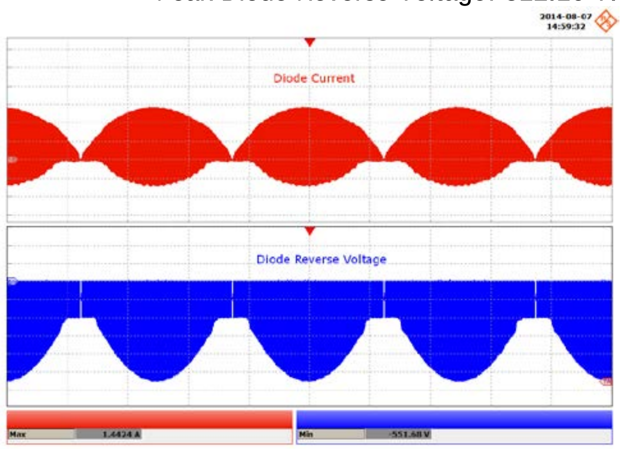

Figure 84 – 300 VAC, 95 V LED Load, Normal.
Upper: I_{DIODE}, 500 mA / div.
Lower: V_{DIODE}, 100 V / div., 4 ms / div.
Peak I_{DIODE}: 1.442 A.
Peak Diode Reverse Voltage: 515.68 V.

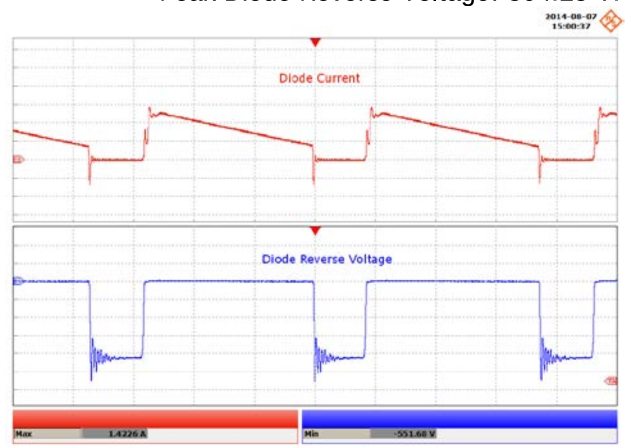

Figure 85 – 300 VAC, 95 V LED Load, Normal.
Upper: I_{DIODE}, 500 mA / div.
Lower: V_{DIODE}, 100 V / div., 2 µs / div.
Peak I_{DIODE}: 1.422 A.
Peak Diode Reverse Voltage: 551.68 V.

13.8 No-Load Characteristic

13.8.1 Drain Current Profile at No-Load

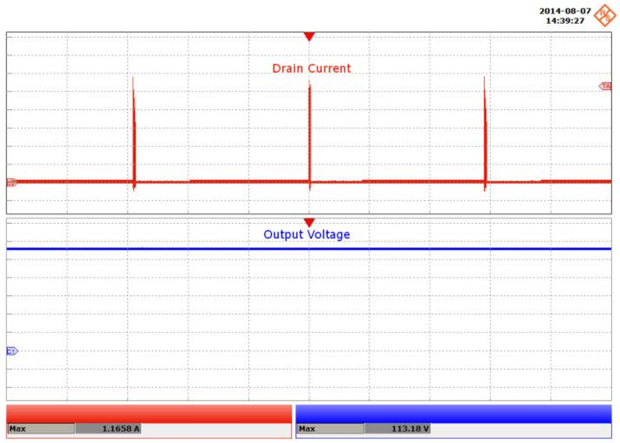

Figure 86 – 170 VAC, No LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{OUT}, 20 V / div., 50 ms / div.
Peak I_{DRAIN}: 1.166 A.
Peak V_{OUT}: 113.18 V.

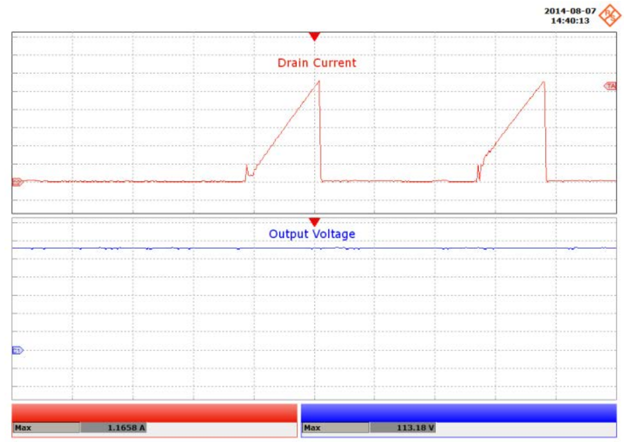

Figure 87 – 170 VAC, No LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{OUT}, 20 V / div., 4 μs / div.
Peak I_{DRAIN}: 1.166 A.
Peak V_{OUT}: 113.18 V.

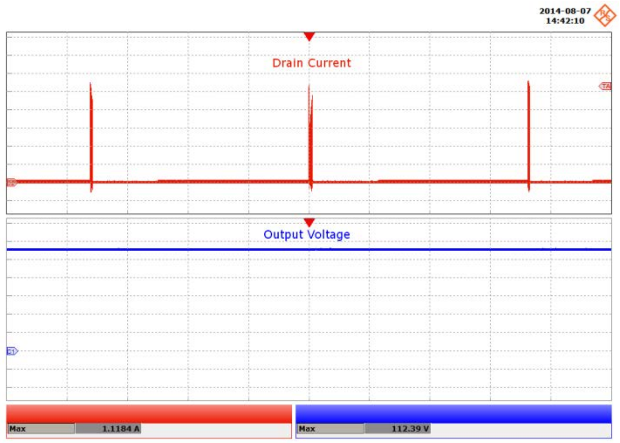

Figure 88 – 230 VAC, No LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{OUT}, 20 V / div., 50 ms / div.
Peak I_{DRAIN}: 1.118 A.
Peak V_{OUT}: 112.39 V.

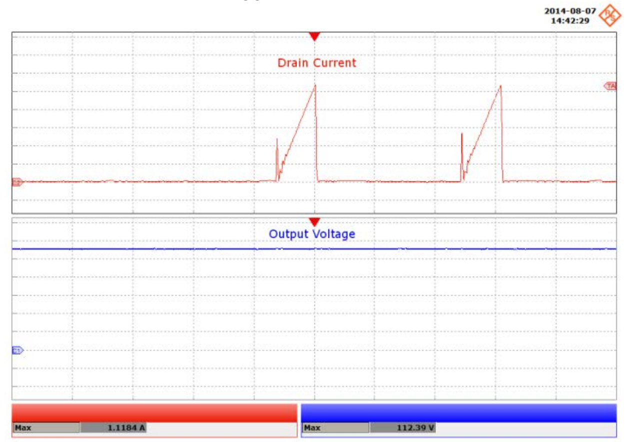

Figure 89 – 230 VAC, No LED Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{OUT}, 20 V / div., 4 μs / div.
Peak I_{DRAIN}: 1.118 A.
Peak V_{OUT}: 112.39 V.

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13.8.2 Output Voltage and Current - Open LED Load

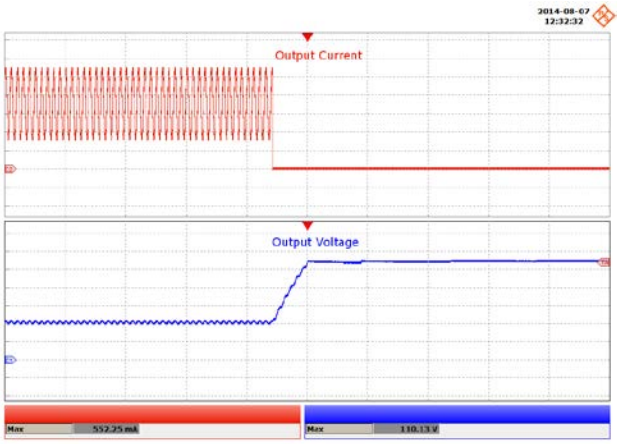

Figure 90 – 230 VAC, 45 V LED Load, Running Open Load. Upper: I_{OUT}, 100 mA / div. Lower: V_{OUT}, 20 V / div., 100 ms / div. Peak I_{OUT}: 552.25 mA. Peak V_{OUT}: 110.13 V.

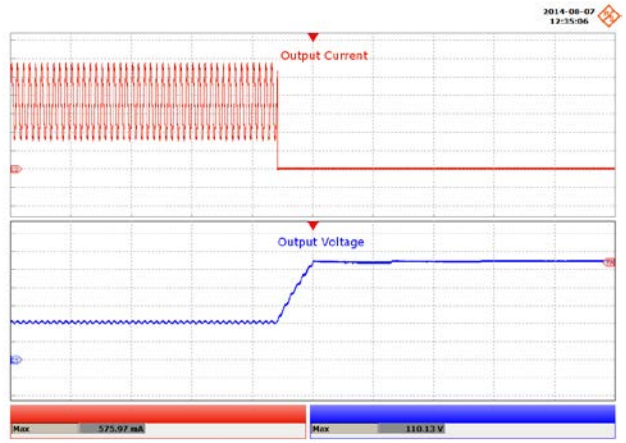

Figure 91 – 300 VAC, 45 V LED Load, Running Open Load. Upper: I_{OUT}, 100 mA / div. Lower: V_{OUT}, 20 V / div., 100 ms / div. Peak I_{OUT}: 575.97 mA. Peak V_{OUT}: 110.13 V.

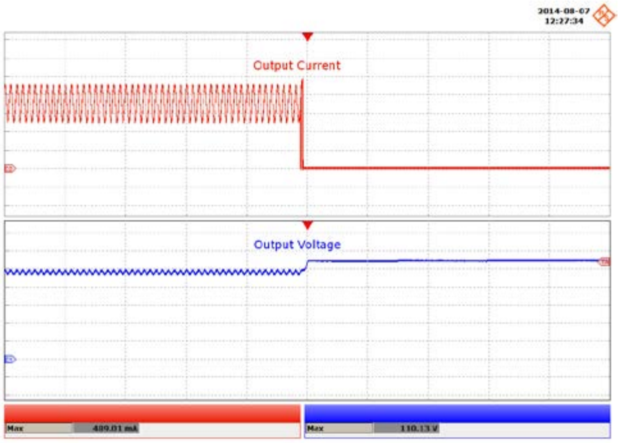

Figure 92 – 230 VAC, 95 V LED Load, Running Open Load. Upper: I_{OUT}, 100 mA / div. Lower: V_{OUT}, 20 V / div., 100 ms / div. Peak I_{OUT}: 449.01 mA. Peak V_{OUT}: 110.13 V.

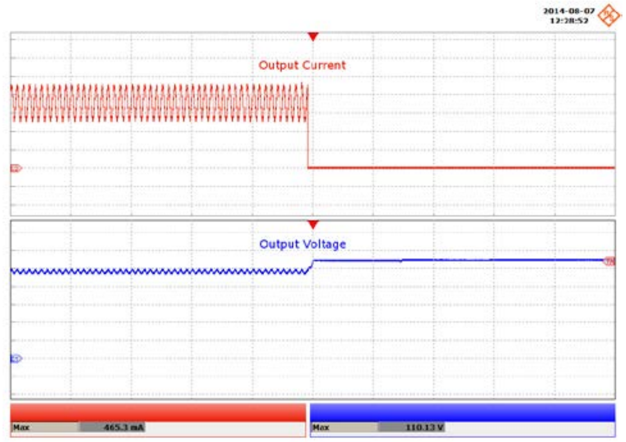

Figure 93 – 300 VAC, 95 V LED Load, Running Open Load. Upper: I_{OUT}, 100 mA / div. Lower: V_{OUT}, 20 V / div., 100 ms / div. Peak I_{OUT}: 465.3 mA. Peak V_{OUT}: 110.13 V.

13.8.3 Output Voltage and Current - Open Load (Start-up)

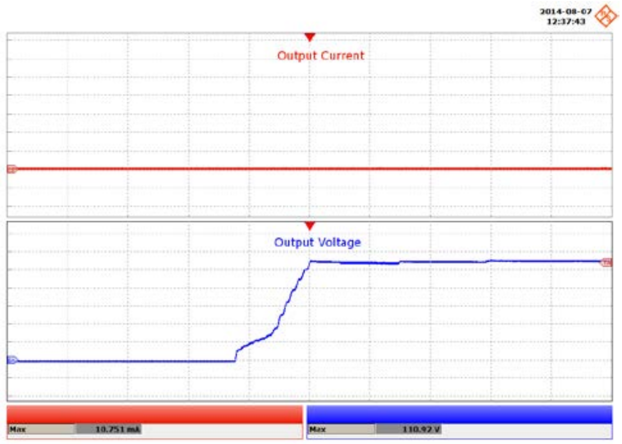

Figure 94 – 170 VAC, 50 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 110.92 V.

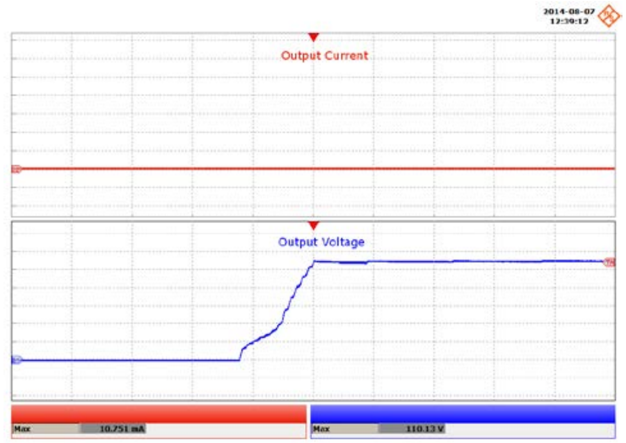

Figure 95 – 230 VAC, 50 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 110.13 V.

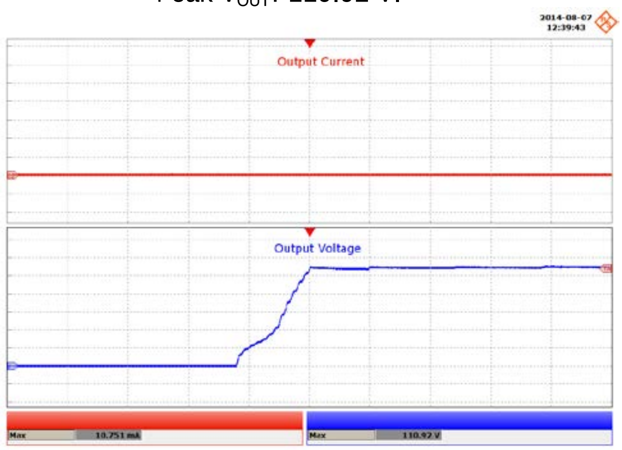

Figure 96 – 265 VAC, 50 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 110.92 V.

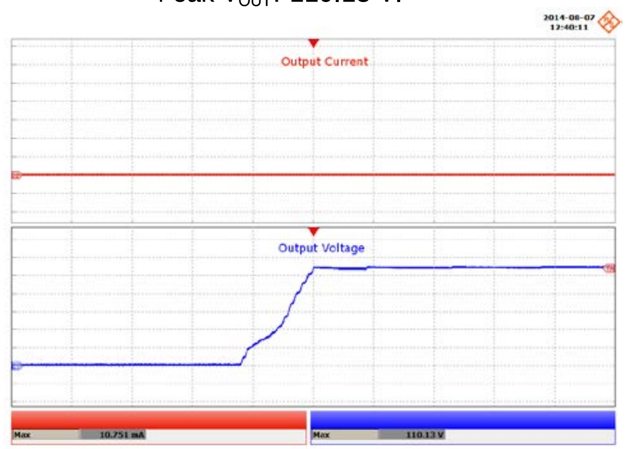

Figure 97 – 300 VAC, 50 Hz, Open Load Start-up.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.
Peak V_{OUT}: 110.13 V.

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13.9 Output Ripple Current

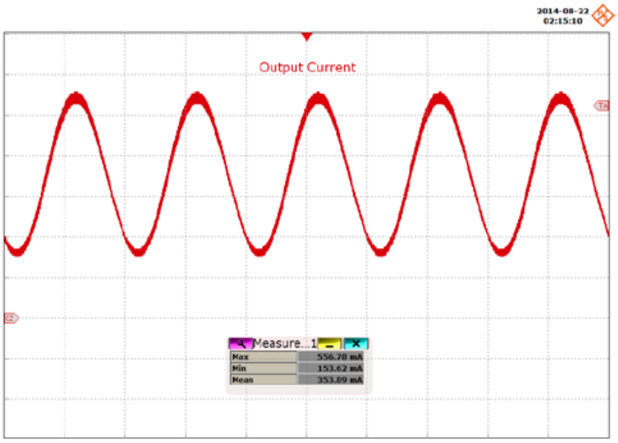

Figure 98 – 220 VAC, 50 Hz, 45 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

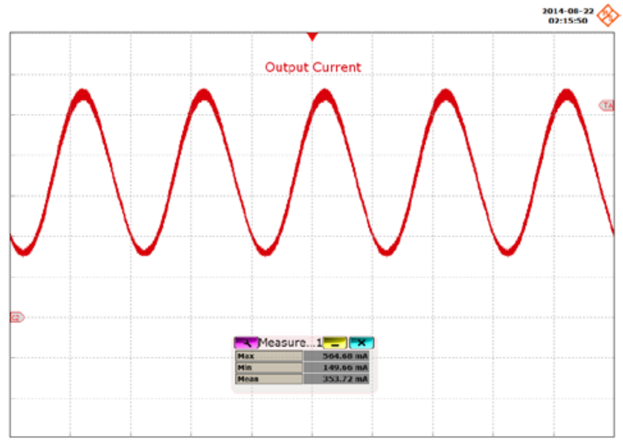

Figure 99 – 240 VAC, 50 Hz, 45 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

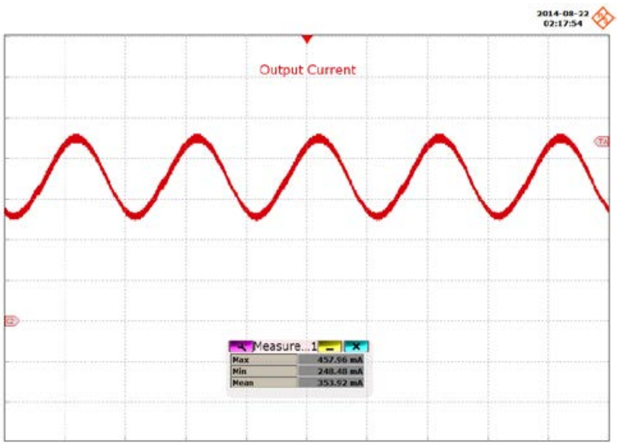

Figure 100 – 220 VAC, 50 Hz, 95 V LED Load.
Upper: I_{OUT}, 100 mA / div, 10 ms / div.

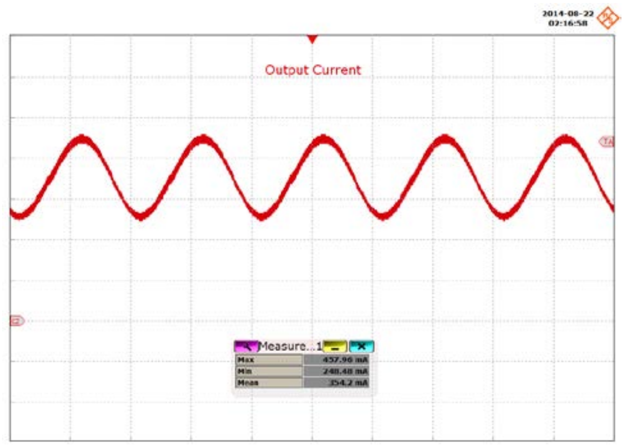

Figure 101 – 240 VAC, 50 Hz, 95 V LED Load.
Upper: I_{OUT}, 100 mA / div., 10 ms / div.

V_{IN}	$I_{O(MAX)}$ (mA)		$I_{O(MIN)}$ (mA)		I_{MEAN}		Ripple Ratio (I_{RP-P} / I_{MEAN})		% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}$ + $I_{O(MIN)}$)	
	45 V	**95 V**	**45 V**	**95 V**	**45 V**	**95 V**	**45 V**	**95 V**	**45 V**	**95 V**
220 V, 50 Hz	556.78	457.96	153.72	248.48	353.89	353.92	1.14	0.59	56.73	29.65
240 V, 50 Hz	564.68	457.96	149.66	248.48	353.72	354.2	1.17	0.59	58.10	29.65

14 AC Cycling Test

No output current overshoot was observed during on - off cycling.

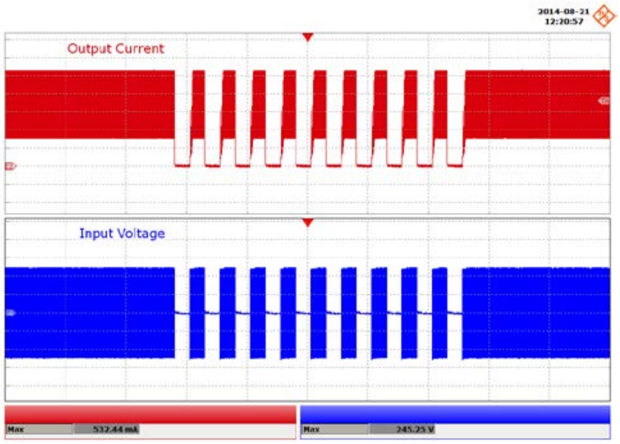

Figure 102 – 170 VAC, 45 V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 532.44 mA.
Peak V_{IN}: 245.25 V.

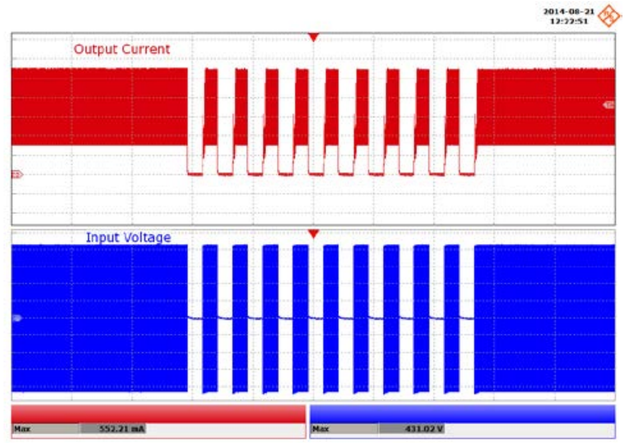

Figure 103 – 170 VAC, 45 V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 552.21 mA.
Peak V_{IN}: 431.02 V.

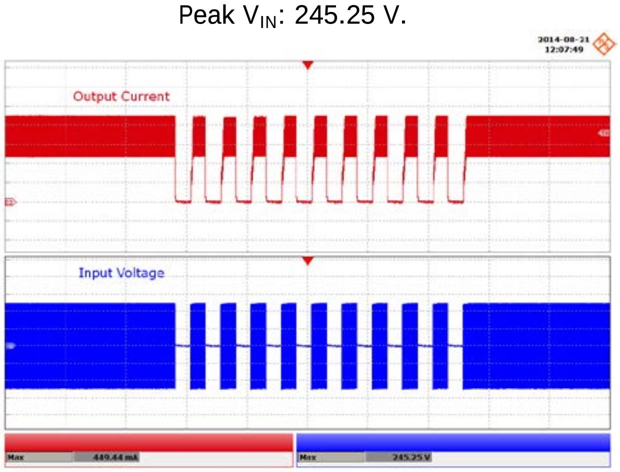

Figure 104 – 300 VAC, 45V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 449.44 mA.
Peak V_{IN}: 245.25 V.

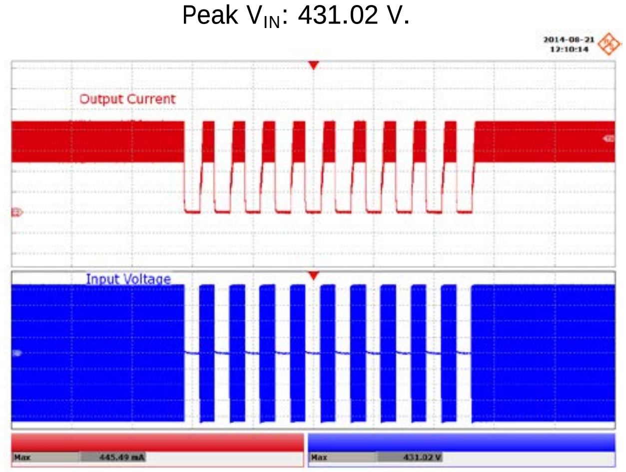

Figure 105 – 300 VAC, 45 V LED Load.
1 s On – 1 Sec Off.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.
Peak I_{OUT}: 445.49 mA.
Peak V_{IN}: 431.02 V.

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15 Conducted EMI

15.1 Test Set-up

15.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. Chroma measurement test fixture.
5. 45 V, 70 V and 95 V LED load with input voltage set at 230 VAC.

Figure 106 – Conducted EMI Test Set-up.

15.2 EMI Test Result

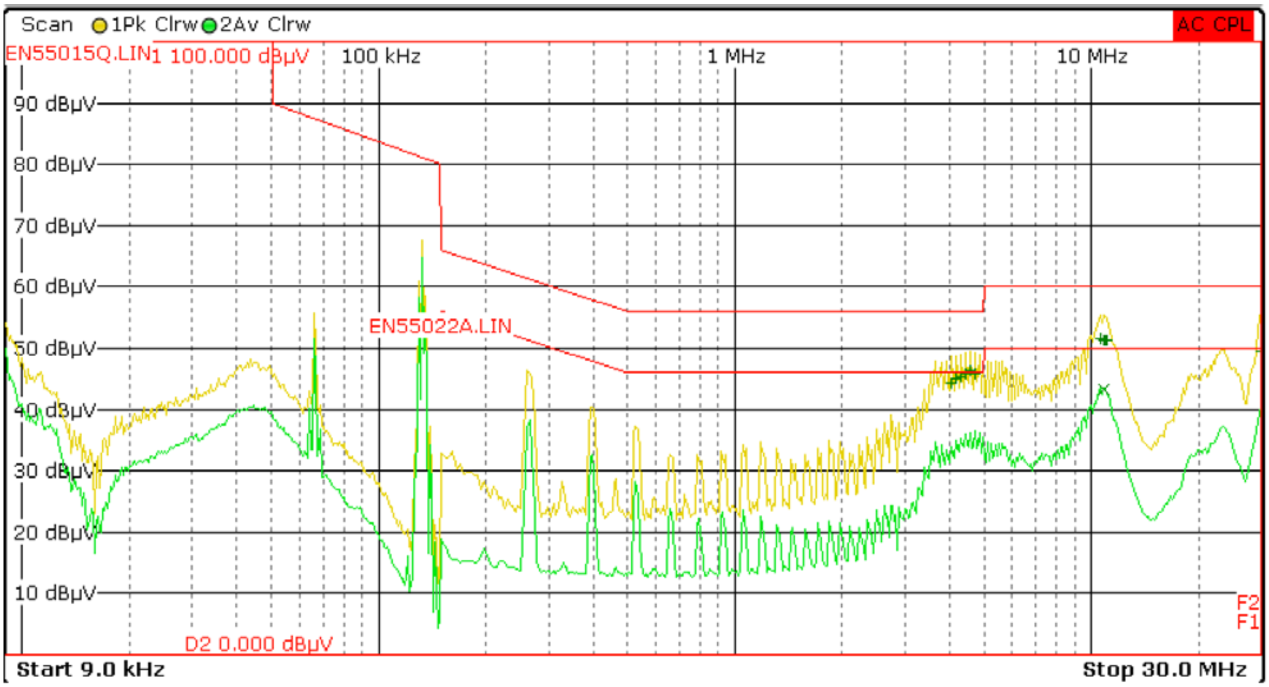

Figure 107 – Conducted EMI, 45 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN		Trace2: EN55022A.LIN	
Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	4.0660 MHz	44.36 L1	-11.64 dB
1 Quasi Peak	4.1980 MHz	44.95 L1	-11.05 dB
1 Quasi Peak	4.3260 MHz	45.24 L1	-10.76 dB
1 Quasi Peak	4.4580 MHz	45.96 L1	-10.04 dB
1 Quasi Peak	4.5900 MHz	46.25 L1	-9.75 dB
1 Quasi Peak	4.7220 MHz	45.89 L1	-10.11 dB
1 Quasi Peak	10.6860 MHz	51.54 L1	-8.46 dB
1 Quasi Peak	10.8180 MHz	51.32 L1	-8.68 dB
2 Average	10.8180 MHz	43.15 L1	-6.85 dB
1 Quasi Peak	10.9500 MHz	51.22 L1	-8.78 dB
1 Quasi Peak	11.0780 MHz	51.30 L1	-8.70 dB
1 Quasi Peak	29.9420 MHz	49.50 N	-10.50 dB

Figure 108 – Conducted EMI, 45 V LED Load, Final Measurement Results for Line and Neutral.

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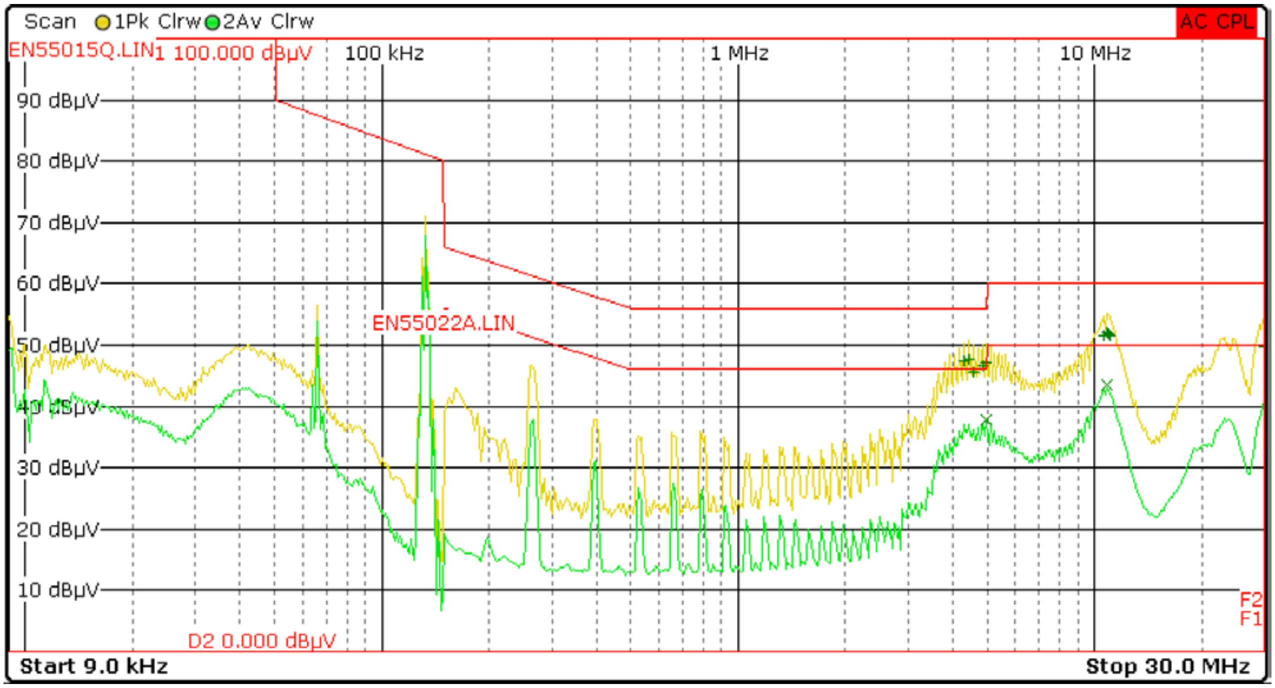

Figure 109 – Conducted EMI, 70 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	4.3260 MHz	47.36 L1	-8.64 dB
1 Quasi Peak	4.4580 MHz	47.79 L1	-8.21 dB
1 Quasi Peak	4.5860 MHz	45.63 L1	-10.37 dB
1 Quasi Peak	4.8500 MHz	46.58 L1	-9.42 dB
1 Quasi Peak	4.9820 MHz	47.21 L1	-8.79 dB
2 Average	4.9820 MHz	37.87 L1	-8.13 dB
1 Quasi Peak	10.6860 MHz	51.62 L1	-8.38 dB
1 Quasi Peak	10.8140 MHz	52.03 L1	-7.97 dB
2 Average	10.8140 MHz	43.46 L1	-6.54 dB
1 Quasi Peak	10.9460 MHz	51.94 L1	-8.06 dB
1 Quasi Peak	11.0780 MHz	51.49 L1	-8.51 dB
1 Quasi Peak	29.9500 MHz	49.64 L1	-10.36 dB

Figure 110 – Conducted EMI, 70 V LED Load, Final Measurement Results for Line and Neutral.

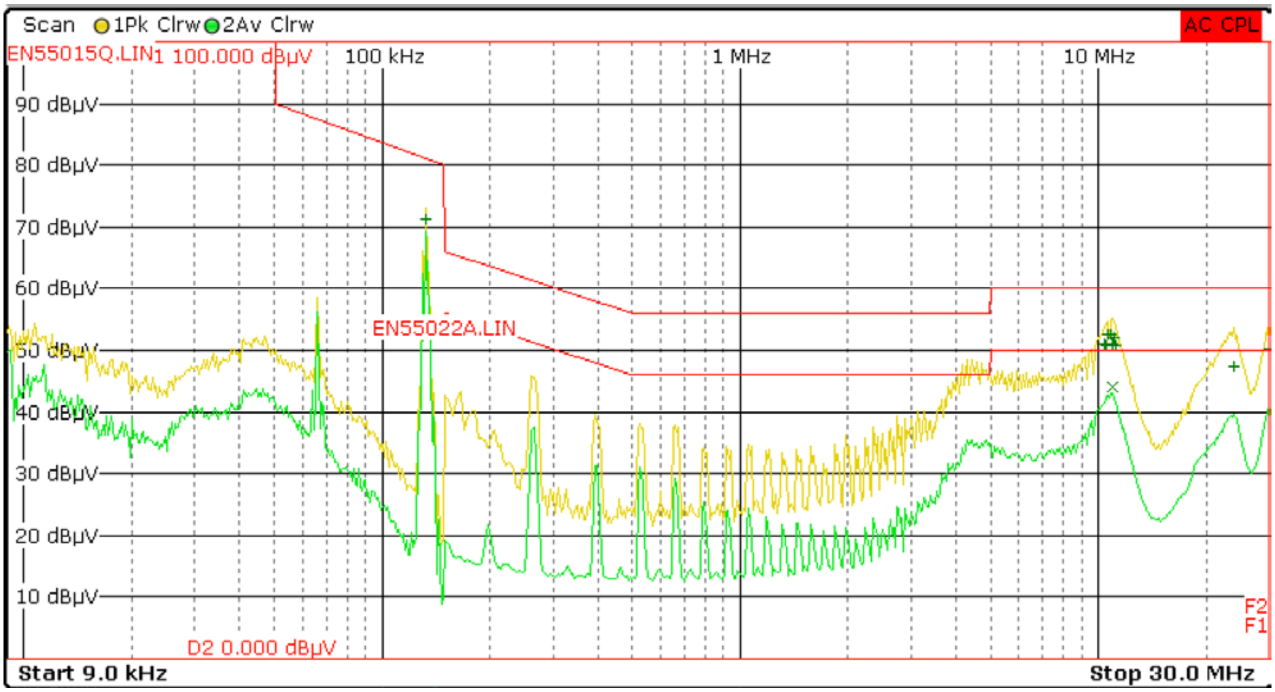

Figure 111 – Conducted EMI, 95 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	132.3600 kHz	71.23 L1	-9.91 dB
1 Quasi Peak	10.4220 MHz	51.07 L1	-8.93 dB
1 Quasi Peak	10.5540 MHz	50.77 N	-9.23 dB
1 Quasi Peak	10.6820 MHz	52.64 L1	-7.36 dB
1 Quasi Peak	10.8140 MHz	52.51 L1	-7.49 dB
2 Average	10.9420 MHz	44.10 L1	-5.90 dB
1 Quasi Peak	10.9460 MHz	50.98 N	-9.02 dB
1 Quasi Peak	11.0740 MHz	52.05 L1	-7.95 dB
1 Quasi Peak	11.2060 MHz	50.79 L1	-9.21 dB
1 Quasi Peak	23.8500 MHz	47.45 L1	-12.55 dB
1 Quasi Peak	29.9340 MHz	50.18 N	-9.82 dB

Figure 112 – Conducted EMI, 70 V LED Load, Final Measurement Results for Line and Neutral.

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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

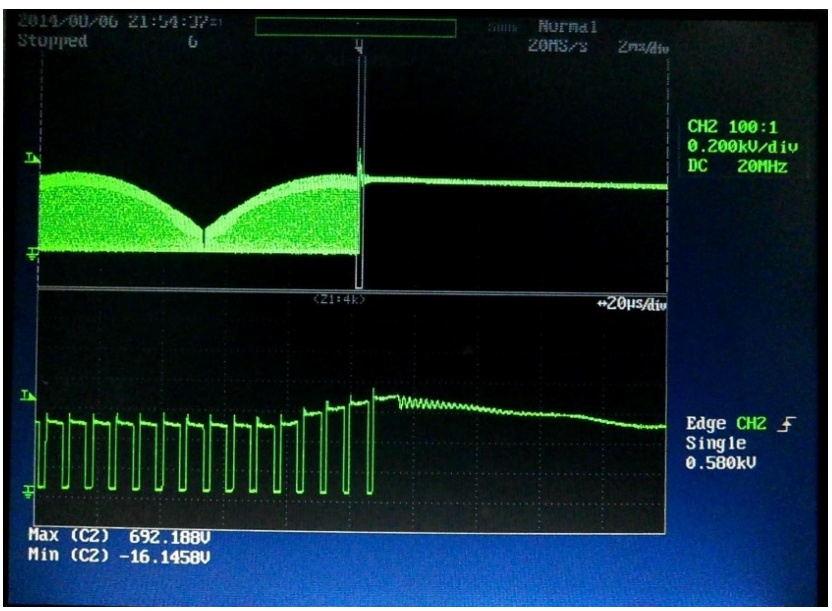

Figure 113 – +1000 kV Differential Surge, 90 °C Phase.
Lower: V_{DRAIN}, 200 V / div., 20 µs / div.
Peak V_{DRAIN}: 692.18 V.

17 Brown-in/Brown-out Test

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

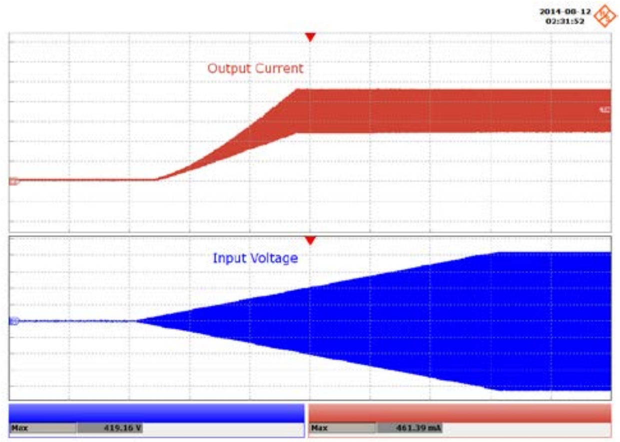

Figure 114 – Brown-in Test at 1 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 100 mA / div.
Time Scale: 50 s / div.

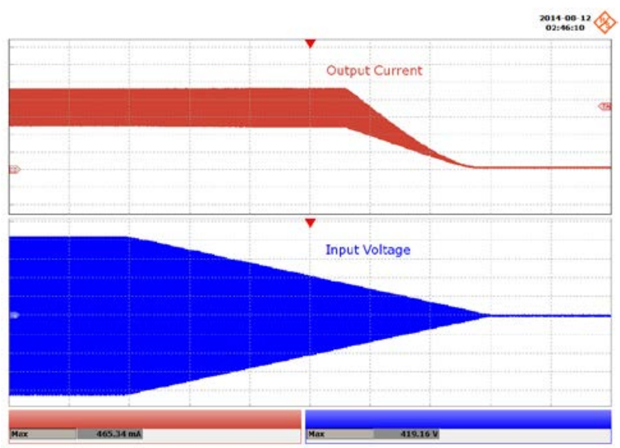

Figure 115 – Brown-out Test at 1 V / s. The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
Ch4: V_{IN}, 100 V / div.
Ch3: I_{OUT}, 100 mA / div.
Time Scale: 50 s / div.

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18 Revision History

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

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