Design Example Report

Title	***12 W Non-Isolated, Buck Topology, Power Factor Corrected, LED Driver Using LinkSwitch®-PH LNK405EG***
Specification	90 VAC – 265 VAC Input 36 V_{TYP}, 0.33 A_{TYP} Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-192
Date	June 9, 2010
Revision	1.0

Summary and Features

- Dramatically simplifies off-line, power factor corrected, LED driver design
  - Single-stage, power factor corrected, low component count, non-isolated LED driver
  - Configurable for TRIAC dimming or non-dimming configurations
  - PF >0.9 across line & load (non-dimming configuration)
  - Eliminates all control loop compensation
  - No output current sensing required
  - High system efficiency both at 115 V and 230 V (>83% non-dimming configuration)
- Advanced performance features
  - Compensates for inductance tolerance
  - Compensates for input voltage variations
  - Compensates for output voltage variations
  - Frequency jittering greatly reduces EMI filter costs
- Advanced protection and safety features
  - Auto-restart protection for short-circuit
  - Hysteretic thermal shutdown

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

1 Introduction

The document describes a non isolated, high power-factor, TRIAC dimmable LED driver designed to drive 36 V at 0.33 A from an input voltage range of 90 VAC to 265 VAC. The LED driver utilizes the LNK405EG device from Power Integrations.

The LinkSwitch-PH has been developed to cost effectively design a single-stage power factor corrected LED driver with primary-side constant current control. The LinkSwitch-PH controller was optimized for LED driver applications with minimal external parts count and control of the output current through the LED load without the use of an optocoupler.

The LinkSwitch-PH monolithically integrates the 725 V power MOSFET and controller. The controller consists of an oscillator, PWM, 6 V regulator, BYPASS pin programming functions, over-temperature protection, frequency jittering, cycle-by-cycle current limit, leading edge blanking, and charge controller for output CC (constant-current) control.

The LinkSwitch-PH also provides a sophisticated range of protection features including auto-restart for control loop open/short faults and output short-circuit conditions. Accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

The non-isolated power factor corrected buck presented in this report shows how LinkSwitch-PH dramatically simplifies off-line, high-efficiency, power factor corrected LED driver design with very low parts count.

This document contains the LED driver specification, schematic, PCB diagram, bill of materials, conducted EMI measurements, thermal measurements, power line transient tests, inductor documentation and typical performance characteristics.

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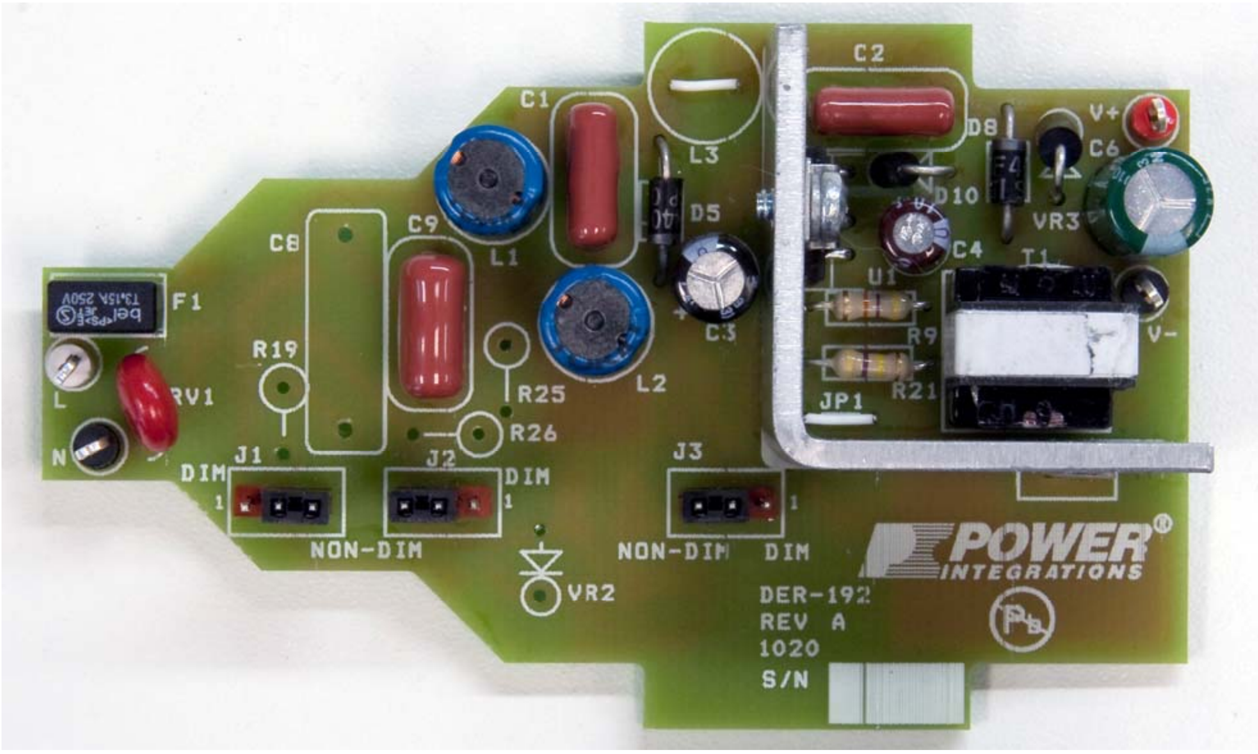

Figure 1 – Populated Circuit Board Photograph, Top (Non-Dimmable).

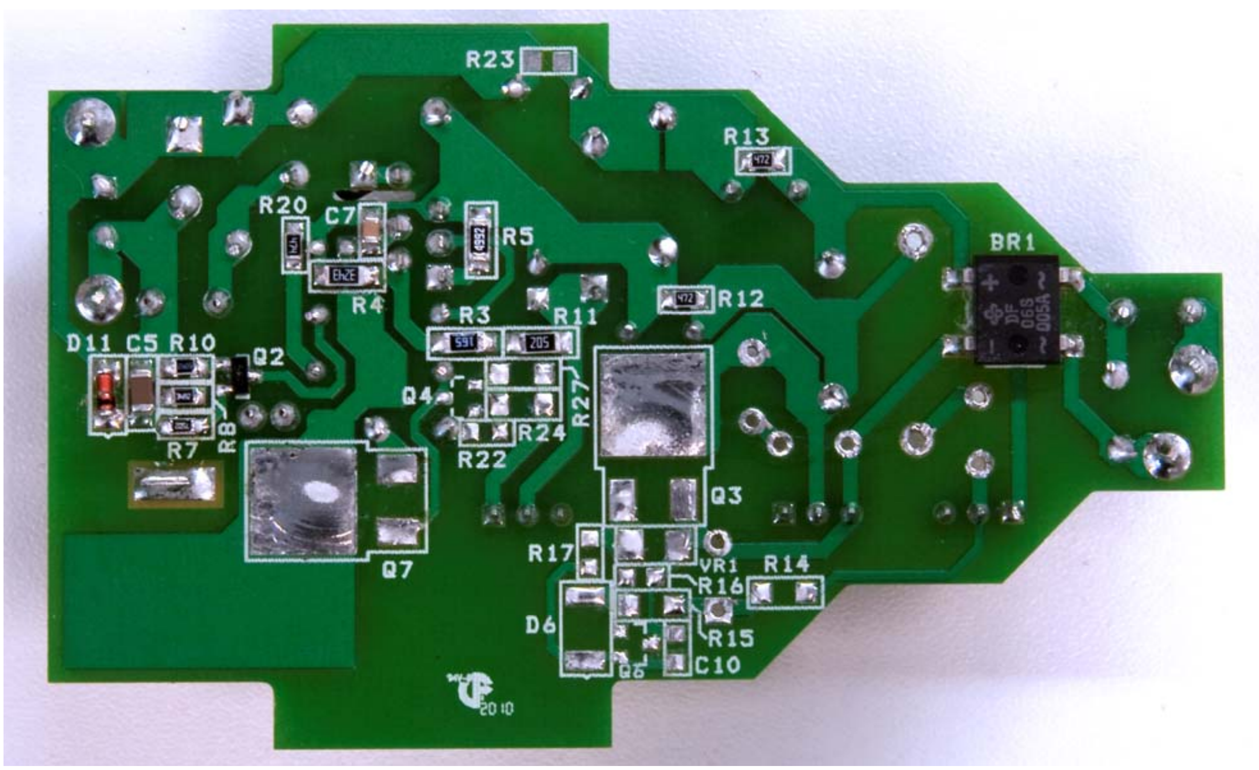

Figure 2 – Populated Circuit Board Photograph, Top (Non-Dimmable).

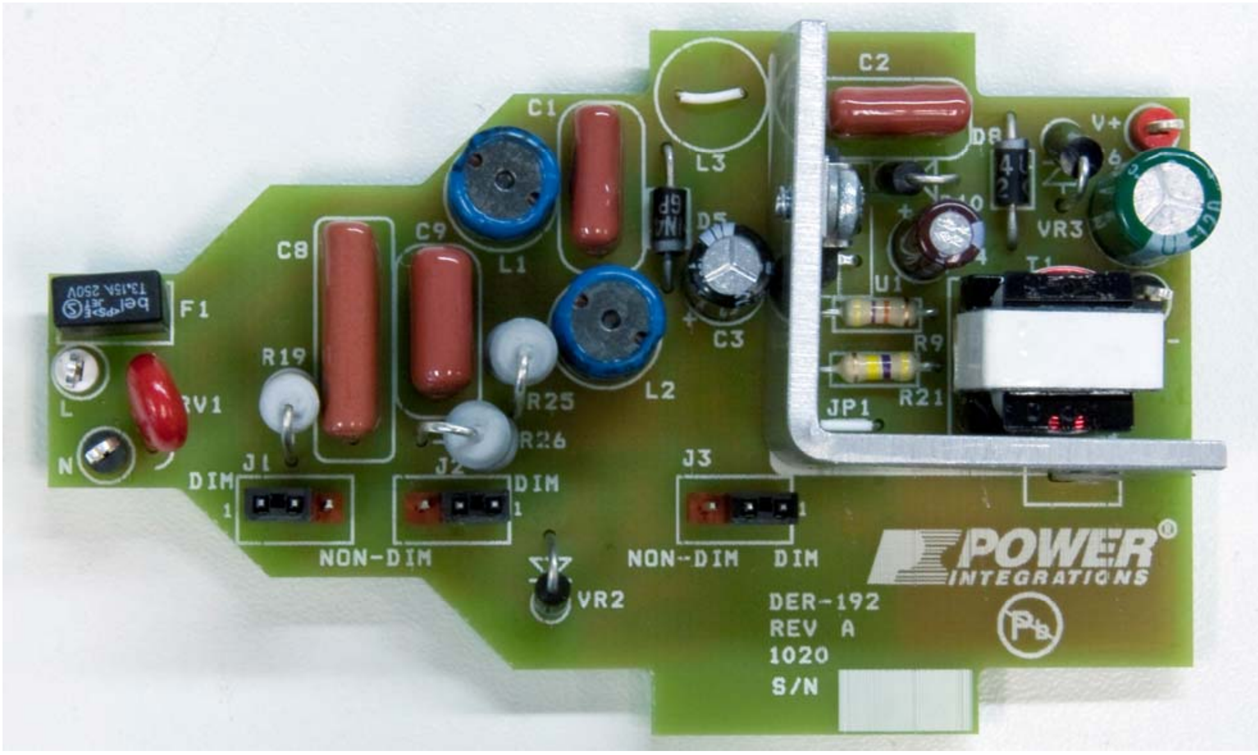

Figure 3 – Populated Circuit Board Photograph, Top (Dimmable).

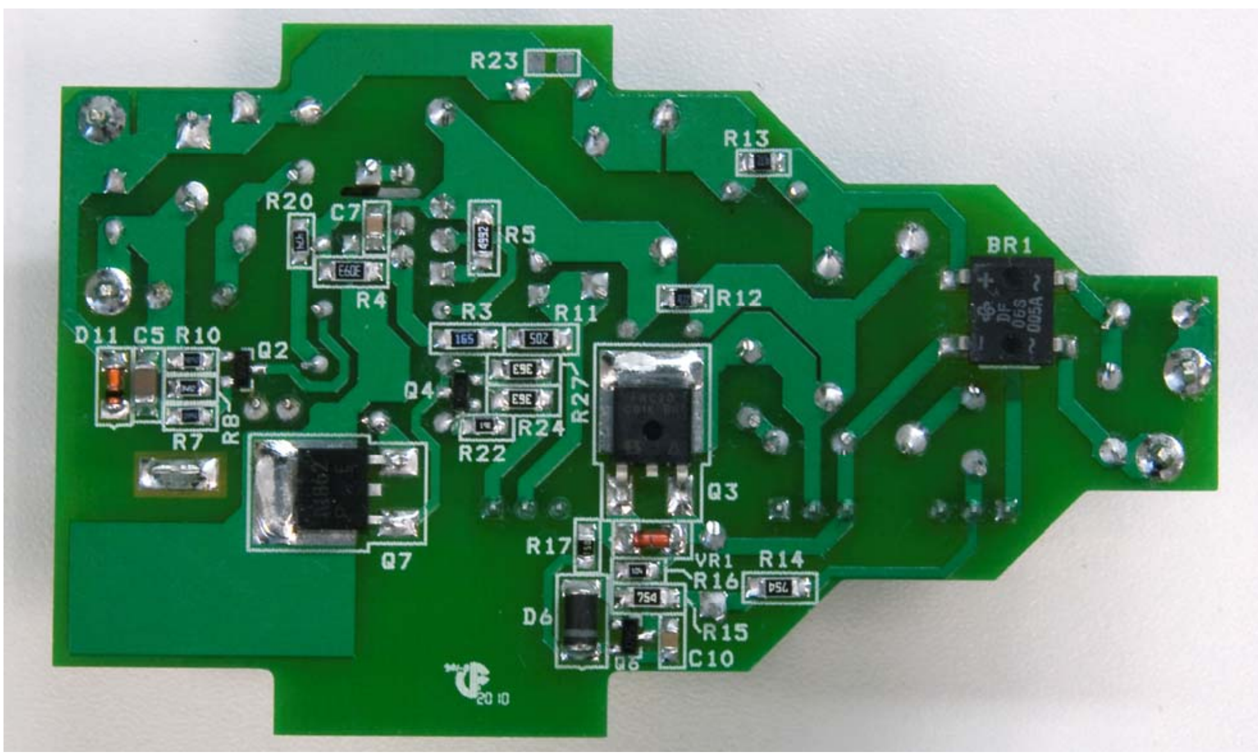

Figure 4 – Populated Circuit Board Photograph, Bottom (Dimmable).

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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.

12 W Non-Dimmable Specifications

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Output						
LED voltage	V_{OUT}	30	36	38	V	
LED Current		300	330	340	mA	
Total Output Power						
Continuous Output Power	P_{OUT}	9	12	13	W	
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Non isolated				
Surge				2.5	kV	Ringwave
Efficiency		80				
Harmonic		Class C				61000-3-2
Power Factor		0.9				
Ambient Temperature	T_{AMB}		25		^{o}C	

12 W TRIAC Dimmable Specifications

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Output						
LED voltage	V_{OUT}	30	36	38	V	
LED Current		260		360	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		12	14	W	
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Nonisolated				
Surge				2.5	kV	Ringwave
Efficiency		79				
Power Factor		0.8				
Ambient Temperature	T_{AMB}		25		^{o}C	

3 Schematic

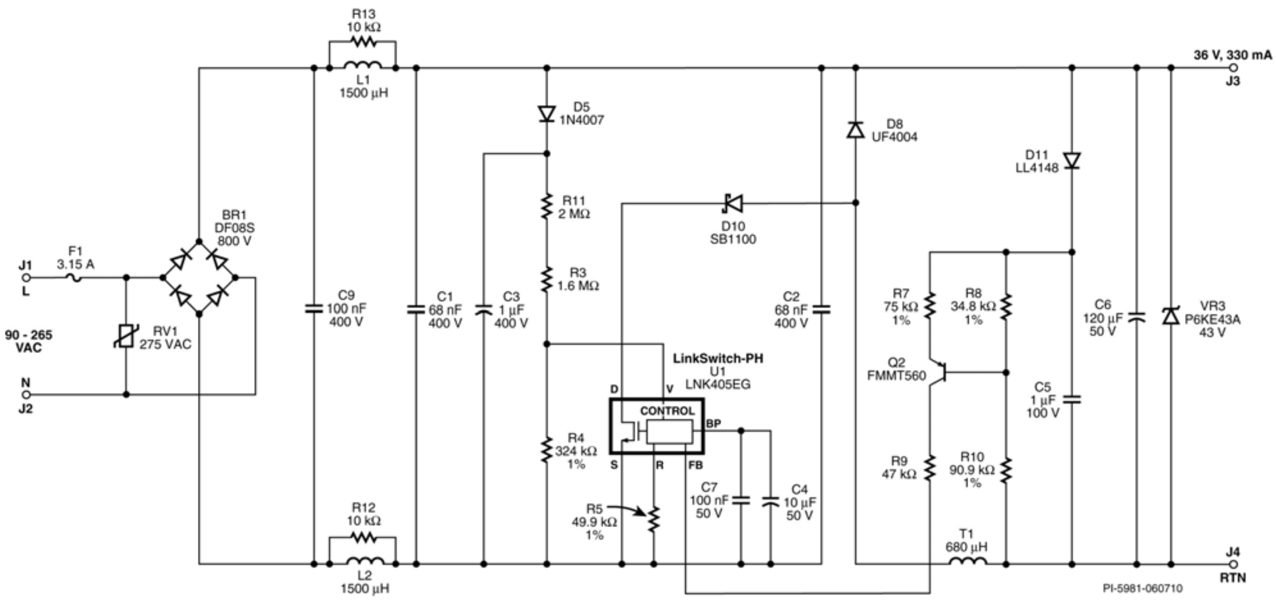

Figure 5 – Schematic (Non-Dimmable)

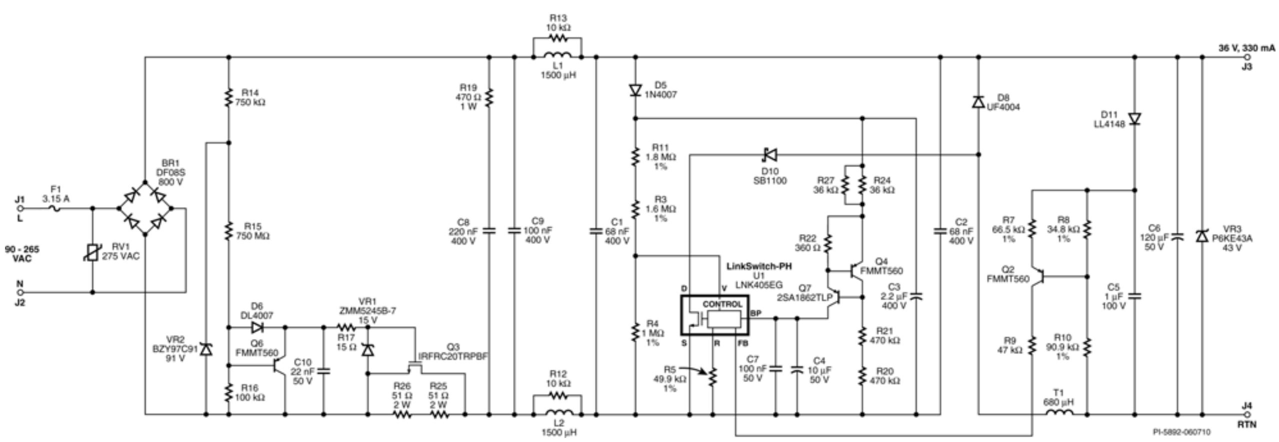

Figure 6 – Schematic (TRIAC Dimmable).

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4 Circuit Description

4.1 Non-Dimming, Power Factor Corrected Buck LED Driver

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

Capacitor C1, C2, C9, L1, and L2 perform EMI filtering while maintaining high-power factor. This input filter network plus the frequency jittering feature of LinkSwitch-PH easily meets Class B emission limits. Resistor R13 and R12 were used to damp the Q of L1 and L2 for lower EMI.

The buck power circuit with floating output connection composed of U1 (power switch + control), D8 (free-wheeling diode), C6 (output capacitor), and L4 (output inductor). Diode D10 was used to prevent negative voltage appearing across drain-source of U1 especially near the zero-crossing of the input voltage. Diode D5 and C3 detect the peak AC line voltage. The voltage across C3 along with R3, R4, and R11 sets input current fed into the V pin. This current is used by U1 to control line undervoltage (UV), overvoltage (OV), and feed-forward current which in conjunction with the FEEDBACK pin current provides constant current to the LED load.

The FEEDBACK pin current used by U1 for output voltage feedback is provided by the voltage to current converter network formed by R7-R10, Q2, C5, and D11. Resistor R7 sets the I_{FB} current for a given output voltage. Changes in output voltage are seen by the voltage across R8 which serves as the reference for the current source formed by R7, R8 and Q2. Voltage across R8 was chosen high enough to eliminate or minimize the effect of the temperature and V_{CE} dependence of Q2's V_{BE} voltage.

The power Zener VR3 protects the output circuitry during an open load condition. If the load is open for extended period, VR3 will fail short and the unit will enter into auto-restart condition.

4.2 TRIAC Dimmable, Power Factor Corrected Buck LED Driver

The board can also be configured for TRIAC dimmable applications. From the original network shown on Figure 3, several circuit blocks need to be added (Figure 4) to enable the power supply to be controlled by a phase-angle controller (TRIAC) and allow the output current, and thus the LED brightness to be controlled.

Three networks were added to realize dimming. A damper network formed by R19 and C8 dampens the ringing created by the input capacitance C1-C9 and L1, and L2, every time the TRIAC fires and applies a transient voltage at the input. The network formed by

R14-R17, R25-R26, D6, VR1, VR2, C10 and Q3 provides inrush limiting during TRIAC firing and R25-R26 also helps in damping during the initial stage of the ringing caused by the inrush currents when the TRIAC fires.

The third network necessary for dimming applications is the linear regulator formed by R20, R21, R22, R24, R27, Q4, and Q7. This network provides a supply current to the BYPASS pin during periods when the TRIAC is not conducting.

4.3 Minimum Dimming Limitations

The minimum dimming angle or TRIAC conduction angle of the driver relies on the TRIAC itself, the BYPASS pin supply current provided by the linear regulator, and the V pin resistor networks which sets UV level of the power supply.

Different TRIAC dimmers have different minimum conduction angles and different power ratings which translate to different minimum holding currents. If the TRIAC minimum conduction angle is the limiting factor, the driver will continue to operate at the minimum angle capacity of the TRIAC as long as the UV (line and BYPASS pin) voltage is above their turn-off thresholds.

For a dimmer with a small minimum conduction angle, minimum dimming relies on the undervoltage threshold (voltage present at the peak detector) of the design and linear regulator cut-off voltage. For very low TRIAC conduction angles, the peak detector voltage will drop to a low value where the linear regulator configured as a current source may no longer maintain the supply and the unit will shutdown. This shutdown is caused by the BYPASS pin voltage reaching the IC UV threshold.

One possible source of power to provide a supply for the BYPASS pin during very low dimming angles is the output itself. As long as the LEDs are conducting a voltage appears across the output and may be used to provide the supply for the BYPASS pin by incorporating a similar network configuration used to feed the FEEDBACK pin. However, these circuit improvements are not covered in this report.

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5 PCB Layout

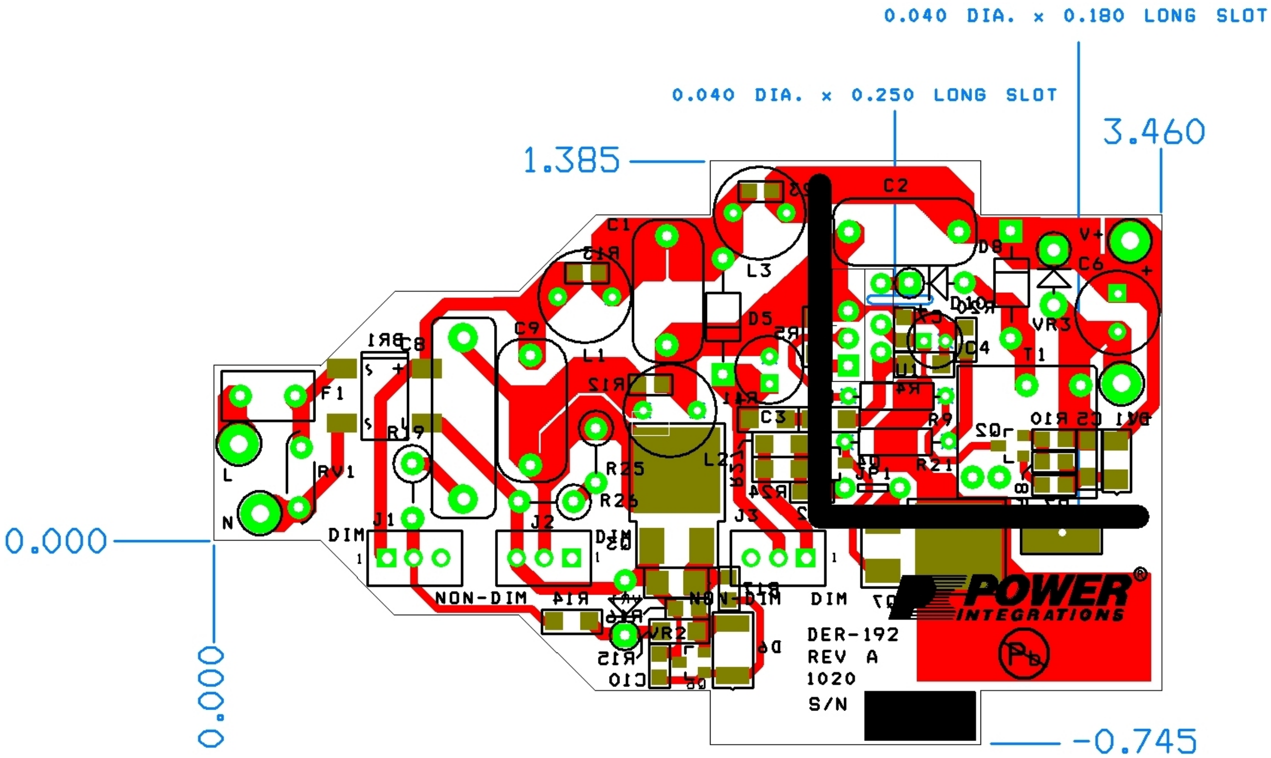

Figure 7 – Printed Circuit Layout (Designed to Fit Inside PAR38 Lamp Form Factor).

6 Bill of Materials

6.1 Non-Dimmable, Power Factor Corrected Buck LED Driver

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	800 V, 1 A, Bridge Rectifier, SMD, DFS	DF08S	Diodes Inc.
2	2	C1 C2	68 nF, 400 V, Film	ECQ-E4683KF	Panasonic
3	1	C3	1 uF, 400 V, Electrolytic, (6.3 x 11)	EKMG401ELL1R0MF11D	United Chemi-Con
4	1	C4	10 μF, 50 V, Electrolytic, Gen Purpose, (5 x 11)	ECA-1HHG100	Panasonic
5	1	C5	1 μF, 100 V, Ceramic, X7R, 1206	ECJ-3YB1E105K	Panasonic
6	1	C6	120 μF, 50 V, Electrolytic, Very Low ESR, 61 mΩ, (8 x 15)	EKZE500ELL121MH15D	Nippon Chemi-Con
7	1	C7	100 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H104K	Panasonic
8	1	C9	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
9	1	D5	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
10	1	D8	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
11	1	D10	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
12	1	D11	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diode Inc.
13	1	ESIP CLIP1	Heatsink Hardware, Edge Clip xxN (xx lbs) 14.33 mm L x 6.35 mm W	TRK-24	Kang Tang Hardware
14	1	F1	3.15 A, 250V, Slow, RST	507-1181	Belfuse
15	3	J1 J2 J3	3 Position (1 x 3) header, 0.1 pitch, Vertical	22-28-4030	Molex
16	1	JP1	Wire Jumper, Insulated, 22 AWG, 0.2 in	C2004-12-02	Gen Cable
17	1	L	Test Point, WHT,THRU-HOLE MOUNT	5012	Keystone
18	3	L1 L2	1500 μH, 0.25 A	SBC3-152-251	Tokin
19	2	N TP4	Test Point, BLK,THRU-HOLE MOUNT	5011	Keystone
20	1	Q2	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
21	1	R23	Jumper		
22	1	R3	1.6 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ165V	Panasonic
23	1	R4	324 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3243V	Panasonic
24	1	R5	49.9 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4992V	Panasonic
25	1	R7	75 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF7502V	Panasonic
26	1	R8	34.8 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3482V	Panasonic
27	1	R9	47 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-47K	Yageo
28	1	R10	90.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9092V	Panasonic
29	1	R11	2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ205V	Panasonic
30	2	R12 R13	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
31	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
32	1	SCREW1	SCREW MACHINE PHIL 4-40X 3/16 SS	67413609	MSC Industrial Supply
33	1	L4	Bobbin, EE13, Vertical, 10 pins	YW-538-02B	Yih-Hwa
34	1	TERMINAL EYELET1	Terminal, Eyelet, Tin Plated Brass, Zierick PN 190	190	Zierick
35	1	TP3	Test Point, RED,THRU-HOLE MOUNT	5010	Keystone
36	1	U1	LinkSwitch, LNK405EG, eSIP	LNK405EG	Power Integrations
37	1	VR3	43 V, 5 W, 5%, DO204AC (DO-15)	P6KE43AG	On Semi
38	1	WASHER1	Washer, Lk, #4 SS	4NSLWS	Olander Co.

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6.2 TRIAC Dimmable, Power Factor Corrected Buck LED Driver

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1	1	BR1	800 V, 1 A, Bridge Rectifier, SMD, DFS	DF08S	Diodes Inc.
2	2	C1 C2	68 nF, 400 V, Film	ECQ-E4683KF	Panasonic
3	1	C3	2.2 μF, 400 V, Electrolytic, (8 x 11.5)	SMG400VB2R2M8X11LL	Nippon Chemi-Con
4	1	C4	10 μF, 50 V, Electrolytic, Gen Purpose, (5 x 11)	ECA-1HHG100	Panasonic
5	1	C5	1 μF, 100 V, Ceramic, X7R, 1206	ECJ-3YB1E105K	Panasonic
6	1	C6	120 μF, 50 V, Electrolytic, Very Low ESR, 61 mΩ, (8 x 15)	EKZE500ELL121MH15D	Nippon Chemi-Con
7	1	C7	100 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H104K	Panasonic
8	1	C8	220 nF, 400 V, Film	ECQ-E4224KF	Panasonic
9	1	C9	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
10	1	C10	22 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H223K	Panasonic
11	1	D5	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
12	1	D6	1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4007-13-F	Diodes Inc
13	1	D8	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
14	1	D10	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
15	1	D11	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diode Inc.
16	1	ESIP CLIP1	Heatsink Hardware, Edge Clip xxN (xx lbs) 14.33 mm L x 6.35 mm W	TRK-24	Kang Tang Hardware
17	1	F1	3.15 A, 250V, Slow, RST	507-1181	Belfuse
18	3	J1 J2 J3	3 Position (1 x 3) header, 0.1 pitch, Vertical	22-28-4030	Molex
19	1	JP1	Wire Jumper, Insulated, 22 AWG, 0.2 in	C2004-12-02	Gen Cable
20	1	L	Test Point, WHT,THRU-HOLE MOUNT	5012	Keystone
21	3	L1 L2	1500 μH, 0.25 A	SBC3-152-251	Tokin
22	2	N TP4	Test Point, BLK,THRU-HOLE MOUNT	5011	Keystone
23	3	Q2 Q4 Q6	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
24	1	Q3	400 V, 2 A, 4.4 Ohm, 600 V, N-Channel, DPAK	IRFRC20TRPBF	Vishay/Siliconix
25	1	Q7	PNP, Power BJT, 400 V, 2 A, SOT-428	2SA1862TLP	Rohm Semi
26	1	R23	Jumper		
27	1	R3	1.6 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ165V	Panasonic
28	1	R4	1 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
29	1	R5	49.9 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4992V	Panasonic
30	1	R7	66.5 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6652V	Panasonic
31	1	R8	34.8 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3482V	Panasonic
32	1	R9	47 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-47K	Yageo
33	1	R10	90.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9092V	Panasonic
34	1	R11	1.8 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ185V	Panasonic
35	2	R12 R13	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
36	2	R14 R15	750 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ754V	Panasonic
37	1	R16	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
38	1	R17	15 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ150V	Panasonic
39	1	R19	470 Ω, 5%, 1 W, Metal Oxide	RSF100JB-470R	Yageo
40	1	R20	470 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ474V	Panasonic
41	1	R21	470 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-470K	Yageo
42	1	R22	360 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ361V	Panasonic

43	2	R24 R27	36 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ363V	Panasonic
44	2	R25 R26	51 Ω, 5%, 2 W, Metal Oxide	RSF200JB-51R	Yageo
45	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
46	1	SCREW1	SCREW MACHINE PHIL 4-40X 3/16 SS	67413609	MSC Industrial Supply
47	1	L4	Bobbin, EE13, Vertical, 10 pins	YW-538-02B	Yih-Hwa
48	1	TERMINAL EYELET1	Terminal, Eyelet, Tin Plated Brass, Zierick PN 190	190	Zierick
49	1	TP3	Test Point, RED,THRU-HOLE MOUNT	5010	Keystone
50	1	U1	LinkSwitch, LNK405EG, eSIP	LNK405EG	Power Integrations
51	1	VR1	15 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5245B-7	Diodes Inc
52	1	VR2	91 V, 1.5 W, DO-41	BZY97C91	Fagor
53	1	VR3	43 V, 5 W, 5%, DO204AC (DO-15)	P6KE43AG	On Semi
54	1	WASHER1	Washer, Lk, #4 SS	4NSLWS	Olander Co.

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7 Heatsink Assembly

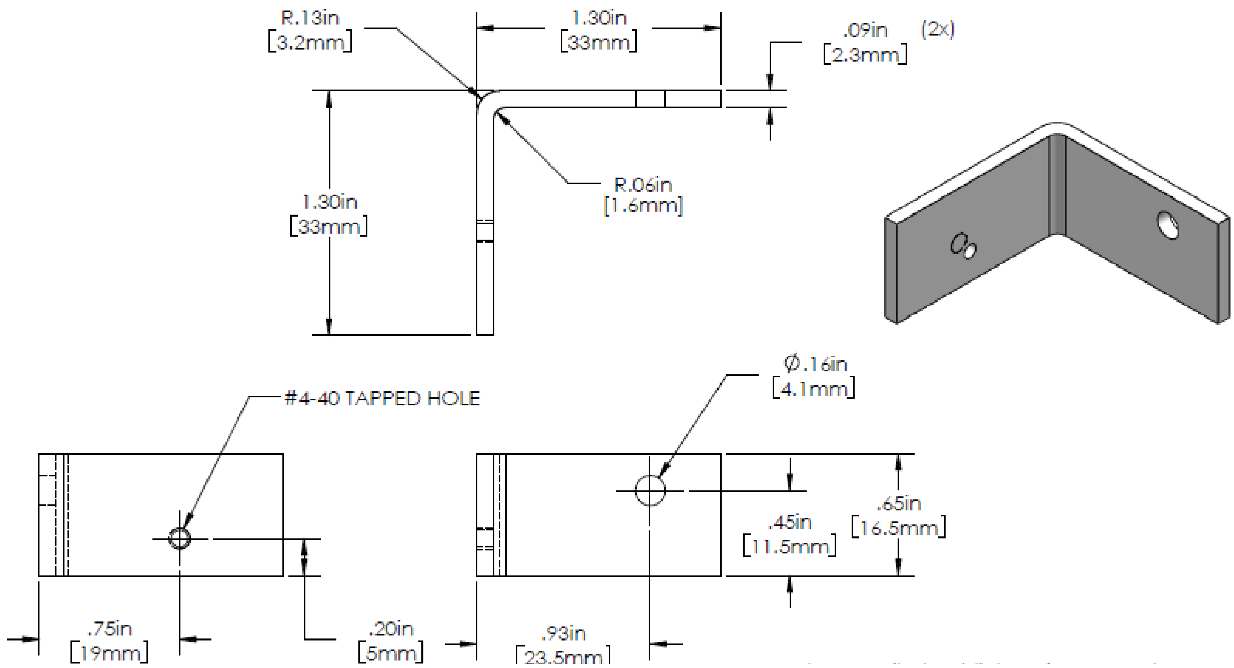
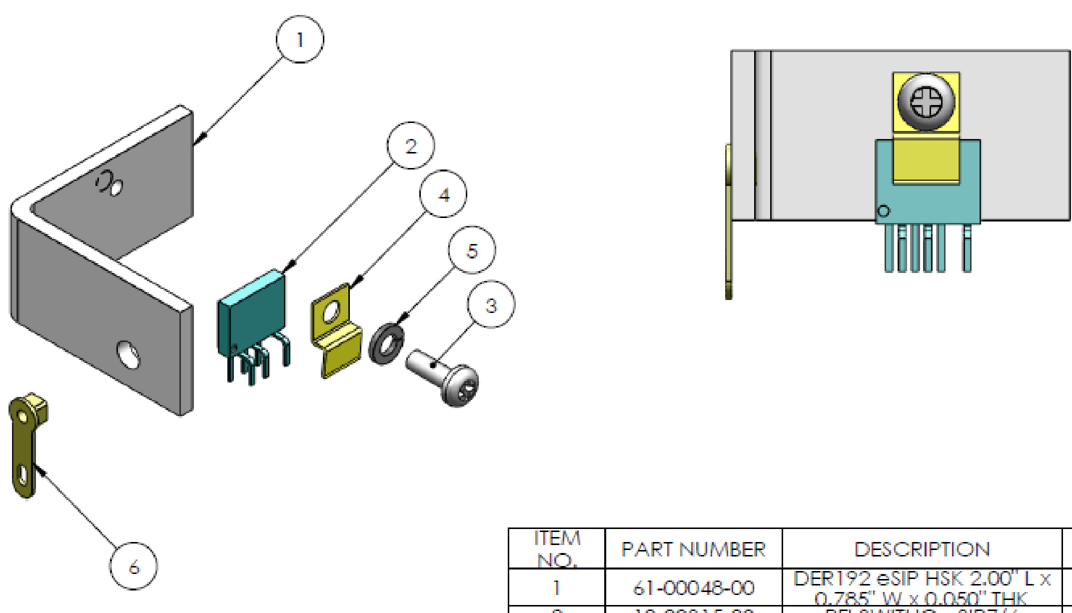


Figure 8 – Heatsink Dimensions



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	61-00048-00	DER192 eSIP HSK 2.00" L x 0.785" W x 0.050" THK	1
2	10-00315-00	PFI SWITHC,eSIP7/6	1
3	75-00002-00	SCREW 4-40 X 5/16 SS	1
4	60-00037-00	EDGE CLIP, 14.33mm L x 6.35mmW	1
5	75-00032-00	WASHER FLAT #4 SS	1
6	60-00016-00	TERMINAL, EYELET, ZIERICK PN 190	1

Figure 9 – Heatsink Assembly Drawing.

8 Inductor Specification

8.1 Electrical Diagram

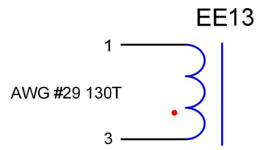


Figure 10 – Inductor Electrical Diagram.

8.2 Electrical Specifications

Inductance	Pins 1-3, all other windings open, measured at 66 kHz, 0.4 VRMS	680 µH ±5%
Resonant Frequency	Pins 1-3, all other windings open	1 MHz (Min.)

8.3 Materials

Item	Description
[1]	Core: PC44 EE13 (NC2H)
[2]	Bobbin: EE13, Vertical, 10 pins, 5/5.
[3]	Magnet Wire: #29 AWG.
[4]	Tape: 3M 1298 Polyester Film, 7.5 mm wide.

8.4 Inductor Build Diagram

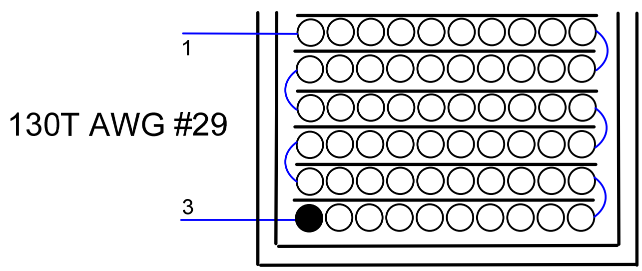


Figure 11 – Inductor Build Diagram.

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9 Performance Data

All measurements performed at room temperature.

9.1 Non-Dimming Configuration Performance Data

The following data were measured using 3 sets of load (i.e. 11, 12, and 13 LED strings to represent the load range of 30 V ~ 36 V output voltage). Refer to the table on Section 9.1.5 for the complete set of test data values.

9.1.1 Efficiency

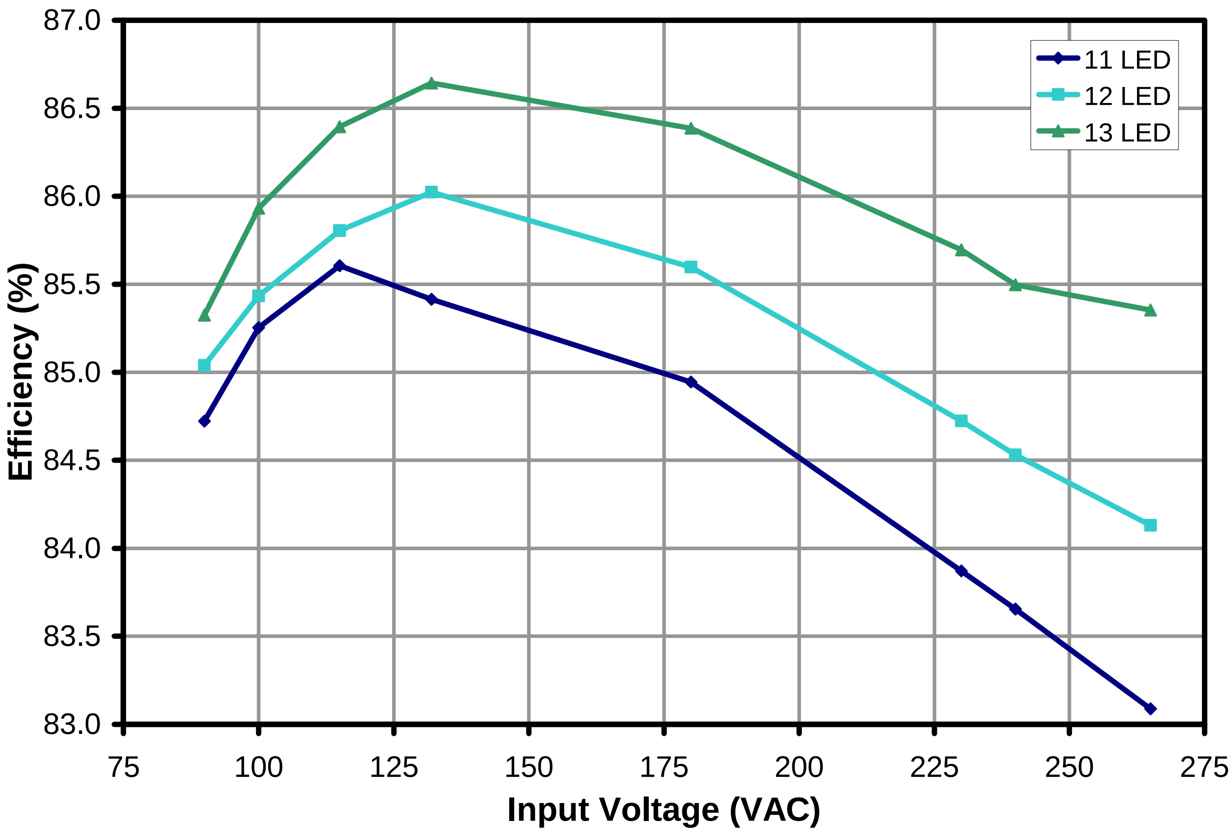

Figure 12 – Efficiency vs. Load and Input Voltage.

9.1.2 Line and Load Regulation

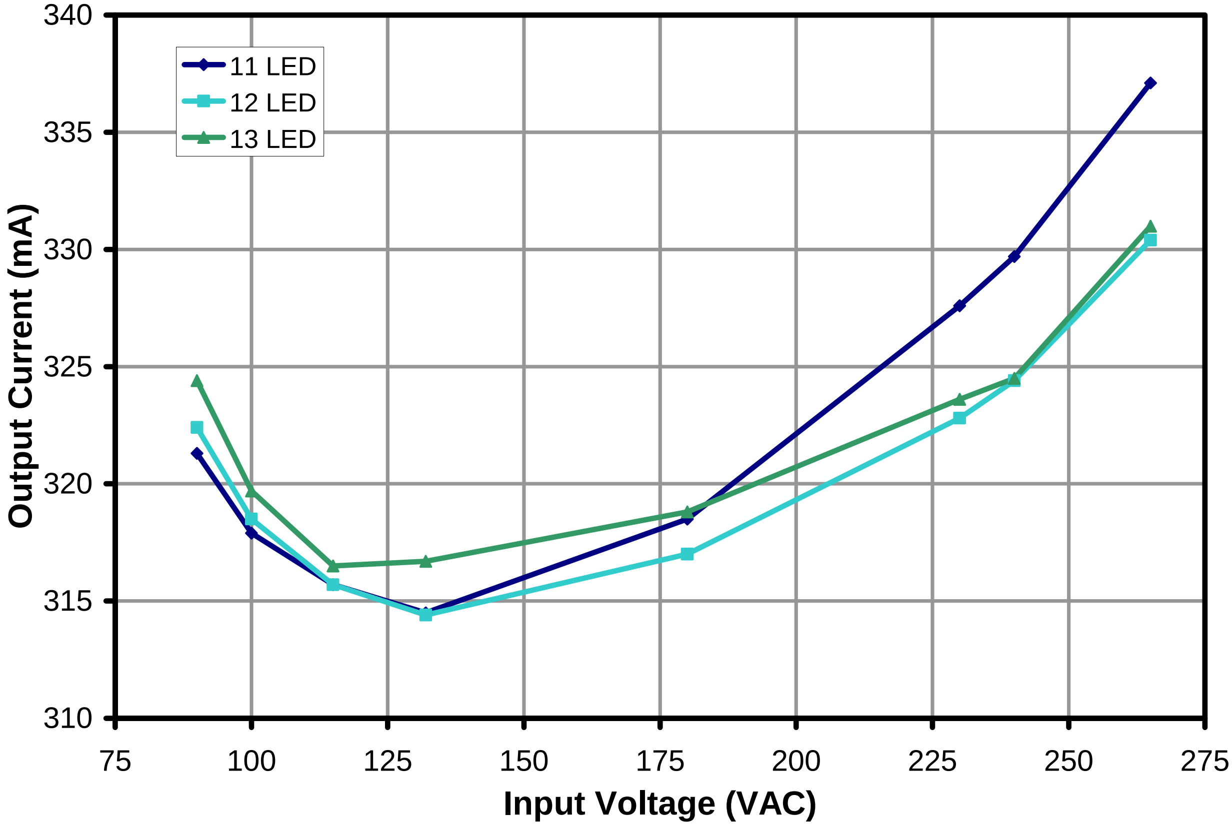

Figure 13 – Regulation vs. Load and Input Voltage.

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9.1.3 Power Factor

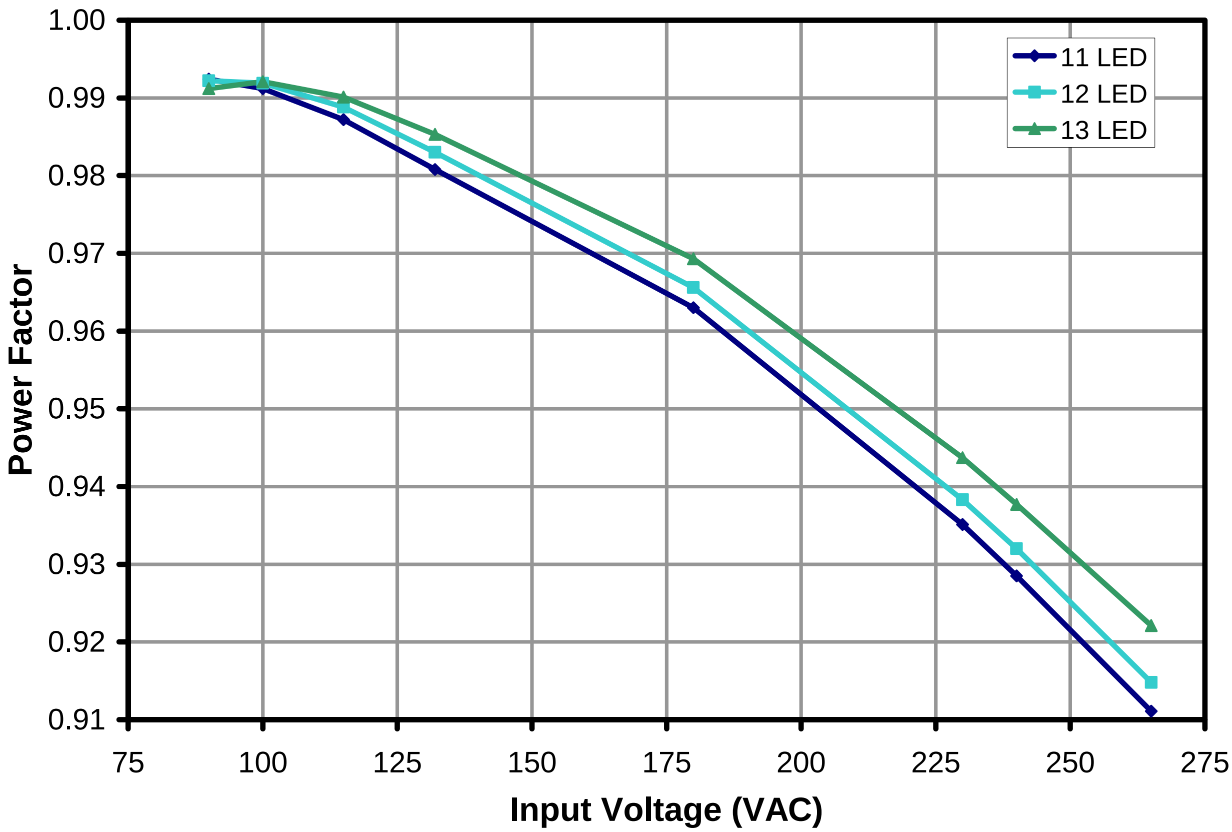

Figure 14 – Power Factor vs. Load and Input Voltage.

9.1.4 Harmonics

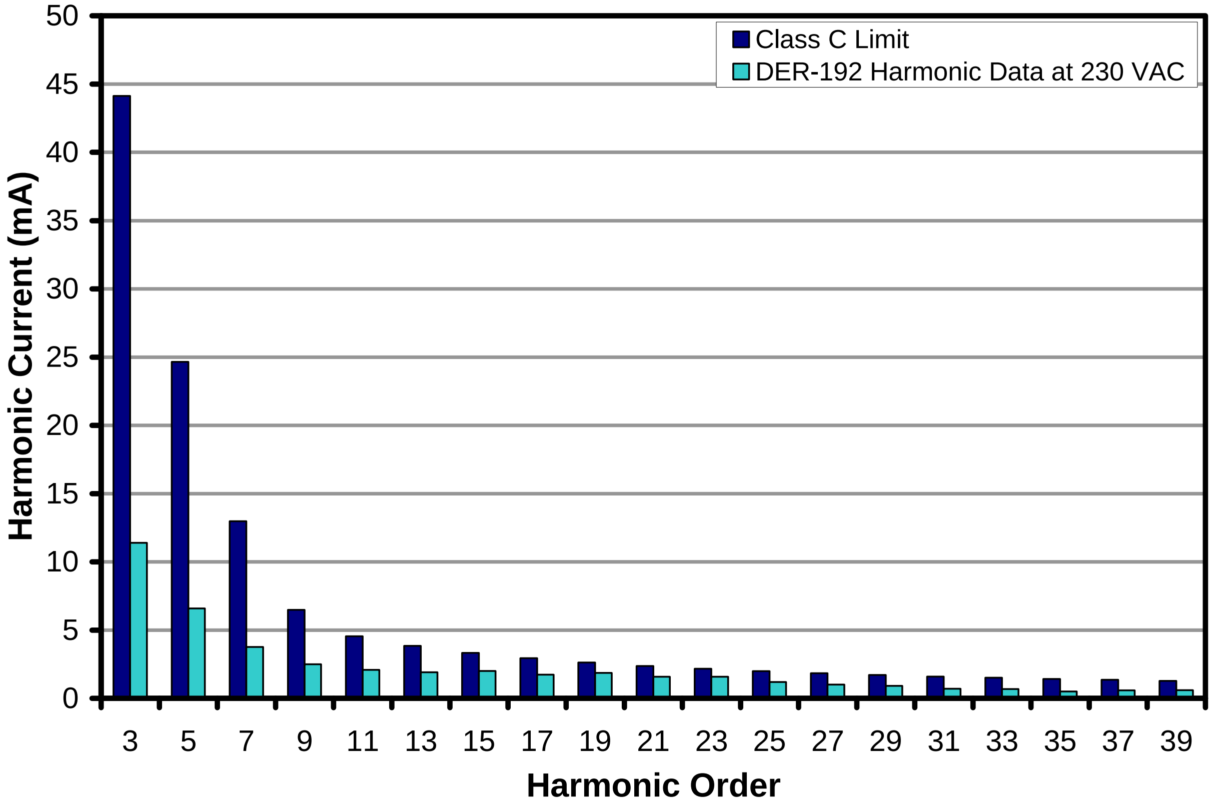

Figure 15 – 230 VAC Input Current Harmonics.

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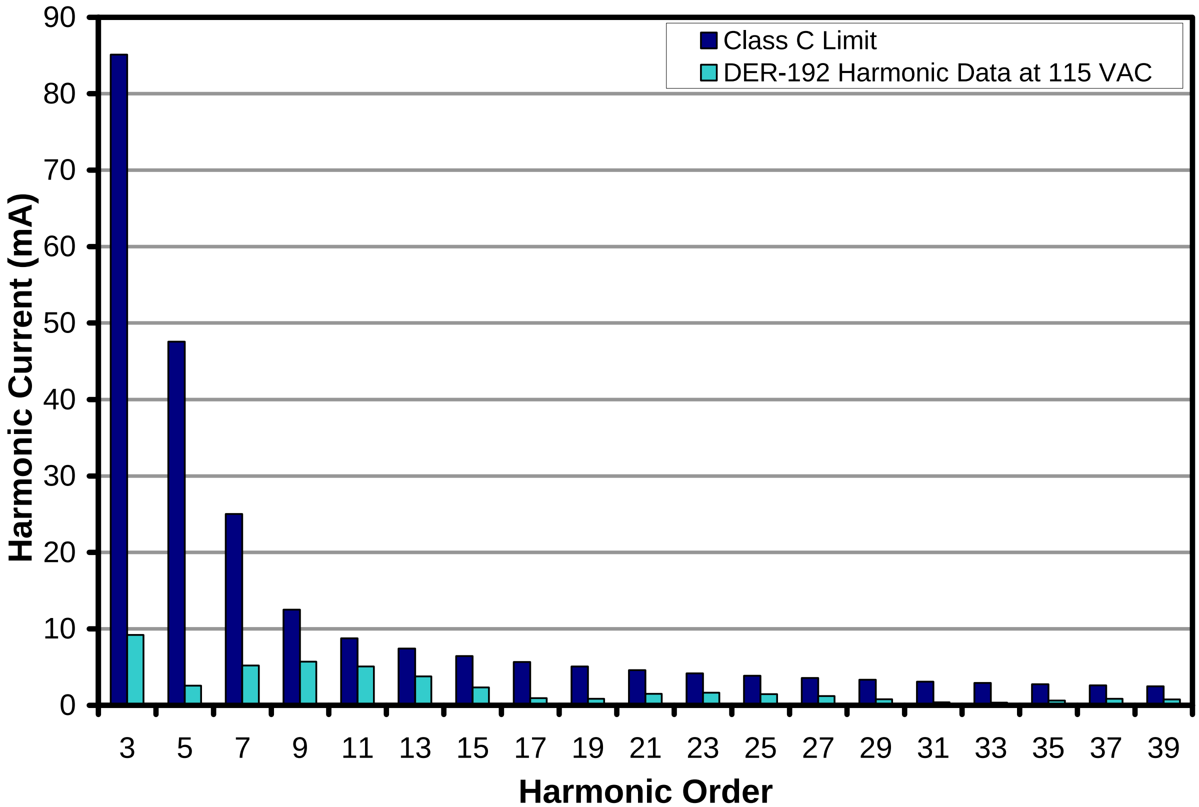

Figure 16 – 115 VAC Input Current Harmonics.

9.1.5 Non-Dimming Configuration Test Data, 11 LED Load.

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.13328	11.927	0.9924	31.45	321.3	10.105	84.72
100	60	0.11815	11.731	0.9912	31.46	317.9	10.001	85.25
115	60	0.10201	11.602	0.9872	31.46	315.7	9.932	85.61
132	60	0.08946	11.58	0.9808	31.45	314.5	9.891	85.41
180	50	0.0679	11.796	0.963	31.46	318.5	10.020	84.94
230	50	0.05705	12.3	0.9351	31.49	327.6	10.316	83.87
240	50	0.05556	12.411	0.9285	31.49	329.7	10.382	83.65
265	50	0.05281	12.78	0.9111	31.50	337.1	10.619	83.09

9.1.6 Non-Dimming Configuration Test Data, 12 LED Load.

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.14437	12.909	0.9922	34.05	322.4	10.978	85.04
100	60	0.12761	12.679	0.9919	34.01	318.5	10.832	85.43
115	60	0.10987	12.517	0.9888	34.02	315.7	10.740	85.80
132	60	0.0957	12.441	0.983	34.04	314.4	10.702	86.02
180	50	0.0724	12.61	0.9656	34.05	317	10.794	85.60
230	50	0.05999	12.977	0.9383	34.06	322.8	10.995	84.72
240	50	0.05832	13.075	0.932	34.07	324.4	11.052	84.53
265	50	0.05508	13.384	0.9148	34.08	330.4	11.260	84.13

9.1.7 Non-Dimming Configuration Test Data, 13 LED Load

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.15729	14.052	0.9912	36.96	324.4	11.990	85.32
100	60	0.13824	13.732	0.9921	36.91	319.7	11.800	85.93
115	60	0.11853	13.518	0.9901	36.9	316.5	11.679	86.39
132	60	0.10355	13.495	0.9853	36.92	316.7	11.693	86.64
180	50	0.07792	13.625	0.9693	36.92	318.8	11.770	86.39
230	50	0.06413	13.953	0.9437	36.95	323.6	11.957	85.69
240	50	0.06223	14.028	0.9377	36.96	324.5	11.994	85.50
265	50	0.05849	14.333	0.9221	36.96	331	12.234	85.35

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9.1.8 230 VAC, 50 Hz Harmonics Data, P_{IN} = 12.977 W

n	Measured (mA)	Base I Harmonics (mA/W)	230 V Limit (mA)	Remarks
1	61.340			
2	0.040			
3	11.390	3.40000	44.122	Pass
5	6.600	1.90000	24.656	Pass
7	3.770	1.00000	12.977	Pass
9	2.500	0.50000	6.489	Pass
11	2.090	0.35000	4.542	Pass
13	1.910	0.29615	3.843	Pass
15	2.020	0.25667	3.331	Pass
17	1.740	0.22647	2.939	Pass
19	1.860	0.20263	2.630	Pass
21	1.590	0.18333	2.379	Pass
23	1.580	0.16739	2.172	Pass
25	1.200	0.15400	1.998	Pass
27	1.020	0.14259	1.850	Pass
29	0.910	0.13276	1.723	Pass
31	0.710	0.12419	1.612	Pass
33	0.690	0.11667	1.514	Pass
35	0.510	0.11000	1.427	Pass
37	0.590	0.10405	1.350	Pass
39	0.610	0.09872	1.281	Pass

9.1.9 115 VAC, 60 Hz Harmonics Data, P_{IN} = 12.517 W

n	Measured (mA)	Base I Harmonics (mA/W)	230 V Limit (mA)	Remarks
1	112.850			
2	0.050			
3	9.220	3.40000	85.11560	Pass
5	2.580	1.90000	47.56460	Pass
7	5.200	1.00000	25.03400	Pass
9	5.700	0.50000	12.51700	Pass
11	5.080	0.35000	8.76190	Pass
13	3.770	0.29615	7.41392	Pass
15	2.330	0.25667	6.42539	Pass
17	0.930	0.22647	5.66946	Pass
19	0.860	0.20263	5.07268	Pass
21	1.490	0.18333	4.58957	Pass
23	1.640	0.16739	4.19047	Pass
25	1.460	0.15400	3.85524	Pass
27	1.210	0.14259	3.56966	Pass
29	0.780	0.13276	3.32348	Pass
31	0.390	0.12419	3.10906	Pass
33	0.340	0.11667	2.92063	Pass
35	0.600	0.11000	2.75374	Pass
37	0.840	0.10405	2.60489	Pass
39	0.770	0.09872	2.47131	Pass

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9.2 Dimming Configuration Performance Data

The following data were measured using 3 sets of load, 11, 12 and 13 LED strings to represent the load range of 30 V ~ 36 V output voltage. Refer to the tables for the complete set of test data values.

9.2.1 Efficiency

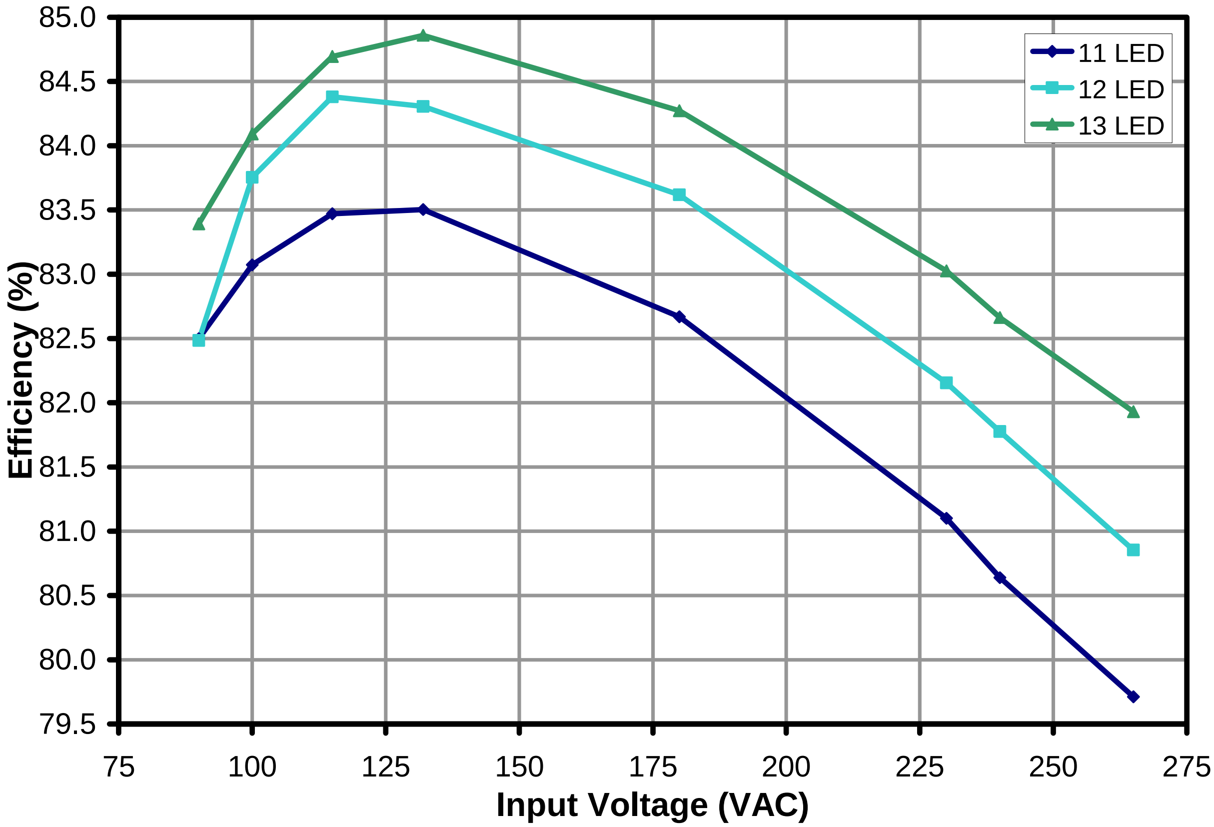

Figure 17 – Efficiency vs Load and Input Voltage.

9.2.2 Line and Load Regulation

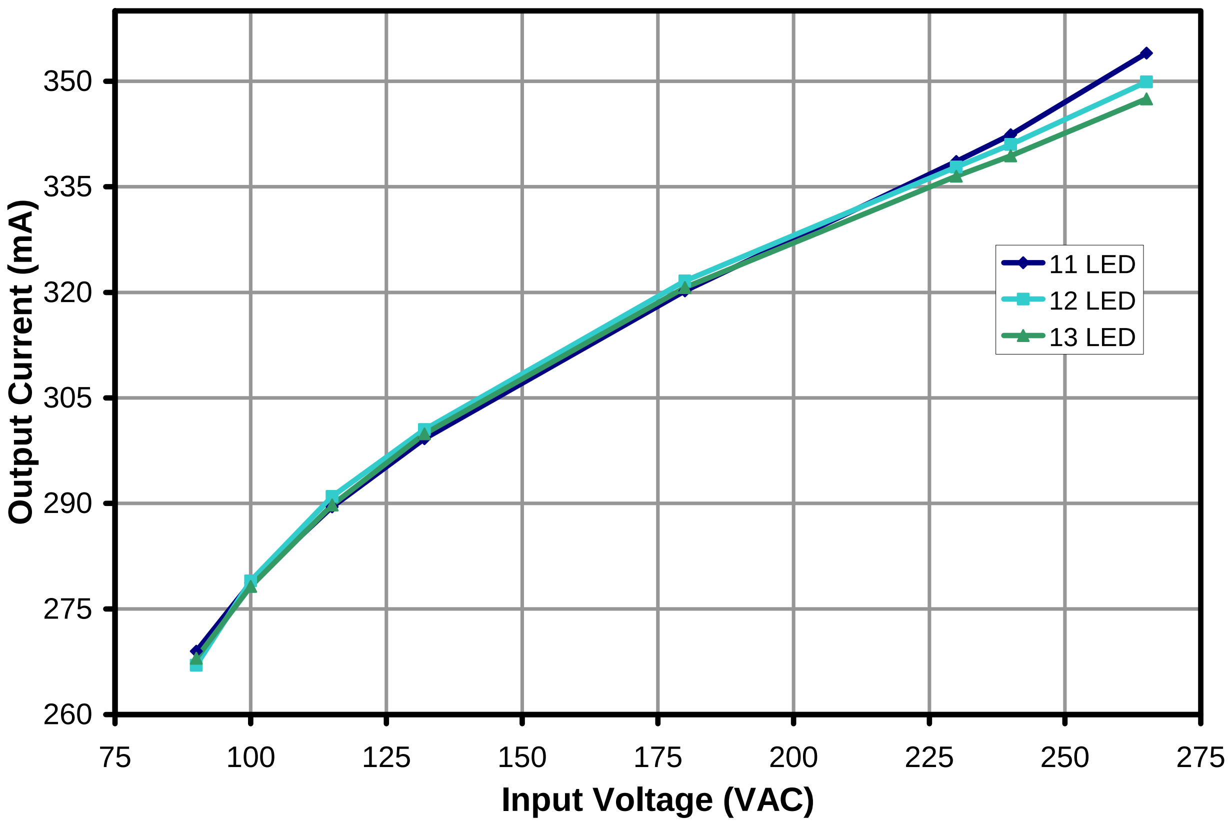

Figure 18– Regulation vs. Load and Input Voltage.

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9.2.3 Power Factor

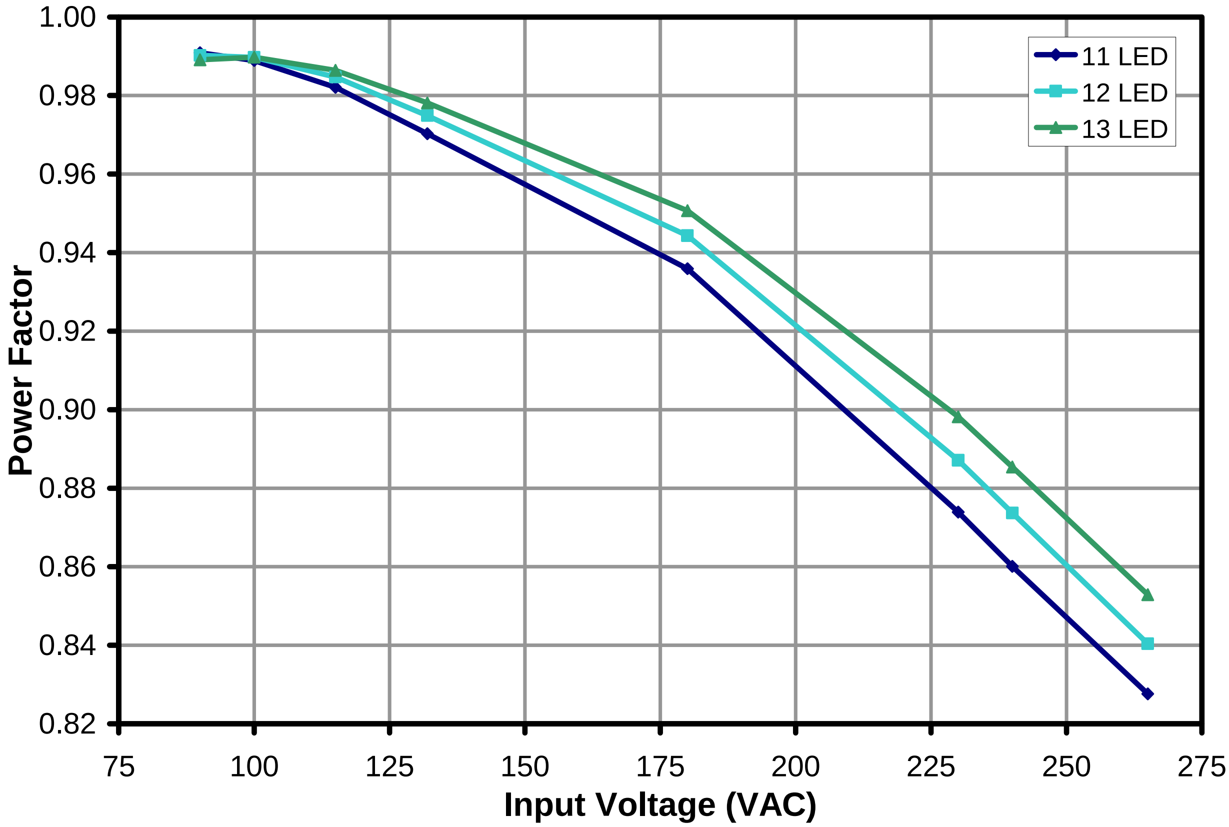

Figure 19 – Power Factor vs. Load and Input Voltage.

9.2.4 Dimming Performance

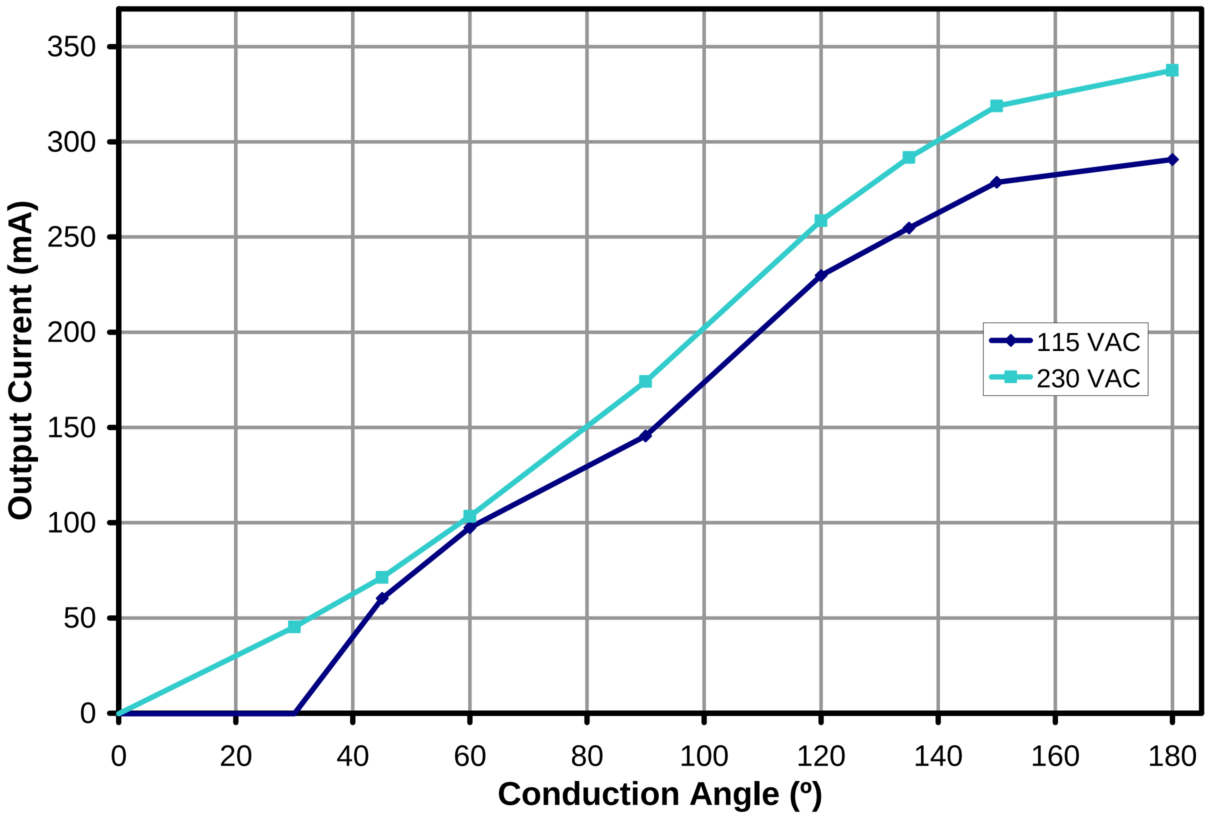

Figure 20 – Dimming Performance.

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9.2.5 Dimming Configuration Test Data, 11 LED Load

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.11532	10.307	0.9909	31.61	269	8.503	82.50
100	60	0.10678	10.578	0.9889	31.53	278.7	8.787	83.07
115	60	0.09667	10.939	0.9821	31.54	289.5	9.131	83.47
132	60	0.08803	11.301	0.9703	31.54	299.2	9.437	83.50
180	50	0.07245	12.232	0.9359	31.58	320.2	10.112	82.67
230	50	0.06558	13.214	0.8739	31.65	338.6	10.717	81.10
240	50	0.06488	13.426	0.8601	31.62	342.4	10.827	80.64
265	50	0.0639	14.047	0.8276	31.63	354	11.197	79.71

9.2.6 Dimming Configuration Test Data, 12 LED Load

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.12442	11.106	0.9902	34.31	267	9.161	82.48
100	60	0.11547	11.446	0.9897	34.36	279	9.586	83.75
115	60	0.1045	11.86	0.9847	34.39	291	10.007	84.38
132	60	0.09498	12.251	0.9749	34.37	300.5	10.328	84.30
180	50	0.07758	13.219	0.9443	34.37	321.6	11.053	83.62
230	50	0.06925	14.165	0.8871	34.45	337.8	11.637	82.15
240	50	0.06825	14.353	0.8737	34.42	341	11.737	81.78
265	50	0.06675	14.904	0.8404	34.44	349.9	12.051	80.85

9.2.7 Dimming Configuration Test Data, 13 LED Load

V_{IN} (VAC)	Line Frequency (Hz)	I_{IN} (A)	P_{IN} (W)	PF	V_{OUT} (V)	I_{OUT} (mA)	P_{OUT} (W)	Efficiency (%)
90	60	0.13307	11.865	0.9891	36.92	268	9.895	83.39
100	60	0.12335	12.234	0.9898	36.98	278.2	10.288	84.09
115	60	0.11153	12.674	0.9864	37.04	289.8	10.734	84.69
132	60	0.10133	13.108	0.9781	37.09	299.9	11.123	84.86
180	50	0.08238	14.126	0.9507	37.12	320.7	11.904	84.27
230	50	0.07279	15.077	0.8982	37.2	336.5	12.518	83.03
240	50	0.07157	15.253	0.8854	37.15	339.4	12.609	82.66
265	50	0.06957	15.761	0.8529	37.16	347.5	12.913	81.93

9.2.8 115 VAC Dimming Data (TRIAC: DING CHUNG 110 V, 800 W)

Conduction Angle (°)	I_{OUT} (mA)
180	291
150	279
135	255
120	230
90	145.8
60	97.66
45	60.58
30	0
0	0

9.2.9 230 VAC Dimming Data (TRIAC: YUEFENG 250 V, 10 A)

Conduction Angle (°)	I_{OUT} (mA)
180	337.8
150	319
135	292
120	258.8
90	174.46
60	103.62
45	71.62
30	45.54
0	0

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10 Waveforms

10.1 Non-Dimming Configuration

10.1.1 Input Line Current

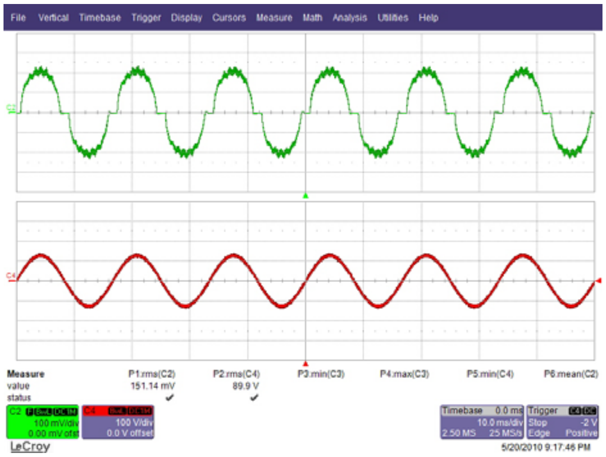

Figure 21 – 90 VAC 60 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

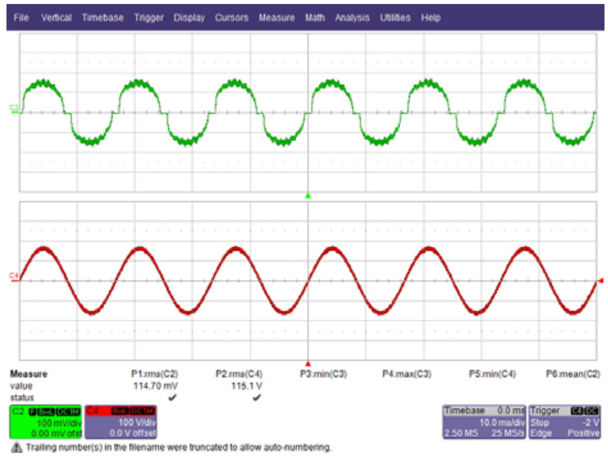

Figure 22 – 115 VAC 60 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

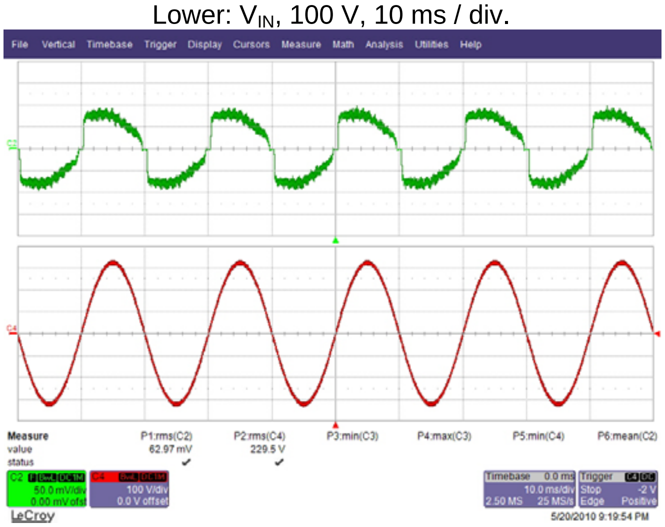

Figure 23 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

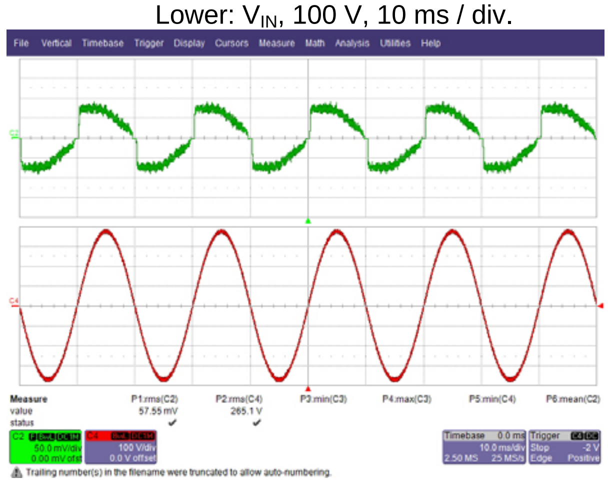

Figure 24 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

10.1.2 Drain Voltage and Current Normal Operation

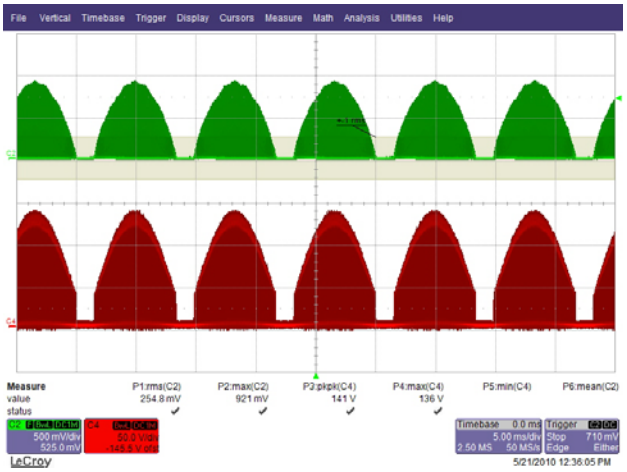

Figure 25 – 90 VAC 60Hz, Full Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 5 ms / div.

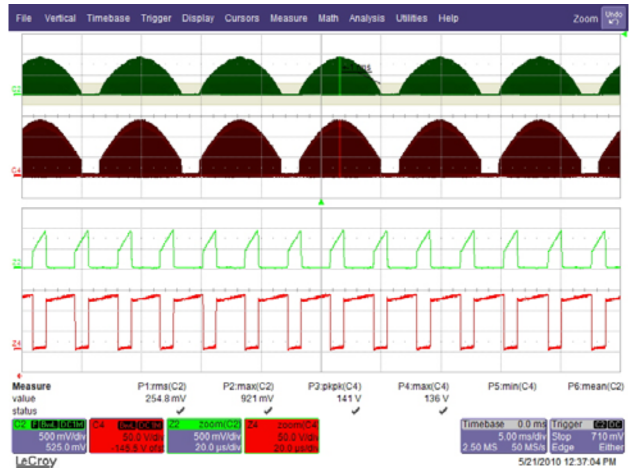

Figure 26 – 90 VAC 60Hz, Full Load.
Upper: Normal.
Lower: Zoomed-in.

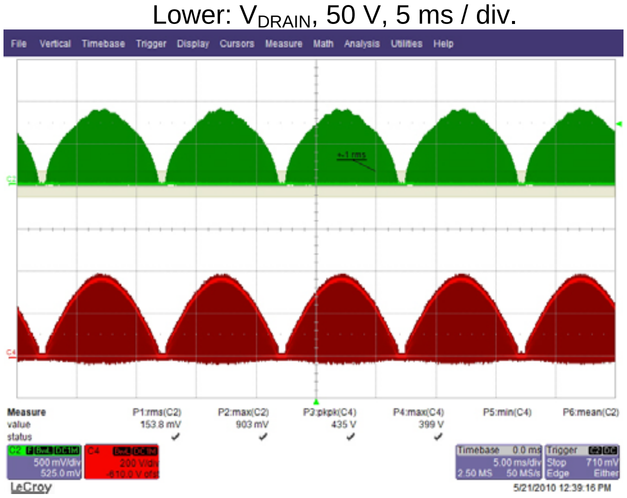

Figure 27 – 265 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

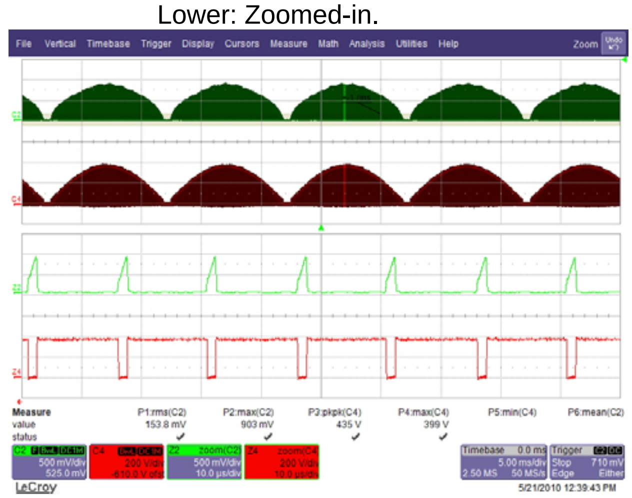

Figure 28 – 265 VAC 50 Hz, Full Load.
Upper: Normal.
Lower: Zoomed-in.

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10.1.3 Drain Voltage and Current Start-up Operation

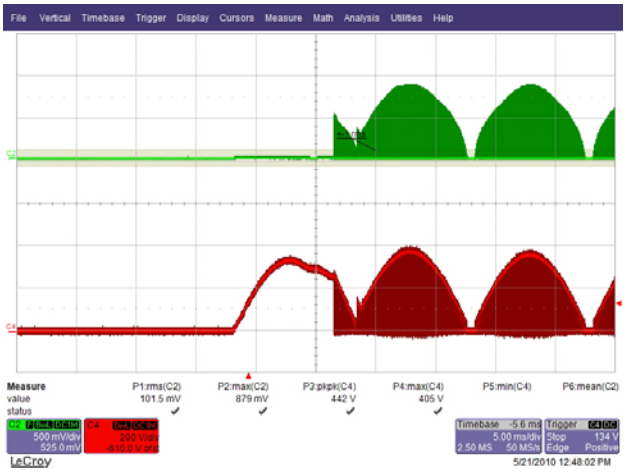

Figure 29 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

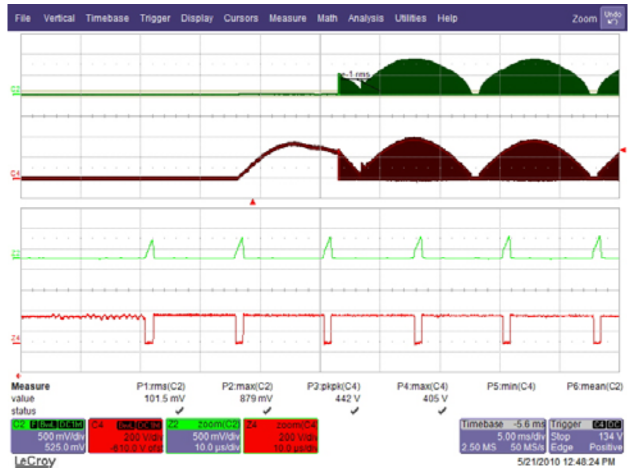

Figure 30 – 265 VAC 50 Hz, Full Load Start-up.
Upper: Normal.
Lower: Zoomed-in.

10.1.4 Output Current and Output Voltage

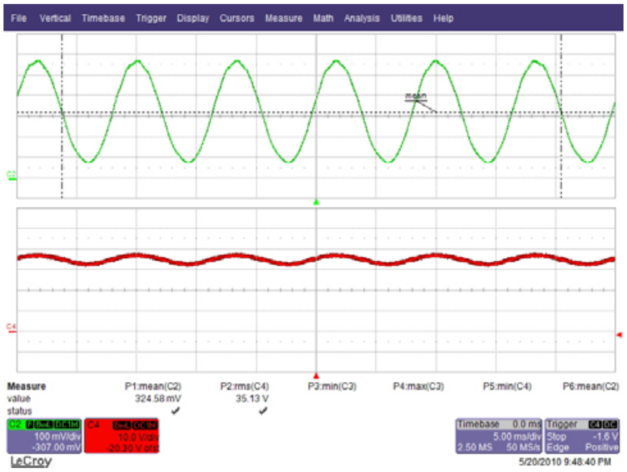

Figure 31 – 90 VAC 60 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

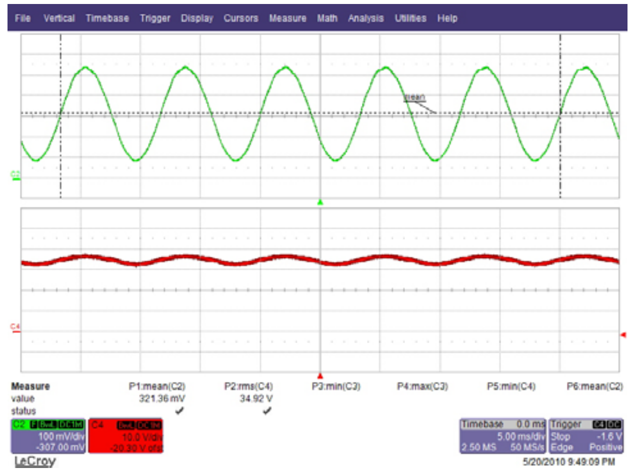

Figure 32 – 115 VAC 60 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

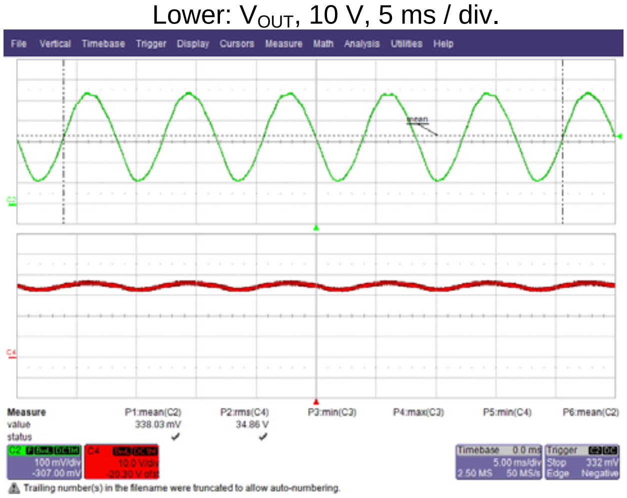

Figure 33 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

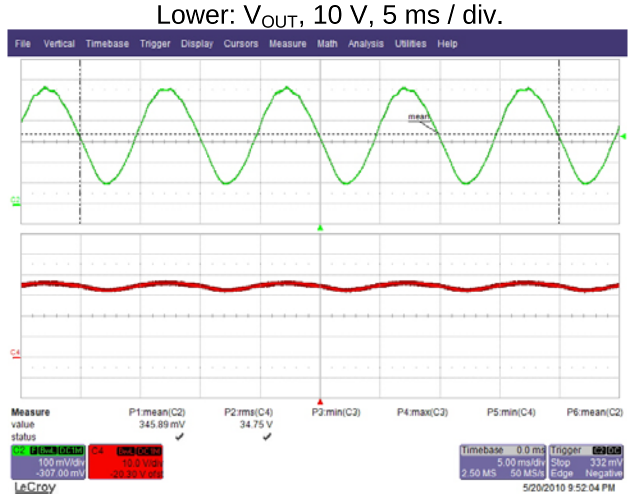

Figure 34 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

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10.1.5 Output Current Ripple

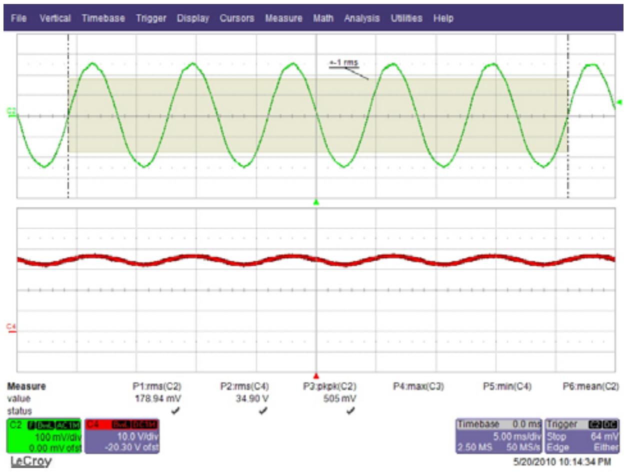

Figure 35 – 90 VAC 60 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

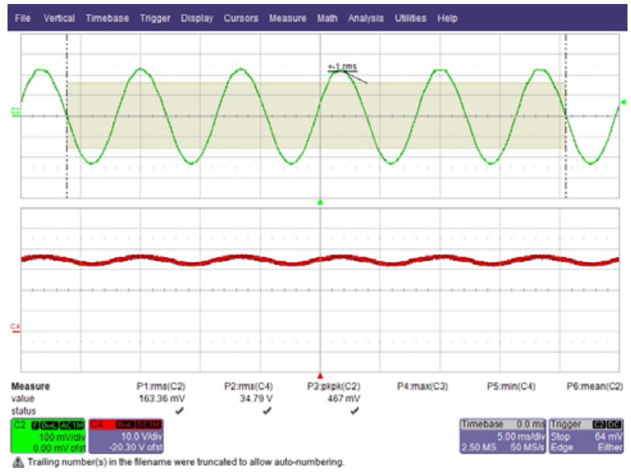

Figure 36 – 115 VAC 60 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

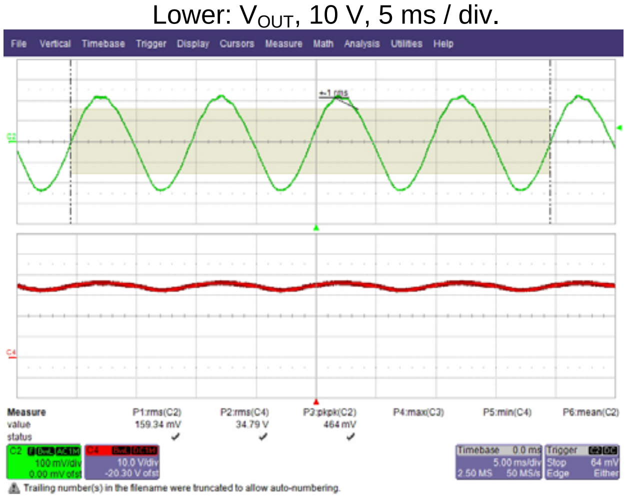

Figure 37 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

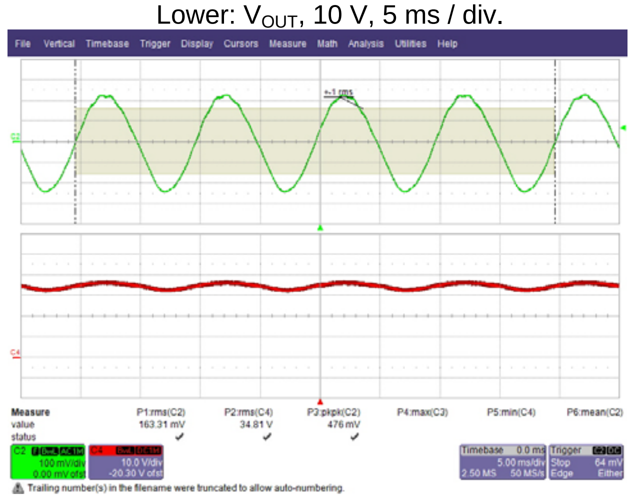

Figure 38 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

10.1.6 Output Current and Voltage at Power-up, Power-down

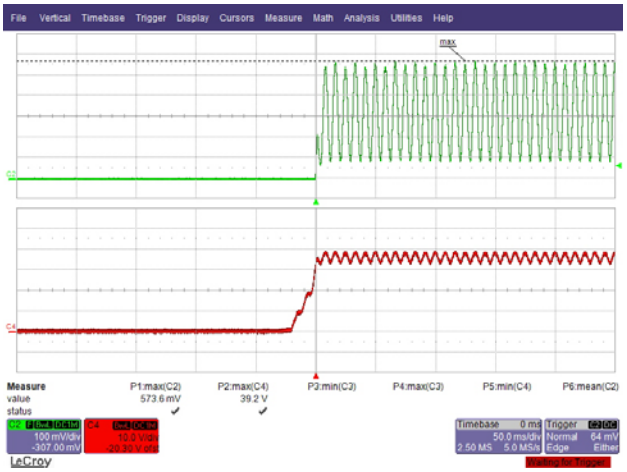

Figure 39 – 90 VAC 60Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 50 ms / div.

Figure 40 – 90 VAC 60Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 50 ms / div.

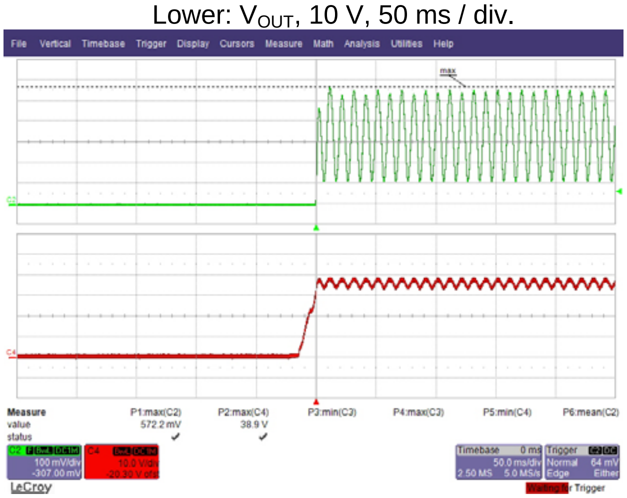

Figure 41 – 265 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 50 ms / div.

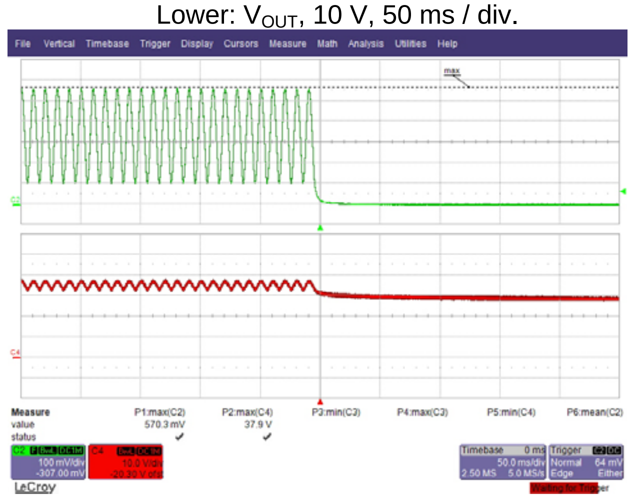

Figure 42 – 265 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 500 ms / div.

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10.1.7 Output Short

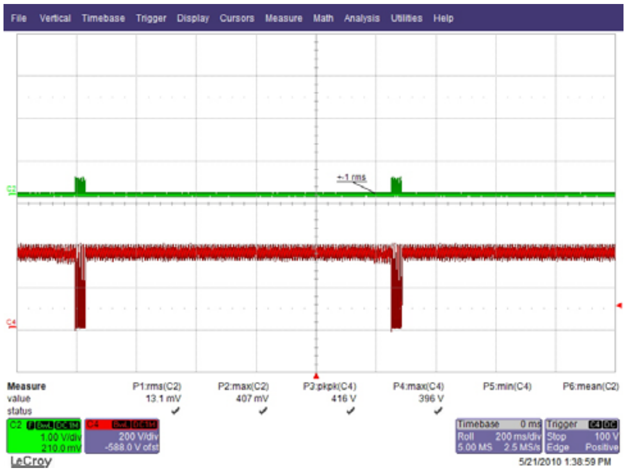

Figure 43 – 265 VAC 60 Hz, Output Short.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V, 200 ms / div.

Figure 44 – 265 VAC 60 Hz, Output Short.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V, 10 ms / div.

10.1.8 Open Load/LED Condition

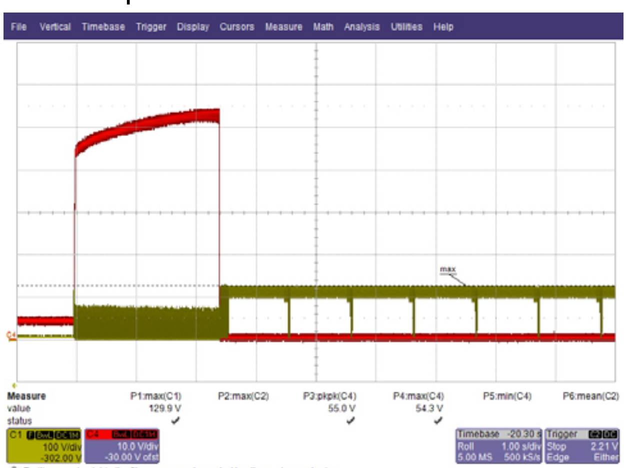

Figure 45 – 90 VAC 60 Hz, Open Load.
CH1: V_{DRAIN}, 100 V / div.
CH4: V_{OUT}, 10 V, 1s / div.

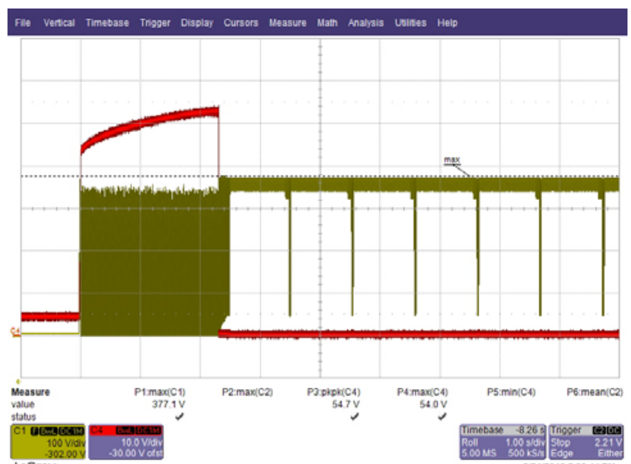

Figure 46 – 265 VAC 60 Hz, Open Load.
CH1: V_{DRAIN}, 100 V / div.
CH4: V_{OUT}, 10 V, 1s / div.

10.2 Dimming Configuration

10.2.1 Input Current at Full Conduction Angle

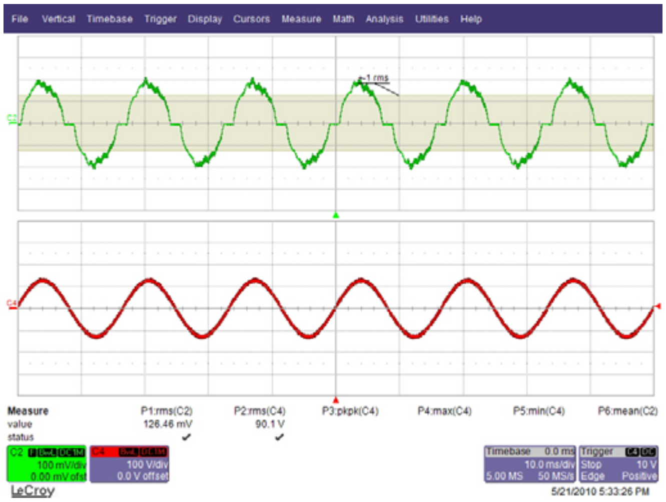

Figure 47 – 90 VAC 60 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

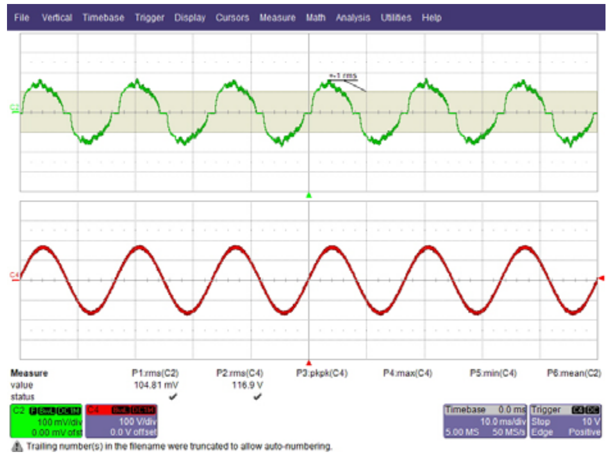

Figure 48 – 115 VAC 60 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

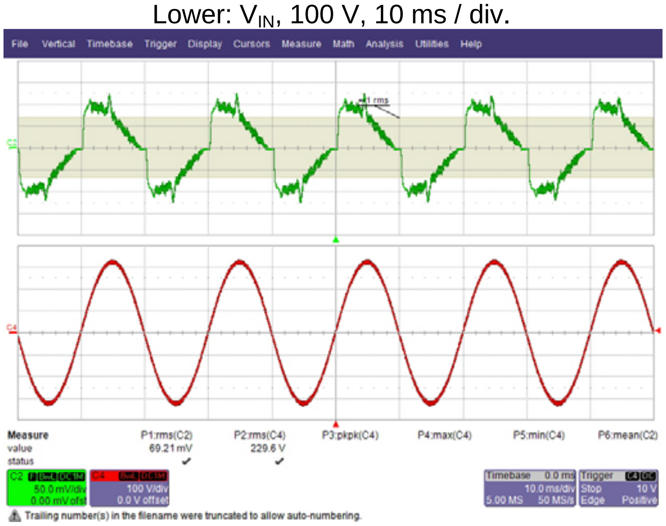

Figure 49 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

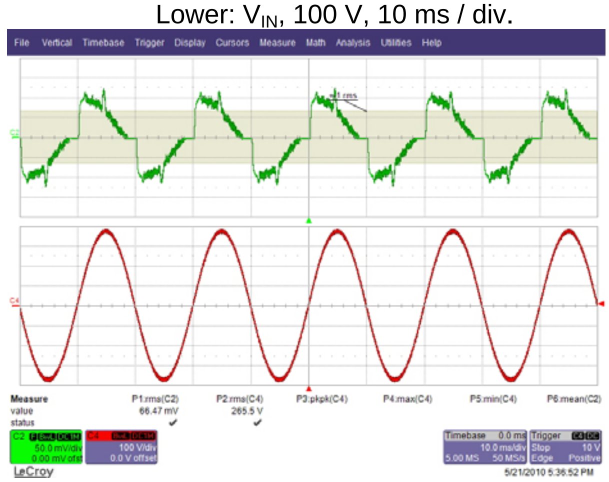

Figure 50 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

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10.2.2 Input Current at Different Dimming Angle

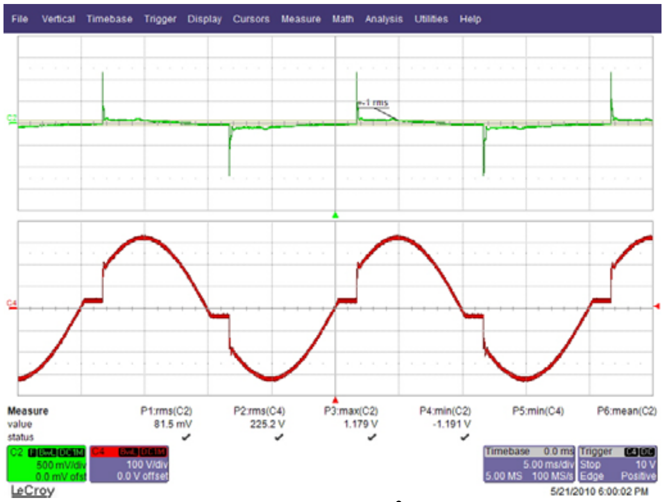

Figure 51 – 230 VAC 50 Hz, 150˚ Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

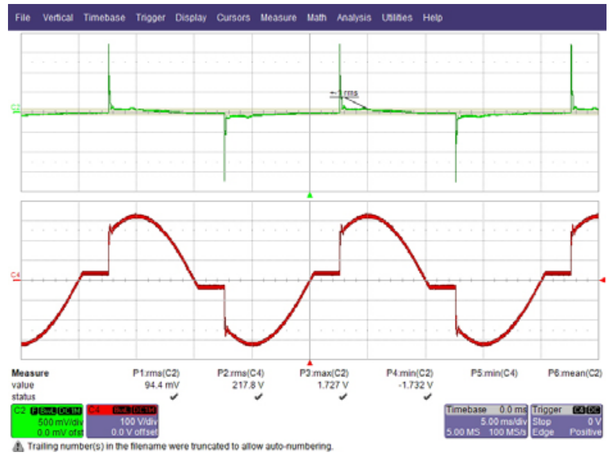

Figure 52 – 230 VAC 50 Hz, 135˚ Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

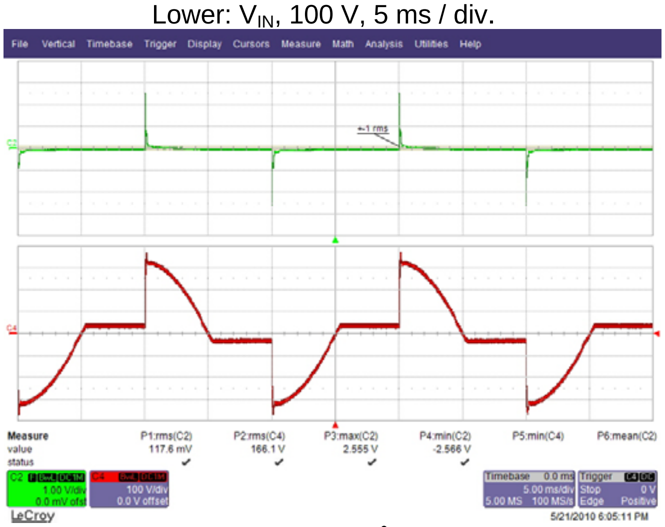

Figure 53 – 230 VAC 50 Hz, 90˚ Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V, 5 ms / div.

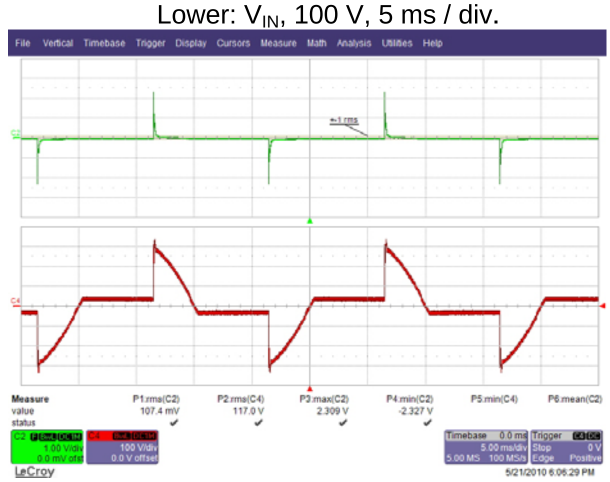

Figure 54 – 230 VAC 50 Hz, 60˚ Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V, 5 ms / div.

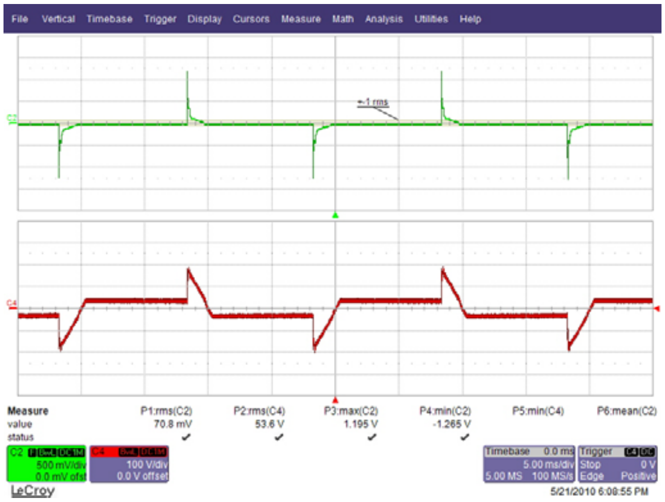

Figure 55 – 230 VAC 50 Hz, 45˚ Conduction Angle.
Upper: I_{IN}, 1 A / div.
Lower: V_{IN}, 100 V, 5 ms / div.

10.2.3 Output Current at Different Conduction Angle: 115 VAC, 60Hz

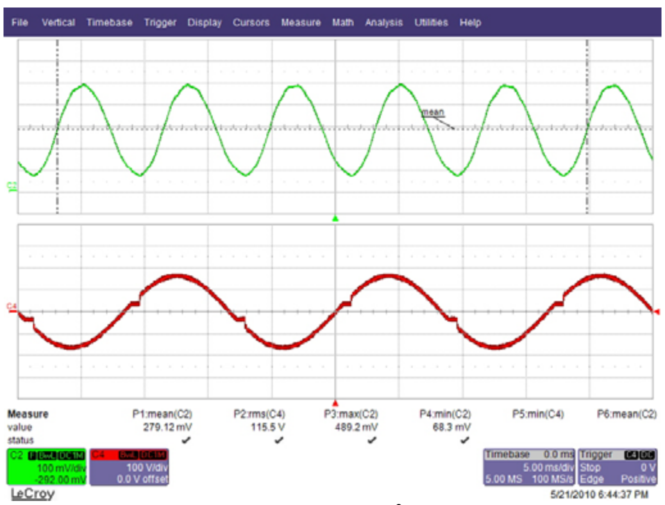

Figure 56 – 115 VAC 60 Hz, 150˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

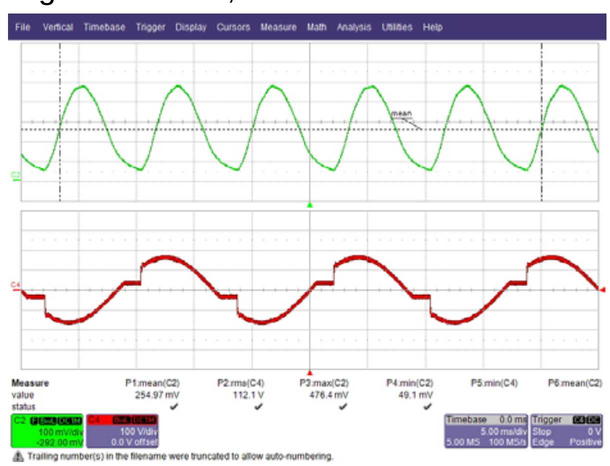

Figure 57 – 115 VAC 60 Hz, 135˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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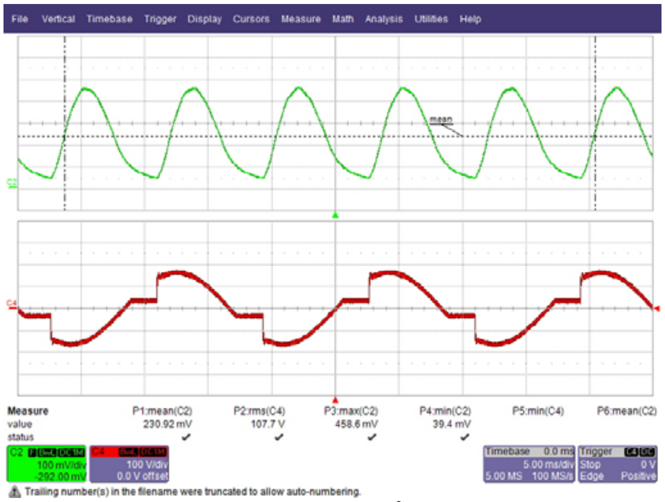

Figure 58 – 115 VAC 60 Hz, 120˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

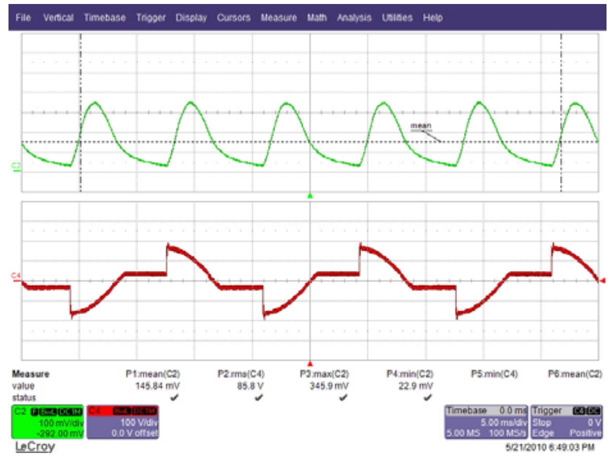

Figure 59 – 115 VAC 60 Hz, 90˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

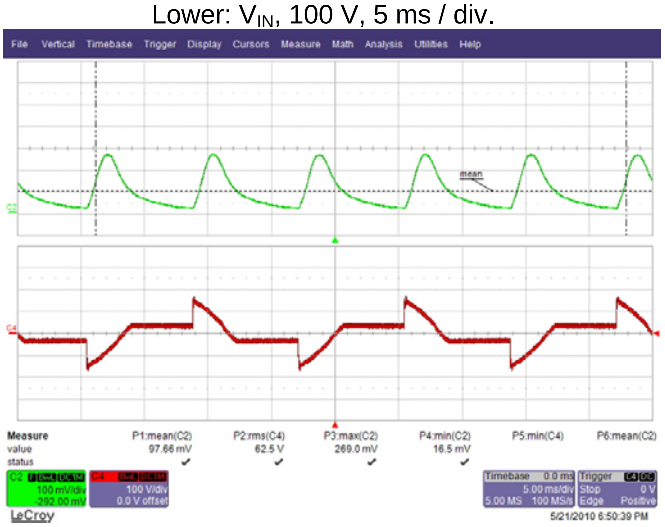

Figure 60 – 115 VAC 60 Hz, 60˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

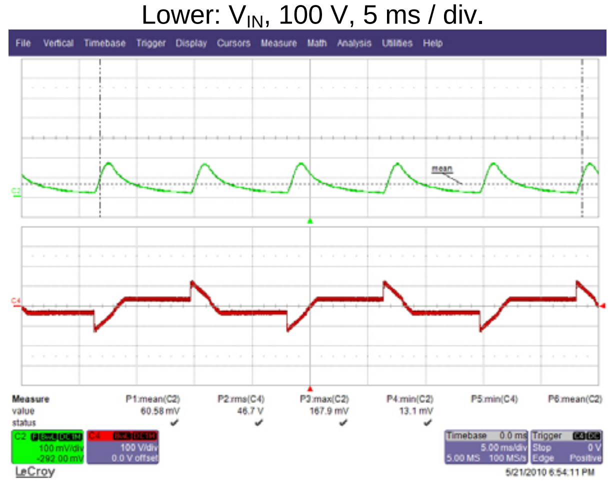

Figure 61 – 115 VAC 60 Hz, 45˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

10.2.4 Output Current at Different Conduction Angle: 230 VAC, 50Hz

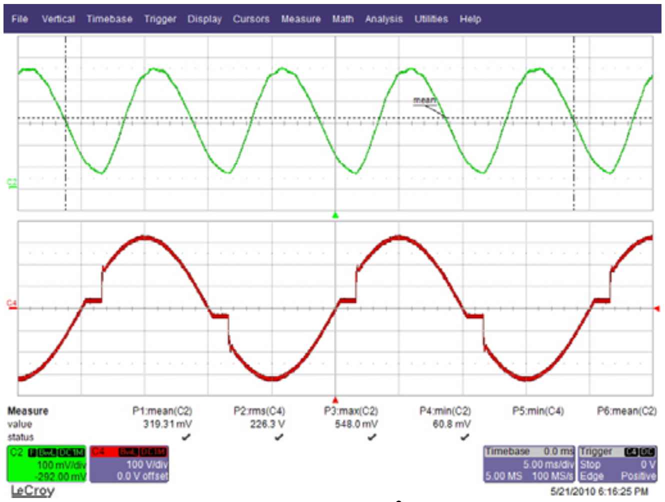

Figure 62 – 230 VAC 50 Hz, 150˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

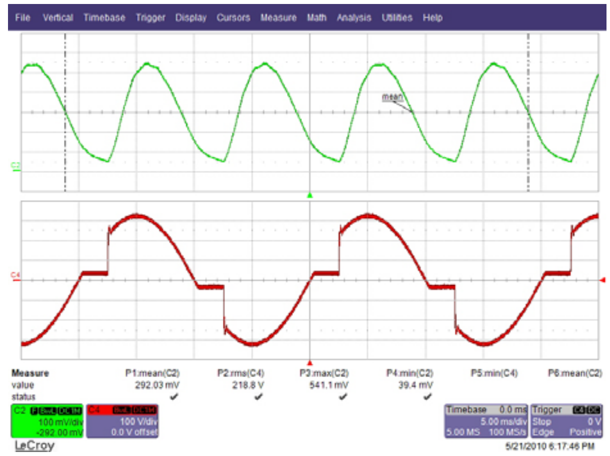

Figure 63 – 230 VAC 50 Hz, 135˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

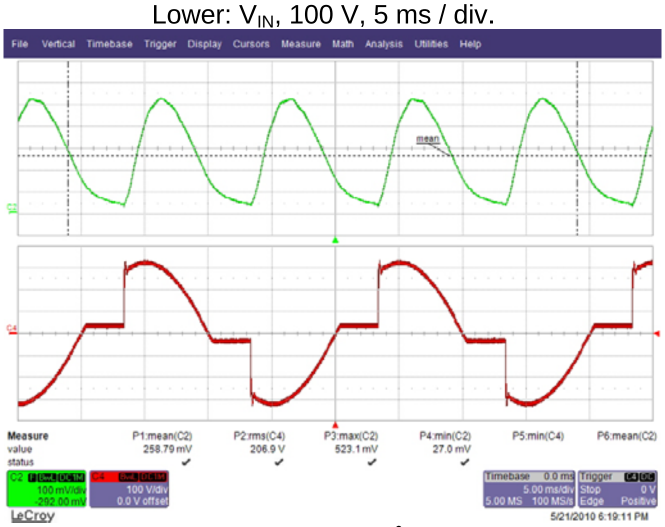

Figure 64 – 230 VAC 50 Hz, 120˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

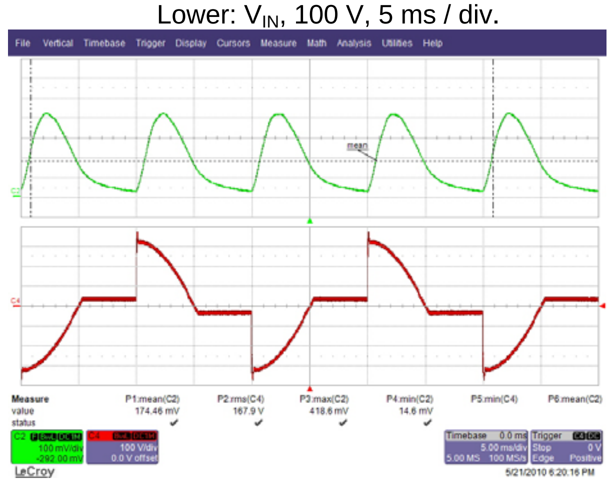

Figure 65 – 230 VAC 50 Hz, 90˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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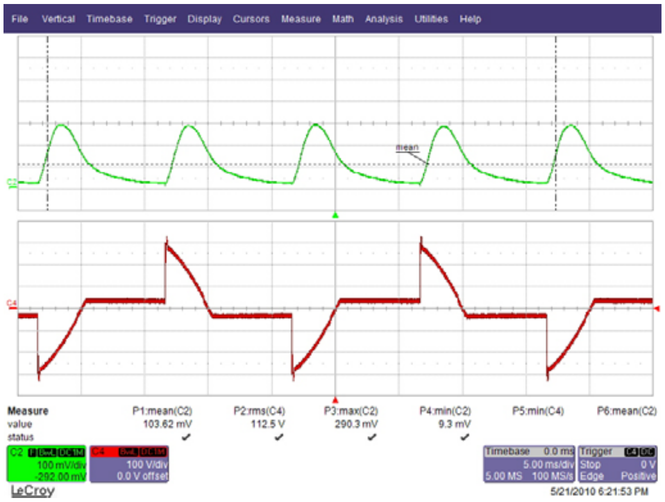

Figure 66 – 230 VAC 50 Hz, 50˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

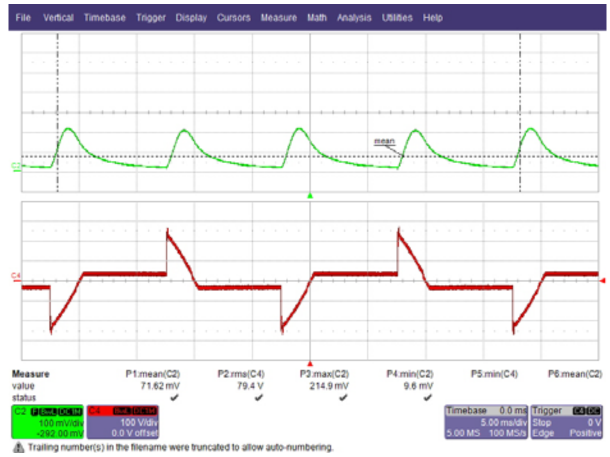

Figure 67 – 230 VAC 50 Hz, 45˚ Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

10.2.5 Drain Voltage and Drain Current During Dimming

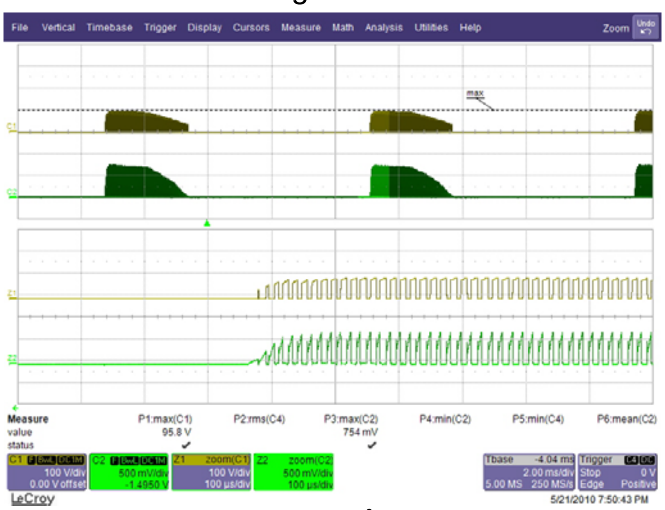

Figure 68 – 90 VAC 60 Hz, 90˚ Conduction Angle.
C2, Z2: I_{DRAIN}, 500 mA / div.
C1, Z1: V_{DRAIN}, 100 V, 2 ms / div.

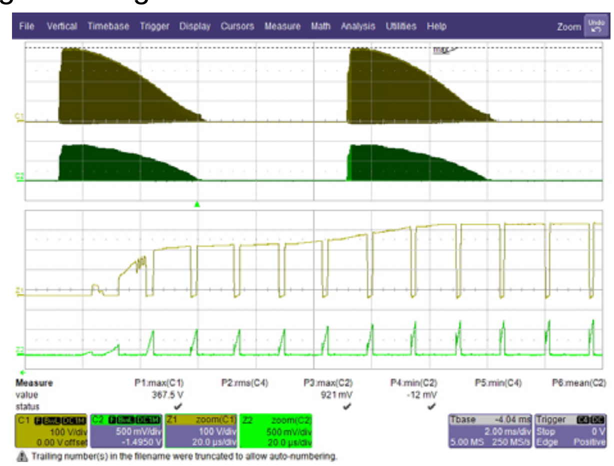

Figure 69 – 265 VAC 50 Hz, 90˚ Conduction Angle.
C2, Z2: I_{DRAIN}, 500 mA / div.
C1, Z1: V_{DRAIN}, 100 V, 2 ms / div.

11 Thermal Measurements

11.1 Thermal Test Set-up

Thermal Measurements were done with the whole assembly (buck board + PAR38 housing + fixture cover) operated at a room temperature. The ambient measurement location inside the assembly is shown below. Output power was adjusted to maximum to obtain worst case thermal measurements.

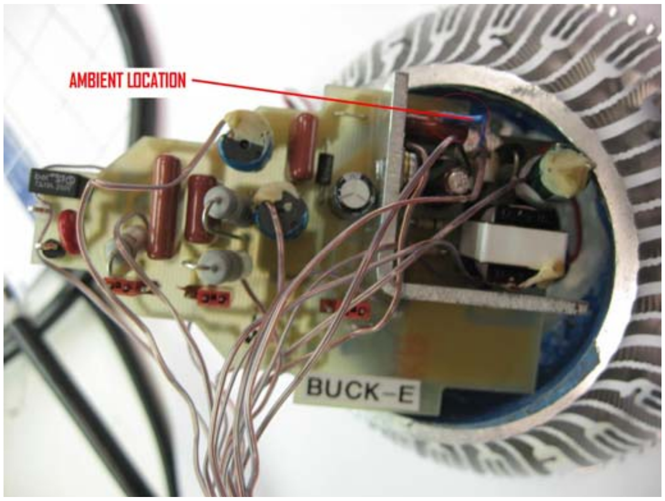

Figure 70 – Ambient2 Location.

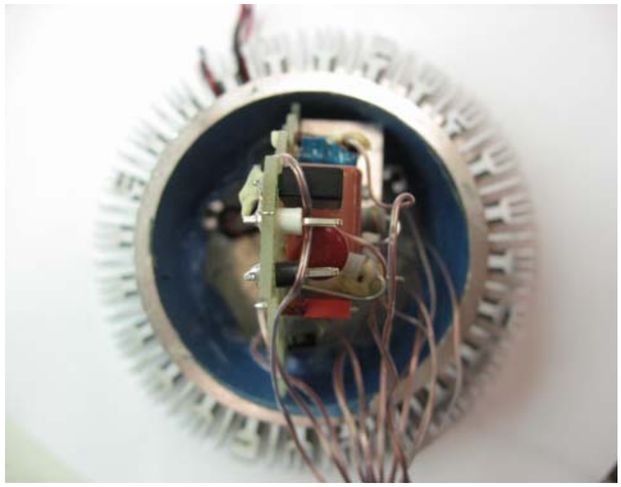

Figure 71 – Board Position on PAR38 Housing.

Figure 72 – PAR38 Assembly.

Figure 73 – PAR38 with Top Cover at Room Temperature.

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11.2 Thermal Test Results

Reference	Description	Temperature (˚C)	Temperature (˚C)
Amb1	Room Temperature	~25	~25
Amb2	Ambient Inside (Component Side)	83	89
Amb3	Ambient Inside (Solder Side)	79	80
U1	LNK405EG	96	101
Q7	Linear Regulator	88	100
D8	Output Rectifier (FWD)	92	96
BR1	Bridge Rectifier	78	65
T1 (Core)	Output Inductor, Core	97	102
T1 (Wire)	Output Inductor, Wire	101	106
L1	Differential Choke	89	74
L2	Differential Choke	96	81
R19	Damper Resistor	75	76
R25	Damper Resistor	98	77
Q3	Damper Transistor	91	79
C6	Output Capacitor	81	83
V_{IN}	Input Voltage, V	**90**	**265**
fL	Line Frequency, Hz	**60**	**50**
P_{IN}	Input Power, W	15.38	15.4
V_{LED}	Output Voltage, V	34.8	34.9
I_{LED}	Output Current, mA	356	355
P_{OUT}	Output Power, W	12.39	12.39
Eff	Efficiency	80.57%	80.45%

12 Conducted EMI Measurements

12.1 Conducted EMI Test Set-up

Conducted EMI were measured with the LED Board inside the PAR38 housing + LED loads (12 LED ~ 36 V at 330 mA). A top cover which is isolated from the PAR38 is also used and this cover is grounded to earth as shown on the Figure below.

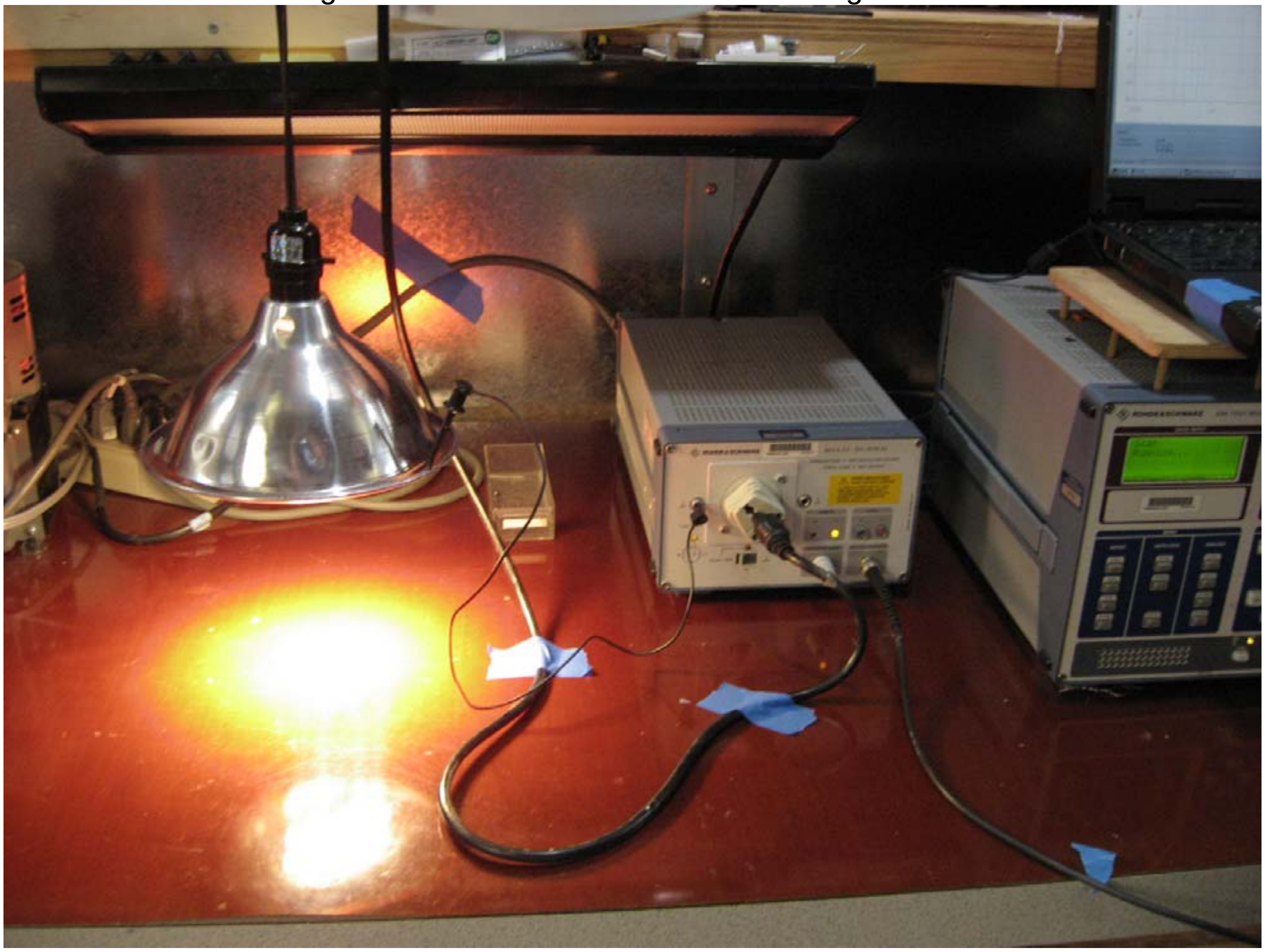

Figure 74 – Conducted EMI Measurement Set-up.

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12.2 Conducted EMI Test Results

12.2.1 Non-Dimming Configuration Conducted Emission

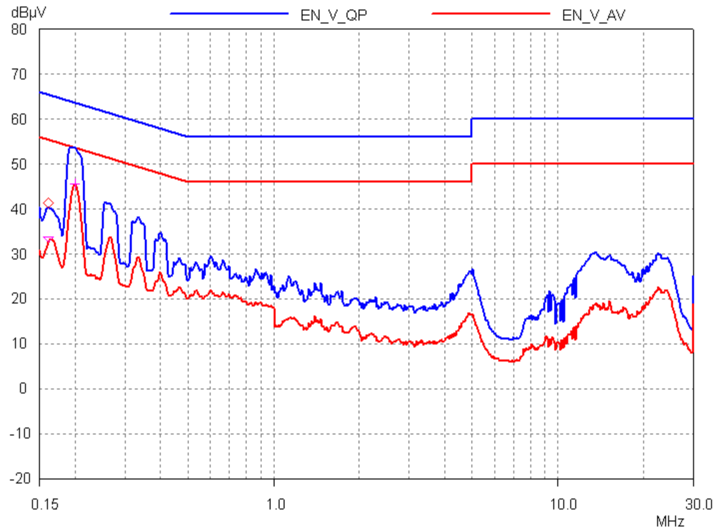

Figure 75 – Phase L1: Conducted EMI, ~36 V Load, 115 VAC, 60 Hz, and EN55022 B Limits.

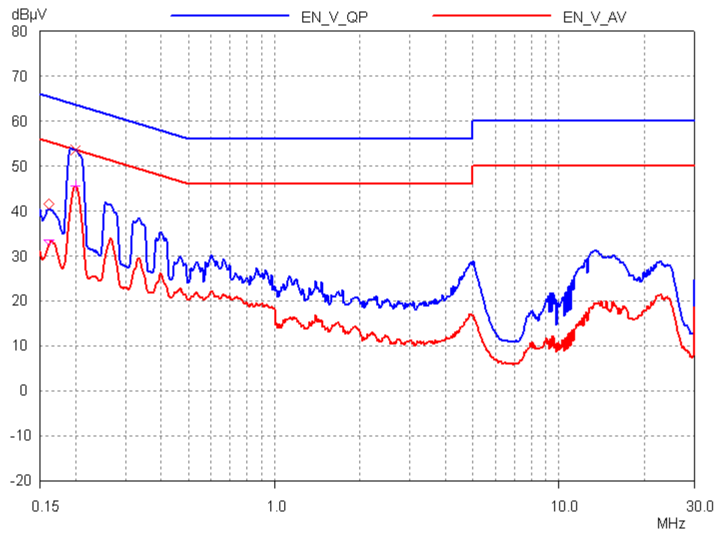

Figure 76 – Phase N: Conducted EMI, ~36 V Load, 115 VAC, 60 Hz, and EN55022 B Limits.

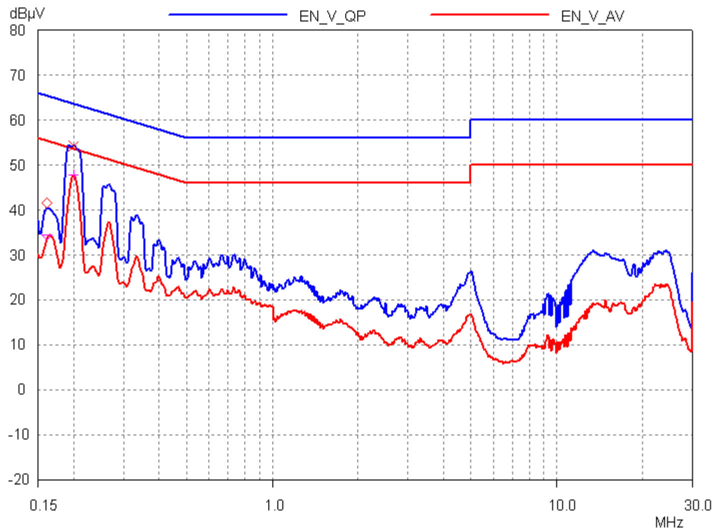

Figure 77 – Phase L1: Conducted EMI, ~36 V Load, 230 VAC, 60 Hz, and EN55022 B Limits.

Figure 78 – Phase N: Conducted EMI, ~36 V Load, 230 VAC, 60 Hz, and EN55022 B Limits.

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12.2.2 Dimming Configuration Conducted Emission

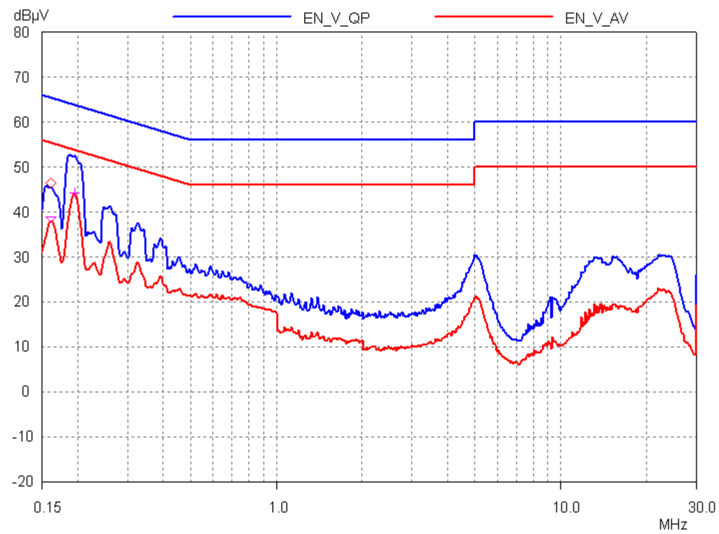

Figure 79 – Phase L1: Conducted EMI, ~36 V Load, 115 VAC, 60 Hz, and EN55022 B Limits.

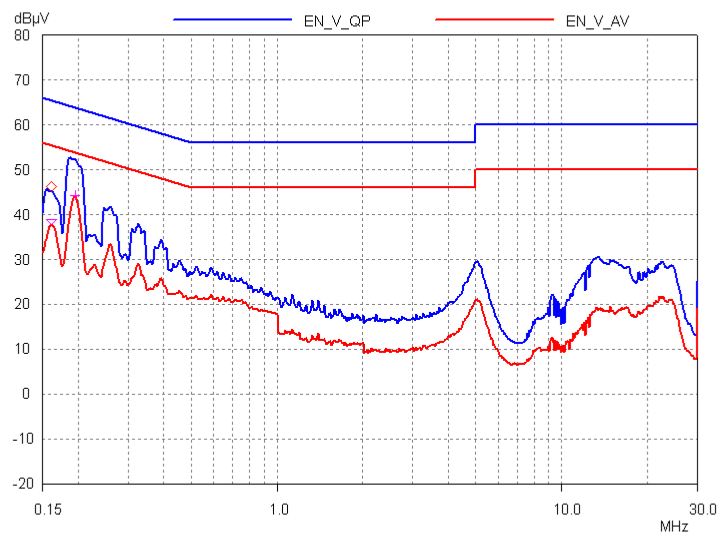

Figure 80 – Phase N: Conducted EMI, ~36 V Load, 115 VAC, 60 Hz, and EN55022 B Limits.

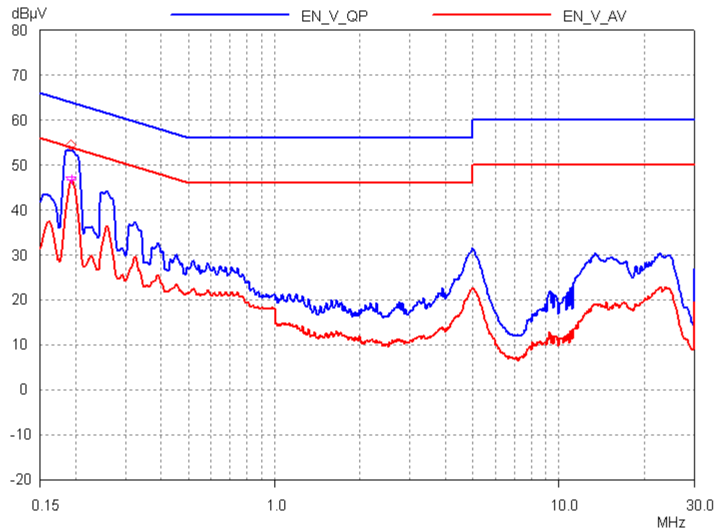

Figure 81 – Phase L1: Conducted EMI, ~36 V Load, 230 VAC, 60 Hz, and EN55022 B Limits.

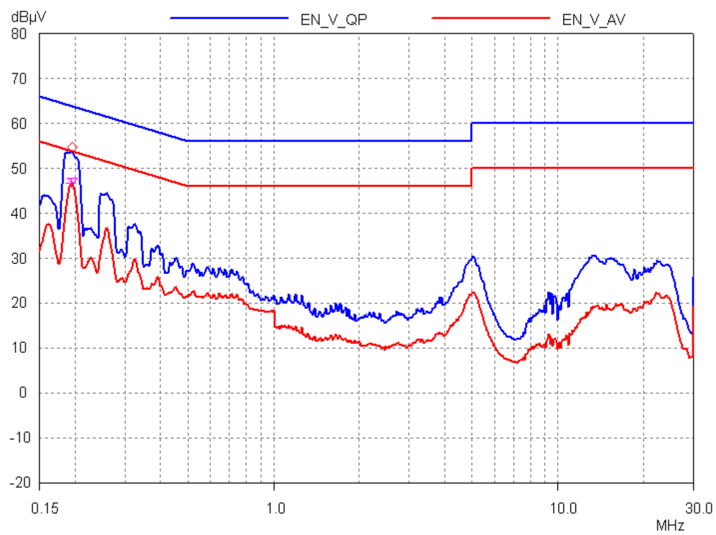

Figure 82 – Phase N: Conducted EMI, ~36 V Load, 230 VAC, 60 Hz, and EN55022 B Limits.

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13 Power Line Transient Tests

The unit was subjected to ±500 V line to line surge and ±2500 V ring wave, both at 115 VAC and 230 VAC. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
±500	115	L1, L2	0	Surge	Pass
±500	115	L1, L2	90	Surge	Pass
±500	230	L1, L2	0	Surge	Pass
±500	230	L1, L2	90	Surge	Pass
±2500	115	L1, L2	0	Ring Wave (200A)	Pass
±2500	115	L1, L2	90	Ring Wave (200A)	Pass
±2500	230	L1, L2	0	Ring Wave (200A)	Pass
±2500	230	L1, L2	90	Ring Wave (200A)	Pass

14 Revision History

Date	Author	Revision	Description & changes	Reviewed
09-Jun-10	CA	1.0	Initial release	Apps & Mktg

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