Design Example Report

Title	***Constant Current (<2% Regulation), Non-Isolated Buck-Boost, Power Factor Corrected, 18 W LED Driver Using LinkSwitch™-PH LNK419EG***
Specification	90 VAC – 265 VAC Input; 200 V, 90 mA Output
Application	T8 Tube Retrofit LED Driver
Author	Applications Engineering Department
Document Number	DER-298
Date	December 8, 2011
Revision	1.3

Summary and Features

- Designed for linear fluorescent LED tube retro fit applications
  - Compact, low component count design – fits into ends of tube enclosure
  - Frequency jitter for smaller, lower cost EMI filter components
  - Excellent line and load regulation, <2% typical
- Highly energy efficient
  - ≥89.5% at 110 VAC
  - ≥90% at 230 VAC
- Power factor corrected
  - PF >0.93 across line and load, EN61000-3-2(c) compliant
  - A-THD <28% (230 VAC), <20% (115 VAC)
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Line input overvoltage shutdown extends voltage withstand during line faults.
  - Auto-recovering thermal shutdown with large hysteresis protects both components and printed circuit board
- IEC 61000-4-5 ring wave and surge and EN55015 B conducted EMI compliant

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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 universal, non-isolated, high efficiency, high power factor (PF) LED driver designed to drive a nominal LED string voltage of 200 V at 90 mA from an input voltage range of 90 VAC to 265 VAC. The LED driver utilizes the LNK419EG from the LinkSwitch-PH family of ICs.

The topology used is a single-stage non-isolated buck-boost that meets the stringent space requirements for this design. Enhanced line and load output current regulation requirement is achieved by directly sensing and regulating the output current.

High power factor and low THD is achieved by employing the LinkSwitch-PH IC which also provides a sophisticated range of protection features including auto-restart for open control loop and output short-circuit conditions. Line overvoltage provides extended line fault and surge withstand, and accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

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

Note: For lowest cost this design did not include output OVP, necessary for operation with no-load connected (an abnormal condition). When testing please ensure a load is connected to prevent output overvoltage and component damage.

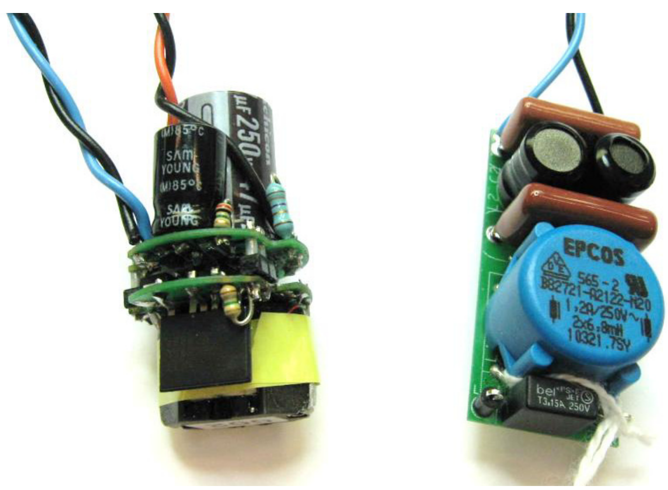

Figure 1 – EMI Board and Buck-Boost Boards.

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Figure 2 – EMI Board Top View.

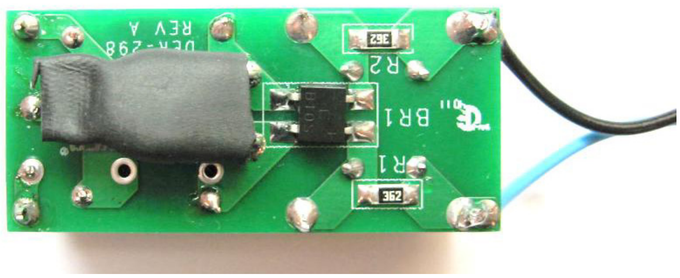

Figure 3 – EMI Board Bottom View.

Figure 4 – Buck-Boost Section.

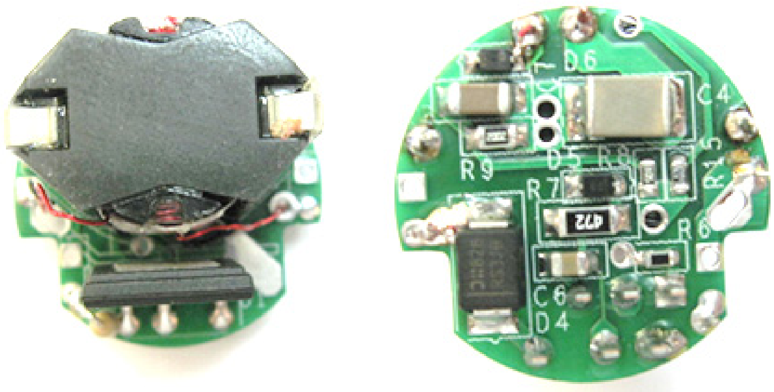

Figure 5 – Buck-Boost Board A, Top and Bottom Side.

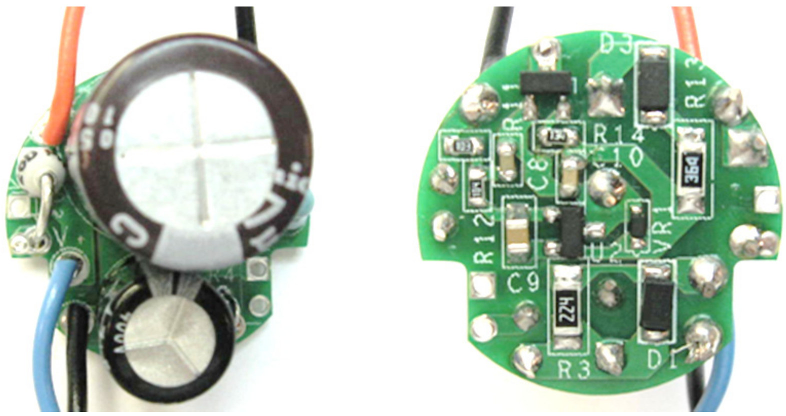

Figure 6 – Buck-Boost Board B, Top and Bottom Side.

Note: See section 5 for dimensions.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	115/230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60/50		Hz	
Output						
Output Voltage	V_{OUT}		200		V	
Output Current	I_{OUT}	85.5	90	94.5	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		18		W	
Efficiency						
Full Load	η	88	90		%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge			1		kV	
Power Factor			0.9			
Harmonic Currents		EN 61000-3-2 Class D (C)				Class C specifies Class D Limits when P_{IN} <25 W
Ambient Temperature	T_{AMB}		40		°C	Open Frame, without heat sink

Note: Maximum ambient temperature can be increased by adding a small heat sink on U1 or/and by potting the buck-boost section assembly.

3 Schematic

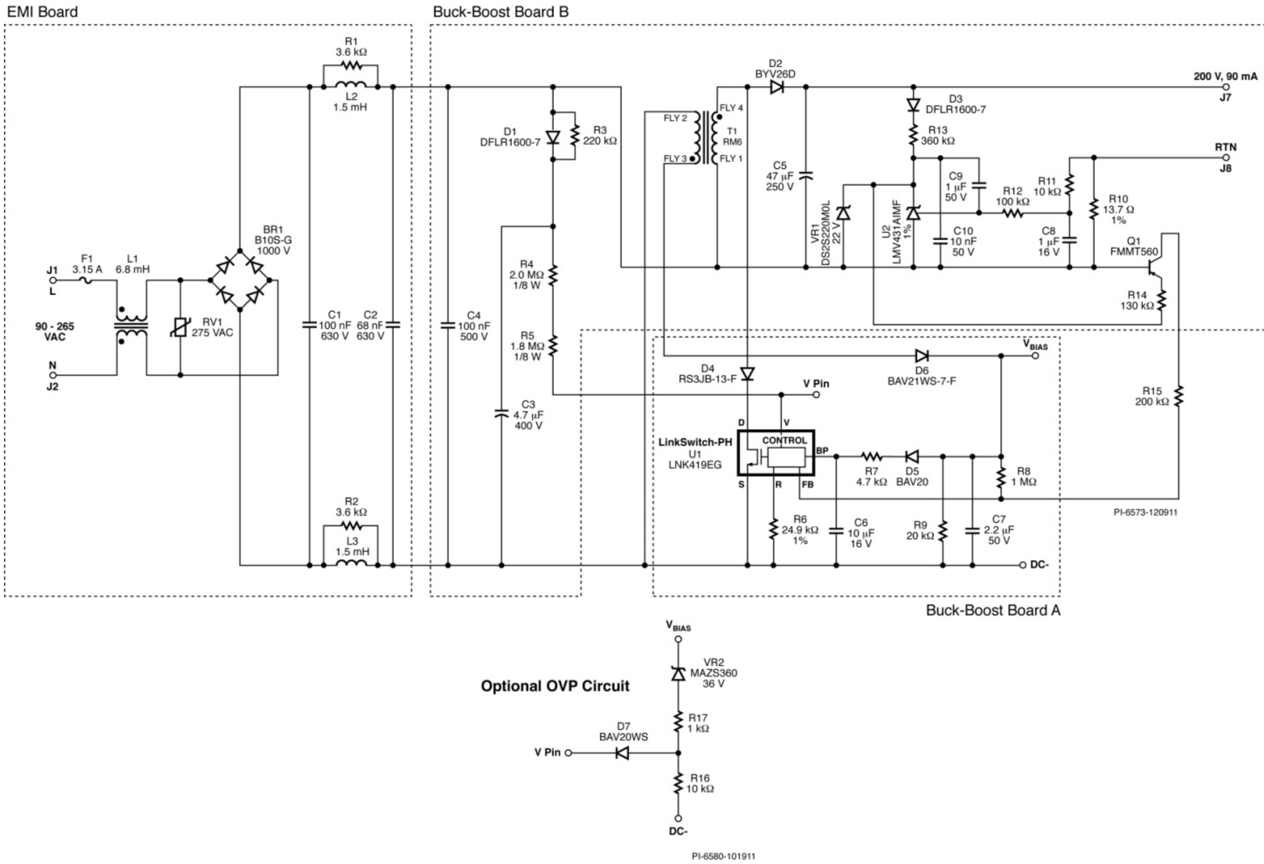

Figure 7 – Schematic Diagram.

Notes:

- Due to the high output voltage significant energy is stored in the output capacitor C5. This energy is sufficient to cause R10 to fail open when the output is short circuited. As an output short represents product failure this was considered acceptable. If this condition needs to survived a voltage clamp (>1.25 V) should be connected across R10. For example a Zener diode or three series PN diodes.
- No open-load / overvoltage protection circuit included in this design. Do not power up without load connected. Overvoltage circuit can be added if needed see schematic.

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4 Circuit Description

The LinkSwitch-PH device is a controller and integrated 725 V power MOSFET intended for use in offline power factor corrected LED driver applications. The LinkSwitch-PH is configured in a single-stage buck-boost topology and provides constant current output while maintaining high power factor from the AC input.

4.1 Input Filtering

Fuse F1 provides protection from component failure and RV1 provides a clamp to limit the maximum voltage during differential line surge events. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage of 265 VAC. Diode bridge BR1 rectifies the AC line voltage with capacitor C4 providing a low impedance path (decoupling) for the primary switching current. A low value of capacitance (sum of C1, C2 and C4) is necessary to maintain a power factor of greater than 0.9.

EMI filtering is provided by inductors L1, L2 and L3, and capacitors C1, C2 and C4. Resistor R1 and R2 across L2 and L3 damp any resonances between the input inductors, capacitors and the AC line impedance which cause peaks in the conducted EMI levels.

4.2 LinkSwitch-PH Primary

One side (FLY1) of the inductor (T1) is connected to the DC bus and the other (FLY4) to the anode of blocking diode D4. Diode D4 is used to prevent reverse current from flowing through U1. During the on-time of the MOSFET, current ramps through the inductor storing energy which is then delivered to the output during the MOSFET off time. An RM6 core size was selected to meet both the power delivery and size requirements of the design.

To provide peak line voltage information to U1, the incoming rectified AC peak charges C3 via D1. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R4 and R5. Resistor R3 provides a discharge path for C3 with a time constant much longer than that of the rectified AC to prevent the V pin current being modulated at the line frequency (which would degrade power factor). Resistors R4 and R5 also provides the line overvoltage shutdown function which extends the rectified line voltage withstand (during surges and line swells) to the 725 BV_{DSS} rating of the internal power MOSFET.

Capacitor C6 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C6 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN (D) pin. Once charged U1 starts switching at which point the operating supply current is provided from the bias winding (FLY2, FLY3) via R7. Diode D5 isolates the BP pin from the bias capacitor C7 to prevent the start-up time increasing due to charging of both C6 and C7. Diode D6 and C7 rectify and filter the bias winding, generating a bias supply of around 28 V.

4.3 Feedback

The VOLTAGE MONITOR (V) pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current.

A current sense resistor R10 and shunt regulator U2 provide very tight output current regulation for this design. Output current sensed by R10 is filtered by R11 and C8. Resistor R11 and C8 were chosen to have a time constant greater than the line frequency in order to limit the line frequency component and thus enable a slow loop response necessary to maintain high power factor and low THD. This voltage is then compared with the internal reference of U2 to provide a regulated output current of 90 mA. Capacitor C9 and R12 provide feedback compensation for the shunt regulator U2.

The output voltage of U2 (cathode to anode voltage) is converted to a current information by the network formed by R14 and Q1. This current is fed to the FB pin of U1 that adjusts the power MOSFET switching to maintain a constant output. Resistor R15 is used for noise filtering and should be placed very close to U1 FB pin. Resistor R8 provides an offset current of ~25 μA into the FB pin to reduce the start-up time.

Zener diode VR1 limits the maximum cathode voltage of U2 to 22 V. Zener diode VR1 together with R14 sets the maximum I_{FB} current fed from Q1.

$$I_{FB\max\_Q1} = \frac{VR1 - V_{BE\_Q1}}{R14} - I_{B\_Q1} \approx 160\mu A$$

Together with the current from R8, the maximum I_{FB} current can be calculated as follows:

$$I_{FB\max} = I_{FB\max\_Q1} + I_{R8\_\max} \approx 185\mu A$$

The maximum operating I_{FB} is selected to provide the specified output power across the operating input voltage range. It also dictates the maximum overshoot of the output current during line transients. This overshoot happens because of the slow loop response of the current sense feedback network to maintain high power factor.

This condition is not present during the initial start-up condition when C8 and C9 are still discharged as shown on the waveforms of Figures 8 and 9.

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Figure 8 – 90 VAC, 0 - 90 VAC Line Transient.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 2 s / div.

Figure 9 – 265 VAC, 0 - 265 VAC Line Transient.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V, 2 s / div.

Maximum peak current capability of the LED must be checked with the maximum peak current during line transients.

Resistor R13 was selected to allow the maximum required I_{FB} from Q1 and bias currents for U2 and VR1.

4.4 Output Rectification

When U1 is off, energy stored in T1 is transferred to the output via the output diode D2. Diode D2 is selected to have a PIV rating of 800 V. Capacitor C5 was selected to give an LED ripple current of less than or equal to ±30% of the mean value. For designs where higher ripple is acceptable, the output capacitance value can be reduced.

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5 PCB Layout

A split board approach was part of the original specification - to enable the converter to be hidden into the two ends of the tube enclosure.

All dimensions in inches / [mm]

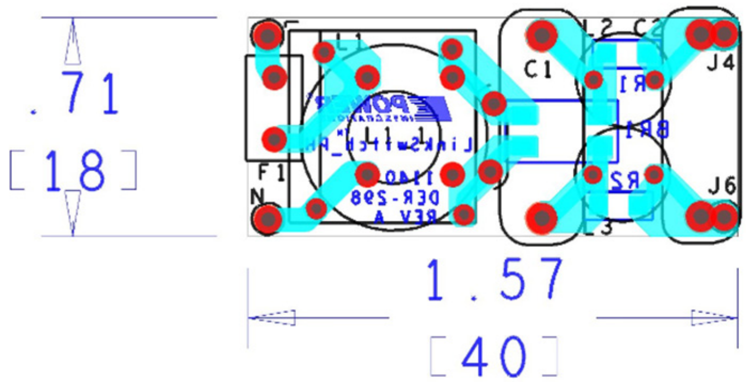

Figure 10 – EMI Board Layout and Outline.

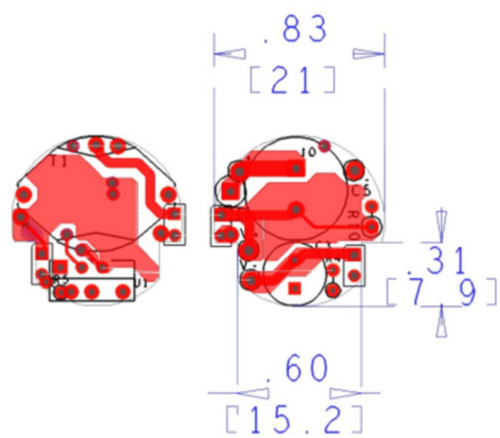

Figure 11 – Buck-Boost Boards Board A and Board B Layout and Outline, Top Side.

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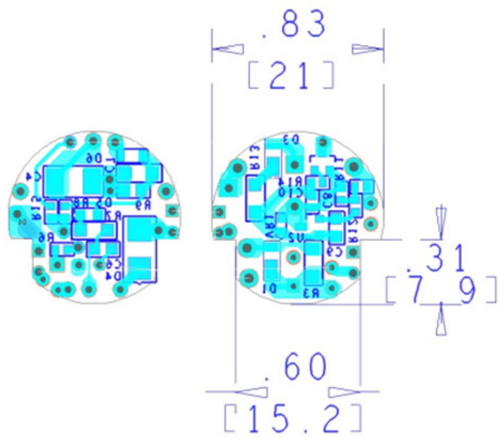

Figure 12 – Buck-Boost Boards Board A and Board B Layout and Outline, Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip Technology
2	1	C1	100 nF, 630 V, Film	ECQ-E6104KF	Panasonic
3	1	C2	68 nF, 630 V, Film	ECQ-E6683KF	Panasonic
4	1	C3	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	SHD400WV 4.7uF	Sam Young
5	1	C4	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
6	1	C5	47 μF, 250 V, Electrolytic, (12.5 x 20)	UCS2E470MHD	Nichicon
7	1	C6	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
8	1	C7	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
9	1	C8	1 μF, 16 V, Ceramic, X5R, 0603	GRM188R61C105KA93D	Murata
10	1	C9	1 μF, 50 V, Ceramic, X7R, 0805	08055D105KAT2A	AVX
11	1	C10	10 nF 50 V, Ceramic, X7R, 0603	ECJ-1VB1H103K	Panasonic
12	2	D1 D3	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
13	1	D2	800 V, 1 A, Ultrafast Recovery, 30 ns, SOD57	BYV26D	Philips
14	1	D4	600 V, 3 A, Fast Recovery, 250 ns, SMB Case	RS3JB-13-F	Diodes, Inc.
15	1	D5	200 V, 200 mW, Diode, SOD323	BAV20WS-7-F	On Semi
16	1	D6	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
17	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
18	1	L1	6.8 mH, 1.2 A, Common Mode Choke	B82721A2122N20	Epcos
19	2	L2 L3	1.5 mH, 0.52 A, 9 x 9 mm	SL1016-152K-B	Yago
20	1	Q1	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
21	2	R1 R2	3.6 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ362V	Panasonic
22	1	R3	220 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ224V	Panasonic
23	1	R4	2 MΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-2M0	Yageo
24	1	R5	1.8 MΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-1M8	Yageo
25	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
26	1	R7	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
27	1	R8	1 MΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ105V	Panasonic
28	1	R9	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
29	1	R10	13.7 Ω, 1%, 1/4 W, Metal Film	MFR-25FBF-13R7	Yageo
30	1	R11	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
31	1	R12	100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
32	1	R13	360 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ364V	Panasonic
33	1	R14	130 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ134V	Panasonic
34	1	R15	200 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ204V	Panasonic
35	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
36	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
37	1	U1	LinkSwitch-PH, eSIP	LNK419EG	Power Integrations
38	1	U2	1.24 V Shunt Regulator IC, 1%, -40 to 85 C, SOT23-3	LMV431AIMF	National Semi
39	1	VR1	22 V, 5%, 150 mW, SSMINI-2	DZ2S220M0L	Panasonic

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7 Inductor Specification

7.1 *Electrical Diagram*

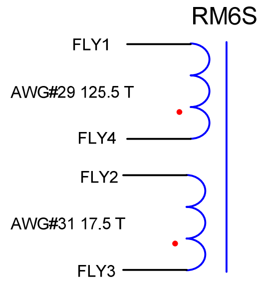

Figure 13 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Primary Inductance	Pins FLY1-FLY4, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	1.2 mH ±7%
Resonant Frequency	Pins FLY1-FLY4, all other windings open	1 MHz (Min.)

7.3 *Materials*

Item	Description
[1]	Core: RM6S PC95.
[2]	Bobbin: CPV-RM6S-1S8PD.
[3]	Magnet Wire: #29 AWG.
[4]	Magnet Wire: #31 AWG.
[5]	Tape: 3M 1298 Polyester Film, 6.4 mm wide.
[6]	RM6 CLIP: B65808B2203X000.

7.4 Inductor Build Diagram

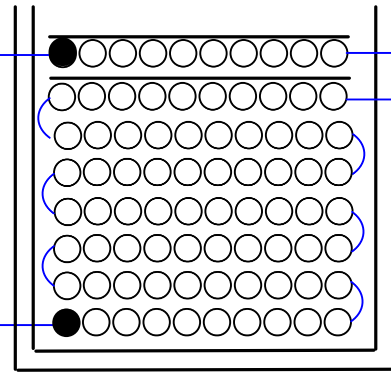

Figure 14 – Inductor Build Diagram.

7.5 Transformer Construction

General Note	For the purpose of these instructions, Bobbin is oriented on winder such that pin 1 side is on the left side (see illustration). Winding direction as shown is counter-clockwise.
WD1	Start on FLY4 and wind 125.5 turns in 7 layers of #29 AWG item [3] from left to right. At the end of 1st layer, continue to wind next layer from right to left. At the end of 2nd layer, continue to wind the next layer from left to right. Continue the same way as in previous 2 layers. Spread windings evenly on each layer, 18 turns per layer on the first 6 layers, and 17.5 turns on the 7th layer. Finish winding on FLY1.
Insulation	1 Layer of tape [5] for insulation.
WD2	Start at pin FLY3, wind 17.5 turns of #31 AWG item [4] from left to right. Finish at pin FLY2.
Insulation	1 layer of tape [5] for insulation.
Finish	Grind core. Assemble core and varnish. Cut bobbin legs as shown in Figure 10.

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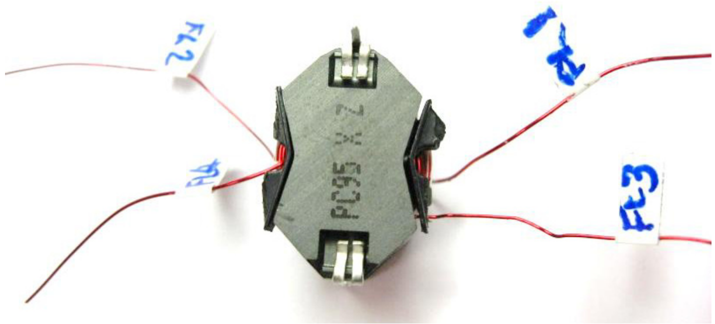

Figure 15 – Inductor Photograph Showing Cut Legs of the Bobbin. Bottom View.

NOTE:
The RM6 bobbin legs were removed to fit the PCB. The clip pins serve as the leg of the inductor. For mass production, the user is expected to tool a RM6 bobbin to meet the stringent space requirement for this design.

8 PIXIs Inductor Design Spreadsheet

For buck-boost it is only required to set the VOR value in the standard spreadsheet (below) to equal the output voltage.

ACDC_LinkSwitch-PH_082311; Rev.1.7; Copyright Power Integrations 2011	INPUT	OUTPUT	UNIT	LinkSwitch-PH_082311: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES				
Dimming required	**No**	**NO**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN		90	V	Minimum AC Input Voltage
VACMAX		265	V	Maximum AC input voltage
fL		50	Hz	AC Mains Frequency
VO	200.00	200	V	Typical output voltage of LED string at full load
VO_MAX		220.00	V	Maximum expected LED string Voltage.
VO_MIN		180.00	V	Minimum expected LED string Voltage.
V_OVP		242.00	V	Over-voltage protection setpoint
IO	0.09	0.09	A	Typical full load LED current
PO		18.0	W	Output Power
N	0.89	0.89		
VB	28	28	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES				
LinkSwitch-PH	**LNK419**	**LNK419**	Universal	115 Doubled/230V
Chosen Device		Power Out	18W	8W
Current Limit Mode	**RED**	**RED**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN		2.35	A	Minimum current limit
ILIMITMAX		2.73	A	Maximum current limit
fS		66000	Hz	Switching Frequency
fSmin		62000	Hz	Minimum Switching Frequency
fSmax		70000	Hz	Maximum Switching Frequency
IV		38.7	uA	V pin current
RV		3.909	M-ohms	Upper V pin resistor
RV2		1.402	M-ohms	Lower V pin resistor
IFB	128.00	128.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1		195.3	k-ohms	FB pin resistor
VDS		10	V	LinkSwitch-PH 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	1.24	1.24		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP		1202	uH	Primary Inductance
VOR	200.50	200.5	V	Reflected Output Voltage.
Expected IO (average)		0.09	A	Expected Average Output Current
KP_VACMAX		1.54		!!! Info. PF at high line may be less than 0.9. Decrease KP for higher PF
TON_MIN		2.16	us	Minimum on time at maximum AC input voltage
PCLAMP		0.12	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES				
Core Type	**RM6S**	**RM6S**		
Bobbin			*P/N:*	CSV-RM6/R-1S-4P
AE		0.31	cm^2	Core Effective Cross Sectional Area
LE		2.73	cm	Core Effective Path Length
AL		2100	nH/T^2	Ungapped Core Effective Inductance

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BW		6.4	mm	Bobbin Physical Winding Width
M		0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	7.00	7		Number of Primary Layers
NS	126	125.5		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS				
VMIN		127	V	Peak input voltage at VACMIN
VMAX		375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS				
DMAX		0.58		Minimum duty cycle at peak of VACMIN
IAVG		0.20	A	Average Primary Current
IP		0.93	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS		0.31	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS				
LP		1202	uH	Primary Inductance
NP		126		Primary Winding Number of Turns
NB		18		Bias Winding Number of Turns
ALG		76	nH/T^2	Gapped Core Effective Inductance
BM		2866	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP		3468	Gauss	Peak Flux Density (BP<3700)
BAC		1433	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur		1472		Relative Permeability of Ungapped Core
LG		0.49	mm	Gap Length (Lg > 0.1 mm)
BWE		44.8	mm	Effective Bobbin Width
OD		0.36	mm	Maximum Primary Wire Diameter including insulation
INS		0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA		0.30	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		407	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
LP_TOL		10		Tolerance of primary inductance
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)				
Lumped parameters				
ISP		0.93	A	Peak Secondary Current
ISRMS		0.25	A	Secondary RMS Current
IRIPPLE		0.23	A	Output Capacitor RMS Ripple Current
CMS		50	Cmils	Secondary Bare Conductor minimum circular mils
AWGS		33	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS		0.18	mm	Secondary Minimum Bare Conductor Diameter
ODS		0.05	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS				
VDRAIN		770	V	!!! REDUCE DRAIN VOLTAGE Vdrain<700, reduce VACMAX, reduce VOR
PIVS		617	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB		88	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		3.91	M-ohms	Upper V Pin Resistor Value
RV2		1.40	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		0.09	A	Measured Output Current at VAC1
IO_VAC2		0.09	A	Measured Output Current at VAC2

RV1 (new)		3.91	M-ohms	New RV1
RV2 (new)		1.40	M-ohms	New RV2
V_OV		318.3	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV		70.8	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning				
RFB1		195	k-ohms	Upper FB Pin Resistor Value
RFB2		1E+12	k-ohms	Lower FB Pin Resistor Value
VB1		25.1	V	Test Bias Voltage Condition1
VB2		30.9	V	Test Bias Voltage Condition2
IO1		0.09	A	Measured Output Current at Vb1
IO2		0.09	A	Measured Output Current at Vb2
RFB1 (new)		195.3	k-ohms	New RFB1
RFB2(new)		1.00E+12	k-ohms	New RFB2
Input Current Harmonic Analysis				
Harmonic		Max Current (mA)	Limit (mA)	
1st Harmonic				
3rd Harmonic		29.74	1237.75	PASS. 3rd Harmonic current content is lower than the limit
5th Harmonic		14.6	691.69	PASS. 5th Harmonic current content is lower than the limit
7th Harmonic		8.8	364.04	PASS. 7th Harmonic current content is lower than the limit
9th Harmonic		5.95	182.02	PASS. 9th Harmonic current content is lower than the limit
11th Harmonic		4.28	127.42	PASS. 11th Harmonic current content is lower than the limit
13th Harmonic		3.21	107.79	PASS. 13th Harmonic current content is lower than the limit
15th Harmonic		2.48	93.41	PASS. 15th Harmonic current content is lower than the limit
THD		28.2	%	Estimated total Harmonic Distortion (THD)

Note: The VDS warning may be ignored as the actual drain voltage was measured in operation and found to be well below the device absolute maximum rating. Refer to section 11 for measurement data.

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9 Performance Data

All measurements performed at room temperature and using LED load. The following data were measured using 3 sets of load to represent the load range of 194 V to 200 V output voltage). Refer to the table on Section 9.8 for the complete set of test data values. All measurements performed at room temperature.

9.1 Efficiency

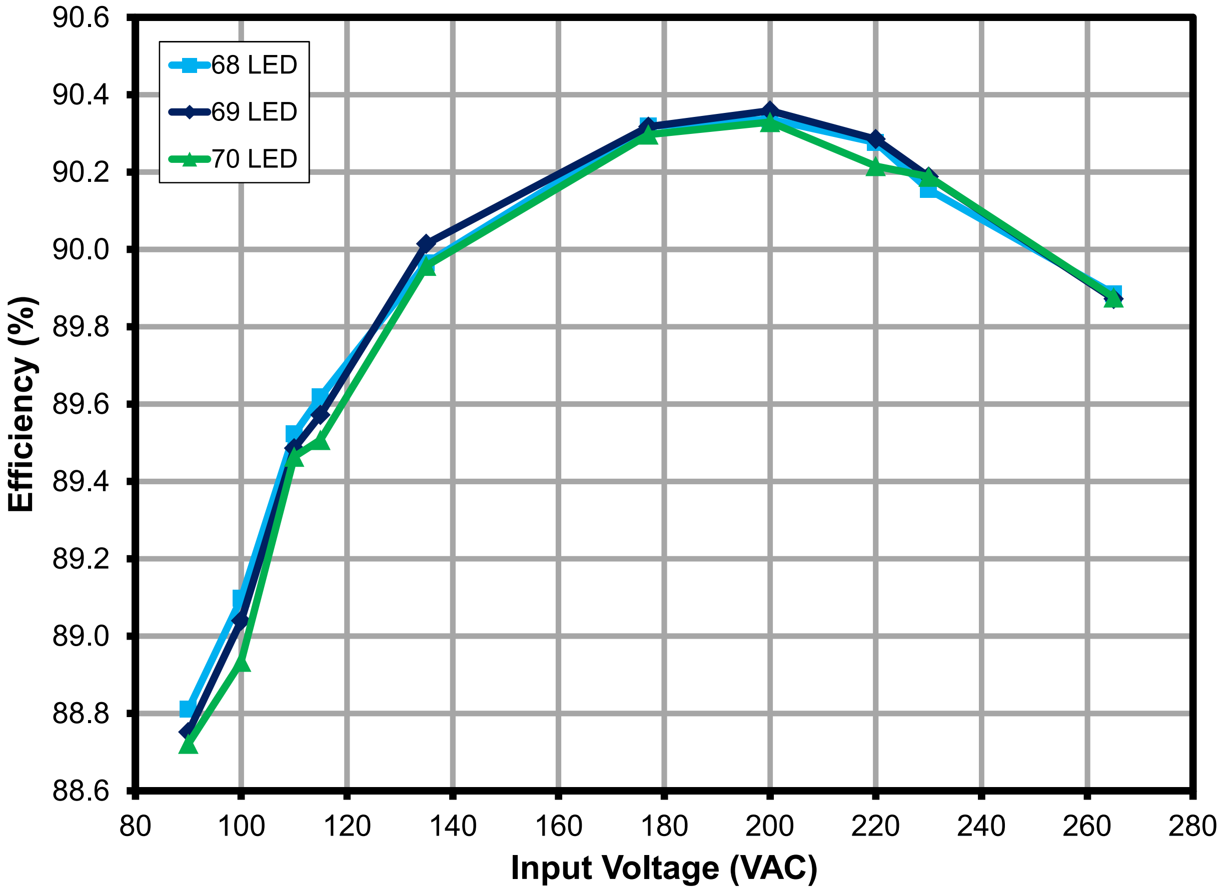

Figure 16 – Efficiency vs. Line and Load.

9.3 Line and Load % Regulation

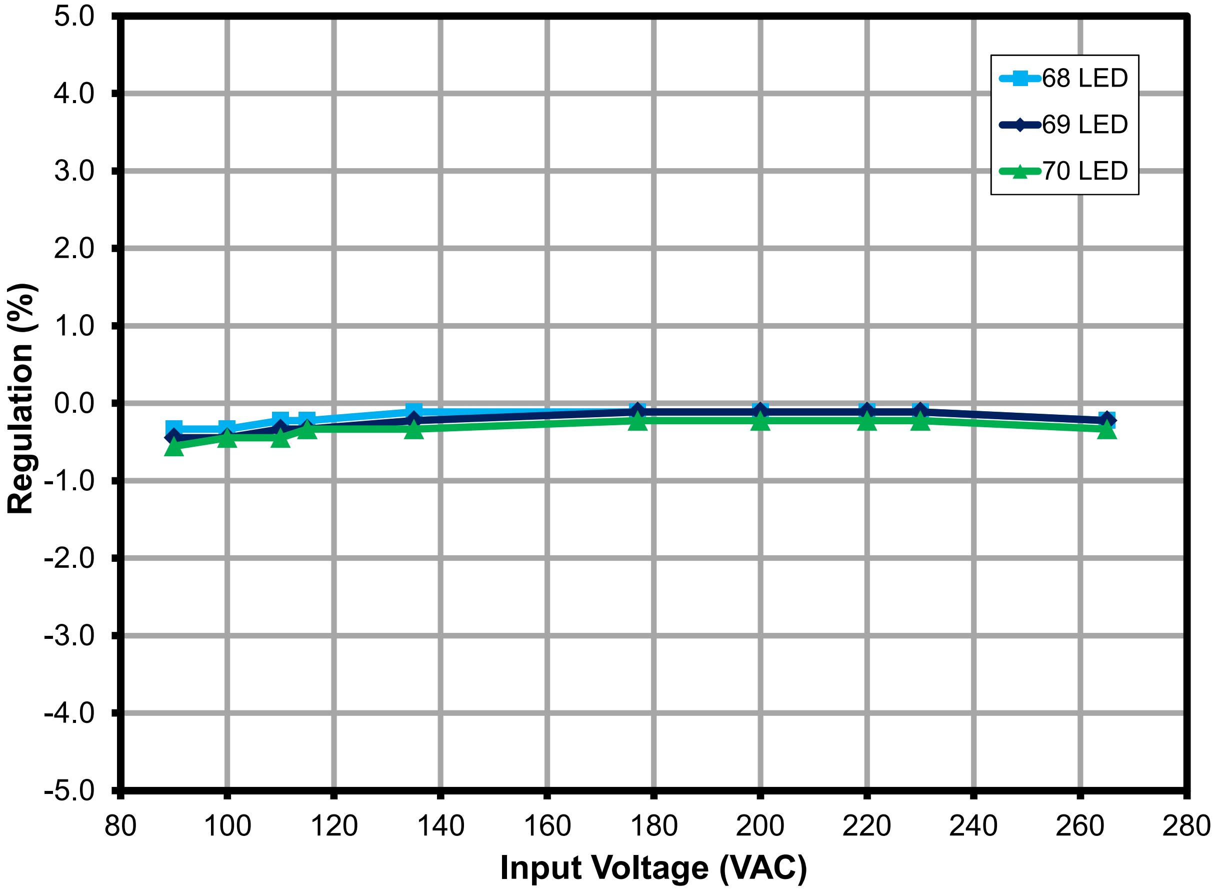

Figure 17 – % Regulation vs. Line and Load (90 mA Nominal Load Current).

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9.4 Line and Load Regulation

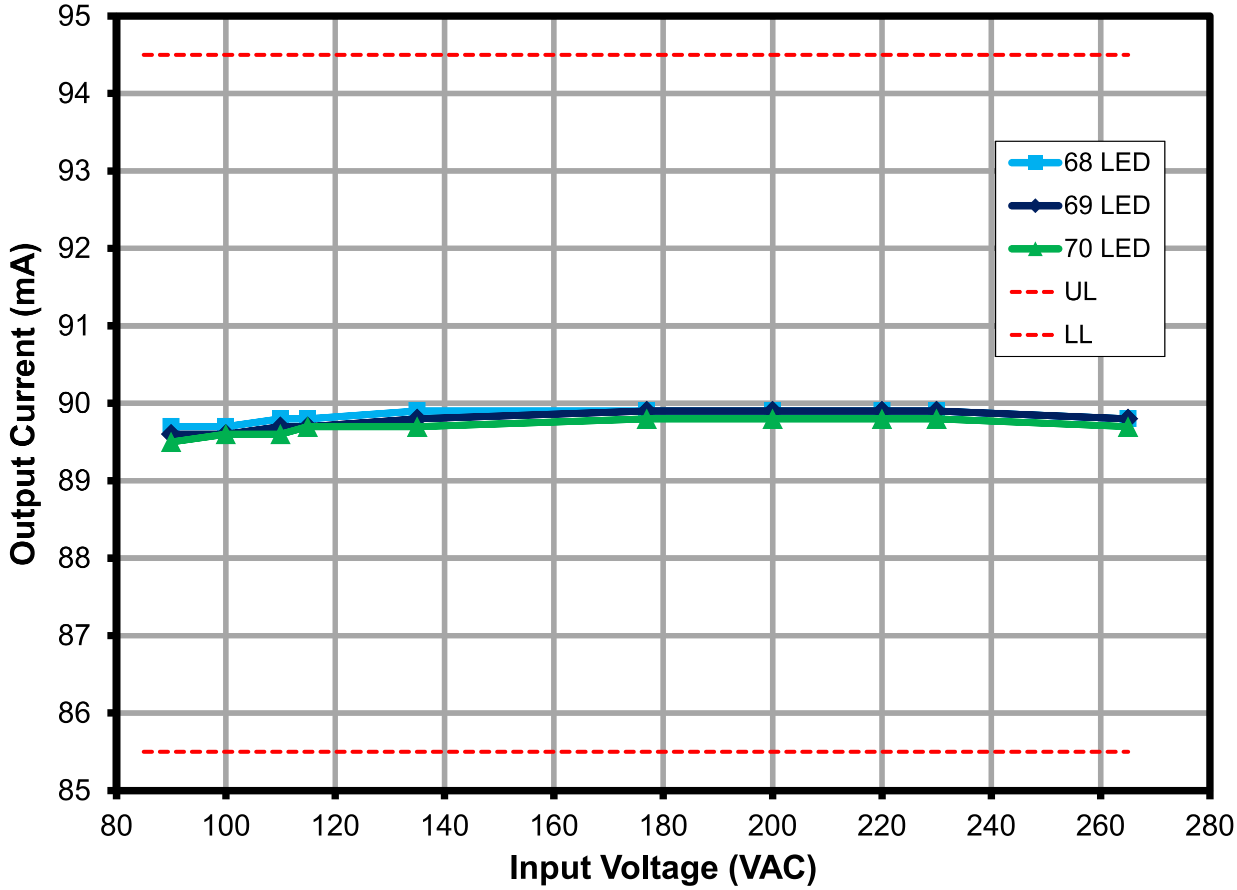

Figure 18 – Regulation vs. Line and Load.

9.5 Power Factor

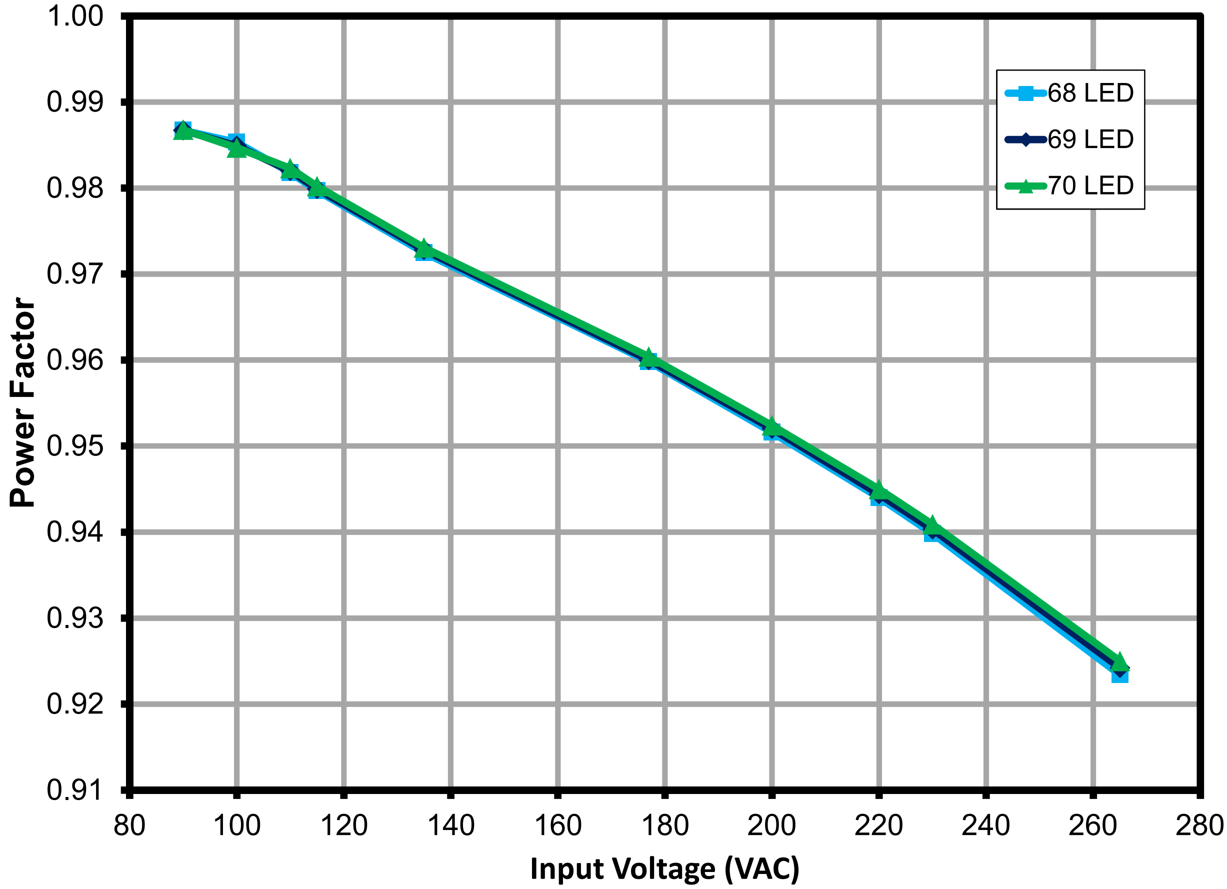

Figure 19 – Power Factor vs. Line and Load.

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9.6 A-THD

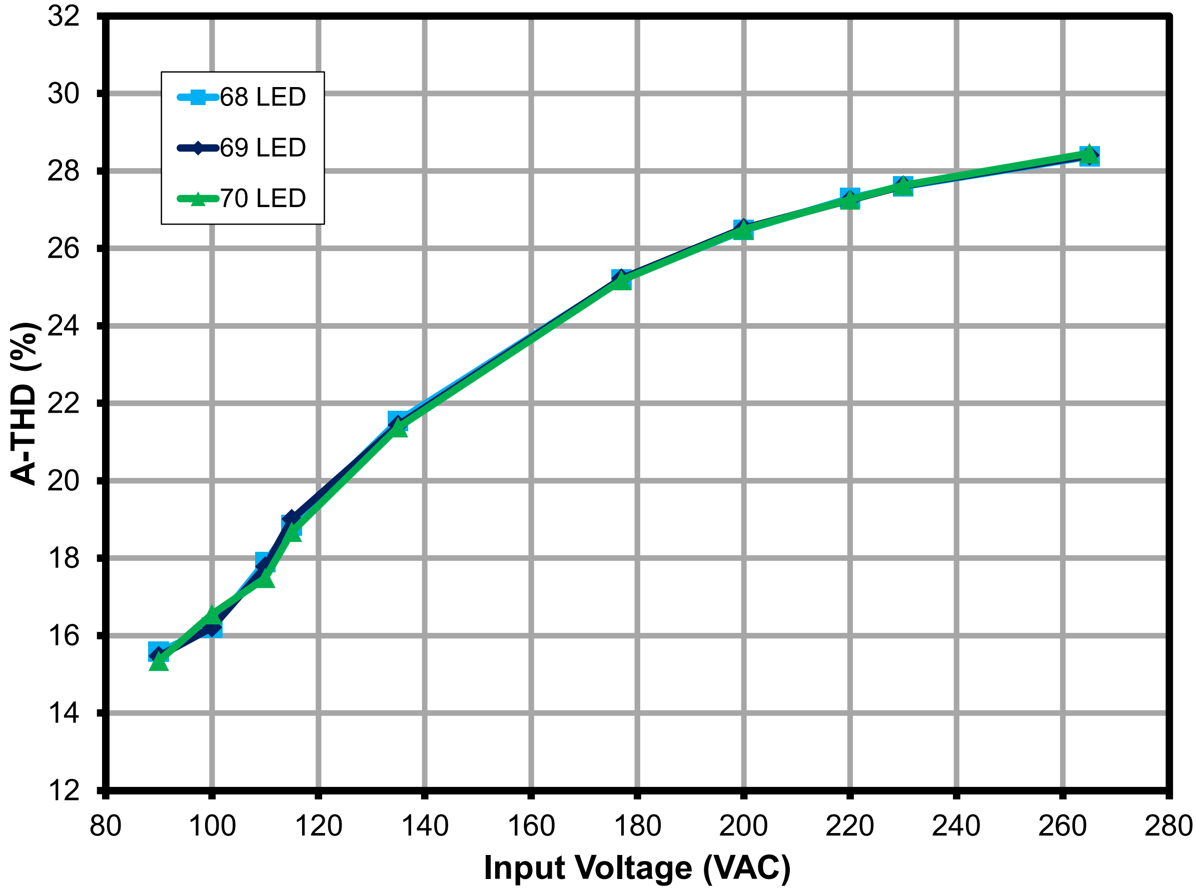

Figure 20 – A-THD vs. Line and Load.

9.7 Harmonic Currents

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

9.7.1 194 V V_{OUT} LED Load

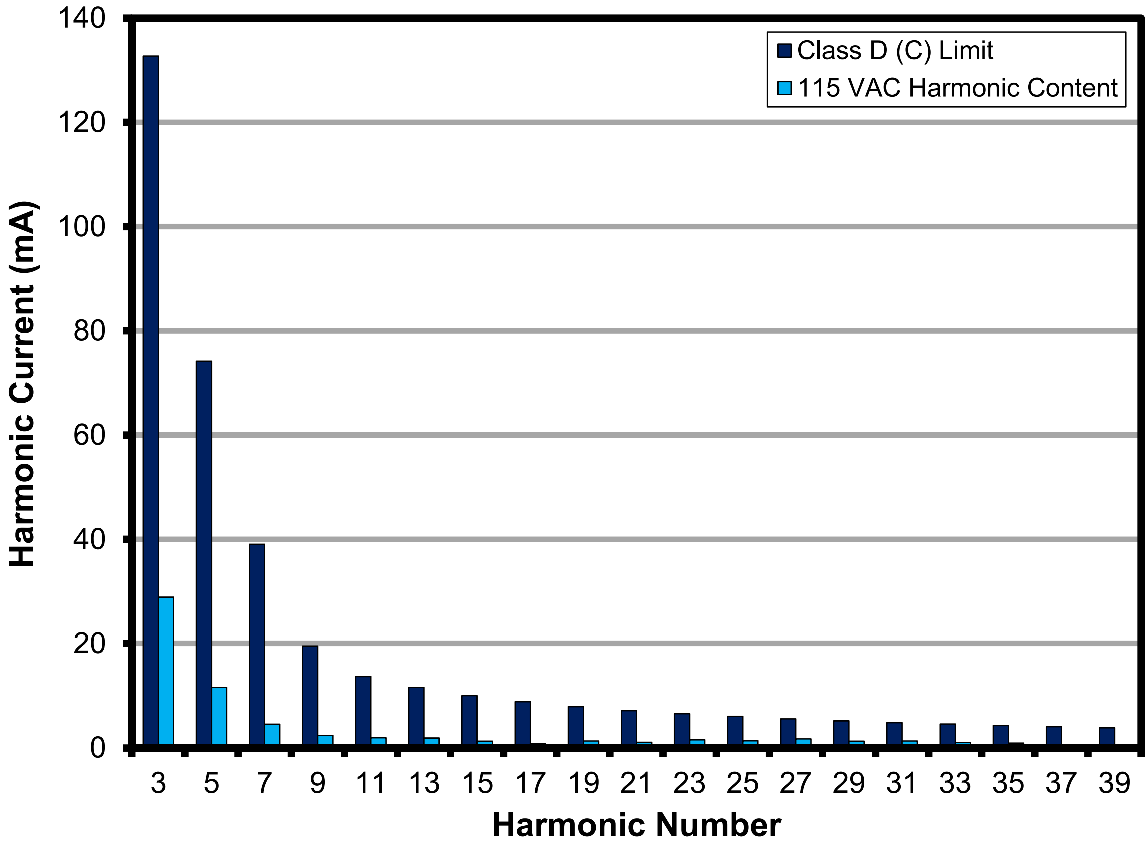

Figure 21 – 194 V V_{OUT} LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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

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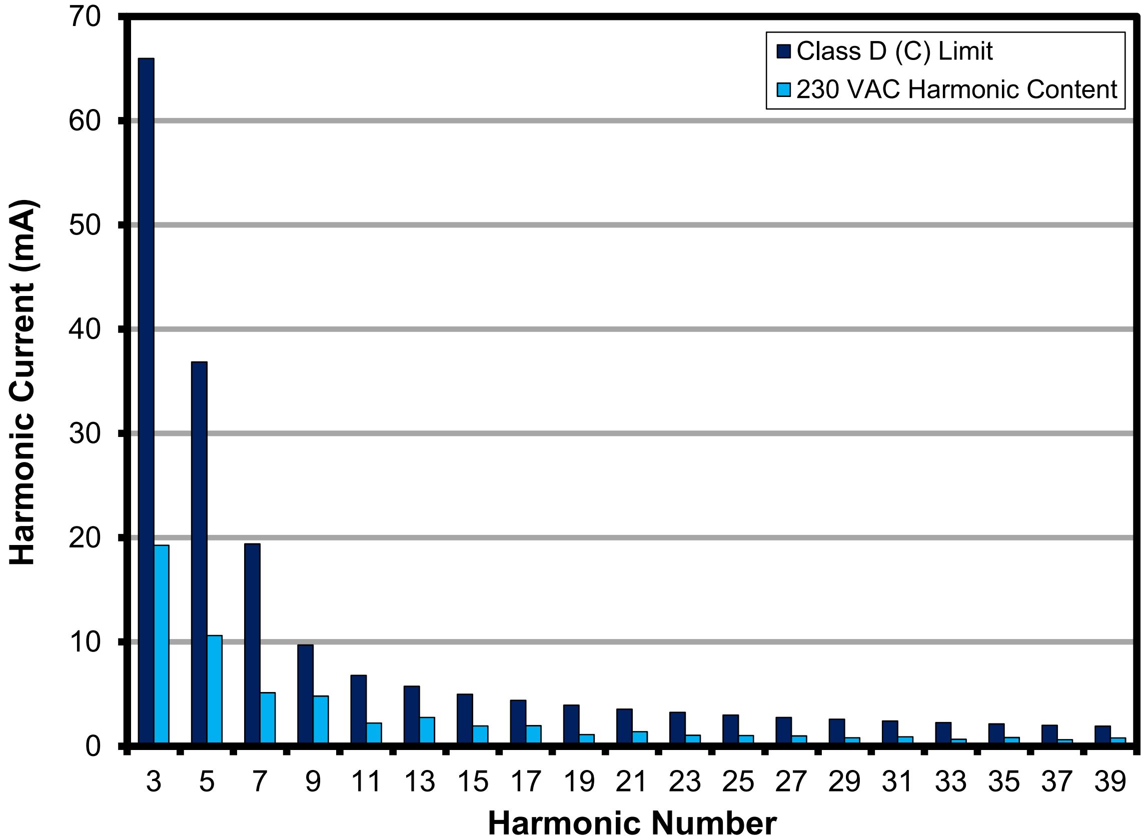

Figure 22 – 194 V V_{OUT} LED Load Input Current Harmonics at 230 VAC, 50 Hz.

9.7.3 197 V V_{OUT} LED Load

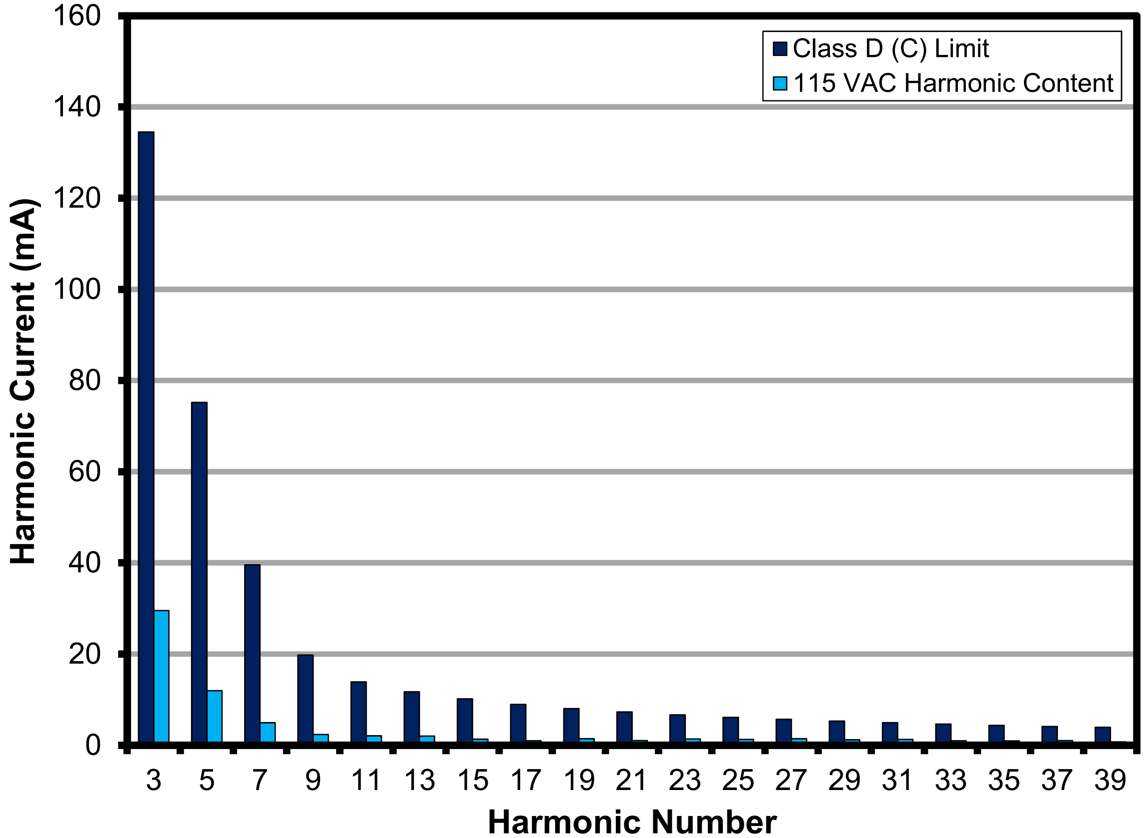

Figure 23 – 197 V V_{OUT} LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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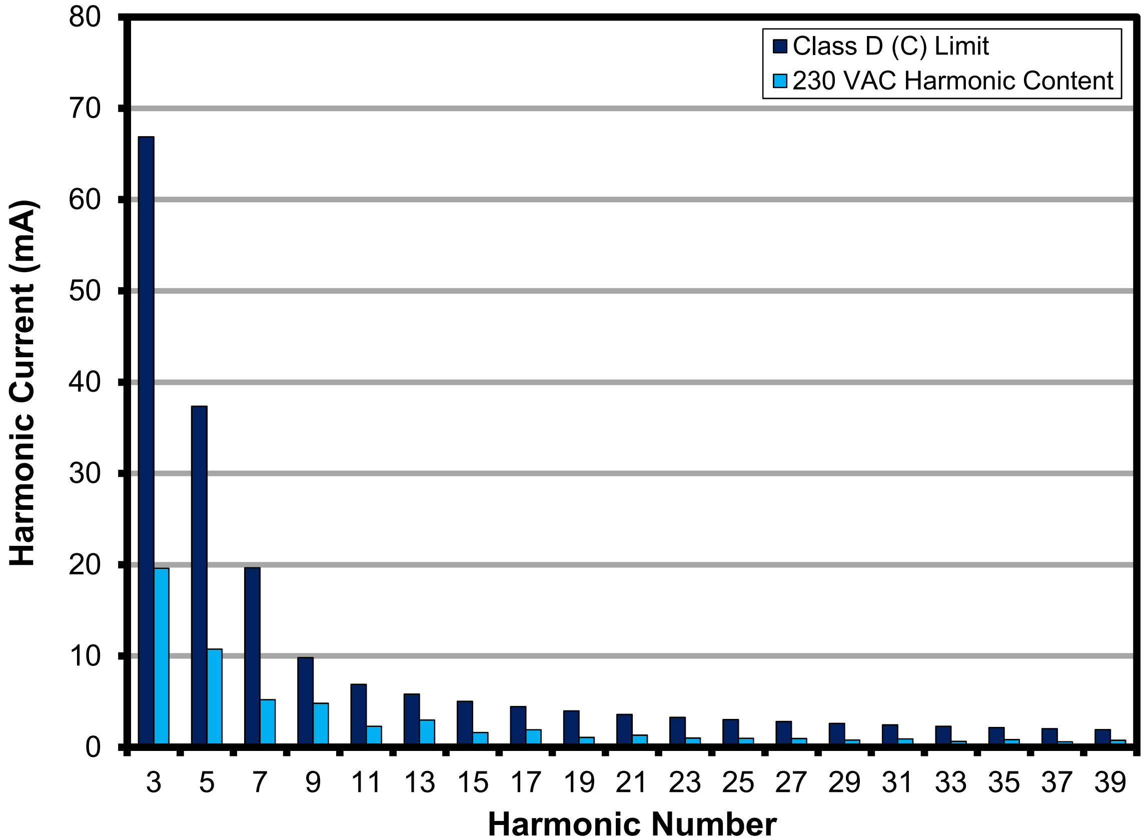

Figure 24 – 197 V V_{OUT} LED Load Input Current Harmonics at 230 VAC, 50 Hz.

9.7.4 200 V V_{OUT} LED Load

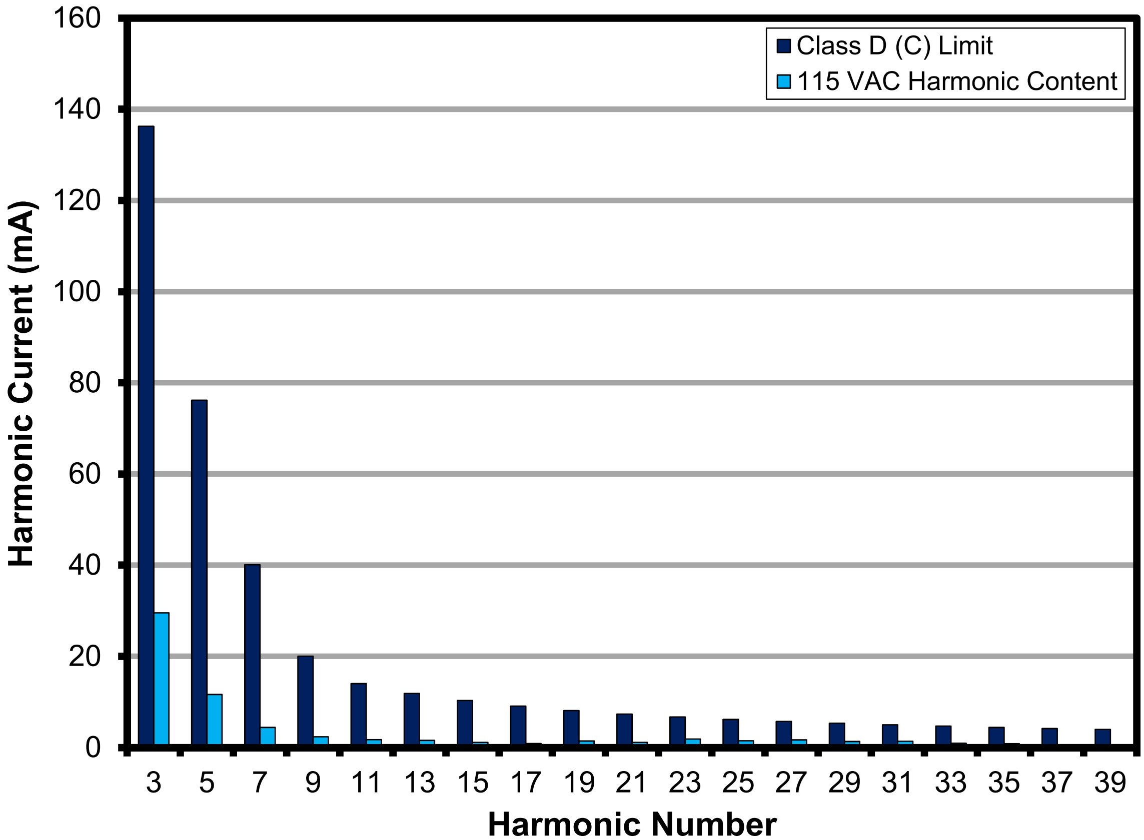

Figure 25 – 200 V V_{OUT} LED Load Input Current Harmonics at 115 VAC, 60 Hz.

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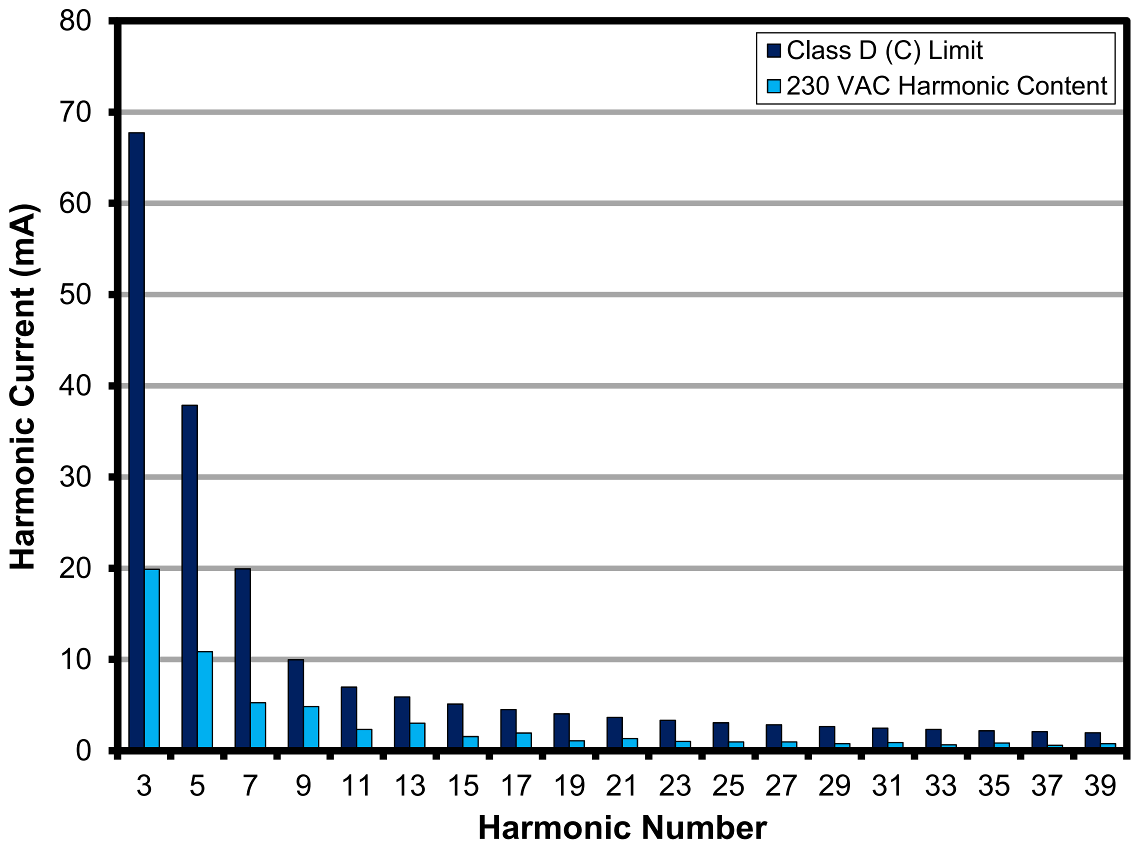

Figure 26 – 200 V V_{OUT} LED Load Input Current Harmonics at 230 VAC, 50 Hz.

9.8 Test Data

All measurements were taken with open frame boards and room temperature ambient.

9.8.1 Test Data, 194 V LED Load

Input Measurement					Load Measurement			Calculation			
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)	% Reg
90.03	221.45	19.671	0.987	15.58	194.60	89.70	17.470	17.46	88.81	2.20	-0.33%
100.00	199.11	19.619	0.985	16.2	194.60	89.70	17.480	17.46	89.10	2.14	-0.33%
110.06	180.81	19.537	0.982	17.9	194.60	89.80	17.490	17.48	89.52	2.05	-0.22%
115.05	173.16	19.516	0.980	18.85	194.60	89.80	17.490	17.48	89.62	2.03	-0.22%
135.07	147.99	19.441	0.973	21.54	194.40	89.90	17.490	17.48	89.96	1.95	-0.11%
177.08	114.07	19.387	0.960	25.2	194.50	89.90	17.510	17.49	90.32	1.88	-0.11%
200.11	101.78	19.383	0.952	26.47	194.50	89.90	17.510	17.49	90.34	1.87	-0.11%
220.14	93.34	19.396	0.944	27.3	194.50	89.90	17.510	17.49	90.28	1.89	-0.11%
230.19	89.68	19.400	0.940	27.6	194.30	89.90	17.490	17.47	90.15	1.91	-0.11%
265.18	79.41	19.447	0.923	28.38	194.40	89.80	17.480	17.46	89.89	1.97	-0.22%

9.8.2 Test Data, 197 V LED Load

Input Measurement					Load Measurement			Calculation			
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)	% Reg
90.03	224.38	19.932	0.987	15.47	197.30	89.60	17.690	17.68	88.75	2.24	-0.44%
100.00	201.95	19.890	0.985	16.21	197.30	89.60	17.710	17.68	89.04	2.18	-0.44%
110.05	183.22	19.802	0.982	17.78	197.20	89.70	17.720	17.69	89.49	2.08	-0.33%
115.04	175.50	19.783	0.980	19.01	197.30	89.70	17.720	17.70	89.57	2.06	-0.33%
135.07	149.99	19.708	0.973	21.44	197.30	89.80	17.740	17.72	90.01	1.97	-0.22%
177.07	115.60	19.653	0.960	25.22	197.30	89.90	17.750	17.74	90.32	1.90	-0.11%
200.11	103.12	19.644	0.952	26.52	197.20	89.90	17.750	17.73	90.36	1.89	-0.11%
220.14	94.56	19.660	0.944	27.25	197.20	89.90	17.750	17.73	90.28	1.91	-0.11%
230.19	90.87	19.670	0.940	27.62	197.20	89.90	17.740	17.73	90.19	1.93	-0.11%
265.18	80.45	19.717	0.924	28.4	197.10	89.80	17.720	17.70	89.87	2.00	-0.22%

9.8.3 Test Data, 200 V LED Load

Input Measurement					Load Measurement			Calculation			
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)	% Reg
90.03	227.34	20.198	0.987	15.35	200.00	89.50	17.920	17.90	88.72	2.28	-0.56%
100.00	204.74	20.161	0.985	16.55	200.00	89.60	17.930	17.92	88.93	2.23	-0.44%
110.06	185.59	20.064	0.982	17.49	200.00	89.60	17.950	17.92	89.46	2.11	-0.44%
115.04	177.75	20.043	0.980	18.68	199.90	89.70	17.940	17.93	89.51	2.10	-0.33%
135.07	151.90	19.965	0.973	21.38	200.00	89.70	17.960	17.94	89.96	2.01	-0.33%
177.07	117.09	19.912	0.960	25.18	199.90	89.80	17.980	17.95	90.30	1.93	-0.22%
200.11	104.45	19.905	0.952	26.49	199.90	89.80	17.980	17.95	90.33	1.93	-0.22%
220.13	95.76	19.919	0.945	27.26	199.90	89.80	17.970	17.95	90.22	1.95	-0.22%
230.19	92.00	19.925	0.941	27.63	199.90	89.80	17.970	17.95	90.19	1.96	-0.22%
265.18	81.42	19.972	0.925	28.46	199.90	89.70	17.950	17.93	89.88	2.02	-0.33%

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9.8.4 194 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD		V	Freq	I (mA)	P	PF	%THD
115	60.00	173.16	19.5160	0.9797	18.85		230	50.00	89.68	19.4000	0.9398	27.6
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**		**nth Order**	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	169.98						**1**	86.16				
2	0.32	0.19%		2.00%			**2**	0.05	0.06%		2.00%	
3	28.94	17.03%	132.7088	29.39%	Pass		**3**	19.27	22.37%	65.9600	28.19%	Pass
5	11.56	6.80%	74.1608	10.00%	Pass		**5**	10.62	12.33%	36.8600	10.00%	Pass
7	4.55	2.68%	39.0320	7.00%	Pass		**7**	5.13	5.95%	19.4000	7.00%	Pass
9	2.41	1.42%	19.5160	5.00%	Pass		**9**	4.80	5.57%	9.7000	5.00%	Pass
11	1.94	1.14%	13.6612	3.00%	Pass		**11**	2.22	2.58%	6.7900	3.00%	Pass
13	1.86	1.09%	11.5595	3.00%	Pass		**13**	2.75	3.19%	5.7454	3.00%	Pass
15	1.27	0.75%	10.0182	3.00%	Pass		**15**	1.94	2.25%	4.9793	3.00%	Pass
17	0.87	0.51%	8.8396	3.00%	Pass		**17**	1.96	2.27%	4.3935	3.00%	Pass
19	1.32	0.78%	7.9091	3.00%	Pass		**19**	1.12	1.30%	3.9311	3.00%	Pass
21	1.05	0.62%	7.1559	3.00%	Pass		**21**	1.39	1.61%	3.5567	3.00%	Pass
23	1.55	0.91%	6.5336	3.00%	Pass		**23**	1.04	1.21%	3.2474	3.00%	Pass
25	1.37	0.81%	6.0109	3.00%	Pass		**25**	1.03	1.20%	2.9876	3.00%	Pass
27	1.69	0.99%	5.5657	3.00%	Pass		**27**	0.98	1.14%	2.7663	3.00%	Pass
29	1.29	0.76%	5.1818	3.00%	Pass		**29**	0.82	0.95%	2.5755	3.00%	Pass
31	1.32	0.78%	4.8475	3.00%	Pass		**31**	0.90	1.04%	2.4094	3.00%	Pass
33	1.02	0.60%	4.5537	3.00%	Pass		**33**	0.66	0.77%	2.2633	3.00%	Pass
35	0.90	0.53%	4.2935	3.00%	Pass		**35**	0.83	0.96%	2.1340	3.00%	Pass
37	0.62	0.36%	4.0614	3.00%	Pass		**37**	0.61	0.71%	2.0186	3.00%	Pass
39	0.57	0.34%	3.8532	3.00%	Pass		**39**	0.79	0.92%	1.9151	3.00%	Pass
41	0.28	0.16%					**41**	0.61	0.71%			
43	0.26	0.15%					**43**	0.72	0.84%			
45	0.22	0.13%					**45**	0.62	0.72%			
47	0.29	0.17%					**47**	0.61	0.71%			
49	0.50	0.29%					**49**	0.62	0.72%			

9.8.5 197 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD		V	Freq	I (mA)	P	PF	%THD
115	60.00	175.50	19.7830	0.9799	19.01		230	50.00	90.87	19.6700	0.9403	27.62
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**		**nth Order**	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	172.38						**1**	87.36				
2	0.31	0.18%		2.00%			**2**	0.05	0.06%		2.00%	
3	29.52	17.12%	134.5244	29.40%	Pass		**3**	19.61	22.45%	66.8780	28.21%	Pass
5	11.97	6.94%	75.1754	10.00%	Pass		**5**	10.75	12.31%	37.3730	10.00%	Pass
7	4.95	2.87%	39.5660	7.00%	Pass		**7**	5.21	5.96%	19.6700	7.00%	Pass
9	2.35	1.36%	19.7830	5.00%	Pass		**9**	4.81	5.51%	9.8350	5.00%	Pass
11	2.06	1.20%	13.8481	3.00%	Pass		**11**	2.31	2.64%	6.8845	3.00%	Pass
13	1.99	1.15%	11.7176	3.00%	Pass		**13**	2.99	3.42%	5.8253	3.00%	Pass
15	1.33	0.77%	10.1553	3.00%	Pass		**15**	1.61	1.84%	5.0486	3.00%	Pass
17	0.99	0.57%	8.9605	3.00%	Pass		**17**	1.92	2.20%	4.4547	3.00%	Pass
19	1.40	0.81%	8.0173	3.00%	Pass		**19**	1.09	1.25%	3.9858	3.00%	Pass
21	1.02	0.59%	7.2538	3.00%	Pass		**21**	1.33	1.52%	3.6062	3.00%	Pass
23	1.38	0.80%	6.6230	3.00%	Pass		**23**	1.00	1.14%	3.2926	3.00%	Pass
25	1.25	0.73%	6.0932	3.00%	Pass		**25**	0.98	1.12%	3.0292	3.00%	Pass
27	1.40	0.81%	5.6418	3.00%	Pass		**27**	0.95	1.09%	2.8048	3.00%	Pass
29	1.17	0.68%	5.2527	3.00%	Pass		**29**	0.79	0.90%	2.6114	3.00%	Pass
31	1.26	0.73%	4.9138	3.00%	Pass		**31**	0.91	1.04%	2.4429	3.00%	Pass
33	0.96	0.56%	4.6160	3.00%	Pass		**33**	0.65	0.74%	2.2948	3.00%	Pass
35	0.91	0.53%	4.3523	3.00%	Pass		**35**	0.84	0.96%	2.1637	3.00%	Pass
37	1.03	0.60%	4.1170	3.00%	Pass		**37**	0.60	0.69%	2.0467	3.00%	Pass
39	0.72	0.42%	3.9059	3.00%	Pass		**39**	0.77	0.88%	1.9418	3.00%	Pass
41	0.39	0.23%					**41**	0.61	0.70%			
43	0.33	0.19%					**43**	0.71	0.81%			
45	0.23	0.13%					**45**	0.62	0.71%			
47	0.33	0.19%					**47**	0.61	0.70%			
49	1.22	0.71%					**49**	0.63	0.72%			

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9.8.6 200 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD		V	Freq	I (mA)	P	PF	%THD
115	60.00	177.75	20.0430	0.9802	18.68		230	50.00	92.00	19.9250	0.9409	27.63
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**		**nth Order**	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	174.55						**1**	88.41				
2	0.14	0.08%		2.00%			**2**	0.06	0.07%		2.00%	
3	29.54	16.92%	136.2924	29.41%	Pass		**3**	19.89	22.50%	67.7450	28.23%	Pass
5	11.60	6.65%	76.1634	10.00%	Pass		**5**	10.85	12.27%	37.8575	10.00%	Pass
7	4.40	2.52%	40.0860	7.00%	Pass		**7**	5.27	5.96%	19.9250	7.00%	Pass
9	2.35	1.35%	20.0430	5.00%	Pass		**9**	4.85	5.49%	9.9625	5.00%	Pass
11	1.70	0.97%	14.0301	3.00%	Pass		**11**	2.33	2.64%	6.9738	3.00%	Pass
13	1.56	0.89%	11.8716	3.00%	Pass		**13**	3.01	3.40%	5.9009	3.00%	Pass
15	1.14	0.65%	10.2887	3.00%	Pass		**15**	1.55	1.75%	5.1141	3.00%	Pass
17	0.89	0.51%	9.0783	3.00%	Pass		**17**	1.93	2.18%	4.5124	3.00%	Pass
19	1.44	0.82%	8.1227	3.00%	Pass		**19**	1.08	1.22%	4.0374	3.00%	Pass
21	1.14	0.65%	7.3491	3.00%	Pass		**21**	1.33	1.50%	3.6529	3.00%	Pass
23	1.85	1.06%	6.7100	3.00%	Pass		**23**	1.00	1.13%	3.3353	3.00%	Pass
25	1.46	0.84%	6.1732	3.00%	Pass		**25**	0.97	1.10%	3.0685	3.00%	Pass
27	1.65	0.95%	5.7160	3.00%	Pass		**27**	0.95	1.07%	2.8412	3.00%	Pass
29	1.33	0.76%	5.3218	3.00%	Pass		**29**	0.77	0.87%	2.6452	3.00%	Pass
31	1.35	0.77%	4.9784	3.00%	Pass		**31**	0.90	1.02%	2.4746	3.00%	Pass
33	0.92	0.53%	4.6767	3.00%	Pass		**33**	0.65	0.74%	2.3246	3.00%	Pass
35	0.82	0.47%	4.4095	3.00%	Pass		**35**	0.85	0.96%	2.1918	3.00%	Pass
37	0.50	0.29%	4.1711	3.00%	Pass		**37**	0.60	0.68%	2.0733	3.00%	Pass
39	0.50	0.29%	3.9572	3.00%	Pass		**39**	0.77	0.87%	1.9670	3.00%	Pass
41	0.22	0.13%					**41**	0.60	0.68%			
43	0.20	0.11%					**43**	0.71	0.80%			
45	0.21	0.12%					**45**	0.61	0.69%			
47	0.31	0.18%					**47**	0.61	0.69%			
49	0.27	0.15%					**49**	0.62	0.70%			

10 Thermal Performance

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

10.1 V_{IN} = 90 VAC, 60 Hz, 200 V LED Load

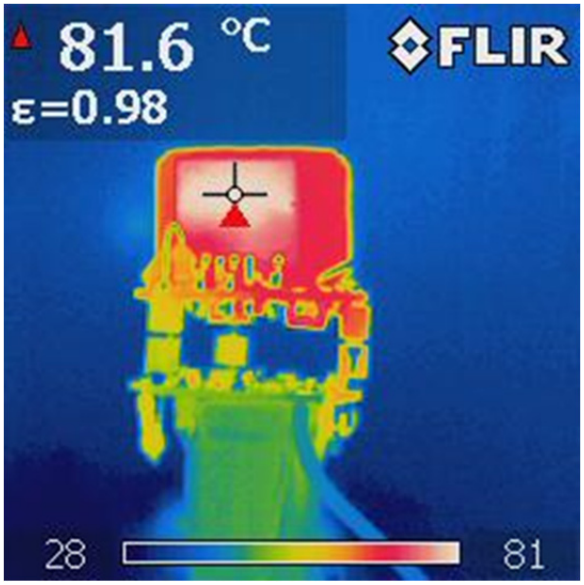

Figure 27 – 90 VAC, 60 Hz, 200 V LED Load. Device: U1: LNK419EG.

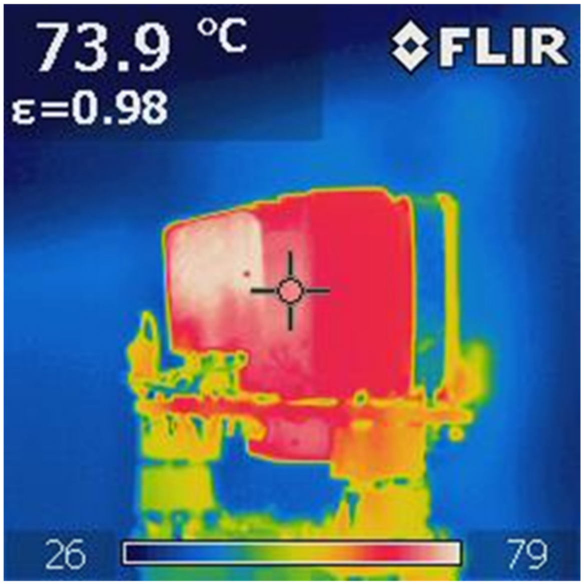

Figure 28 – 90 VAC, 60 Hz, 200 V LED Load. Device: T1: Winding.

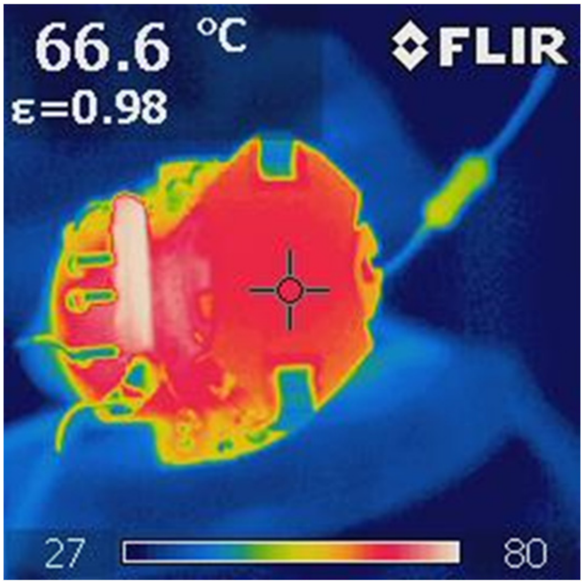

Figure 29 – 90 VAC, 60 Hz, 200 V LED Load. Device: T1: Core.

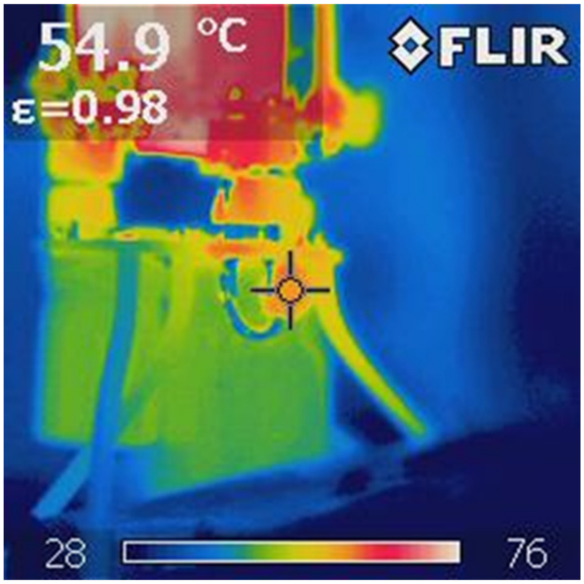

Figure 30 – 90 VAC, 60 Hz, 200 V LED Load. Device: D2: BYV26D.

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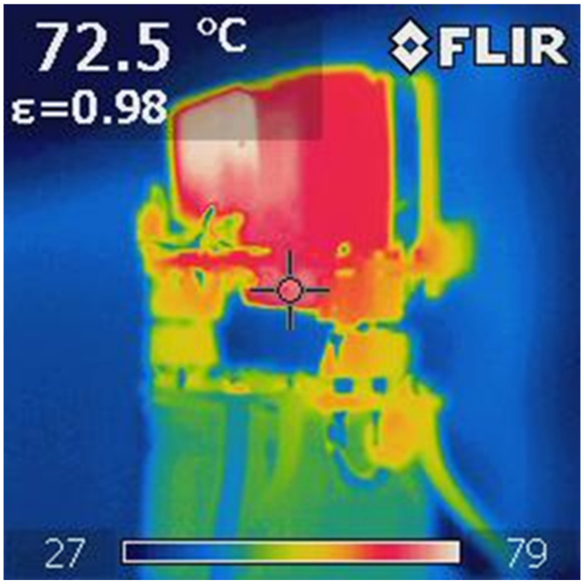

Figure 31 – 90 VAC, 60 Hz, 200 V LED Load.
Device: D4: RS3JB-13F.

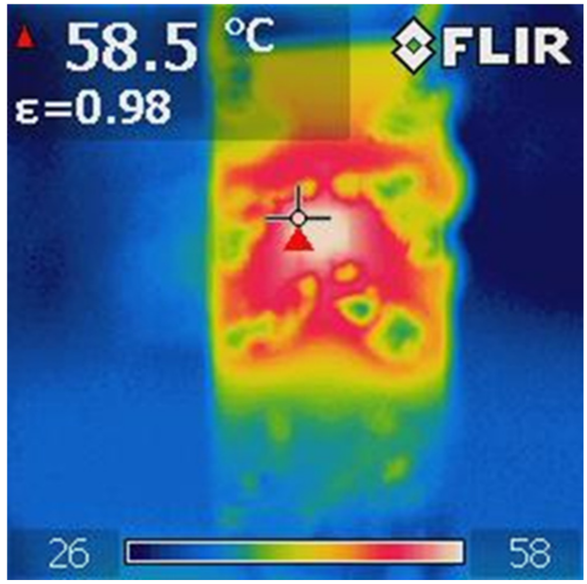

Figure 32 – 90 VAC, 60 Hz, 200 V LED Load.
Device: BR1: B10S-G.

10.2 V_{IN} = 265 VAC, 50 Hz, 200 V LED Load

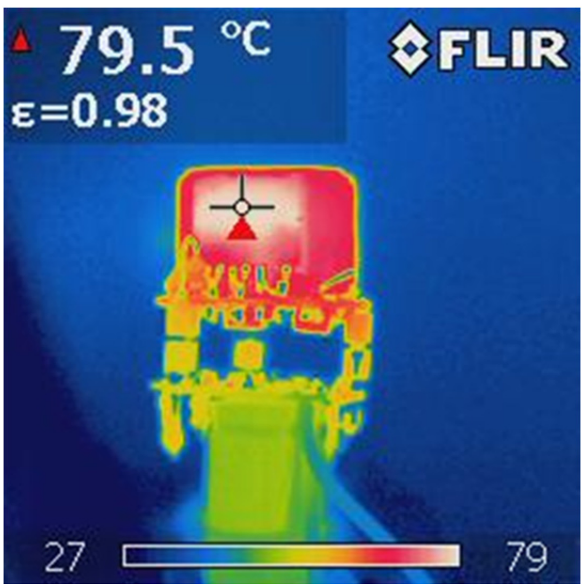

Figure 33 – 265 VAC, 50 Hz, 200 V LED Load.
Device: U1: LNK419EG.

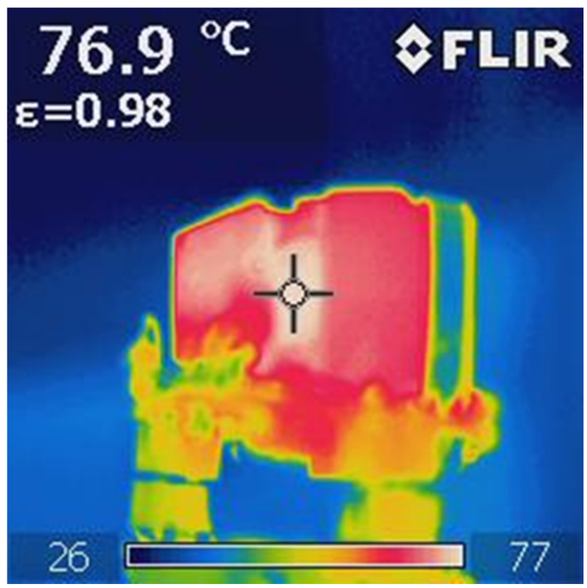

Figure 34 – 265 VAC, 50 Hz, 200 V LED Load.
Device: T1: Winding.

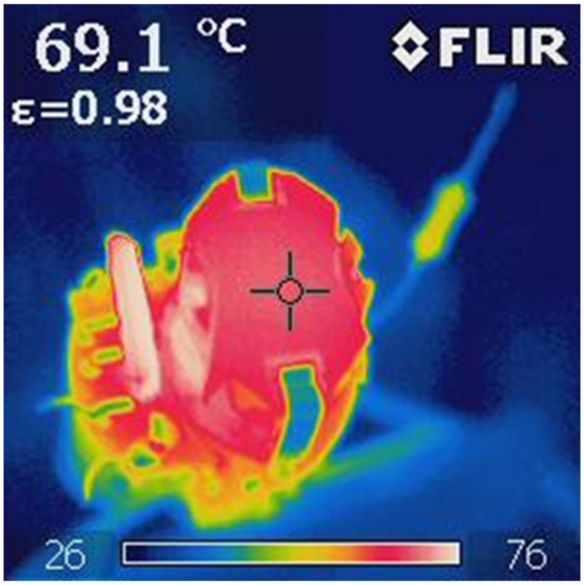

Figure 35 – 265 VAC, 50 Hz, 200 V LED Load.
Device: T1: Core.

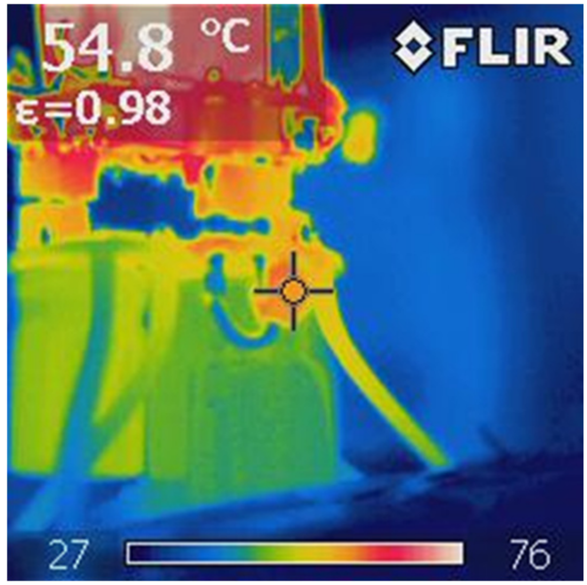

Figure 36 – 265 VAC, 50 Hz, 200 V LED Load.
Device: D2: BYV26D.

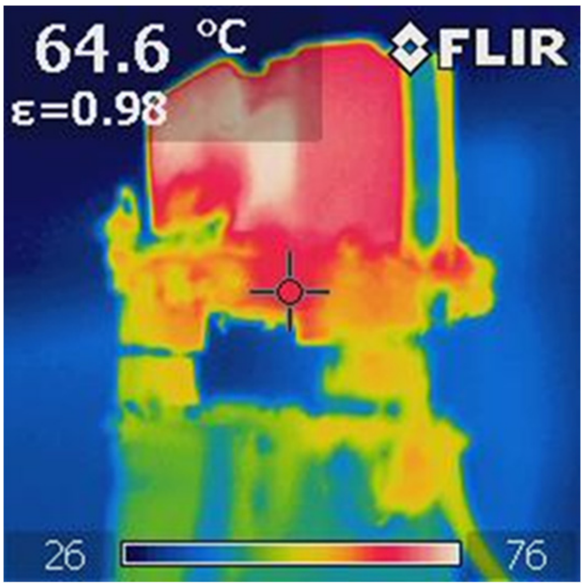

Figure 37 – 265 VAC, 50 Hz, 200 V LED Load.
Device: D4: RS3JB-13F.

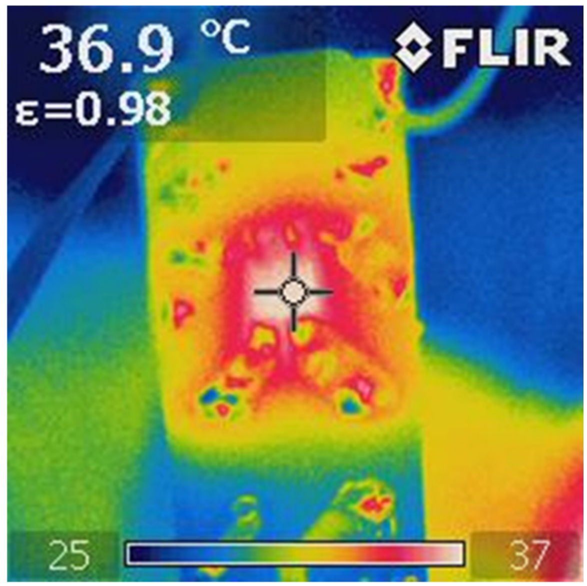

Figure 38 – 265 VAC, 50 Hz, 200 V LED Load.
Device: BR1: B10S-G.

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11 Waveforms

11.1 Input Line Voltage and Current

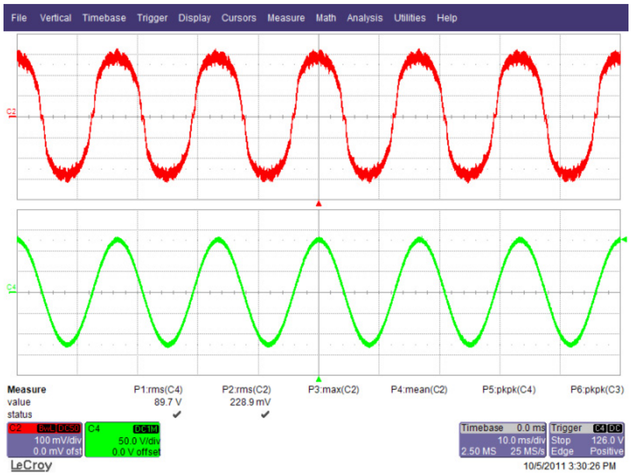

Figure 39 – 90 VAC, 60 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

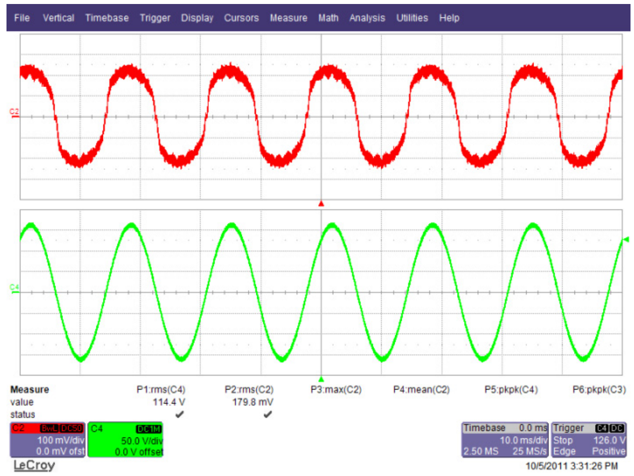

Figure 40 – 115 VAC, 60 Hz Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V, 10 ms / div.

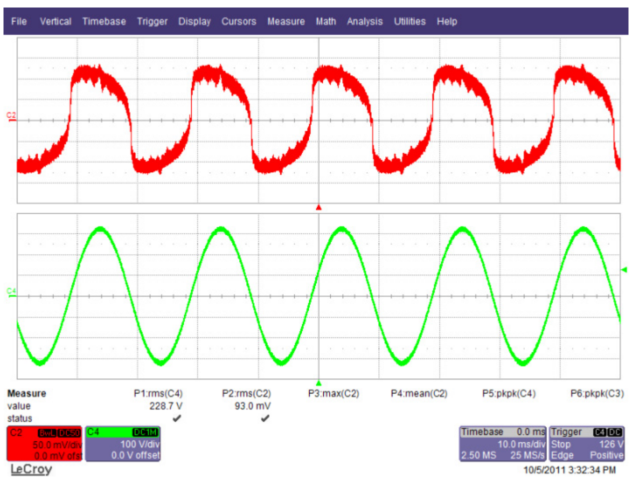

Figure 41 – 230 VAC, 50 Hz Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

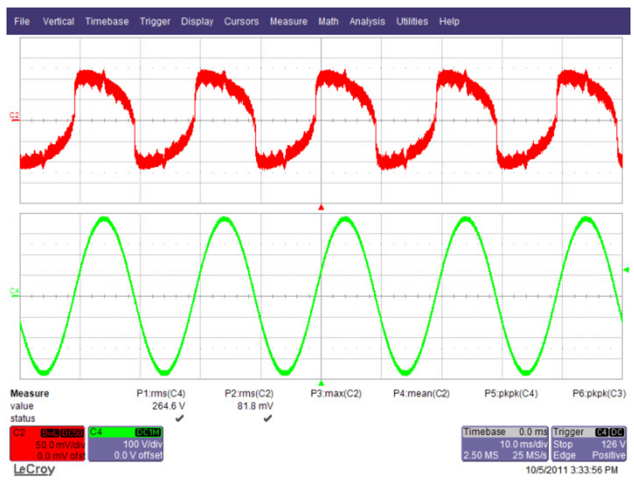

Figure 42 – 265 VAC, 50 Hz Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

11.2 Output Current and Output Voltage at Normal Operation

Input Condition	I_{OUT}, Mean	I_{OUT}, Peak to Peak	I_{OUT} Ripple
90 VAC, 60 Hz	89.67 mA	44.8 mA	±24.98%
115 VAC, 60 Hz	89.71 mA	43.5 mA	±24.24%
230 VAC, 50 Hz	89.88 mA	47.4 mA	±26.37%
265 VAC, 50 Hz	89.87 mA	46.7 mA	±25.98%

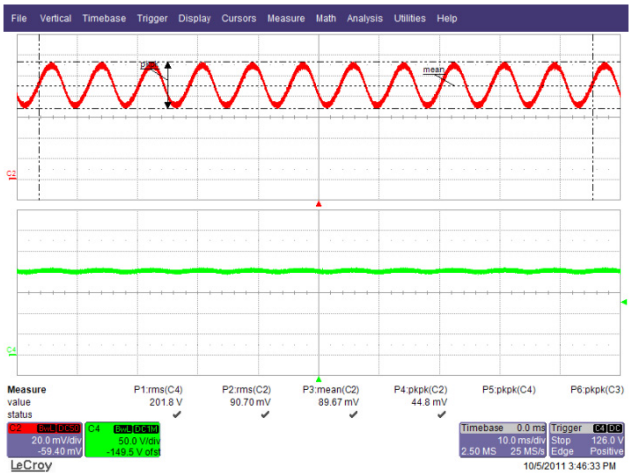

Figure 43 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 50 V, 10 ms / div.

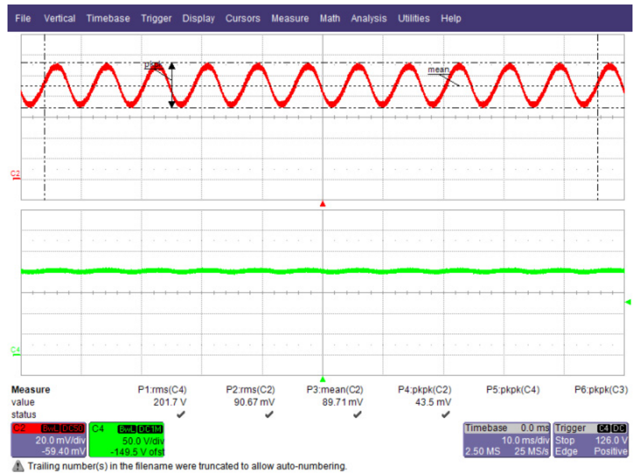

Figure 44 – 115 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 50 V, 10 ms / div.

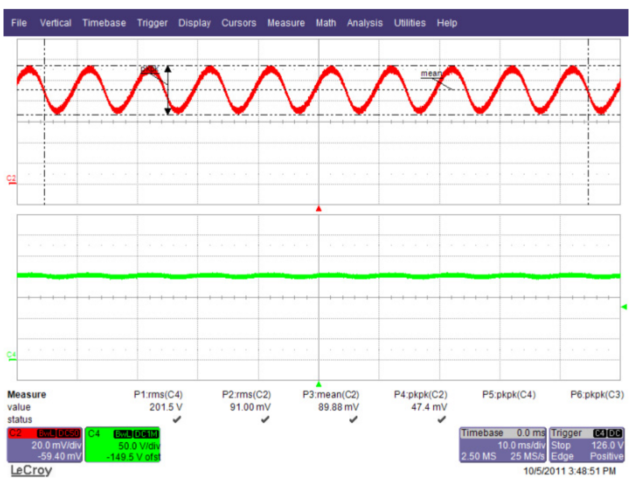

Figure 45 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 50 V, 10 ms / div.

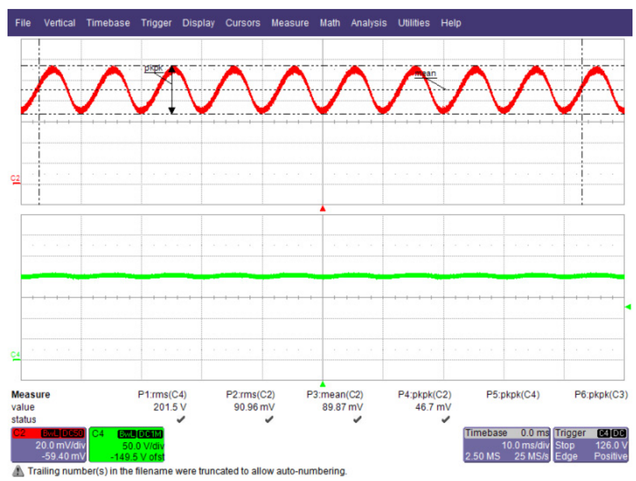

Figure 46 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 50 V, 10 ms / div.

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11.3 Output Current Rise and Fall

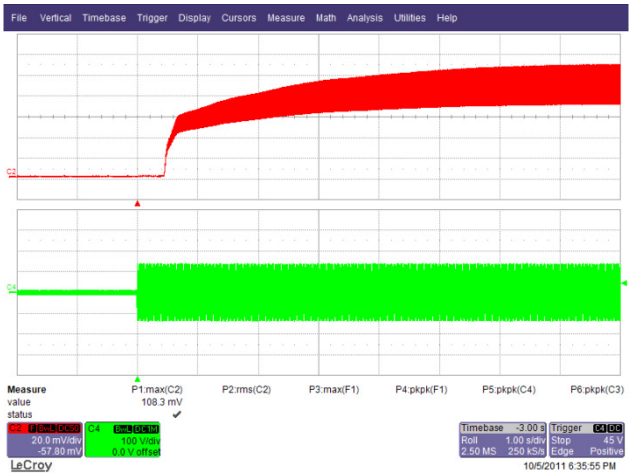

Figure 47 – 90 VAC, 60 Hz Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 1 s / div.

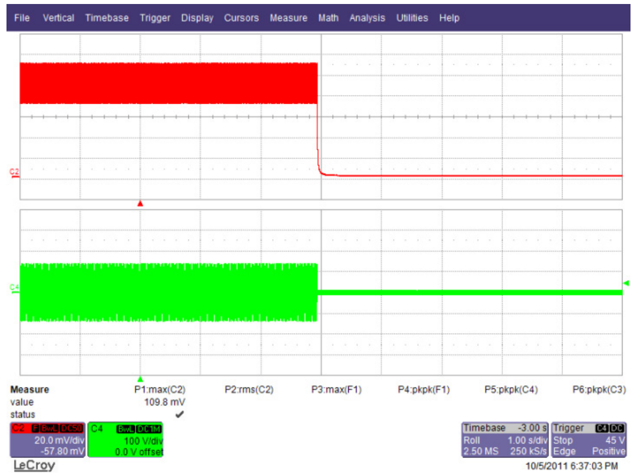

Figure 48 – 90 VAC, 60 Hz Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 1 s / div.

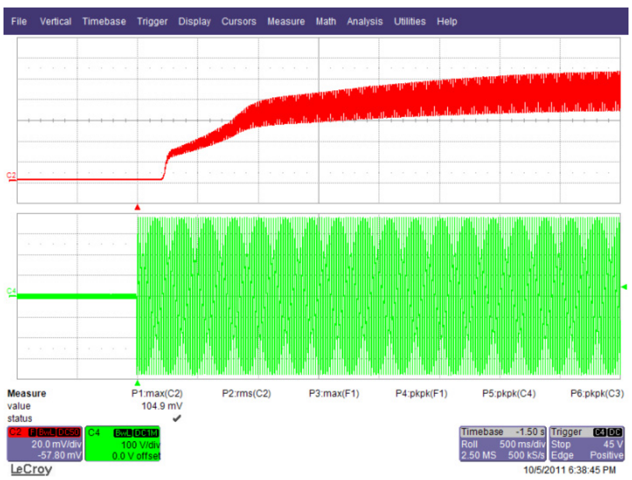

Figure 49 – 265 VAC, 50 Hz Output Rise.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 500 ms / div.

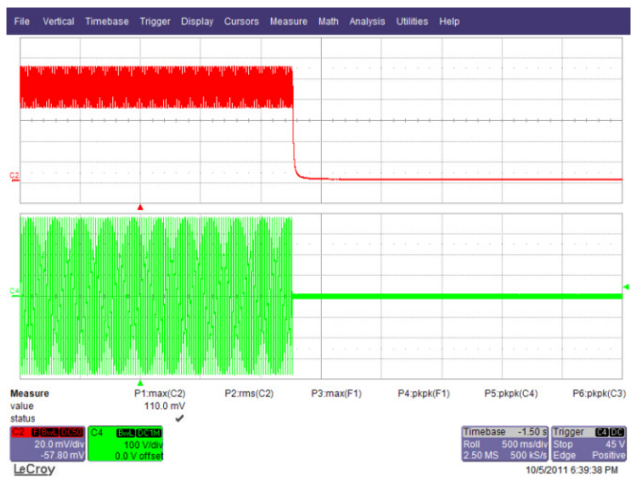

Figure 50 – 265 VAC, 50 Hz Output Fall.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{OUT}, 100 V, 500 ms / div.

11.4 Drain Voltage and Current at Normal Operation

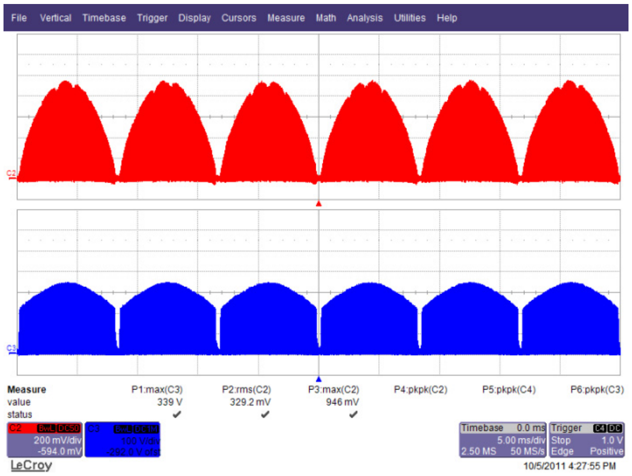

Figure 51 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

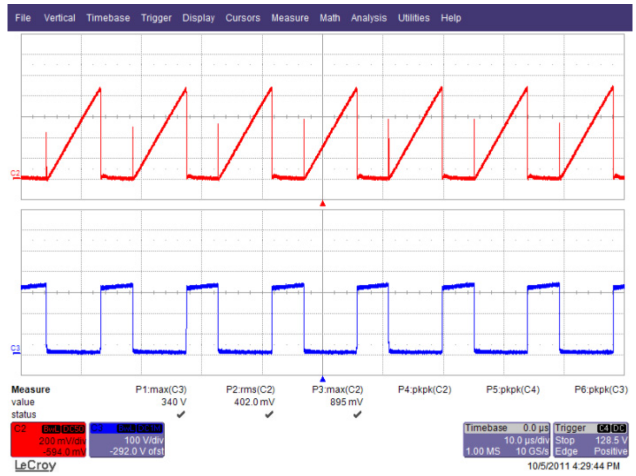

Figure 52 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

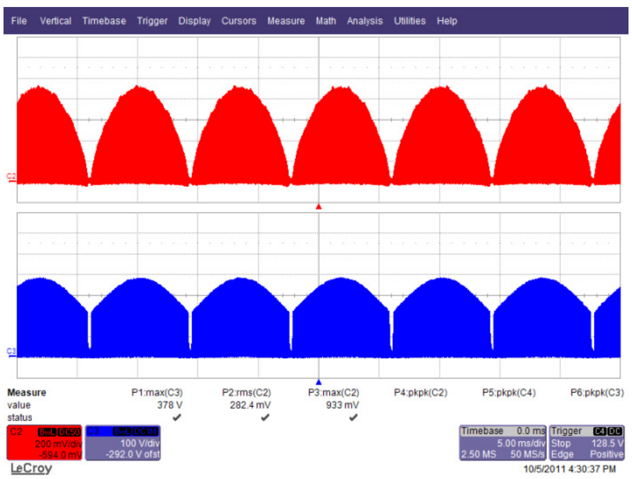

Figure 53 – 115 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

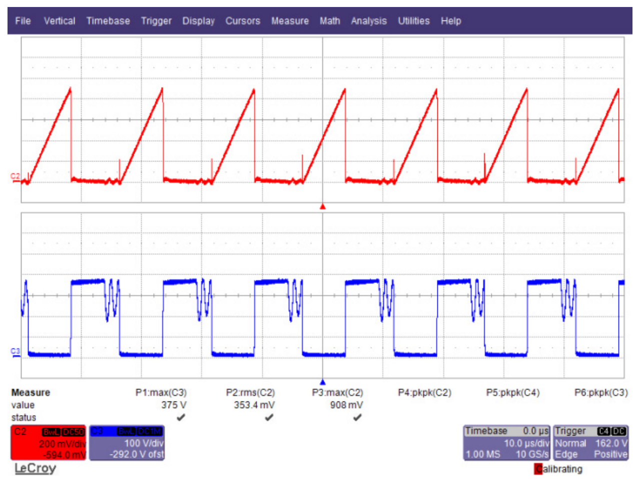

Figure 54 – 115 VAC, 60 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

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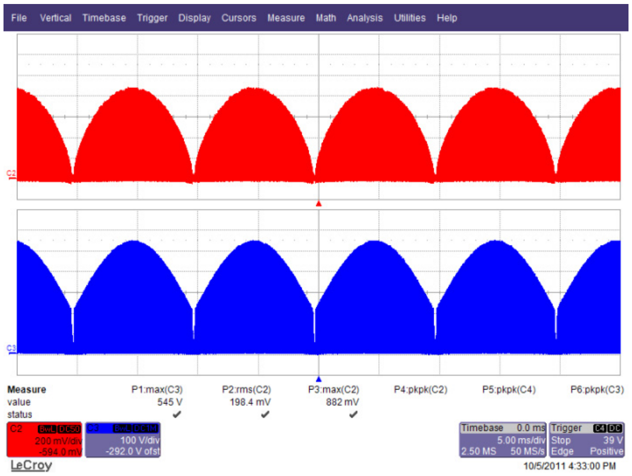

Figure 55 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

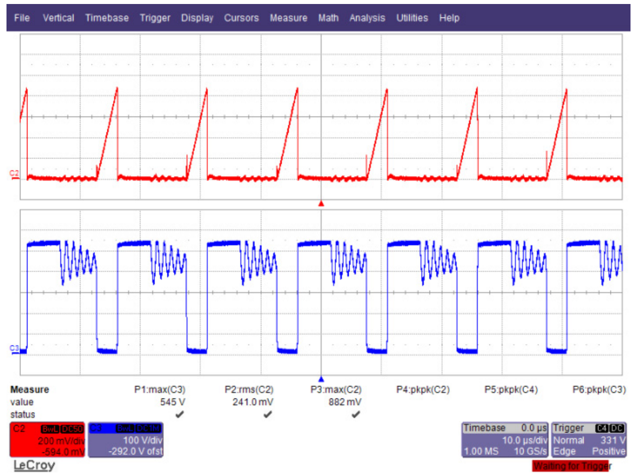

Figure 56 – Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

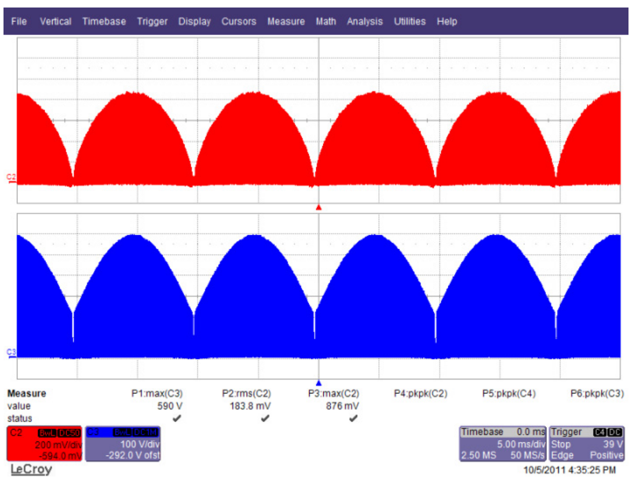

Figure 57 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

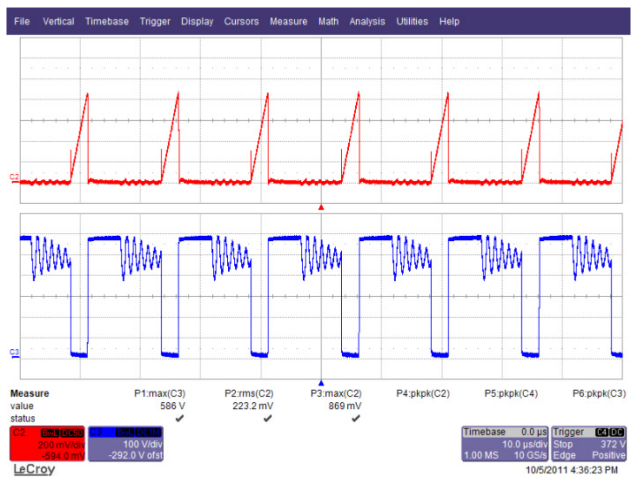

Figure 58 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

11.5 *Start-up Drain Voltage and Current Waveform*

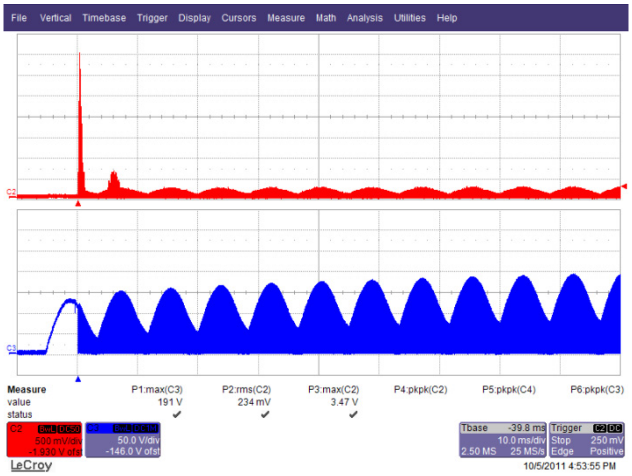

Figure 59 – 90 VAC, 60 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V, 10 ms / div.

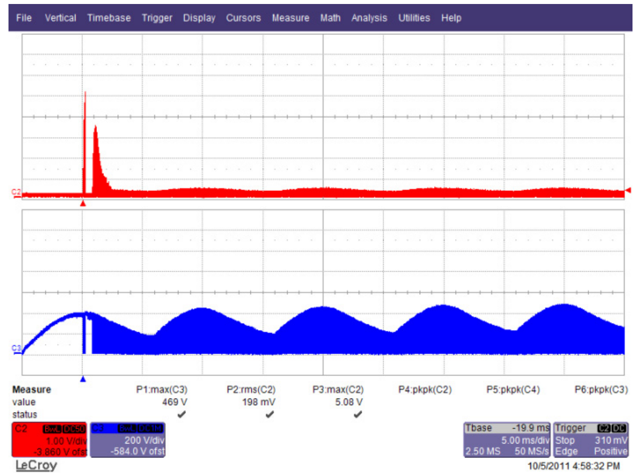

Figure 60 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

11.6 *Output Short Drain Voltage and Current Waveform*

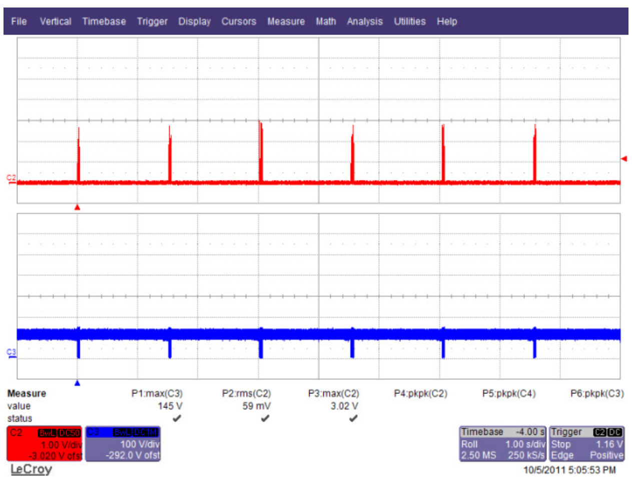

Figure 61 – 90 VAC, 60 Hz Output Short.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

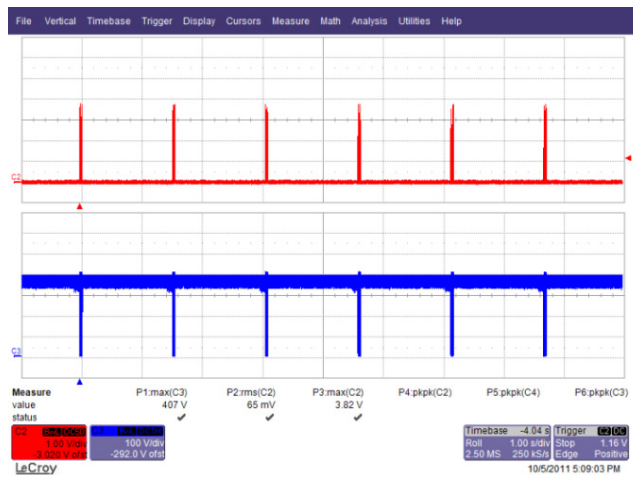

Figure 62 – 265 VAC, 50 Hz Output Short.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

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11.7 Output Diode PIV

The output diode D2 PIV was measured during normal and output short-circuit conditions and are well below the maximum rating (800 V) of the device.

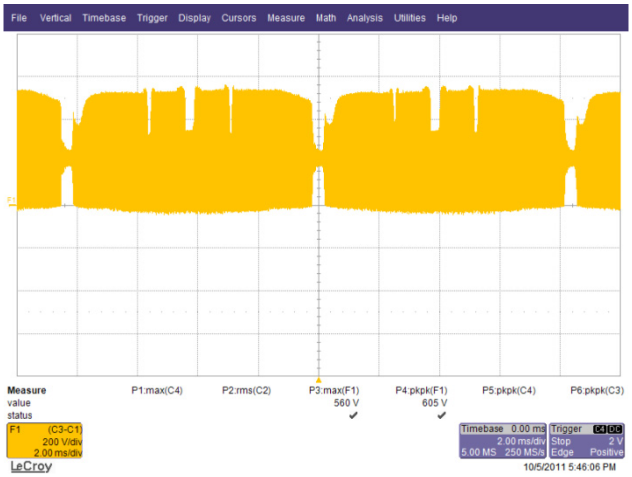

Figure 63 – 90 VAC, 60 Hz Normal Operation.
PIV: 200 V, 2 ms / div.

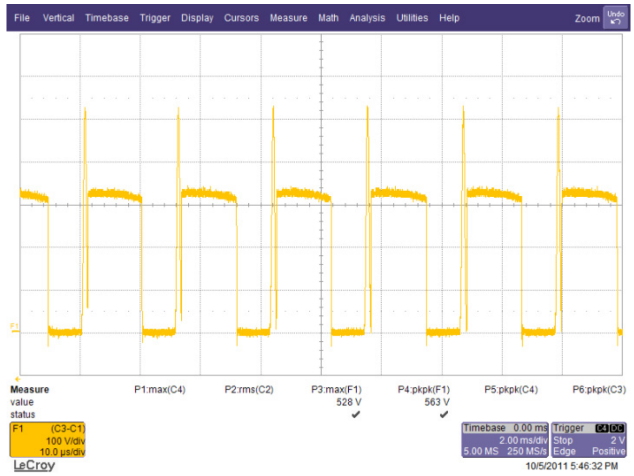

Figure 64 – 90 VAC, 60 Hz Normal Operation.
PIV: 200 V, 10 µs / div.

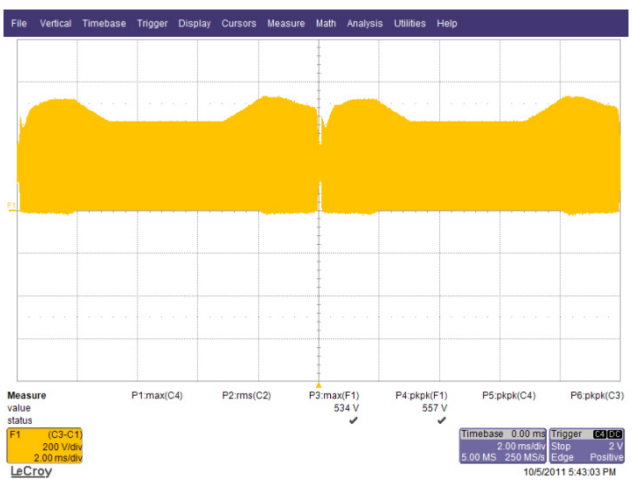

Figure 65 – 265 VAC, 50 Hz Normal Operation.
PIV: 200 V, 2 ms / div.

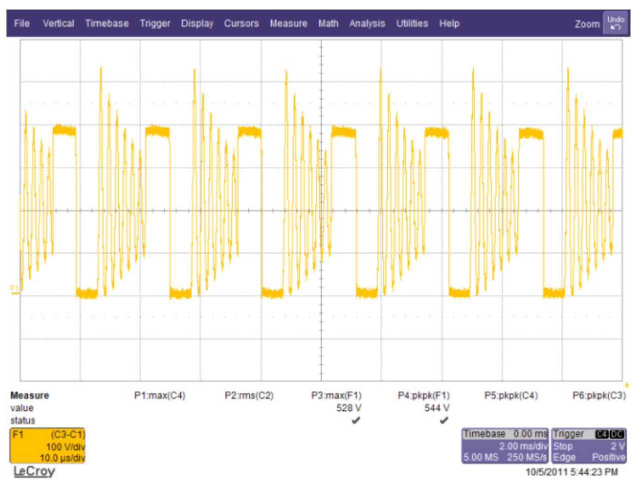

Figure 66 – 265 VAC, 50 Hz Normal Operation.
PIV: 200 V, 10 µs / div.

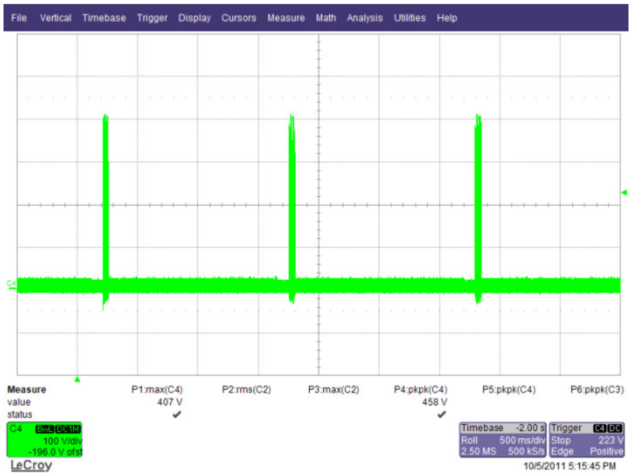
Figure 67 – 265 VAC, 50 Hz Output Short.
PIV: 100 V, 500 ms / div.

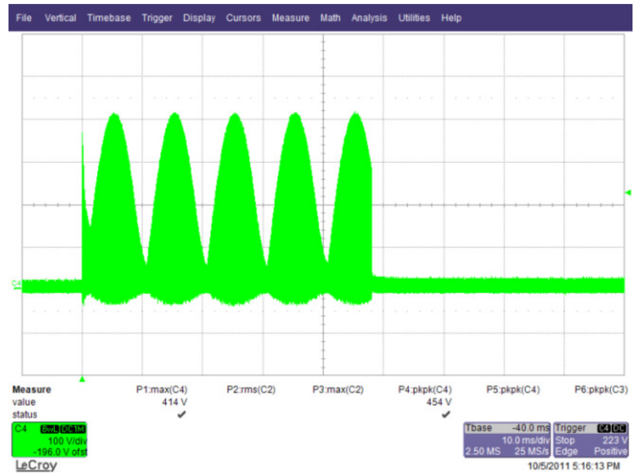
Figure 68 – 265 VAC, 50 Hz Output Short.
PIV: 100 V, 10 ms / div.

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12 Conducted EMI

The unit was tested using LED load (200 V V_{OUT}) with input voltage of 115 VAC, 60 Hz and 230 VAC, 60 Hz at room temperature. The EMI section and buck-boost section were separated by a 4ft twisted pair of #22 AWG wire to simulate the actual application in a 4ft T8 tube. The LED load is placed above this 4ft twisted pair of wires as shown in the pictures below.

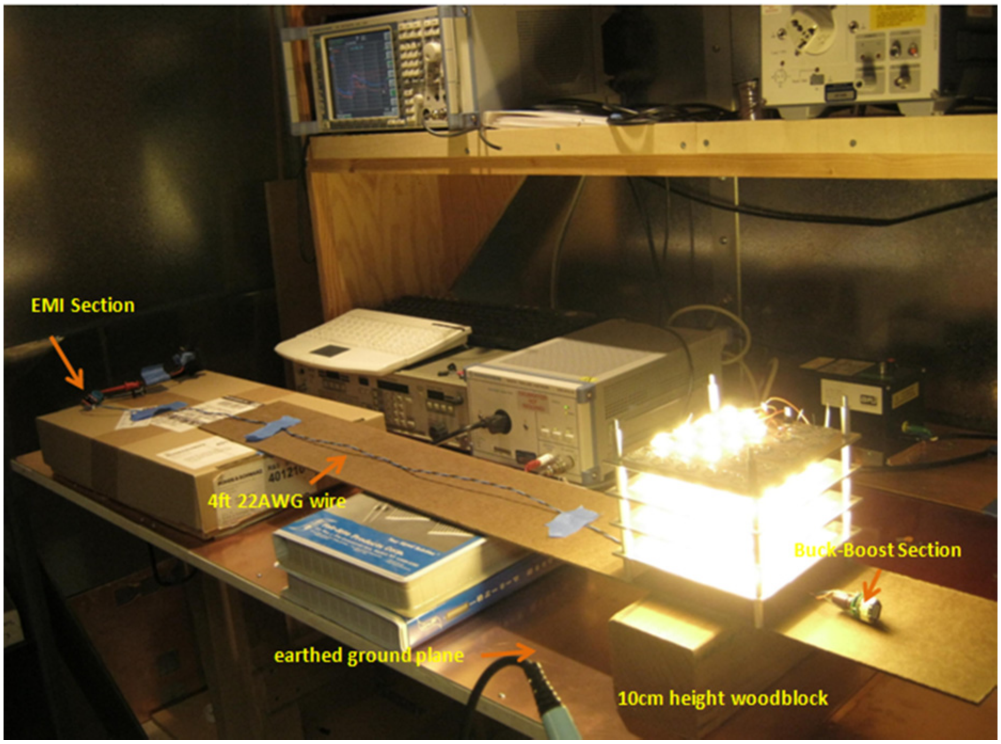
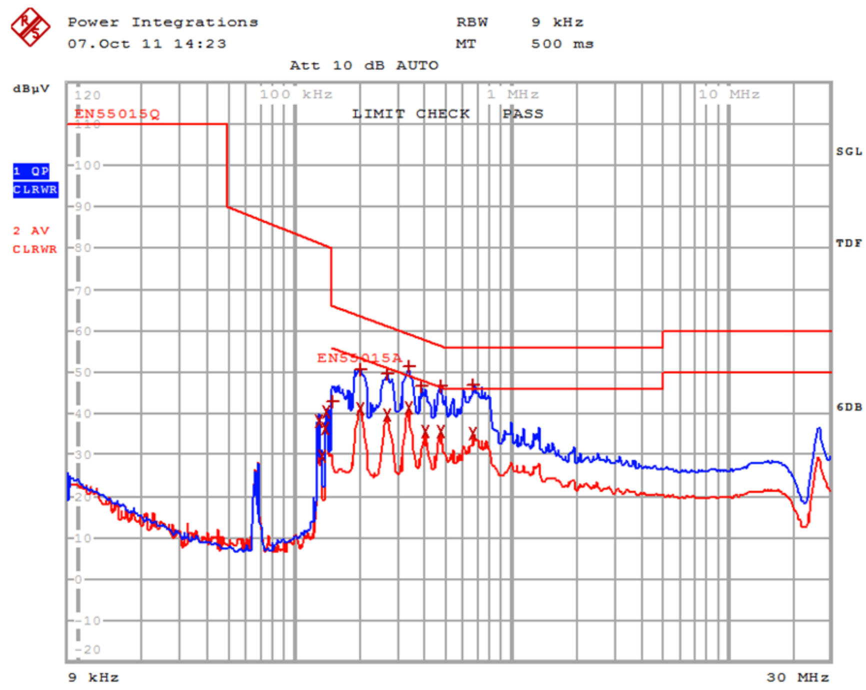


Figure 69 – EMI Test Set-up.

13.2 Test Results



EDIT PEAK LIST (Final Measurement Results)				
Trace1:	EN55015Q			
Trace2:	EN55015A			
Trace3:	---			
TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2 Average	129.530094744 kHz	38.17	L1 gnd	
2 Average	134.789536006 kHz	29.82	L1 gnd	
2 Average	137.49880568 kHz	36.58	N gnd	
2 Average	140.262531674 kHz	40.51	L1 gnd	
1 Quasi Peak	151.5 kHz	42.94	L1 gnd	-22.97
1 Quasi Peak	200.175581485 kHz	50.70	L1 gnd	-12.89
2 Average	200.175581485 kHz	41.31	L1 gnd	-12.28
1 Quasi Peak	267.135089486 kHz	49.56	N gnd	-11.64
2 Average	267.135089486 kHz	39.57	N gnd	-11.63
1 Quasi Peak	335.832355405 kHz	51.39	N gnd	-7.90
2 Average	335.832355405 kHz	41.47	N gnd	-7.82
1 Quasi Peak	382.208547038 kHz	46.70	N gnd	-11.52
2 Average	401.705024172 kHz	35.65	N gnd	-12.16
1 Quasi Peak	471.030732902 kHz	46.65	N gnd	-9.84
2 Average	471.030732902 kHz	35.51	N gnd	-10.98
1 Quasi Peak	667.263434405 kHz	47.00	N gnd	-8.99
2 Average	667.263434405 kHz	35.45	N gnd	-10.54

Figure 70 – Conducted EMI, 200 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits**.**

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EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.84316745416 kHz	22.32	N gnd	
2	Average	65.8441606665 kHz	29.07	N gnd	
2	Average	67.1676282959 kHz	26.92	L1 gnd	
2	Average	128.247618558 kHz	35.40	N gnd	
2	Average	140.262531674 kHz	38.02	N gnd	
1	Quasi Peak	151.5 kHz	54.72	L1 gnd	-11.19
2	Average	200.175581485 kHz	40.69	L1 gnd	-12.90
2	Average	269.806440381 kHz	40.32	N gnd	-10.80
2	Average	335.832355405 kHz	40.33	N gnd	-8.96
2	Average	471.030732902 kHz	34.56	N gnd	-11.93
2	Average	26.2351923234 MHz	29.13	L1 gnd	-20.86

Figure 71 – Conducted EMI, 200 V LED Load, 115 VAC, 60 Hz, and EN55015 B Limits**.**

13 Line Surge

A single unit was subjected to ±2500 V 100 kHz ring wave and ±1 kV differential surge at 115 VAC and 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

Level (V)	**Input Voltage (VAC)**	**Injection Location**	**Injection Phase (°)**	**Type**	**Test Result (Pass/Fail)**
+2500	115 / 230	L1, L2	0	100 kHz Ring Wave (200 A)	Pass
-2500	115 / 230	L1, L2	0	100 kHz Ring Wave (200 A)	Pass
+2500	115 / 230	L1, L2	90	100 kHz Ring Wave (200 A)	Pass
-2500	115 / 230	L1, L2	90	100 kHz Ring Wave (200 A)	Pass

Level (kV)	**Input Voltage (VAC)**	**Injection Location**	**Injection Phase (°)**	**Type**	**Test Result (Pass/Fail)**
+1	115 / 230	L1, L2	0	Surge (2Ω)	Pass
-1	115 / 230	L1, L2	0	Surge (2Ω)	Pass
+1	115 / 230	L1, L2	90	Surge (2Ω)	Pass
-1	115 / 230	L1, L2	90	Surge (2Ω)	Pass

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14 Revision History

Date	Author	Revision	Description and Changes	Reviewed
08-Dec-11	ME	1.2	Initial Release	Apps & Mktg

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