Design Example Report

Title	***T8 25 W, Non-Isolated, Buck-Boost Topology, Power Factor Corrected, LED Driver Using LinkSwitch™-PH LNK409EG***
Specification	180 VAC – 265 VAC Input; 100 V, 250 mA Output
Application	T8 Tube Lamp LED Driver
Author	Applications Engineering Department
Document Number	DER-287
Date	15-July-2011
Revision	1.0

Summary and Features

- Dramatically simplifies off-line, power factor corrected, LED driver design
  - Single-stage, power factor corrected and constant current, non-isolated LED driver
  - Compact with extremely low component count
  - High PF >0.9 across line and load
  - High efficiency >91% at 230 VAC
  - Low THD, <25% at 230 VAC
  - IEC61000-3-2 CLASS C compliant
  - Eliminates all control loop compensation
  - No output current sensing required
- 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

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200   Fax: +1 408 414 9201
www.powerint.com

Table of Contents

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

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

1 Introduction

This document describes a non-isolated, power factor corrected, low THD, high-efficiency LED driver designed to drive ~100 V LED string at 250 mA from an input voltage range of 180 VAC to 265 VAC.

The LinkSwitch-PH has been developed to cost effectively implement a single-stage power factor corrected LED driver and primary-side constant-current control. The LinkSwitch-PH controller is optimized for LED driver applications and requires minimal external parts. It provides 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, over-temperature protection, frequency jittering, cycle-by-cycle current limit, leading edge blanking, and a charge controller for output CC (constant current) control.

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

The non-isolated power factor corrected buck-boost design 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 and enables a Class C harmonic currents compliant implementation of a very high efficiency, high output voltage design

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

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

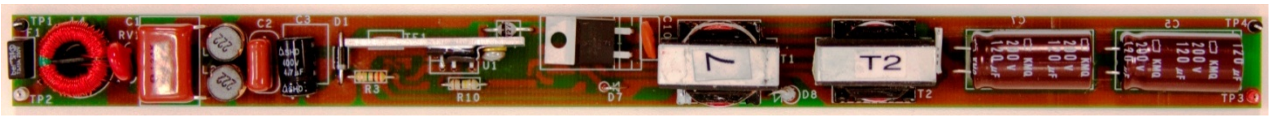


Figure 1 – Populated Circuit Board Photograph, Top.

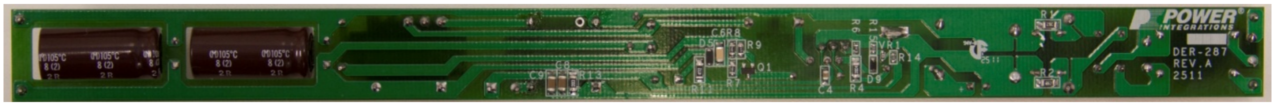


Figure 2 – Populated Circuit Board Photograph, Bottom.

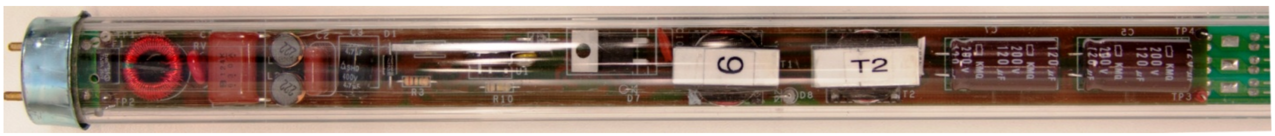


Figure 3 – Photo showing LED Driver inside the T8 Tube.

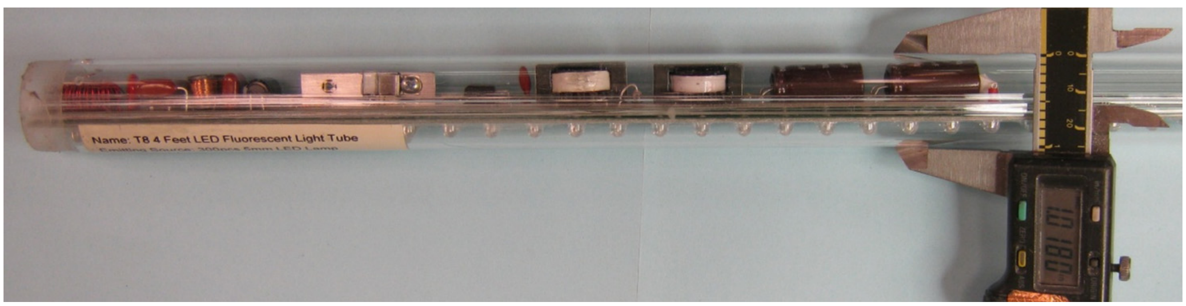


Figure 4 – Photo showing LED Driver inside the T8 Tube.

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}	180		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
LED voltage	V_{OUT}		100		V	
LED Current			250		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		25		W	
Environmental						
Conducted EMI		Meets EN55015B				
Safety		Non-isolated				
Efficiency		90	91			
Harmonic Currents		Class C				61000-3-2
Power Factor		0.95				
Ambient Temperature	T_{AMB}		50		^{o}C	

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

3 Schematic

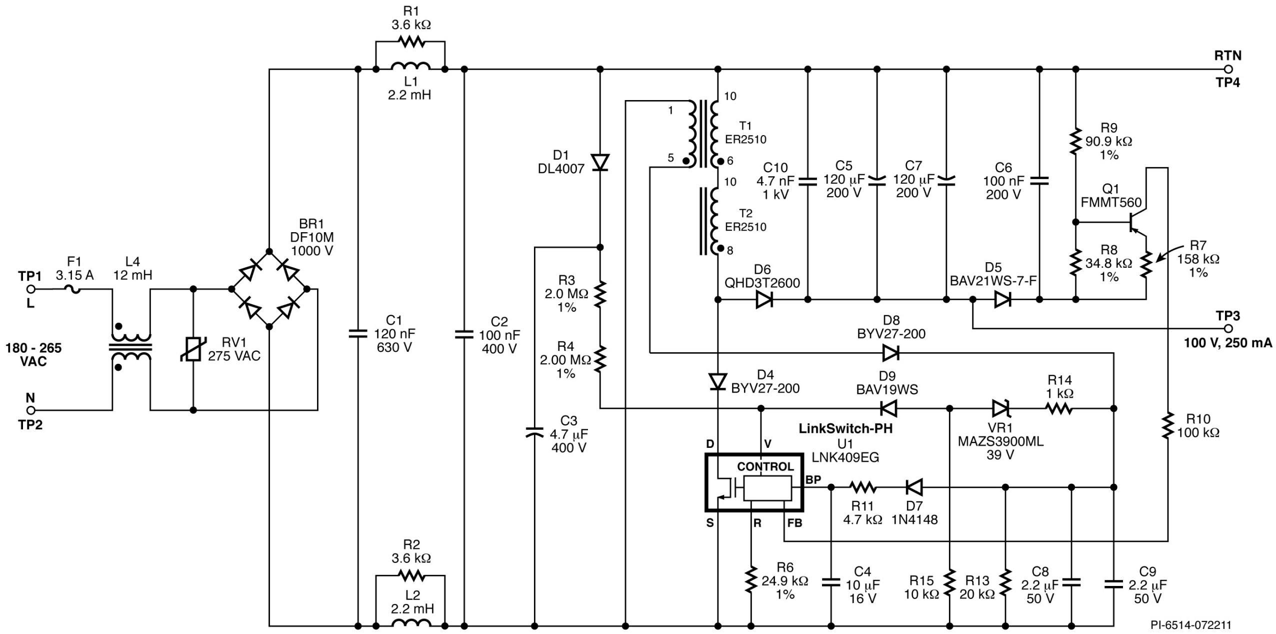


Figure 5 – Schematic.

4 Circuit Description

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 across the range of input and output voltage conditions expected in a typical LED driver environment. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET is incorporated into the device.

Capacitor C1, C2, differential chokes L1, and L2, plus common mode choke L4 perform EMI filtering and are sized to maintain a high-power factor. Resistor R1 and R2 are used to damp the Q of L1 and L2 to prevent a resonant peak in the EMI spectrum.

The buck-boost power circuit with floating output is composed of U1 (power switch + control), output diode D6, output capacitor C5 and C7, and output inductors T1 and T2. Inductor T1 has a second winding configured in flyback configuration used to provide a bias supply to U1. Two inductors were used due to space constraints of the tube. Diode D4 was used to prevent negative voltage appearing across drain-source of U1 near the zero-crossing of the input voltage. Diode D1 and C3 detect the peak AC line voltage. The voltage across C3 along with R3 and R4 sets the input current fed into the VOLTAGE MONITOR (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 (FB) pin current provides a constant current to the LED load.

The FB pin current used by U1 for output current regulation is provided by the voltage to current converter network formed by R7-R10, Q1, C6, and D5. Output voltage is related to feedback current by the following equation:

$$I_{FB} \approx I_{R7} = \frac{V_{OUT} \times \frac{R8}{R8 + R9} - V_{BE}}{R7}$$

Voltage across R8 was chosen to eliminate or minimize the effect of temperature and V_{CE} dependence of the V_{BE} voltage of Q1.

Want More?
Use your smartphone and free software from www.neoreader.com (or any other free QR Code Reader from your smartphone's App Store) and you will be connected to related content

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

5 PCB Layout

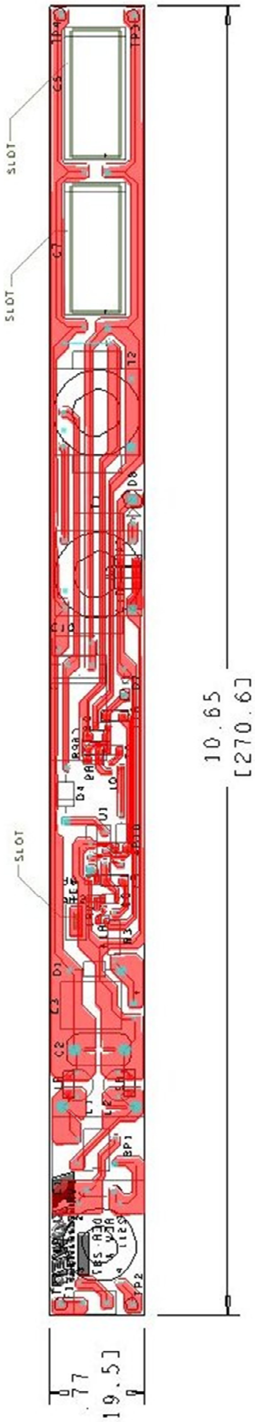
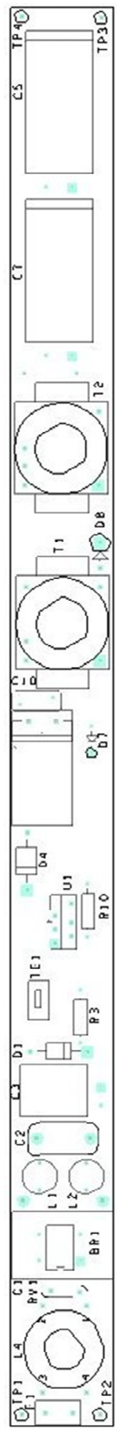
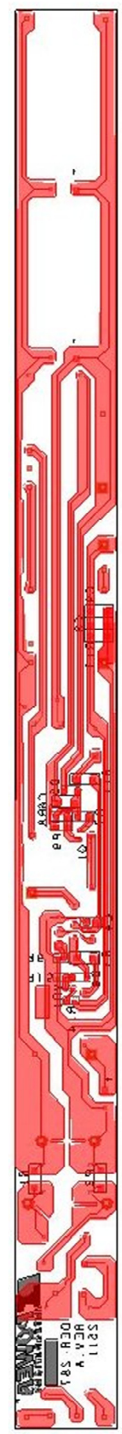
		

Figure 6 – Printed Circuit Layout, Top and Bottom, 10.65" (270.6 mm) x 0.77" (19.5 mm).	**Figure 7 –** Printed Circuit Layout, Top.	**Figure 8 –** Printed Circuit Layout, Bottom.

6 Bill of Materials

6.1 Electrical BOM

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 1 A, Bridge Rectifier, DF-M, Glass Passivated, 4-EDIP	DF10M	Diodes, Inc.
2	1	C1	120 nF, 630 V, Film	ECQ-E6124KF	Panasonic
3	1	C2	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
4	1	C3	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	SHD400WV 4.7uF	Sam Young
5	1	C4	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
6	2	C5 C7	120uF, 200 V, Electrolytic, (12.5 x 25)	EKMQ201ELL121MK25S	Nippon Chemi-Con
7	1	C6	100 nF, 200 V, Ceramic, X7R, 1206	VJ1206Y104KXCAT	Vishay
8	2	C8 C9	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
9	1	C10	4700 pF, 1 kV, Disc Ceramic	562R5GAD47	Vishay
10	1	D1	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
11	2	D4 D8	200 V, 2 A, Ultrafast Recovery, 25 ns, SOD57	BYV27-200-TR	Vishay
12	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
13	1	D6	600 V, 3 A, TO-220AC	QH03TZ600	Power Integrations
14	1	D7	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
15	1	D9	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
16	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
17	2	L1 L2	2.2 mH, 0.19 A, Ferrite Core	CTCH895F-222K	CT Parts
18	1	L4	12 mH, Common Mode Choke		
19	1	Q1	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
20	2	R1 R2	3.6 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ362V	Panasonic
21	1	R3	2.0 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M0	Yageo
22	1	R4	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
23	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
24	1	R7	158 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1583V	Panasonic
25	1	R8	34.8 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3482V	Panasonic
26	1	R9	90.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF9092V	Panasonic
27	1	R10	100 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-100K	Yageo
28	1	R11	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
29	1	R13	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
30	1	R14	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
31	1	R15	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
32	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
33	2	T1 T2	Bobbin, ER2510, Horizontal, 10 pins		
34	1	U1	LinkSwitch-PH, eSIP	LNK409EG	Power Integrations
35	1	VR1	39 V, 5%, 150 mW, SSMINI-2	MAZS39000L	Panasonic

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

7 Magnetics Specification

7.1 T1 Transformer Specification

7.1.1 Electrical Diagram

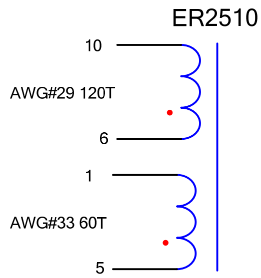


Figure 9 – T1 Electrical Diagram.

7.1.2 Electrical Specification

Primary Inductance	Pins 6-10, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	1.7 mH ±5%
Resonant Frequency	Pins 6-10, all other windings open	0.8 MHz (Min.)

7.1.3 Materials

Item	Description
[1]	Core: ER2510.
[2]	Bobbin: ER2510, Vertical, 10 pins, 5/5.
[3]	Magnet Wire: #29 AWG.
[4]	Magnet Wire: #33 AWG.
[4]	Tape: 3M 1298 Polyester Film, 4.5 mm wide.

7.1.4 Transformer Build Diagram

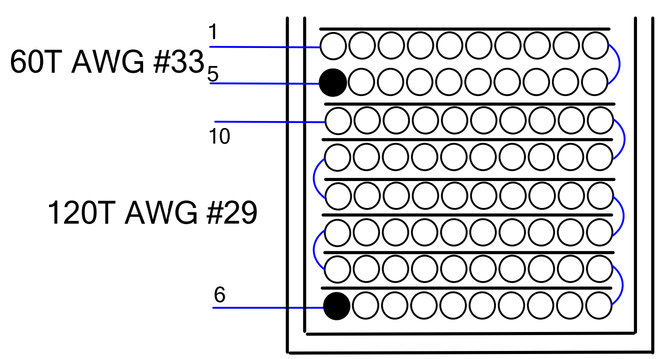


Figure 10 – T1 Transformer Build Diagram.

7.2 *T2 Inductor Specification*

7.2.1 Electrical Diagram

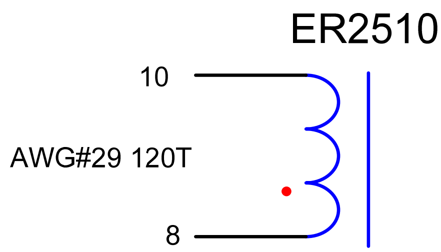


Figure 11 – T2 Inductor Electrical Diagram.

7.2.2 Electrical Specification

Primary Inductance	Pins 8-10, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	1.7 mH ±5%
Resonant Frequency	Pins 8-10, all other windings open	1 MHz (Min.)

7.2.3 Materials

Item	Description
[1]	Core: ER2510.
[2]	Bobbin: ER2510, Vertical, 10 pins, 5/5.
[3]	Magnet Wire: #29 AWG.
[4]	Tape: 3M 1298 Polyester Film, 4.5 mm wide.

7.2.4 Inductor Build Diagram

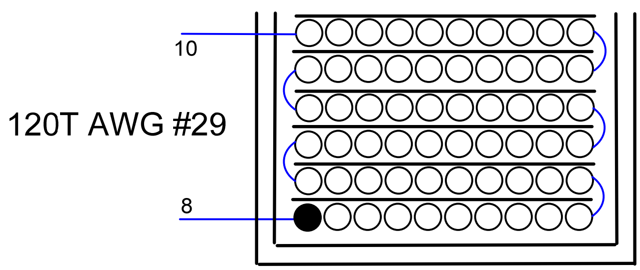


Figure 12 – T2 Inductor Build Diagram.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

7.3 L4 CMC Specification

7.3.1 Electrical Diagram

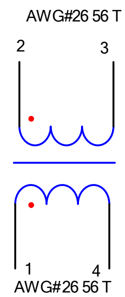


Figure 13 – L4 CMC Electrical Diagram.

7.3.2 Electrical Specification

Inductance (LCM)	Pins 1-4 or 2-3. measured at 100 kHz	12 mH ±10%
Leakage (LL)	Pins 1-4 with pins 2-3 shorted or versa at 100 kHz	80 μH (Max.) ±20%
Core Effective Inductance		3795 nH/N²

7.3.3 Materials

Item	Description
[1]	Toroid Core: MN-ZN T14X9X5 R10K U1000; Dimension: OD:14.35 mm / ID:7.5mm / HT:5.3mm
[2]	Magnet Wire: #28 AWG, Heavy Nyleze

7.3.4 Inductor Build Diagram

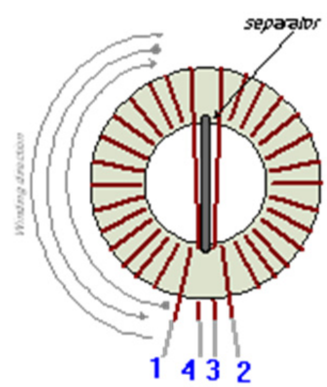


Figure 14 – L4 CMC Build Diagram.

8 Inductor Design Spreadsheet

Buck-boost inductor parameters can be calculated using LinkSwitch-PH PIXIs spreadsheet using VO=VOR. For series choke configuration, Ae is multiplied by the number of chokes in series.

ACDC_LinkSwitch-PH_011111; Rev.1.2; Copyright Power Integrations 2011	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LinkSwitch-PH_011111: Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Dimming required	**NO**		**NO**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN	180		180	V	Minimum AC Input Voltage
VACMAX			265	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	100.00			V	Typical output voltage of LED string at full load
VO_MAX			110.00	V	Maximum expected LED string Voltage.
VO_MIN			90.00	V	Minimum expected LED string Voltage.
V_OVP			121.00	V	Over-voltage protection setpoint
IO	0.25				Typical full load LED current
PO			25.0	W	Output Power
n	0.90		0.9		Estimated efficiency of operation
VB			20	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK419**			Universal	115 Doubled/230V
Chosen Device		LNK419	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			78.4	uA	V pin current
RV	4.00		4	M-ohms	Upper V pin resistor
RV2			1.402	M-ohms	Lower V pin resistor
IFB	150.00		150.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			113.3	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	0.48		0.48		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			3375	uH	Primary Inductance
VOR	100.00		100	V	Reflected Output Voltage.
Expected IO (average)			0.25	A	Expected Average Output Current
KP_VACMAX			0.51		Expected ripple current ratio at VACMAX
TON_MIN			3.19	us	Minimum on time at maximum AC input voltage
PCLAMP			0.35	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**ER2510**		**ER2510**		
Bobbin		*#N/A*		*P/N:*	#N/A
AE	0.9490		0.949	cm^2	Core Effective Cross Sectional Area
LE	2.1400		2.14	cm	Core Effective Path Length
AL			#N/A	nH/T^2	Ungapped Core Effective Inductance
BW	4.5		4.5	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

L	10.00		10		Number of Primary Layers
NS	121		121		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			255	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.29		Minimum duty cycle at peak of VACMIN
IAVG			0.18	A	Average Primary Current
IP			0.96	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.33	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			3375	uH	Primary Inductance
NP			120		Primary Winding Number of Turns
NB			25		Bias Winding Number of Turns
ALG			233	nH/T^2	Gapped Core Effective Inductance
BM			2850	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3448	Gauss	Peak Flux Density (BP<3700)
BAC			684	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			#N/A		Relative Permeability of Ungapped Core
LG		*#N/A*	#N/A	mm	#N/A
BWE			45	mm	Effective Bobbin Width
OD			0.37	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.32	mm	Bare conductor diameter
AWG			29	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			128	Cmils	Bare conductor effective area in circular mils
CMA			392	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			0.96	A	Peak Secondary Current
ISRMS			0.47	A	Secondary RMS Current
IRIPPLE			0.40	A	Output Capacitor RMS Ripple Current
CMS			94	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			30	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.26	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.04	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			582	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			498	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			102	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)					
V pin Resistor Fine Tuning					
RV1	4		4.00	M-ohms	Upper V Pin Resistor Value
RV2	100		100.00	M-ohms	Lower V Pin Resistor Value
VAC1	180		180.0	V	Test Input Voltage Condition1
VAC2	265		265.0	V	Test Input Voltage Condition2
IO_VAC1	0.253		0.25	A	Measured Output Current at VAC1
IO_VAC2	0.231		0.23	A	Measured Output Current at VAC2
RV1 (new)			4.00	M-ohms	New RV1
RV2 (new)			100.00	M-ohms	New RV2

V_OV			319.6	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			66.4	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			113	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+012	k-ohms	Lower FB Pin Resistor Value
VB1			17.9	V	Test Bias Voltage Condition1
VB2			22.1	V	Test Bias Voltage Condition2
IO1			0.25	A	Measured Output Current at Vb1
IO2			0.25	A	Measured Output Current at Vb2
RFB1 (new)			113.3	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

9 U1 Heat Sink Dimensions

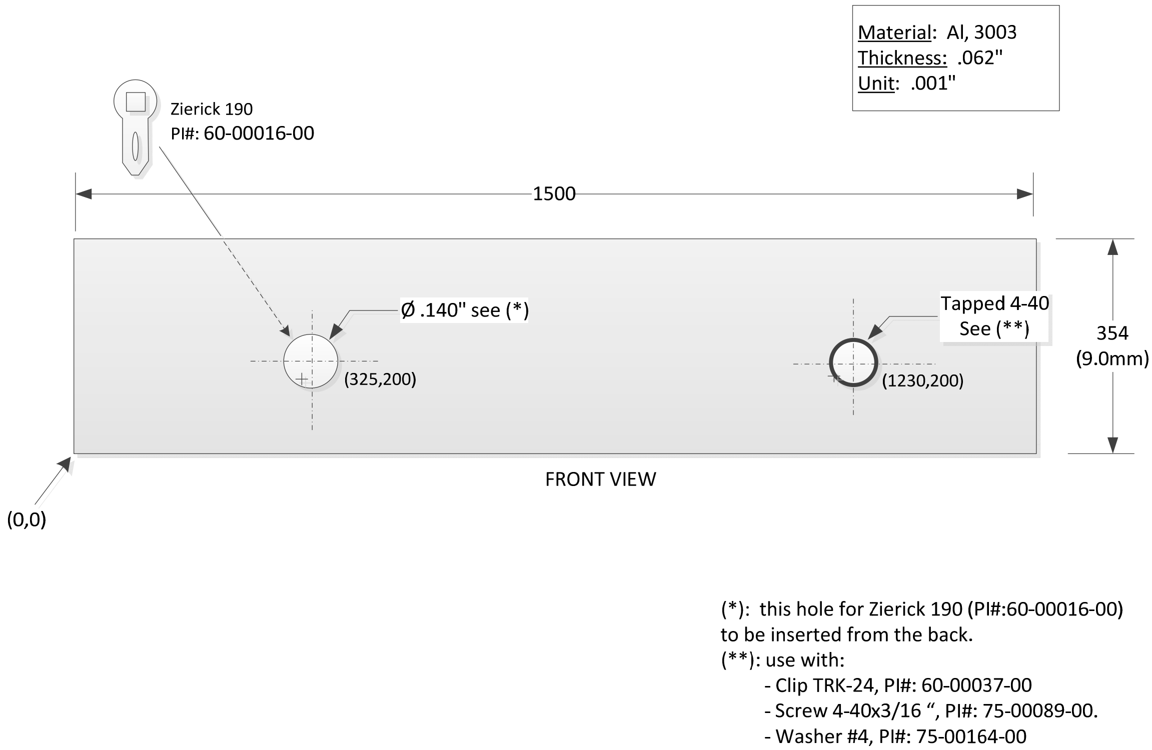


Figure 15 – U1 Heat Sink Dimensions.

10 Performance Data

The following data was compiled using 3 sets of load (33, 34, and 35 LED strings representing an output load range of 97 V ~ 103 V). Refer to the table on section 10.6 for the complete set of test values. All measurements were performed at room temperature.

10.1 Efficiency

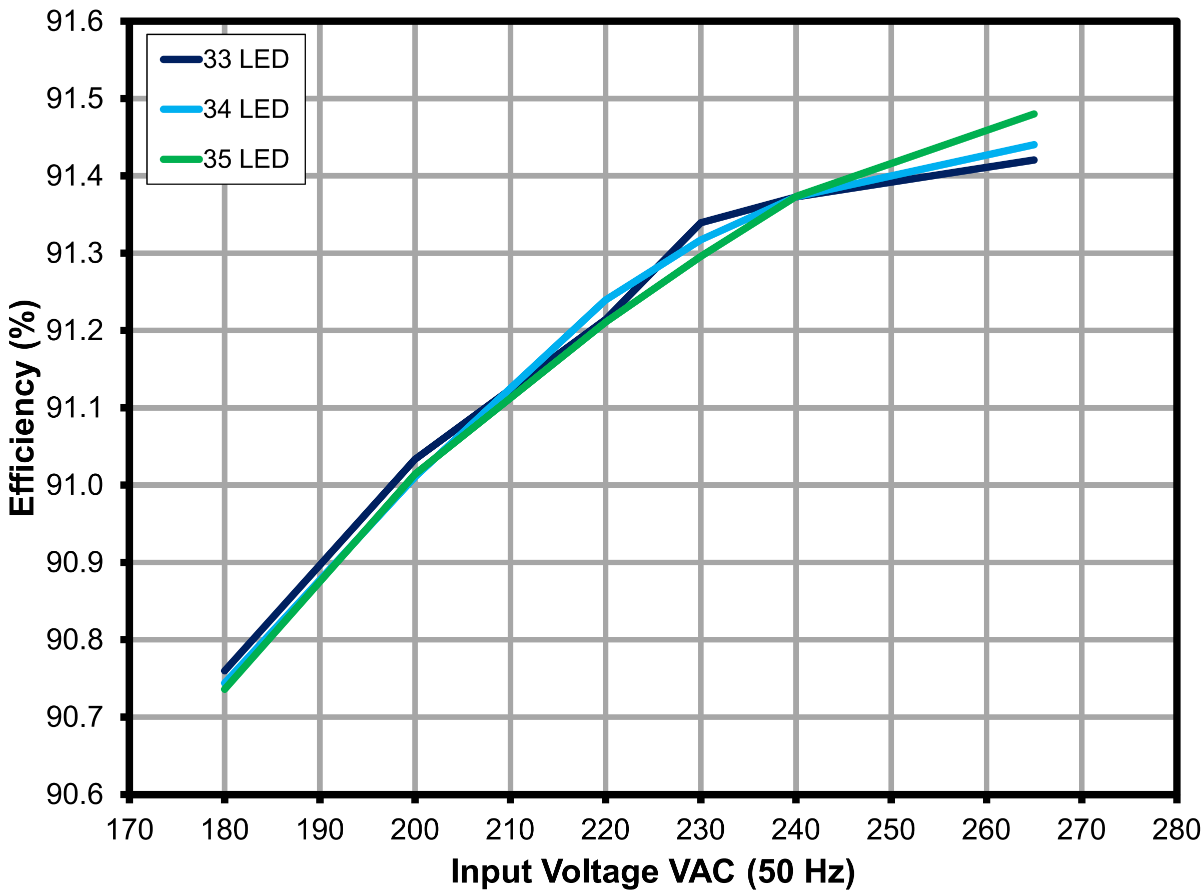


Figure 16 – Efficiency vs. Line and Load.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.2 Line and Load Regulation

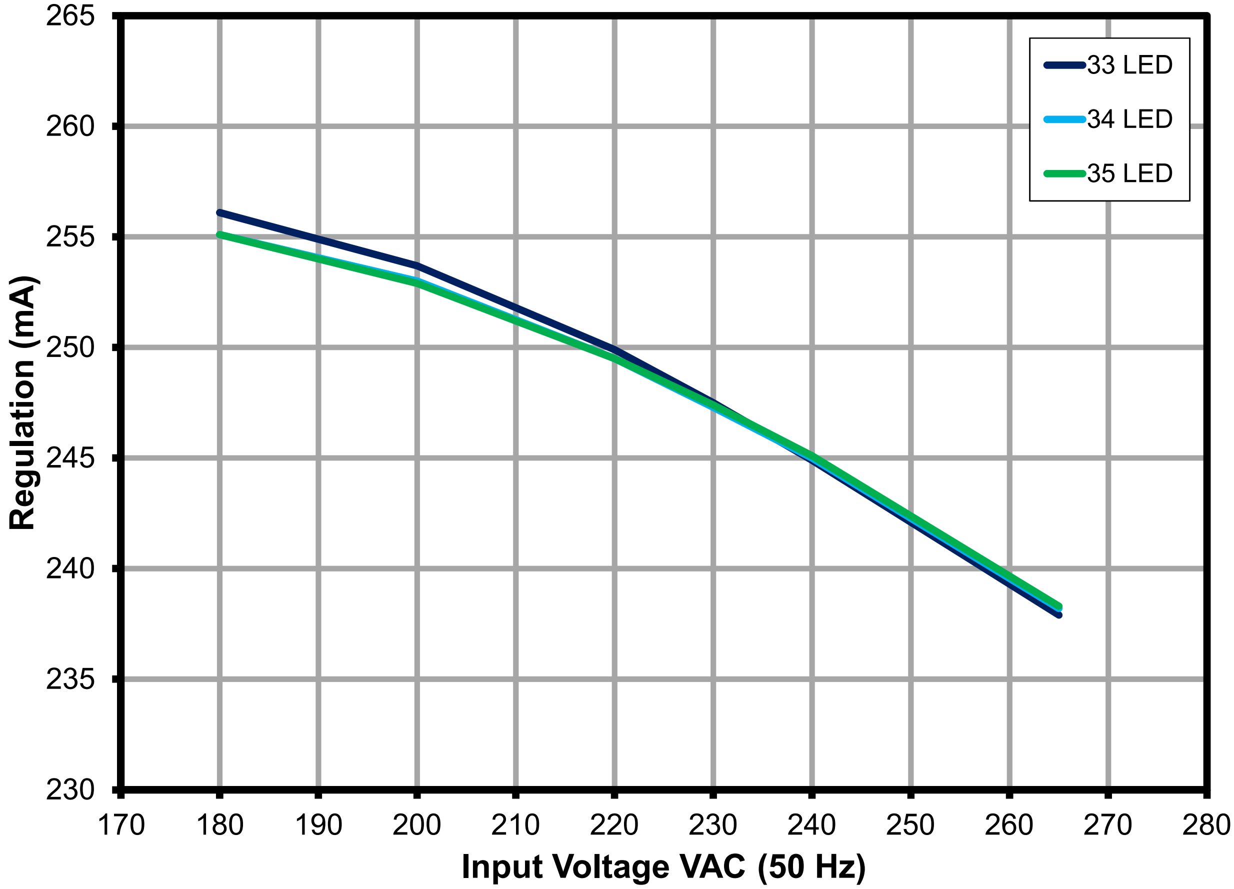


Figure 17 – Regulation vs. Line and Load.

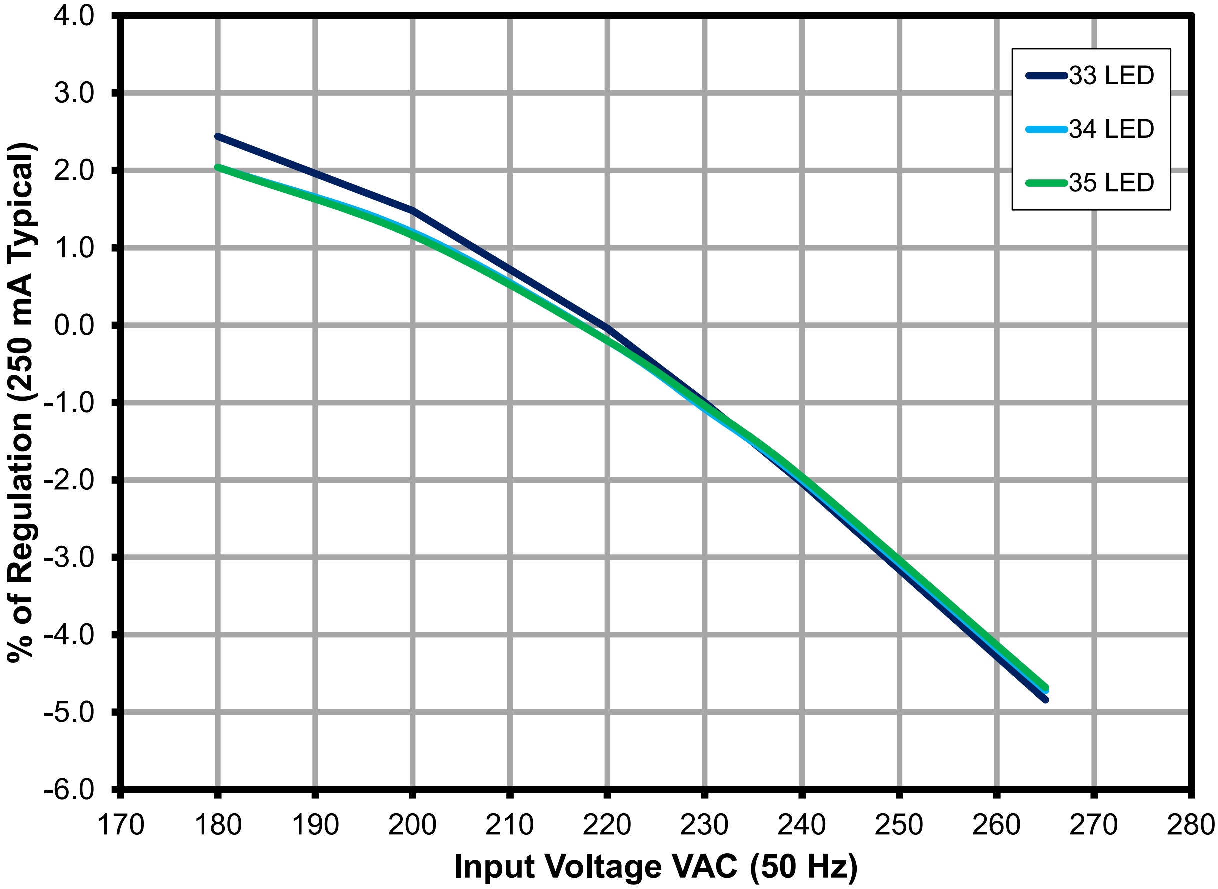


Figure 18 – Percent Line/Load Regulation.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.3 Power Factor

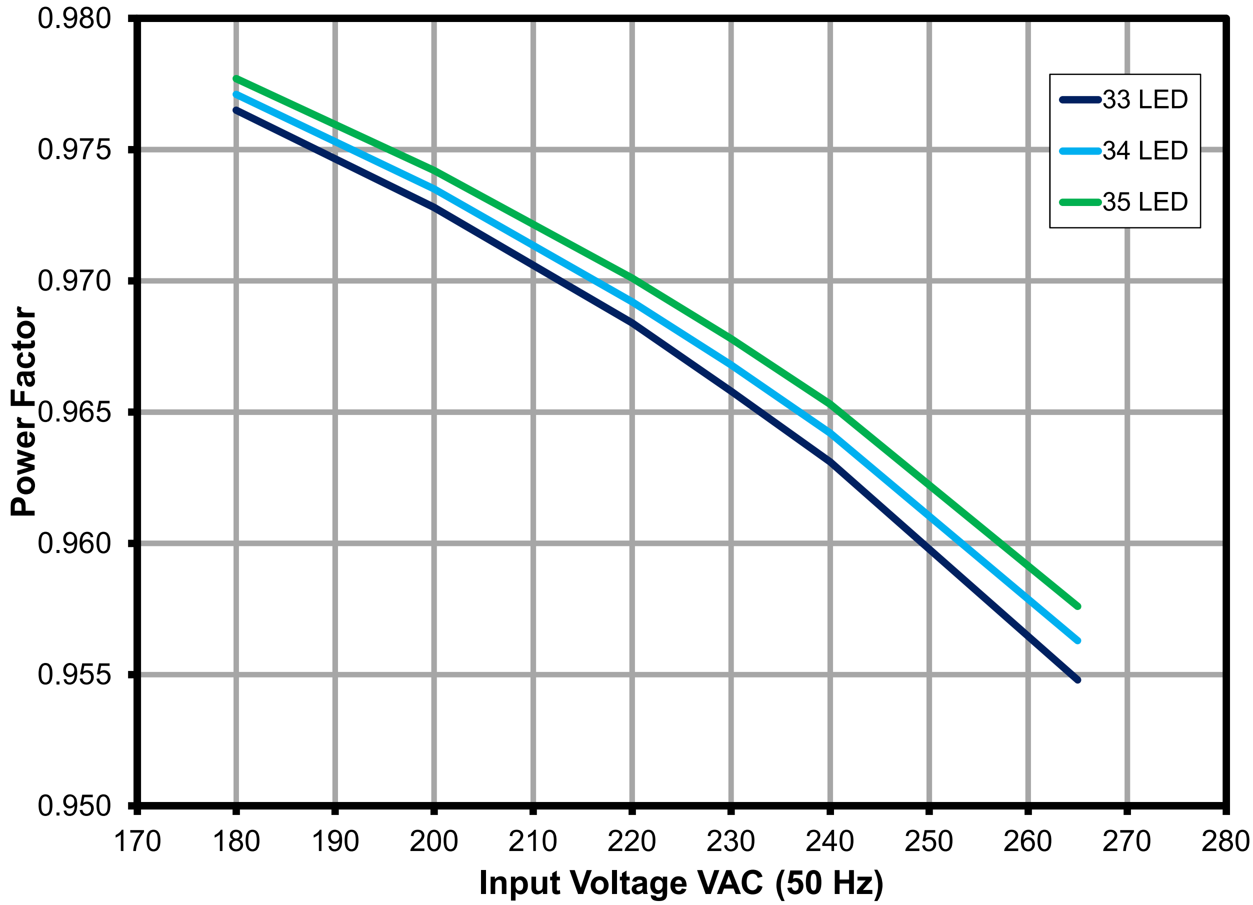


Figure 19 – Power Factor vs. Line and Load.

10.4 A-THD

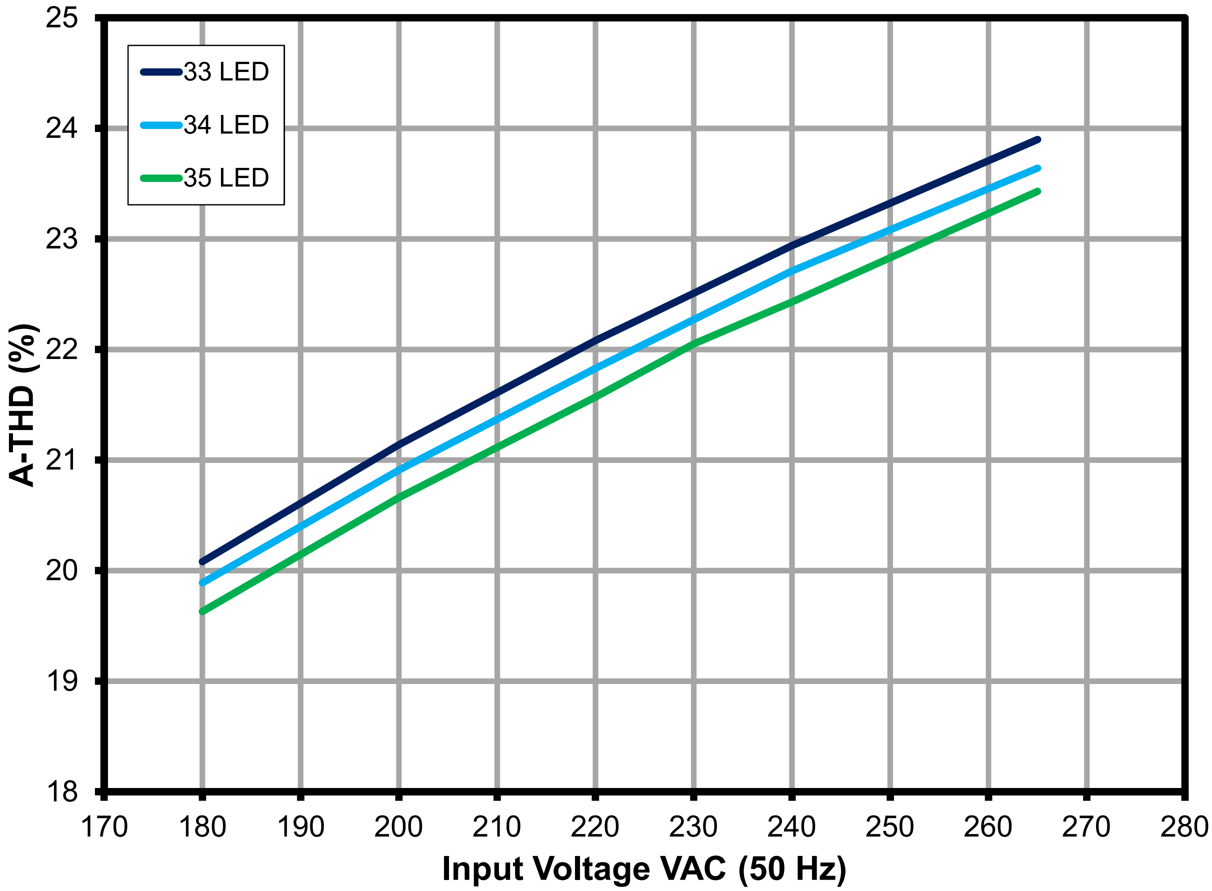


Figure 20 – A-THD vs. Line and Load.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.5 Harmonics

10.5.1 33 LED Load

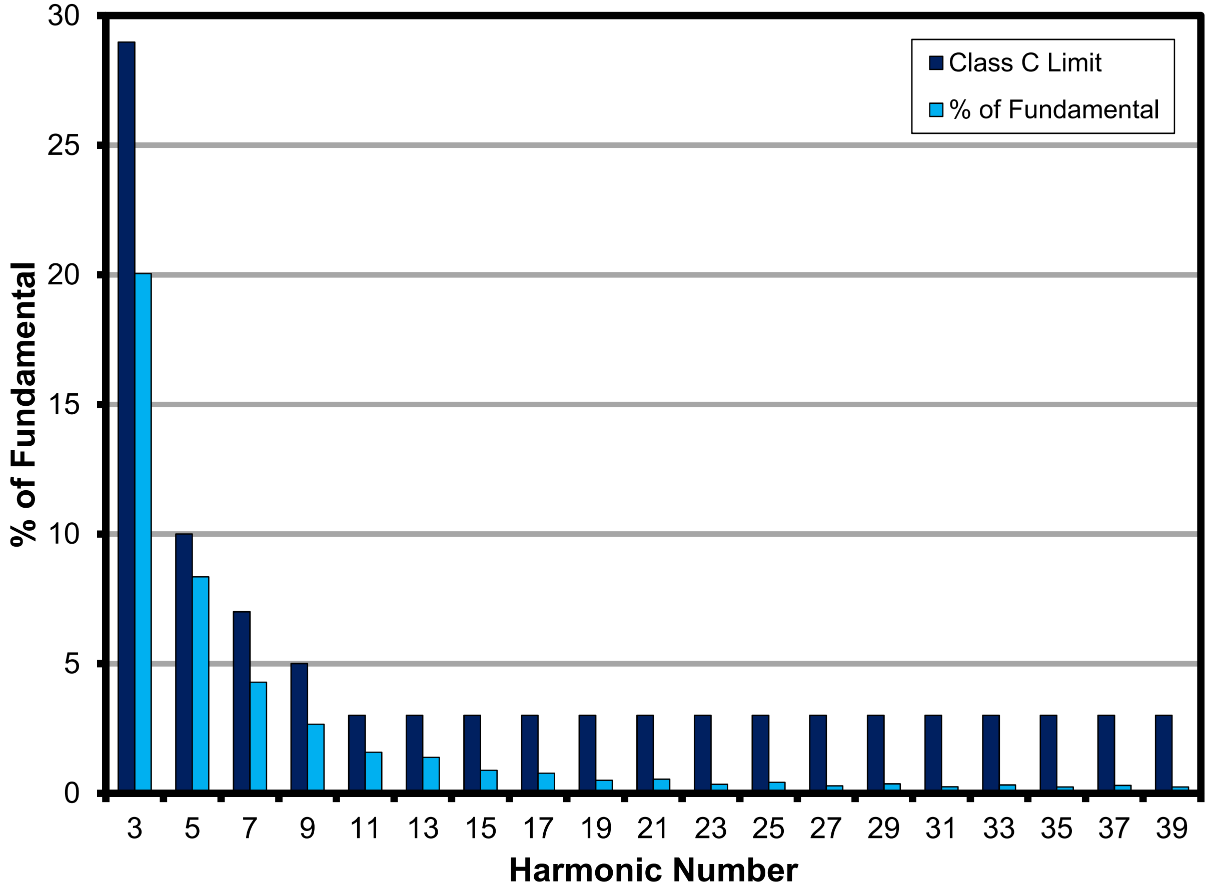


Figure 21 – 33 LED Load Input Current Harmonics at 230 VAC, 50 Hz.

10.5.3 34 LED Load

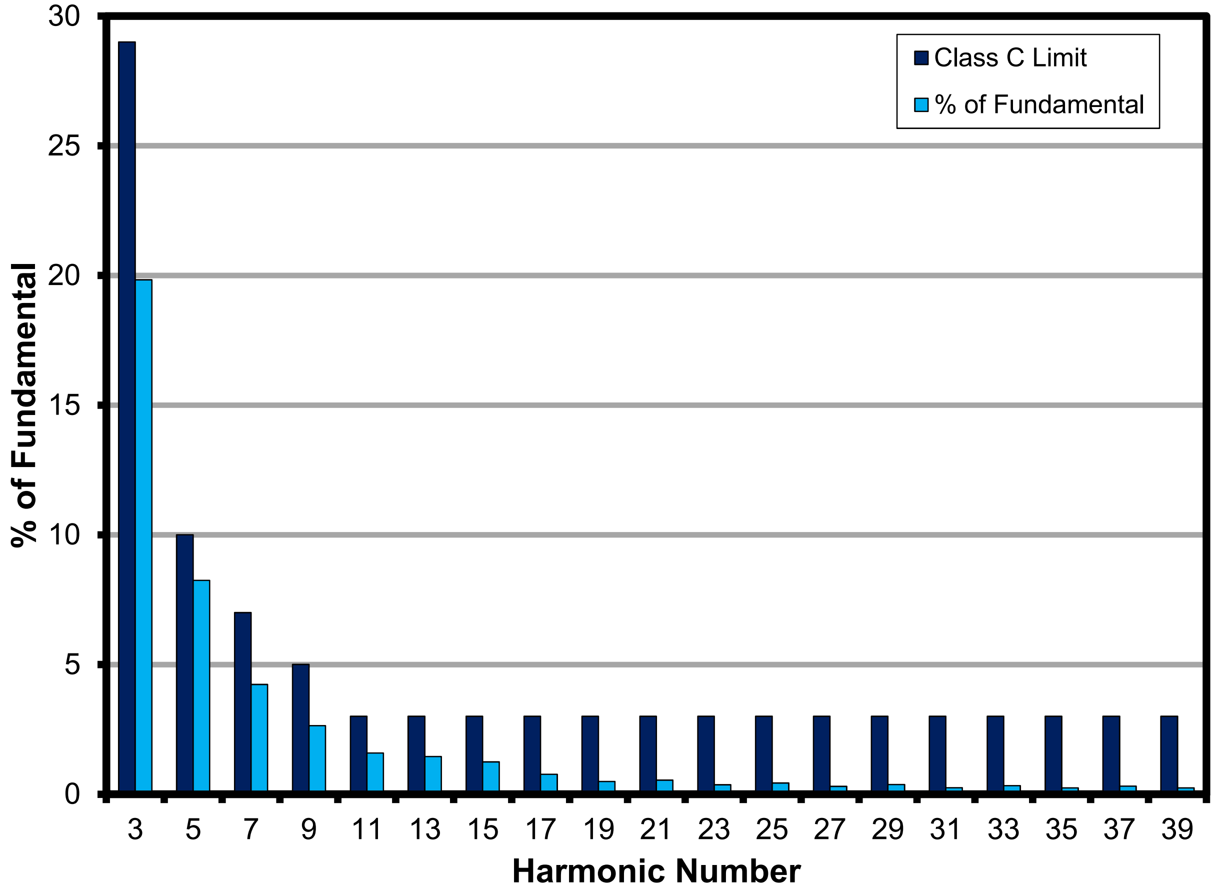


Figure 22 – 34 LED Load Input Current Harmonics at 230 VAC, 50 Hz.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.5.4 35 LED Load

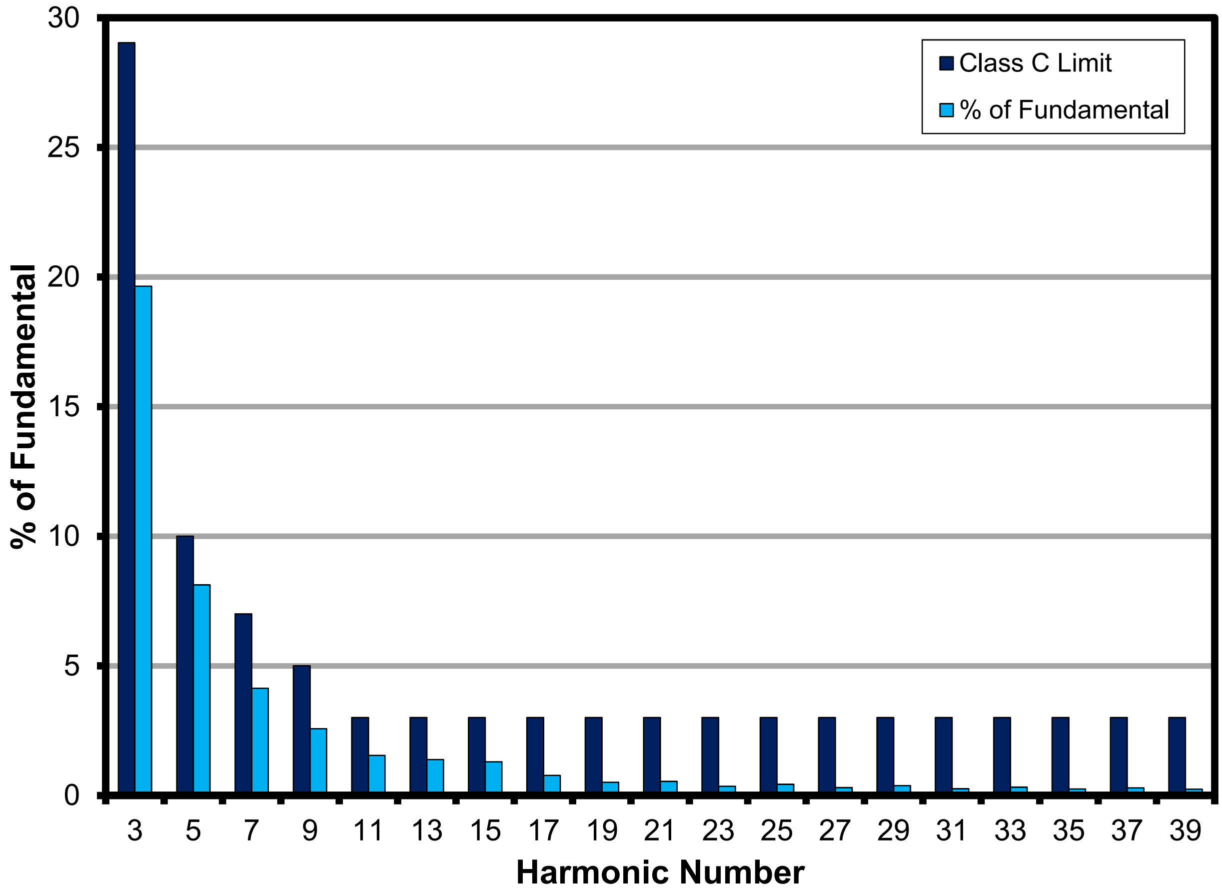


Figure 23 – 35 LED Load Input Current Harmonics at 230 VAC, 50 Hz.

10.6 Test Data

All measurements were taken with the board in open frame configuration, 25 °C ambient, and 50 Hz line frequency.

10.6.1 Test Data, 33 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
179.99	155.90	27.40	0.977	20.08	97.00	256.10	24.87	24.84	90.76	2.53	2.4%
200.02	138.89	27.02	0.973	21.14	96.80	253.70	24.60	24.56	91.03	2.42	1.5%
220.04	124.46	26.52	0.968	22.08	96.70	249.90	24.19	24.17	91.21	2.33	0.0%
230.09	117.90	26.20	0.966	22.51	96.50	247.50	23.93	23.88	91.34	2.27	-1.0%
240.05	111.96	25.88	0.963	22.94	96.40	244.90	23.65	23.61	91.37	2.23	-2.0%
265.07	99.06	25.07	0.955	23.9	96.20	237.90	22.92	22.89	91.42	2.15	-4.8%

10.6.2 Test Data, 34 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
180.00	159.66	28.08	0.977	19.89	99.70	255.10	25.48	25.43	90.74	2.60	2.0%
200.02	142.37	27.72	0.974	20.91	99.60	253.00	25.23	25.20	91.01	2.49	1.2%
220.04	127.76	27.25	0.969	21.83	99.50	249.50	24.86	24.83	91.24	2.39	-0.2%
230.09	121.15	26.95	0.967	22.27	99.40	247.30	24.61	24.58	91.32	2.34	-1.1%
240.05	115.13	26.65	0.964	22.71	99.30	245.00	24.35	24.33	91.37	2.30	-2.0%
265.07	101.94	25.84	0.956	23.64	99.10	238.20	23.63	23.61	91.44	2.21	-4.7%

10.6.3 Test Data, 35 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
179.99	164.15	28.89	0.978	19.63	102.60	255.10	26.21	26.17	90.74	2.68	2.0%
200.01	146.33	28.51	0.974	20.66	102.50	252.90	25.95	25.92	91.01	2.56	1.2%
220.03	131.28	28.02	0.970	21.57	102.30	249.50	25.56	25.52	91.21	2.46	-0.2%
230.08	124.55	27.73	0.968	22.05	102.20	247.40	25.32	25.28	91.30	2.41	-1.0%
240.05	118.36	27.43	0.965	22.43	102.10	245.10	25.06	25.02	91.37	2.37	-2.0%
265.06	104.73	26.59	0.958	23.43	101.90	238.30	24.32	24.28	91.48	2.27	-4.7%

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.6.4 230 VAC 50 Hz, 33 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.998	230.08	118.27	26.28	0.9659	22.5
	nth order	mA content	% of Fundamental	Class C Limit	Remarks
	1	115.06			
	3	23.07	20.05%	29.0%	PASS
	5	9.61	8.35%	10.0%	PASS
	7	4.93	4.28%	7.0%	PASS
	9	3.06	2.66%	5.0%	PASS
	11	1.82	1.58%	3.0%	PASS
	13	1.59	1.38%	3.0%	PASS
	15	1.02	0.89%	3.0%	PASS
	17	0.89	0.77%	3.0%	PASS
	19	0.57	0.50%	3.0%	PASS
	21	0.62	0.54%	3.0%	PASS
	23	0.4	0.35%	3.0%	PASS
	25	0.49	0.43%	3.0%	PASS
	27	0.33	0.29%	3.0%	PASS
	29	0.42	0.37%	3.0%	PASS
	31	0.29	0.25%	3.0%	PASS
	33	0.37	0.32%	3.0%	PASS
	35	0.28	0.24%	3.0%	PASS
	37	0.35	0.30%	3.0%	PASS
	39	0.28	0.24%	3.0%	PASS

10.6.5 230 VAC 50 Hz, 34 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.998	230.08	121.39	27	0.9669	22.27
	nth order	mA content	% of Fundamental	Class C Limit	Remarks
	1	118.23			
	3	23.45	19.83%	29.0%	PASS
	5	9.75	8.25%	10.0%	PASS
	7	5	4.23%	7.0%	PASS
	9	3.13	2.65%	5.0%	PASS
	11	1.88	1.59%	3.0%	PASS
	13	1.72	1.45%	3.0%	PASS
	15	1.47	1.24%	3.0%	PASS
	17	0.9	0.76%	3.0%	PASS
	19	0.58	0.49%	3.0%	PASS
	21	0.64	0.54%	3.0%	PASS
	23	0.43	0.36%	3.0%	PASS
	25	0.51	0.43%	3.0%	PASS
	27	0.36	0.30%	3.0%	PASS
	29	0.44	0.37%	3.0%	PASS
	31	0.3	0.25%	3.0%	PASS
	33	0.39	0.33%	3.0%	PASS
	35	0.29	0.25%	3.0%	PASS
	37	0.37	0.31%	3.0%	PASS
	39	0.29	0.25%	3.0%	PASS

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.6.6 230 VAC 50 Hz, 35 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.998	230.08	124.87	27.81	0.9679	22.03
	nth order	mA content	% of Fundamental	Class C Limit	Remarks
	1	121.68			
	3	23.9	19.64%	29.0%	PASS
	5	9.89	8.13%	10.0%	PASS
	7	5.03	4.13%	7.0%	PASS
	9	3.13	2.57%	5.0%	PASS
	11	1.88	1.55%	3.0%	PASS
	13	1.68	1.38%	3.0%	PASS
	15	1.58	1.30%	3.0%	PASS
	17	0.94	0.77%	3.0%	PASS
	19	0.62	0.51%	3.0%	PASS
	21	0.66	0.54%	3.0%	PASS
	23	0.43	0.35%	3.0%	PASS
	25	0.52	0.43%	3.0%	PASS
	27	0.37	0.30%	3.0%	PASS
	29	0.46	0.38%	3.0%	PASS
	31	0.32	0.26%	3.0%	PASS
	33	0.39	0.32%	3.0%	PASS
	35	0.3	0.25%	3.0%	PASS
	37	0.36	0.30%	3.0%	PASS
	39	0.29	0.24%	3.0%	PASS

11 Waveforms

10.1 Input Line Current

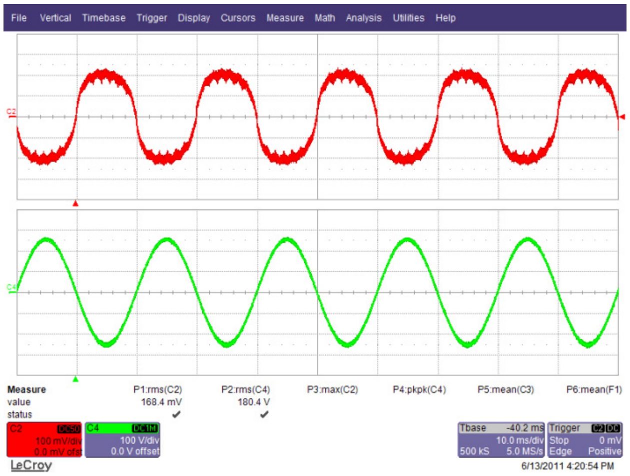


Figure 24 – 180 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

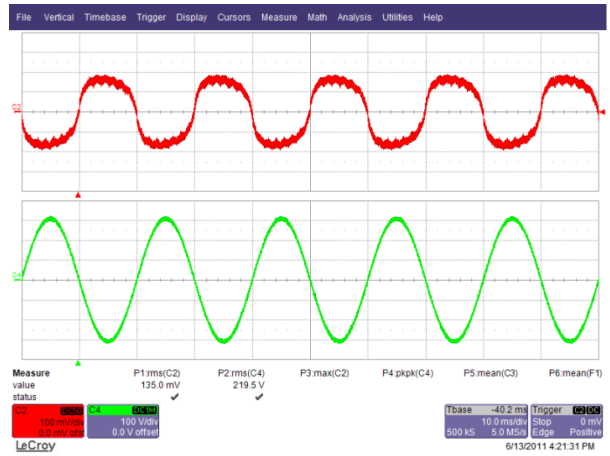


Figure 25 – 220 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

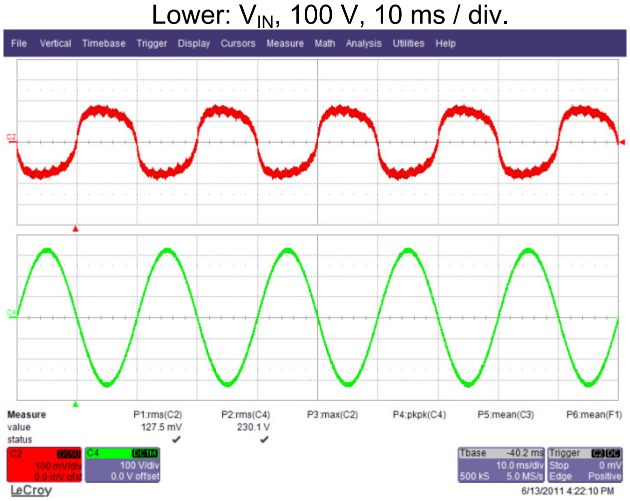


Figure 26 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

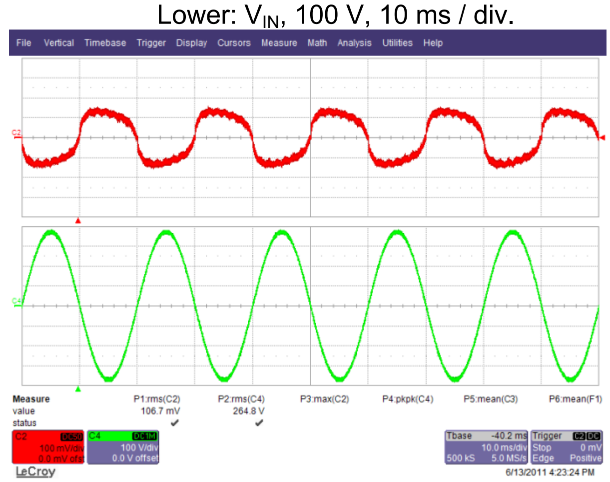


Figure 27 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.2 Drain Voltage and Current Normal Operation

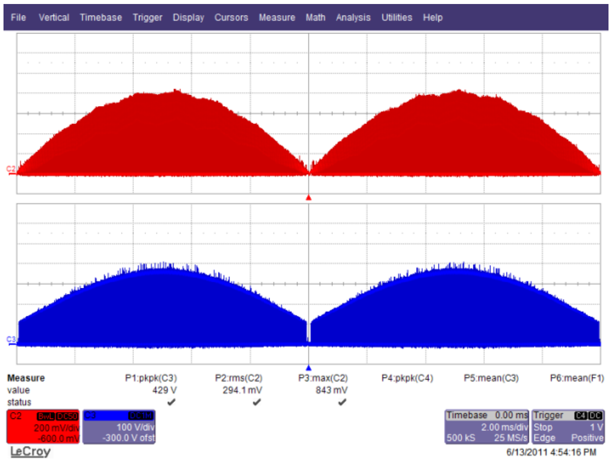


Figure 28 – 180 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

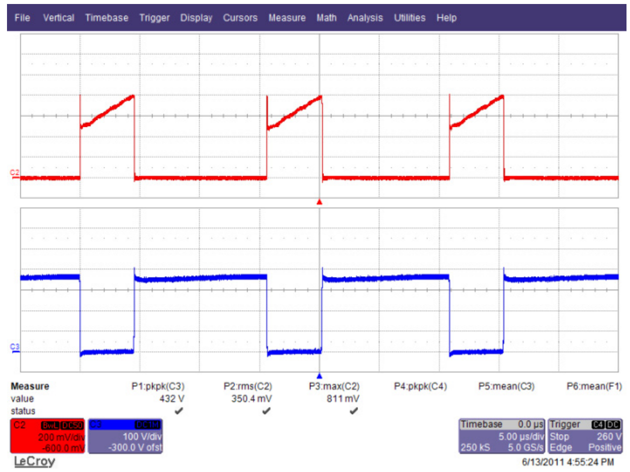


Figure 29 – 180 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

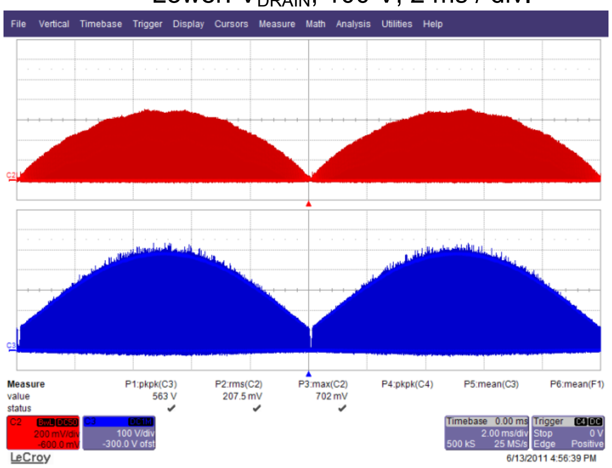


Figure 30 – 265 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

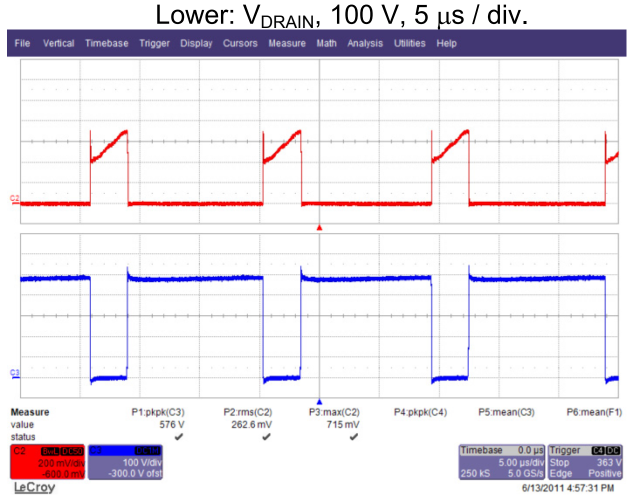


Figure 31 – 265 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

10.3 Drain Voltage and Current Start-up Operation

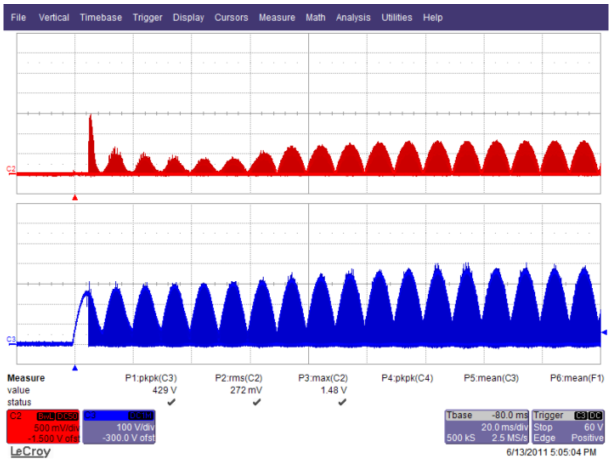


Figure 32 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

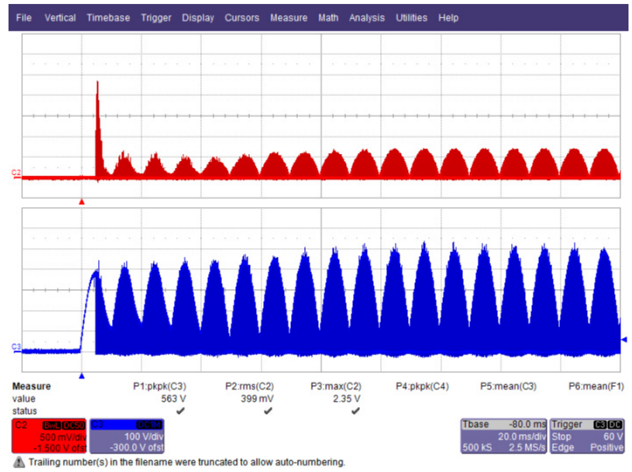


Figure 33 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.4 Output Current and Output Voltage

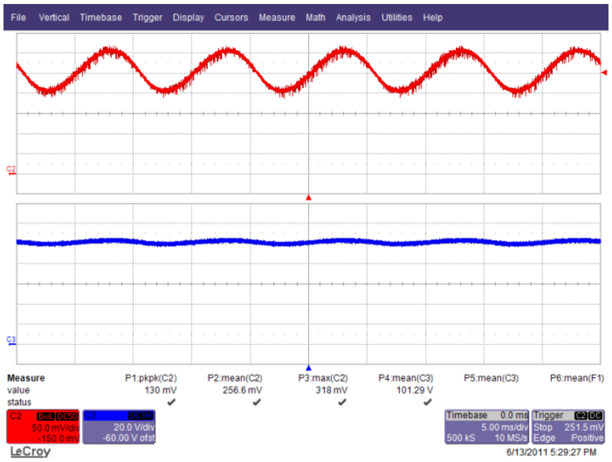


Figure 34 – 180 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

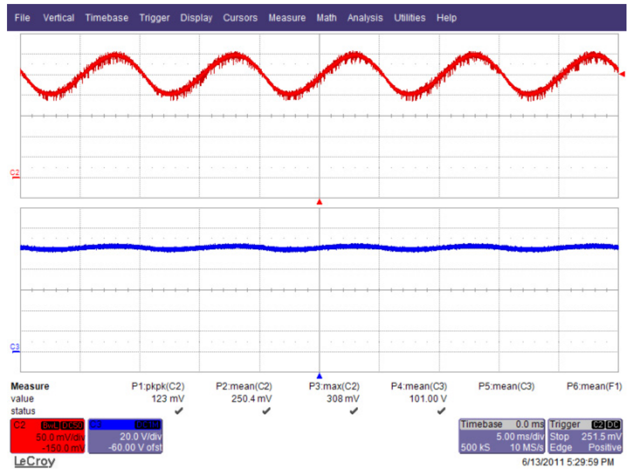


Figure 35 – 220 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

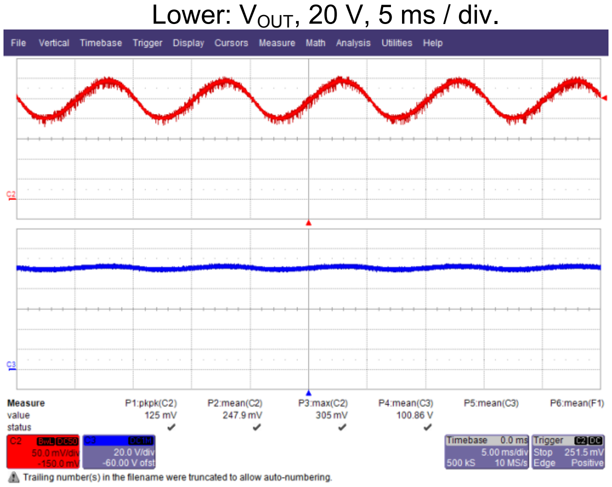


Figure 36 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

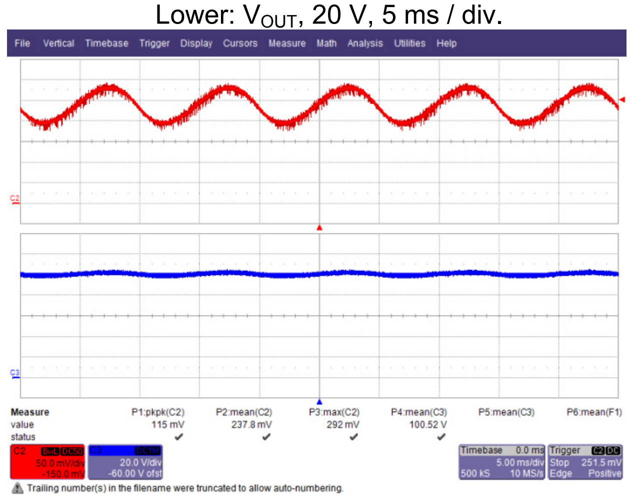


Figure 37 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

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

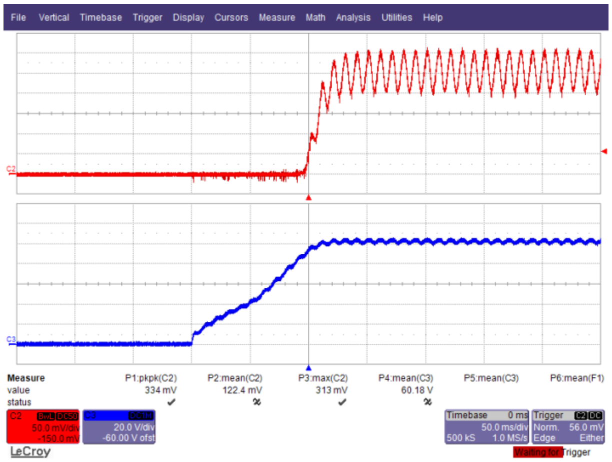


Figure 38 – 180 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

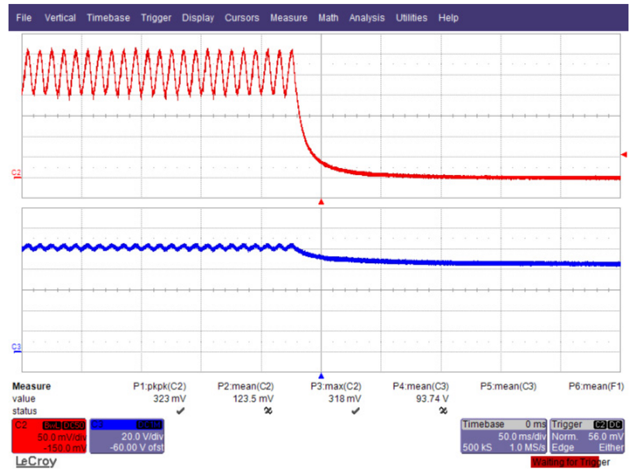


Figure 39 – 180 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

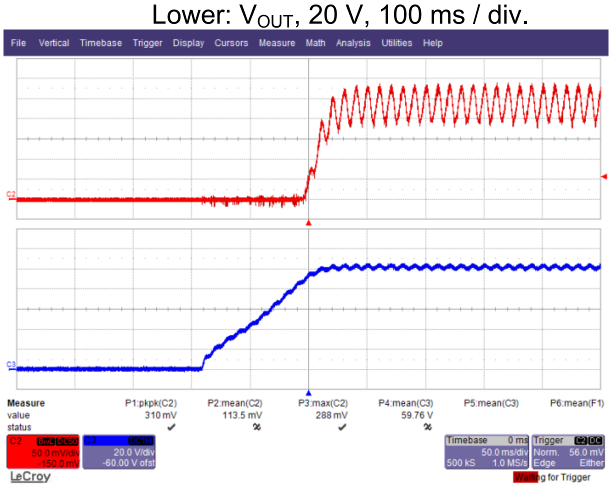


Figure 40 – 265 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

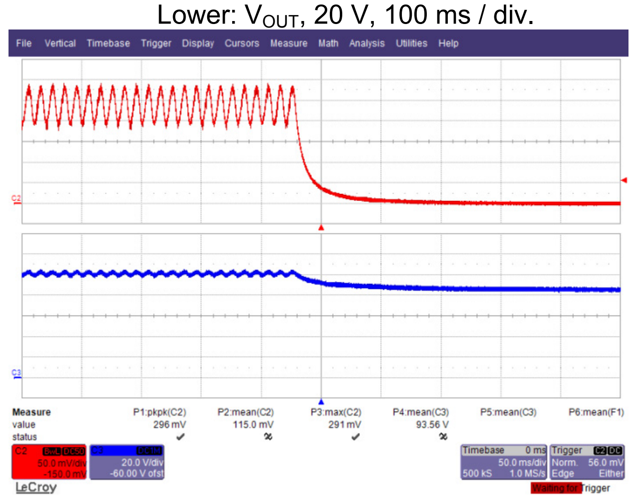


Figure 41 – 265 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.6 Output Short

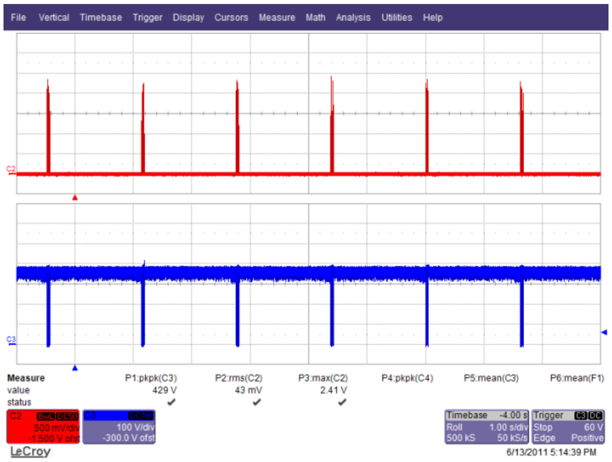


Figure 42 – 265 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

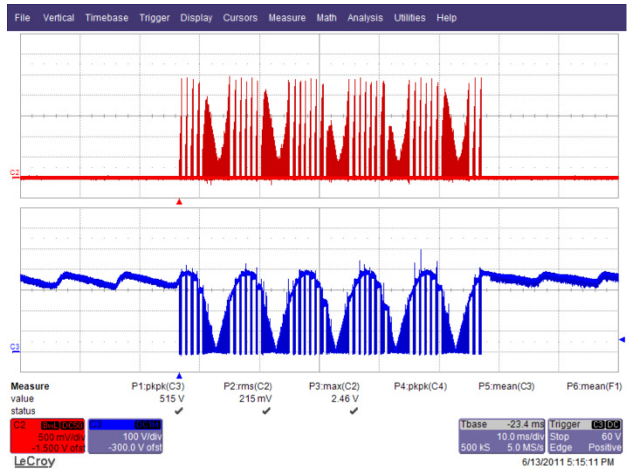


Figure 43 – 265 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

10.7 Open Load

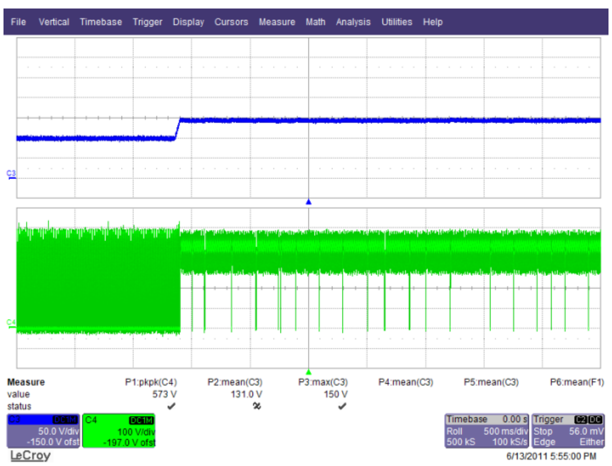


Figure 44 – 265 VAC 50 Hz, Open Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

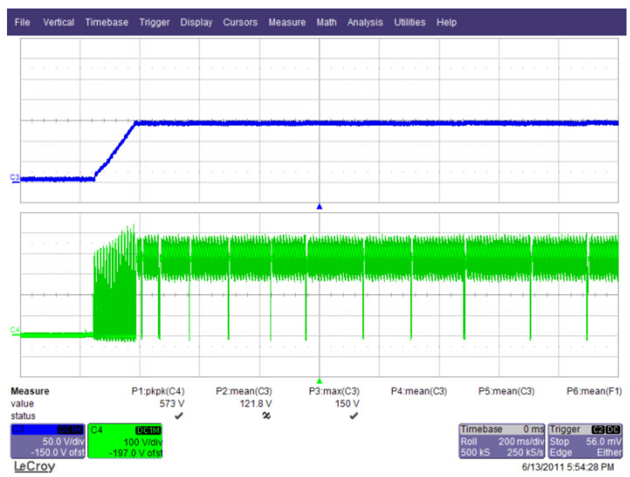


Figure 45 – 265 VAC 50 Hz, Open Load Start-up
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

12 Thermal Measurements

Thermal measurements were done with the EUT operated at room temperature, string containing 34 series connected LEDs, and 230 VAC, 50 Hz line input.

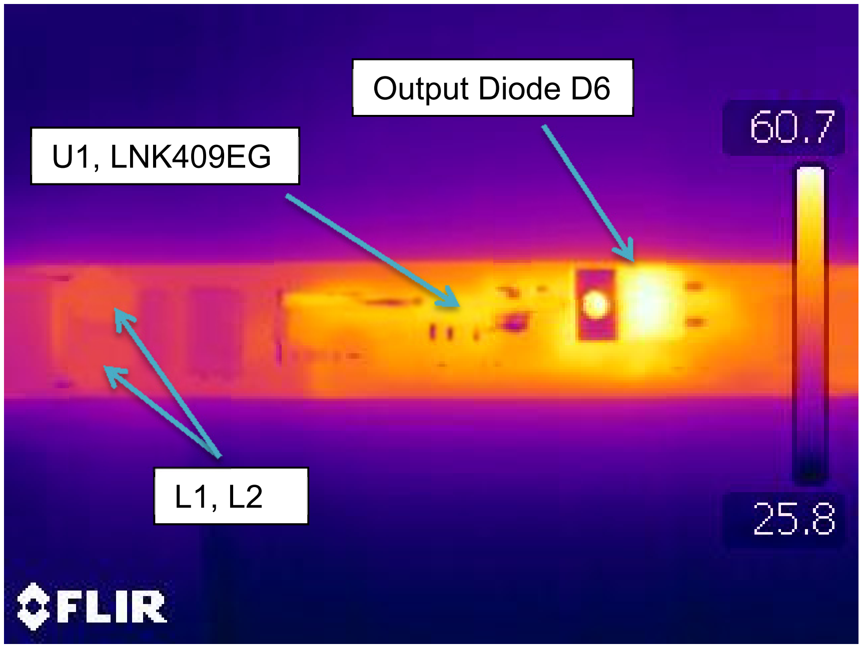


Figure 46 – Top-Side (Front) Thermal Measurements.

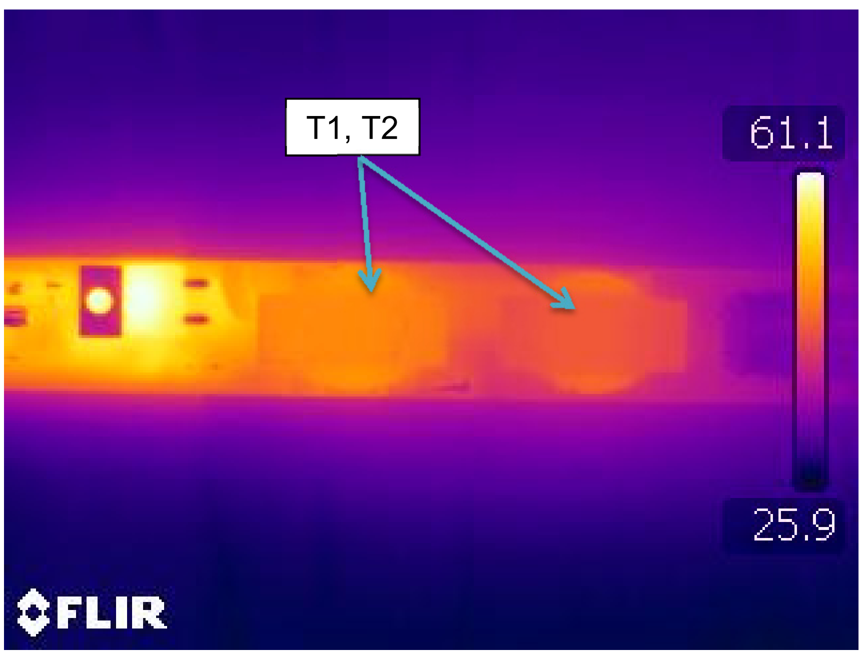


Figure 47 – Top-Side (Middle) Thermal Measurements.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

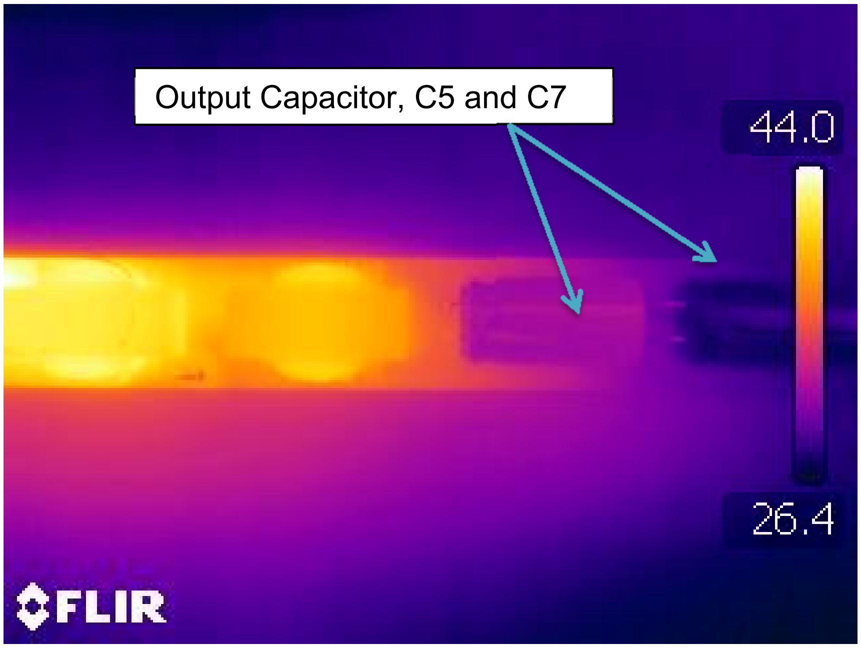


Figure 48 – Top-Side (End) Thermal Measurements.

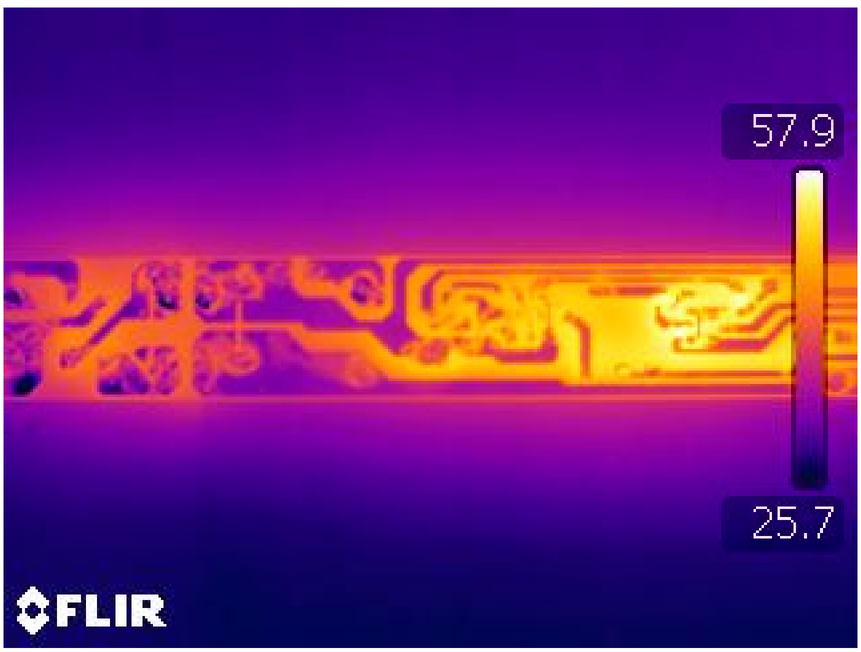


Figure 49 – Bottom-Side (Front) Thermal Measurements.

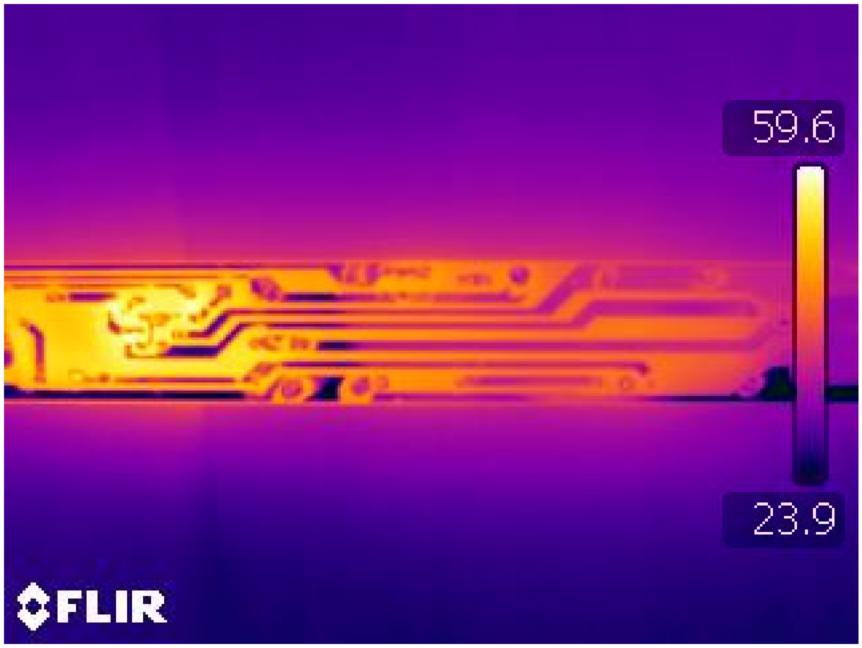


Figure 50 – Bottom-Side (Middle) Thermal Measurements.

Figure 51 – Bottom-Side (End) Thermal Measurements.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

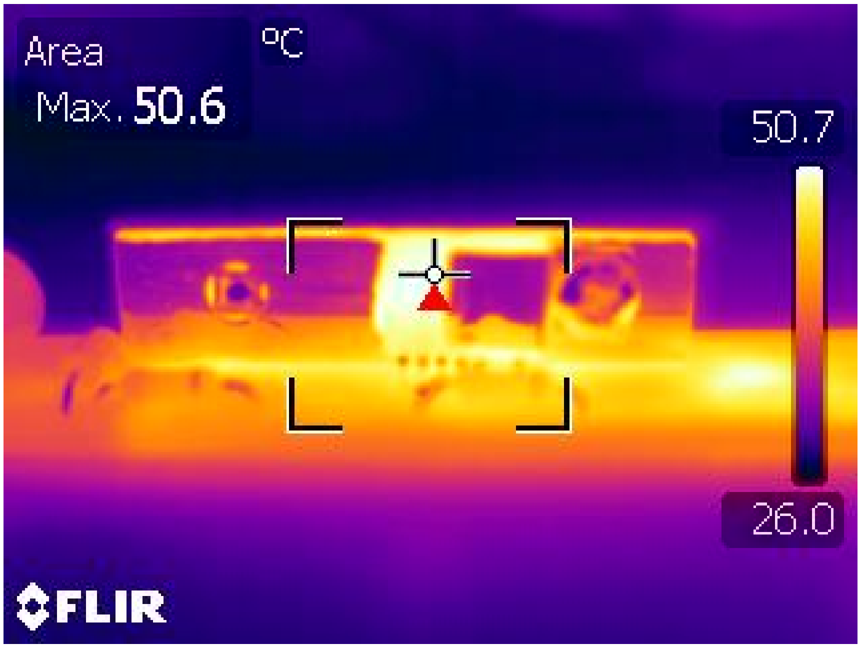


Figure 52 – U1 Device Temperature at 230 VAC, 50 Hz.

13 Conducted EMI Measurements

13.1 Conducted EMI Test Set-up

The unit was tested using strings of 34 LEDs as load (~100 V V_{OUT}) with input voltage of 230 VAC, 60 Hz at room temperature.

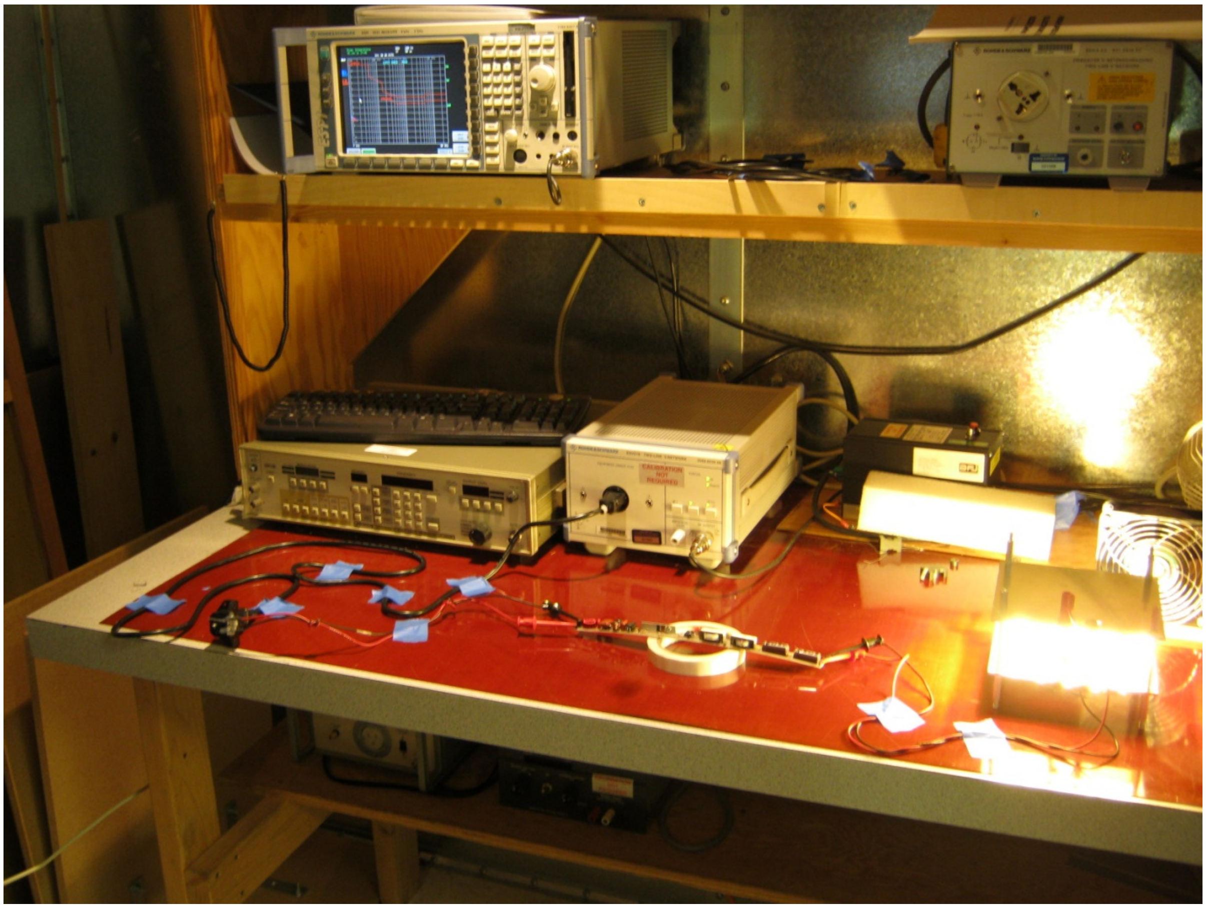
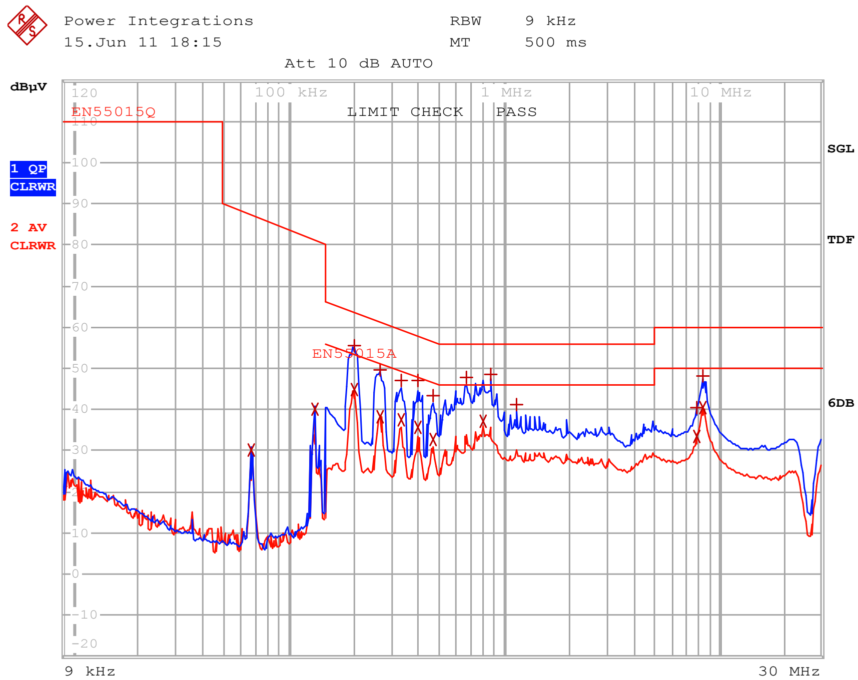


Figure 53 – EMI Measurement Set-up.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

13.2 Conducted EMI Test Results



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	66.5026022731 kHz	30.28	L1 gnd	
2	Average	132.133649648 kHz	39.99	L1 gnd	
1	Quasi Peak	200.175581485 kHz	55.47	N gnd	-8.12
2	Average	200.175581485 kHz	45.01	N gnd	-8.58
1	Quasi Peak	264.49018761 kHz	49.50	N gnd	-11.78
2	Average	264.49018761 kHz	38.35	N gnd	-12.93
1	Quasi Peak	332.507282579 kHz	46.96	N gnd	-12.42
2	Average	332.507282579 kHz	37.51	N gnd	-11.87
1	Quasi Peak	397.727746704 kHz	47.13	N gnd	-10.76
2	Average	397.727746704 kHz	35.75	N gnd	-12.14
1	Quasi Peak	466.367062279 kHz	43.56	N gnd	-13.01
2	Average	466.367062279 kHz	32.57	N gnd	-14.00
1	Quasi Peak	667.263434405 kHz	47.65	N gnd	-8.34
2	Average	798.145472681 kHz	36.98	N gnd	-9.01
1	Quasi Peak	864.277177159 kHz	48.63	N gnd	-7.36
1	Quasi Peak	1.13065507631 MHz	41.05	N gnd	-14.94
1	Quasi Peak	7.94912631806 MHz	40.32	N gnd	-19.67
2	Average	7.94912631806 MHz	33.45	N gnd	-16.55
1	Quasi Peak	8.4381577663 MHz	48.17	N gnd	-11.82
2	Average	8.4381577663 MHz	40.51	N gnd	-9.48

Figure 54 – Conducted EMI, 34 LED Load, 230 VAC, 60 Hz, EN55015B Limits.

14 Power Line Transient Test

The unit was subjected to ±2500 V, 100 kHz ring wave and ±500 V differential surge at 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	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass
+2500	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+500	230	L1, L2	0	Surge (2Ω)	Pass
-500	230	L1, L2	90	Surge (2Ω)	Pass
+500	230	L1, L2	0	Surge (2Ω)	Pass
-500	230	L1, L2	90	Surge (2Ω)	Pass

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

15 Revision History

Date	Author	Revision	Description and Changes	Reviewed
15-Jul-11	CA	1.0	Initial Release	Apps and Mktg

For the latest updates, visit our website: www.powerint.com

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail:
usasales@powerint.com

GERMANY
Rueckertstrasse 3
D-80336, Munich
Germany
Phone: +49-89-5527-3911
Fax: +49-89-5527-3920
e-mail:
eurosales@powerint.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@powerint.com

TAIWAN
5F, No. 318, Nei Hu Rd., Sec. 1
Nei Hu District
Taipei 114, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@powerint.com

CHINA (SHANGHAI)
Rm 1601/1610, Tower 1
Kerry Everbright City
No. 218 Tianmu Road West
Shanghai, P.R.C. 200070
Phone: +86-021-6354-6323
Fax: +86-021-6354-6325
e-mail:
chinasales@powerint.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail:
indiasales@powerint.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D, 159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728
Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@powerint.com

EUROPE HQ
1st Floor, St. James's House
East Street, Farnham
Surrey GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
e-mail:
eurosales@powerint.com

CHINA (SHENZHEN)
Rm A, B & C 4th Floor, Block C,
Electronics Science and
Technology Building
2070 Shennan Zhong Road
Shenzhen, Guangdong,
P.R.C. 518031
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
e-mail:
chinasales@powerint.com

ITALY
Via De Amicis 2
20091 Bresso MI
Italy
Phone: +39-028-928-6000
Fax: +39-028-928-6009
e-mail:
eurosales@powerint.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail:
singaporesales@powerint.com

APPLICATIONS HOTLINE
World Wide +1-408-414-9660

APPLICATIONS FAX
World Wide +1-408-414-9760