Design Example Report

Title	***25 W Non-Isolated, Buck-Boost Topology, Power Factor Corrected, LED Driver Using LinkSwitch™-PH LNK409EG***
Specification	180 VAC – 265 VAC Input; 72 V, 350 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-285
Date	July 19, 2011
Revision	1.0

Summary and Features

- Dramatically simplifies off-line, power factor corrected, LED driver design
  - Single-stage, power factor corrected, non-isolated LED driver
  - Compact with extremely low component count
  - High PF >0.9 across line and load
  - High efficiency >90%
  - Low THD, <20% at 230 VAC
  - IEC61000-3-2 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

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

1 Introduction

The document describes a non-isolated, power factor corrected, low THD, high-efficiency LED driver designed to drive a 72 V LED string at 350 mA from an input voltage range of 180 VAC to 265 VAC.

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

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

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

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

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

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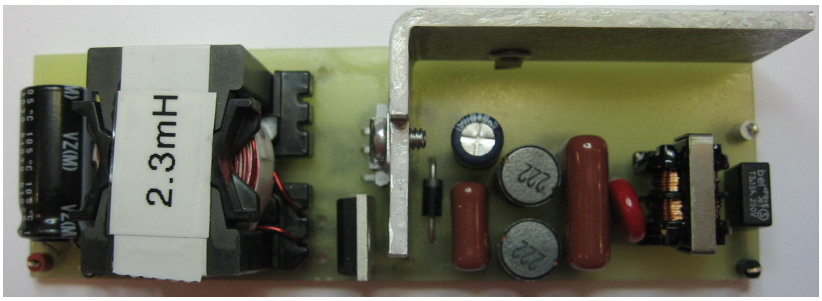

Figure 1 – Populated Circuit Board Photograph with PQ2620 Inductor, Top.

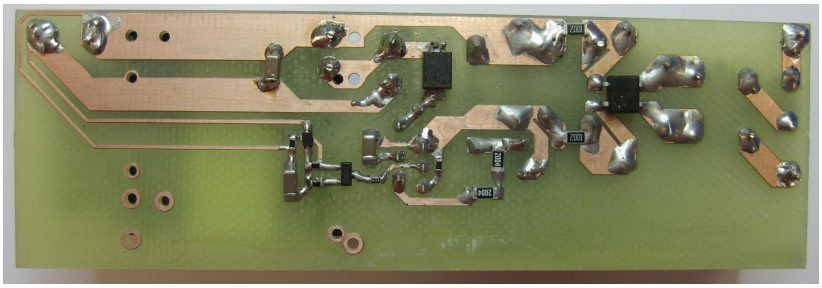

Figure 2 – Populated Circuit Board Photograph, Bottom.

Performance data using RM8 and EFD30 inductors are also presented in Chapter 17 and 18 respectively. RM8 inductor option will shrink both the length and width of the board while an EFD30 is an option if height is a limitation in the application. All waveforms (including thermals and EMI) were taken using the PQ2620 inductor which gives the highest efficiency. The improvement in efficiency using PQ2620 comes from the reduced copper losses from the inductor (more copper area and reduced number of turns because of the bigger core area of PQ2620).

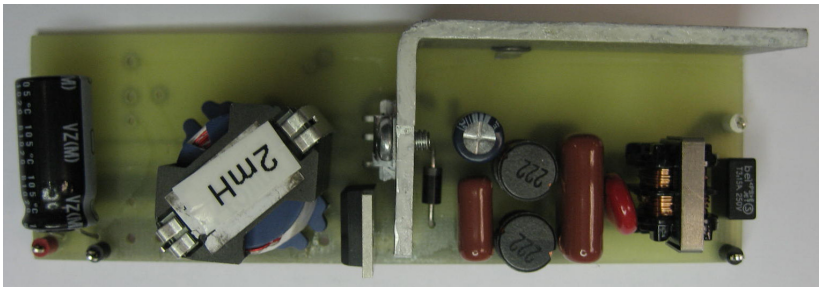

Figure 3 – Populated Circuit Board Photograph with RM8 Inductor.

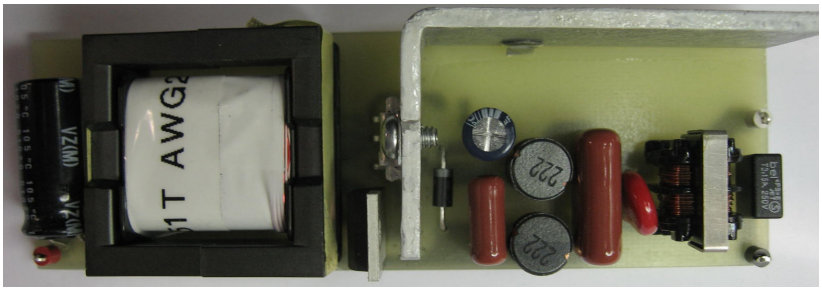

Figure 4 – Populated Circuit Board Photograph with EFD30 Inductor.

The figure below shows the comparison in efficiency between the 3 inductors.

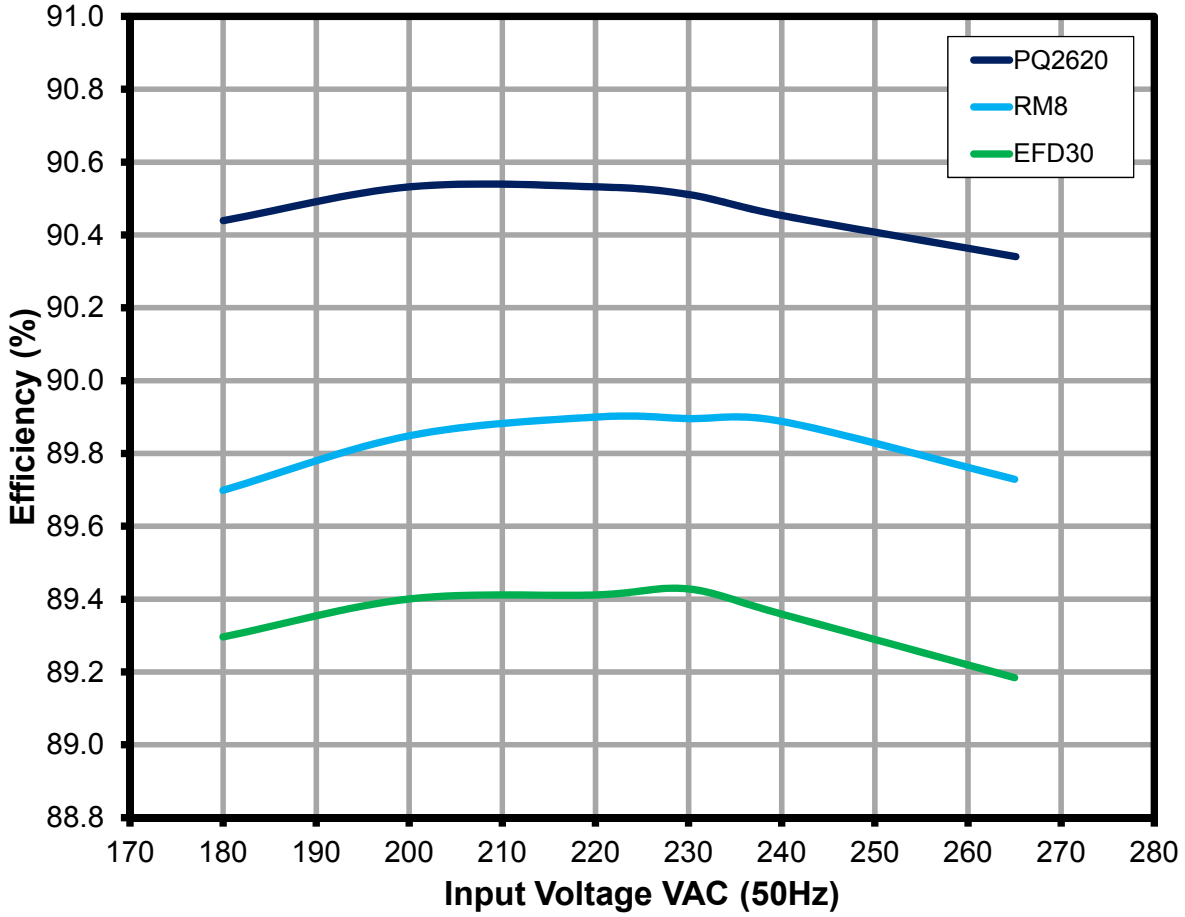

Figure 5 – Efficiency Comparison Between the 3 Inductors. String of 25 LEDs Used for Loading.

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2 Design Key Points

- High Efficiency
  - Qspeed output diode for almost no recovery losses.
  - Big core area with high quality ferrite material such as PC44 or 4F4 for low copper and core losses.
  - Z-winding construction for inductor with inter layer tape for low inter-winding capacitance.
  - Although not implemented in this design, the addition of a bias supply for the LinkSwitch-PH IC would increase efficiency.
- Meet Class C Limits per EN61000-3-2
  - KP <0.4 with the use of Buck-Boost topology.
  - Least amount of input capacitance (such as X capacitor).
- Low Conducted EMI
  - Differential choke + common mode choke.
  - Qspeed output diode with low noise recovery characteristic.

3 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}		72		V	
LED Current			350		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		25.2		W	
Environmental						
Conducted EMI			Meets EN55015B			
Safety			Non-isolated			
Efficiency			90			
Harmonic Currents			Class C			61000-3-2
Power Factor		0.9				
Ambient Temperature	T_{AMB}		50		°C	

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4 Schematic

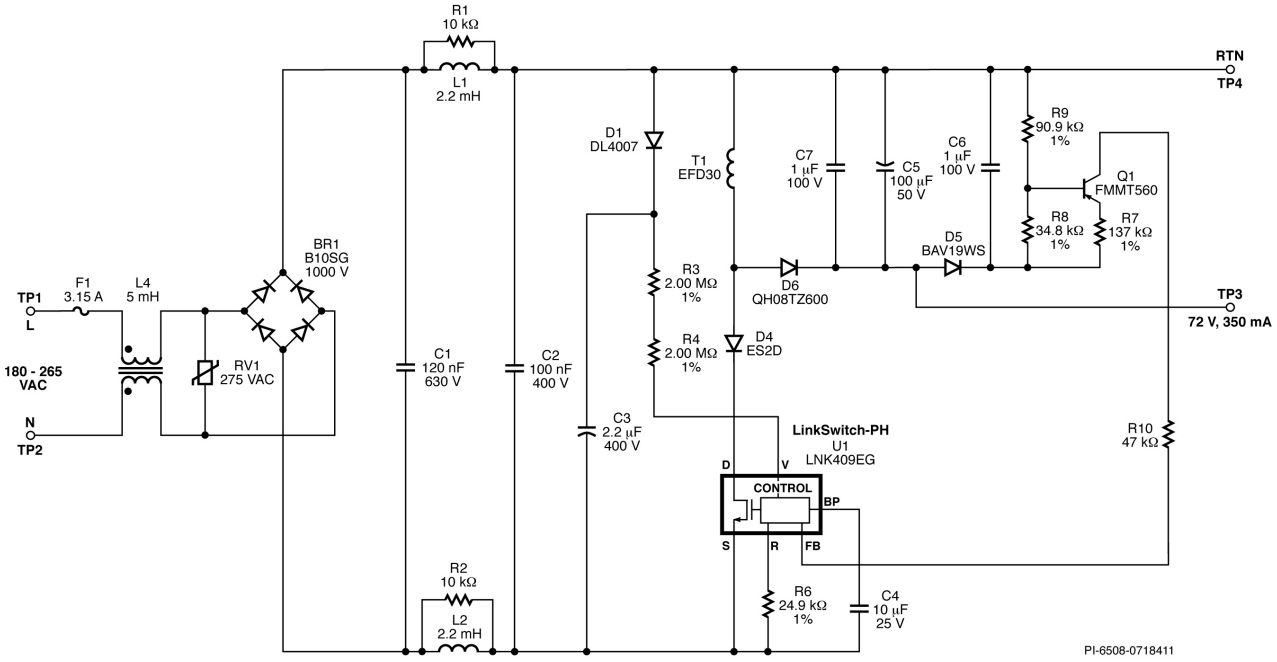

Figure 6 – Schematic Diagram. T1 Footprint can fit EFD30, PQ2620, and RM8 Bobbins.

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

Capacitor C1, C2, differential choke L1, and L2, and CMC L3 perform EMI filtering while maintaining high-power factor. This input filter network plus the frequency jittering feature of LinkSwitch-PH easily meets Class B emission limits. Resistor R1 and R2 are used to damp the Q of L1 and L2 for lower EMI.

The buck-boost power circuit with floating output connection composed of U1 (power switch + control), output diode D6, output capacitor C5, and output inductor L3. Diode D4 is 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 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 constant current to the LED load.

The FB pin current used by U1 for output voltage feedback is provided by the voltage to current converter network formed by R7-R10, Q1, C6, and D4. Output voltage is converted to feedback current by the following relation:

$$I_{FB} \approx k \times V_{OUT}$$

where

$$k = \frac{1}{R7} \times \frac{R8}{R8 + R9}$$

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

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6 PCB Layout

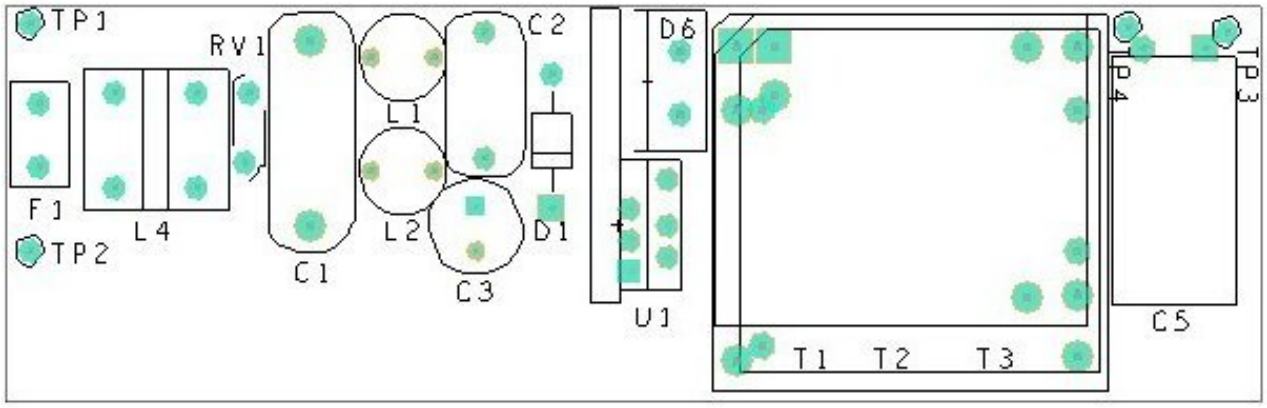

Figure 7 – Printed Circuit Layout, Top, 3.98” (101.2 mm) x 1.26” (32 mm).

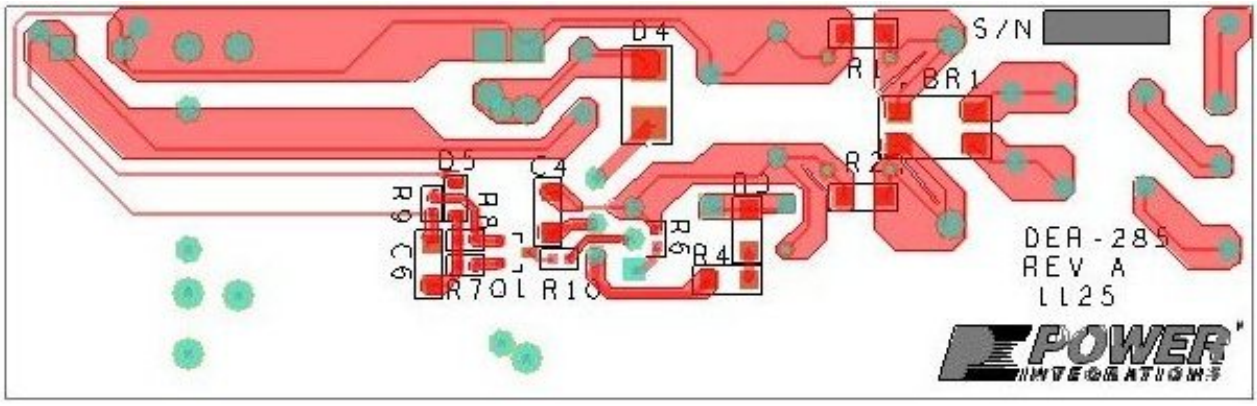

Figure 8 – Printed Circuit Layout, Bottom.

7 Bill of Materials

7.1 Electrical BOM

Item	Qty	Part Ref	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
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	2.2 μF, 400 V, Electrolytic, (8 x 11.5)	SMG400VB2R2M8X11LL	Nippon Chemi-Con
5	1	C4	10 μF, 25 V, Ceramic, X7R, 1206	ECJ-3YB1E106M	Panasonic
6	1	C5	100 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 20)	UVZ2A101MPD	Nichicon
7	2	C6 C7	1 μF, 100 V, Ceramic, X7R, 1206	ECJ-3YB1E105K	Panasonic
8	1	D1	1000 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4007-E3	Vishay
9	1	D4	200 V, 2 A, Ultrafast Recovery, 20 ns, DO-214AA	ES2D	Diodes, Inc.
10	1	D5	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
11	1	D6	600 V, 8 A, TO-220AC	QH08TZ600	Power Integrations
12	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
13	2	L1 L2	2.2 mH, 0.19 A, Ferrite Core	CTCH895F-222K	CTParts
14	1	L4	5 mH, 0.3 A, Common Mode Choke	SU9V-03050	Tokin
15	1	Q1	PNP, Small Signal BJT, 500 V, 0.15 A, SOT23	FMMT560TA	Zetex
16	2	R1 R2	10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
17	2	R3 R4	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
18	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
19	1	R7	137 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1373V	Panasonic
20	1	R8	34.8 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3482V	Panasonic
21	1	R9	90.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF9092V	Panasonic
22	1	R10	47 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ473V	Panasonic
23	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
24	1	T1	Bobbin, PQ26/20, Vertical, 12 pins	BPQ26/20-1112CPFR	TDK
25	1	U1	LinkSwitch-PH, eSIP	LNK409EG	Power Integrations

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8 Inductor Specification

8.1 Electrical Diagram

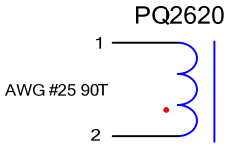

Figure 9 – Inductor Electrical Diagram.

8.2 Electrical Specifications

Inductance	Pins 1-2, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	2300 µH ±5%
Resonant Frequency	Pins 1-2, all other windings open	0.7 MHz (Min.)

8.3 Materials

Item	Description
[1]	Core: PC44 PQ26/20.
[2]	Bobbin: PQ26/20, Vertical, 12 pins.
[3]	Magnet Wire: #25 AWG.
[4]	Tape: 3M 1298 Polyester Film, 9.2 mm wide.

8.4 Inductor Build Diagram

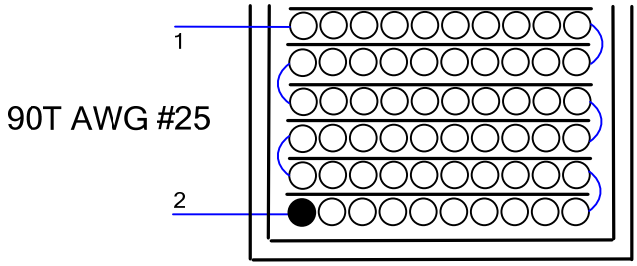

Figure 10 – Inductor Build Diagram.

9 Inductor Design Spreadsheet

Buck-boost inductor parameters can be calculated using LINKSWITCH-PH PIXIs spreadsheet. VO = VOR

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	72.00			V	Typical output voltage of LED string at full load
VO_MAX			79.20	V	Maximum expected LED string Voltage.
VO_MIN			64.80	V	Minimum expected LED string Voltage.
V_OVP			87.12	V	Over-voltage protection setpoint
IO	0.35				Typical full load LED current
PO			25.2	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/230 V
Chosen Device		LNK419	Power Out	18W	8 W
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	140.00		140.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			121.4	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	0.44		0.44		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			2299	uH	Primary Inductance
VOR	72.00		72	V	Reflected Output Voltage.
Expected IO (average)			0.35	A	Expected Average Output Current
KP_VACMAX			0.46		Expected ripple current ratio at VACMAX
TON_MIN			2.44	us	Minimum on time at maximum AC input voltage
PCLAMP			0.38	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**PQ2620**		**PQ2620**		
Bobbin		*#N/A*		*P/N:*	#N/A
AE	1.1900		1.19	cm^2	Core Effective Cross Sectional Area
LE	4.6300		4.63	cm	Core Effective Path Length
AL	6170.0		6170	nH/T^2	Ungapped Core Effective Inductance
BW	9.2		9.2	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	4.00		4		Number of Primary Layers
NS	91		91		Number of Secondary Turns

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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			0.23		Minimum duty cycle at peak of VACMIN
IAVG			0.19	A	Average Primary Current
IP			1.21	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.37	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			2299	uH	Primary Inductance
NP			90		Primary Winding Number of Turns
NB			26		Bias Winding Number of Turns
ALG			281	nH/T^2	Gapped Core Effective Inductance
BM			2596	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3141	Gauss	Peak Flux Density (BP<3700)
BAC			571	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1910		Relative Permeability of Ungapped Core
LG			0.51	mm	Gap Length (Lg > 0.1 mm)
BWE			36.8	mm	Effective Bobbin Width
OD			0.41	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.35	mm	Bare conductor diameter
AWG			28	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			161	Cmils	Bare conductor effective area in circular mils
CMA			432	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			1.21	A	Peak Secondary Current
ISRMS			0.63	A	Secondary RMS Current
IRIPPLE			0.52	A	Output Capacitor RMS Ripple Current
CMS			125	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			29	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.29	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.10	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			529	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			464	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			132	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			4.00	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			0.35	A	Measured Output Current at VAC1
IO_VAC2			0.35	A	Measured Output Current at VAC2
RV1 (new)			4.00	M-ohms	New RV1
RV2 (new)			1.40	M-ohms	New RV2
V_OV			325.6	V	Typical AC input voltage at which OV shutdown will

					be triggered
V_UV			72.4	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			121	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			0.35	A	Measured Output Current at Vb1
IO2			0.35	A	Measured Output Current at Vb2
RFB1 (new)			121.4	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

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10 Performance Data

The following data were measured using 3 sets of loads (i.e. 23, 24, and 25 LED strings to represent the load range of 67 V ~ 74 V output voltage). Refer to the table on Section 12.6 for the complete set of data values. All measurements were performed at room temperature.

10.1 Efficiency

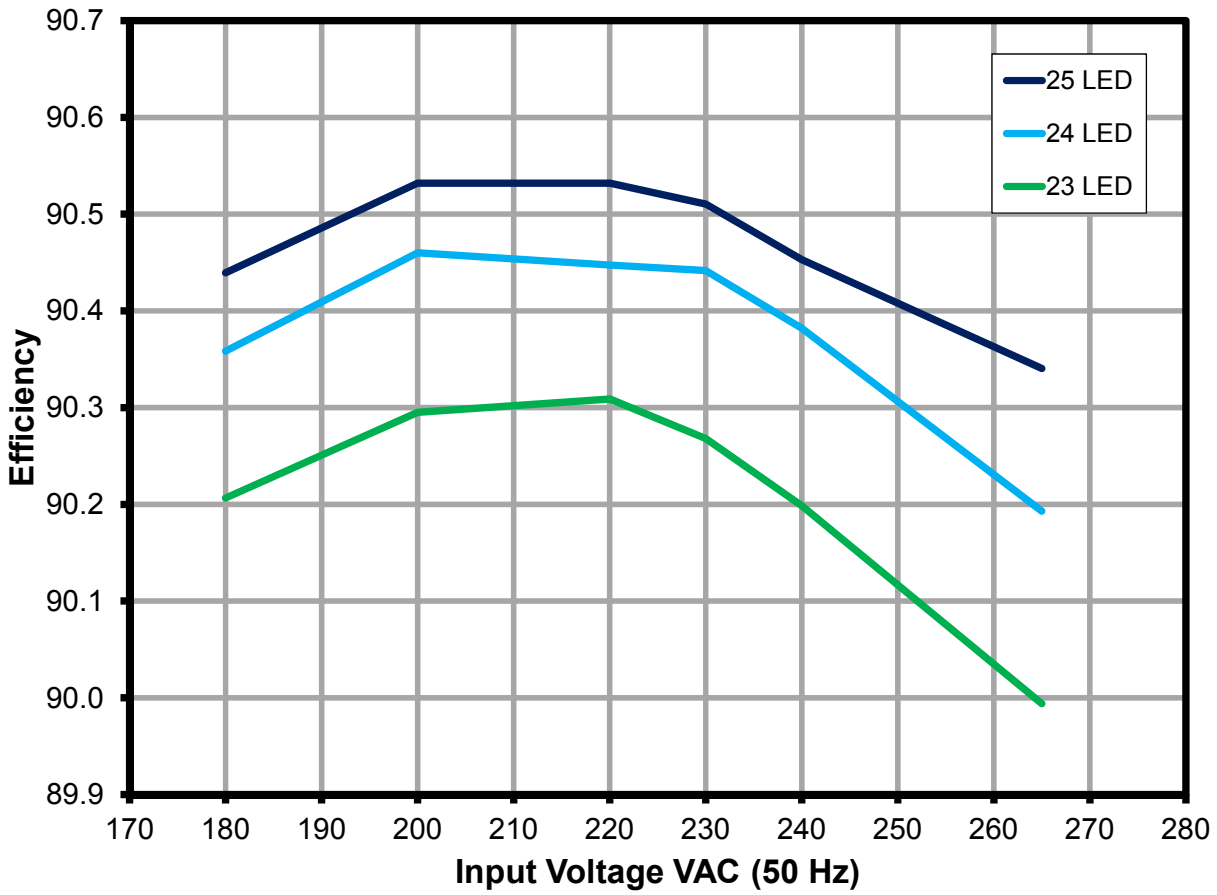

Figure 11 – Efficiency vs. Line and Load.

10.2 Line and Load Regulation

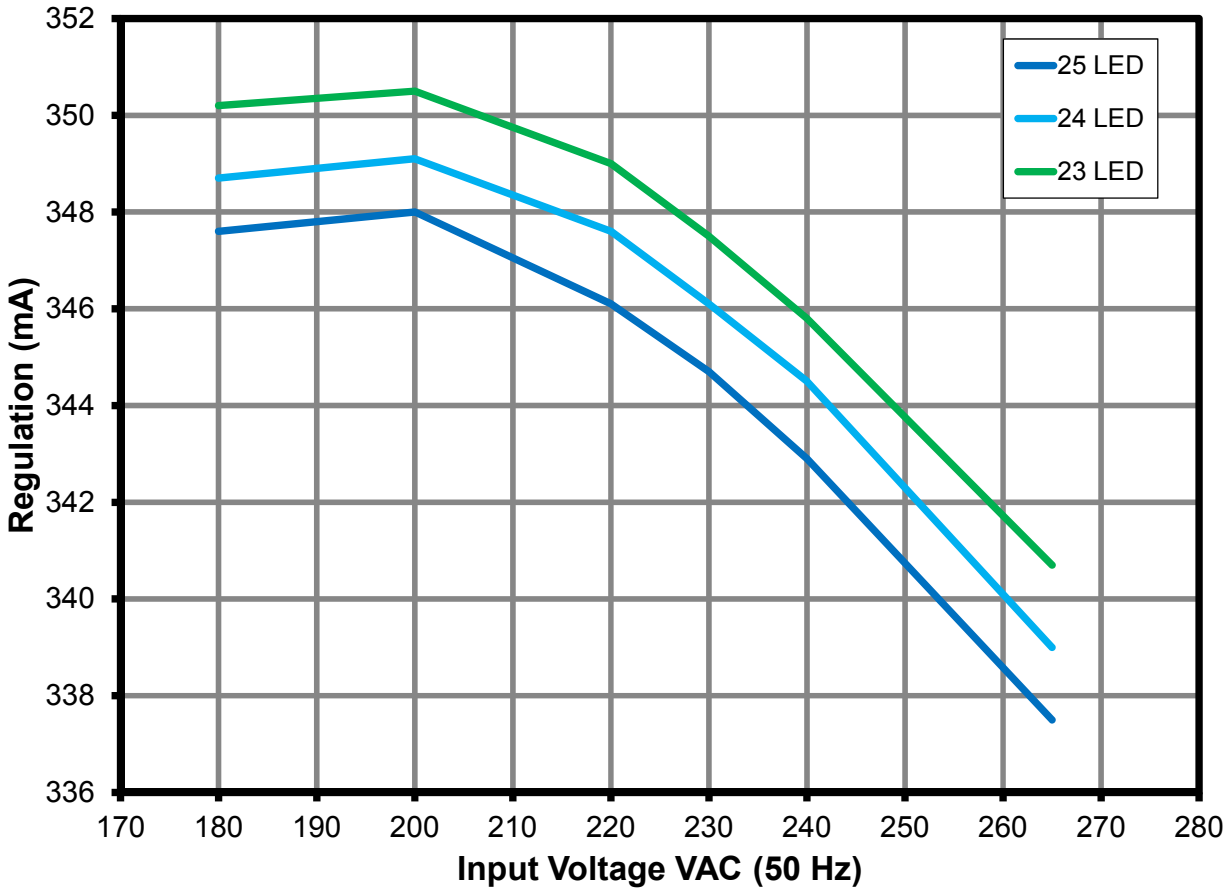

Figure 12 – Regulation vs. Line and Load.

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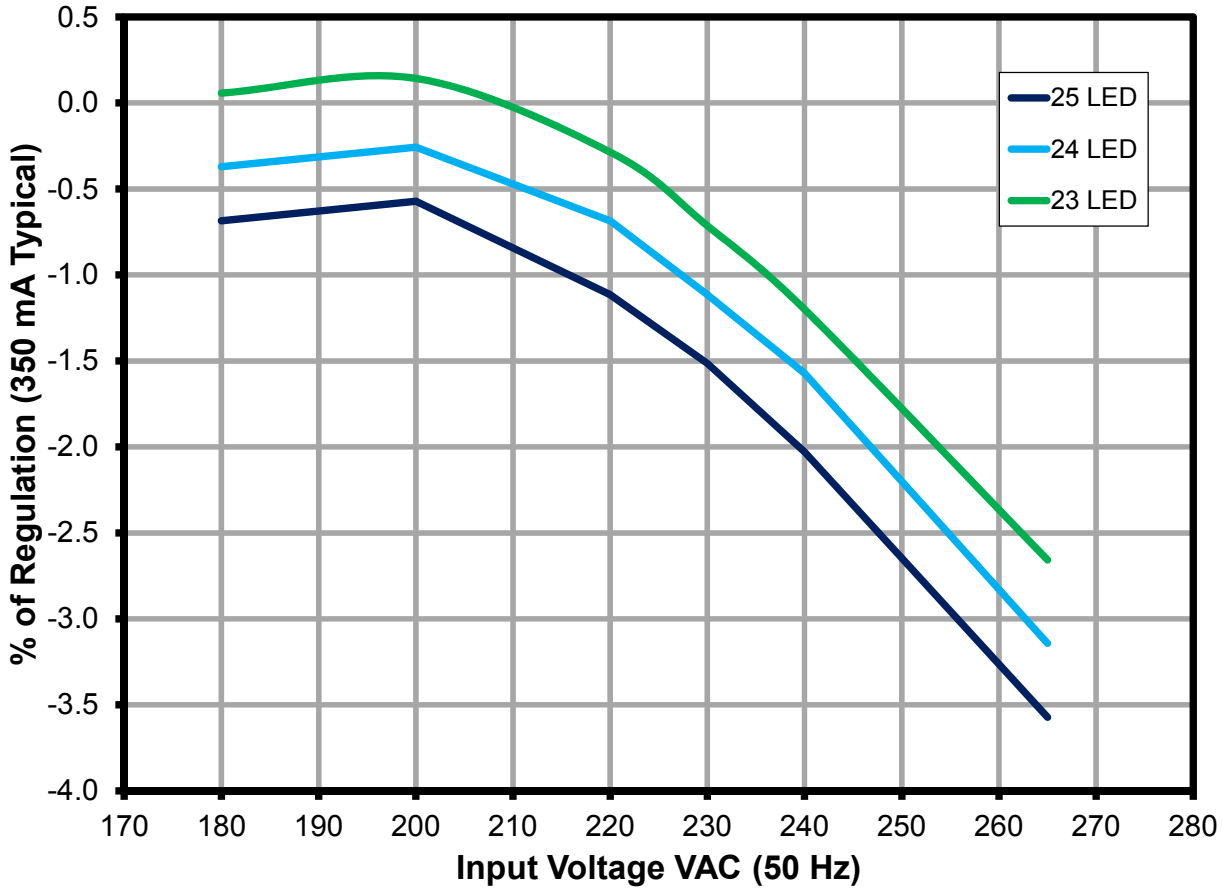

Figure 13 – Percent Line/Load Regulation.

10.3 Power Factor

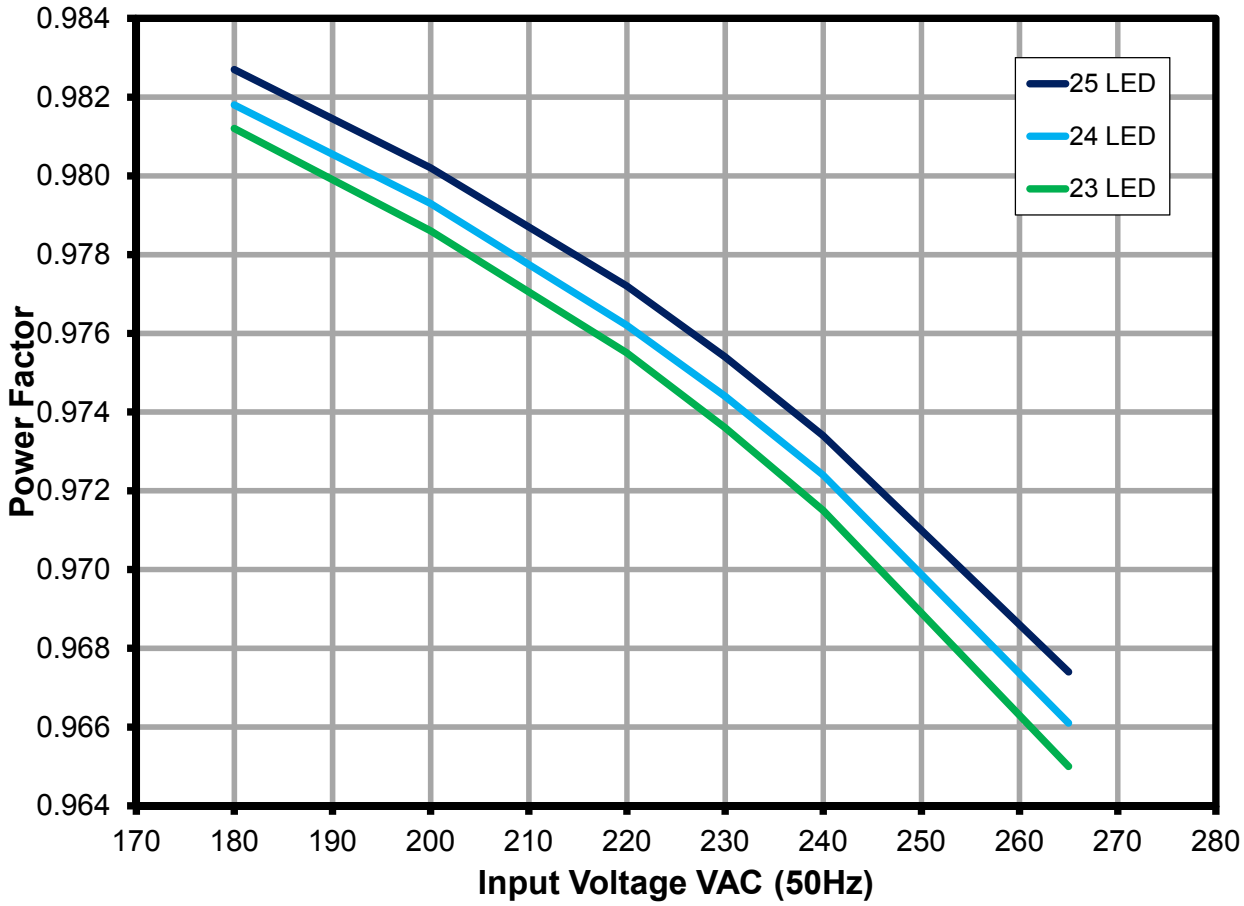

Figure 14 – Power Factor vs. Line and Load.

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10.4 A-THD

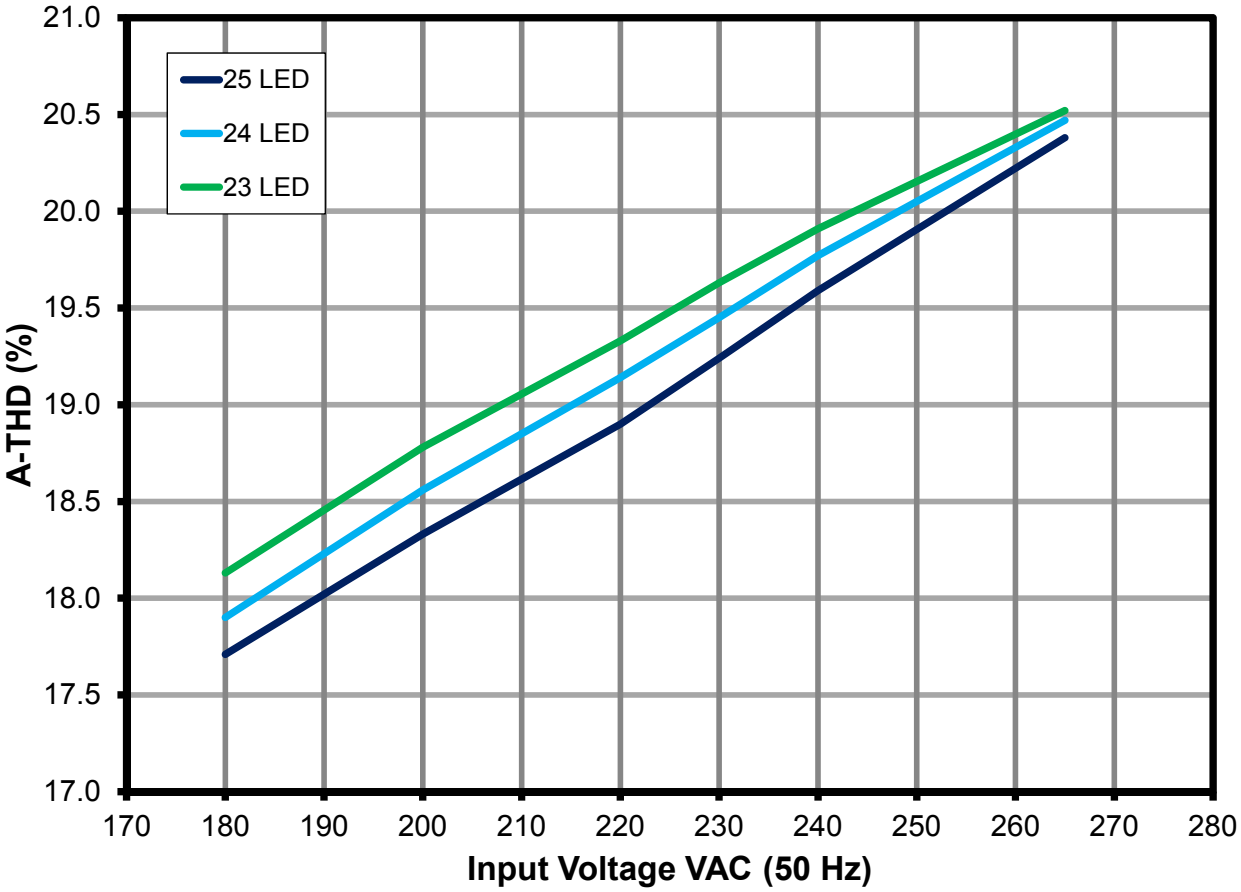

Figure 15 – A-THD vs. Line and Load.

10.5 Harmonics

10.5.1 25 LED Load

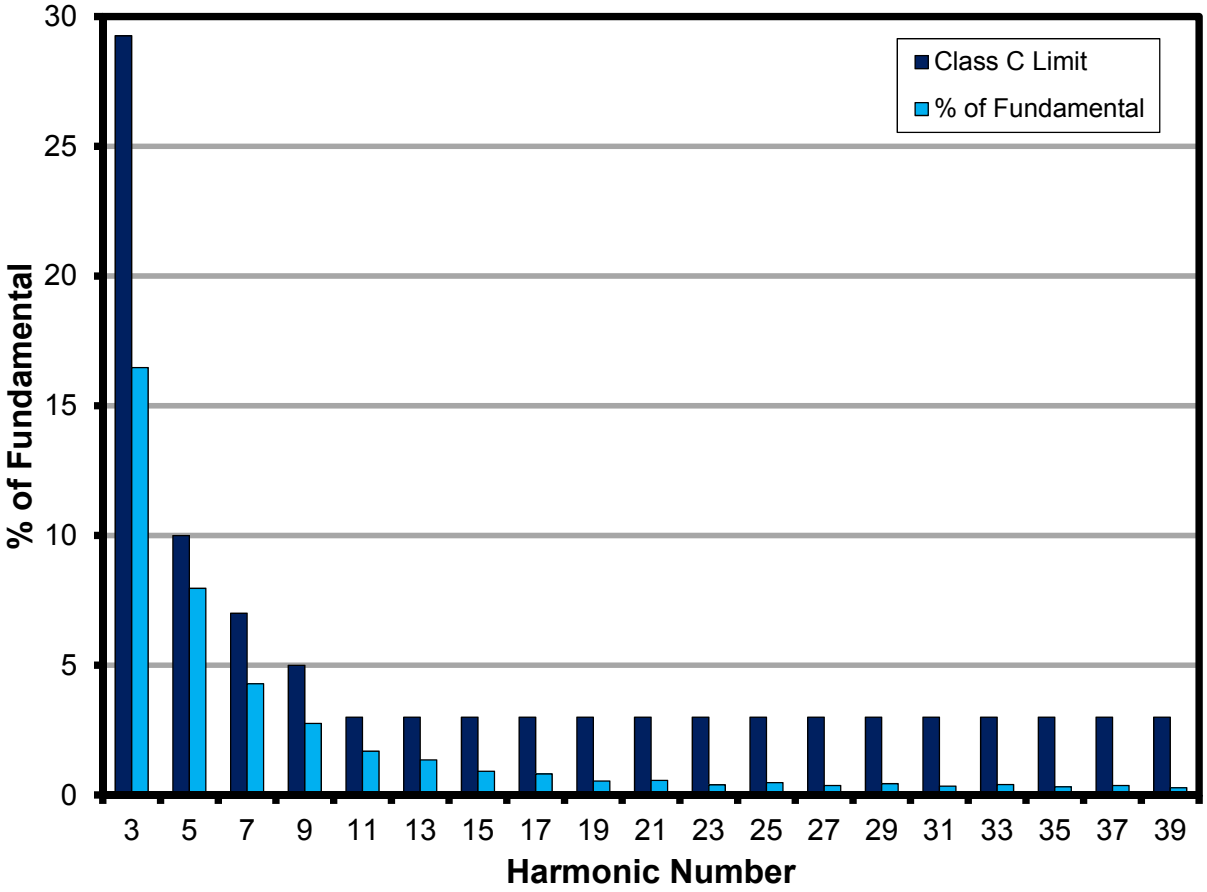

Figure 16 – Input Current Harmonics. CLASS C EN61000-3-2.

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10.5.3 24 LED Load

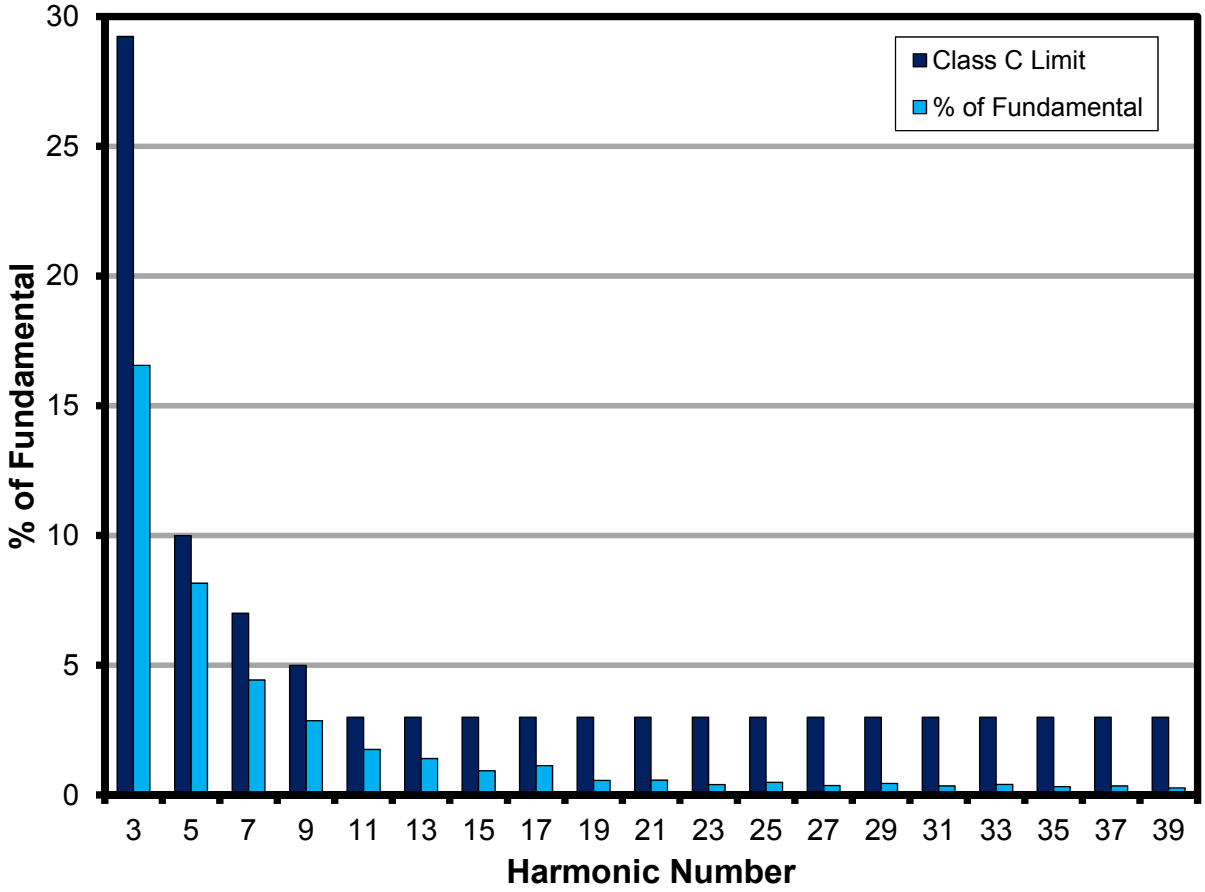

Figure 17 – Input Current Harmonics. CLASS C EN61000-3-2.

10.5.4 23 LED Load

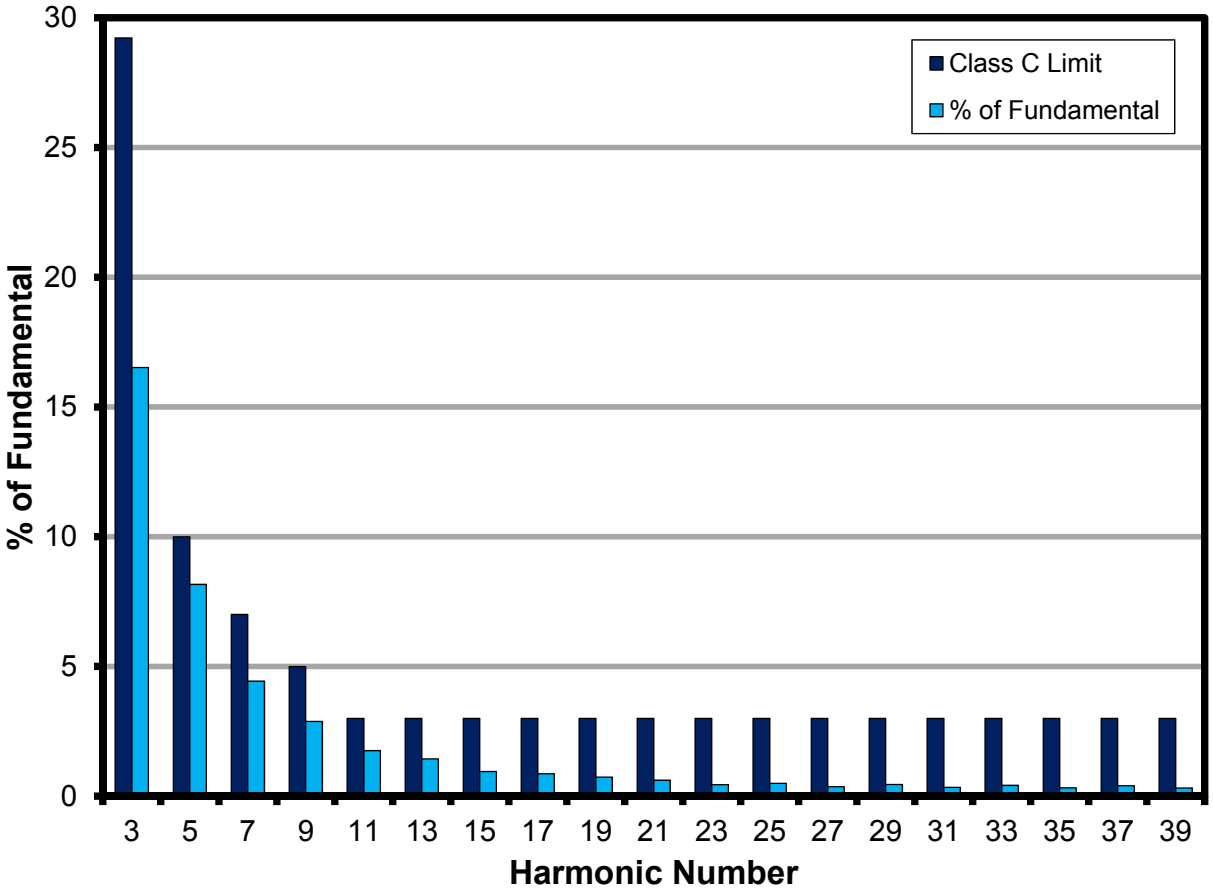

Figure 18 – Input Current Harmonics. CLASS C EN61000-3-2.

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10.6 Test Data

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

10.6.1 Test Data, 25 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
180.03	164.12	29.04	0.983	17.71	74.60	347.60	26.26	25.93	90.44	2.78	-0.7
200.06	147.58	28.94	0.980	18.33	74.40	348.00	26.20	25.89	90.53	2.74	-0.6
220.08	133.43	28.70	0.977	18.9	74.20	346.10	25.98	25.68	90.53	2.72	-1.1
230.14	126.98	28.51	0.975	19.24	74.00	344.70	25.80	25.51	90.51	2.71	-1.5
240.11	121.09	28.30	0.973	19.59	73.80	342.90	25.60	25.31	90.45	2.70	-2.0
265.13	108.45	27.82	0.967	20.38	73.60	337.50	25.13	24.84	90.34	2.69	-3.6

10.6.2 Test Data, 24 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
180.01	155.99	27.57	0.982	17.90	70.50	348.70	24.91	24.58	90.36	2.66	-0.4
200.04	140.57	27.54	0.979	18.56	70.50	349.10	24.91	24.61	90.46	2.63	-0.3
220.06	127.42	27.38	0.976	19.14	70.40	347.60	24.76	24.47	90.45	2.62	-0.7
230.13	121.45	27.23	0.974	19.45	70.30	346.10	24.63	24.33	90.44	2.60	-1.1
240.10	116.02	27.09	0.972	19.77	70.20	344.50	24.48	24.18	90.38	2.61	-1.6
265.13	104.10	26.67	0.966	20.47	70.10	339.00	24.05	23.76	90.19	2.62	-3.1

10.6.3 Test Data, 23 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
180.05	150.16	26.53	0.981	18.13	67.40	350.20	23.93	23.60	90.21	2.60	0.1
200.08	135.35	26.50	0.979	18.78	67.40	350.50	23.93	23.62	90.30	2.57	0.1
220.10	122.75	26.35	0.976	19.33	67.30	349.00	23.80	23.49	90.31	2.55	-0.3
230.16	117.07	26.23	0.974	19.63	67.30	347.50	23.68	23.39	90.27	2.55	-0.7
240.13	111.88	26.10	0.972	19.91	67.20	345.80	23.54	23.24	90.20	2.56	-1.2
265.15	100.58	25.74	0.965	20.52	67.10	340.70	23.16	22.86	89.99	2.58	-2.7

10.6.4 230 VAC 50 Hz, 25 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN} (W)	PF	%THD
50	230.1	126.45	28.38	0.975	19.22
	nth Order	mA Content	% of Fundamental	Class C Limit	Remarks
	1	124.02			
	3	20.43	16.47%	29.3%	PASS
	5	9.88	7.97%	10.0%	PASS
	7	5.32	4.29%	7.0%	PASS
	9	3.42	2.76%	5.0%	PASS
	11	2.09	1.69%	3.0%	PASS
	13	1.68	1.35%	3.0%	PASS
	15	1.13	0.91%	3.0%	PASS
	17	1.01	0.81%	3.0%	PASS
	19	0.67	0.54%	3.0%	PASS
	21	0.7	0.56%	3.0%	PASS
	23	0.49	0.40%	3.0%	PASS
	25	0.59	0.48%	3.0%	PASS
	27	0.45	0.36%	3.0%	PASS
	29	0.54	0.44%	3.0%	PASS
	31	0.42	0.34%	3.0%	PASS
	33	0.5	0.40%	3.0%	PASS
	35	0.39	0.31%	3.0%	PASS
	37	0.45	0.36%	3.0%	PASS
	39	0.35	0.28%	3.0%	PASS

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10.6.5 230 VAC 50 Hz, 24 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN} (W)	PF	%THD
50	230.2	121.22	27.18	0.974	19.54
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	118.83			
	3	19.68	16.56%	29.2%	PASS
	5	9.7	8.16%	10.0%	PASS
	7	5.27	4.43%	7.0%	PASS
	9	3.4	2.86%	5.0%	PASS
	11	2.09	1.76%	3.0%	PASS
	13	1.67	1.41%	3.0%	PASS
	15	1.11	0.93%	3.0%	PASS
	17	1.34	1.13%	3.0%	PASS
	19	0.67	0.56%	3.0%	PASS
	21	0.68	0.57%	3.0%	PASS
	23	0.48	0.40%	3.0%	PASS
	25	0.58	0.49%	3.0%	PASS
	27	0.44	0.37%	3.0%	PASS
	29	0.53	0.45%	3.0%	PASS
	31	0.41	0.35%	3.0%	PASS
	33	0.49	0.41%	3.0%	PASS
	35	0.38	0.32%	3.0%	PASS
	37	0.42	0.35%	3.0%	PASS
	39	0.32	0.27%	3.0%	PASS

10.6.6 230 VAC 50Hz, 23 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN} (W)	PF	%THD
50	230.1	117.68	26.38	0.974	19.43
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	115.37			
	3	19.06	16.52%	29.2%	PASS
	5	9.42	8.17%	10.0%	PASS
	7	5.11	4.43%	7.0%	PASS
	9	3.32	2.88%	5.0%	PASS
	11	2.03	1.76%	3.0%	PASS
	13	1.66	1.44%	3.0%	PASS
	15	1.1	0.95%	3.0%	PASS
	17	1	0.87%	3.0%	PASS
	19	0.85	0.74%	3.0%	PASS
	21	0.71	0.62%	3.0%	PASS
	23	0.51	0.44%	3.0%	PASS
	25	0.57	0.49%	3.0%	PASS
	27	0.42	0.36%	3.0%	PASS
	29	0.52	0.45%	3.0%	PASS
	31	0.39	0.34%	3.0%	PASS
	33	0.48	0.42%	3.0%	PASS
	35	0.37	0.32%	3.0%	PASS
	37	0.46	0.40%	3.0%	PASS
	39	0.36	0.31%	3.0%	PASS

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11 Waveforms

10.1 Input Line Current

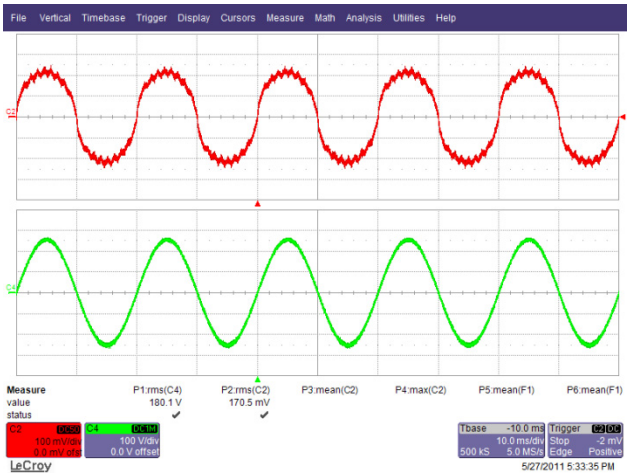

Figure 19 – 180 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

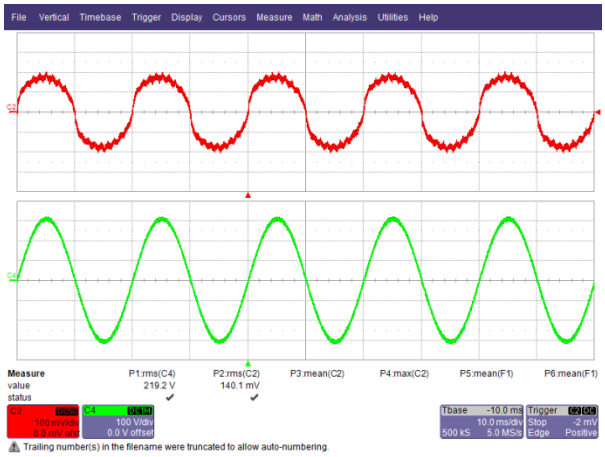

Figure 20 – 220 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

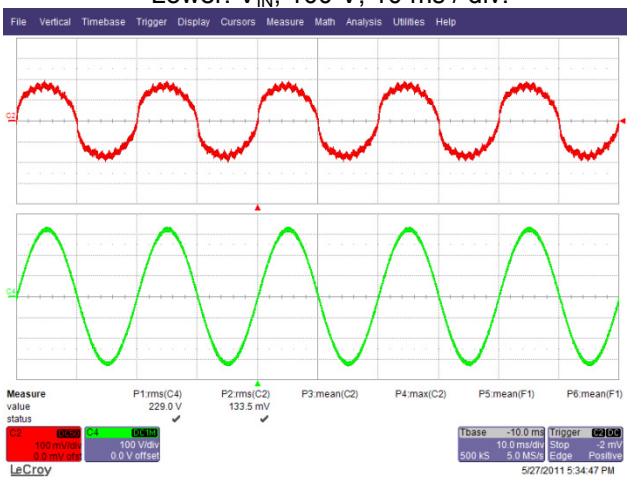

Figure 21 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

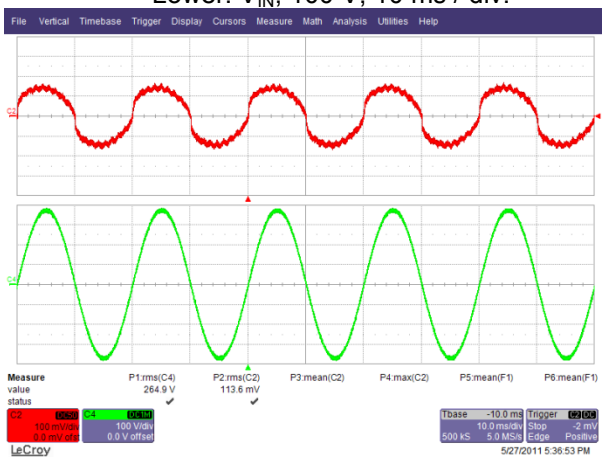

Figure 22 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

10.2 Drain Voltage and Current Normal Operation

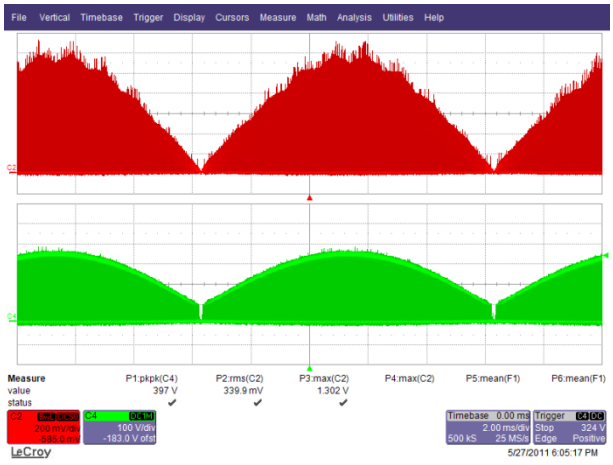

Figure 23 – 180 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

Figure 24 – 180 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

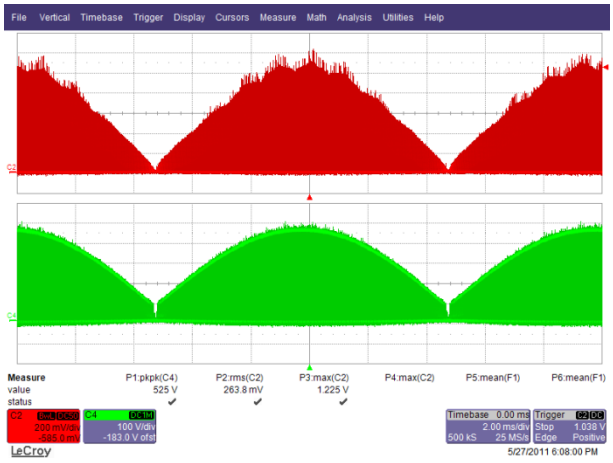

Figure 25 – 265 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

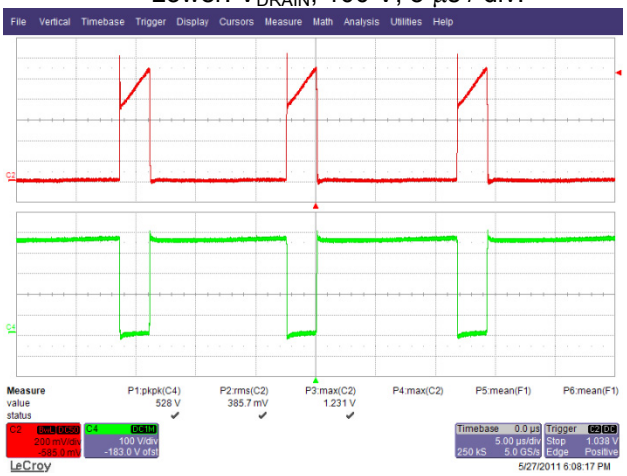

Figure 26 – 265 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

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10.3 Drain Voltage and Current Start-up Operation

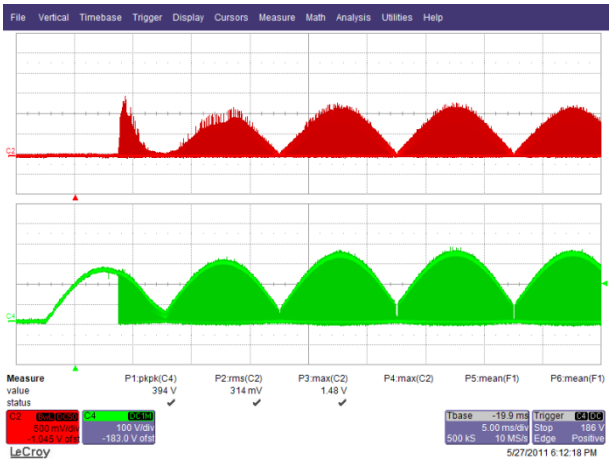

Figure 27 – 180 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

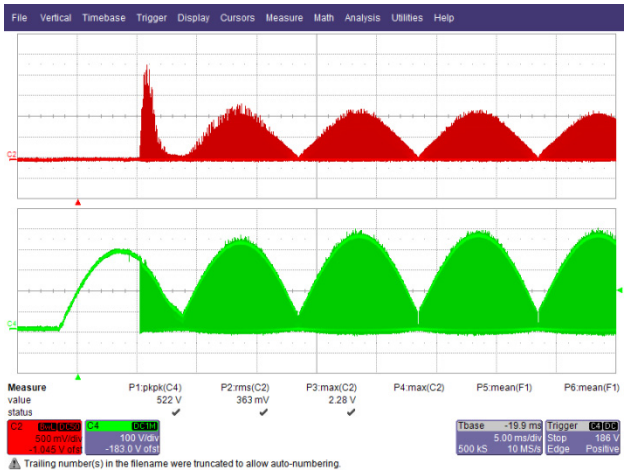

Figure 28 – 265 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

10.4 Output Current and Output Voltage

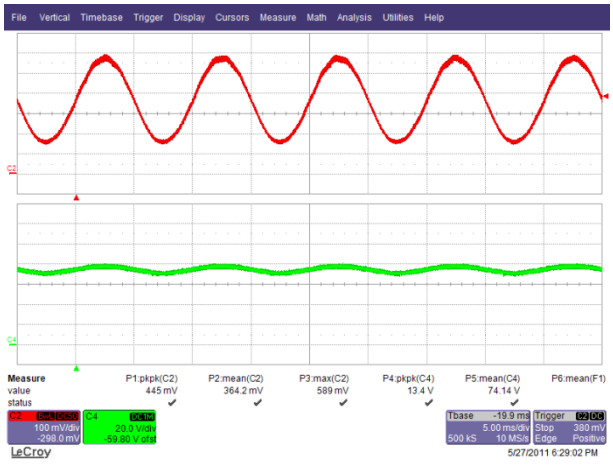

Figure 29 – 180 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

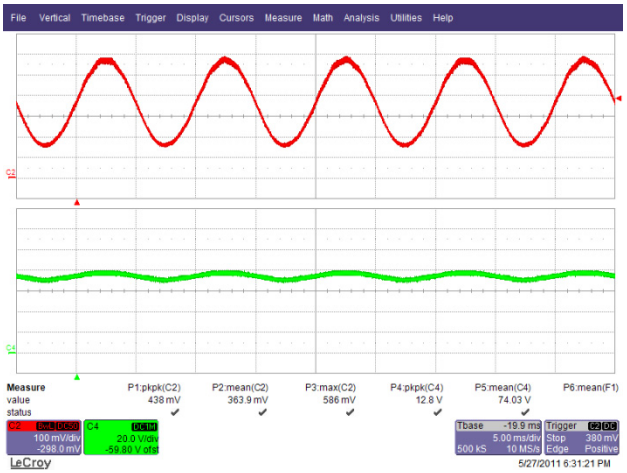

Figure 30 – 220 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

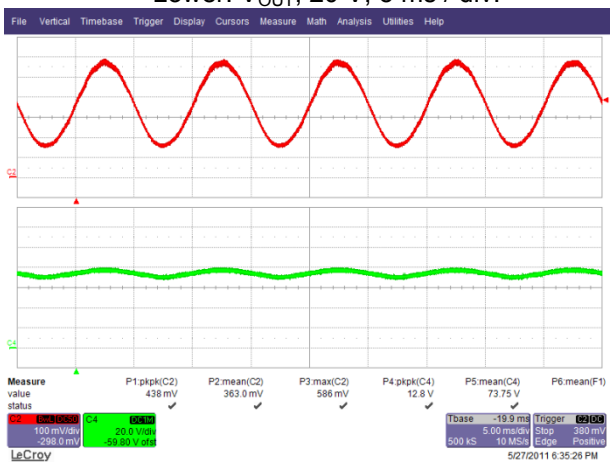

Figure 31 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

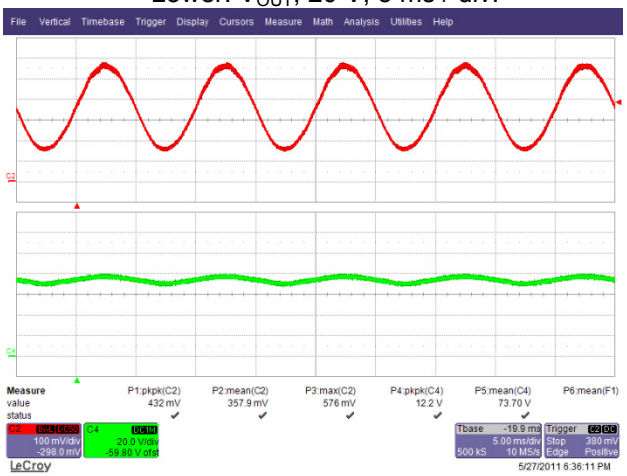

Figure 32 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 5 ms / div.

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10.5 Output Current and Voltage at Power-Up, Power-Down

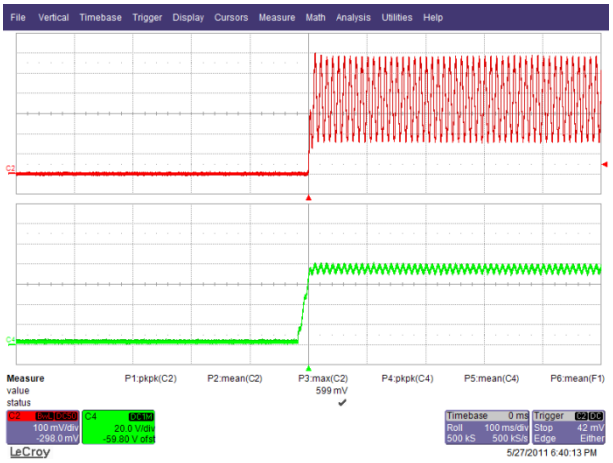

Figure 33 – 180 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

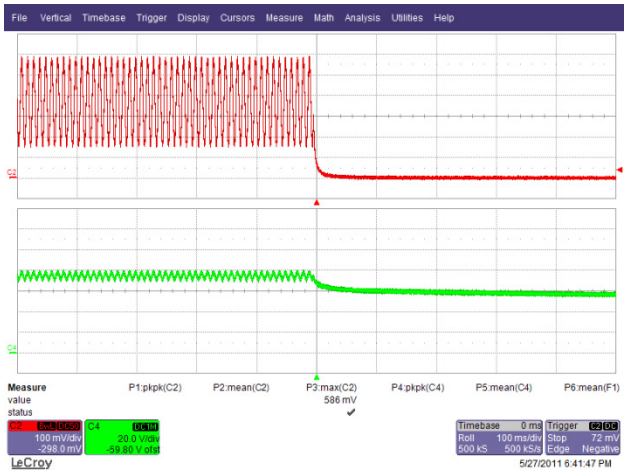

Figure 34 – 180 VAC 60 Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

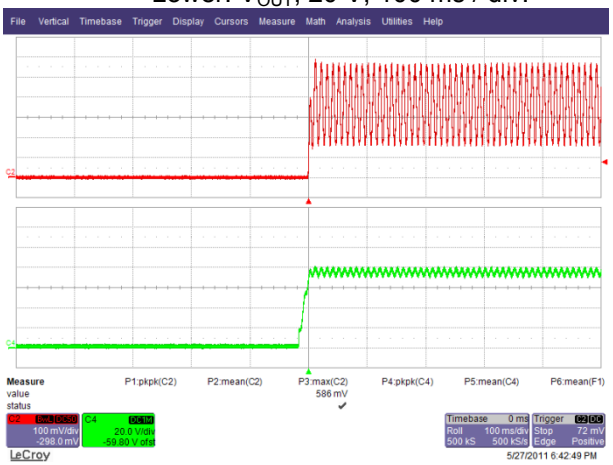

Figure 35 – 265 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

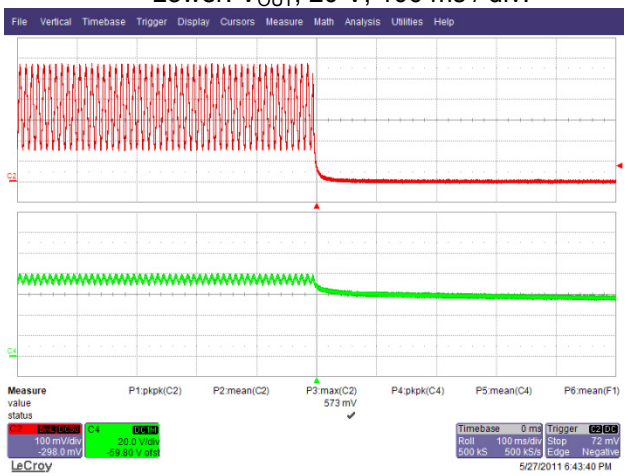

Figure 36 – 265 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

10.6 Output Short

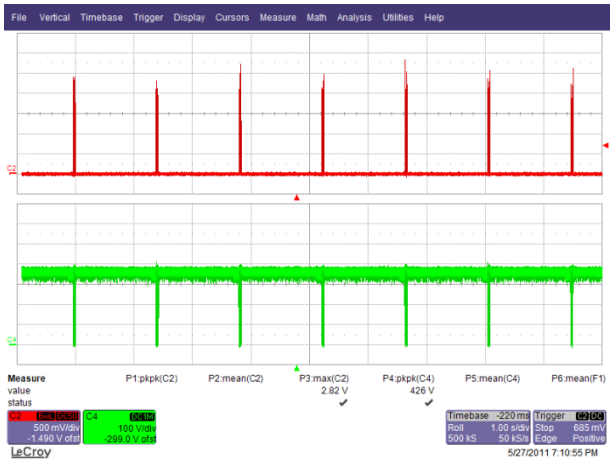

Figure 37 – 265 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 500 ms / div.

Figure 38 – 265 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

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12 Thermal Measurements

Thermal measurements were done with the EUT operated at room temperature, 25 strings of LED, and 230 VAC, 50 Hz line input.

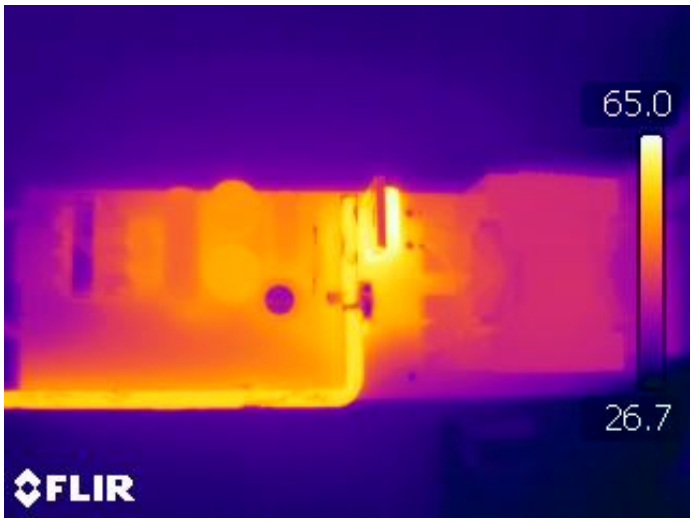

Figure 39 – Top-Side Thermal Measurements.

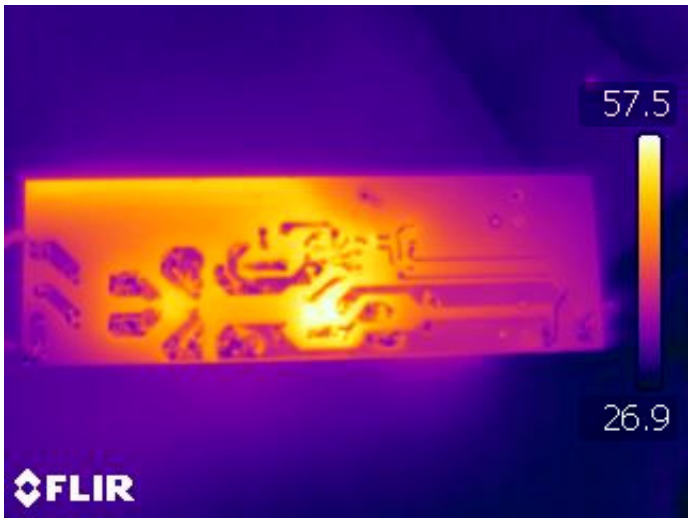

Figure 40 – Bottom-Side Thermal Measurements.

13 Conducted EMI Measurements

13.1 Conducted EMI Test Set-up

The EUT is placed 10 mm above a ground plane as shown below together with the LED load.

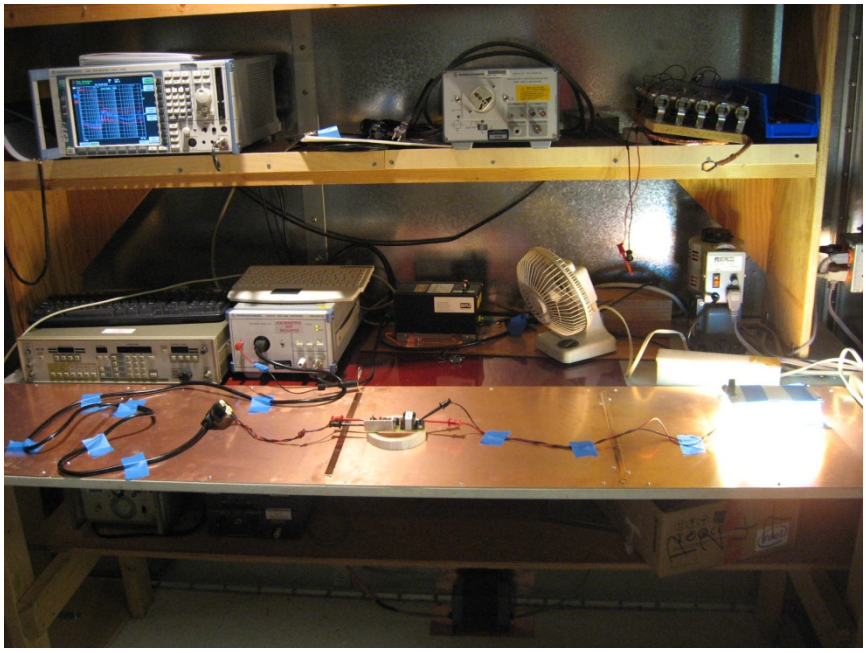

Figure 41 – EMI Measurement Set-up.

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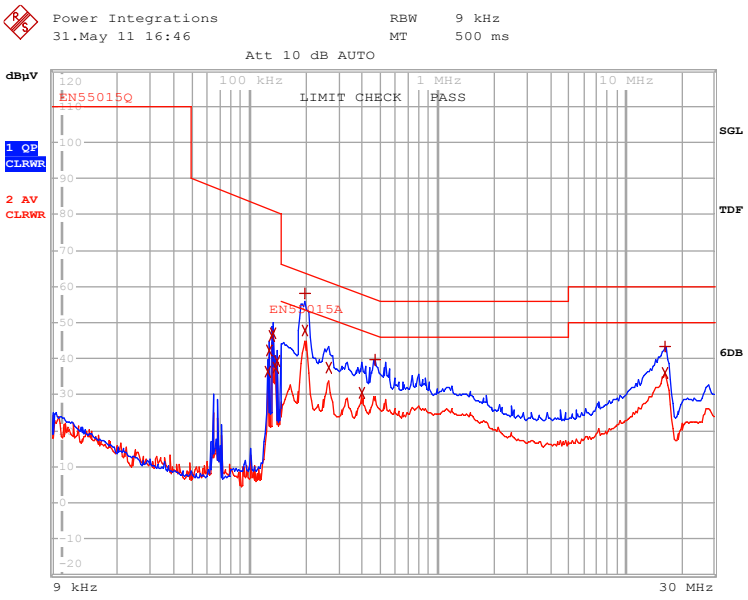
13.2 Conducted EMI Test Results



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	125.720633819 kHz	36.47	N gnd	
2	Average	128.247618558 kHz	42.14	N gnd	
2	Average	130.825395691 kHz	46.34	N gnd	
2	Average	133.454986145 kHz	46.96	N gnd	
2	Average	137.49880568 kHz	37.46	N gnd	
2	Average	140.262531674 kHz	39.28	N gnd	
1	Quasi Peak	198.193645035 kHz	58.05	N gnd	-5.63
2	Average	198.193645035 kHz	47.80	N gnd	-5.88
2	Average	264.49018761 kHz	37.35	N gnd	-13.94
2	Average	397.727746704 kHz	30.60	N gnd	-17.29
1	Quasi Peak	466.367062279 kHz	39.55	L1 gnd	-17.02
1	Quasi Peak	16.2726510175 MHz	43.27	N gnd	-16.73
2	Average	16.2726510175 MHz	36.13	N gnd	-13.86

Figure 42 – Conducted EMI, 25 LED Load, 230 VAC, 60 Hz, and EN55015 Limits.

14 Design Using RM8 Inductor

14.1 RM8 Inductor Specification

14.1.1 Electrical Diagram

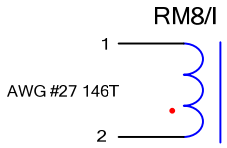


Figure 43 – Electrical Diagram.

14.1.2 Electrical Specifications

Inductance	Pins 1-2, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	2000 µH ±5%
Resonant Frequency	Pins 1-2, all other windings open	0.7 MHz (Min.)

14.1.3 Materials

Item	Description
[1]	Core: PC44 RM8/I
[2]	Bobbin: RM8, Vertical, 12 pins
[3]	Magnet Wire: #27 AWG.
[4]	Tape: 3M 1298 Polyester Film, 9 mm wide.

14.1.4 Inductor Build Diagram

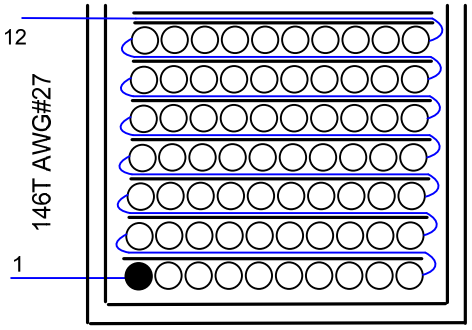


Figure 44 – RM8 Inductor Build Diagram.

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14.2 RM8 Inductor Design Spreadsheet

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	72.00			V	Typical output voltage of LED string at full load
VO_MAX			79.20	V	Maximum expected LED string Voltage.
VO_MIN			64.80	V	Minimum expected LED string Voltage.
V_OVP			87.12	V	Over-voltage protection setpoint
IO	0.35				Typical full load LED current
PO			25.2	W	Output Power
n	0.89		0.89		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			80.3	uA	V pin current
RV			3.909	M-ohms	Upper V pin resistor
RV2			1.402	M-ohms	Lower V pin resistor
IFB	148.00		148.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			114.9	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			2030	uH	Primary Inductance
VOR	72.00		72	V	Reflected Output Voltage.
Expected IO (average)			0.35	A	Expected Average Output Current
KP_VACMAX			0.50		Expected ripple current ratio at VACMAX
TON_MIN			2.44	us	Minimum on time at maximum AC input voltage
PCLAMP			0.37	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM8/I**		**RM8/I**		
Bobbin		*RM8/I_BOBBIN*		*P/N:*	*
AE			0.63	cm^2	Core Effective Cross Sectional Area
LE			3.84	cm	Core Effective Path Length
AL			3000	nH/T^2	Ungapped Core Effective Inductance
BW			8.6	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	8.00		8		Number of Primary Layers
NS	147		147		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			0.23		Minimum duty cycle at peak of VACMIN
IAVG			0.19	A	Average Primary Current
IP			1.28	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.39	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			2030	uH	Primary Inductance
NP			146		Primary Winding Number of Turns
NB			42		Bias Winding Number of Turns
ALG			95	nH/T^2	Gapped Core Effective Inductance
BM			2821	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3413	Gauss	Peak Flux Density (BP<3700)
BAC			677	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1455		Relative Permeability of Ungapped Core
LG			0.80	mm	Gap Length (Lg > 0.1 mm)
BWE			68.8	mm	Effective Bobbin Width
OD			0.47	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.41	mm	Bare conductor diameter
AWG			27	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			203	Cmils	Bare conductor effective area in circular mils
CMA			524	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			1.27	A	Peak Secondary Current
ISRMS			0.65	A	Secondary RMS Current
IRIPPLE			0.55	A	Output Capacitor RMS Ripple Current
CMS			130	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			28	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.32	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.06	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			529	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			464	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			132	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			0.35	A	Measured Output Current at VAC1
IO_VAC2			0.35	A	Measured Output Current at VAC2

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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			115	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			0.35	A	Measured Output Current at Vb1
IO2			0.35	A	Measured Output Current at Vb2
RFB1 (new)			114.9	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

14.3 RM8 Performance Data

14.3.1 RM8 Efficiency

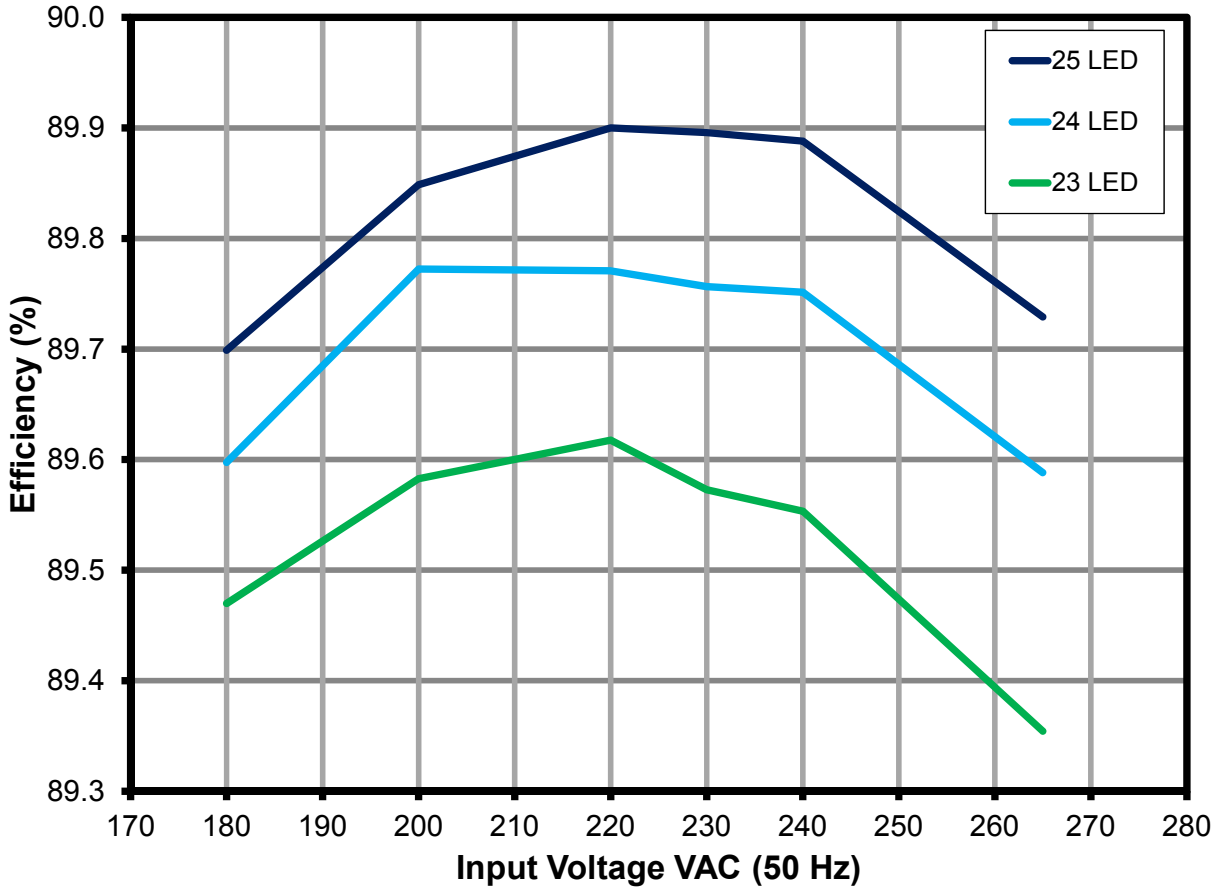

Figure 45 – Efficiency vs. Line and Load.

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14.3.2 RM8 Line and Load Regulation

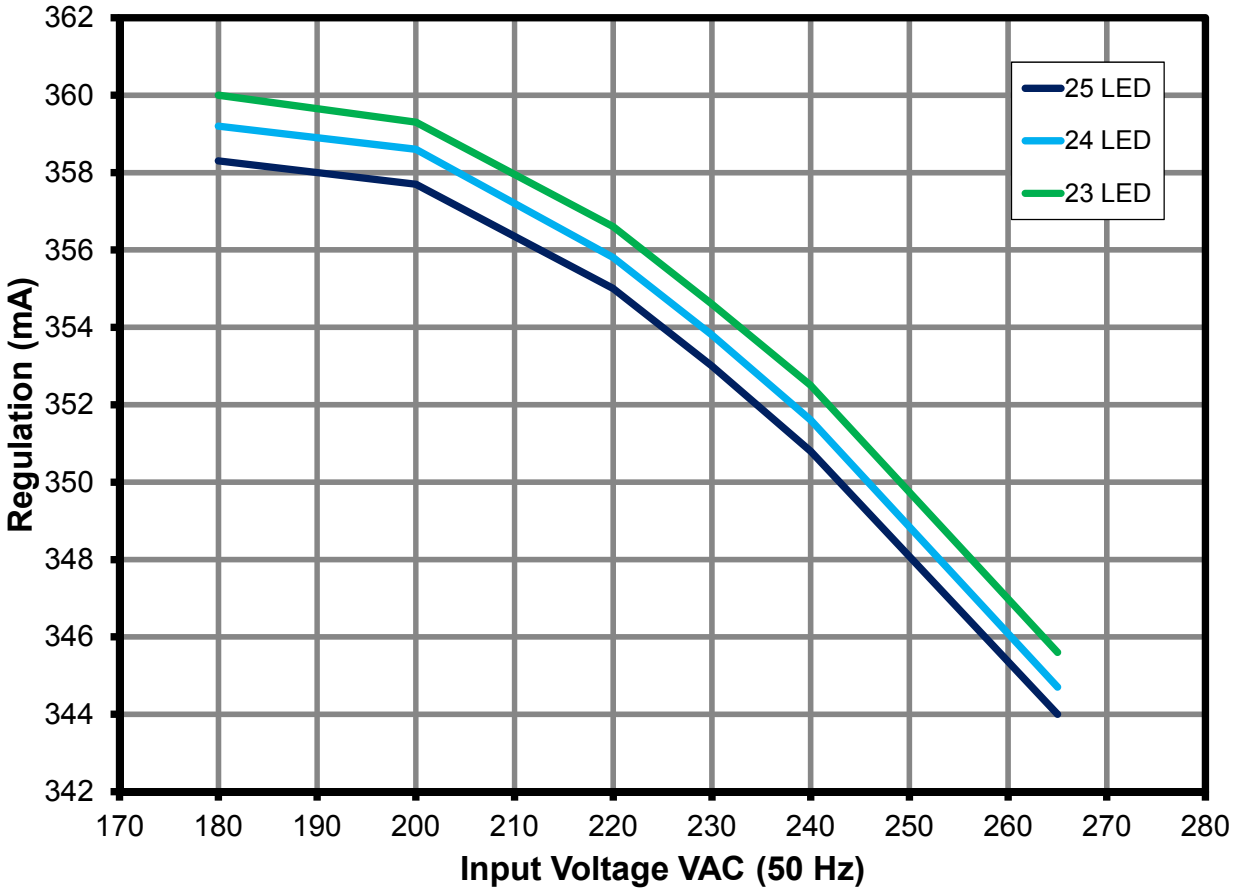

Figure 46 – Regulation vs. Line and Load.

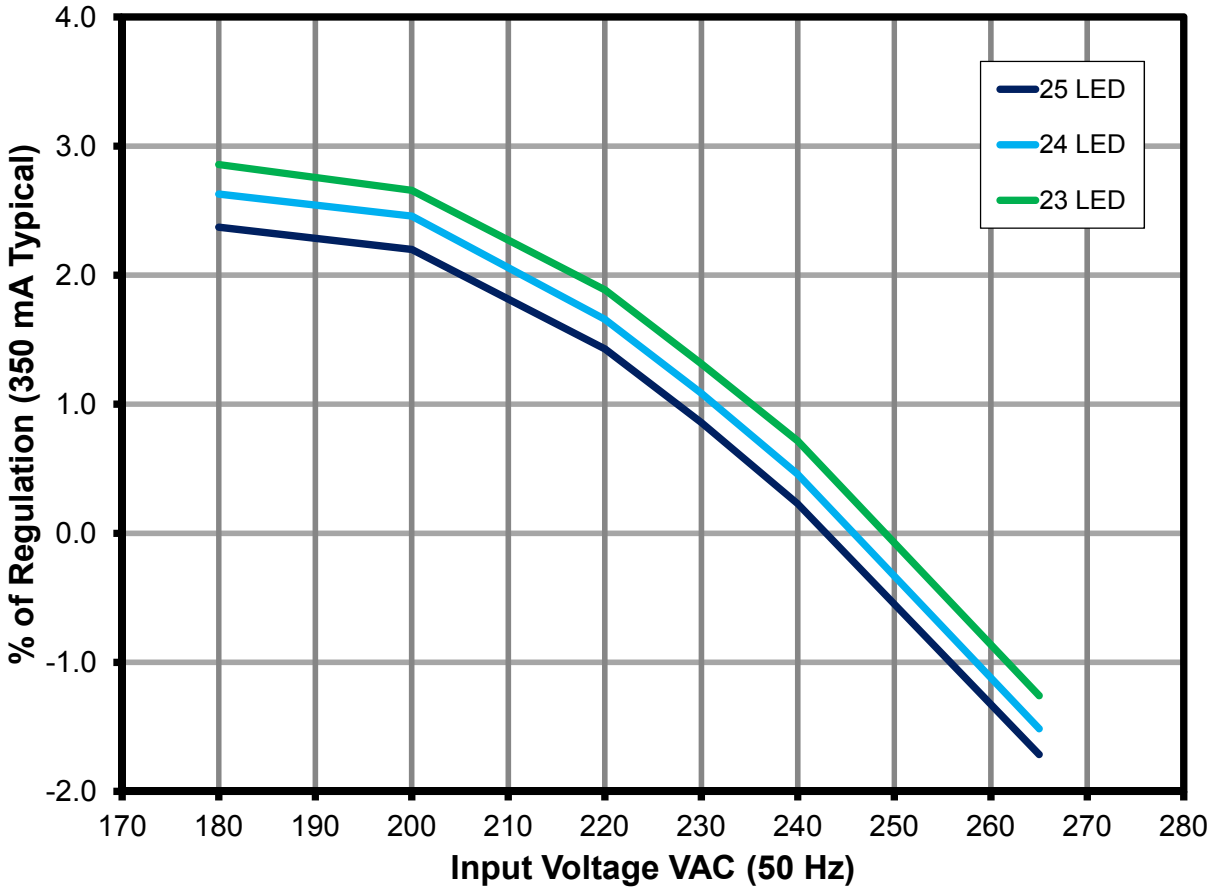

Figure 47 – Percent Line/Load Regulation.

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14.3.3 RM8 Power Factor

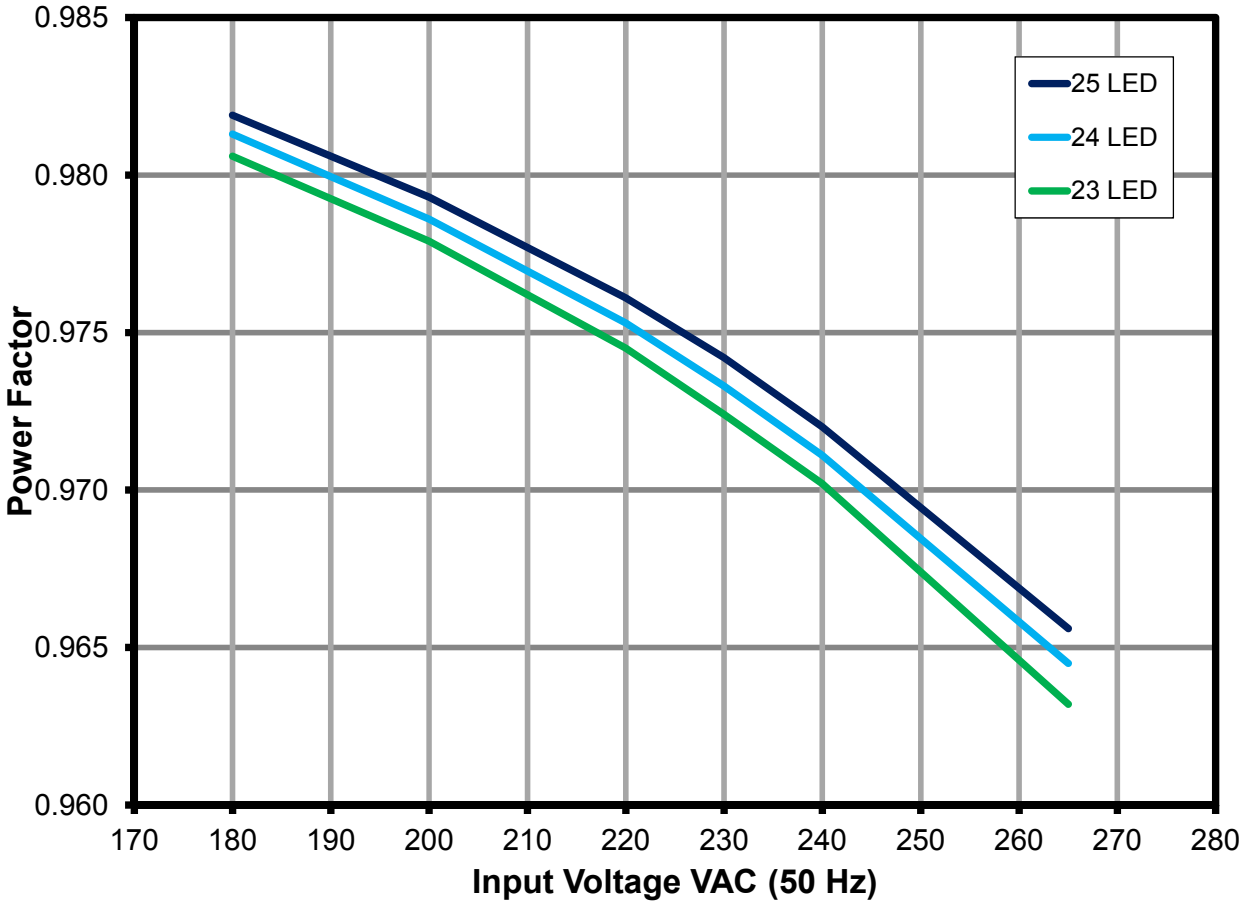

Figure 48 – Power Factor vs. Line and Load.

14.3.4 RM8 A-THD

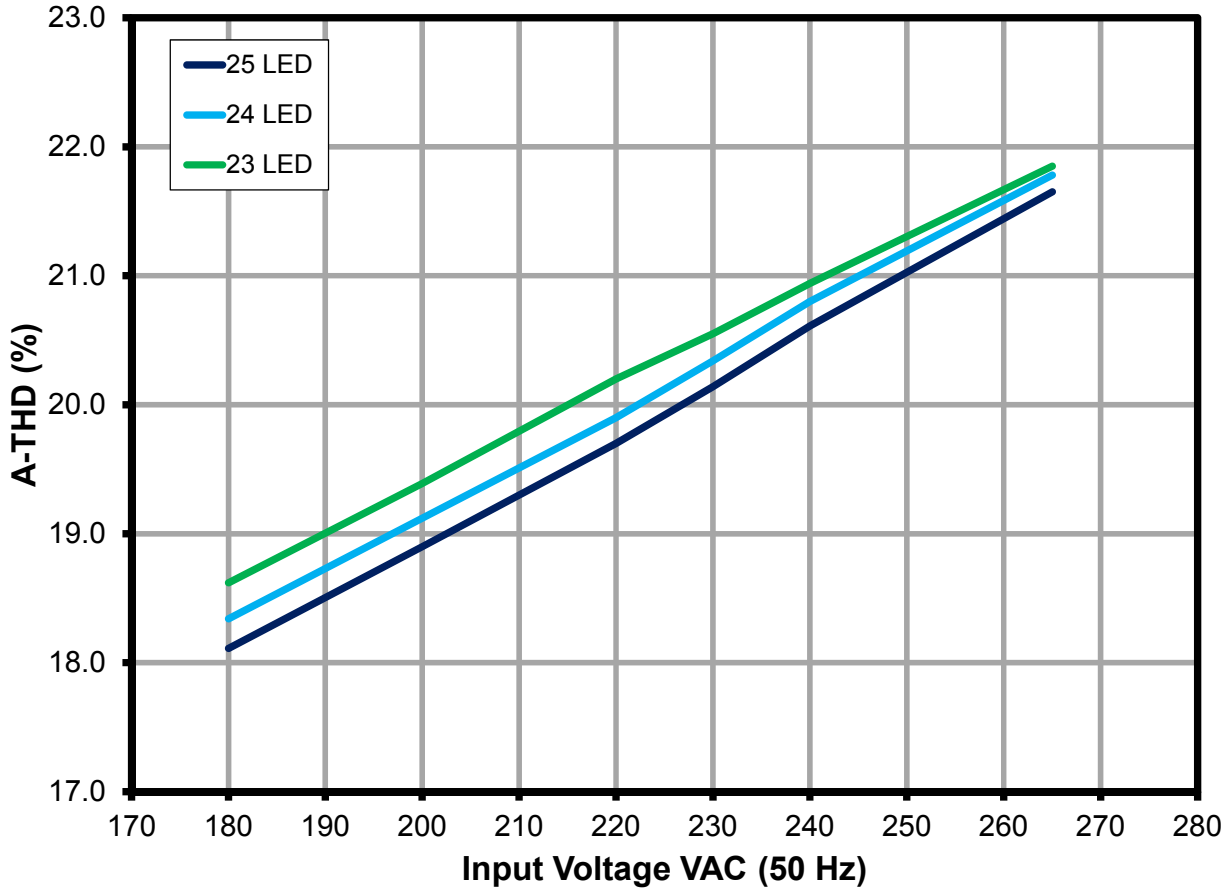

Figure 49 – A-THD vs. Line and Load.

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14.3.5 RM8 Harmonics

14.3.5.1 25 LED Load

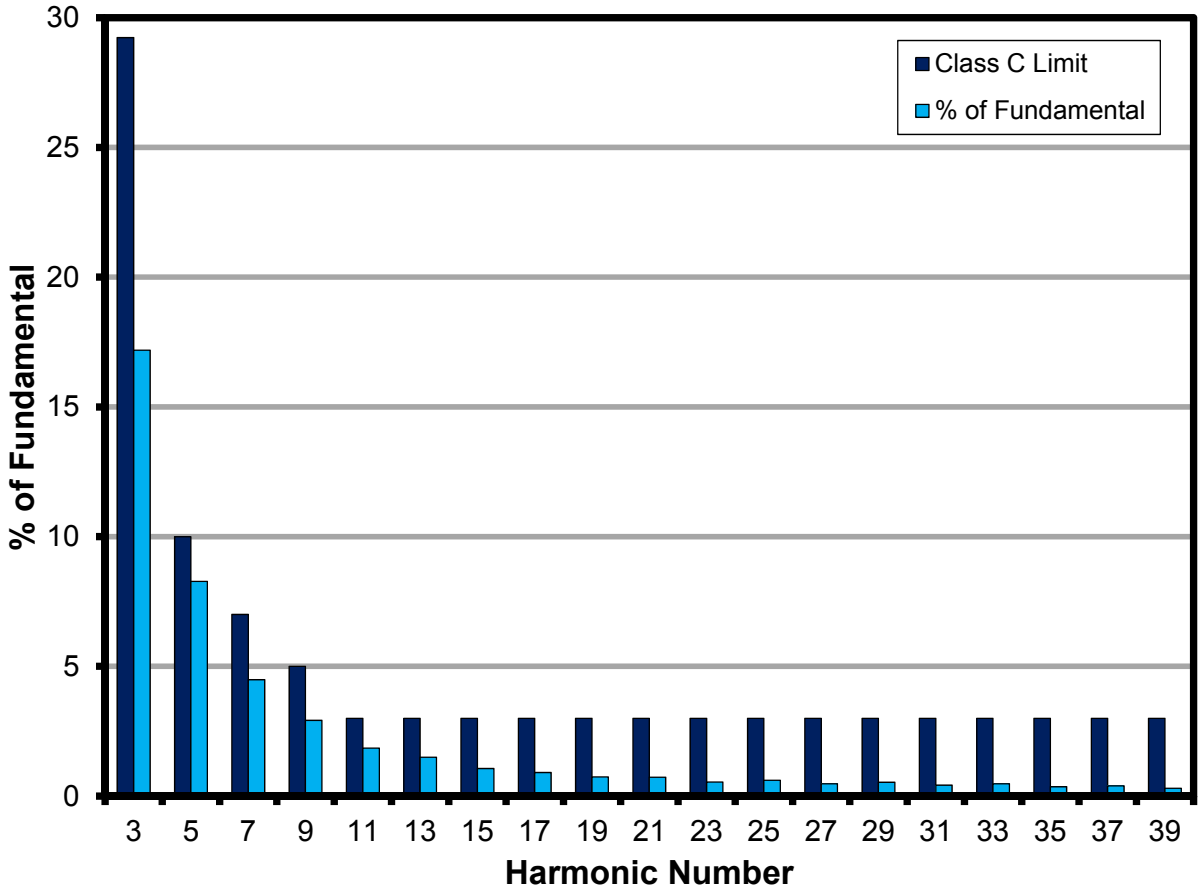

Figure 50 – Harmonic Data with 25 LED Load and 230 VAC 50 Hz Input CLASS C EN61000-3-2.

14.3.5.2 24 LED load

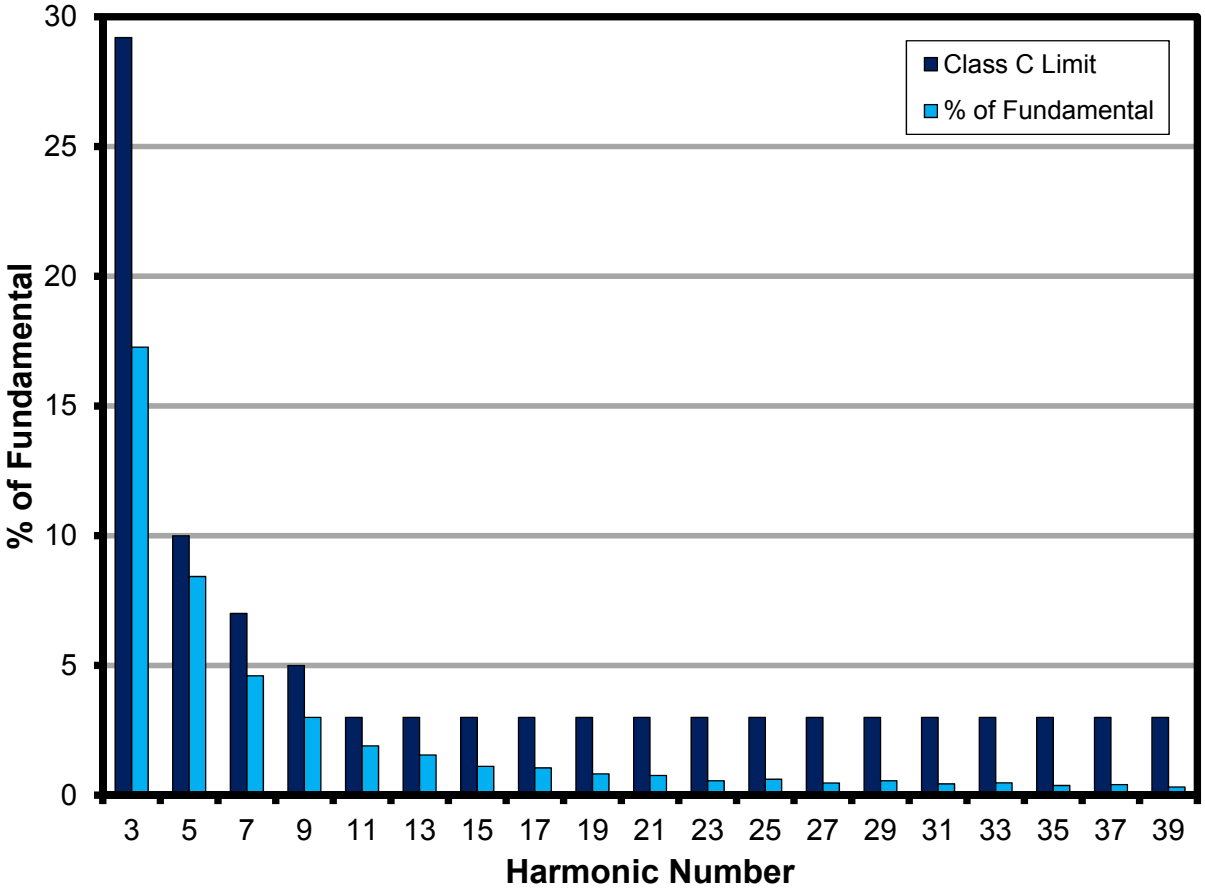

Figure 51 – Harmonic Data with 24 LED Load and 230 VAC 50 Hz Input CLASS C EN61000-3-2.

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14.3.5.3 23 LED Load

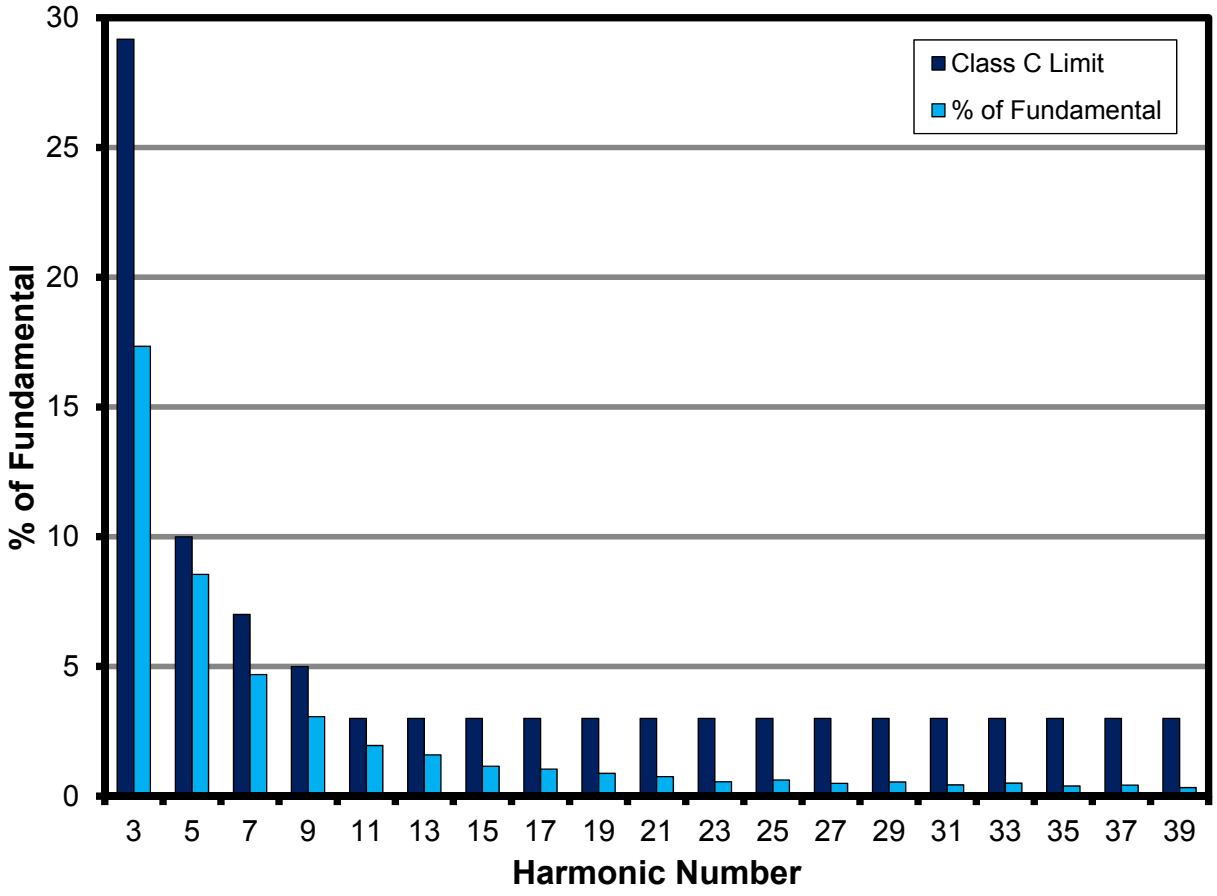

Figure 52 – Harmonic Data with 23 LED Load and 230 VAC 50 Hz Input CLASS C EN61000-3-2.

14.3.6 RM8 Test Data

14.3.6.1 25 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
180.03	168.71	29.82	0.982	18.11	73.70	358.30	26.75	26.41	89.70	3.07	2.4
200.06	151.40	29.66	0.979	18.9	73.60	357.70	26.65	26.33	89.85	3.01	2.2
220.09	136.70	29.37	0.976	19.7	73.50	355.00	26.40	26.09	89.90	2.97	1.4
230.15	130.05	29.16	0.974	20.14	73.40	353.00	26.21	25.91	89.90	2.95	0.9
240.11	123.97	28.94	0.972	20.61	73.30	350.80	26.01	25.71	89.89	2.93	0.2
265.14	110.74	28.35	0.966	21.65	73.10	344.00	25.44	25.15	89.73	2.91	-1.7

14.3.6.2 24 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
180.04	162.42	28.70	0.981	18.34	70.70	359.20	25.71	25.40	89.60	2.99	2.6
200.07	145.82	28.55	0.979	19.12	70.60	358.60	25.63	25.32	89.77	2.92	2.5
220.10	131.70	28.27	0.975	19.9	70.50	355.80	25.38	25.08	89.77	2.89	1.7
230.15	125.33	28.08	0.973	20.34	70.40	353.80	25.20	24.91	89.76	2.88	1.1
240.12	119.55	27.88	0.971	20.8	70.30	351.60	25.02	24.72	89.75	2.86	0.5
265.14	106.85	27.33	0.965	21.78	70.20	344.70	24.48	24.20	89.59	2.85	-1.5

14.3.6.3 23 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
180.05	155.98	27.54	0.981	18.62	67.50	360.00	24.64	24.30	89.47	2.90	2.9
200.08	140.13	27.42	0.978	19.39	67.50	359.30	24.56	24.25	89.58	2.86	2.7
220.10	126.68	27.17	0.975	20.2	67.40	356.60	24.35	24.03	89.62	2.82	1.9
230.16	120.66	27.01	0.972	20.55	67.30	354.60	24.19	23.86	89.57	2.82	1.3
240.12	115.14	26.82	0.970	20.94	67.30	352.50	24.02	23.72	89.55	2.80	0.7
265.15	103.02	26.31	0.963	21.85	67.20	345.60	23.51	23.22	89.35	2.80	-1.3

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14.3.6.4 230 VAC 50 Hz, 25 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.997	230	130.18	29.1900	0.9743	20.09
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	127.48			
	3	21.91	17.19%	29.2%	PASS
	5	10.55	8.28%	10.0%	PASS
	7	5.72	4.49%	7.0%	PASS
	9	3.72	2.92%	5.0%	PASS
	11	2.36	1.85%	3.0%	PASS
	13	1.91	1.50%	3.0%	PASS
	15	1.36	1.07%	3.0%	PASS
	17	1.16	0.91%	3.0%	PASS
	19	0.94	0.74%	3.0%	PASS
	21	0.93	0.73%	3.0%	PASS
	23	0.69	0.54%	3.0%	PASS
	25	0.78	0.61%	3.0%	PASS
	27	0.6	0.47%	3.0%	PASS
	29	0.68	0.53%	3.0%	PASS
	31	0.54	0.42%	3.0%	PASS
	33	0.6	0.47%	3.0%	PASS
	35	0.46	0.36%	3.0%	PASS
	37	0.5	0.39%	3.0%	PASS
	39	0.38	0.30%	3.0%	PASS

14.3.6.5 230 VAC 50 Hz, 24 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.998	230	125.23	28.05	0.9733	20.35
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	122.58			
	3	21.17	17.27%	29.2%	PASS
	5	10.33	8.43%	10.0%	PASS
	7	5.64	4.60%	7.0%	PASS
	9	3.68	3.00%	5.0%	PASS
	11	2.33	1.90%	3.0%	PASS
	13	1.9	1.55%	3.0%	PASS
	15	1.36	1.11%	3.0%	PASS
	17	1.29	1.05%	3.0%	PASS
	19	1.01	0.82%	3.0%	PASS
	21	0.93	0.76%	3.0%	PASS
	23	0.68	0.55%	3.0%	PASS
	25	0.75	0.61%	3.0%	PASS
	27	0.58	0.47%	3.0%	PASS
	29	0.68	0.55%	3.0%	PASS
	31	0.53	0.43%	3.0%	PASS
	33	0.59	0.48%	3.0%	PASS
	35	0.46	0.38%	3.0%	PASS
	37	0.5	0.41%	3.0%	PASS
	39	0.39	0.32%	3.0%	PASS

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14.3.6.6 230 VAC 50 Hz, 23 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P_{IN}(W)	PF	%THD
49.998	230	120.67	27.01	0.9725	20.5
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	118.09			
	3	20.47	17.33%	29.2%	PASS
	5	10.09	8.54%	10.0%	PASS
	7	5.54	4.69%	7.0%	PASS
	9	3.62	3.07%	5.0%	PASS
	11	2.31	1.96%	3.0%	PASS
	13	1.88	1.59%	3.0%	PASS
	15	1.36	1.15%	3.0%	PASS
	17	1.23	1.04%	3.0%	PASS
	19	1.04	0.88%	3.0%	PASS
	21	0.89	0.75%	3.0%	PASS
	23	0.66	0.56%	3.0%	PASS
	25	0.74	0.63%	3.0%	PASS
	27	0.58	0.49%	3.0%	PASS
	29	0.65	0.55%	3.0%	PASS
	31	0.51	0.43%	3.0%	PASS
	33	0.59	0.50%	3.0%	PASS
	35	0.46	0.39%	3.0%	PASS
	37	0.5	0.42%	3.0%	PASS
	39	0.39	0.33%	3.0%	PASS

15 Design Using EFD30 Inductor

15.1 EFD30 Inductor Specification

15.1.1 Electrical Diagram

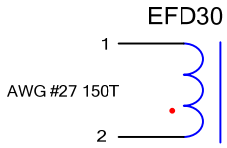

Figure 53 – Inductor Electrical Diagram.

15.1.2 Electrical Specifications

Inductance	Pins 1-2, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	2300 µH ±5%
Resonant Frequency	Pins 1-2, all other windings open	0.7 MHz (Min.)

15.1.3 Materials

Item	Description
[1]	Core: PC44 EFD30.
[2]	Bobbin: EFD30, Horizontal, 12 pins.
[3]	Magnet Wire: #27 AWG.
[4]	Tape: 3M 1298 Polyester Film, 20 mm wide.

15.1.4 Inductor Build Diagram

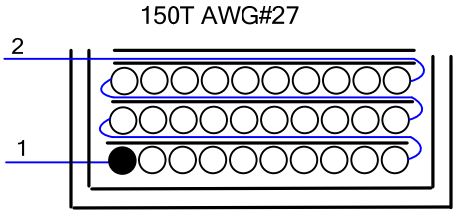

Figure 54 – EFD30 Inductor Build Diagram.

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15.2 EFD30 Inductor Design Spreadsheet

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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	72.00			V	Typical output voltage of LED string at full load
VO_MAX			79.20	V	Maximum expected LED string Voltage.
VO_MIN			64.80	V	Minimum expected LED string Voltage.
V_OVP			87.12	V	Over-voltage protection setpoint
IO	0.35				Typical full load LED current
PO			25.2	W	Output Power
n	0.88		0.88		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			80.3	uA	V pin current
RV			3.909	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	0.43		0.43		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			2314	uH	Primary Inductance
VOR	72.00		72	V	Reflected Output Voltage.
Expected IO (average)			0.36	A	Expected Average Output Current
KP_VACMAX			0.45		Expected ripple current ratio at VACMAX
TON_MIN			2.44	us	Minimum on time at maximum AC input voltage
PCLAMP			0.41	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EFD30**		**EFD30**		
Bobbin		*EFD30_BOBBIN*		*P/N:*	CSH-EFD30-1S-10P
AE			0.69	cm^2	Core Effective Cross Sectional Area
LE			6.8	cm	Core Effective Path Length
AL			1900	nH/T^2	Ungapped Core Effective Inductance
BW			20.1	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L			3		Number of Primary Layers
NS	151		151		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			0.23		Minimum duty cycle at peak of VACMIN
IAVG			0.20	A	Average Primary Current
IP			1.27	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.39	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			2314	uH	Primary Inductance
NP			150		Primary Winding Number of Turns
NB			43		Bias Winding Number of Turns
ALG			103	nH/T^2	Gapped Core Effective Inductance
BM			2839	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3435	Gauss	Peak Flux Density (BP<3700)
BAC			610	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1490		Relative Permeability of Ungapped Core
LG			0.80	mm	Gap Length (Lg > 0.1 mm)
BWE			60.3	mm	Effective Bobbin Width
OD			0.40	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.34	mm	Bare conductor diameter
AWG			28	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			161	Cmils	Bare conductor effective area in circular mils
CMA			411	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			1.26	A	Peak Secondary Current
ISRMS			0.66	A	Secondary RMS Current
IRIPPLE			0.56	A	Output Capacitor RMS Ripple Current
CMS			132	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			28	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.32	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.13	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			529	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			464	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			132	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			0.35	A	Measured Output Current at VAC1

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IO_VAC2			0.35	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			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			0.35	A	Measured Output Current at Vb1
IO2			0.35	A	Measured Output Current at Vb2
RFB1 (new)			113.3	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

15.3 EFD30 Performance Data

15.3.1 Efficiency

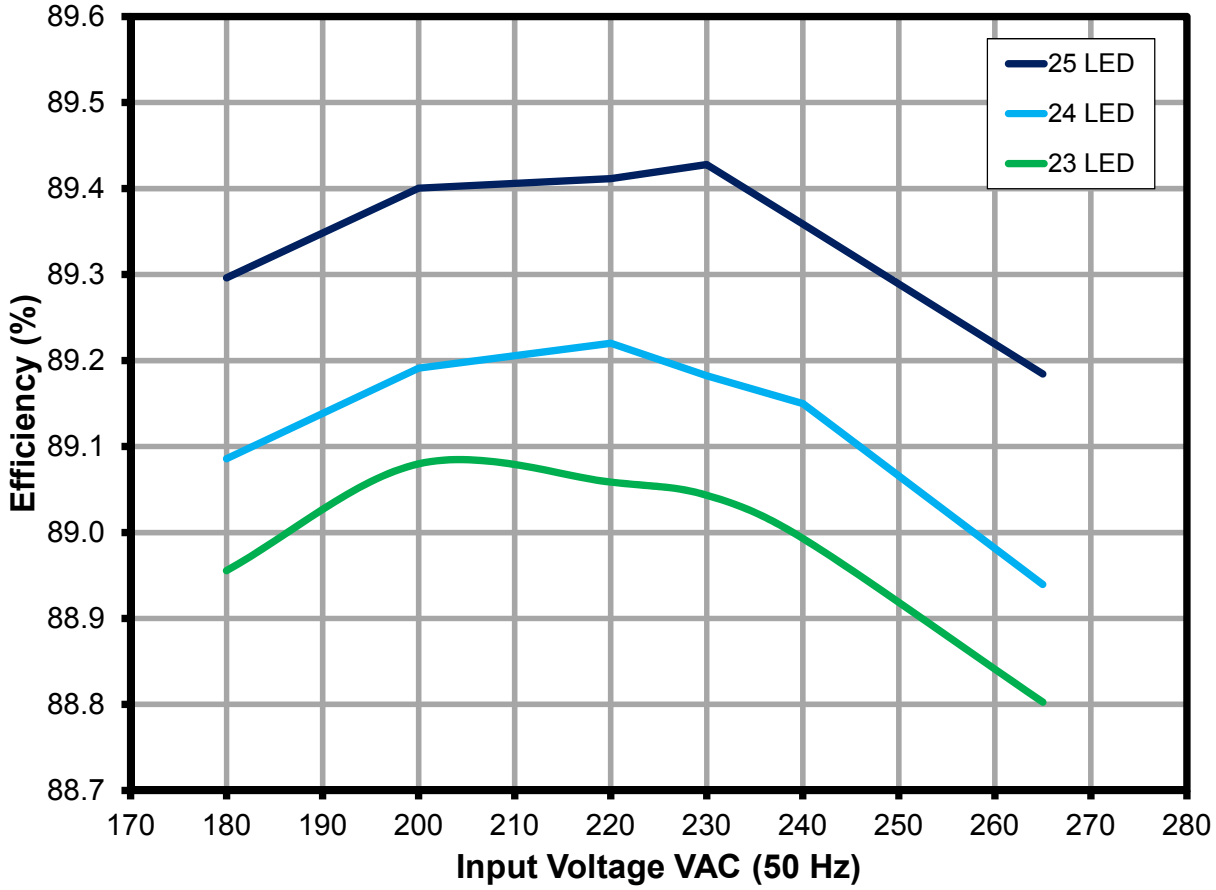

Figure 55 – Efficiency vs. Line and Load.

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15.3.2 Line and Load Regulation

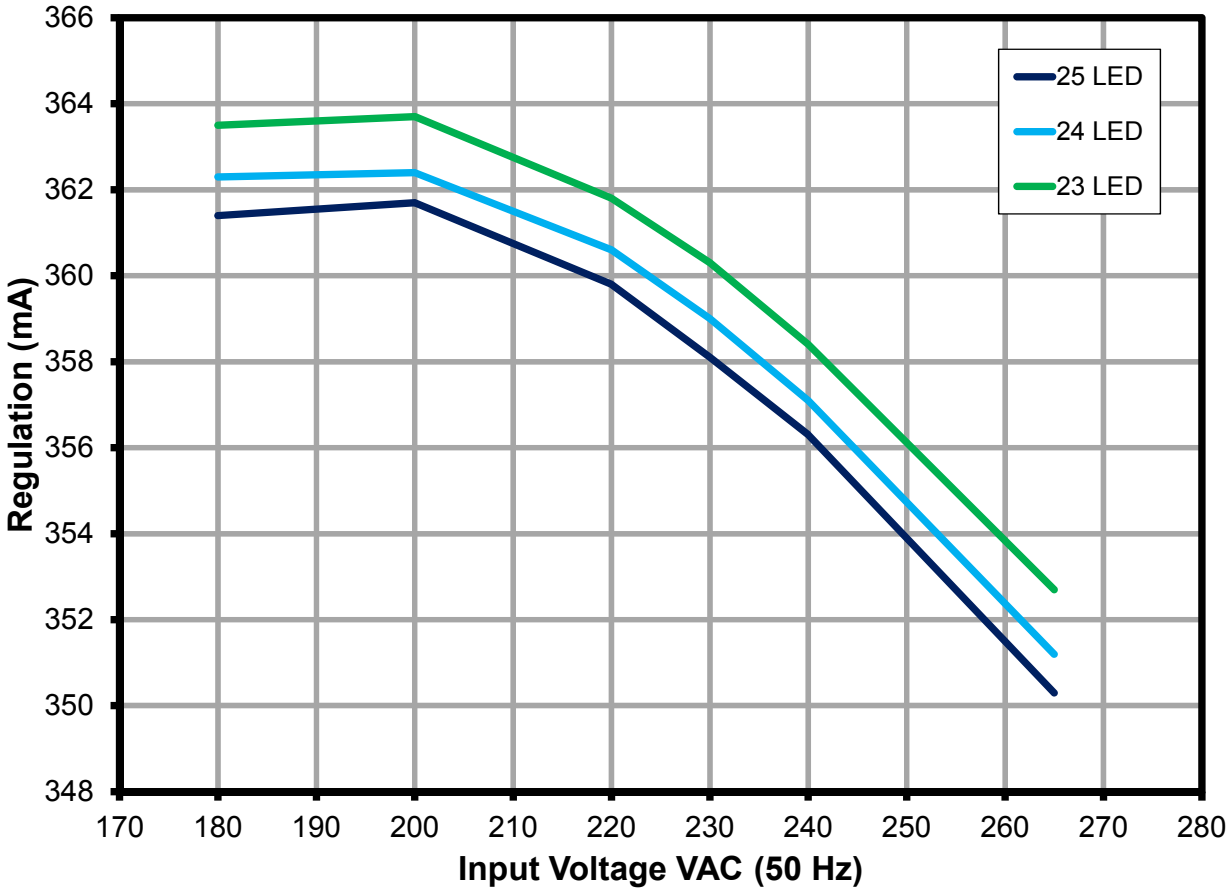

Figure 56 – Regulation vs. Line and Load.

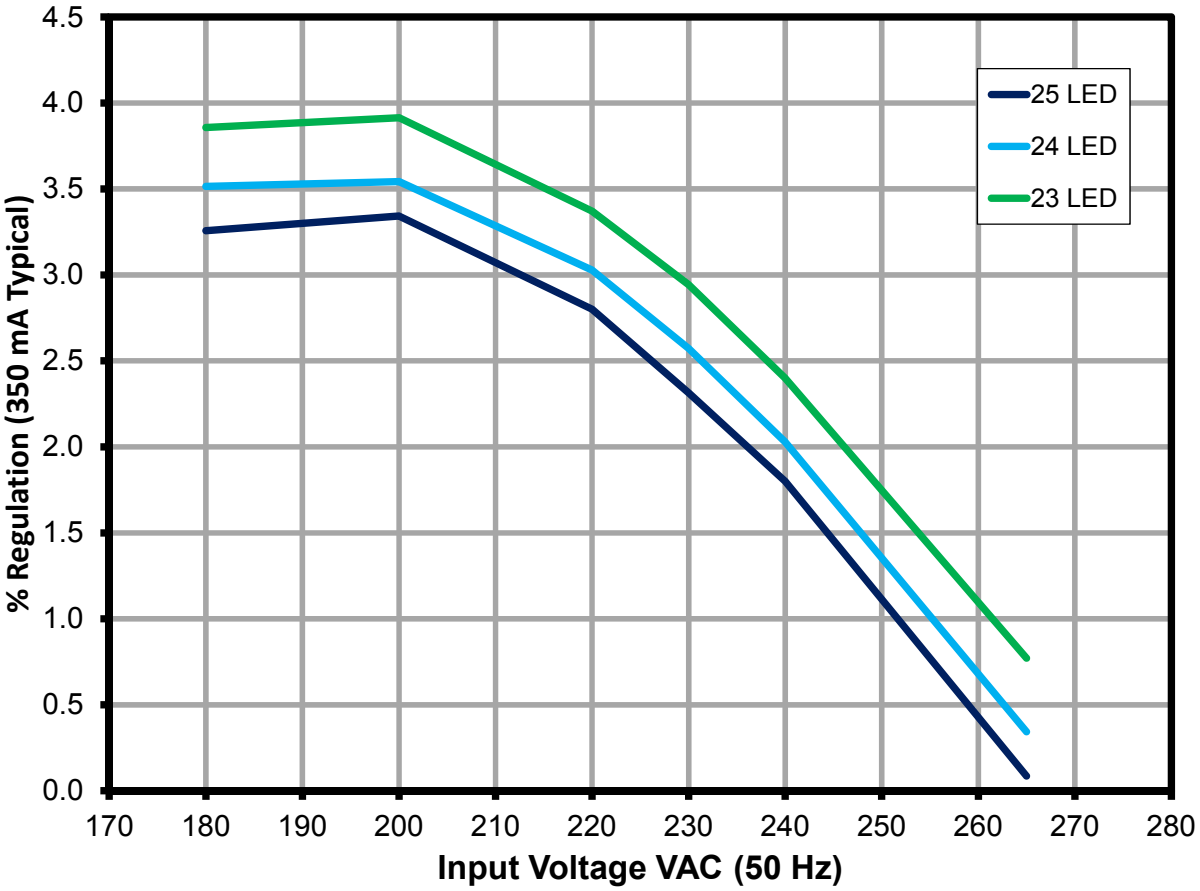

Figure 57 – Percent Regulation vs. Line and Load.

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15.3.3 Power Factor

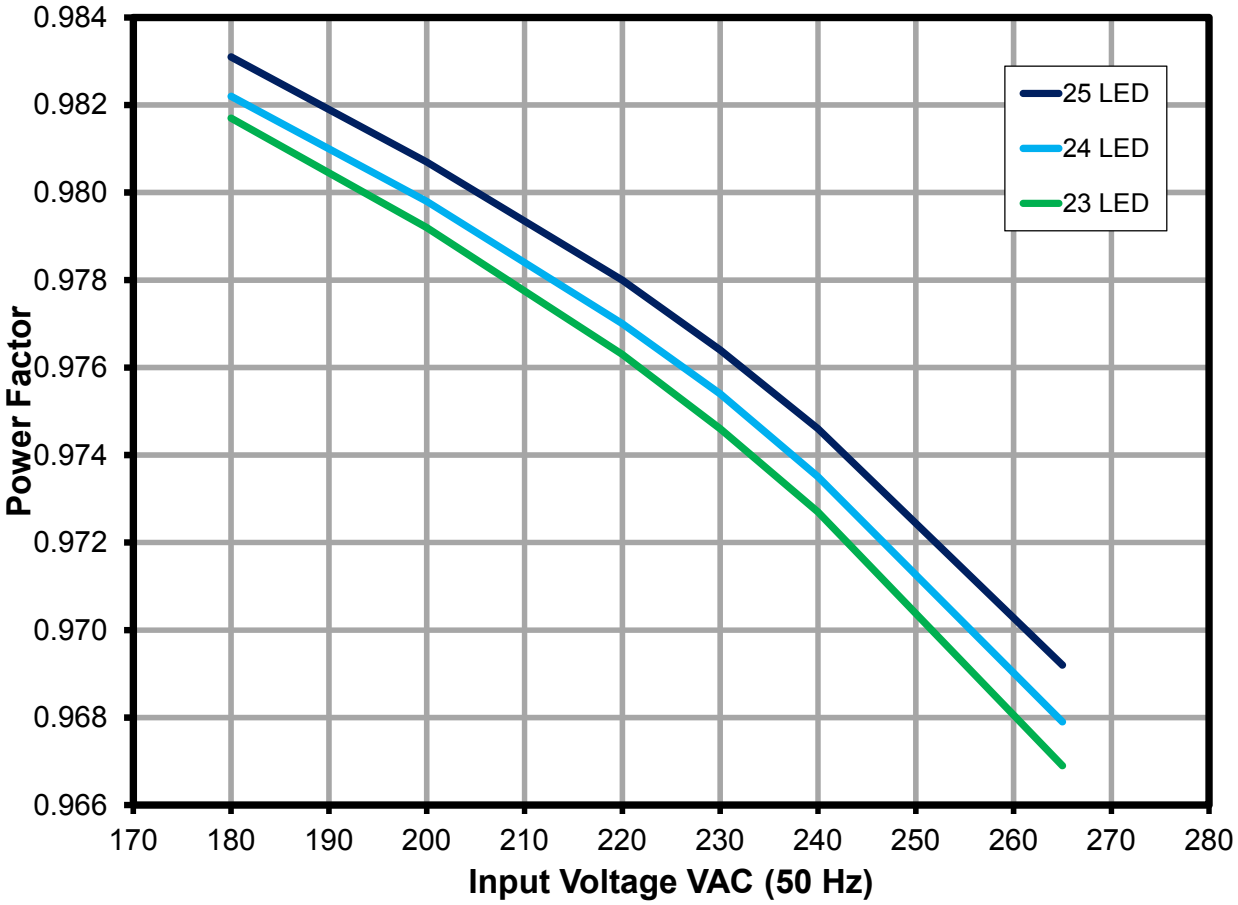

Figure 58 – Power Factor vs. Line and Load.

15.3.4 A-THD

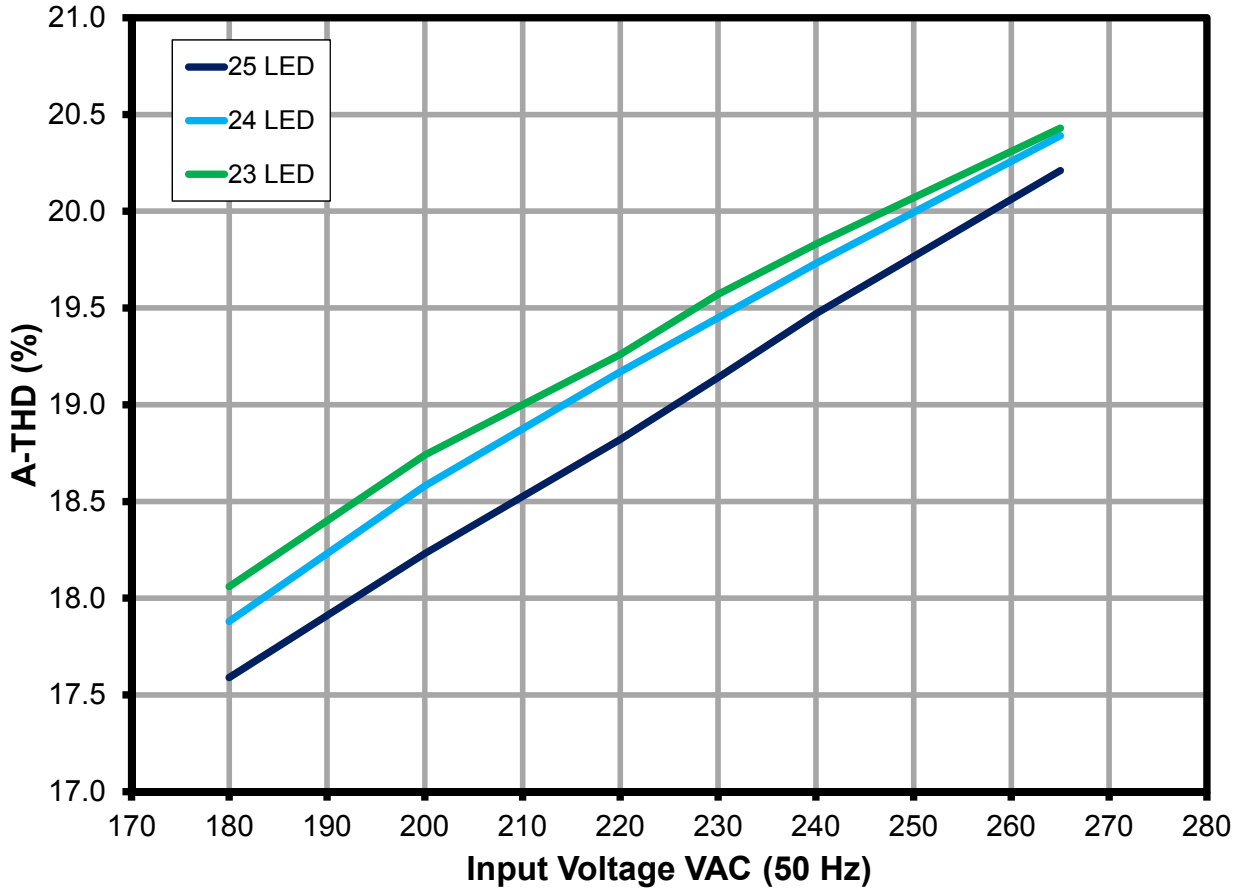

Figure 59 – A-THD vs. Line and Load.

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15.3.5 Harmonics

15.3.5.1 25 LED Load

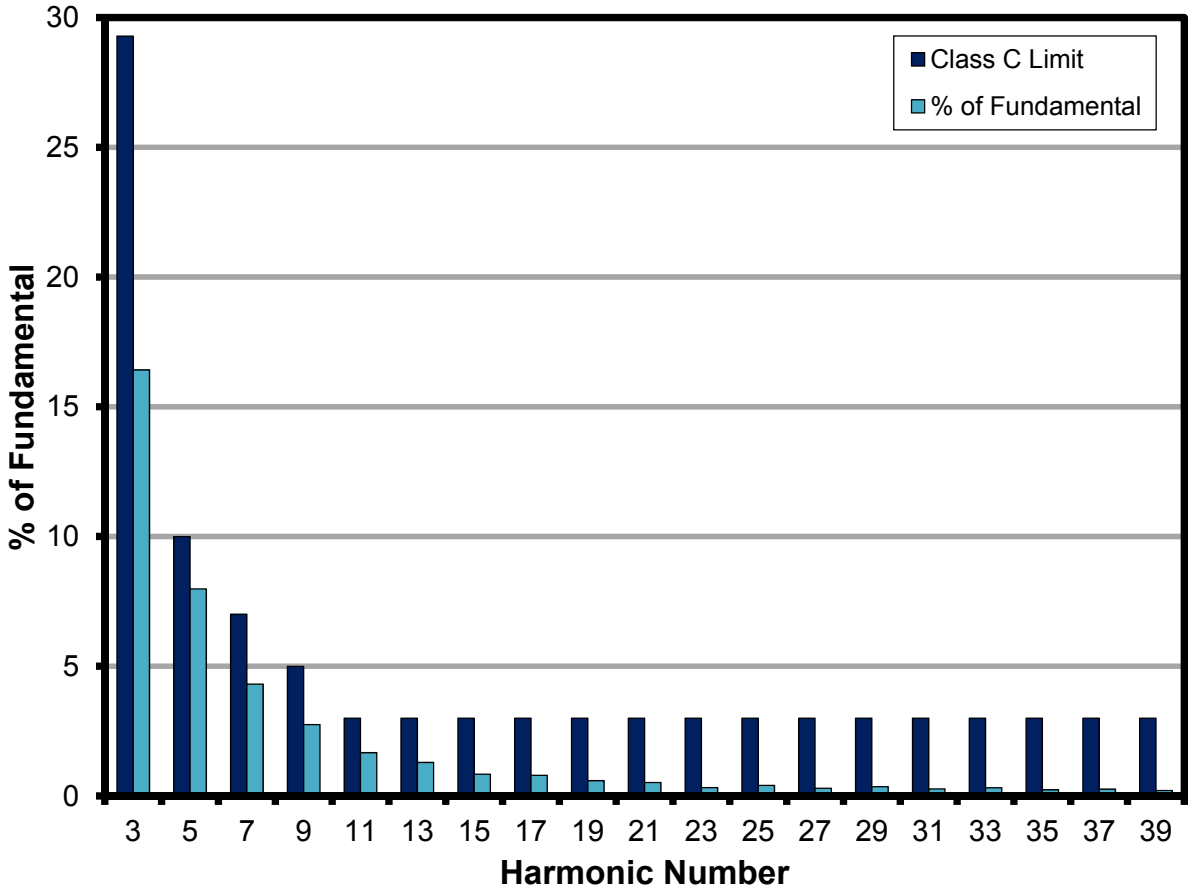

Figure 60 – Harmonic Data with 25 LED Load and 230 VAC 50 Hz Input.

15.3.5.2 24 LED load

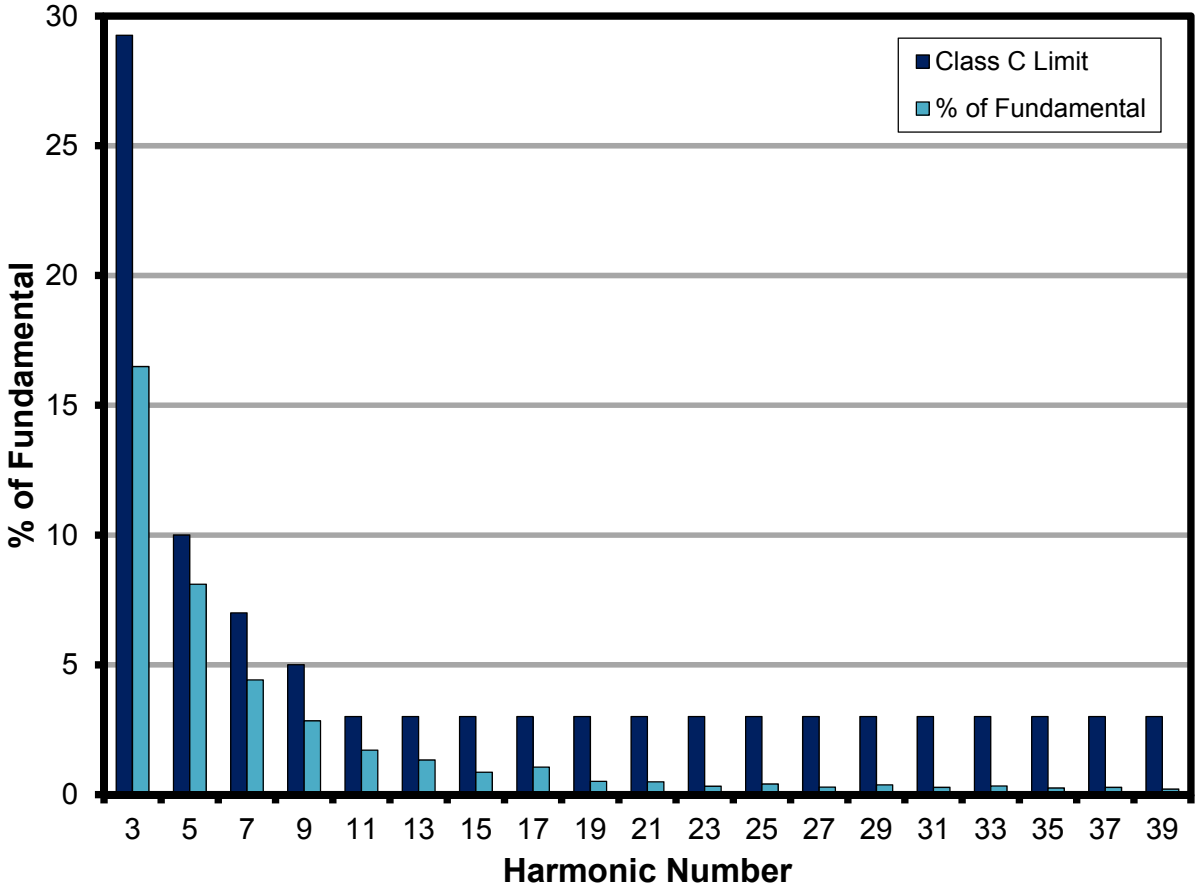

Figure 61 – Harmonic Data with 24 LED Load and 230 VAC 50 Hz Input.

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15.3.5.3 23 LED Load

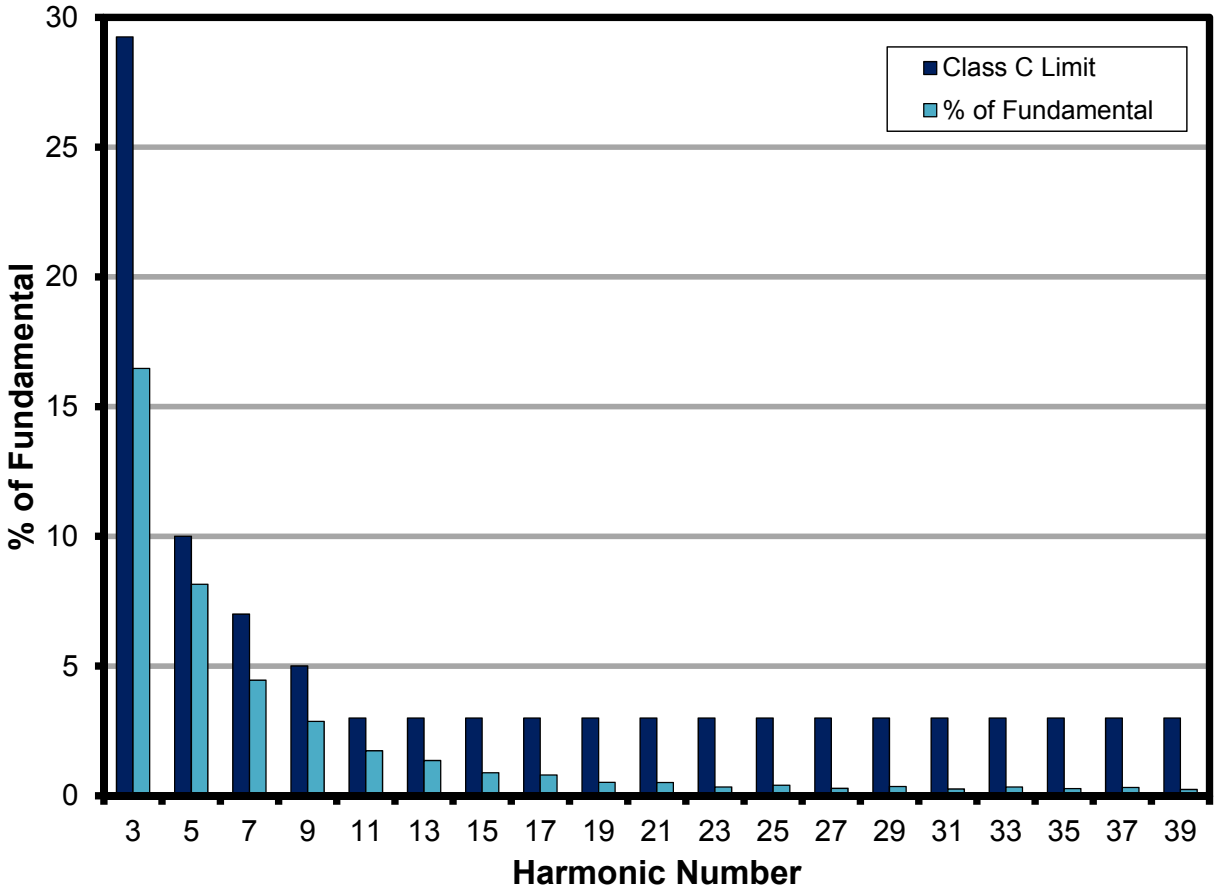

Figure 62 – Harmonic Data with 23 LED Load and 230 VAC 50 Hz Input.

15.3.6 EFD30 Test Data

15.3.6.1 25 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
180.01	172.94	30.61	0.983	17.59	74.70	361.40	27.33	27.00	89.30%	3.28	3.3
200.04	155.42	30.49	0.981	18.23	74.50	361.70	27.26	26.95	89.40%	3.23	3.3
220.07	140.46	30.23	0.978	18.82	74.20	359.80	27.03	26.70	89.41%	3.20	2.8
230.13	133.57	30.01	0.976	19.14	74.00	358.10	26.84	26.50	89.43%	3.17	2.3
240.10	127.31	29.79	0.975	19.47	73.80	356.30	26.62	26.29	89.36%	3.17	1.8
265.13	113.84	29.25	0.969	20.21	73.60	350.30	26.09	25.78	89.18%	3.16	0.1

15.3.6.2 24 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
180.04	164.66	29.12	0.982	17.88	70.70	362.30	25.94	25.61	89.09	3.18	3.5
200.07	148.19	29.05	0.980	18.58	70.60	362.40	25.91	25.59	89.19	3.14	3.5
220.09	134.16	28.85	0.977	19.17	70.50	360.60	25.74	25.42	89.22	3.11	3.0
230.15	127.82	28.69	0.975	19.45	70.40	359.00	25.59	25.27	89.18	3.10	2.6
240.11	122.03	28.53	0.974	19.73	70.30	357.10	25.43	25.10	89.15	3.10	2.0
265.14	109.35	28.06	0.968	20.39	70.20	351.20	24.96	24.65	88.94	3.10	0.3

15.3.6.3 23 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
180.04	158.24	27.97	0.982	18.06	67.50	363.50	24.88	24.54	88.96	3.09	3.9
200.07	142.56	27.93	0.979	18.74	67.50	363.70	24.88	24.55	89.08	3.05	3.9
220.09	129.17	27.76	0.976	19.26	67.40	361.80	24.72	24.39	89.06	3.04	3.4
230.15	123.16	27.63	0.975	19.57	67.40	360.30	24.60	24.28	89.04	3.03	2.9
240.12	117.63	27.47	0.973	19.83	67.30	358.40	24.45	24.12	88.99	3.02	2.4
265.14	105.56	27.06	0.967	20.43	67.30	352.70	24.03	23.74	88.80	3.03	0.8

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15.3.6.4 230 VAC 50 Hz, 25 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P (W)	PF	%THD
49.996	230	132.88	29.8500	0.9762	19.21
	nth Order	mA Content	% of Fundamental	Class C Limit	Remarks
	1	130.38			
	3	21.41	16.42%	29.3%	PASS
	5	10.41	7.98%	10.0%	PASS
	7	5.62	4.31%	7.0%	PASS
	9	3.59	2.75%	5.0%	PASS
	11	2.18	1.67%	3.0%	PASS
	13	1.68	1.29%	3.0%	PASS
	15	1.09	0.84%	3.0%	PASS
	17	1.04	0.80%	3.0%	PASS
	19	0.77	0.59%	3.0%	PASS
	21	0.68	0.52%	3.0%	PASS
	23	0.42	0.32%	3.0%	PASS
	25	0.53	0.41%	3.0%	PASS
	27	0.39	0.30%	3.0%	PASS
	29	0.47	0.36%	3.0%	PASS
	31	0.35	0.27%	3.0%	PASS
	33	0.41	0.31%	3.0%	PASS
	35	0.31	0.24%	3.0%	PASS
	37	0.34	0.26%	3.0%	PASS
	39	0.28	0.21%	3.0%	PASS

15.3.6.5 230 VAC 50 Hz, 24 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P (W)	PF	%THD
49.998	230.13	127.67	28.66	0.9754	19.4
	nth Order	mA Content	% of Fundamental	Class C Limit	Remarks
	1	125.22			
	3	20.65	16.49%	29.3%	PASS
	5	10.15	8.11%	10.0%	PASS
	7	5.53	4.42%	7.0%	PASS
	9	3.56	2.84%	5.0%	PASS
	11	2.14	1.71%	3.0%	PASS
	13	1.67	1.33%	3.0%	PASS
	15	1.07	0.85%	3.0%	PASS
	17	1.32	1.05%	3.0%	PASS
	19	0.63	0.50%	3.0%	PASS
	21	0.61	0.49%	3.0%	PASS
	23	0.4	0.32%	3.0%	PASS
	25	0.51	0.41%	3.0%	PASS
	27	0.36	0.29%	3.0%	PASS
	29	0.46	0.37%	3.0%	PASS
	31	0.34	0.27%	3.0%	PASS
	33	0.41	0.33%	3.0%	PASS
	35	0.31	0.25%	3.0%	PASS
	37	0.34	0.27%	3.0%	PASS
	39	0.26	0.21%	3.0%	PASS

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15.3.6.6 230 VAC 50 Hz, 24 LED Load Harmonics Data

F (Hz)	V_{IN} (V)	I (mA)	P (W)	PF	%THD
49.998	230.13	123.71	27.76	0.9749	19.34
	nth Order	**mA Content**	**% of Fundamental**	**Class C Limit**	**Remarks**
	1	121.3			
	3	19.98	16.47%	29.2%	PASS
	5	9.89	8.15%	10.0%	PASS
	7	5.4	4.45%	7.0%	PASS
	9	3.48	2.87%	5.0%	PASS
	11	2.11	1.74%	3.0%	PASS
	13	1.65	1.36%	3.0%	PASS
	15	1.08	0.89%	3.0%	PASS
	17	0.97	0.80%	3.0%	PASS
	19	0.63	0.52%	3.0%	PASS
	21	0.62	0.51%	3.0%	PASS
	23	0.41	0.34%	3.0%	PASS
	25	0.49	0.40%	3.0%	PASS
	27	0.35	0.29%	3.0%	PASS
	29	0.43	0.35%	3.0%	PASS
	31	0.32	0.26%	3.0%	PASS
	33	0.41	0.34%	3.0%	PASS
	35	0.34	0.28%	3.0%	PASS
	37	0.39	0.32%	3.0%	PASS
	39	0.3	0.25%	3.0%	PASS

16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
19-Jul-11	CA	1.0	First release	ME

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