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Title	***Reference Design Report for a 4.5 W Non-Dimmable, High Efficiency (>87%), Power Factor Corrected, Non-Isolated Buck LED Driver Using LYTSwitch™-1 LYT1402D***
Specification	90 VAC – 300 VAC Input; 48 V_{TYP}, 95 mA_{TYP} Output
Application	Candelabra (E12) Bulb
Author	Applications Engineering Department
Document Number	RDK-465
Date	August 4, 2016
Revision	1.0

Summary and Features

- Single-stage power factor corrected, PF >0.8 at 115 V and 230 V
- Accurate constant current regulation, ±5%
- Meets <30% flicker percent requirement
- Highly energy efficient, >87% at 115 V and 230 V
- Low cost and low component count for compact PCB solution
- Integrated auto-restart protection features
  - No-load / open-load output
  - Output short-circuit
  - Line surge or line overvoltage
- Thermal foldback for power reduction
- Over temperature shutdown with hysteretic automatic power recovery
- No damage during line brown-out or brown-in conditions
- Meets IEC 2.5 kV ring wave, 500 V differential surge
- Meets EN55015 conducted EMI

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PATENT INFORMATION

The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <http://www.powerint.com/ip.htm>.

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

1 Introduction

This engineering report describes a low component count, non-isolated, non-dimmable LED driver in buck topology, designed to drive a 48 V LED voltage string at 95 mA output current from an input voltage range of 90 VAC to 300 VAC. The LED driver utilizes the LYT1402D from the LYTSwitch-1 family of devices.

LYTSwitch-1 is a SO-8 package LED driver controller IC designed for non-isolated buck topology applications. The LYTSwitch-1 provides high efficiency, high power factor and accurate LED current regulation. LYTSwitch-1 incorporates a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode control engine for tight current regulation, high power factor and proprietary MOSFET utilization for high efficiency. The controller also integrates protection features such as input and output overvoltage protection, thermal fold-back, over temperature shutdown, output short-circuit and overcurrent protection.

RDK-465 offers a compact size solution for 4.5 W LED drivers ideal for bulb applications. The key design goals were high efficiency, accurate constant current regulation and low component count.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet, and performance data.

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Figure 1 – Populated Circuit Board.

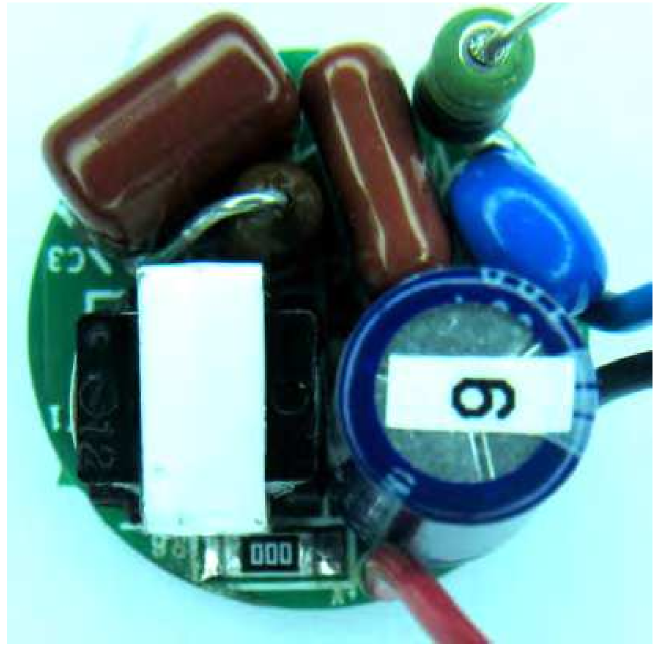

Figure 2 – Populated Circuit Board, Top View.

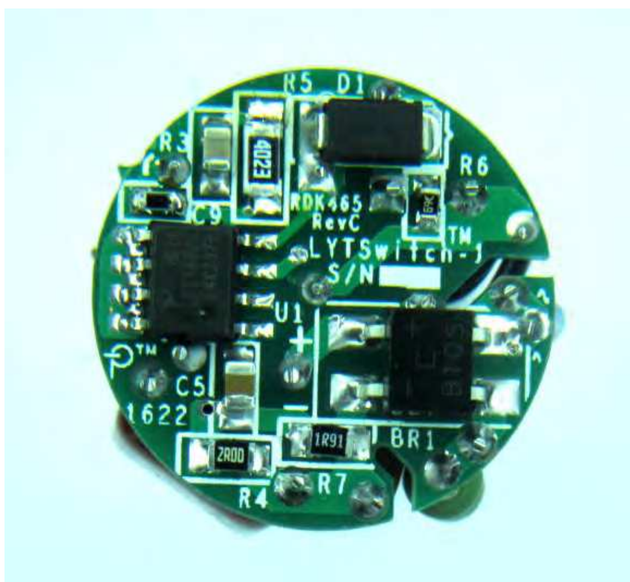

Figure 3 – Populated Circuit Board, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90	230	300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		48		V	
Output Current	I_{OUT}		95		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		4.5		W	
Efficiency						
Full Load	η		87		%	230 V / 50 Hz at 25 ºC. 115 V / 60 Hz at 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			2.5		kV	
Differential Mode (L1-L2)			0.5		kV	
Power Factor			0.8			Measured at 115 VAC / 60 Hz. Measured at 230 VAC / 50 Hz.
Ambient Temperature	T_{AMB}		85		ºC	Free Convection, Sea Level.

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3 Schematic

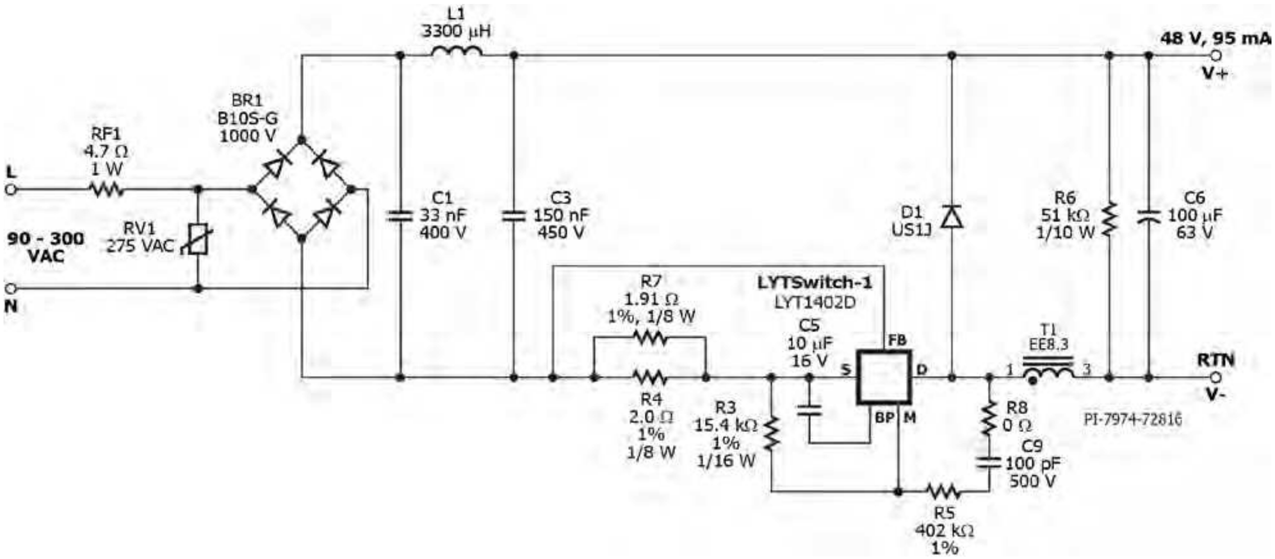

Figure 4 – Schematic.

4 Circuit Description

The LYTSwitch-1 device (U1-LYT1402D) combines a high-voltage power MOSFET and variable frequency / variable on-time, critical conduction mode controller in a single SO-8 package. LYT1402D is configured to drive a 48 V output non-isolated buck LED driver with 95 mA constant current output. The LYT1402D device was selected from the power table based on maximum output power in the datasheet.

4.1 *Input Stage*

The input fuse RF1 provides safety protection. Varistor RV1 acts as a voltage clamp that limits the voltage spike on the primary during line transient voltage surge events. The AC input voltage is full wave rectified by BR1 to achieve good power factor and low THD. For higher surge requirement such as >500 V, C1 and L1 can be placed before the bridge rectifier BR1, but a safety X-capacitor is required for C1.

4.2 *EMI Filter*

Inductor L1 serves as differential choke. Inductor L1, C1 and C3 capacitors form an EMI pi filter which works to filter differential and common mode noise. LYTSwitch-1's variable frequency/on-time states and critical conduction mode control engine limit RFI emission to significantly low levels which enables design to use simple EMI pi filter even for high power bulb and tube applications.

4.3 *LYTSwitch-1 Control Circuit*

The LED driver circuit topology is a low side buck configuration, where the MOSFET of U1 and the inductor L1 are connected to the ground rail. When the MOSFET switches ON, the current will begin to increase and will be flowing through the load via the inductor. During this time the inductor stores energy in the form of magnetic field. When the MOSFET switches OFF, the energy stored in the magnetic field around the inductor is released back into the circuit. During this time current will be flowing through the load via the inductor and the flywheel diode D1.

The output capacitor C6 provides output voltage ripple filtering to minimize the output ripple current. To avoid long ghosting effect of light output after power off, resistor R6 preload discharges the output capacitor voltage below the LED voltage.

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1, which provides power to the IC during the switch on time. The IC internal regulator draws power from high voltage DRAIN (D) pin and charges the bypass capacitor C5 during the power switch off time. The typical BP pin voltage is 5.22 V. To keep the IC operating normally especially during the dead zone, where $V_{IN} < V_{OUT}$, the value of capacitor should be large enough to keep the BP voltage above the $V_{BP\ (RESET)}$ reset value of 4.5 V. Recommended minimum value for the BP capacitor is 4.7 μF.

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Constant output current regulation is achieved through the FEEDBACK (FB) pin which senses the drain current through current sense resistors (R_{FB}) R4 and R7. The voltage across the current sense resistors is then compared to a fixed internal reference voltage (V_{FB_REF}) of absolute value 280 mV typical.

$$R_{FB} = V_{FB\_REF} / k \times I_{OUT}$$

Where: k is the ratio between I_{PK} and $I_{OUT;}$ such that k = 3 for LYT14xx, and k = 3.6 for LYT16xx)

In some cases, trimming R_{FB} is necessary to center I_{OUT} at the nominal input voltage.

The MULTIFUNCTION (M) pin monitors the line for any line overvoltage event. When the internal MOSFET is in on-state, the M pin is shorted internally to SOURCE (S) pin in order to detect the rectified input line voltage. Input line OVP can be computed from the voltage across the inductor when the MOSFET switches ON, i.e. (V_{IN}-V_{OUT}) and the current flowing out of the M pin via resistor R5. Thus line overvoltage detection is calculated as; where R5 is assumed to be 402 kΩ ±1%.

$$V_{LINE\_OVP} = I_{IOV} \times R5 + V_{OUT}$$

Once the measured current exceeds the input overvoltage threshold (I_{IOV}) of 1 mA typical, the IC will inhibit switching instantaneously and initiate auto-restart to protect the internal MOSFET of the IC.

The M pin also monitors the output for any overvoltage and undervoltage event. When the internal MOSFET is in off-state, the output voltage is monitored through a coupling capacitor (C9) and divider resistors R5 and R3. When an output open-load condition occurs, the voltage at the M pin will rise abruptly and when it exceeds the threshold of 2.4 V, the IC will inhibit switching instantaneously and initiate auto-restart to limit the output voltage from further rising. The overvoltage cut-off is typically 120% of the output voltage, which is equivalent to 2 V at the M pin ($V_{OUT\_OVP} = V_{OUT} \times 2.4\ V / 2\ V$). Resistors R5 and R8 are set to a total fixed value of 402 kΩ ±1% and R3 will determine the output overvoltage limit. Any output short circuit at the output will be detected once the M pin voltage falls below the undervoltage threshold (V_{OUV}) of 1 V typical, then the IC will inhibit switching instantaneously and initiate auto-restart to limit the average input less than 1 W, preventing any components from overheating.

Resistor R3 can be calculated as follows:

$R3 = 2\ V \times R5 / (V_{OUT} - 2\ V)$; this is applicable only to low-side configuration buck.

Another function of the M pin is for zero current detection (ZCD). This is to ensure operation in critical conduction mode. The inductor demagnetization is sensed when the voltage across the inductor begins to collapse towards zero as flywheel diode (D1) conduction expires.

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5 PCB Layout

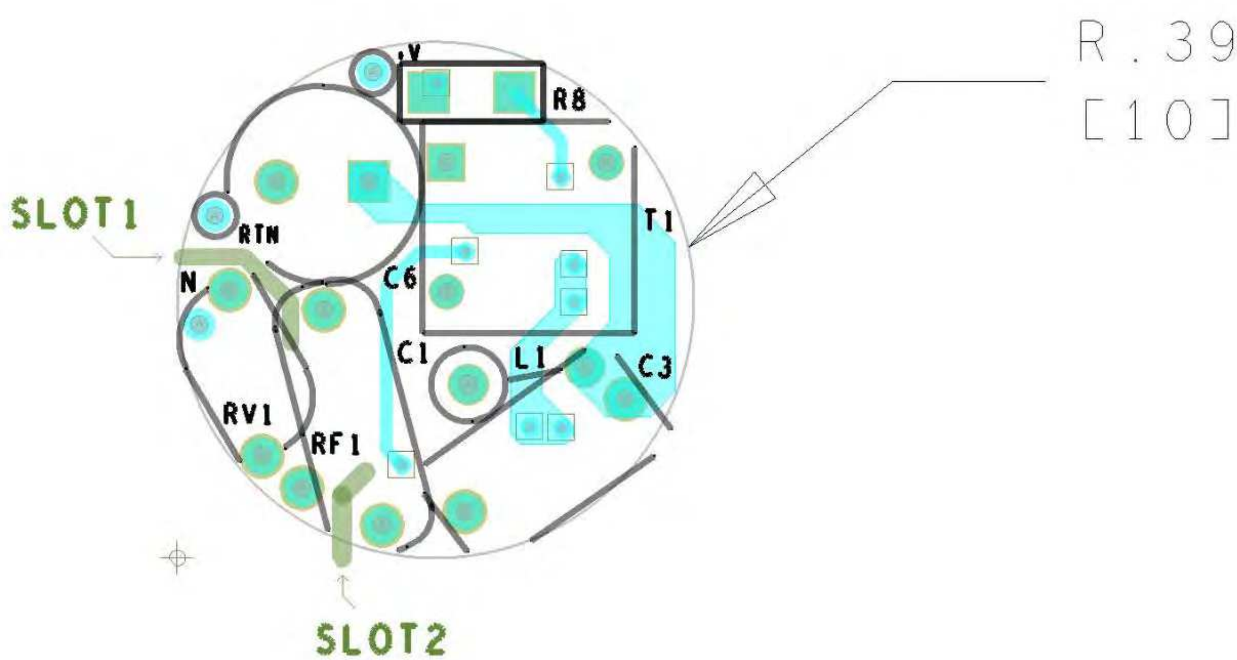

Figure 5 – Top Side.

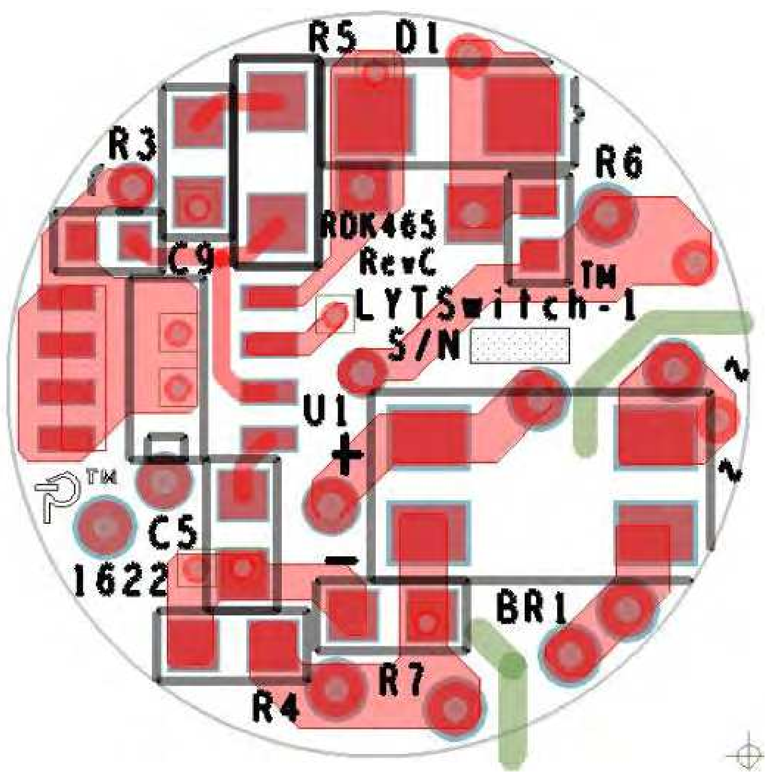

Figure 6 – Bottom Side.

6 Bill of Materials

Item	Ref Des	Qty	Description	Mfg Part Number	Manufacturer
1	BR1	1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	C1	1	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
3	C3	1	150 nF, 450 V, 10%, Polypropylene Metalized	C222S154K30	Faratronic
4	C5	1	10 μF, ±10%, 16 V, X7R, Ceramic Capacitor, -55°C ~ 125°C, Surface Mount, MLCC 0805 (2012 Metric), 0.079" L x 0.049" W (2.00mm x 1.25mm)	CL21B106KOQNNNG	Samsung
5	C6	1	100 μF, 63, Electrolytic, Low ESR, 270 mΩ, (8 x 15)	ELXZ630ELL101MH15D	Nippon Chemi-Con
6	C9	1	100 pF, 500 V, Ceramic, NPO, 0805	501R15N101KV4T	Johanson Dielectrics
7	D1	1	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
8	L1	1	3300 μH, 62 mA, 59.5 Ω, Axial Ferrite Inductor	B78108S1335J	Epcos
9	R3	1	RES, 15.4 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1542V	Panasonic
10	R4	1	RES, 2.00 Ω, 1%, 1/8 W, Thick Film, 0805	RC0805FR-072RL	Yageo
11	R5	1	RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4023V	Panasonic
12	R6	1	RES, 51 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ513V	Panasonic
13	R7	1	RES, 1.91 Ω, 1%, 1/8 W, Thick Film, 0805	RC0805FR-071R91L	Yageo
14	R8	1	RES, 0 R, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
15	RF1	1	RES, 4.7 Ω, 1 W, Fusible/Flame Proof Wire Wound	FKN1WSJR-52-4R7	Yago
16	RV1	1	275 V, 8.6 J, 5 mm, RADIAL	S05K275	Epcos
17	T1	1	Bobbin, EE8.3, Vertical, 6 pins (8.2 mm W x 8.2 mm L x 6.9 mm H)	EE-0802	Zhenhui
18	U1	1	LYTSwitch-1, Wide Range, 4W, 25V-50V, SO-8	LYT1402D	Power Integrations

Miscellaneous

19	WIRE24A WG_INS1	1	Wire, UL1007, #24 AWG, Wht, PVC, 40 mm	1007-24/7-9	Anixter
20	WIRE24A WG_INS2	1	Wire, UL1007, #24 AWG, Red, PVC, 40 mm	1007-24/7-2	Anixter
21	WIRE24A WG_INS3	1	Wire, UL1007, #24 AWG, Blk, PVC, 40 mm	1007-24/7-0	Anixter

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7 Inductor Specification

7.1 *Electrical Diagram*

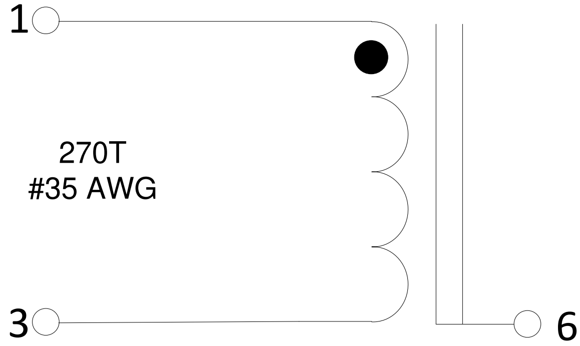

Figure 7 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V_{PK-PK}, 100 kHz switching frequency, between pin 1 and pin 3, with all other windings open.	1500 μH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE8.3 Note: Use EE8.3D P4 Material from ACME for high ambient temperature application.
[2]	Bobbin, EE8.3, Vertical, 6 pins
[3]	Magnet Wire: #35 AWG.
[4]	Transformer Tape: 4.5 mm.
[5]	Tin Wire (Bare).
[6]	Transformer Tape: 3.5 mm.

7.4 *Inductor Build Diagram*

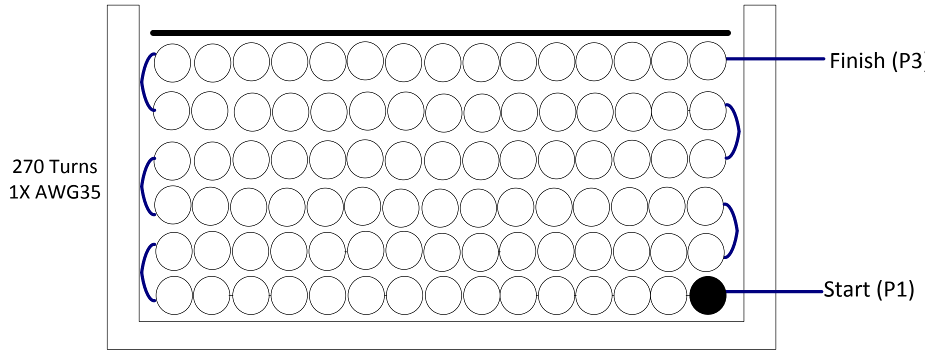

Figure 8 – Transformer Build Diagram.

7.5 *Inductor Construction*

Winding Directions	Bobbin is oriented on winder jig such that terminal pins are in the right side. The winding direction is clockwise.
Winding 1	Use wire item [3], start at pin 1 and wind 270 turns in 8 layers, then finish the winding on pin 3.
Insulation	Add 2 layers of tape, item [4], for insulation.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 1500 μH.
Assemble Core	Assemble the 2 cores on the bobbin.
Core Wire	Use wire item [5], two turns on the core, terminate on pin 6 and wrap with 2 layers of tape, Item (6).
Pins	Pull out Terminal pin no. 2, 4 and 5
Finish	Dip the transformer assembly in varnish.

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7.6 *Winding Illustrations*

<table>
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Winding Directions

Bobbin is oriented on winder jig such that terminal pin 1-6 is in the Left side. The winding direction is clockwise as shown in the figure.

Winding 1

Use wire item [3], start at pin 1 and wind 270 turns, then finish the winding on pin 3.

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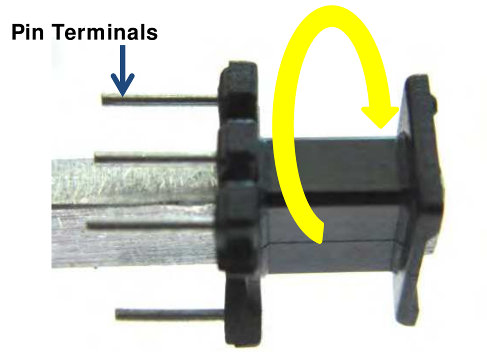

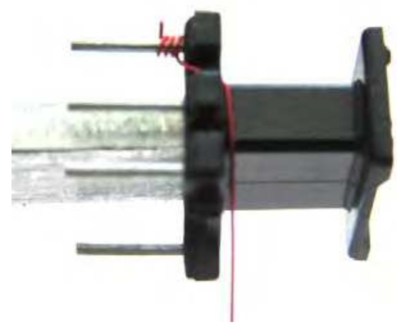

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Insulation

Add 2 layers of tape, item [4], for insulation.

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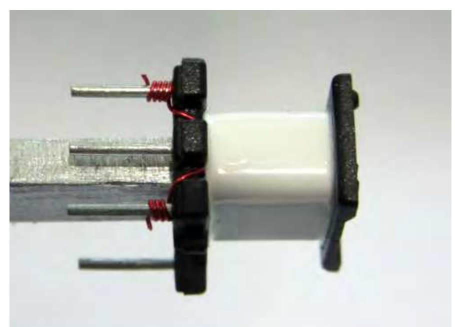

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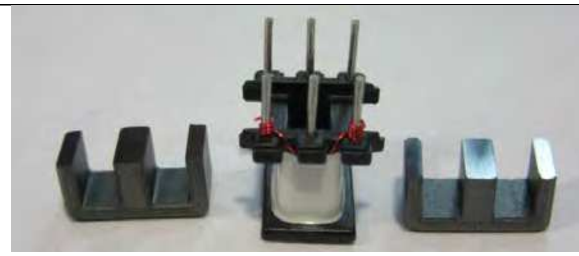
Core Grinding

Grind the center leg of one core until it meets the nominal inductance of 1500 μH.



Core Assembly

Assemble the 2 cores on the bobbin. Use wire item [5], 2 turns around the cores as shown. Terminate the wire on pin6.

Wrap the 2 cores with polyester tape Item [6]. See figure on the right side.

Finish

Dip the transformer assembly in 2:1 thinner and Varnish solution.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch1_ Buck_031816; Rev.0.1; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-1 Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMIN	90.00		90.00	Volts AC	Minimum AC line voltage
VACTYP	230.00		230.00	Volts AC	Typical AC line voltage
VACMAX	300.00		300.00	Volts AC	Maximum AC line voltage
fL	50.00		50.00	Hz	AC mains frequency
VO	48.00		48.00	Volts DC	Worst case normal operating output voltage
IO	0.095		0.095	Amperes	Average output current specification
EFFICIENCY	0.87		0.87		Efficiency estimate
PO			4.56	Watts	Continuous output power
VD			0.70	Volts DC	Output diode forward voltage drop
OPTIMIZATION PARAMETER	BOM		BOM		Parameter to be optimized
ENTER LYTSWITCH-1 VARIABLES					
DEVICE BREAKDOWN VOLTAGE	725		725	Volts DC	Choose between 650V and 725V
GENERIC DEVICE	Auto		LYT1XX2D		Generic LYTSwitch-1 device based on power
DEVICE CODE			LYT1402D		Actual LYTSwitch-1 device code
ILIMITMIN			0.59	Amperes	Minimum Current Limit
ILIMITTYP			0.64	Amperes	Typical Current Limit
ILIMITMAX			0.68	Amperes	Maximum Current Limit
TON			1.83	us	On-time during the fixed on-time region at VACTYP
FSW			95.71	kHz	Maximum switching frequency in the fixed current limit region at VACTYP
DMAX			0.52		Maximum duty cycle possible in the fixed on-time region
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
CORE	EE8.3		EE8.3		Enter Transformer Core
CUSTOM CORE NAME					If custom core is used - Enter part number here
AE			7.00	mm^2	Core effective cross cectional area
LE			19.20	mm	Core effective path length
AL			610.00	nH/turn^2	Core ungapped effective inductance
AW			14.00	mm^2	Window Area of the bobbin
BW			4.80	mm	Bobbin physical winding width
MARGIN			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
LAYERS			8		Number of Layers
INDUCTOR DESIGN PARAMETERS					
LP_MIN_ABSOLUTE			1294	uH	Absolute minimum design inductance
LP_TYP	1500		1500	uH	Typical design inductance
LP_TOLERANCE	5		5	%	Tolerance of the design inductance
LP_MAX			2195	uH	Absolue maximum design inductance
TURNS	270		270	Turns	Number of inductor turns
ALG			20.58	nH/turn^2	Inductance per turns squared
BMAX			3700	Gauss	Operating maximum flux density in the fixed peak current region
BMAX_ACTUAL			2850	Gauss	Actual saturation flux density in the fixed peak current region
BAC			1850	Gauss	AC flux density in the fixed peak current region
LG			0.413	mm	Core air gap
BWE			38.40	mm	Effective bobbin width
OD			0.142	mm	Outer diameter of the wire with insulation
INS			0.033	mm	Wire insulation
DIA			0.109	mm	Outer diameter of the wire without insulation
AWG			35		AWG of the bare wire.

CM			32	Cmils	Bare wire circular mils
CMA			256.6	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY			7.8	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR			39.01%		Decrease the number of layers to ensure that the wire fits in the bobbin.
CURRENT WAVEFORM SHAPE PARAMETERS					
IAVERAGE_INDUCTOR			0.093	Amperes	Average inductor current at VACTYP obtained from half-line cycle emulation
IPEAK_MOSFET			0.285	Amperes	MOSFET peak current at VACTYP when operating in the current limit region
IRMS_MOSFET			0.053	Amperes	MOSFET RMS current at VACTYP obtained from half-line cycle emulation
IRMS_DIODE			0.113	Amperes	Diode RMS current at VACTYP obtained from half-line cycle emulation
IRMS_INDUCTOR			0.125	Amperes	Inductor RMS current at VACTYP obtained from half-line cycle emulation
LYTSWITCH EXTERNAL COMPONENTS					
FB Pin Resistor					
RFB (Non standard value)			1.053	Ohms	Non standard value of the feedback pin sense resistor
RFB (Standard 1% Value)			1.050	Ohms	Standard 1% value of the feedback pin sense resistor
M Pin Resistor					
RUPPER (Standard 1% Value)			400.00	kOhms	Standard 1% value of the upper (fixed) resistor on the M-pin divider network
RLOWER (Non standard value)			17.39	kOhms	Non standard value of the lower resistor on the M-pin divider network
RLOWER (Standard 1% Value)	15.40		15.40	kOhms	Standard 1% value of the lower resistor on the M-pin divider network
LOAD OVERVOLTAGE THRESHOLD			64.738	Volts DC	Load overvoltage threshold
LINE OVERVOLTAGE THRESHOLD			448.00	Volts DC	Line overvoltage threshold
VOLTAGE STRESS PARAMETERS					
VDRAIN			424.26	Volts DC	Estimated worst case drain voltage
PIVD			424.26	Volts DC	Output Rectifier Maximum Peak Inverse Voltage

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9 Performance Data

All measurements were performed at room temperature using LED load string. 1 minute soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

9.1 *Efficiency*

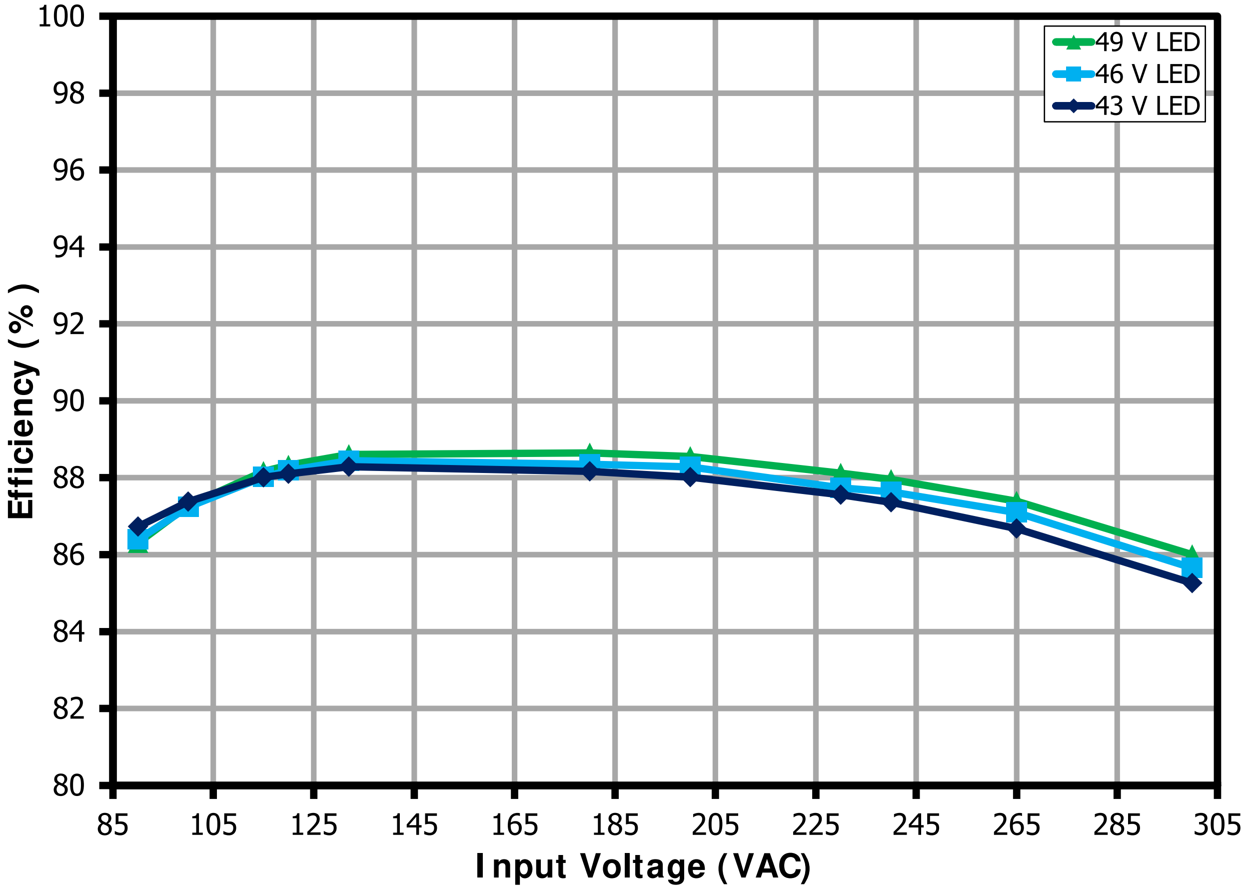

Figure 9 – Efficiency vs. Line and LED Load.

9.2 *Line Regulation*

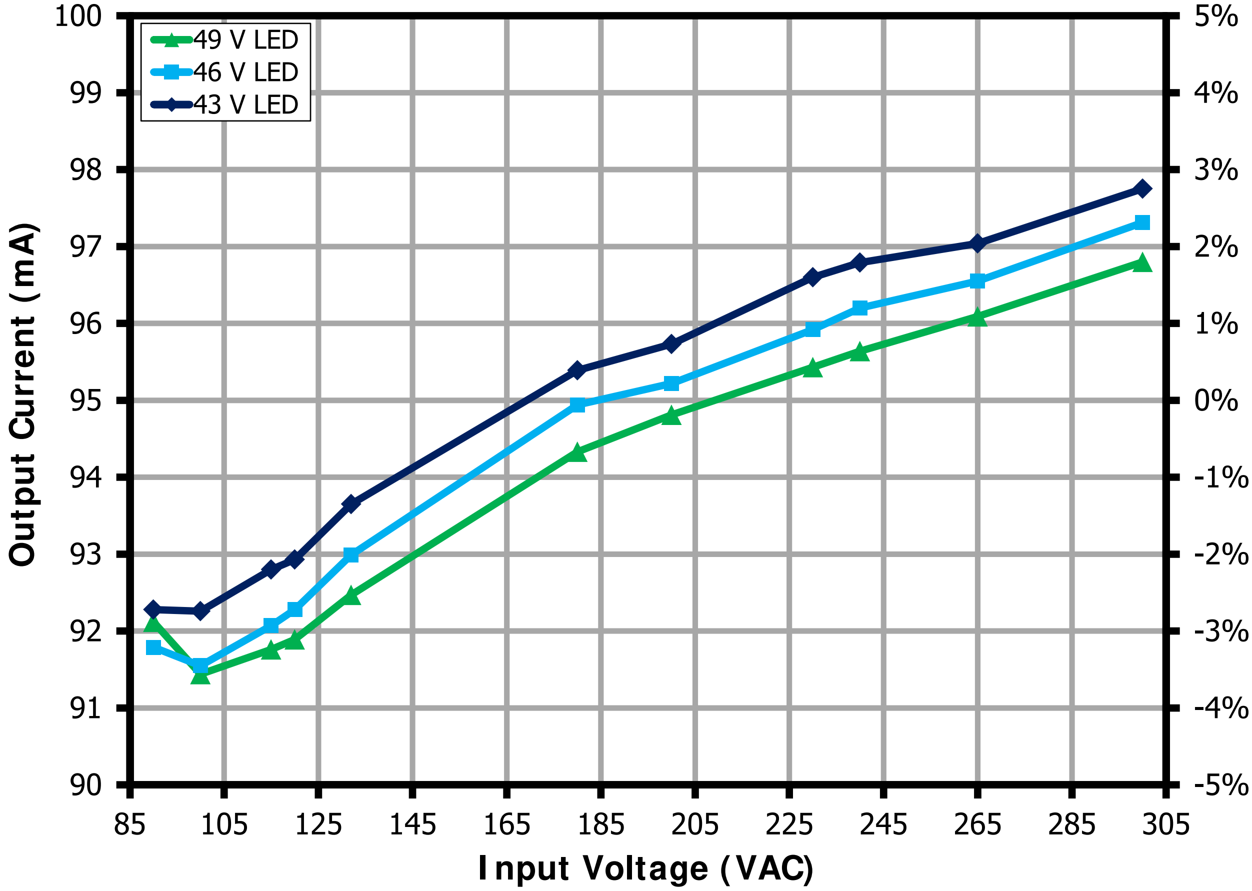

Figure 10 – Regulation vs. Line and LED Load.

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9.3 *Power Factor*

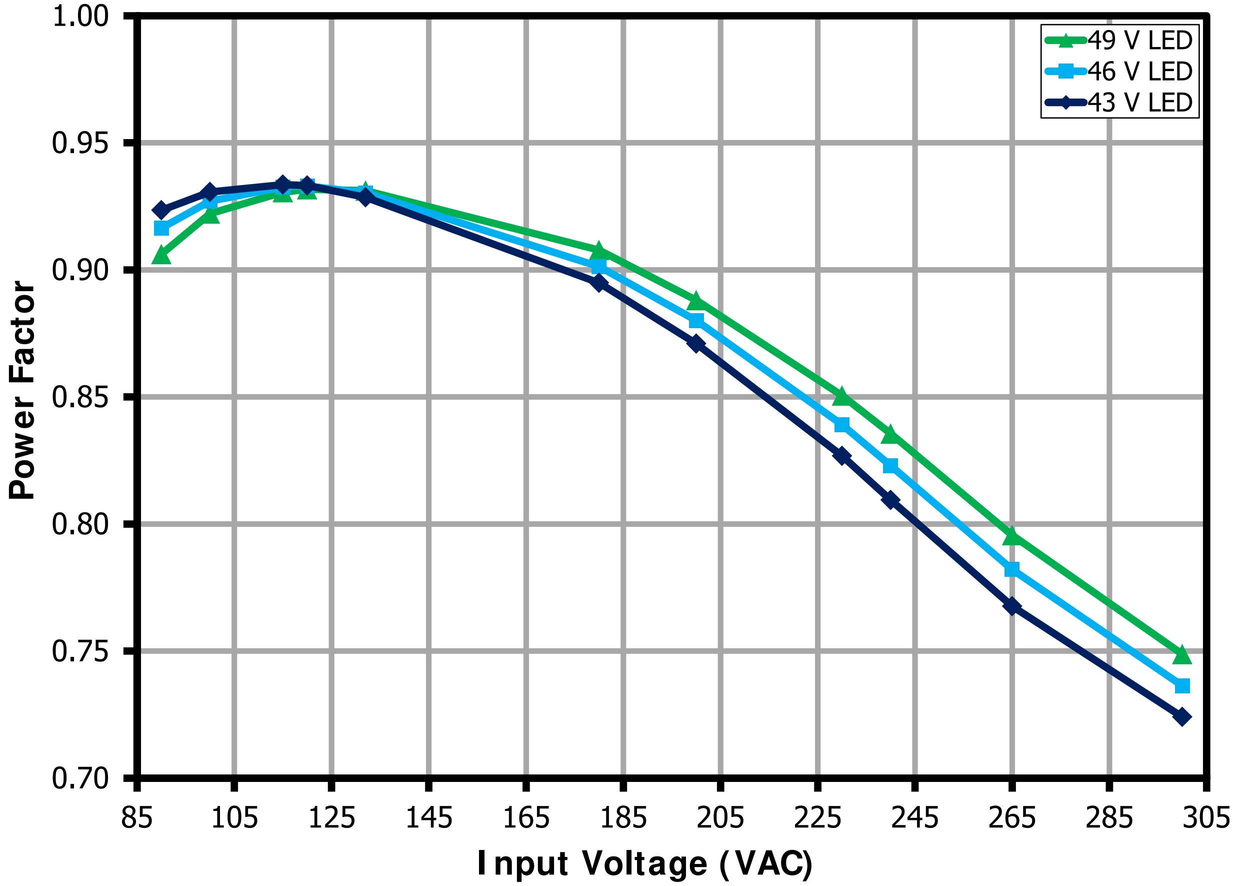

Figure 11 – Power Factor vs. Line and LED Load.

9.4 *%ATHD*

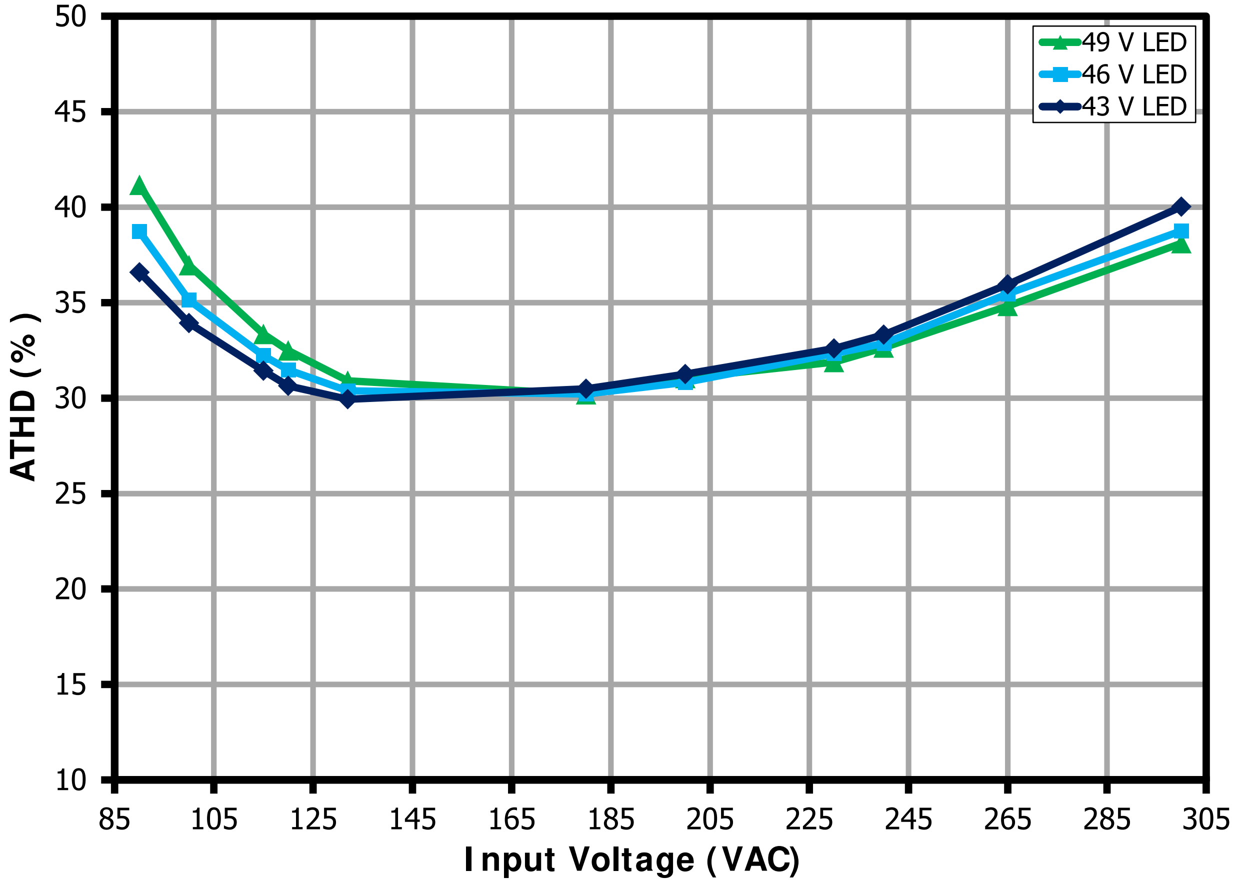

Figure 12 – %ATHD vs. Line and LED Load.

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9.5 *Individual Harmonics Content*

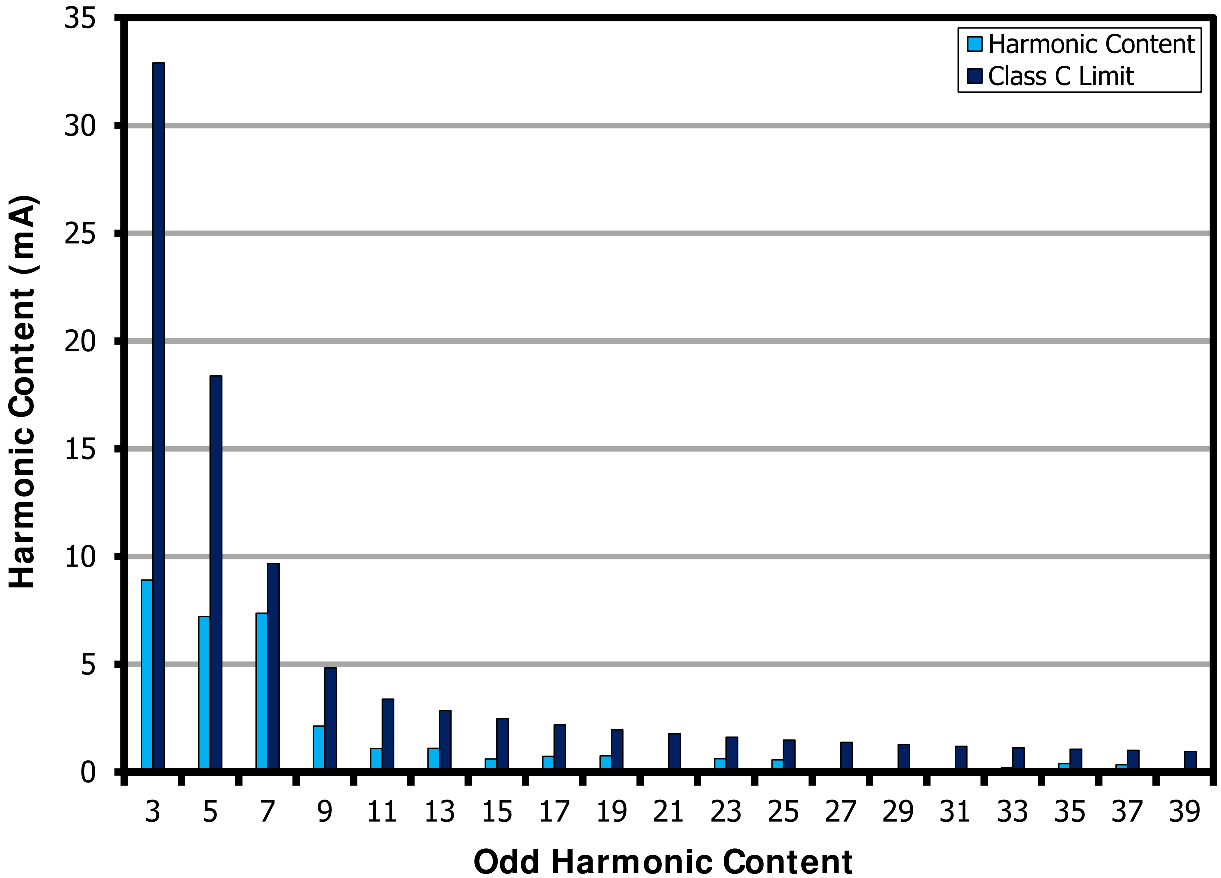

Figure 13 – 48 V LED Load Input Current Harmonics at 115 VAC, 60 Hz.

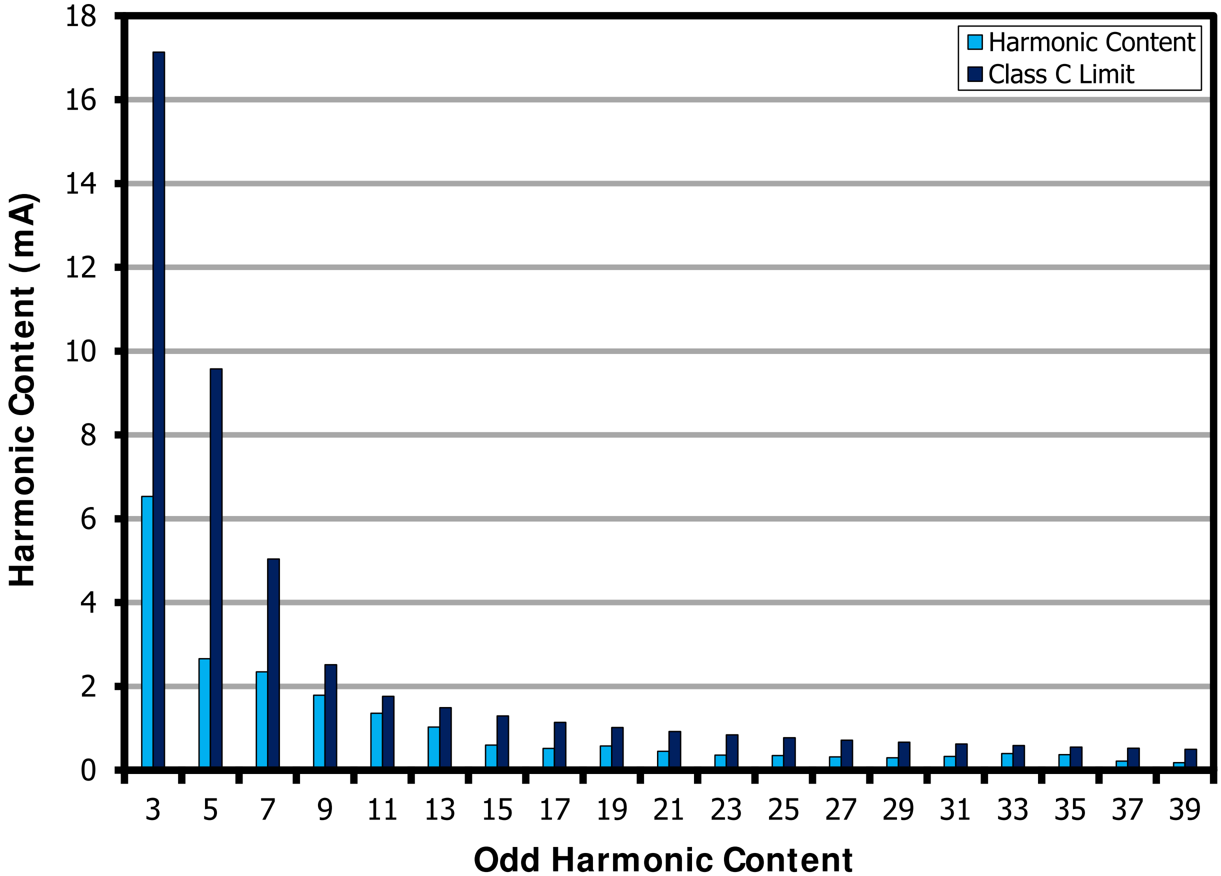

Figure 14 – 48 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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