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Power integrations[™]

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

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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.



RDR-465 4.5 W Buck LED Driver Using LYT1402D



Figure 1 – Populated Circuit Board.

Figure 2 – Populated Circuit Board, Top View.

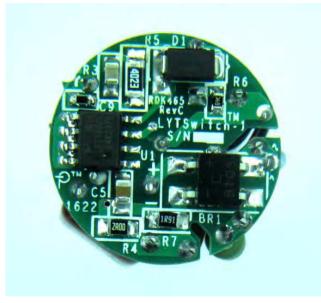


Figure 3 – Populated Circuit Board, Bottom View.



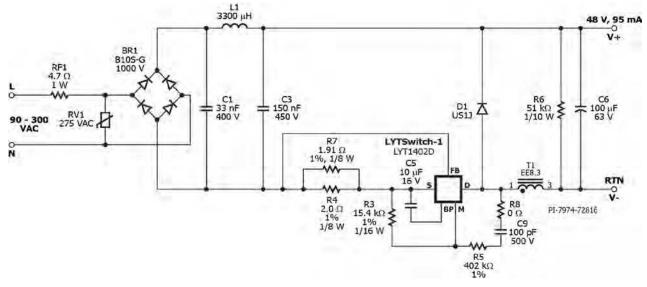
2 Power Supply Specification

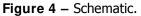
The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Тур	Max	Units	Comment
Input						
Voltage	VIN	90	230	300	VAC	2 Wire – no P.E.
Frequency	f _{line}		50		Hz	
Output						
Output Voltage	V _{OUT}		48		V	
Output Current	Ι _{ουτ}		95		mA	
Total Output Power						
Continuous Output Power	POUT		4.5		W	
Efficiency						
Full Load	η		87		%	230 V / 50 Hz at 25 °C. 115 V / 60 Hz at 25 °C.
Environmental						
Conducted EMI			CISPR 15B	/ EN55015	В	
Safety			Isol	ated		
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	Т _{АМВ}		85		٥C	Free Convection, Sea Level.



3 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 load via the inductor is released back into the circuit. During this time current will be flowing through the load via the load via 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 μ F.



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 k $\Omega \pm 1\%$.

$V_{LINE_{OVP}} = I_{IOV} \times R5 + V_{OUT}$

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 k $\Omega \pm 1\%$ 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.

5 PCB Layout

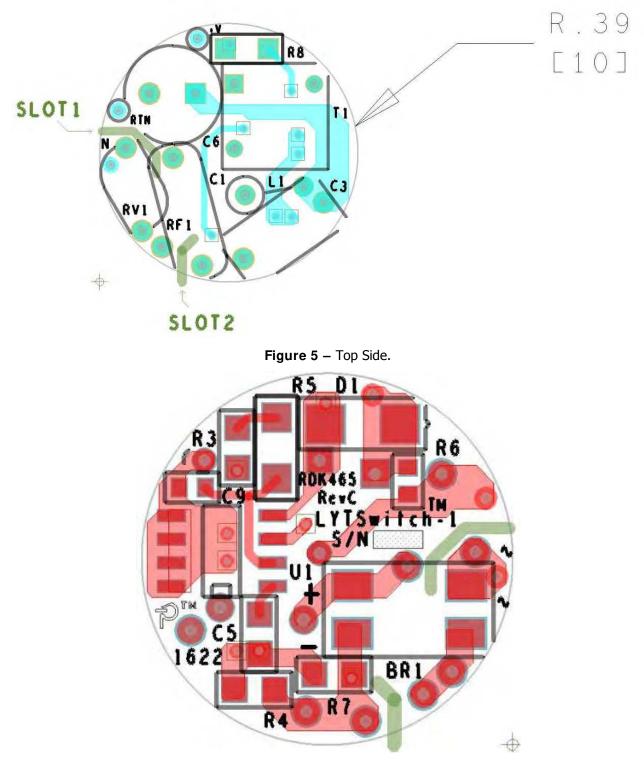


Figure 6 – Bottom Side.



ERJ-8GEY0R00V

FKN1WSJR-52-4R7

S05K275

EE-0802

LYT1402D

Comchip

Panasonic

Faratronic

Samsung

Epcos

Panasonic

Yageo

Panasonic

Panasonic

Yageo

Panasonic

Yago

Epcos

Zhenhui

Power Integrations

Item Ref Des Qtv Description Mfg Part Number Manufacturer BR1 1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC B10S-G 1 1 ECQ-E4333KF 2 C1 33 nF, 400 V, Film 1 3 150 nF, 450 V, 10%, Polypropylene Metalized C222S154K30 C3 1 10 μ F, ±10%, 16 V, X7R, Ceramic Capacitor, -55°C ~ 125°C, Surface Mount, MLCC 0805 (2012 Metric), 0.079" 4 C5 1 CL21B106KOQNNNG L x 0.049" W (2.00mm x 1.25mm) 5 C6 100 μ F, 63, Electrolytic, Low ESR, 270 m Ω , (8 x 15) ELXZ630ELL101MH15D 1 Nippon Chemi-Con 6 C9 100 pF, 500 V, Ceramic, NPO, 0805 501R15N101KV4T Johanson Dielectrics 1 7 D1 1 Diode Ultrafast, SW 600 V, 1 A, SMA US1J-13-F Diodes, Inc. 3300 μ H, 62 mA, 59.5 Ω , Axial Ferrite Inductor 8 L1 B78108S1335J 1 9 R3 1 RES, 15.4 kΩ, 1%, 1/16 W, Thick Film, 0603 ERJ-3EKF1542V 10 R4 RES, 2.00 Ω, 1%, 1/8 W, Thick Film, 0805 RC0805FR-072RL 1 11 R5 1 RES, 402 kΩ, 1%, 1/4 W, Thick Film, 1206 ERJ-8ENF4023V 12 R6 RES, 51 kΩ, 5%, 1/10 W, Thick Film, 0603 ERJ-3GEYJ513V 1 13 R7 RES, 1.91 Ω, 1%, 1/8 W, Thick Film, 0805 RC0805FR-071R91L 1

RES, 0 R, 5%, 1/4 W, Thick Film, 1206

275 V, 8.6 J, 5 mm, RADIAL

6.9 mm H)

RES, 4.7 Ω , 1 W, Fusible/Flame Proof Wire Wound

LYTSwitch-1, Wide Range, 4W, 25V-50V, SO-8

Bobbin, EE8.3, Vertical, 6 pins (8.2 mm W x 8.2 mm L x

Bill of Materials 6

Miscellaneous

R8

RF1

RV1

Τ1

U1

1

1

1

1

1

14

15

16

17

18

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



7 Inductor Specification

7.1 *Electrical Diagram*

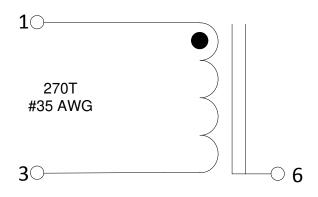


Figure 7 – Inductor Electrical Diagram.

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

ltem	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

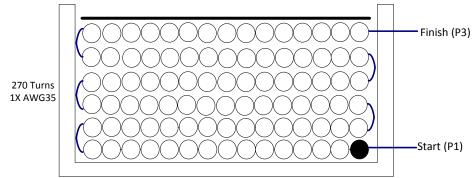


Figure 8 – Transformer Build Diagram.

7.5 Inductor Construction

Winding Directions	Bobbin is oriented on winder jig such that terminal pins are in the right side. The vinding 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 μ H.						
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.						



7.6 Winding Illustrations	
Winding Directions	Pin Terminals
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.	
Insulation	
Add 2 layers of tape, item [4], for insulation.	



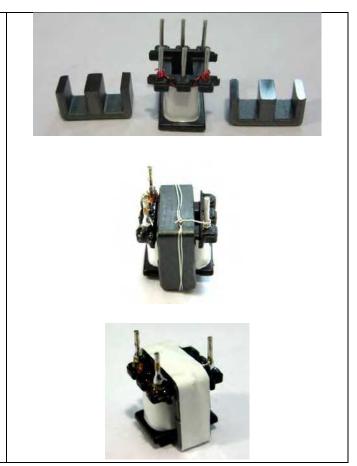
Core Grinding

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

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.



8 Inductor Design Spreadsheet

ENTER APPLI CATI ON VARI ABLES UNIVE 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 Minimum AC line voltage VACMAX 300.00 50.00 Hz AC mains frequency VACMAX 300.00 48.00 48.00 Volts AC VACMAX 300.00 50.00 Hz Ac mains frequency VO 48.00 48.00 Volts AC Fordinous output correct specification EFFICIENCY 0.87 0.87 Efficiency estimate PO - 4.56 Watts DC Origitad Case normal operating output voltage VD 0.70 Volts DC Output diode forward voltage drop Parameter to be optimized PARAMETER 725 Volts DC Choose between 650V and 725V CENERC DEVICE Auto LYT1bX2D Choose between 650V and 725V DEVICE Reach DOWN 725 Volts DC Aronainum Current Limit LIMITHT	ACDC_LYTSwitch1_ Buck_031816; Rev.0.1; Copyright Power Integrations 2016	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-1 Buck Design Spreadsheet
VACTIN 90.00 90.00 Volts AC Minimum AC line voltage VACTYP 230.00 230.00 Volts AC Maximum AC line voltage VACMAX 300.00 500.00 Hiz AC, mains frequency V0 48.00 48.00 Volts AC Maximum AC line voltage IO 0.095 0.095 Arreage output current specification FFICIENCY 0.87 0.87 Efficiency estimate PO 4.55 Watts Continuous output power VD 0.70 Volts DC Controuss output power VD 0.70 Volts DC Choose between 650V and 725V CENERIC CEROE Atot LYT1XV3D Eeneric LYTSwitch-1 device based on power DEVICE RAKENDWN 0.54 Anperes Maximum Current Limit LIMITTYP 0.64 Anperes Maximum		I ABLES				
VACTYP 230.00 230.00 Volts AC Typical AC line voltage A 50.00 50.00 Volts AC Maximum AC line voltage A 60.00 50.00 Volts AC Maximum AC line voltage VO 48.00 48.00 Volts AC Maximum AC line voltage VO 48.00 48.00 Volts AC Maximum AC line voltage FFICIENCY 0.87 0.87 Efficiency estimate Continuous output power VD 0.70 Volts DC Output diode forward voltage drop Parameter to be optimized PTER LYTSWITCH-1 VARI ABLES EVICE Auto LYT1V2D Generic LYTSwitch-1 device based on power DEVICE BREAKDOWN 725 725 Volts DC Choose between 650V and 725V GENERIC DEVICE Auto LYT1V2D Generic LYTSwitch-1 device code Illmittmit ILIMITNIN 0.59 Amperes Maximum ac finiting frequency in the fixed on-time region at VACTYP The Auto 0.64 Amperes Typical Current limit Time code TIMAX 0.62	LINE VOLTAGE RANGE			Universal		AC line voltage range
VACMAX 300.00 300.00 Volts AC Maximum AC line voltage R 50.00 48.00 48.00 Volts DC Armage output current specification IO 0.095 0.095 Amperes Average output current specification EFFICIENCY 0.87 0.87 Continuous output power VD 0.70 Volts DC Continuous output power VD 0.70 Volts DC Continuous output power VD 0.70 Volts DC Contrusous output power VD 725 725 Volts DC Choose between 650V and 725V EVICE BRAKDOWN 725 725 Volts DC Choose between format one tower EVICE CODE L LYT1402D Centeric LYTSwitch-1 device code ILIMITIN 0.64 Amperes Maximum Current Limit ILIMITINAX		90.00		90.00	Volts AC	
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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 PARAMETER BOM BOM Parameter to be optimized ENTER LYTSWITCH-1 VARI ABLES ENTER LYTSWITCH-1 VARI ABLES Entern LYTSWITCH-1 VARI ABLES DEVICE RERANDOWN 725 725 Volts DC Choose between 650V and 725V GENERIC DEVICE Auto LYT1X02D Generic LYTSwitch-1 device based on power DEVICE CODE LYT1402D Actual LYTSwitch-1 device code LIMITTMN 0.64 Amperes TON 1.83 us On-time during the fixed on-time region at VACTYP MAX 0.52 Maximum duty cycle possible in the fixed our-time region at VACTYP DMAX 0.52 If custom core is used - here ant number here AE CORE EE8.3 Effect reasformer Core CUSTOM CORE NAME EB.3 Effect reasformer Core CUSTOM CORE NAME E8 If custom core is used - here ant number here AE 7.00 mm^2 Core effective cross cectional area LE 19.20 mm						
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		+				
	AWG	+		35	11111	AWG of the bare wire.



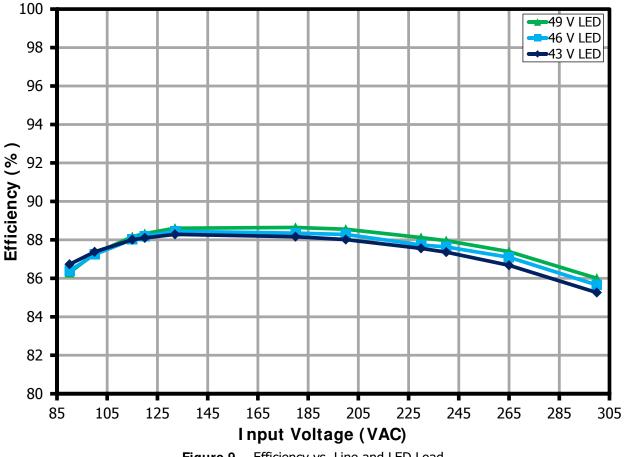
СМ		32	Cmils	Bare wire circular mils
СМА		256.6	Cmils/A	Bare wire circular mils per ampere
CURRENT DENSITY		7.8	A/mm^2	Bare wire current density
BOBBIN FILL FACTOR		39.01%		Decrease the number of layers to ensure that the
				wire fits in the bobbin.
CURRENT WAVEFORM SI	HAPE PARAME	TERS		
IAVERAGE_INDUCTOR		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 O	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 PARAM	METERS	•	•	
VDRAIN		424.26	Volts DC	Estimated worst case drain voltage
PIVD		424.26	Volts DC	Output Rectifier Maximum Peak Inverse Voltage

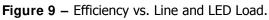


9 Performance Data

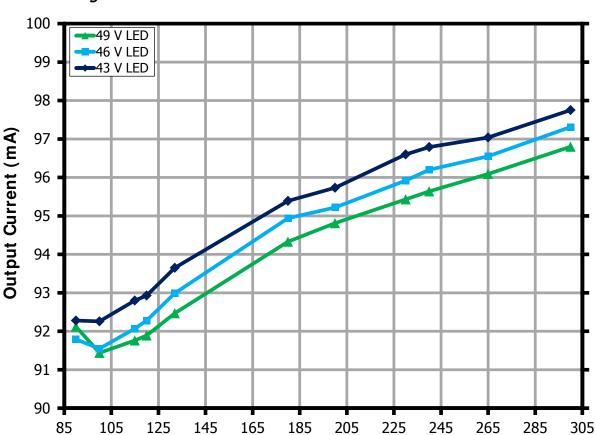
All measurements were performed at room temperature using LED load string. 1 minute soak time was applied before measurement with AC source turned-off for 5 seconds every succeeding input line measurement.

9.1 *Efficiency*









9.2 Line Regulation

Figure 10 – Regulation vs. Line and LED Load.

Input Voltage (VAC)



5%

4%

3%

2%

1%

0%

-1%

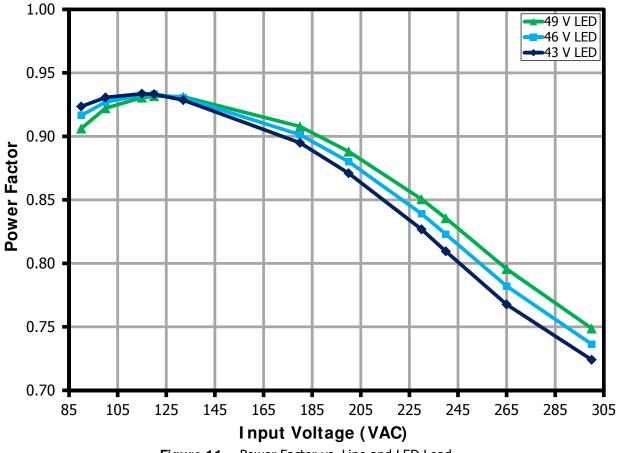
-2%

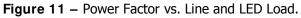
-3%

-4%

-5%

9.3 Power Factor







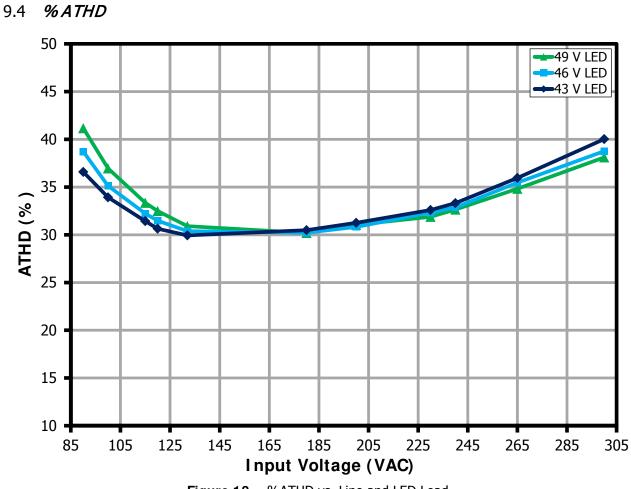
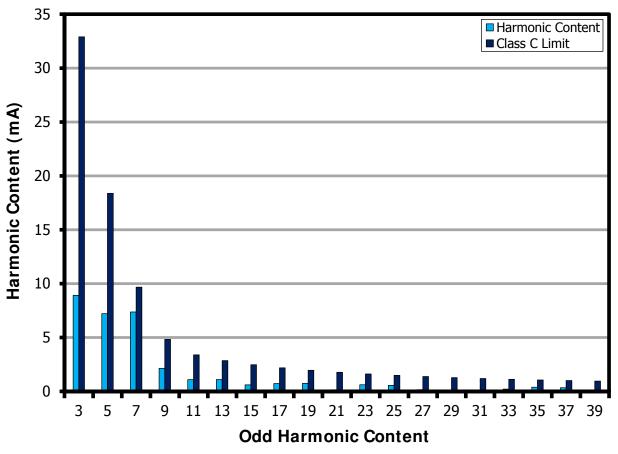


Figure 12 – %ATHD vs. Line and LED Load.











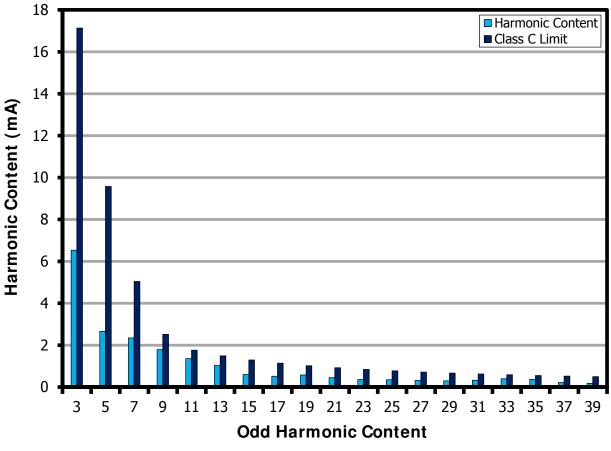


Figure 14 – 48 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

