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Title	<i>Reference Design Report for a 12.6 W, TRIAC Dimmable, High Efficiency (>86%) Isolated Flyback, Power Factor Corrected (>0.97) LED Driver Using LYTSwitch™ LYT4313E</i>
Specification	90 VAC – 132 VAC Input; 34 V, 370 mA Output
Application	Down Light LED Driver
Author	Applications Engineering Department
Document Number	RDR-347
Date	February 11, 2013
Revision	1.2

Summary and Features

- High efficiency, $\geq 86\%$ at 120 VAC
- Low cost
 - Single-stage converter
 - Single sided PCB
 - Low component count
- Works with a wide range of leading edge and trailing edge TRIAC dimmers
 - Wide dimming range
 - No pop-on, reduced dead band and very fast start-up
- Enhanced user experience
 - Flicker-free, fast monotonic start-up (<250 ms) – no perceptible delay
 - Thermal fold back prevents shut off in high output temperatures
- Integrated protection and reliability features
 - Output open circuit / output short-circuit protected with auto-recovery
 - Line input overvoltage shutdown extends voltage withstand during line faults
 - Auto-recovering thermal shutdown with large hysteresis protects both components and printed circuit board
- IEC 61000-4-5 ring wave, IEC 61000-3-2 C combination and EN55015 B conducted EMI compliant

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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<p>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.</p>



1 Introduction

The document describes an isolated high power factor (PF) TRIAC dimmable LED driver designed to drive an LED string voltage of 34 V at 370 mA from an input voltage range of 90 VAC to 132 VAC. The LED driver utilizes the LYT4313E from the LYTSwitch family of ICs.

The topology used is a single-stage power factor corrected flyback that delivers high efficiency, high power factor, low THD, isolation, low component count, and dimming performance required for this design.

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

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

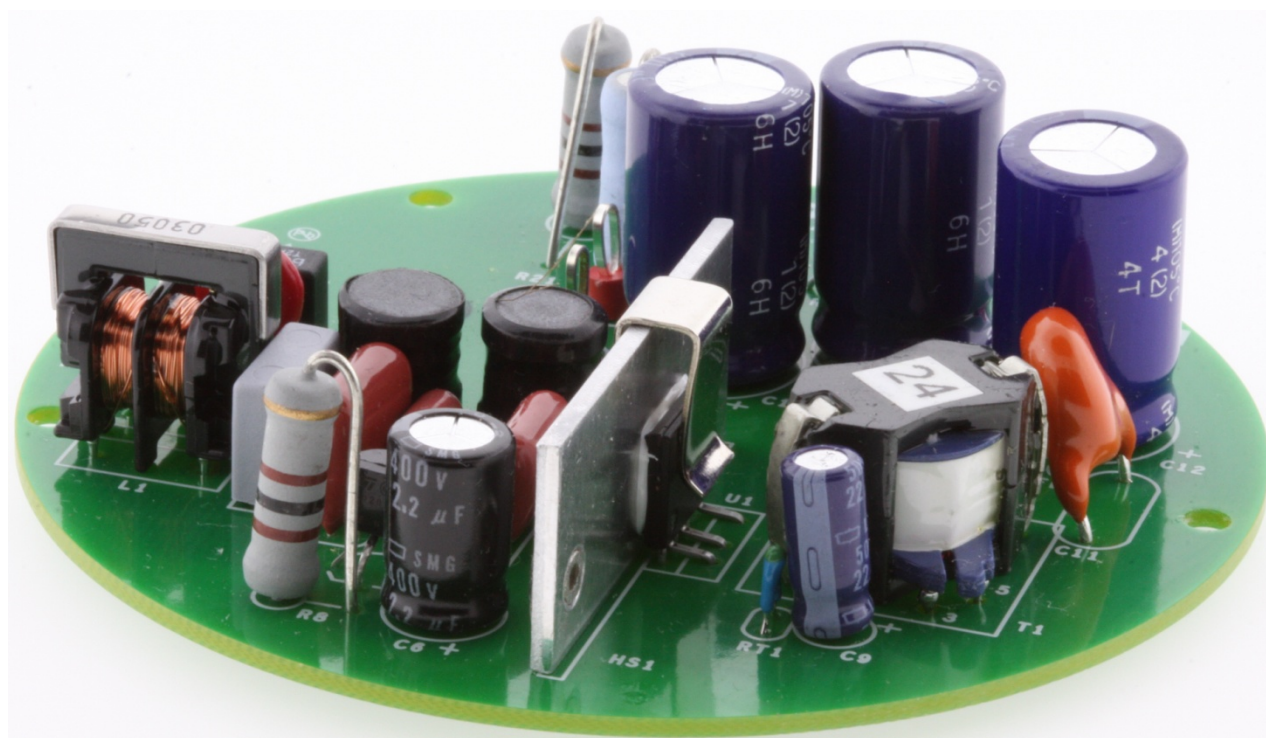


Figure 1 – Populated Circuit Board Photograph.



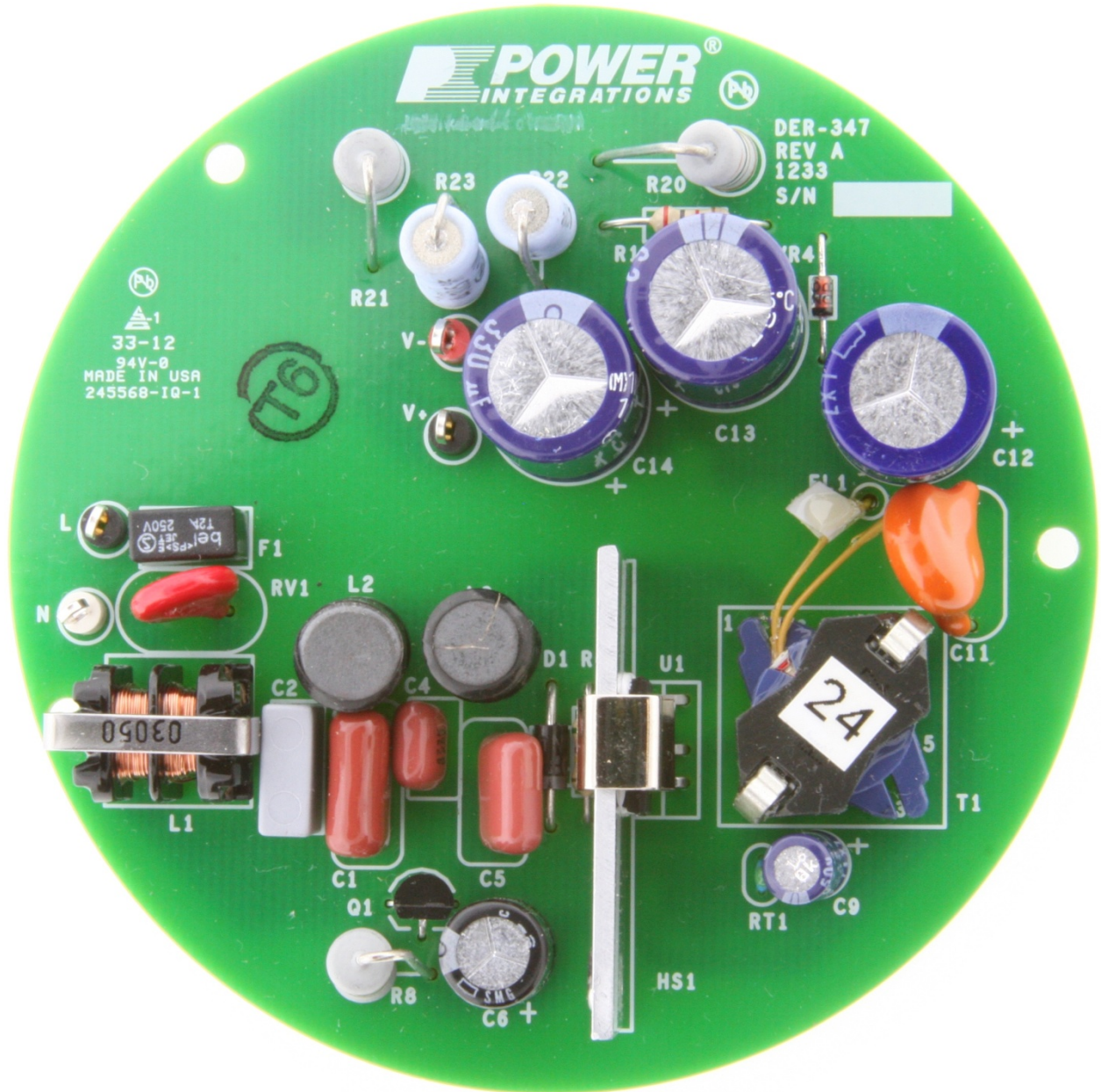


Figure 2 – Populated Circuit Board Photograph (Top View).

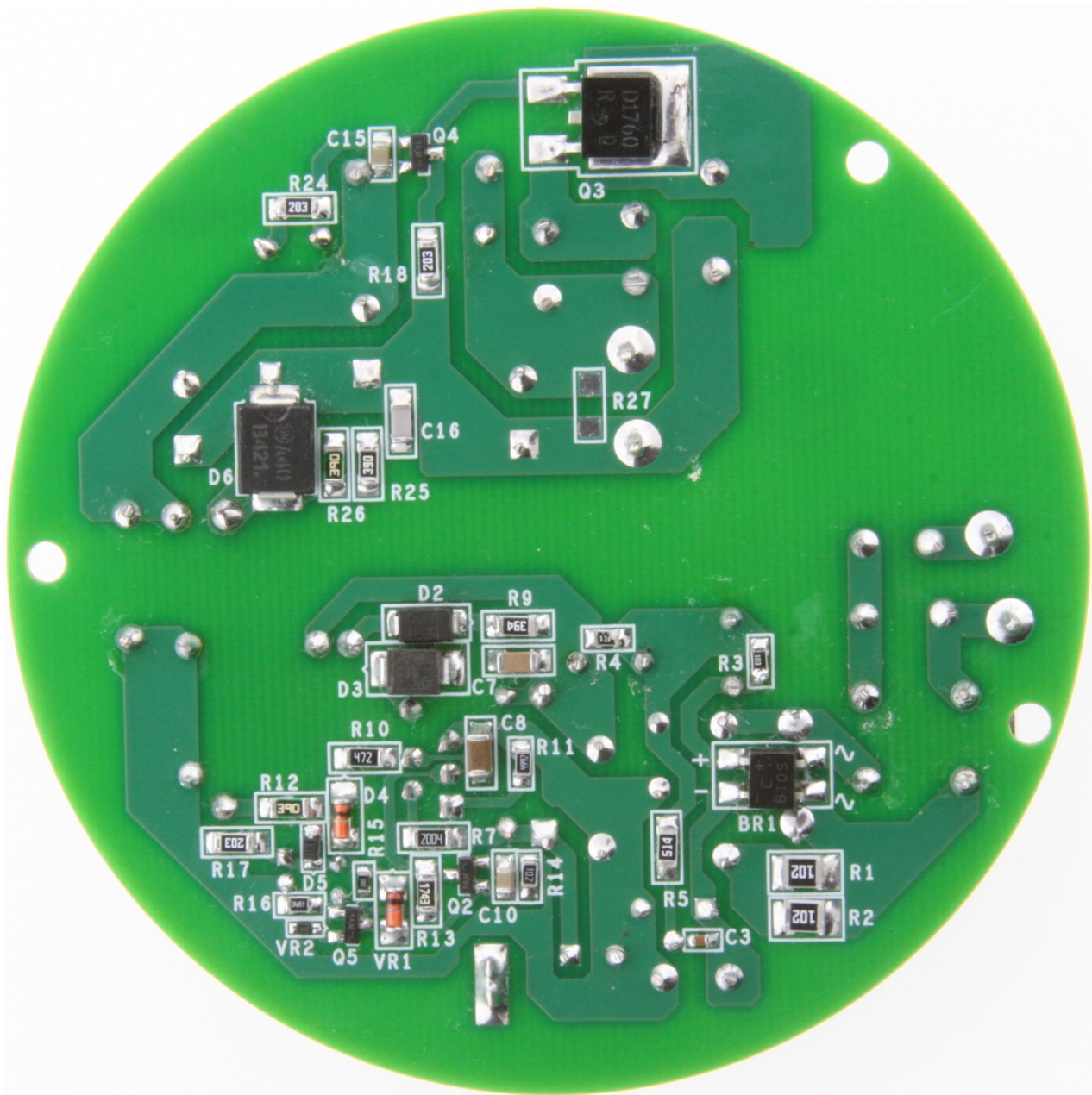


Figure 3 – Populated Circuit Board Photograph (Bottom View).



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 Frequency	V_{IN} f_{LINE}	90	120 60	132	VAC Hz	
Output Output Voltage Output Current	V_{OUT} I_{OUT}	352	34 370	388	V mA	$V_{OUT} = 34$, $V_{IN} = 120$ VAC, 25 °C; +/- 5%
Total Output Power Continuous Output Power	P_{OUT}		12.6		W	
Efficiency Full Load	η		86		%	
Environmental Conducted EMI Safety Ring Wave (100 kHz) Differential Mode (L1-L2) Common mode (L1/L2-PE) Differential Surge (1.2/50 μ s)		CISPR 15B / EN55015B Isolated				
			2.5		kV	
			500		V	
Power Factor			0.97			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 120 VAC, 60 Hz
Harmonic Currents		EN 61000-3-2 Class D (C)				Class C specifies Class D Limits when $P_{IN} < 25$ W
Ambient Temperature	T_{AMB}		50		°C	Free convection, sea level

3 Schematic

3.1 Typical Schematic

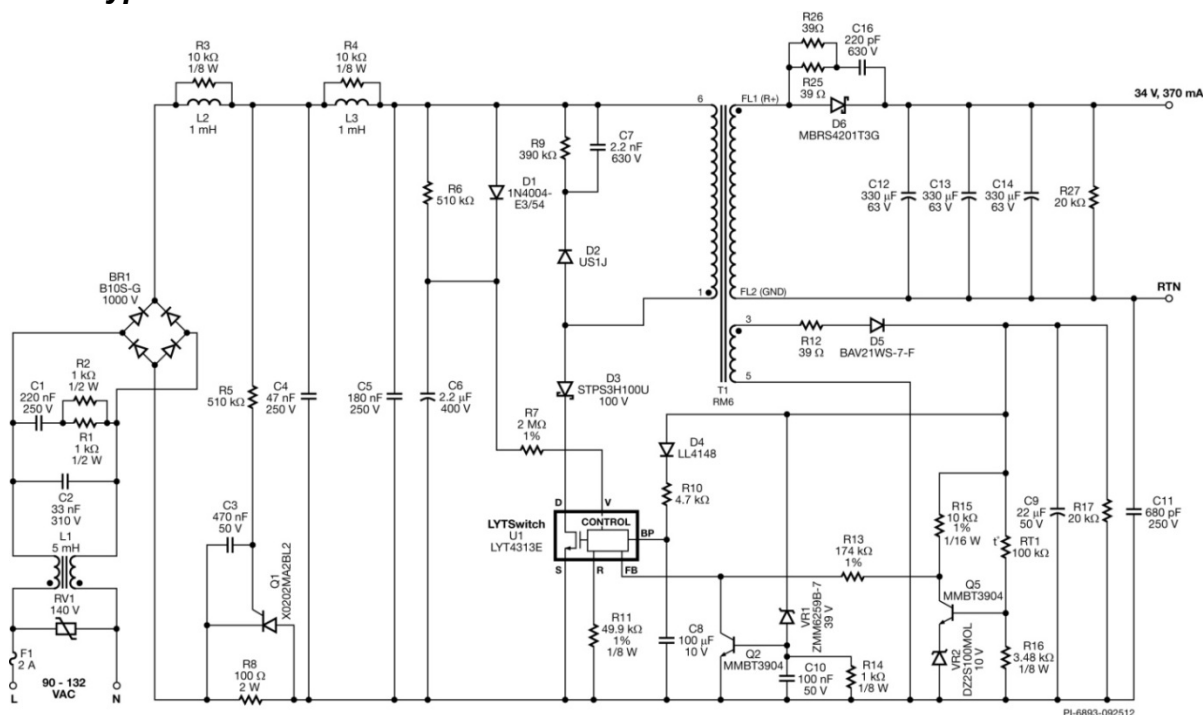


Figure 4 – Typical Schematic with Thermal Fold Back (Full performance report in Section 16)

3.2 Active Pre-load Option

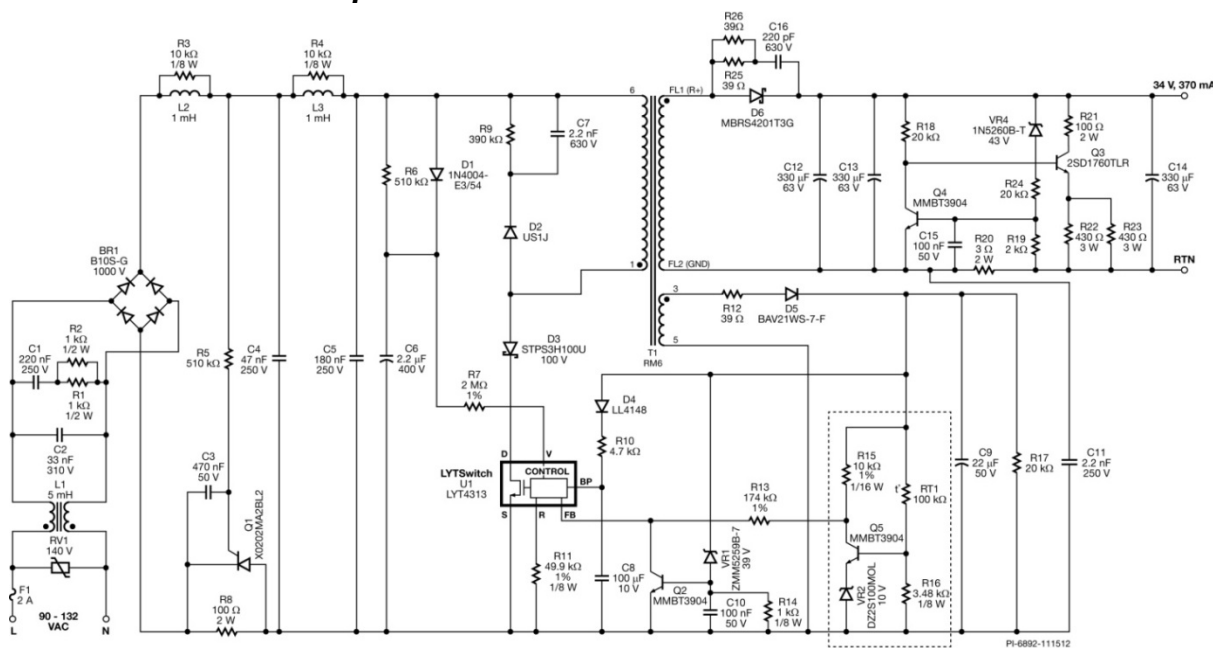


Figure 5 – Schematic with Optional Active Pre-load (Improved Dimming) and Thermal Fold Back Highlighted



4 Circuit Description

The LYTSwitch device is a controller with an integrated 650 V power MOSFET for use in LED driver applications. The LYTSwitch is configured for use in a single-stage flyback topology which provides a primary side regulated, constant current output while maintaining high power factor.

4.1 Input Filtering

Fuse F1 provides protection from component failure. A relatively high current rating was selected to prevent failure during differential (1.2 μ s / 50 μ s) line surge. Varistor RV1 provides a clamp to limit the maximum voltage during differential line surges. A 140 VAC rated part was selected, being slightly above the maximum specified operating voltage of 132 VAC. Diode bridge BR1 rectifies the AC line voltage with capacitor C5 providing a low impedance path (decoupling) for the primary switching current.

EMI filtering is provided by inductors L1, L2, and L3, and capacitors C2, C4, and C5. Resistor R3 and R4 positioned across L2 and L3 damp any LC resonances due to the filter components and the AC line impedance which would otherwise cause increased conducted EMI.

4.2 LYTSwitch Primary

One side of the transformer (T1) is connected to the DC bus and the other to the DRAIN (D) pin of the LYTSwitch via blocking diode D3. During the on-time of the power MOSFET, current ramps through the primary, storing energy which is then delivered to the output during the power MOSFET off-time. An RM6S/I core size was selected to meet the power processing requirements of the design.

To provide peak line voltage information to U1 the incoming rectified AC voltage peak charges C6 via D1. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R7. Resistor R6 provides a discharge path for C6 with a time constant much longer than that of the rectified AC to prevent the V pin current being modulated at the line frequency (which would degrade power factor).

The line overvoltage shutdown function extends the rectified line voltage withstand (during surges and line swells) to the 650 BV_{DSS} rating of the internal power MOSFET.

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. For phase angle dimming applications a 49.9 k Ω resistor is used on the REFERENCE (R) pin (R11) and 2 M Ω (R7) on the V pin to provide a linear relationship between input voltage and the output current. This maximizes the dimming range when used with TRIAC dimmers.

During the power MOSFET off-time, D2, R9, and C7 clamp the drain voltage to a safe level due to the effects of leakage inductance. Diode D3 is necessary to prevent reverse current from flowing through U1 while the voltage across C5 (rectified input AC) falls to



below the reflected output voltage (parameter V_{OR} in the design spreadsheet). For lower cost an ultrafast type may be selected (US1B) with a slight (0.3%) reduction in efficiency.

Diode D5, C9, R12 and R17 generate a primary bias supply from an auxiliary winding on the transformer. Resistor R12 provides filtering so that the bias voltage tracks the output voltage closely and maintains a constant output current with changes in LED voltage. Resistor R17 prevents C9 peak charging during output short circuit condition, ensuring the driver safely enters auto-restart.

Capacitor C8 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C8 is charged to ~6 V from an internal high-voltage current source connected to the D pin. Once charged U1 starts switching at which point the operating supply current is provided from the bias supply via R10.

The use of an external bias supply (via D4 and R10) is recommended to give the lowest device dissipation and provide sufficient supply to U1 during deep dimming conditions.

Capacitor C8 also selects the output power mode, 100 μ F was selected (reduced power mode) to minimize the device dissipation and minimize heat sinking requirements.

4.3 Feedback

The bias winding voltage is used to sense the output voltage indirectly, eliminating secondary side feedback components. The voltage on the bias winding is proportional to the output voltage (set by the turn ratio between the bias and secondary windings). Resistors R13 and R15 converts the bias voltage into a current which is fed into the FB pin of U1. The internal engine within U1 combines the FB pin current, the V pin current, and internal drain current information to provide a constant output current whilst maintaining high input power factor.

4.4 Temperature Fold Back Circuit

The board also includes an optional temperature fold back circuit. This reduces the output power linearly as the driver temperature increases beyond a set value. This feature effectively extends the maximum operating ambient temperature of a given LYTSwitch LED driver while protecting the driver components and LED array from excess temperature.

Zener diode VR2 and the voltage across the node of resistor R16 and thermistor (NTC) RT1 dictate the start of temperature fold back. As the monitored temperature rises, so does the base voltage of Q5. Once this exceeds the voltage of VR2 plus a V_{BE} drop, Q5 is biased on. Further increases in temperature will start diverting current from the FB pin, which will cause a reduction in output current / power.

Resistor R16 can be adjusted to vary the temperature trip point at which output power reduction starts desired.



4.5 Output Rectification

The transformer secondary winding is rectified by D6 and filtered by capacitors C12, C13, and C14.

For designs where higher ripple is acceptable and lower cost, the output capacitance value can be reduced.

4.6 Disconnected and Shorted Load Protection

The part enters auto-restart whenever the FB current falls below the $I_{FB(AR)}$ threshold for longer than the ~76 ms.

In case of open (disconnected) load fault, Zener diode VR1 will conduct turning on transistor Q2. Transistor Q2 then pulls down the FB pin to force the IC into auto-restart mode.

During an output short circuit the output voltage and therefore bias voltage collapses. This causes the current into the FB pin to drop below $I_{FB(AR)}$.

Once in auto-restart dissipation is limited to ~25% of the rated output power, providing a safe condition. Once either fault is removed the driver returns to normal operation at the completion of the current auto-restart cycle off period (~225 ms).

4.7 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading edge phase dimmers introduced a number of tradeoffs in the design.

Due to the much lower power consumed by LED based lighting the current drawn by the lamp can fall below the holding current of the TRIAC within the dimmer. This causes undesirable behavior such as the lamp turning off before the end of the dimmer control range and/or flickering as the TRIAC fires inconsistently. The relatively large impedance the LED lamp presents to the line allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This too can cause similar undesirable behavior as the ringing may cause the TRIAC current to fall to zero.

To overcome these issues, active damper and passive bleeder circuits were added. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming applications these components can simply be omitted.

The active damper consists of components R5, Q1, C3 and R8. This circuit limits the inrush current that flows to charge C4 and C5 when the TRIAC turns on by placing R8 in series for the first 1 ms of the conduction period. After approximately 1 ms, Q1 turns on and shorts R8. This keeps the power dissipation on R8 low and allows a larger value to be used for more effective during current limiting. Resistor R5 and C3 provide the 1 ms delay after the TRIAC conducts. The SCR selected for Q1 is a low current, low cost



device in a TO-92 package. Resistor R28 (typical value 10 – 22 Ω) in series with R8 is optional placement for additional damping for Triac rated > 1000W.

The passive bleeder circuit is comprised of C1 and parallel combination of R1, and R2. The bleeder keeps the input current above the TRIAC holding current while the driver input current increases during each AC half-cycle, preventing the TRIAC switch from oscillating at the start (and end) of each conduction angle period.

4.7.1 Active Pre-Load Circuit

The active pre-load circuit is added to extend dimming range capability and provide additional loading during TRIAC dimming.

Resistor R20 senses the output current. If the output current falls below ~200 mA, transistor Q4 turns-off and transistor Q3 turns-on decreasing the output current flowing into the LED. This arrangement provides minimum output current of <0.1 mA at a conduction angle of ~50°. At an output current of >200 mA, the active pre-load circuit disengages, minimizing the reduction in efficiency. Resistors R21, R22, and R23 sets the maximum current flowing into the pre-load circuit and can be used to control the dimming curve. VR4 and R24 are also employed to disable the active pre-load during open load condition. The temperature rise of R22 and R23 can be significant.



5 PCB Layout

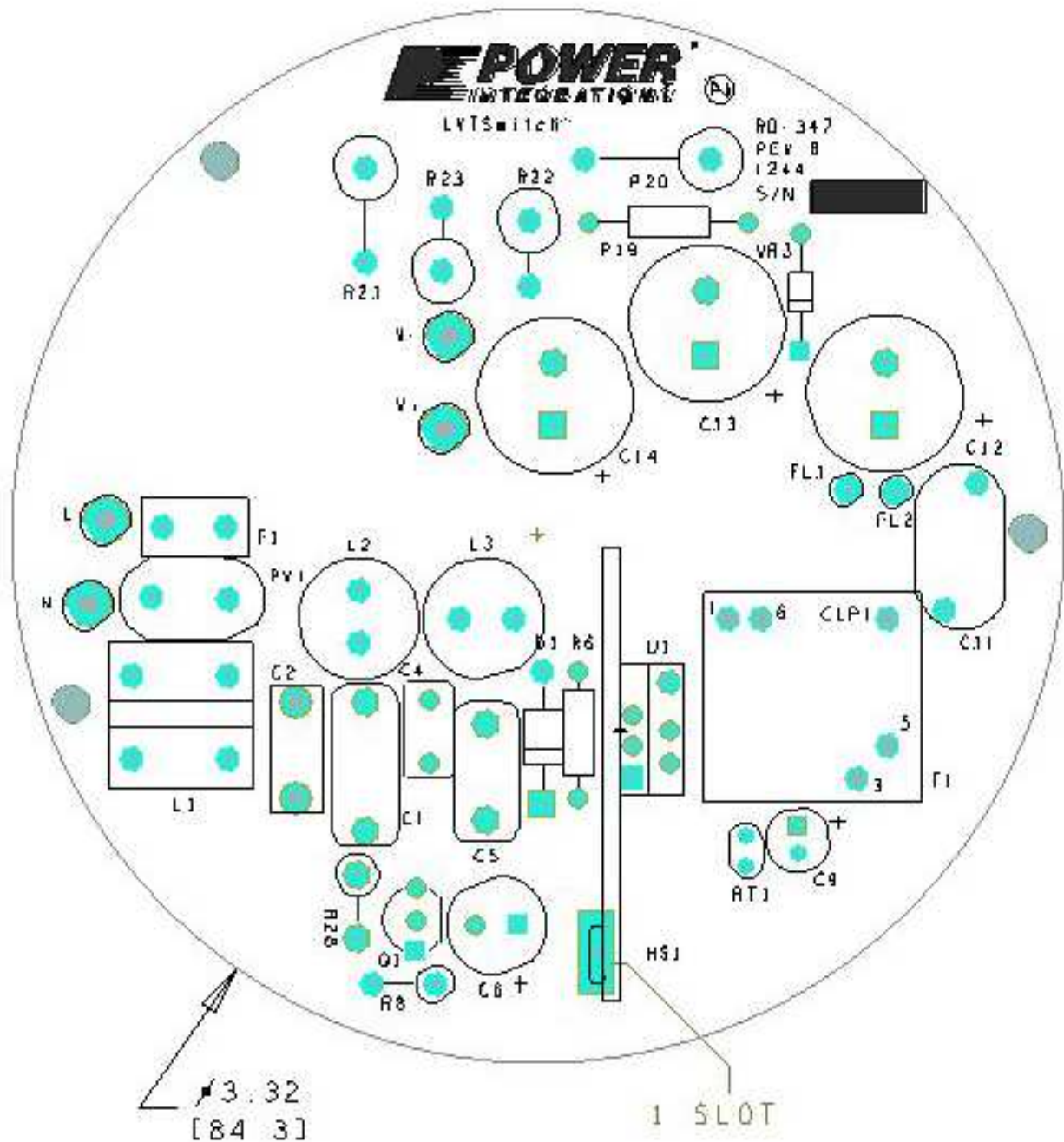
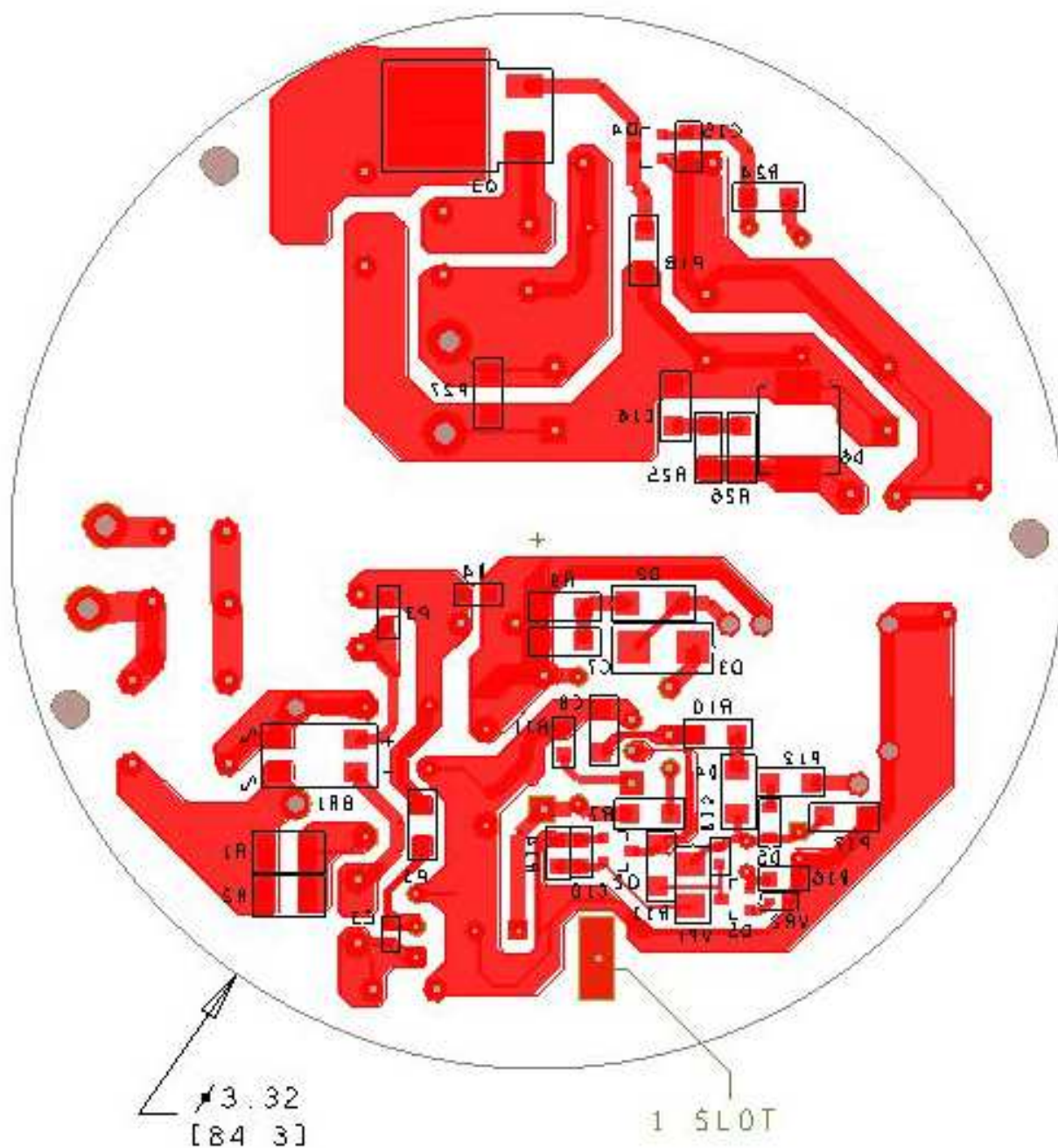


Figure 6 – Top Side.

**Figure 7 – Bottom Side.**

6 Bill of Materials

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	220 nF, 250 V, Film	ECQ-E2224KF	Panasonic
3	1	C2	33 nF, 310 VAC, Polyester Film, X2	BFC233920333	Vishay
4	1	C3	470 nF, 50 V, Ceramic, Y5G, 0603	C1608Y5V1H474Z	TDK
5	1	C4	47 nF, 250 V, Film	ECQ-E2473KB	Panasonic
6	1	C5	180 nF, 250 V, Film	ECQ-E2184KB	Panasonic
7	1	C6	2.2 μ F, 400 V, Electrolytic, (8 x 11.5)	SMG400VB2R2M8X11LL	Nippon Chemi-Con
8	1	C7	2.2 nF, 630 V, Ceramic, X7R, 1206	ECJ-3FBJ222K	Panasonic
9	1	C8	100 μ F, 10 V, Ceramic, X5R, 1210	C3216X5R1A107M-T	TDK
10	1	C9	22 μ F, 50 V, Electrolytic, Low ESR, 900 m Ω , (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
11	2	C10 C15	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
12	1	C11	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
13	3	C12 C13 C14	330 μ F, 63, Electrolytic, Low ESR, 85 m Ω , (12.5 x 20)	ELXZ630ELL331MK20S	Nippon Chemi-Con
14	1	C16	220 pF, 630 V, Ceramic, NPO, 1206	C3216C0G2J221J	TDK
15	1	D1	400 V, 1 A, Rectifier, DO-41	1N4004-E3/54	Vishay
16	1	D2	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
17	1	D3	100 V, 3 A, Schottky, DO-214AA	STPS3H100U	ST Micro
18	1	D4	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diodes, Inc.
19	1	D5	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
20	1	D6	200 V, 4 A, Schottky, SMC, DO-214AB	MBRS4201T3G	ON Semi
21	1	F1	2 A, 250 V, Slow, Long Time Lag, RST	RST 2	Belfuse
22	1	L1	5 mH, 0.3 A, Common Mode Choke	SU9V-03050	Tokin
23	2	L2 L3	1mH, 350m A	HTB2-102-281	CUI
24	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
25	3	Q2 Q4 Q5	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
26	1	Q3	NPN, Power BJT, 400 V, 2 A, SOT-428	2SD1760TLR	Rohm
27	2	R1 R2	1 k Ω , 5%, 1/2 W, Thick Film, 1210	ERJ-14YJ102U	Panasonic
28	2	R3 R4	10 k Ω , 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
29	1	R5	510 k Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
30	1	R6	510 k Ω , 5%, 1/4 W, Carbon Film	CFR-25JB-510K	Yageo
31	1	R7	2.00 M Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
32	1	R8	100 Ω , 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
33	1	R9	390 k Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
34	1	R10	4.7 k Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
35	1	R11	49.9 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4992V	Panasonic
36	3	R12 R25 R26	39 Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ390V	Panasonic
37	1	R13	174 k Ω , 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1743V	Panasonic
38	1	R14	1 k Ω , 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
39	1	R15	10 k Ω , 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1002V	Panasonic
40	1	R16	3.48 k Ω , 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3481V	Panasonic
41	3	R17 R18 R24	20 k Ω , 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
42	1	R19	2 k, 5%, 1/4 W, Carbon Film	CFR-25JB-2K0	Yageo
43	1	R20	3 Ω , 5%, 2 W, Metal Oxide	RSF200JB-3R0	Yageo
44	1	R21	100 R, 5%, 2 W, Metal Oxide	RSF200JB-100R	Yageo
45	2	R22 R23	430 Ω , 5%, 3 W, Metal Oxide	ERG-3SJ431	Panasonic
46	1	R28	0 Ω , 5%, 1/4 W, Metal Oxide	Z0R-25-R-52-0R	Yageo



47	1	RT1	NTC Thermistor, 100 k Ω , 0.00014 A	NTSA0WF104EE1B0	Murata
48	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
49	1	T1	Bobbin, RM6, Vertical, 6 pins Transformer	B65808-N1006-D1 SNX-R1664	Epcos Santronics USA
50	1	U1	LYTSwitch, eSIP	LYT4313E	Power Integrations
51	1	VR1	39 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5259B-7	Diodes, Inc.
52	1	VR2	10 V, 5%, 150 mW, SSMINI-2	DZ2S100M0L	Panasonic
53	1	VR4	43 V, 5%, 500 mW, DO-35	1N5260B-T	Diodes, Inc.



7 Transformer Specification

7.1 Electrical Diagram

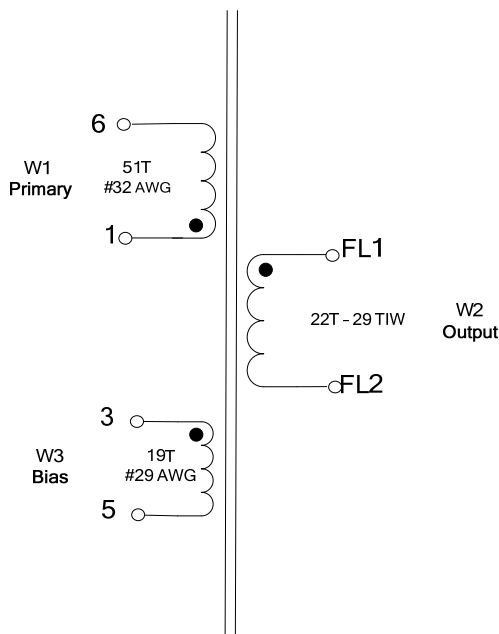


Figure 8 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 3, 5, 6 to FL1, FL2	3000 VAC
Primary Inductance	Pins 1-6, all other windings open, measured at 132 kHz, 0.4 V _{RMS}	720 μ H \pm 2%
Resonant Frequency	Pins 1-6, all other windings open	1000 kHz (Min.)
Primary Leakage Inductance	Pins 1-6, with FL1-FL2 shorted, measured at 132 kHz, 0.4 V _{RMS}	10 μ H max

7.3 Materials

Item	Description
[1]	Core: RM6S/I 3F3.
[2]	B-RM6-V 6pins (3/3) or equivalent. With mounting clip, CLI/P-RM6.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 6.4 mm wide.
[4]	Wire: Magnet, #32 AWG, solderable double coated.
[5]	Wire: Magnet, #29 AWG, solderable double coated.
[6]	Wire, Triple Insulated, Furukawa TEX-E or Equivalent, 29 TIW
[7]	Transformer Varnish, Dolph BC-359 or equivalent.

7.4 Transformer Build Diagram

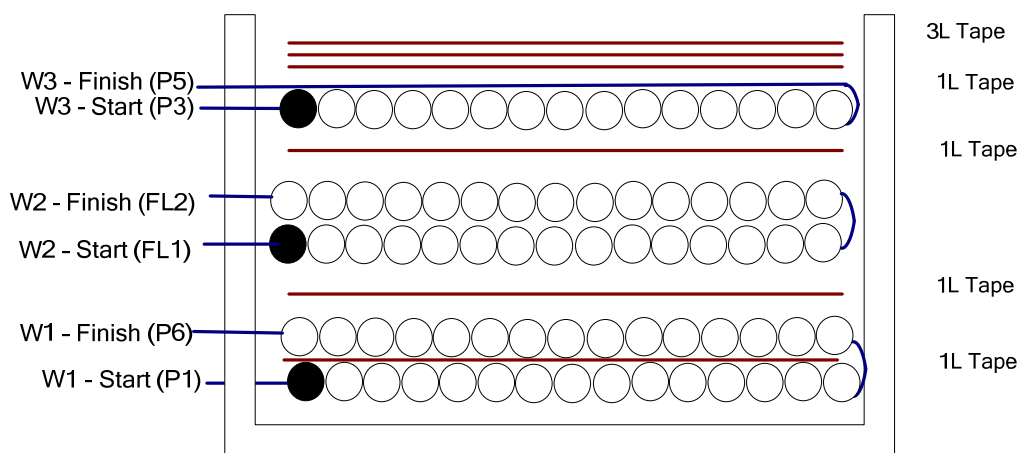


Figure 9 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel such that pin side on the left side. Winding direction is the clockwise direction.
WDG 1 (Primary)	Starting at pin 1, wind 51 turns of wire item [4] in two layers. Apply one layer of tape item [3] between 1 st and 2 nd layer. Finish at pin 6.
Insulation	Apply one layer of tape item [3].
WDG 2 (Secondary)	Leave about 2" of wire item [6], use small tape to mark as FL1, wind 22 turns in two layers. At the last turn exit the same slot, leave about 2", and mark as FL2.
Insulation	Apply one layer of tape item [3].
WDG 3 (Bias)	Starting at pin 3, wind 19 turns of wire item [5], spreading the wire, and finish at pin 5.
Finish Wrap	Apply three layers of tape item [3] for finish wrap.
Final Assembly	Cut FL1 to 1.2" and FL2 to 1.5". Grind core to get 720 μ H inductance. Assemble and secure core halves. Dip impregnate using varnish item [7]. Cut pins 2 and 4.

8 U1 Heat Sink Assembly

8.1 U1 Heat Sink Fabrication Drawing

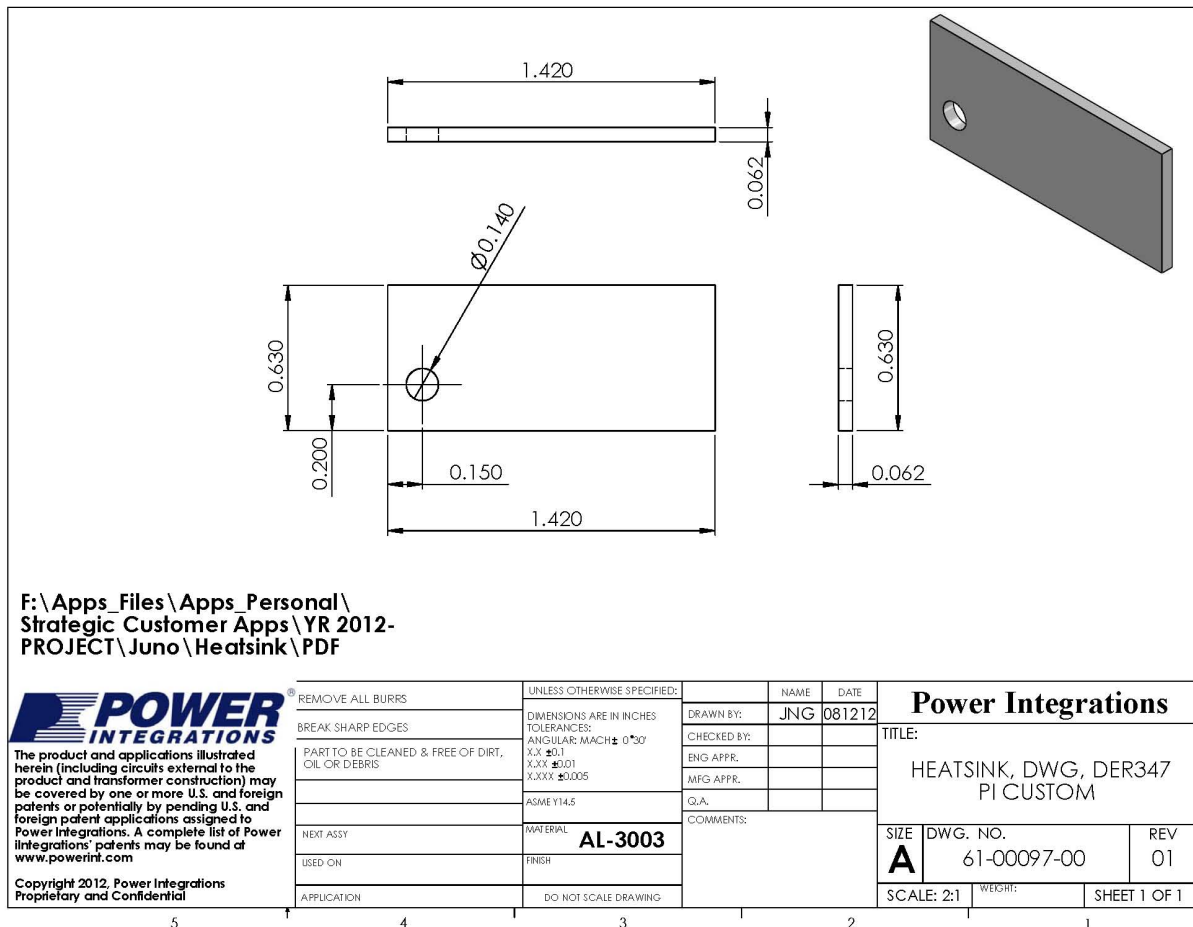


Figure 10 – Heat Sink Fabrication Drawing.

8.2 U1 Heat Sink Assembly Drawing

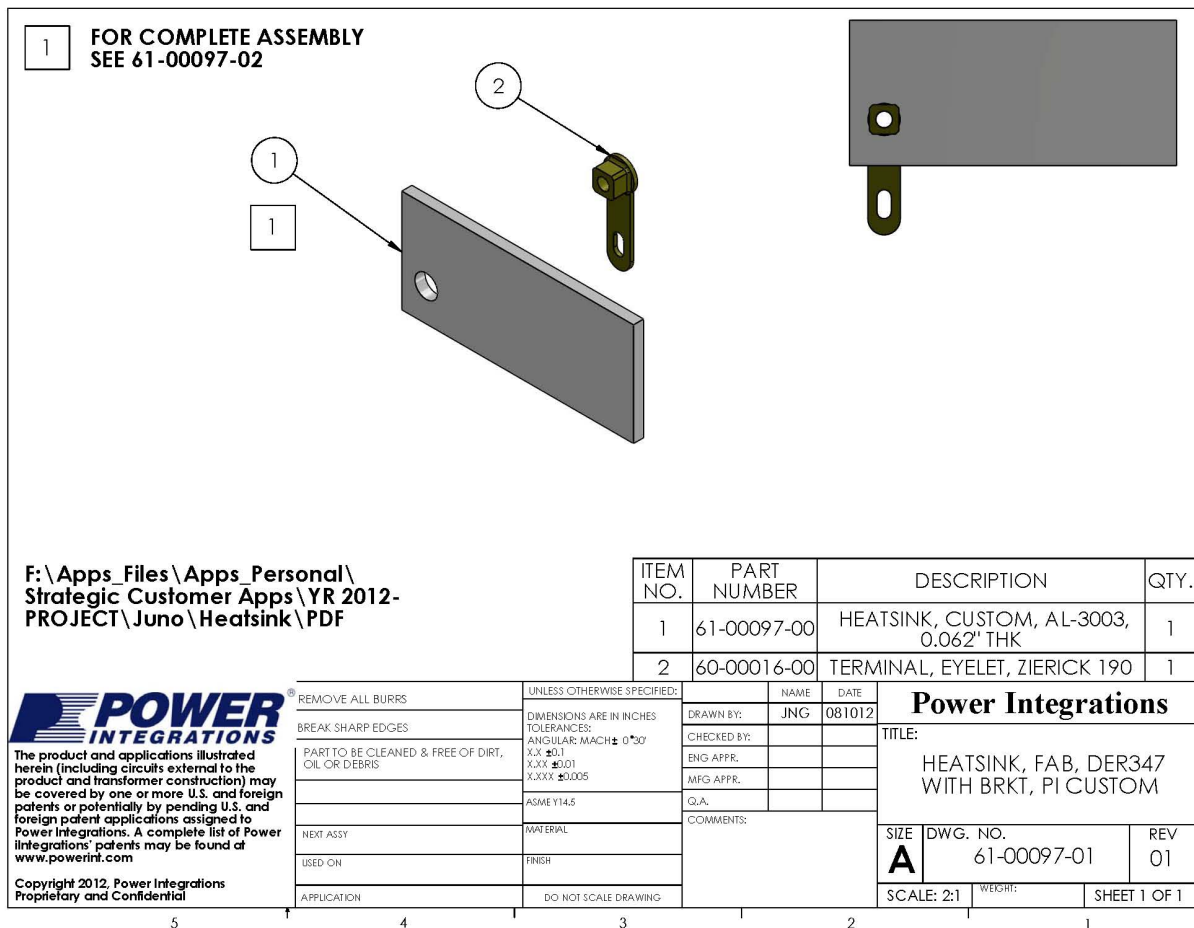


Figure 10a – Heat Sink Fabrication Drawing.



8.3 U1 and Heat Sink Assembly Drawing

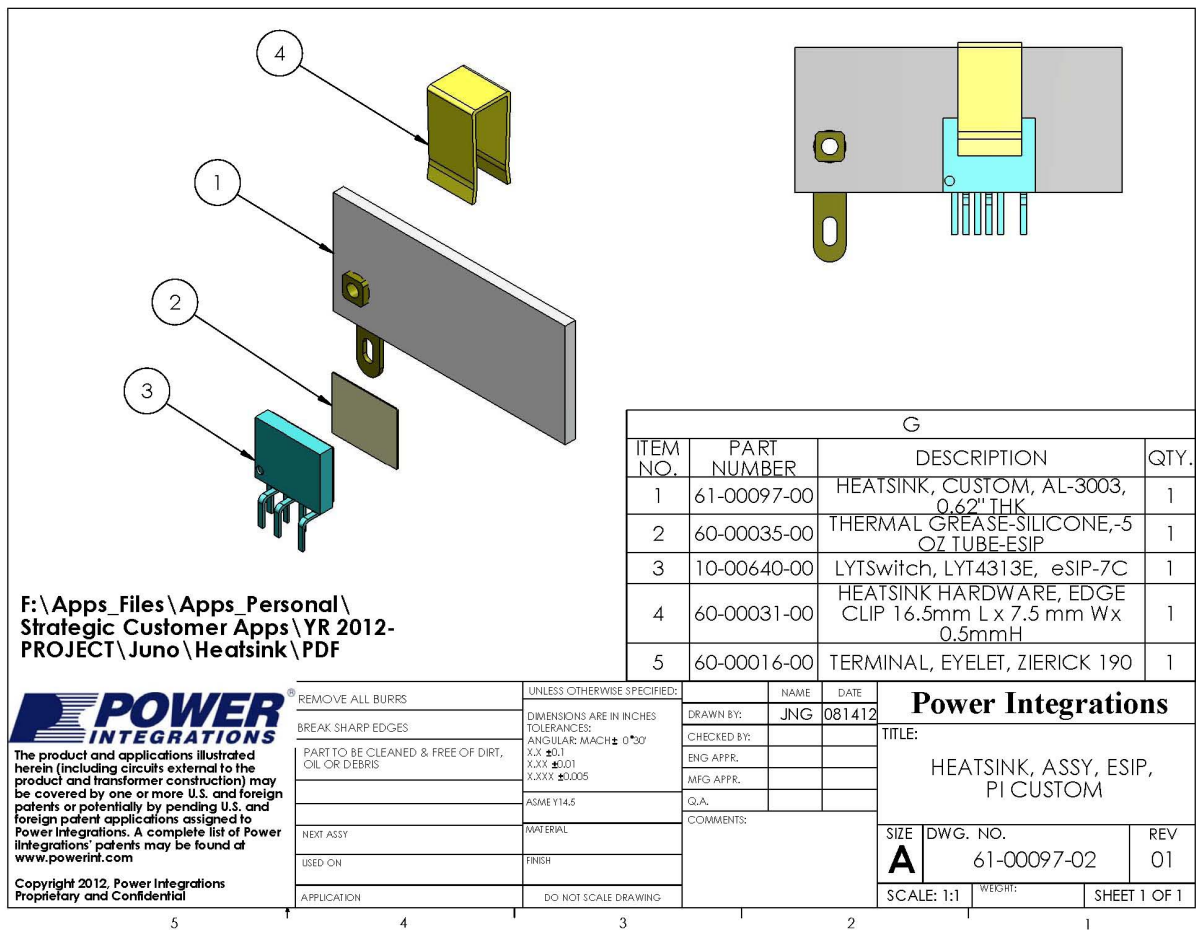


Figure 11 – U1 Heat Sink Assembly Drawing.

9 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent a voltage of 30 V ~ 38 V. The table in Section 9.6 and 16.8 show complete test data values for figures 13 and 12 respectively.

9.1 Efficiency

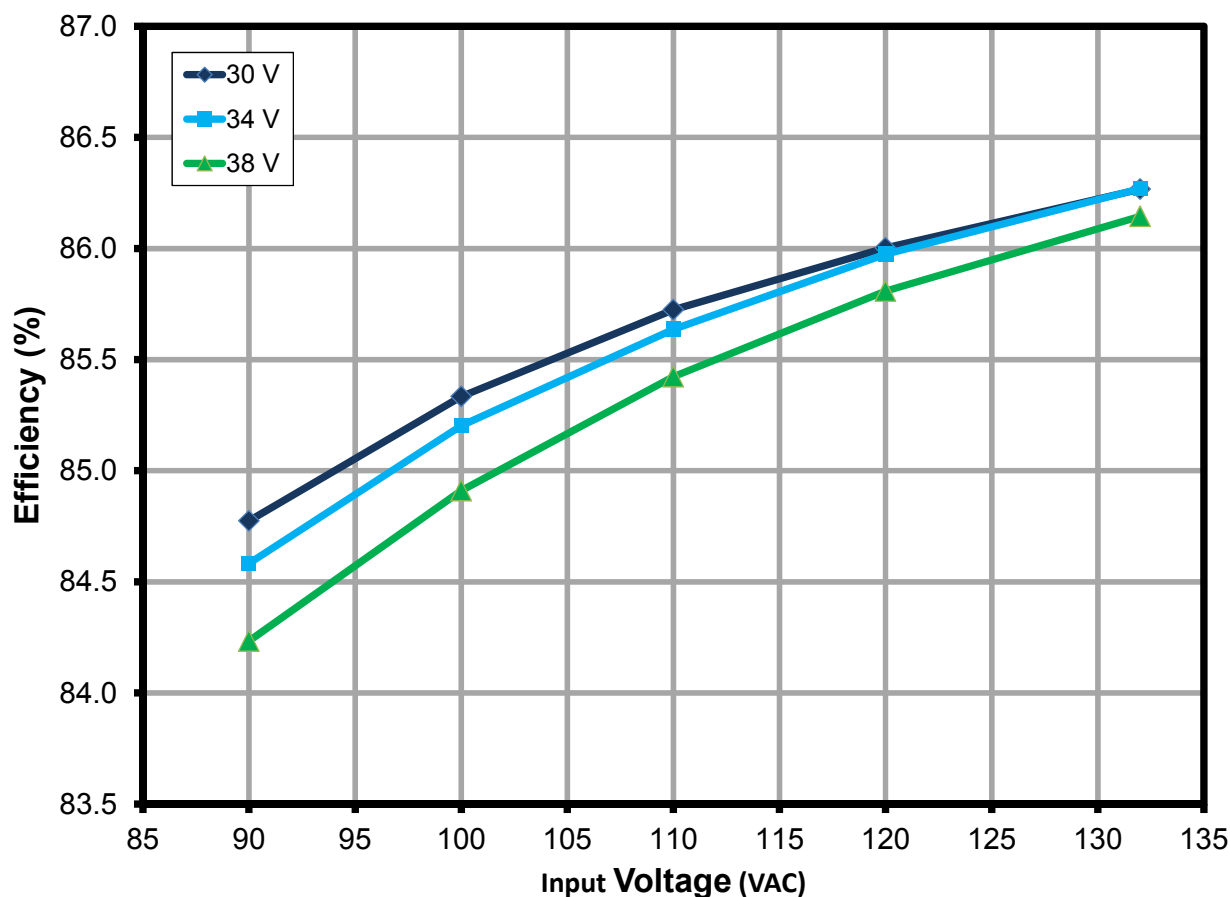


Figure 12 – Efficiency vs. Line and Load from the schematic shown in **Figure 4** (Full performance report in Section 16)



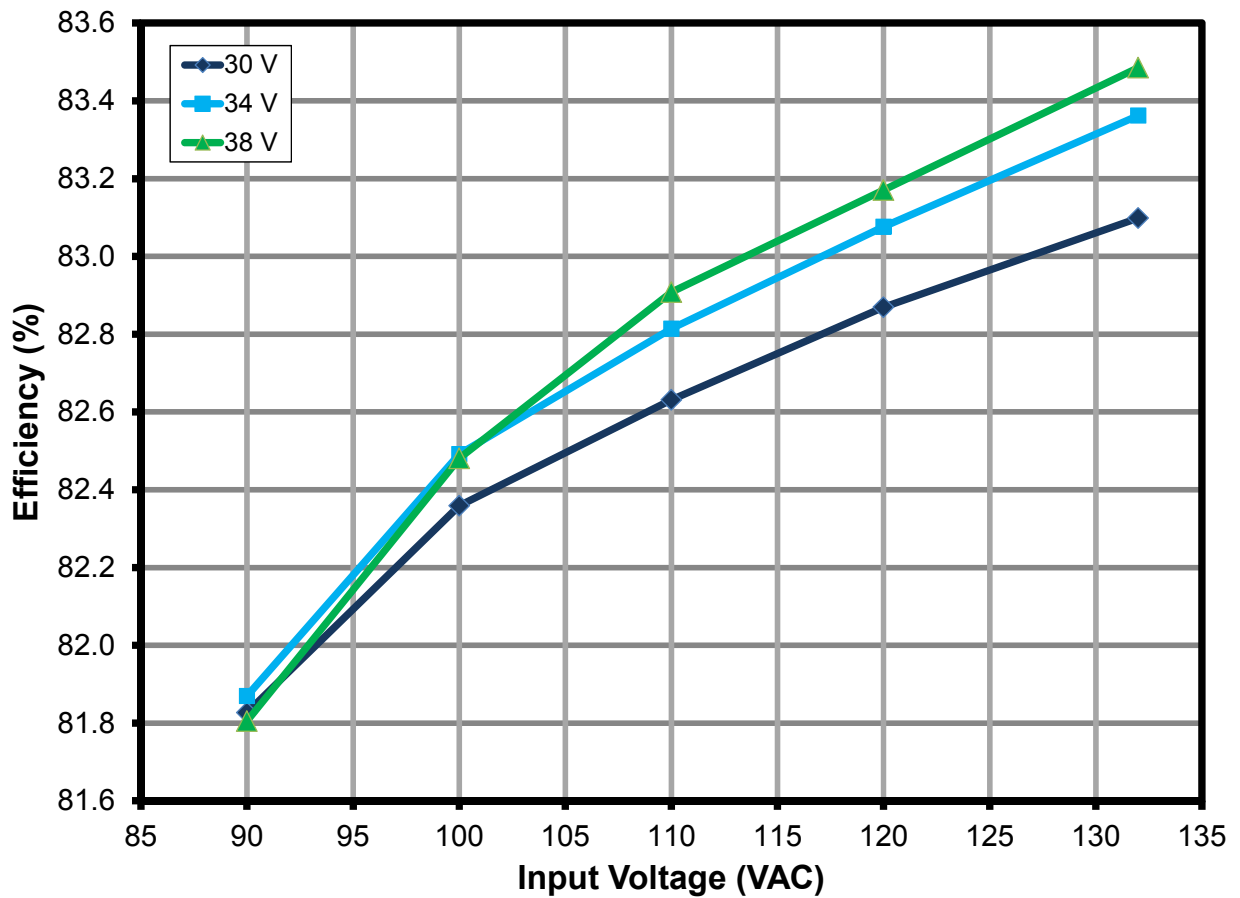


Figure 13 – Efficiency vs. Line and Load from the schematic shown in Figure 5