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Title	*Reference Design Report for a 150 W Power Factor Corrected LLC Power Supply Using HiperPFS™ -2 (PFS7326H) and HiperLCS™ (LCS702HG)*
Specification	90 VAC – 265 VAC Input; 150 W (~43 V at 0 - 3.5 A) Output (Constant Current)
Application	LED Streetlight
Author	Applications Engineering Department
Document Number	RDR-382
Date	February 17, 2017
Revision	6.4

Summary and Features

- Integrated PFC and LLC stages for a very low component count design
- Continuous mode PFC using low cost ferrite core
- High frequency (250 kHz) LLC for extremely small transformer size.
- >95% full load PFC efficiency at 115 VAC
- >95% full load LLC efficiency
  - System efficiency 91% / 93% at 115 VAC / 230 VAC
- Start-up circuit eliminates the need for a separate bias supply
- On-board current regulation and analog dimming

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Important Notes:

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

Since there is no separate bias converter in this design, ~280 VDC is present on bulk capacitor C14 immediately after the supply is powered down. For safety, this capacitor must be discharged with an appropriate resistor (10 k / 2 W is adequate), or the supply must be allowed to stand ~10 minutes before handling.

1 Introduction

This engineering report describes a 43 (nominal) V, 150 W reference design for a power supply for 90-265 VAC LED street lights and other high power lighting applications. The power supply is designed with a constant current output in order to directly drive a 150 W LED panel at 43 V.

The design is based on the PFS7326H for the PFC front-end and a LCS702HG for the LLC output stage.

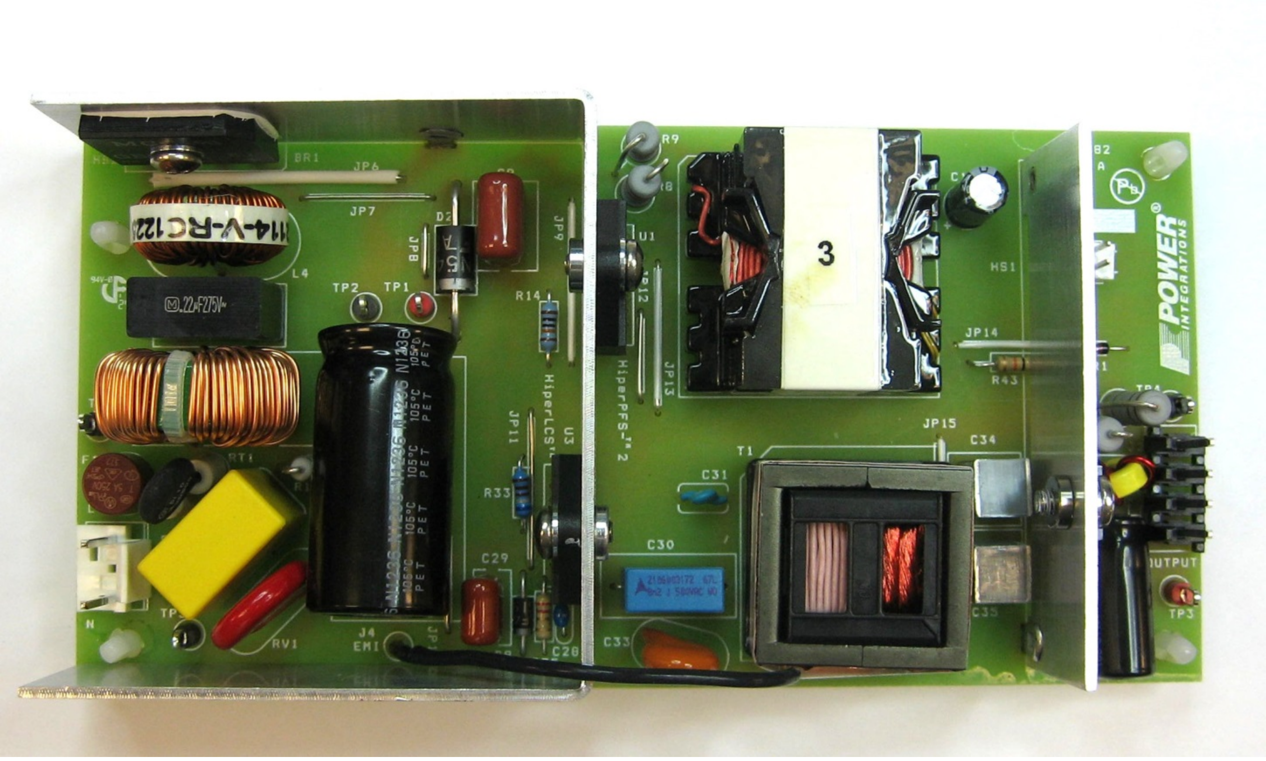

Figure 1 – RD-382 Photograph, Top View.

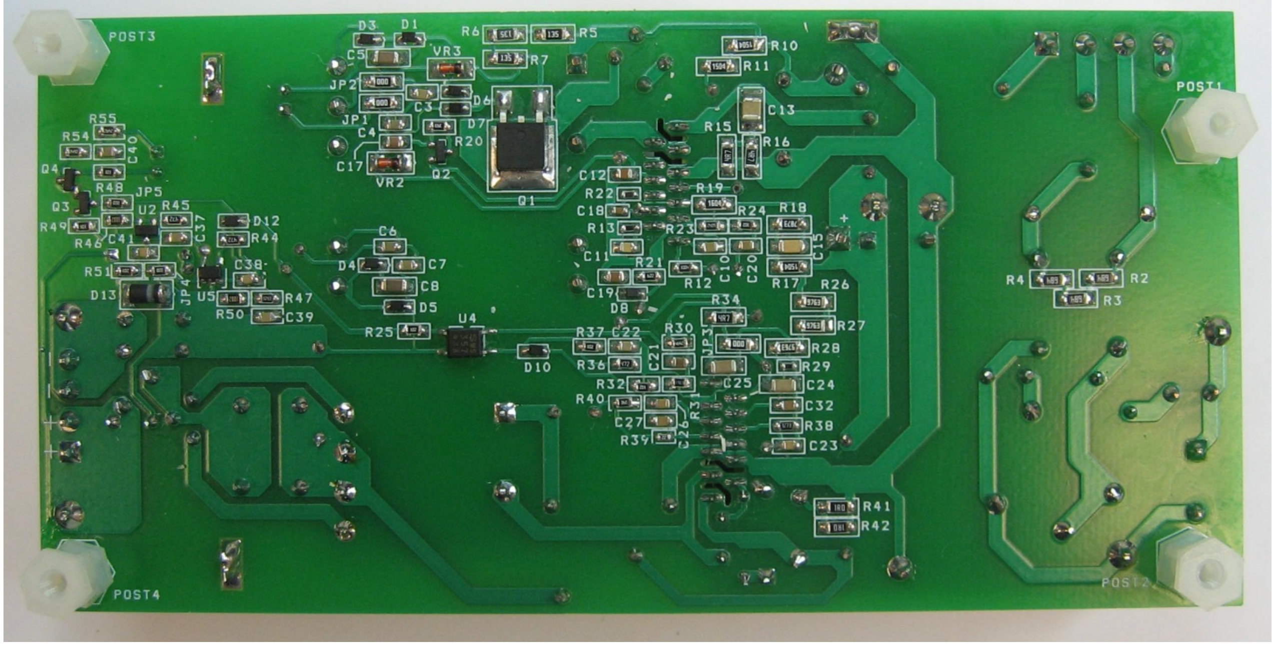

Figure 2 – RD-382 Photograph, Bottom View.

2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	90		265	VAC	3 Wire input.
Frequency	f_{LINE}	47	50/60	64	Hz	
Power Factor	**PF**	0.97				Full load, 230 VAC
Main Converter Output						
Output Voltage	V_{LG}		43		V	43 VDC (nominal - defined by LED load)
Output Ripple	$V_{RIPPLE(LG)}$			300	mV P-P	20 MHz bandwidth
Output Current	I_{LG}	0.00	3.5		A	Constant Current Supply protected for no-load condition
Total Output Power						
Continuous Output Power	P_{OUT}		150		W	
Peak Output Power	$P_{OUT(PK)}$			N/A	W	
Efficiency						
Total system at Full Load	η_{Main}		91 93		%	Measured at 115 VAC, Full Load Measured at 230 VAC, Full Load
Environmental						
Conducted EMI		Meets CISPR22B / EN55022B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Surge						1.2/50 µs surge, IEC 1000-4-5,
Differential		2			kV	Differential Mode: 2 Ω
Common Mode		4			kV	Common Mode: 12 Ω
Ambient Temperature	T_{AMB}	0		60	°C	See thermal section for conditions

3 Schematic

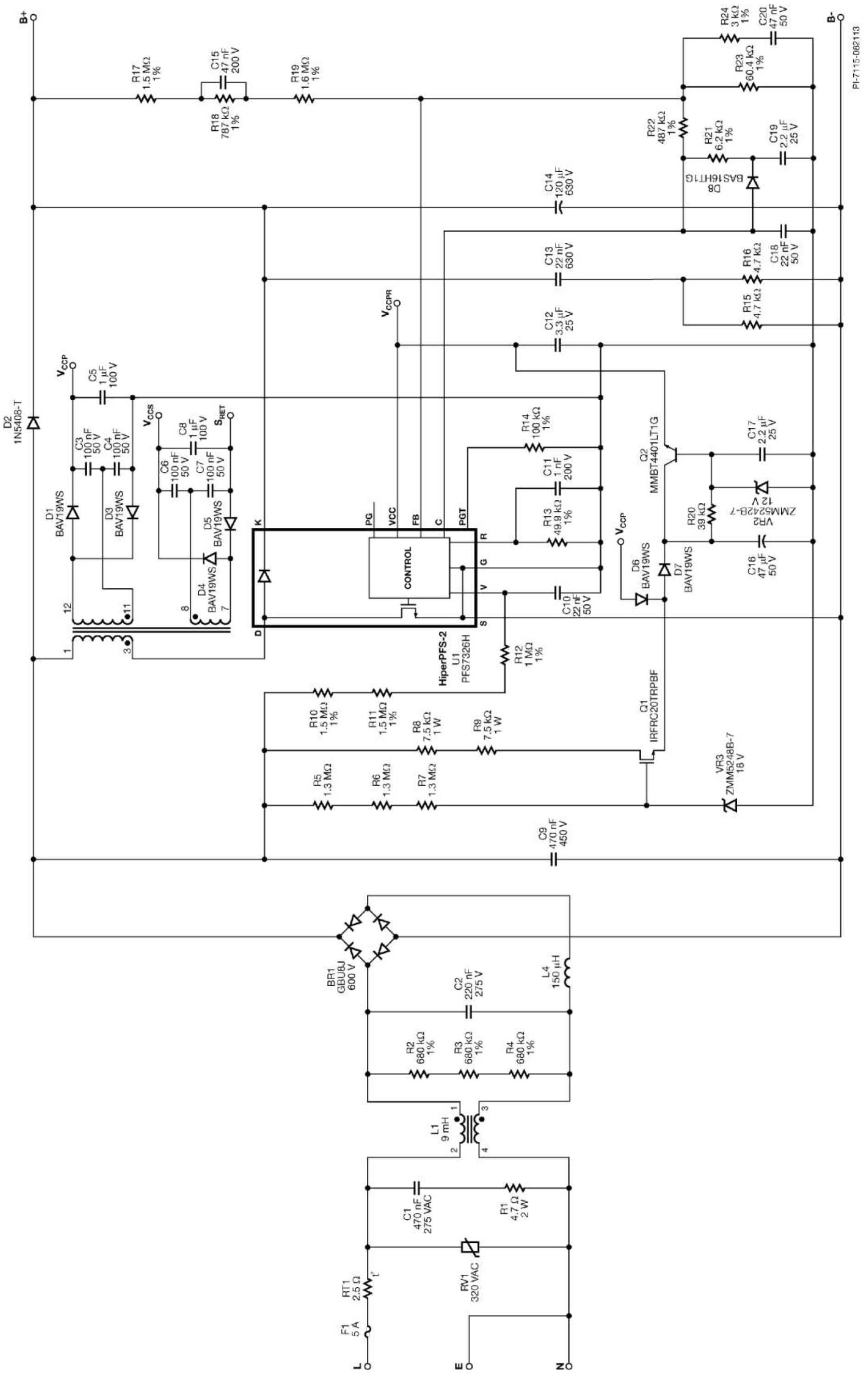

Figure 3 – Schematic RD-382 Street Light Power Supply Application Circuit - Input Filter, PFC Power Stage, and Bias Supplies.

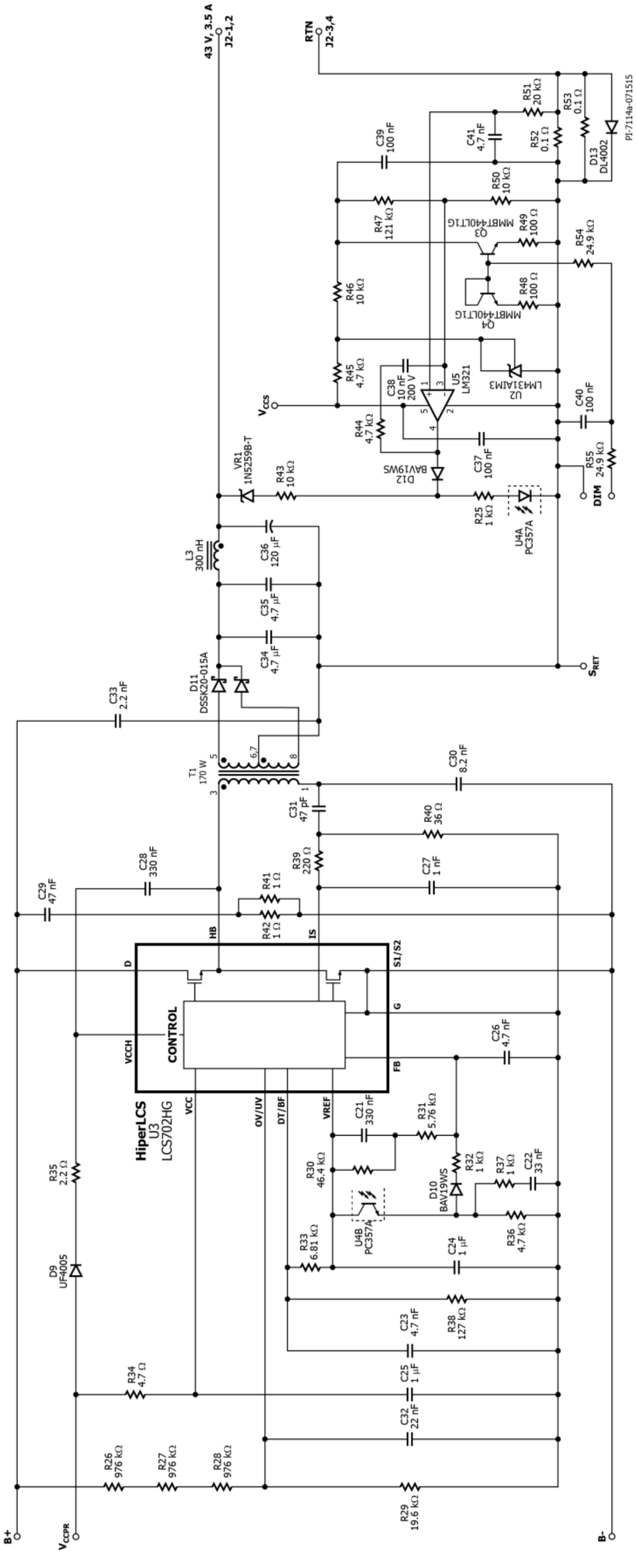

Figure 4 – Schematic of RD-382 Street light Power Supply Application Circuit, LLC Stage.

4 Circuit Description

4.1 *Input Filter / Boost Converter / Bias Supply*

The schematic in Figure 3 shows the input EMI filter, PFC stage, and primary bias supply/startup circuit. The power factor corrector utilizes the PFS7326H. The primary and secondary bias supplies are derived from windings on the PFC inductor (L2).

4.2 *EMI Filtering / Inrush Limiting*

Capacitors C1 and C2 are used to control differential mode noise. Resistor R1 is used for damping, improving power factor and reducing EMI. Resistors R2-4 discharge C1 and C2 when AC power is removed. Inductor L1 controls common mode EMI. The heat sink for U1, U3, and BR1 is connected to primary return to eliminate the heat sink as a source of radiated/capacitively coupled noise. Thermistor RT1 provides inrush limiting. Capacitor C33 (Figure 4) filters common mode EMI. Inductor L4 filters differential mode EMI.

4.3 *Main PFC Stage*

Components R17-19 and R23 provide output voltage feedback. Capacitor C15 provides fast dv/dt feedback to the U1 FB pin for rapid undershoot and overshoot response of the PFC circuit. Frequency compensation is provided by C19, C20, and R21, R22, and R24. Resistors R10-12 (filtered by C10) provide input voltage information to U1. Resistor R13 (filtered by C11) programs the U1 for “efficiency” mode. For more information about HiperPFS-2 efficiency mode, please refer to the HiperPFS-2 data sheet. Resistor R14 programs the “power good” threshold for U1.

Capacitor C12 provides local bypassing for U1. Diode D2 charges the PFC output capacitor (C14) when AC is first applied, routing the inrush current away from PFC inductor L2 and the internal output diode of U1. Capacitor C13 and R15-16 are used to reduce the length of the high frequency loop around components U1 and C14, reducing EMI. The resistors in series with C13 damp mid-band EMI peaks. The incoming AC is rectified by BR1 and filtered by C9. Capacitor C9 was selected as a low-loss polypropylene type to provide the high instantaneous current through L2 during U1 on-time. Thermistor RT1 limits inrush current at startup.

4.4 *Primary Bias Supply / Start-up*

Components R5-7, R8-R9, Q1, and VR3 provide startup bias for U1. Once U1 starts, components D1, D3, and, C3-5 generate a primary-referred bias supply via a winding on PFC choke L2. This is used to power both the PFC and LLC stages of the power supply. Once the primary bias supply voltage is established, it is used to turn off MOSFET Q1 via diode D6, reducing power consumption. Resistors R8 and R9 protect Q1 from excessive power dissipation if the power supply fails to start.

Components D7, Q2, C16-17 and VR2 regulate the bias supply voltage for U1 and U3. Components D4 and D5 and C6-8 generate a bias supply for the secondary control circuitry via a triple insulated winding on L2.

4.5 *LLC Converter*

The schematic in Figures 4 depicts a ~43 V, 150 W LLC DC-DC converter with constant current output implemented using the LCS702HG.

4.6 *Primary*

Integrated circuit U3 incorporates the control circuitry, drivers and output MOSFETs necessary for an LLC resonant half-bridge (HB) converter. The HB output of U3 drives output transformer T1 via a blocking/resonating capacitor (C30). This capacitor was rated for the operating ripple current and to withstand the high voltages present during fault conditions.

Transformer T1 was designed for a leakage inductance of 49 μH. This, along with resonating capacitor C30, sets the primary series resonant frequency at ~259 kHz according to the equation:

$$f_R = \frac{1}{6.28\sqrt{L_L \times C_R}}$$

Where f_R is the series resonant frequency in Hertz, L_L is the transformer leakage inductance in Henries, and C_R is the value of the resonating capacitor (C30) in Farads.

The transformer turns ratio was set by adjusting the primary turns such that the operating frequency at nominal input voltage and full load is close to, but slightly less than, the previously described resonant frequency.

An operating frequency of 250 kHz was found to be a good compromise between transformer size, output filter capacitance (enabling ceramic/film capacitors), and efficiency.

The number of secondary winding turns was chosen to provide a good compromise between core and copper losses. AWG #44 Litz wire was used for the primary and AWG #42 Litz wire, for the secondary, this combination providing high-efficiency at the operating frequency (~250 kHz). The number of strands within each gauge of Litz wire was chosen in order to achieve a balance between winding fit and copper losses.

The core material selected was PW4 (from Itacoil). This material provided good (low loss) performance.

Components D9, R35, and C28 comprise the bootstrap circuit to supply the internal high-side driver of U3.

Components R34 and C25 provide filtering and bypassing of the +12 V input and the V_{CC} supply for U1. *Note:* V_{CC} *voltage of >15 V may damage U3.*

Voltage divider resistors R26-29 set the high-voltage turn-on, turn-off, and overvoltage thresholds of U3. The voltage divider values are chosen to set the LLC turn-on point at 360 VDC and the turn-off point at 285 VDC, with an input overvoltage turn-off point at 473 VDC. Built-in hysteresis sets the input undervoltage turn-off point at 280 VDC.

Capacitor C29 is a high-frequency bypass capacitor for the +380 V input, connected with short traces between the D and S1/S2 pins of U3. Series resistors R41-42 provide EMI damping.

Capacitor C31 forms a current divider with C30, and is used to sample a portion of the primary current. Resistor R40 senses this current, and the resulting signal is filtered by R39 and C27. Capacitor C31 should be rated for the peak voltage present during fault conditions, and should use a stable, low-loss dielectric such as metalized film, SL ceramic, or NPO/COG ceramic. The capacitor used in the RD-382 was a ceramic disc with “SL” temperature characteristic, commonly used in the drivers for CCFL tubes. The values chosen set the 1 cycle (fast) current limit at 4.25 A, and the 7-cycle (slow) current limit at 2.35 A, according to the equation:

$$I_{CL} = \frac{0.5}{\left(\frac{C31}{C30 + C31}\right) \times R40}$$

I_{CL} is the 7-cycle current limit in Amperes, R40 is the current limit resistor in Ohms, and C30 and C31 are the values of the resonating and current sampling capacitors in nanofarads, respectively. For the one-cycle current limit, substitute 0.9 V for 0.5 V in the above equation.

Resistor R39 and capacitor C27 filter primary current signal to the IS pin. Resistor R39 is set to 220 Ω, the minimum recommended value. The value of C27 is set to 1 nF to avoid nuisance tripping due to noise, but not so high as to substantially affect the current limit set values as calculated above. These components should be placed close to the IS pin for maximum effectiveness. The IS pin can tolerate negative currents, the current sense does not require a complicated rectification scheme.

The Thevenin equivalent combination of R33 and R38 sets the dead time at 330 ns and maximum operating frequency for U3 at 847 kHz. The DT/BF input of U3 is filtered by

C23. The combination of R33 and R38 also selects burst mode “1” for U3. This sets the lower and upper burst threshold frequencies at 382 kHz and 437 kHz, respectively.

The FEEDBACK pin has an approximate characteristic of 2.6 kHz per μA into the FEEDBACK pin. As the current into the FEEDBACK pin increases so does the operating frequency of U3, reducing the output voltage. The series combination of R30 and R31 sets the minimum operating frequency for U3 at ~160 kHz. This value was set to be slightly lower than the frequency required for regulation at full load and minimum bulk capacitor voltage. Resistor R30 is bypassed by C21 to provide output soft start during start-up by initially allowing a higher current to flow into the FEEDBACK pin when the feedback loop is open. This causes the switching frequency to start high and then decrease until the output voltage reaches regulation. Resistor R31 is typically set at the same value as the parallel combination of R33 and R38 so that the initial frequency at soft-start is equal to the maximum switching frequency as set by R33 and R38. If the value of R31 is less than this, it will cause a delay before switching occurs when the input voltage is applied.

Optocoupler U4 drives the U3 FEEDBACK pin through R32, which limits the maximum optocoupler current into the FEEDBACK pin. Capacitor C26 filters the FEEDBACK pin. Resistor R36 loads the optocoupler output to force it to run at a relatively high quiescent current, increasing its gain. Resistors R32 and R36 also improve large signal step response and burst mode output ripple. Diode D10 isolates R36 from the F_{MAX}/soft start network.

4.7 *Output Rectification*

The output of transformer T1 is rectified and filtered by D11 and C34-35. These capacitors have a polyester dielectric, chosen for output ripple current rating. Output rectifier D11 is a 150 V Schottky rectifier chosen for high efficiency. Intertwining the transformer secondary halves (see transformer construction details in section 8) reduces leakage inductance between the two secondary halves, reducing the worst-case peak inverse voltage and allowing use of a 150V Schottky diode with consequent higher efficiency. Additional output filtering is provided by L3 and C36. Capacitor C36 also damps the LLC output impedance peak at ~30 kHz caused by the LLC “virtual” output series R-L and output capacitors C34-35.

4.8 *Output Current and Voltage Control*

Output current is sensed via resistors R52 and R53. These resistors are clamped by diode D13 to avoid damage to the current control circuitry during an output short circuit. Components R45 and U2 provide a voltage reference for current sense amplifier U5. The reference voltage is divided down by R46-47 and R50, and filtered by C39. Voltage from the current sense resistor is filtered by R51 and C41 and applied to the non-inverting input of U5. Opamp U5 drives optocoupler U4 via D12 and R25. Components R25, R44, R51, C38, and C41 are used for frequency compensation of the current loop.

Components VR1 and R43 provide output voltage sensing to protect the power supply in case the output load is removed. These components were selected using a relatively large value for R43 and a relatively low voltage for VR1 to provide a soft voltage limiting characteristic. This helps prevent oscillation at the knee of the V-I curve and improves the startup characteristics of the supply into the specified LED load.

Components J3, Q3-4, R48-49, R54-55, R46, and C40 are used to provide a remote dimming capability. A dimming voltage at J3 is converted to a current by R54 and R55 and applied to R46 via current mirror Q3-Q4. This current pulls down on the reference voltage to current sense amplifier U5 and reduces the programmed output current. A dimming voltage of 0-10 VDC provides an output current range of 100% at 0 V to ~20% at 10 VDC input.

5 PCB Layout

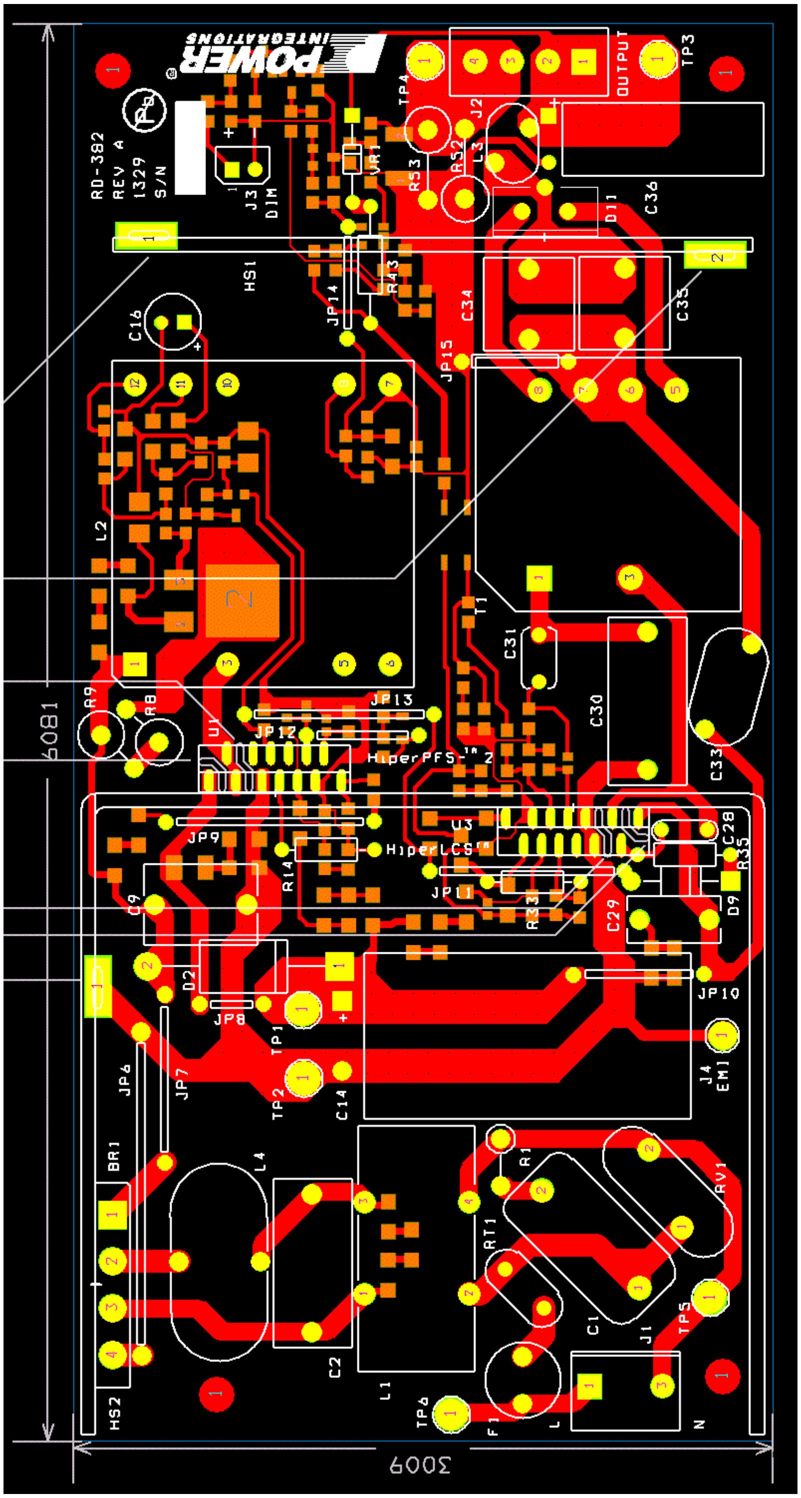

Figure 5 – Printed Circuit Layout, Top Side.

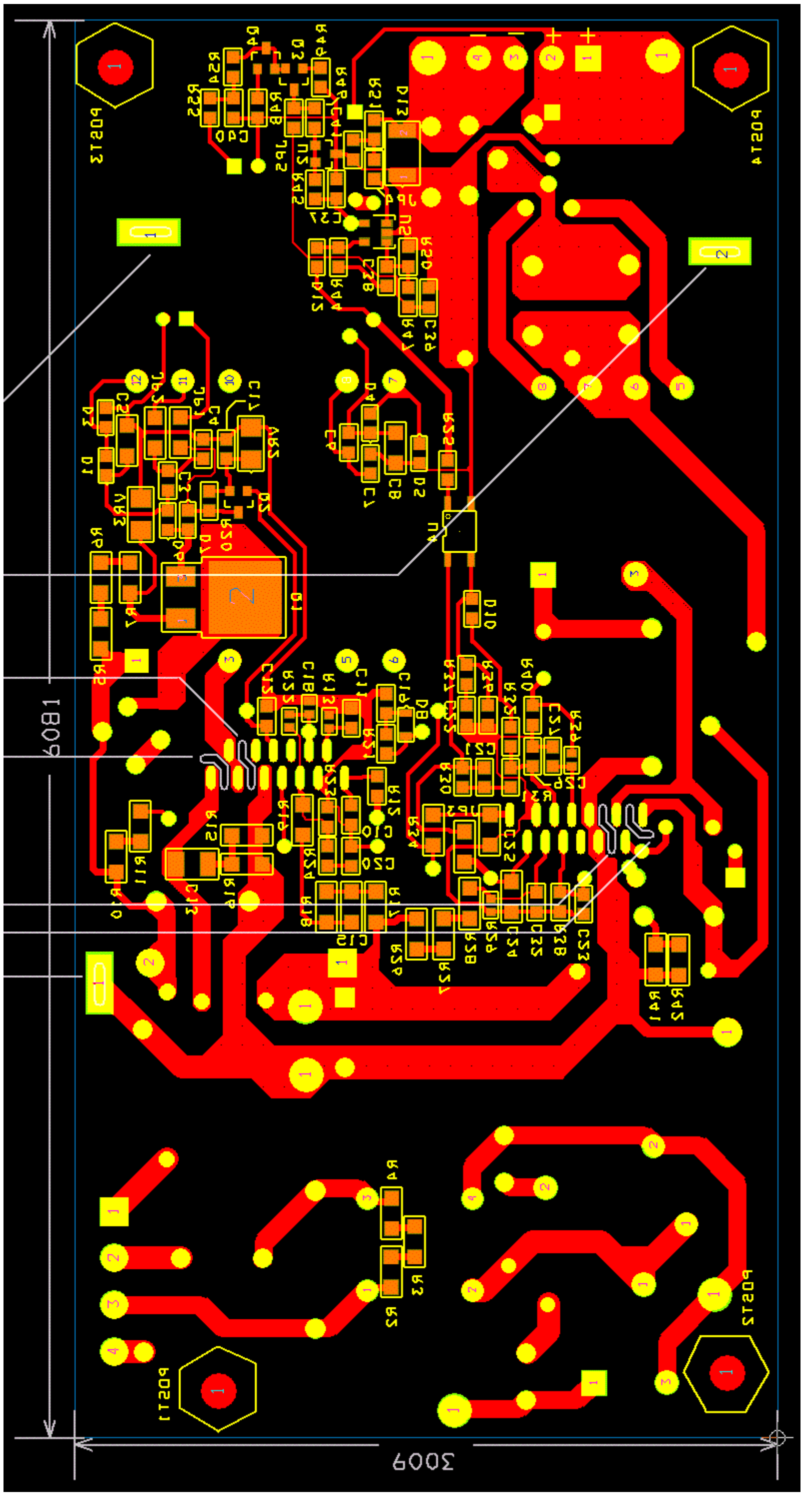

Figure 6 – Printed Circuit Layout, Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 8 A, Bridge Rectifier, GBU Case	GBU8J-BP	Micro Commercial
2	1	C1	470 nF, 275 VAC, Film, X2	PX474K31D5	Carli
3	1	C2	220 nF, 275 VAC, Film, X2	ECQ-U2A224ML	Panasonic
4	7	C3 C4 C6 C7 C37 C39 C40	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
5	2	C5 C8	1 µF, 100 V, Ceramic, X7R, 1206	HMK316B7105KL-T	Taiyo Yuden
6	1	C9	470 nF, 450 V, METALPOLYPRO	ECW-F2W474JAQ	Panasonic
7	1	C10	22 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H223K	Panasonic
8	1	C11	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
9	1	C12	3.3 µF, 25 V, Ceramic, X7R, 0805	C2012X7R1E335K	TDK
10	1	C13	22 nF, 630 V, Ceramic, X7R, 1210	GRM32QR72J223KW01L	Murata
11	1	C14	120 µF, 450 V, Electrolytic, 20 %, (18 x 37mm)	450BXW120MEFC18X35	Rubycon
12	1	C15	47 nF, 200 V, Ceramic, X7R, 1206	12062C473KAT2A	AVX
13	1	C16	47 µF, 50 V, Electrolytic, 20 %, (6.3 x 12.5 mm)	50YXM47MEFC6.3X11	Rubycon
14	2	C17 C19	2.2 µF, 25 V, Ceramic, X7R, 0805	C2012X7R1E225M	TDK
15	1	C18	22 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H223K	TDK
16	1	C20	47 nF, 50 V, Ceramic, X7R, 0805	GRM21BR71H473KA01L	Murata
17	1	C21	330 nF, 50 V, Ceramic, X7R, 0805	GRM219R71H334KA88D	Murata
18	1	C22	33 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB333	Yageo
19	3	C23 C26 C41	4.7 nF, 200 V, Ceramic, X7R, 0805	08052C472KAT2A	AVX
20	2	C24 C25	1 µF, 25 V, Ceramic, X7R, 1206	C3216X7R1E105K	TDK
21	1	C27	1 nF, 200 V, Ceramic, X7R, 0805	08052C102KAT2A	AVX
22	1	C28	330 nF, 50 V, Ceramic, X7R	FK24X7R1H334K	TDK
23	1	C29	47 nF, 630 V, Film	MEXPD24704JJ	Duratech
24	1	C30	8.2 nF, 1000V VDC, Film	B32671L0822J000	Epcos
25	1	C31	47 pF, 1 kV, Disc Ceramic	DEA1X3A470JC1B	Murata
26	1	C32	22 nF, 200 V, Ceramic, X7R, 0805	08052C223KAT2A	AVX
27	1	C33	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
28	2	C34 C35	4.7 µF, 63 V, Polyester Film	B32560J475K	Epcos
29	1	C36	120 µF, 63 V, Electrolytic, Gen. Purpose, (8 x 22)	EEU-FR1J121LB	Panasonic
30	1	C38	10 nF, 200 V, Ceramic, X7R, 0805	08052C103KAT2A	AVX
31	2	CLIP_LCS_PFS1 CLIP_LCS_PFS2	Heat sink Hardware, Clip LCS_II/PFS	EM-285V0	Kang Yang Hardware Enterprise
32	8	D1 D3 D4 D5 D6 D7 D10 D12	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
33	1	D2	1000 V, 3 A, Recitifier, DO-201AD	1N5408-T	Diodes, Inc.
34	1	D8	75 V, 200 mA, Rectifier, SOD323	BAS16HT1G	ON Semi
35	1	D9	600 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4005-E3	Vishay
36	1	D11	150 V, 20 A, Schottky, TO-220AB	DSSK 20-015A	IXYS
37	1	D13	100 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4002-13-F	Diodes, Inc.
38	1	F1	5 A, 250V, Slow, TR5	37215000411	Wickman
39	1	HS1	HEAT SINK, Custom, Al, 3003, 0.062" Thk		Custom
40	1	HS2	HEAT SINK, Custom, Al, 3003, 0.062" Thk		Custom
41	1	J1	3 Position (1 x 3) header, 0.156 pitch, Vertical	B3P-VH	JST
42	1	J2	4 Position (1 x 4) header, 0.156 pitch, Vertical	26-48-1045	Molex
43	1	J3	2 Position (1 x 2) header, 0.1 pitch, Vertical	22-23-2021	Molex
44	3	JP1 JP2 JP3	0 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic

45	2	JP4 JP5	0 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEY0R00V	Panasonic
46	1	JP6	Wire Jumper, Insulated, TFE, #18 AWG, 1.4 in	C2052A-12-02	Alpha
47	1	JP7	Wire Jumper, Non insulated, #22 AWG, 0.7 in	298	Alpha
48	1	JP8	Wire Jumper, Non insulated, #22 AWG, 0.3 in	298	Alpha
49	1	JP9	Wire Jumper, Insulated, #24 AWG, 0.9 in	C2003A-12-02	Gen Cable
50	1	JP10	Wire Jumper, Non insulated, #22 AWG, 0.6 in	298	Alpha
51	1	JP11	Wire Jumper, Non insulated, #22 AWG, 0.8 in	298	Alpha
52	2	JP12 JP15	Wire Jumper, Non insulated, #22 AWG, 0.5 in	298	Alpha
53	1	JP13	Wire Jumper, Insulated, #24 AWG, 0.8 in	C2003A-12-02	Gen Cable
54	1	JP14	Wire Jumper, Insulated, #24 AWG, 0.5 in	C2003A-12-02	Gen Cable
55	1	L1	9 mH, 5 A, Common Mode Choke	T22148-902S P.I. Custom	Fontaine
56	1	L2	Custom, RD-382 PFC Choke, 437 uH, PQ32/30, Vertical, 9 pins		Power Integrations
57	1	L3	Output Inductor, Custom, 300 nH, ±15%, constructed on Micrometals T30-26 toroidal core		Power Integrations
58	1	L4	150 µH, 3.4 A, Vertical Toroidal	2114-V-RC	Bourns
59	4	POST1 POST2 POST3 POST4	Post, Circuit Board, Female, Hex, 6-32, snap, 0.375L, Nylon	561-0375A	Eagle Hardware
60	1	Q1	400 V, 2 A, 4.4 Ohm, 600 V, N-Channel, DPAK	IRFRC20TRPBF	Vishay
61	3	Q2 Q3 Q4	NPN, Small Signal BJT, GP SS, 40 V, 0.6 A, SOT-23	MMBT4401LT1G	Diodes, Inc.
62	1	R1	4.7 Ω, 2 W, Flame Proof, Pulse Withstanding, Wire Wound	WHS2-4R7JA25	IT Elect_Welwyn
63	3	R2 R3 R4	680 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ684V	Panasonic
64	3	R5 R6 R7	1.3 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ135V	Panasonic
65	2	R8 R9	7.5 kΩ, 5%, 1 W, Metal Oxide	RSF100JB-7K5	Yageo
66	3	R10 R11 R17	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
67	1	R12	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
68	1	R13	49.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4992V	Panasonic
69	1	R14	100 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-100K	Yageo
70	3	R15 R16 R34	4.7 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ4R7V	Panasonic
71	1	R18	787 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7873V	Panasonic
72	1	R19	1.60 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1604V	Panasonic
73	1	R20	39 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ393V	Panasonic
74	1	R21	6.2 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ622V	Panasonic
75	1	R22	487 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4873V	Panasonic
76	1	R23	60.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6042V	Panasonic
77	1	R24	3 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ302V	Panasonic
78	3	R25 R32 R37	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
79	3	R26 R27 R28	976 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF9763V	Panasonic
80	1	R29	19.6 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1962V	Panasonic
81	1	R30	46.4 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4642V	Panasonic
82	1	R31	5.76 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5761V	Panasonic
83	1	R33	6.81 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-6K81	Yageo
84	1	R35	2.2 Ω, 5%, 1/4 W, Carbon Film	CFR-25JB-2R2	Yageo
85	3	R36 R44 R45	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
86	1	R38	127 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1273V	Panasonic
87	1	R39	220 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ221V	Panasonic
88	1	R40	36 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ360V	Panasonic
89	2	R41 R42	1 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ1R0V	Panasonic
90	1	R43	10 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-10K	Yageo
91	2	R46 R50	10 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1002V	Panasonic

92	1	R47	121 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1213V	Panasonic
93	2	R48 R49	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
94	1	R51	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
95	2	R52 R53	0.1 Ω, 5%, 2 W, Thick Oxide	MO200J0R1B	Synton-Tech
96	2	R54 R55	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	Panasonic
97	1	RT1	NTC Thermistor, 2.5 Ω, 5 A	SL10 2R505	Ametherm
98	4	RTV1 RTV2 RTV3 RTV4	Thermally conductive Silicone Grease	120-SA	Wakefield
99	1	RV1	320 V, 80 J, 14 mm, RADIAL	V320LA20AP	Littlefuse
100	4	SCREW1 SCREW2 SCREW3 SCREW4	SCREW MACHINE PHIL 6-32 X 5/16 SS	PMSSS 632 0031 PH	Building Fasteners
101	2	SPACER_CER1 SPACER_CER2	SPACER RND, Steatite C220 Ceramic	CER-2	Richco
102	1	T1	Integrated Resonant Transformer, Horizontal, 8 pins	TRLEV25043A	Itacoil
103	2	TP1 TP3	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
104	4	TP2 TP4 TP5 TP6	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
105	1	U1	HiperPFS-2, ESIP16/13	PFS7326H	Power Integrations
106	1	U2	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semi
107	1	U3	HiperLCS, ESIP16/13	LCS702HG	Power Integrations
108	1	U4	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N1TJ00F	Sharp
109	1	U5	OP AMP SINGLE LOW PWR SOT23-5	LM321MF	National Semi
110	1	VR1	39 V, 5%, 500 mW, DO-35	1N5259B-T	Diodes, Inc.
111	1	VR2	12 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5242B-7	Diodes, Inc.
112	1	VR3	18 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5248B-7	Diodes, Inc.
114	4	WASHER1 WASHER2 WASHER3 WASHER4	Washer Flat #6, SS, Zinc Plate, 0.267 OD x 0.143 ID x 0.032 Thk	620-6Z	Olander

7 LED Panel Characterization

A commercial 150 W LED streetlight was used to test the RD-382 power supply. The LED array consisted of (6) 7 X 4 panels, as 4 wide, 7 deep. For the purposes of testing, the six panels were connected in series-parallel, resulting in an LED array 12 wide, 14 deep (see Figures 8 and 9). The V-I characteristic of the LED panels connected in this manner is shown below in Figure 7.

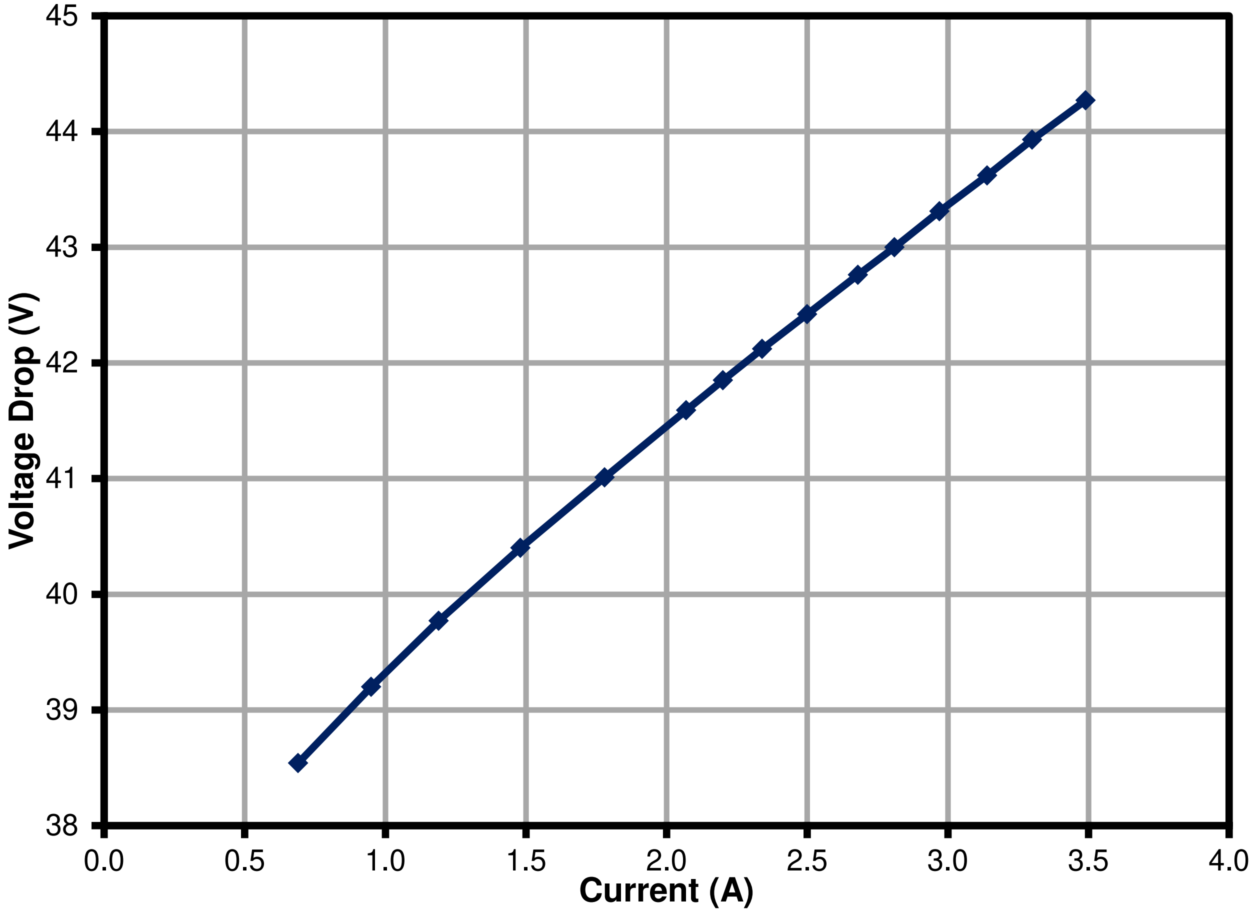

Figure 7 – Streetlight LED Array V-I Characteristic.

7.1 *LED Panel Current Sharing*

For the purpose of this report, the six LED panels in the street light were partitioned into 3 sections, each section consisting of two LED panels in series. Each panel was internally connected as an array of LEDs 4 wide and 7 deep so that two panels connected in series consisted of an array of LEDS 4 wide by 14 deep. The three sections were connected in parallel, forming a total LED load 12 wide and 14 deep. Using a DC current probe, the current in each 4 wide by 14 deep section was measured to determine the current distribution between sections, with results shown below.

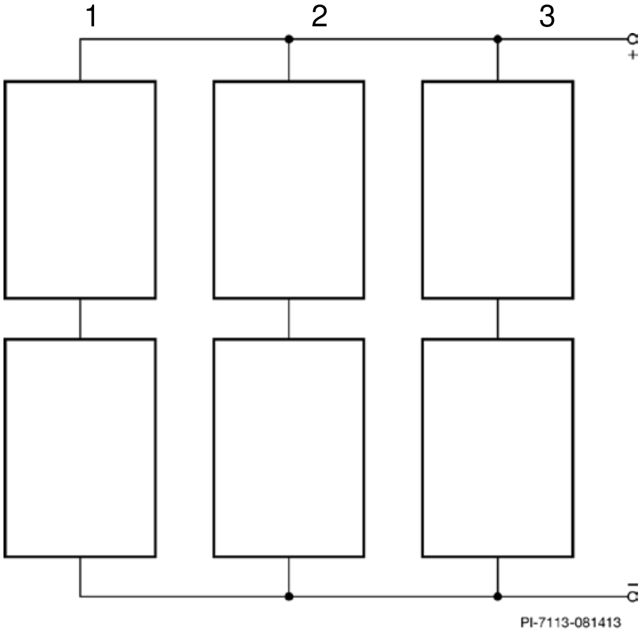

Figure 8 – LED Test Panel Layout.

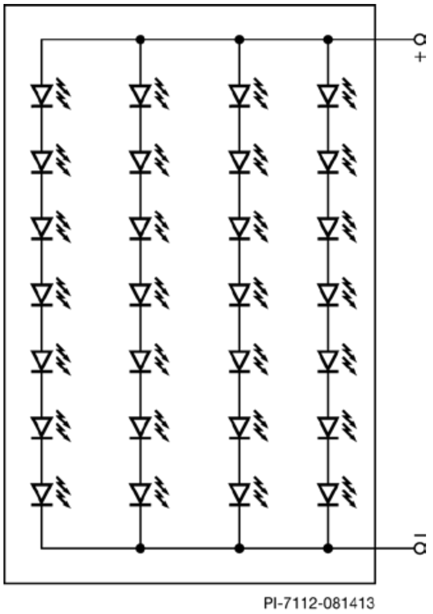

Figure 9 – Array of LEDs in Each Test Panel.

Section #	1	2	3
Current (A)	1.113 A	1.159 A	1.126 A

Maximum difference between sections was <5%.

7.2 *Constant Voltage Load*

Since this power supply has a constant current output tailored for a relatively fixed constant voltage load, the usual constant current electronic load cannot be used for testing. For bench testing at maximum power, a constant resistance load can be used, set such that the supply output is at maximum current and an output voltage of 43-44 V, as indicated by the V-I curve shown in Figure 7. Other testing, including dimming and gain-phase, will require the actual LED load or a constant voltage load that closely mimics its characteristics.

The streetlight LED as a load was both large and heavy. In order to facilitate EMI and surge testing, a constant voltage load was constructed to emulate the behavior of the LED array in a much smaller package. The circuit is shown in Figure 8. The load consists of paralleled power Darlington transistors Q1-5, each with an emitter resistor (R1-5) to facilitate current sharing. Base resistors R6-10 help prevent oscillation. A string of thirteen 3 mm blue LEDs (D1-13) are used as a voltage reference to mimic the characteristics of the LED panel. Resistor R11 is adjusted to vary the voltage at which the load turns on to match the characteristics of the LED panel. Resistors R12-14 add extra impedance in series with the load to approximate the characteristics of the LED panel. The completed array with heat sink is shown in Figure 9. A small fan was used to cool the heat sink when the load was operated for extended periods at full power. The V-I characteristics of the CV load are shown superimposed on those of the LED array in Figure 10. An electronic load with appropriate rating and a constant voltage option (with some series resistance) could also be used for testing, but this load has the advantage that no external AC power is needed.

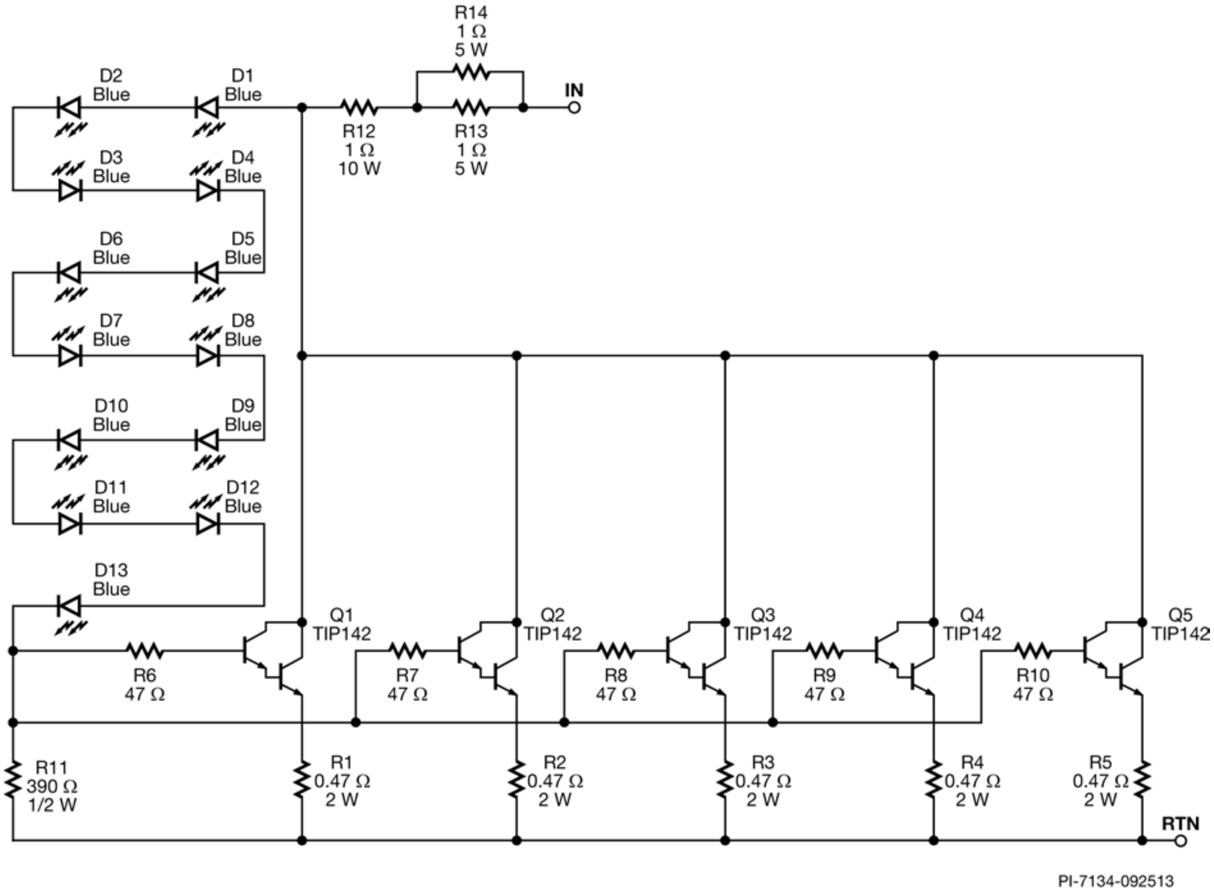

Figure 10 – Constant Voltage Load Schematic.

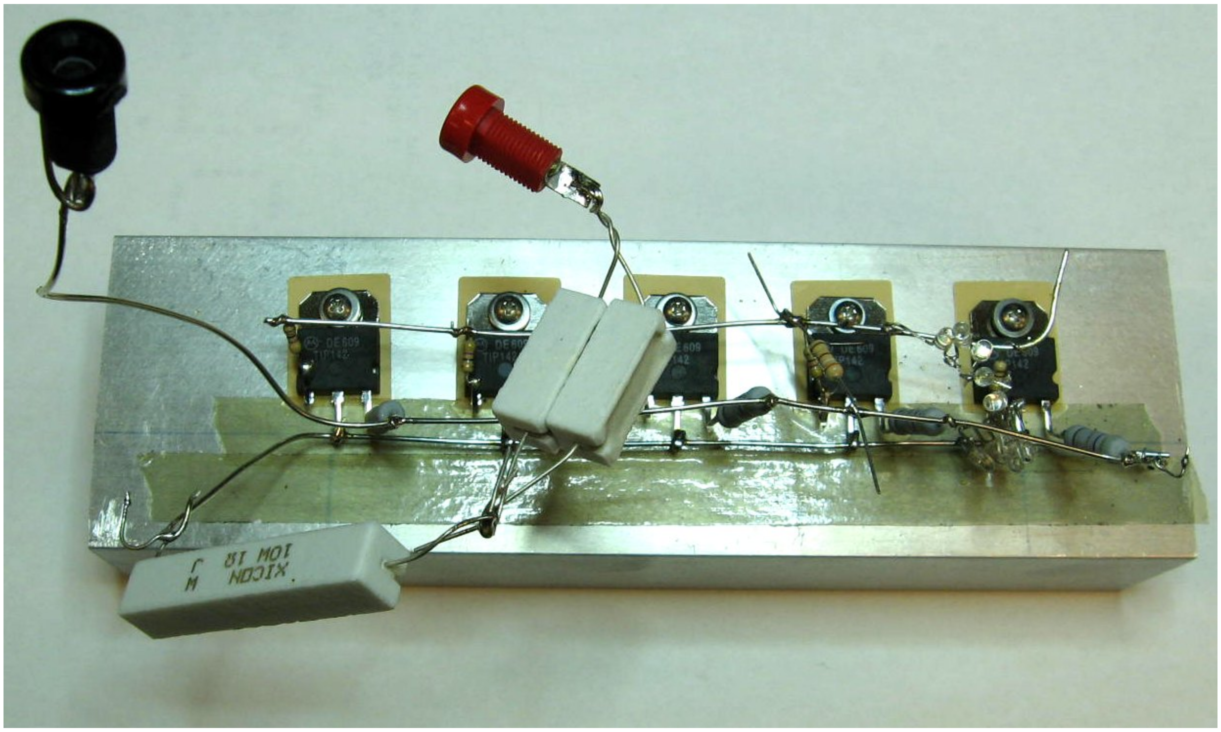

Figure 11 – Constant Voltage Load with Heat Sink.

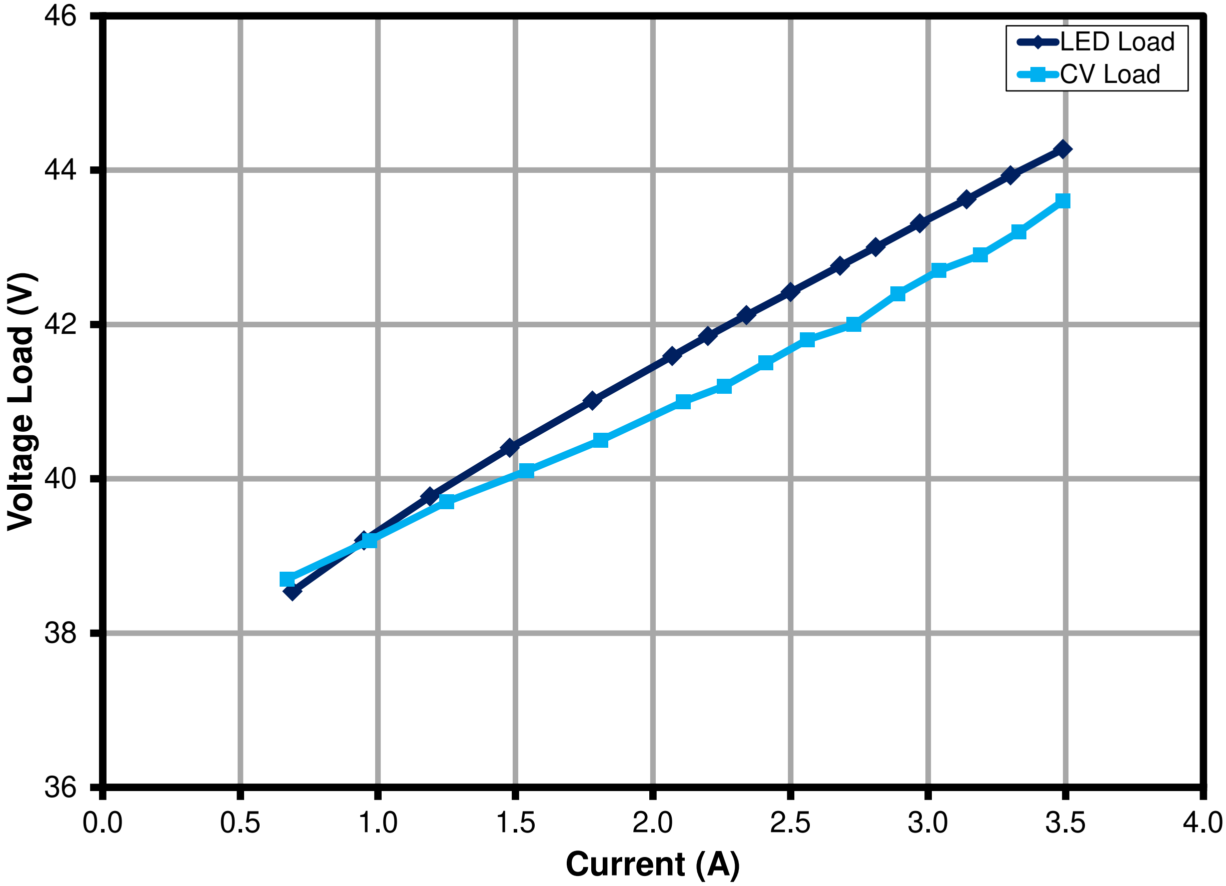

Figure 12 – Comparison of Streetlight LED Array V-I Characteristic with CV Load**.**