



High intensity LED driver using the L5970D/L5973D

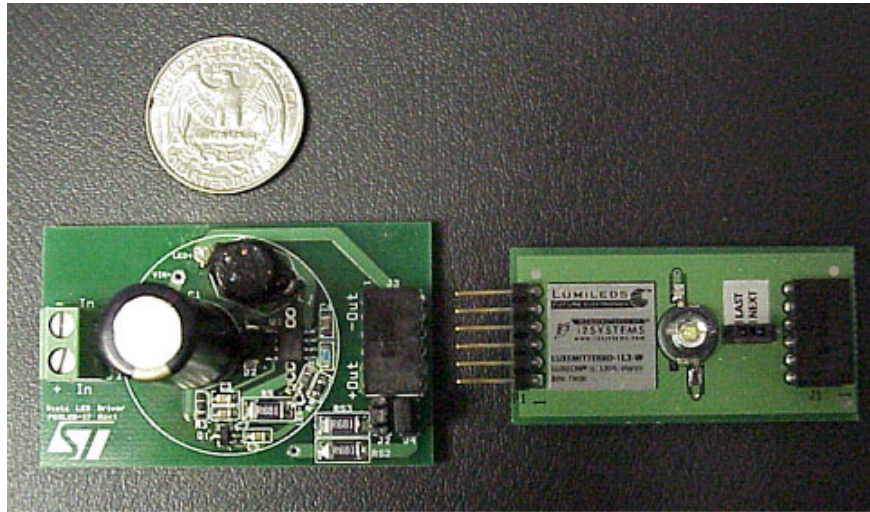
Introduction

High brightness LEDs are becoming a prominent source of light and often have better efficiency and reliability than conventional light sources. While LEDs can operate from an energy source as simple as a battery and resistor, most applications require an efficient energy source not only for the reduction of losses, but also to maintain the brightness of the LED itself. For applications that are powered from low voltage AC sources typically used in landscape lighting or low voltage DC sources that may be used in automotive applications or to meet safety requirements, high efficiency DC-DC converters configured for constant output current provide a high efficiency driver that can operate over a relatively wide range of input voltages to drive series strings of one to several LEDs

This application note describes a DC-DC converter circuit that can easily be configured to drive LEDs at several different output currents and can be configured for either AC or DC input. The circuit uses the L5973D monolithic step down converter configured to drive a series string of LEDs in a constant current mode.

L5970D is a step down monolithic power switching regulator capable of delivering 1A while the L5973D is able to deliver 2A at output voltages from 1.25V to 35V. Both devices use internal P-Channel D-MOS transistors (with typical $R_{DS(on)}$ of 250m Ω) as the switching element to minimize the size of external components. An internal oscillator fixes the switching frequency at 250kHz.

The brightness of the LED (Light Emitting Diode), or light intensity as measured in Lumens, is proportional to the forward current flowing through the LED. Since the forward voltage drop of the LED can vary from device to device it is important to drive the LEDs with a constant current driver to be able to get good matching of the light output, especially when they are located side by side where variations in light intensity are quickly noticed. A typical way to drive LEDs in the constant current mode is to use a DC-DC converter configured to give a constant current output. The circuit shown in [Figure 7](#), uses the L5973D in a constant current configuration to drive LEDs

Figure 1. Board Layout

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1 DESCRIPTION OF BOARD

The evaluation board shown in [Figure 1](#). was designed so that it can be configured to accept several different input voltages that are common for automotive and lighting applications. The most common input voltages are 12Vac, 12Vdc (for automotive) and 24Vdc. The board also allows the user to select the output current using the jumpers J2 and J4 on the board without having to change any components on the evaluation board. The standard configuration of the board includes a full wave bridge rectifier that is required for an AC input

2 INPUT CAPACITOR SELECTION

For DC input, the input capacitor, C1, is selected based on its ripple current rating for the capacitor. The ripple current is calculated based on its duty cycle as outlined below.

$$D = \frac{V_o}{V_{in}}$$

Where D = duty cycle

V_o = output voltage

V_{in} = input voltage

The RMS current through the capacitor therefore is:

$$I_{ripple} = I_o \sqrt{D - \frac{2 \cdot D^2}{\eta} + \frac{D^2}{\eta^2}}$$

μ = efficiency

For an AC input voltage, the input capacitor is selected primarily to have enough capacity to supply the LED between the peaks of the AC input. The capacitor must be selected so that the minimum voltage at the input to the L5973D is maintained during each half cycle of the AC input.

$$V_{peak} = \sqrt{2} \cdot V_{in}$$

If the application is driving only one LED, the V_{min} is determined by the minimum operating voltage specification for the L5973D (4.4V). When driving more than one LED in series, the minimum input voltage is determined by the output voltage and the minimum differential input to output voltage for the regulator (the drop out voltage). In this case $V_{min} = (x \cdot V_f) + (I_{out} \cdot R_{sense}) + V_{DO}$

Where: x = number of LED in series

V_f = forward voltage of one LED

I_o = LED drive current

V_{DO} = Drop out voltage

The capacitor can then be selected using the equation:

$$C = \frac{5 \cdot 10^{-3} \cdot I_o \cdot V_o}{\eta \cdot \left(\frac{1}{2} \cdot V_{peak}^2 - \frac{1}{2} \cdot V_{min}^2 \right)}$$

The ripple current rating will have two parts where in the low frequency range, the capacitor will be charged by 120Hz while at the high frequency range the capacitor is discharged by 250kHz. For the low frequency part, it is approximately the same as the input RMS current and the power factor is approximately 0.7 for a full wave rectifier.

$$I_{in} = \frac{I_o \cdot V_o}{V_{in} \cdot \eta \cdot 0.7}$$

For the high frequency part (ignoring output current ripple), we have:

$$I_{ripple} = \sqrt{D_{av} - \frac{2 \cdot D_{av}^2}{\eta} + \frac{D_{av}^2}{\eta^2}} \cdot I_o$$

where D_{av} is the average duty cycle.

We will use the average duty cycle assuming that the voltage on the capacitor changes from the peak to the minimum voltage linearly.

$$D_{av} = \frac{V_o}{V_{av}} \quad V_{av} = \frac{V_{peak} + V_{min}}{2}$$

$$I_{ripple} = \sqrt{D_{av} - \frac{2 \cdot D_{av}^2}{\eta} + \frac{D_{av}^2}{\eta^2}} \cdot I_o$$

The equivalent series resistance of an aluminum capacitor has different frequency characteristics. There is a coefficient associated with different frequencies. Typically, for 120Hz, $K_{fl}=1$; for frequency greater than 10 kHz, $K_{fh}=1.5$.

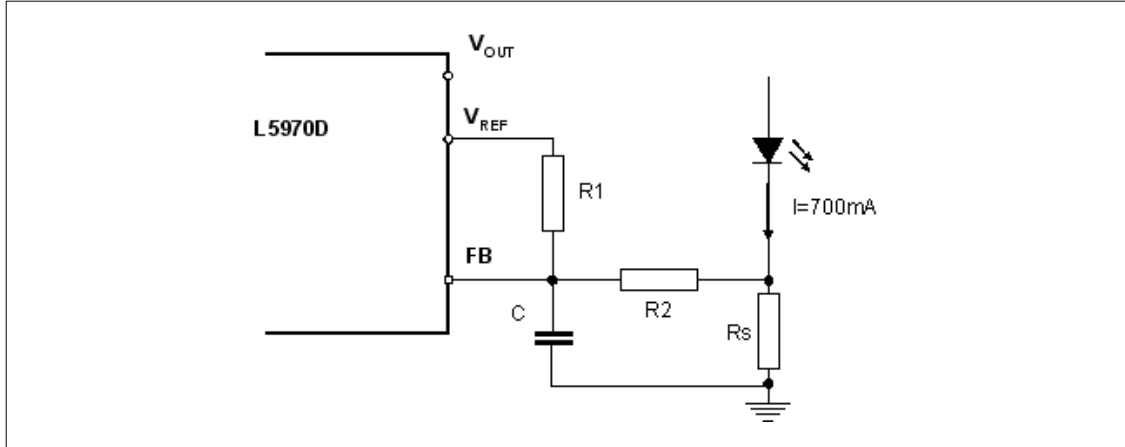
$$I_{cap} = \sqrt{\left(\frac{I_{in}}{K_{fl}}\right)^2 + \left(\frac{I_{ripple}}{K_{fh}}\right)^2}$$

Therefore, the ripple current rating of the capacitor has to be greater than I_{cap}

3 CURRENT FEEDBACK LOOP

To drive LEDs in a constant current mode, the feedback for the regulator is taken by sensing the voltage drop across the current sense resistor, R_s , as shown in [Figure 2](#). The voltage divider between the sense resistor and the feedback pin (R_1 and R_2) scales the voltage at the feedback pin so that it equals the internal reference voltage at the desired current level.

Figure 2. Current feedback



In order to get $I_o = 350 \text{ mA}$, the values of R_1 , R_2 and R_s are selected based on the following values.

$V_{ref} = 3.3 \text{ V}$; $V_{fb} = 1.235 \text{ V}$; $I_{fb_bias} = 2.5 \cdot 10^{-6} \text{ A}$; $R_s = 0.68 \Omega$

$V_{sense} = R_s \cdot I_o$

Using the superposition method:

$$V_{fb} = V_{ref} \cdot \frac{R_2}{R_1 + R_2} + V_{sense} \cdot \frac{R_1}{R_1 + R_2} + I_{fb_bias} \cdot \frac{R_1 \cdot R_2}{R_1 + R_2}$$

$$V_{sense} = V_{fb} - (V_{ref} - V_{fb}) \cdot \frac{R_2}{R_1} - I_{fb_bias} \cdot R_2 \quad I_o = \frac{V_{sense}}{R_s}$$

$$I_o = \frac{V_{fb} - (V_{ref} - V_{fb}) \cdot \frac{R_2}{R_1} - I_{fb_bias} \cdot R_2}{R_s}$$

Since V_{ref} and V_{fb} come from same band gap, they are directly correlated. $K = V_{ref}/V_{fb} = 2.672$. Therefore, the equation can be simplified to:

$$I_o = \frac{\left[1 - (K - 1) \cdot \frac{R_2}{R_1} \right] \cdot V_{fb} - I_{fb_bias} \cdot R_2}{R_s}$$

For 350mA output the selected values are:

$R_1 = 2.74 \text{ k}\Omega$,

$R_2 = 1.30 \text{ k}\Omega$ and

$R_s = 0.68 \Omega$.

For an output current of 700mA the value of R_s would be 0.34Ω . If R_1 and R_2 are small enough, the effect of the bias current can be ignored.

On the evaluation board, the value of R_s is selected by jumpers J2 and J4. When both J2 and J4 are open, the output current is set to 350mA. Inserting each jumper connects a 0.68Ω resistor in parallel with the 0.68Ω R_s . With J2 shorted, the output current will be set to 700mA and the output current becomes 1A with both J2 and J4 shorted.

4 INDUCTOR SELECTION

The output inductor is selected to limit the ripple current in the LEDs.

For example, for a given DC input voltage and an output current of 350mA, the peak current can be fixed to 500mA. This implies a $\Delta I_{max} = 300\text{mA}$.

For an output current of 700mA, the peak current can be fixed to 1000mA. This implies a $\Delta I_{max} = 600\text{mA}$

$$L_{min} = \frac{V_{in} - V_o}{\Delta I_{max}} \cdot T_{on}$$

Figure 3. Ripple Current (One 1W LED)

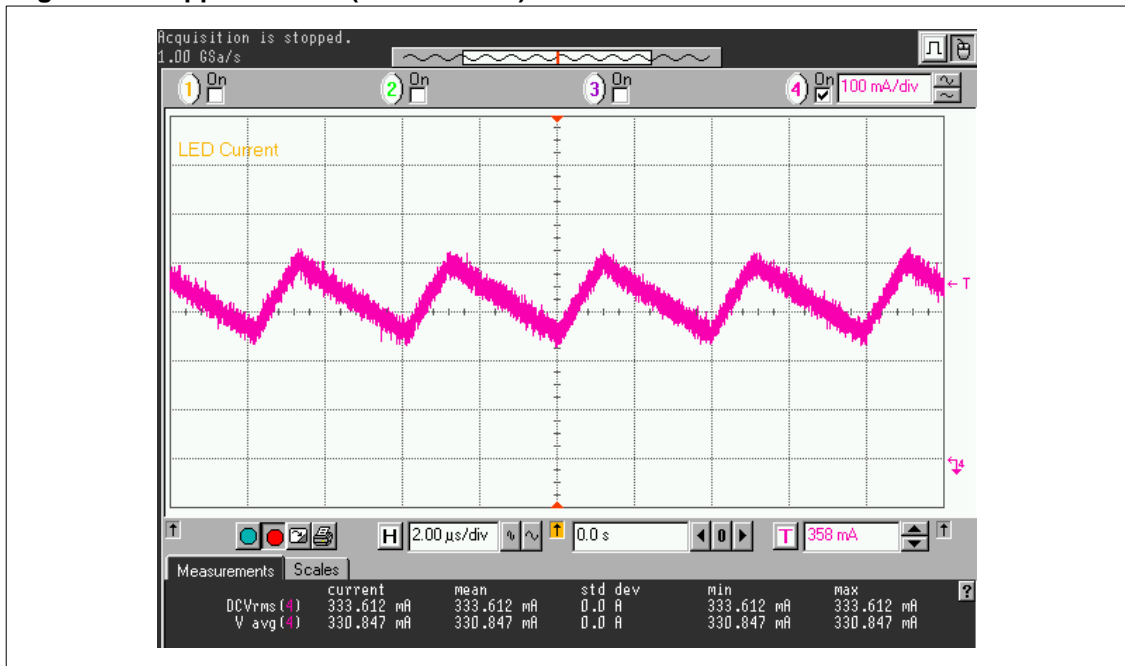


Figure 3. shows the ripple current measured with one 1W LED (warm white) at the output with 12Vac input. The measured ripple current is 180mA.

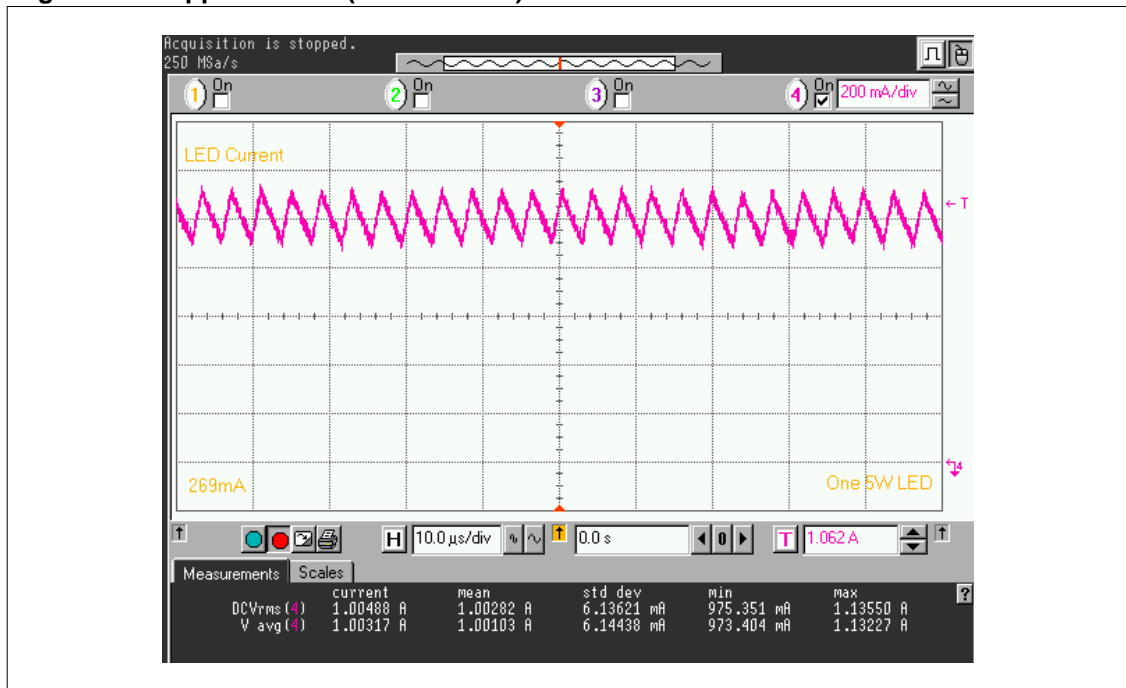
Figure 4. Ripple current (One 5W LED)

Figure 4. shows the ripple current driving one 5W LED at 1.05 A from a 12Vac input. The input current is 269mA.

5 BOARD LAYOUT

The layout for the evaluation board is shown below in [Figure 5](#) and [Figure 6](#). The area within the circle in the center of the board illustrates the required area for the final application. The components outside of the circle are connectors for convenience and the auxiliary devices that allow the current to be selected on this board without changing the resistor values. Obviously the final application would use a single resistor for R_S that is optimized for the application.

Figure 5. Top side of Board (not in scale)

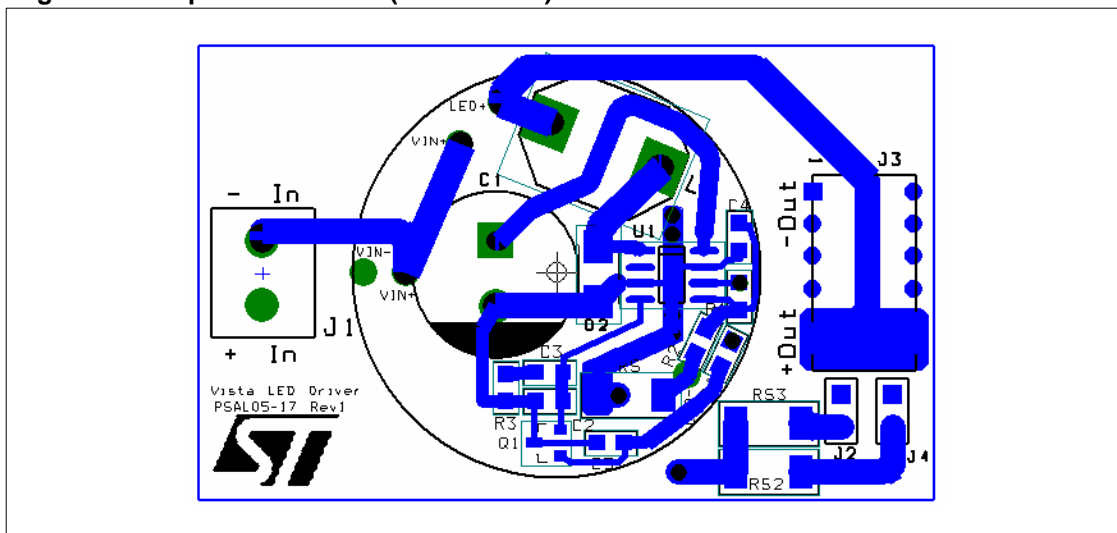


Figure 6. Bottom side of Board (not in scale)

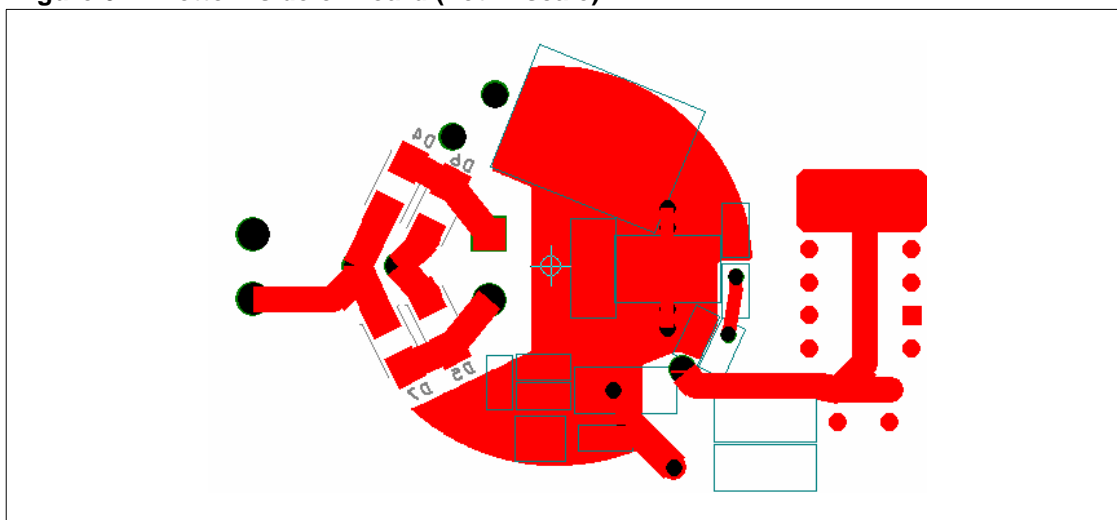


Figure 7. Board Schematic

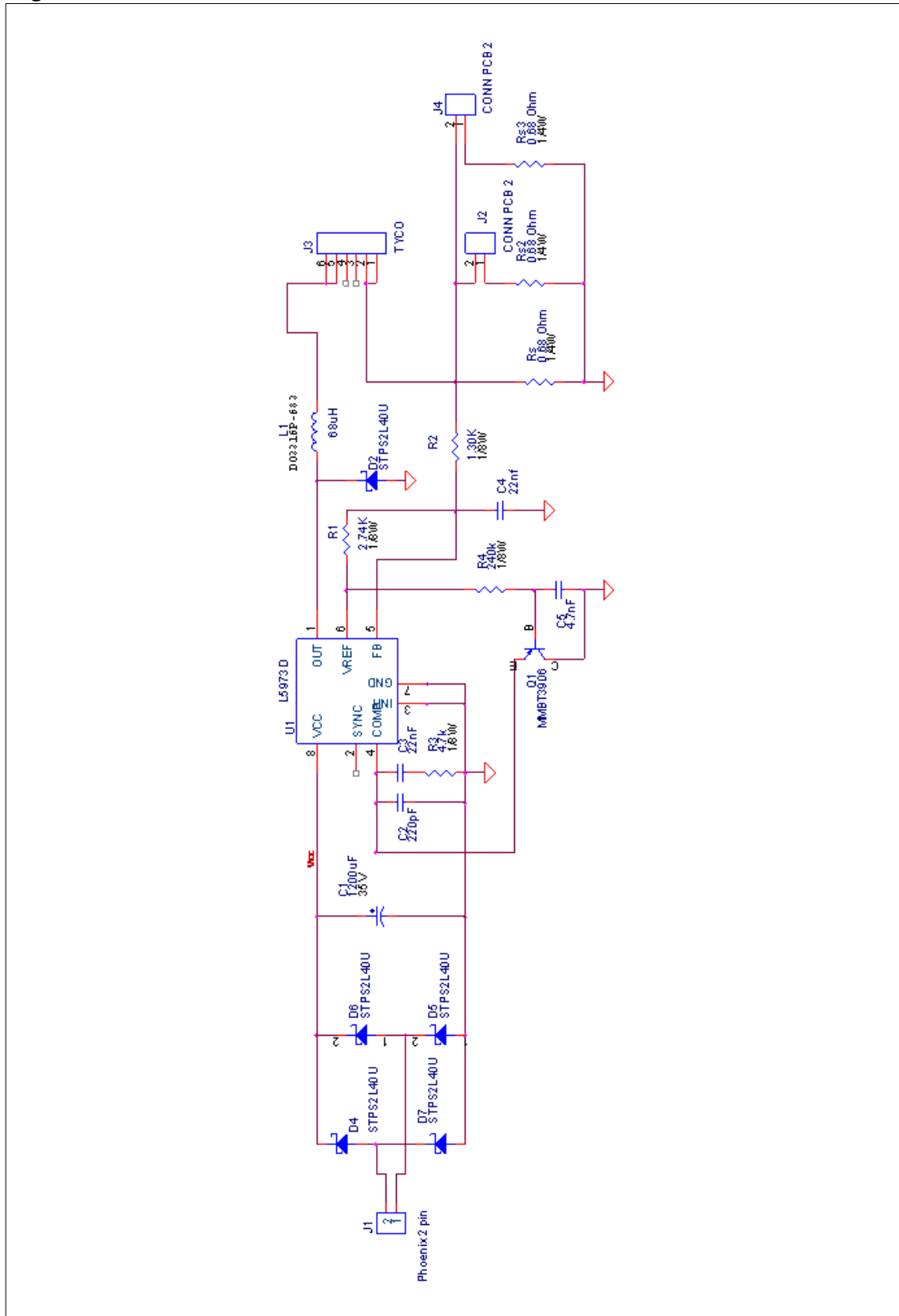


Table 1. Bill of Materials

Qty	Part Reference	Part Description	Mfg P/N	Mfg	Geometry	Mounting
1	C1	1200uF/35V electrolytic	EEU-FC1V22L	Panasonic	Radial	TH
1	C2	220pF/50V ceramic				SMD
1	C3	22nF/50V ceramic				SMD
1	C4	22nF/50V ceramic				SMD
1	C5	4.7nF/50V ceramic				SMD
5	D2 D4 D5 D6 D7	Low Drop Power Schottky Rectifier	STPS2L40U	STMicroelectronics	SMB	SMD
1	J1	Phoenix 2 Pin Connector	MKDSN1.5/2	Phoenix Contact		TH
1	J2	Current Select Jumper	22-28-8020	Molex		TH
1	J3	Stackable Receptacle	535676-5	Tyco		TH
1	J4	Current Select Jumper	22-28-8020	Molex	6 Pin	TH
1	L1	Inductor	DO3316P-683	Coilcraft		SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT23	SMD
1	Rs	0.68ohms 1% 1/4W			2010	SMD
1	Rs2	0.68ohms 1% 1/4W			2010	SMD
1	Rs3	0.68ohms 1% 1/4W			2010	SMD
1	R1	2.74kohms 1% 1/8W			0805	SMD
1	R2	1.30kohms 1% 1/8W			0805	SMD
1	R3	4.7kohms 5% 1/8W			0805	SMD
1	R4	240kohms 5% 1/8W			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

6 REFERENCE DESIGN VERSIONS

The evaluation board is designed to display the full functionality of L5973D as a LED driver to drive one to three 1W, 3W as well as 5W LEDs at 12Vac input. The components selected for the demo board are optimized for 5W LED driver application. Based on this circuit, there are nine different configurations with different input voltages and output power levels that could be derived by making minor components changes to the evaluation board. [Table 1.](#) shows the component changes needed in order to obtain each configuration. The final schematics and bill of materials for each configuration are shown in the subsequent pages. The 6 to 12 Vdc input configuration was designed for automotive applications that must survive a reverse battery condition. In this case one of the rectifiers remains on the board to provide protection against reversing the power supply leads.

Table 2. Components Changes For Different Configuration

LED Driver	U1	D4	D5	D6	D7
12Vac 1W LED	L5970D	STPS1L40A	STPS1L40A	STPS1L40A	STPS1L40A
12Vac 3W LED	L5973D	STPS2L40U	STPS2L40U	STPS2L40U	STPS2L40U
12Vac 5W LED	L5973D	STPS2L40U	STPS2L40U	STPS2L40U	STPS2L40U
6-12Vdc 1W LED	L5970D	Not used	Not used	STPS1L40A	Jumper wire
6-12Vdc 3W LED	L5973D	Not used	Not used	STPS2L40U	Jumper wire
6-12Vdc 5W LED	L5973D	Not used	Not used	STPS2L40U	Jumper wire
6-24Vdc 1W LED	L5970D	Not used	Not used	Jumper wire	Jumper wire
6-24Vdc 3W LED	L5973D	Not used	Not used	Jumper wire	Jumper wire
6-24Vdc 5W LED	L5973D	Not used	Not used	Jumper wire	Jumper wire

Table 2. (Continued)

C1	R2	Rs	L1	D2
680uF/35V	1.30k 1%	0.68	47uH	STPS1L40A
1200uF/35V	1.33k 1%	0.33	33uH	STPS2L40U
1200uF/35V	1.30k 1%	0.24	68uH	STPS2L40U
27uF/50V	1.30k 1%	0.68	47uH	STPS1L40A
68uF/50V	1.33k 1%	0.33	33uH	STPS2L40U
100uF/50V	1.30k 1%	0.24	68uH	STPS2L40U
22uF/35V	1.30k 1%	0.68	100uH	STPS1L40A
68uF/35V	1.33k 1%	0.33	100uH	STPS2L40U
100uF/35V	1.30k 1%	0.24	100uH	STPS2L40U

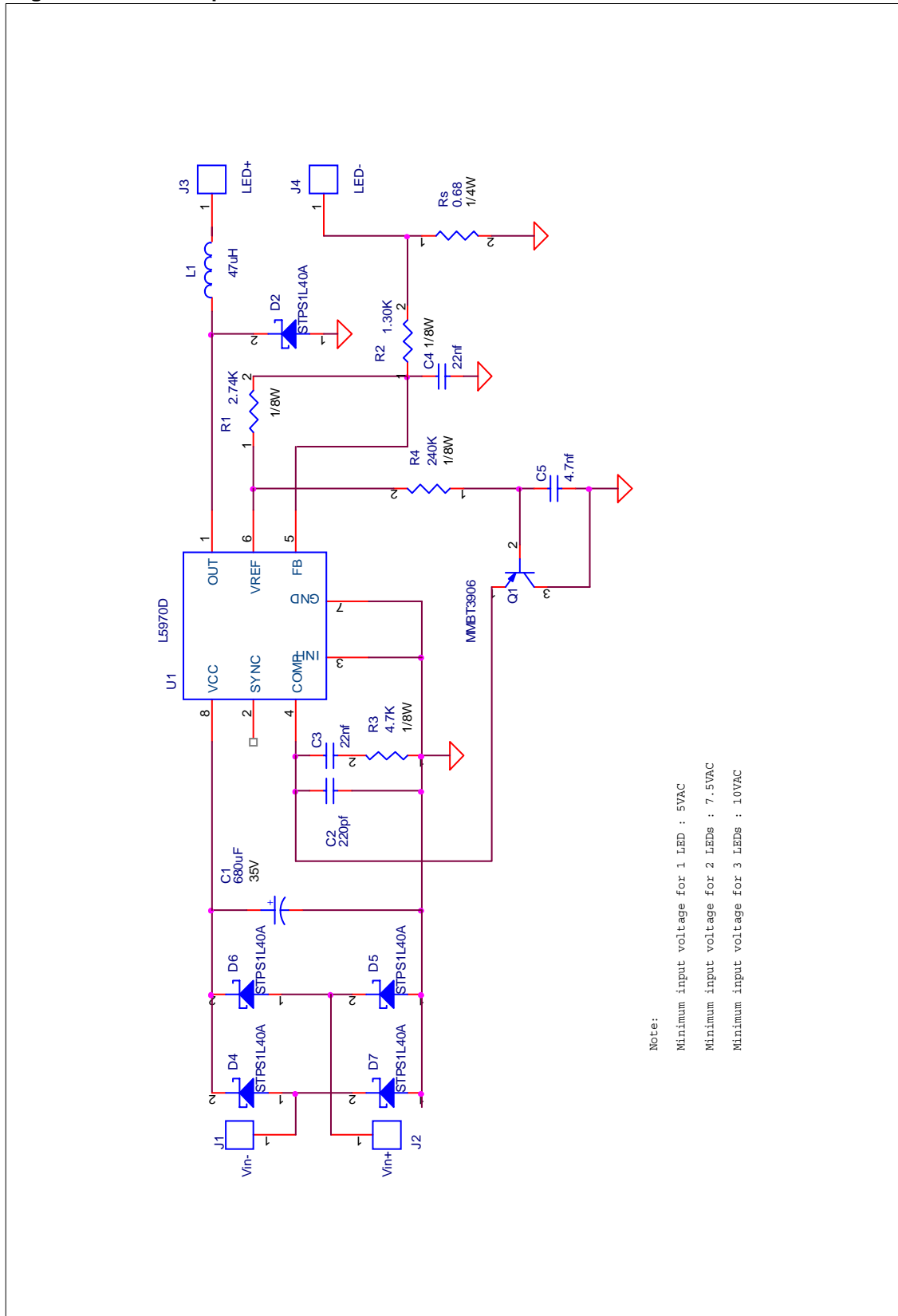
Figure 8. 12Vac Input 1W LED Driver Schematic

Table 3. 12Vac Input 1W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	680uF/35V Electrolytic	EEU-FC1V681	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
5	D2, D4, D5, D6, D7	Schottky Diode 1A/40V	STPS1L40A	STMicroelectronics	SMA	SMD
1	L1	47uH Inductor	DO3308P-473	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.68 Ohm 1%			1206	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5970D	STMicroelectronics	0SO8	SMD

Table 4. 12Vac Input 3W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	1200uF/35V Electrolytic	EEU-FC1V122L	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
5	D2, D4, D5, D6, D7	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	L1	33uH Inductor	DO3308P-333	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.33 Ohm 1%	CRL2010-FW-R330E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.33k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

Figure 10. 12Vac Input 5W LED Driver Schematic

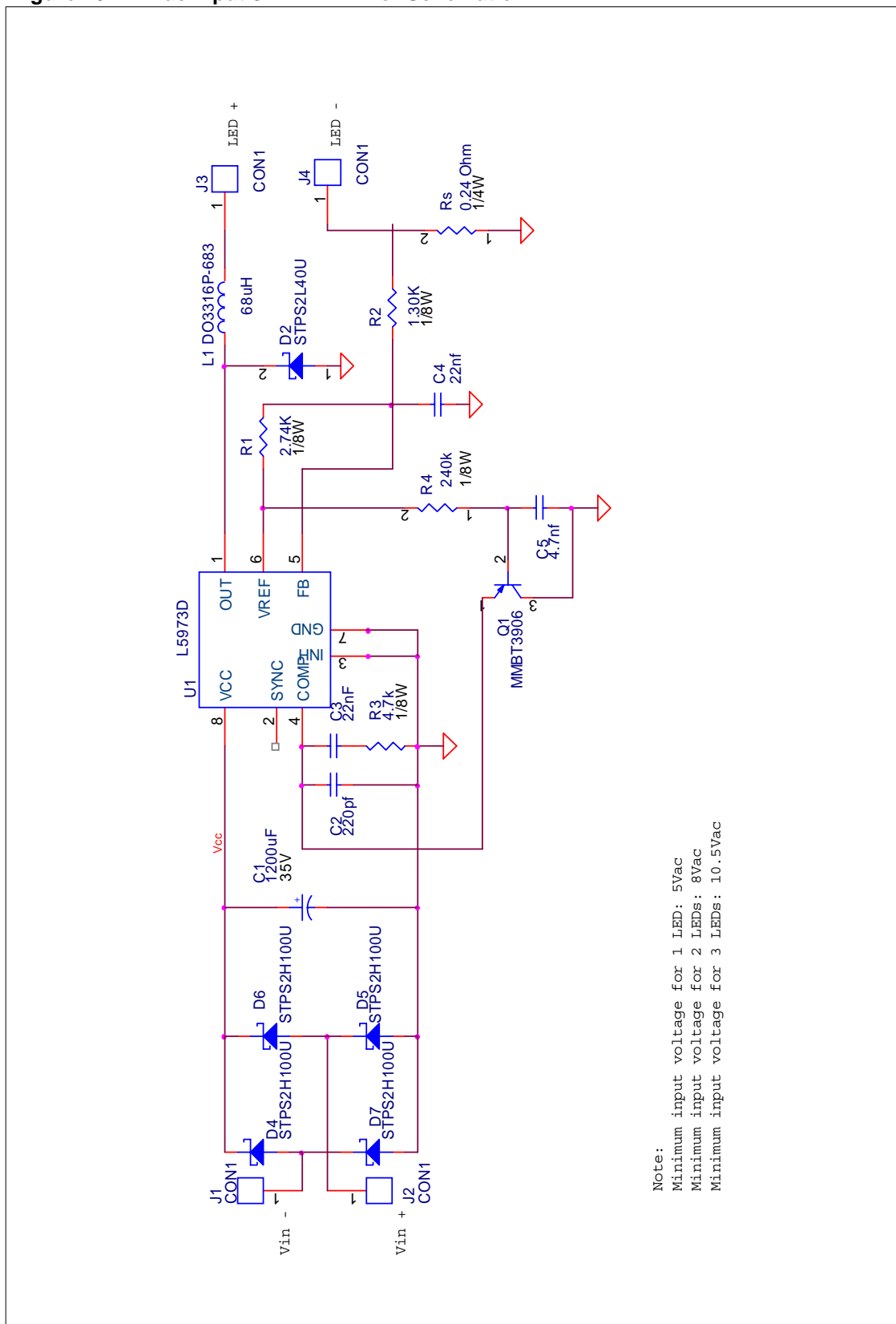


Table 5. 12Vac Input 5W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	1200uF/35V Electrolytic	EEU-FC1V122L	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
5	D2, D4, D5, D6, D7	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	L1	68uH Inductor	DO3316P-683	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.24 Ohm 1%	CRL2010-FW-R240E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

Figure 11. 6 to 12Vdc Input 1W LED Driver Schematic

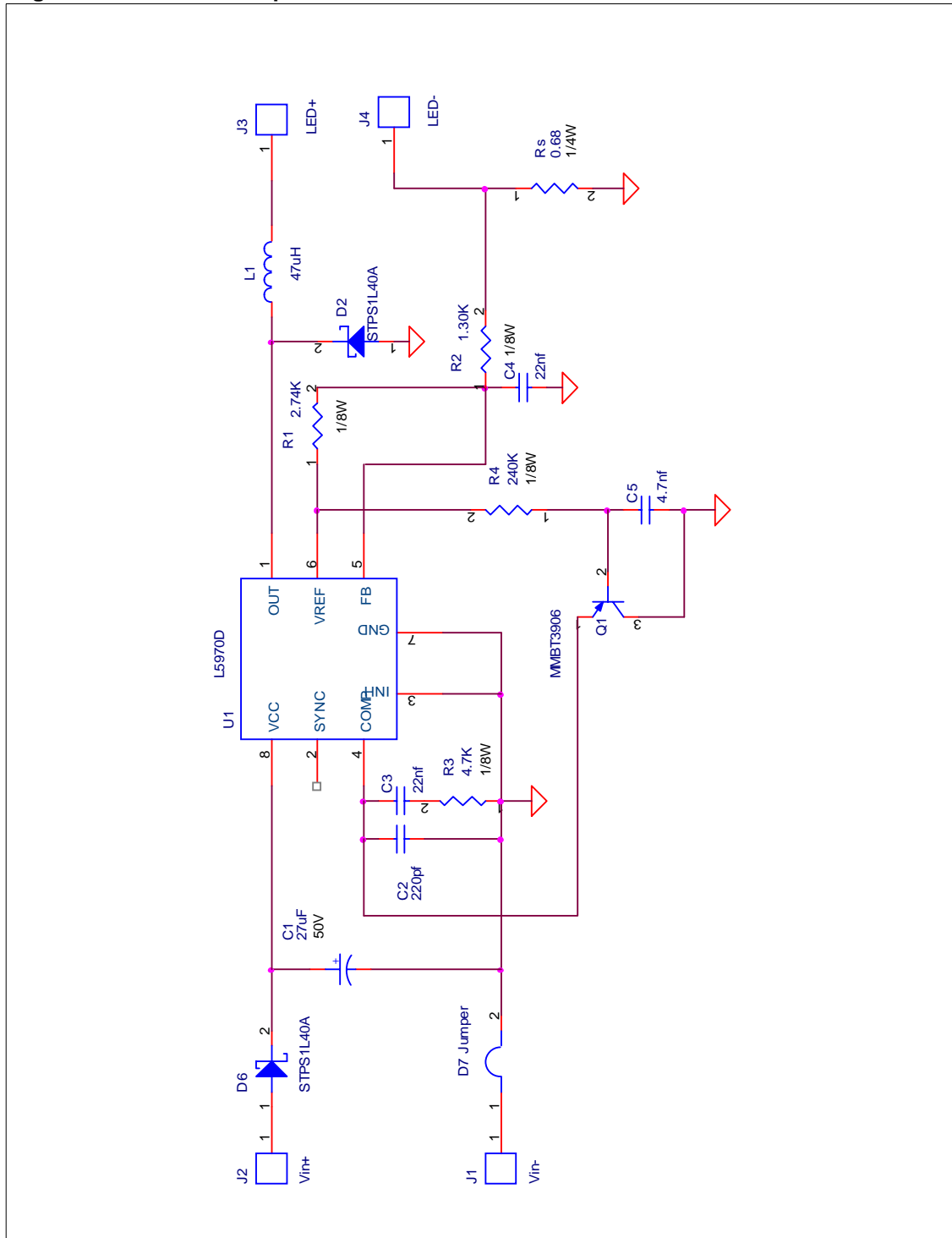


Table 6. 6 to 12Vdc Input 1W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	27uF/50V Electrolytic	EEU-FC1H270	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
2	D2, D6	Schottky Diode 1A/40V	STPS1L40A	STMicroelectronics	SMA	SMD
1	D7	Jumper at D7 position				SMD
1	L1	47uH Inductor	DO3308P-473	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.68 Ohm 1%			1206	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 5%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5970D	STMicroelectronics	SO8	SMD

Figure 12. 6 to 12Vdc Input 3W LED Driver Schematic

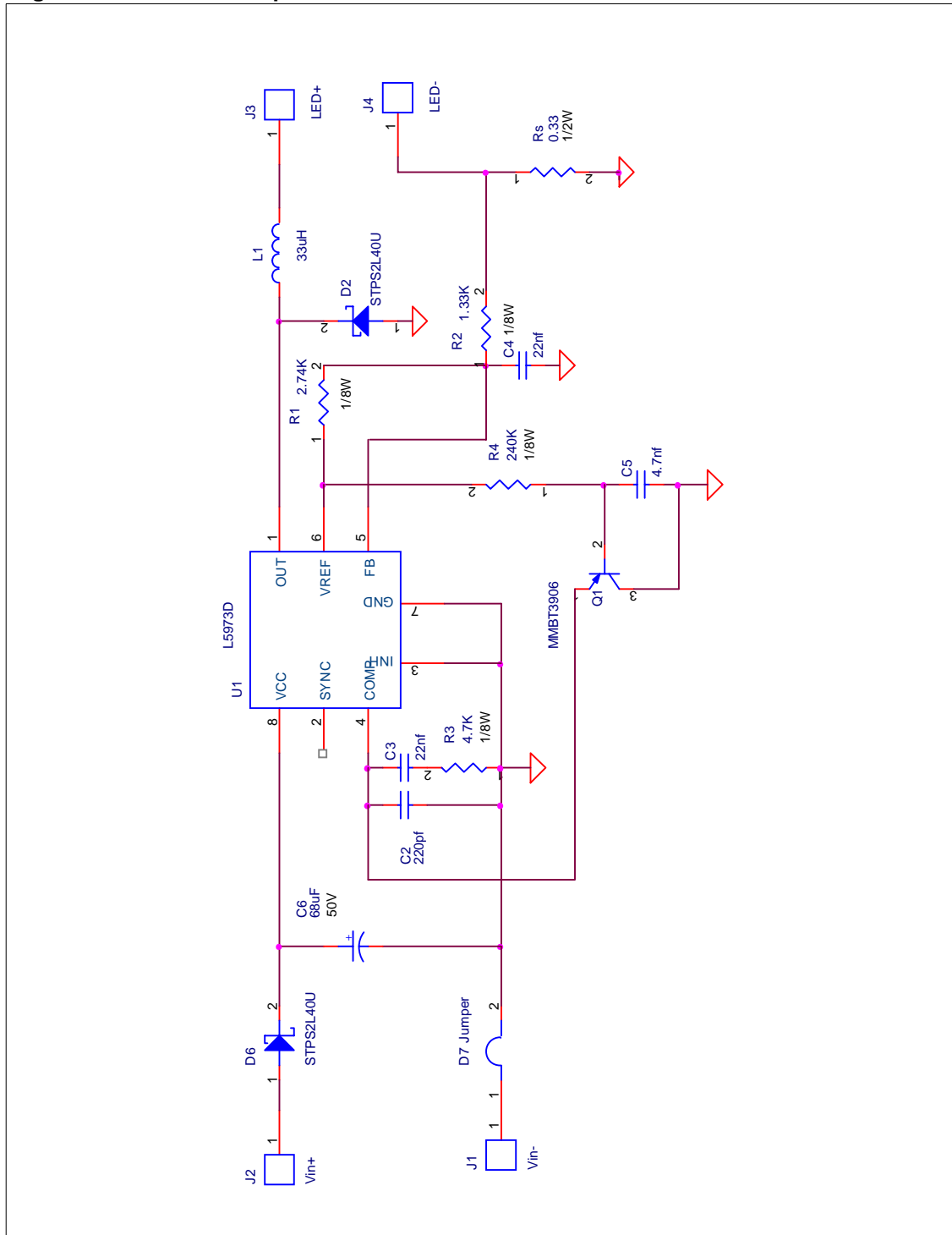


Table 7. 6 to 12Vdc Input 3W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	68uF/50V Electrolytic	EEU-FC1H680	Panasonic	Radial D8mm	TH
1	C2	220pF/50V Ceramic			805	SMD
2	C3, C4	22nF/50V Ceramic			805	SMD
1	C5	4.7nF/50V Ceramic			805	SMD
2	D2, D6	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	D7	Jumper at D7 position				SMD
1	L1	33uH Inductor	DO3308P-333	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.33 Ohm 1%	CRL2010-FW-R330E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.33k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

Figure 13. 6 to 12Vdc Input 5W LED Driver Schematic

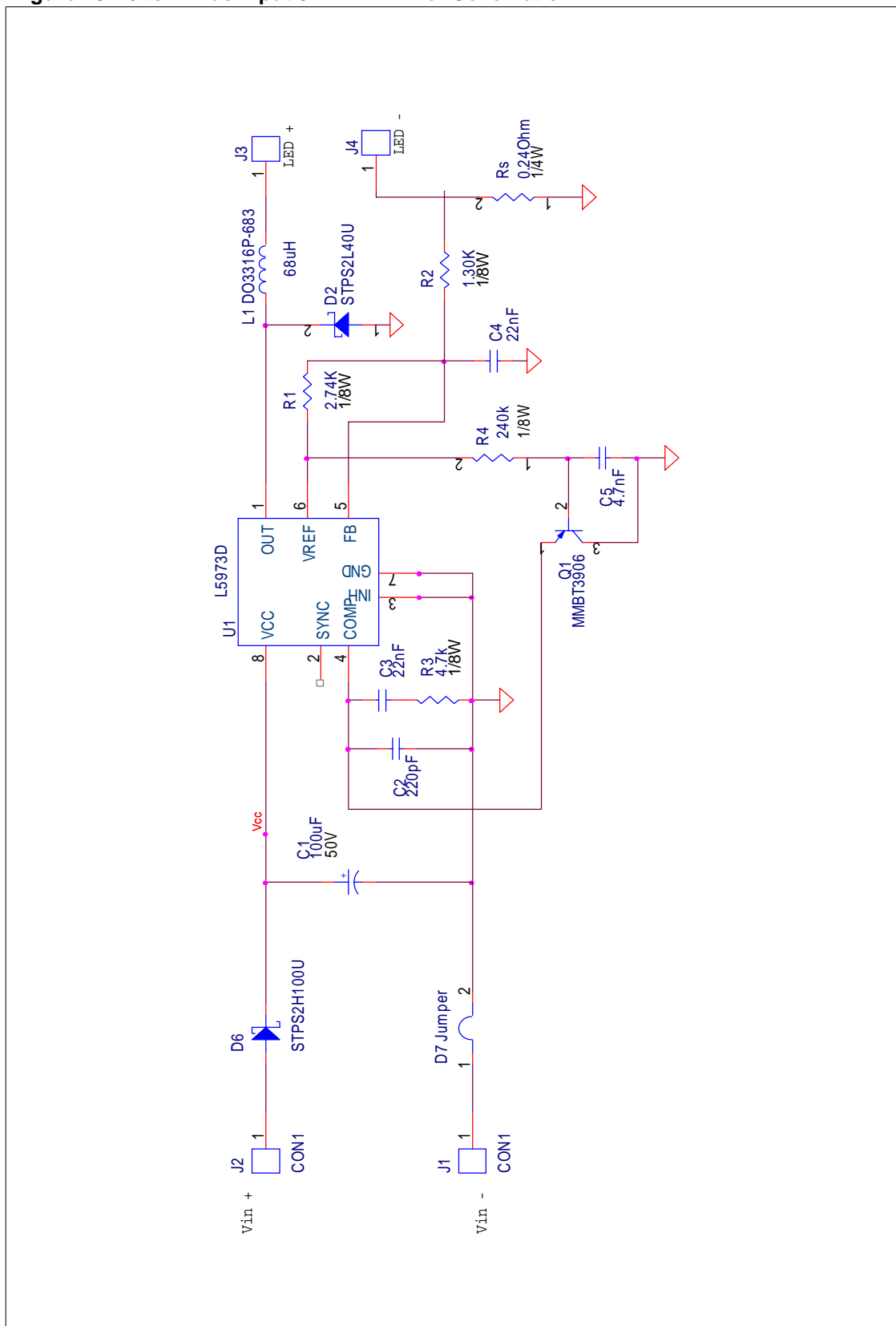


Table 8. 6 to 12Vdc Input 5W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	100uF/50V Electrolytic	EEU-FC1H101	Panasonic	Radial D8mm	TH
1	C2	220pF/50V Ceramic			805	SMD
2	C3, C4	22nF/50V Ceramic			805	SMD
1	C5	4.7nF/50V Ceramic			805	SMD
2	D2, D6	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	D7	Jumper at D7 position				SMD
1	L1	68uH Inductor	DO3316P-683	Coilcraft	9.4mmx12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.24 Ohm 1%	CRL2010-FW-R240E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

Figure 14. 6 to 24Vdc Input 1W LED Driver Schematic

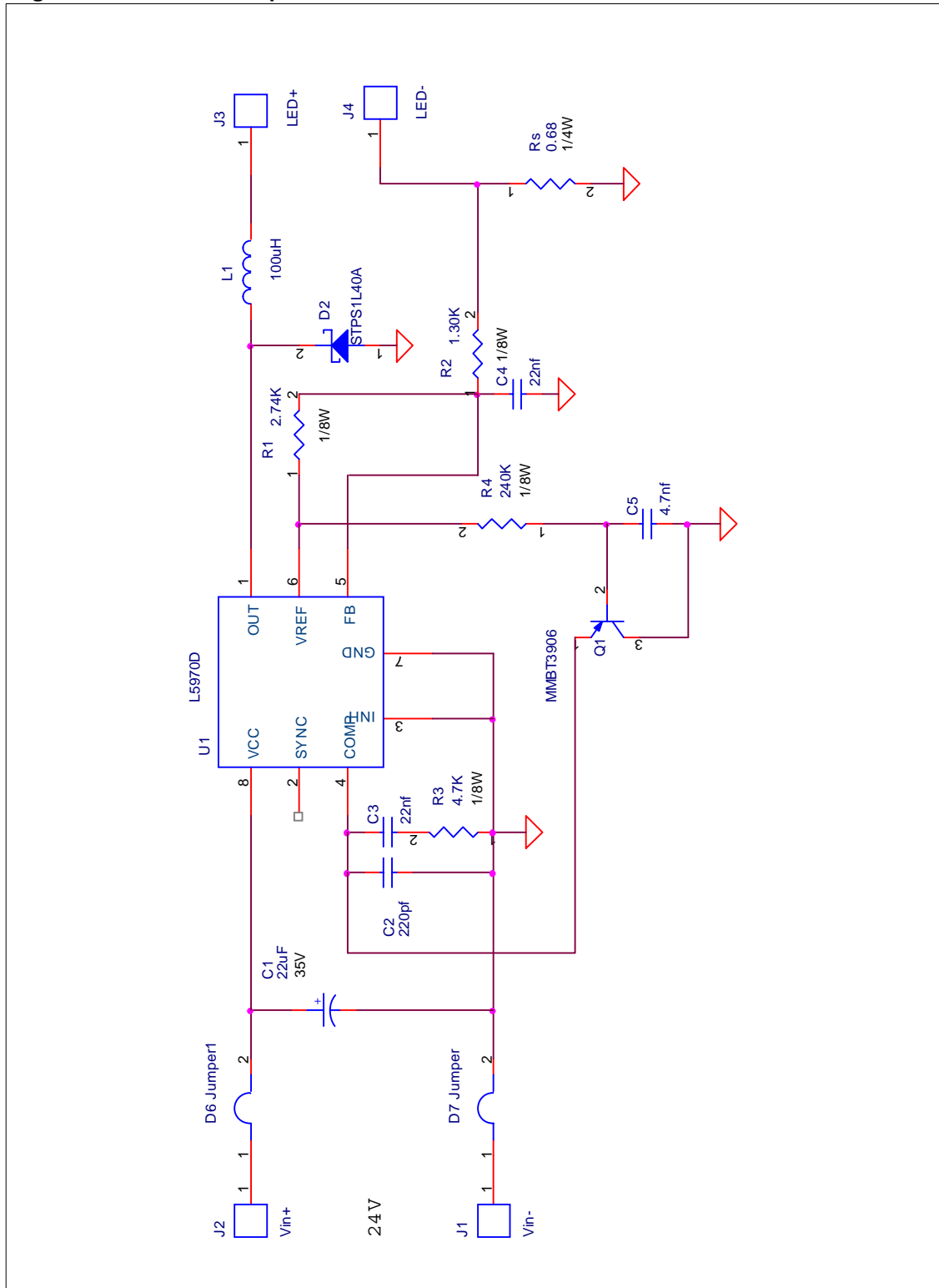


Table 9. 6 to 24Vdc Input 1W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	22uF/35V Electrolytic	EEU-FC1H220	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
1	D2	Schottky Diode 1A/40V	STPS1L40A	STMicroelectronics	SMA	SMD
1	D7	Jumper at D7 position				SMD
1	D6	Jumper at D6 position				SMD
1	L1	100uH Inductor	DO3308P-104	Coilcraft	9.4mm x 12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.68 Ohm 1%			1206	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5970D	STMicroelectronics	SO8	SMD

Figure 15. 6 to 24Vdc Input 3W LED Driver Schematic

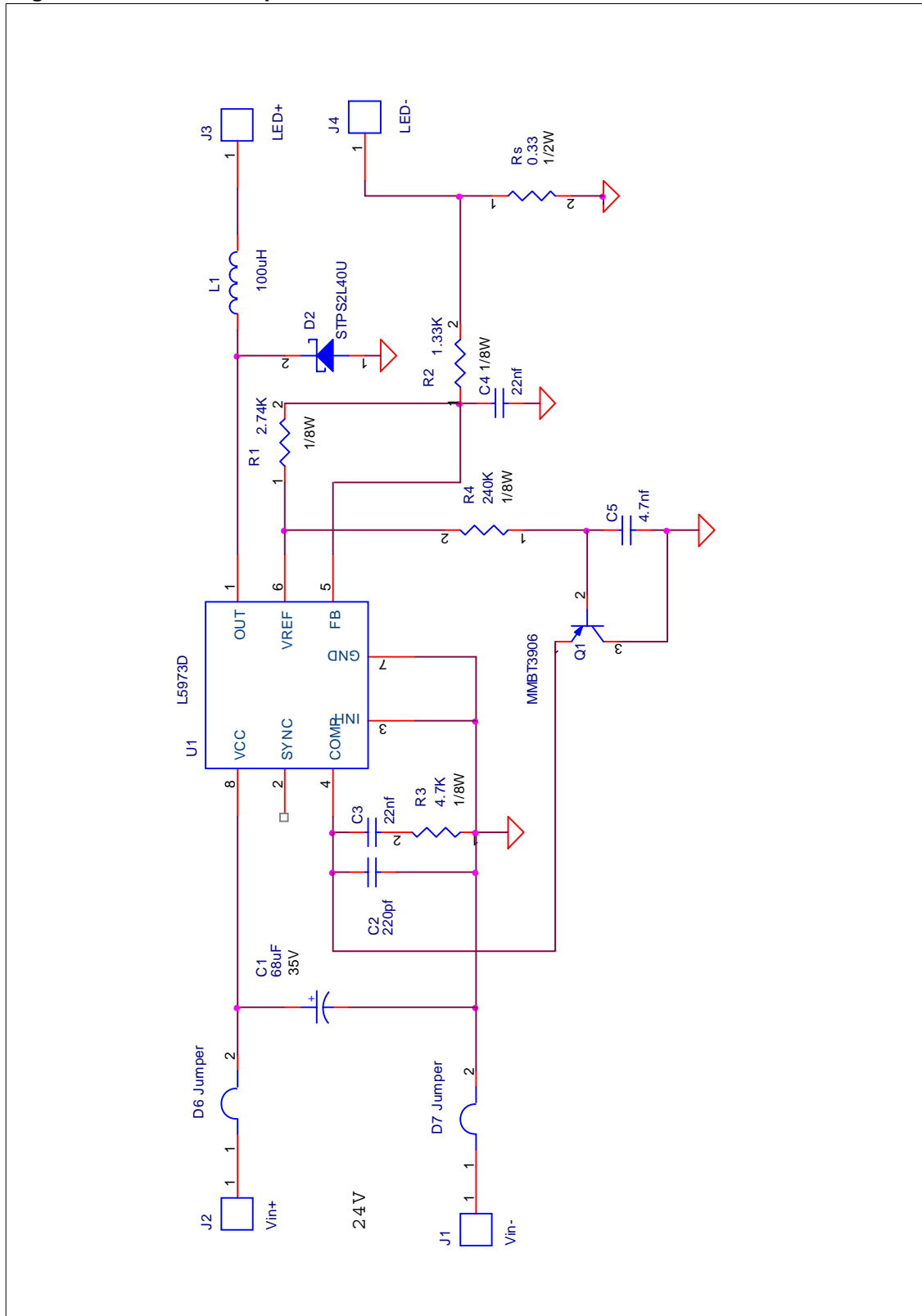


Table 10. 6 to 24Vdc Input 3W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	68uF/35V Electrolytic	EEU-FC1V680	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
1	D2	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	D6	Jumper at D6 position				SMD
1	D7	Jumper at D7 position				SMD
1	L1	100uH Inductor	DO3316P-104	Coilcraft	9.4mm x 12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.33 Ohm 1%	CRL2010-FW-R330E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.33k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

Figure 16. 6 to 24Vdc Input 5W LED Driver Schematic

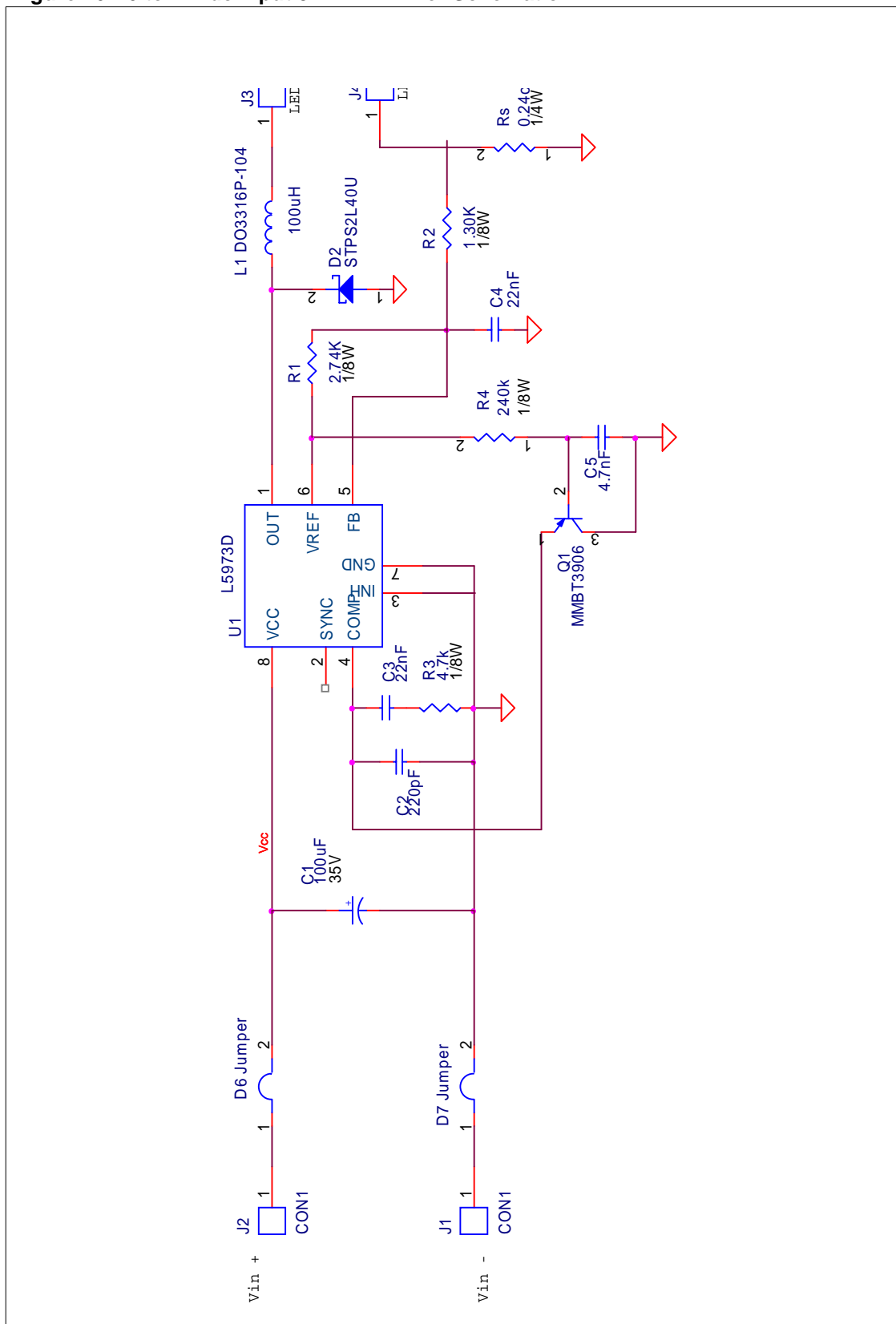


Table 11. 6 to 24Vdc Input 5W LED Driver Bill of Materials

Qty	Reference	Part Description	Mfg P/N	Mfg	Geometry	Mtg
1	C1	100uF/35V Electrolytic	EEU-FC1V101	Panasonic	Radial	TH
1	C2	220pF/50V Ceramic				SMD
2	C3, C4	22nF/50V Ceramic				SMD
1	C5	4.7nF/50V Ceramic				SMD
1	D2	Schottky Diode 2A/40V	STPS2L40U	STMicroelectronics	SMB	SMD
1	D6	Jumper at D6 position				SMD
1	D7	Jumper at D7 position				SMD
1	L1	100uH Inductor	DO3316P-104	Coilcraft	9.4mm x 12.95mm	SMD
1	Q1	PNP Transistor	MMBT3906	STMicroelectronics	SOT-23	SMD
1	Rs	0.24 Ohm 1%	CRL2010-FW-R240E	Bourns	2010	SMD
1	R1	2.74k 1%			0805	SMD
1	R2	1.30k 1%			0805	SMD
1	R3	4.7k 5%			0805	SMD
1	R4	240k 5%			0805	SMD
1	U1	Step-down controller	L5973D	STMicroelectronics	SO8	SMD

7 REVISION HISTORY

Date	Revision	Changes
04-Nov-2005	1.0	First edition

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