White Light LED Load System

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Senior Project

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Abstract

This senior project analyzes the use of high-powered LEDs and its feasibility to replace existing lighting fixtures, especially for residential purposes. This was begun by Joseph Zukowski in 2007 as part of the Cal Poly SuPER project and since technology has grown rapidly since then, this project will focus on more recently available LEDs. Light emitting diodes are fast becoming a cost-effective alternative to incandescent and fluorescent light bulbs in many applications. The first step was to design a circuit that would allow LEDs to function in series even though one may malfunction. Throughout the process of this project, multiple components and designs were considered until one was deemed as most viable. Analysis as a result of testing and data measurements provides evidence to support LED technology for the future. This project consists of either a 12V or 48V battery, an appropriate LED driver to deliver 350mA to the LED circuit, and the series of LEDs with a fail-safe design. Testing was done using the components on breadboards in the lab.

Introduction

The goal of this senior project is to utilize high-powered LED's to provide an efficient source of lighting to areas that have a DC power supply. This is a continuation of the work that Joseph Zukowski completed in 2007 [1]. Since then, the technology of high-powered LED's has improved drastically especially in the areas of performance and efficiency. Testing will involve current and voltage measurements which will provide the amount of power used and dissipated by the circuit. Additionally, the circuit will have proper thermal management to prevent overheating. The results will demonstrate that these LED's can be a viable provider of lighting and someday will find a place for use in residential areas.

Our system will use a series implementation of LED's with a fail-safe design. A preliminary simulation provided an early glimpse of the components that might be used and their limitations. An LED driver will receive an input of 12V and have an output of about 350mA. By controlling the current, the LEDs will be able to run with a high efficiency. Select BJT's and resistors were chosen to provide acceptable performance to the circuit in short and open cases as part of the fail-safe design. Table 1 summarizes the main components of this project.

Table 1. List of components

Component Name	Part Number/Description
LED	Philips Rebel High Power LED LXML-PWC1-0120
LED Driver	V-Infinity VLD24-350
LED Driver	RECOM RCD-48-0.35
BJT	PN2222AFS
NMOSFET	2N7000
Resistor (25 ohm)	UB5C-25RF1

The background section provides information about previous research and the Senior Project that Joseph A. Zukowski completed. Presented are various characteristics of LEDs such as life cycle, heat dissipation, and operating and color temperatures. The prototype study/testing section details the thought process behind component selection as well as some analysis of the testing. Following this, applications of this Senior Project as a viable alternative to existing lighting solutions are discussed. In conclusion, final thoughts, and recommendations are presented. Refer to the appendices for the total cost of the project, test data, and the senior project analysis.

Background

Over the years, the advancement in high-powered LED's technology has brought forth higher and brighter luminous output while decreasing size and cost. Joseph A. Zukowski stated in his paper, "Implementation of High Powered LED Load into the SuPER System", from March 2007 that the expected life cycle for white LED's at that time was around 20,000 hours [1]. Now in a paper released in May 2010 titled "Evaluating the Lifetime Behavior of LED Systems" by the company and branch Phillips Lumileds, the average life cycle for LED's has been increased to an average of 50,000 hours [2]. Figure 1 below shows the light output over time as an example.

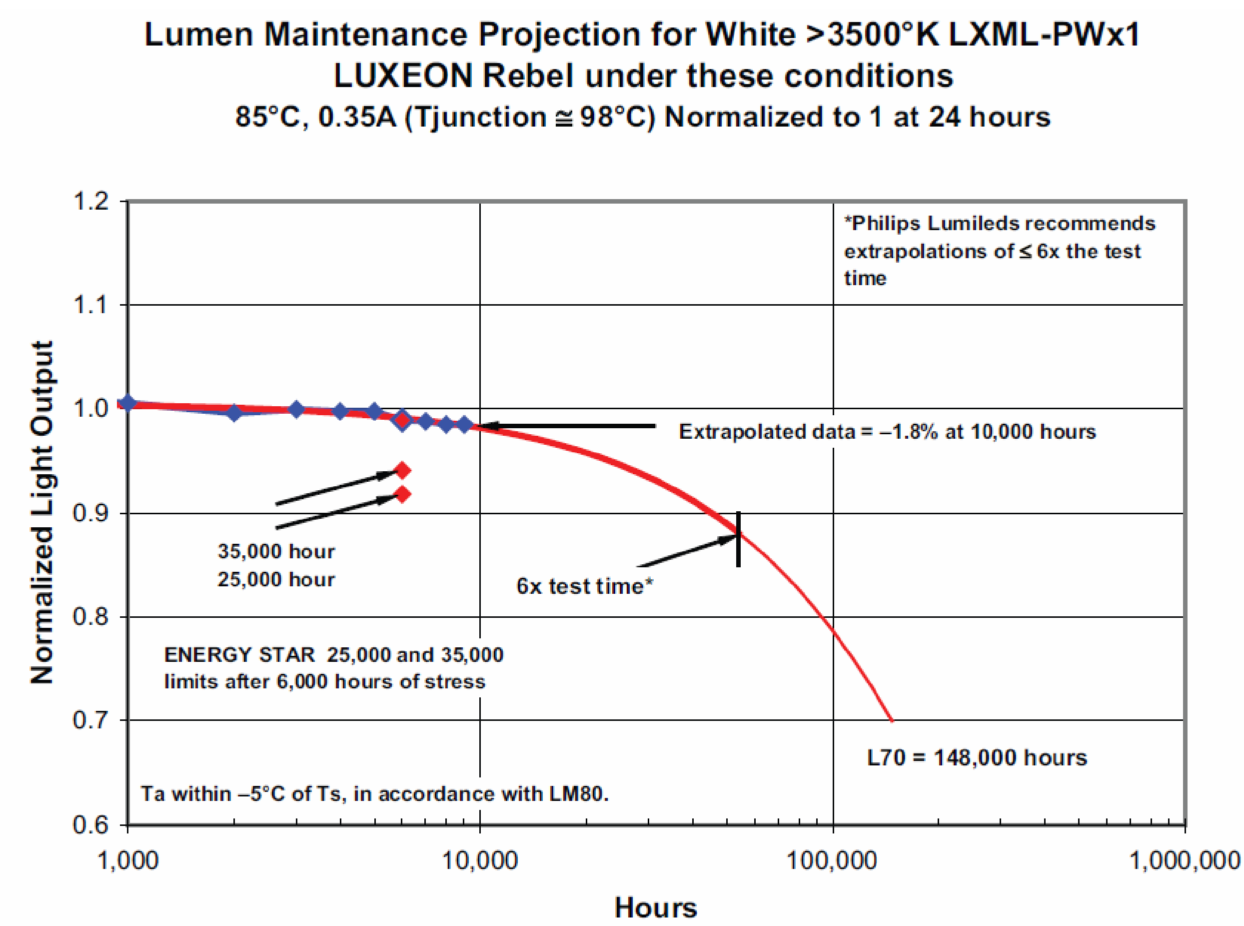


Figure 1. Extrapolation of White LED life-cycle

According to “Understanding LED Performance”, Rudi Hechfellner and Steve Landau of Philips Lumileds explain how to compare different LEDs from the datasheets. It is important to state the operating conditions and to test all the LEDs in the same environment. An example would be with four different LEDs by different manufacturers where each has a minimum flux and drive current. In order to accurately test them all, they will all be tested at the higher drive current in order to understand the LEDs nominal performances [3].

The next step is to examine the “temperature derating” graph in each datasheet. This will tell you how temperature will affect the power dissipation of the LEDs. Normal environment temperature is assumed to be 25°C. Below in Figure 2 is a chart from the LXML-PWC1-0120 LED datasheet [4].

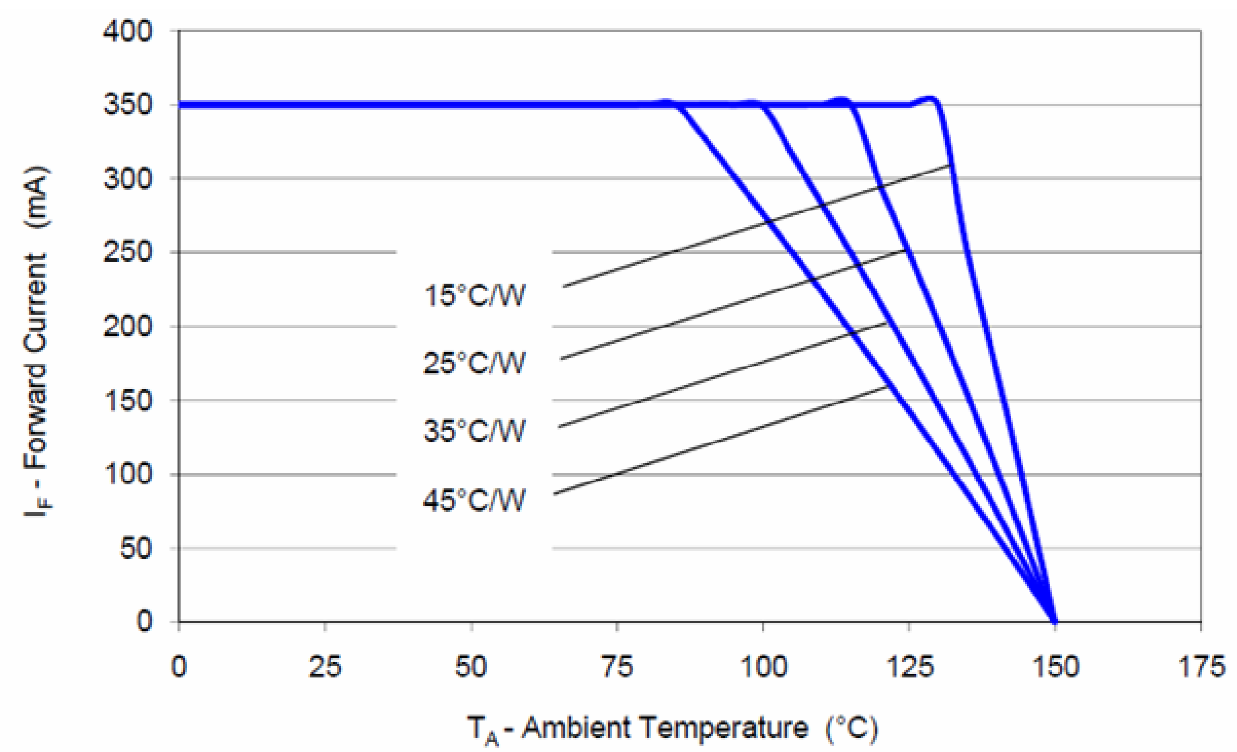


Figure 2. Current derating curve for 350 mA

This brings up another issue regarding heat dissipation. LEDs under normal operations tend to get pretty warm to the touch, thus requiring some form of heat sink. The heatsink will need to be large enough to dissipate heat from a single spot (the LED) into a more open area. Nowadays, breakout boards have been used as the conventional heatsinks for high-powered LEDs. Other types of heatsinks that are also commonly used are long and flat strips of metal which are attached to the bottom of the LEDs.

Another important aspect of LEDs is the color temperature. Color temperature of LEDs can range from as low as 1000°K to 10000°K for a single color. In the case of this project, the color white was chosen, and having different color temperatures is equivalent to having different "shades" of white such as yellow-white like candlelight and blue-white like High-Intensity Discharge (HID) headlights on cars. The lower the color temperature, the "warmer" the color is deemed to be. A color temperature of 1000°K is white with a shade of the color of candlelight. As color temperature goes up, the "cooler" and more intense the color is considered. At 10000°K, the white light has a tinge of blue mixed in. These kinds of lights are usually found in aftermarket car headlights [5]. Color temperatures higher than 10000°K begins to turn from white-blue to white-purple and makes things harder to see and read. The ideal color temperature for reading would be in the lower end of the spectrum of around 2500°K, which is equivalent to an incandescent bulb where light is much "softer" as opposed to "harsher" and more "intense" lighting such as high-powered LEDs.

The size of the standard high-powered LED these days are very small and they'll keep getting smaller as technology advances. Smaller sizes mean less space on a PCB thus saving money. The size of the LED used in this project is about $3mm^2$. The small size makes the LEDs sturdy as the chances of small LEDs breaking when dropped is quite low unlike its bigger counterparts such as fluorescent bulbs. However, with such a small size, heat is much more concentrated in a given area and hence the required heatsinks.

The efficiency of LEDs is much better than traditional sources of lighting. LED "efficiency is not affected by shape and size, unlike fluorescent light bulbs or tubes" [6]. Below in Figure 3 is a chart from an article on LEDs Magazine's website summarizing the different efficiencies [7]. The chart is a little outdated since it's from 2006, hence the low luminous efficacy for the power LED, but the chart is a good representation of the differences in different sources of lighting.

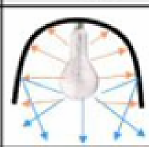
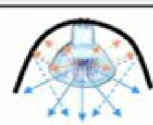
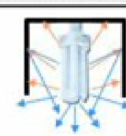
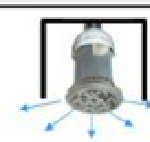
Item	Incandescent	Halogen	Fluorescent	Compact Fluorescent	Power LED
Lighting device					
Source luminous efficacy(lm/W)	15	30	70	50	50
Electric power source Efficiency(%)	100 %	100 %	80~87 % Loss of ballast	80~90 % Loss of Inverter	80 % Loss of converter
Directional Fixture Efficiency(%)	30~50 %	30~50 %	60~70 %	50~60 %	95 %
Actual System luminous efficacy(lm/w)	7	14	38	23	38
Power consumption (W) (800 lm benchmark)	114	57	21	35	21
Lifetime (6Hr/day)	1,000 (167d)	3,000 (500d)	8,000 (1,333d)	8,000 (1,333d)	25,000 (4,166d) Dependent on lifetime of converter

Figure 3. Chart depicting efficiencies of different lighting sources

Prototype Study

The following Gantt chart in Figure 4 depicts our proposed timeline for the completion of the project. The weeks that have “TBD” are reserved for any unforeseen conflicts that might occur and for additional testing if necessary.

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Research and Order Parts	■										
Design fail-safe system	■	■									
Simulate fail-safe system and make any necessary adjustments and re-simulate. Record data			■	■							
Characterize LEDs and LED drivers and compare to datasheet specs. Re-simulate again if necessary and record data.				■							
More simulations. Build and solder series LED load and test/measure.					■						
Combine subsystems and test. Troubleshoot.					■	■					
TBD						■					
TBD							■	■	■	■	
Present prototype											■

Figure 4. Proposed Gantt chart for the project

Our first step was to design a fail-safe configuration for LEDs in series. What we had in mind during the beginning brainstorming stage was something that acted like a switch. It was to remain off until it was needed. We chose to use a BJT as we were most familiar with that as opposed to FETs. Since the simulation program we used, LTSpice, did not present a visual result of the LED being lit, we used the idea of “path of least resistance” and chose resistive values of 1MΩ to maximize the amount of current that flows through the LED under normal operating conditions (without shorts or opens). Figure 5 shows a screen capture of the simulation results.

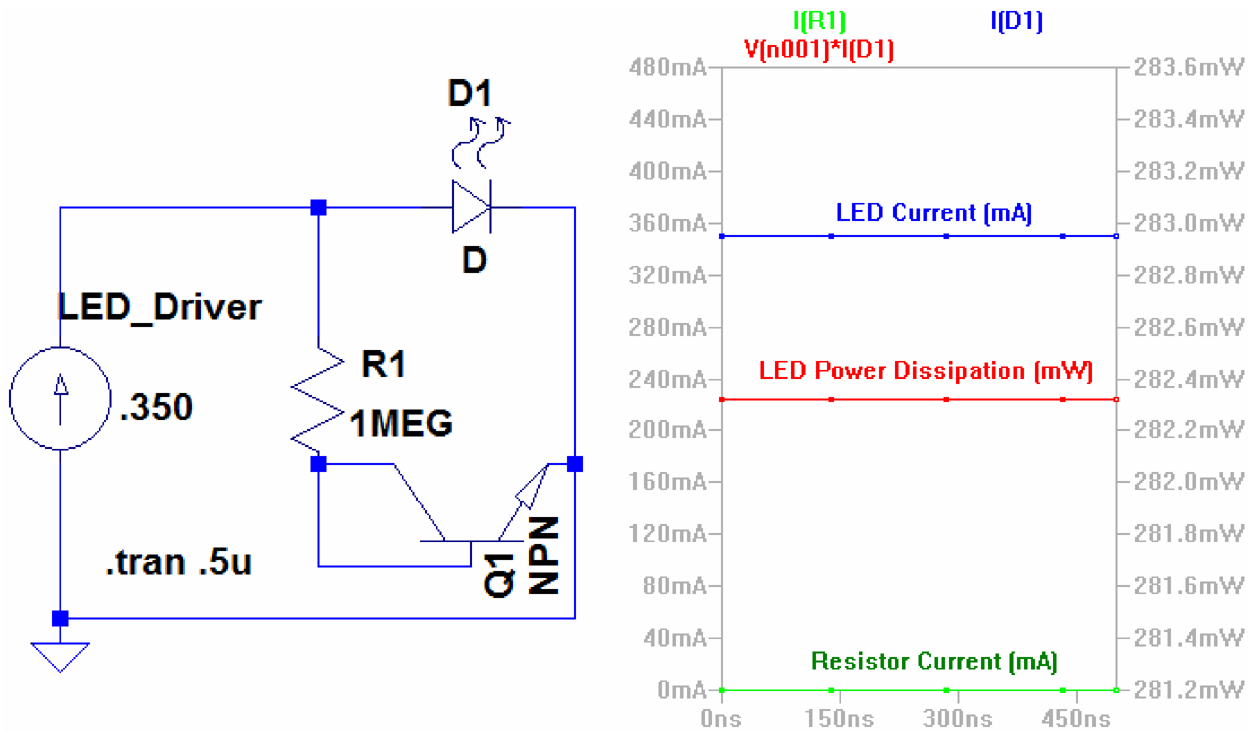


Figure 5. LTSpice simulation results of the fail-safe using BJT

However, when we tested for the open case, we realized that there would be an extremely massive voltage drop across the resistor which means massive power loss would occur. Using 1MΩ resistors would damage the resistors whenever there is an open. The simulation for the open case is shown in Figure 6. As for the short case, everything in that section of the circuit gets bypassed and the current flows right through onto the next LED in the circuit.

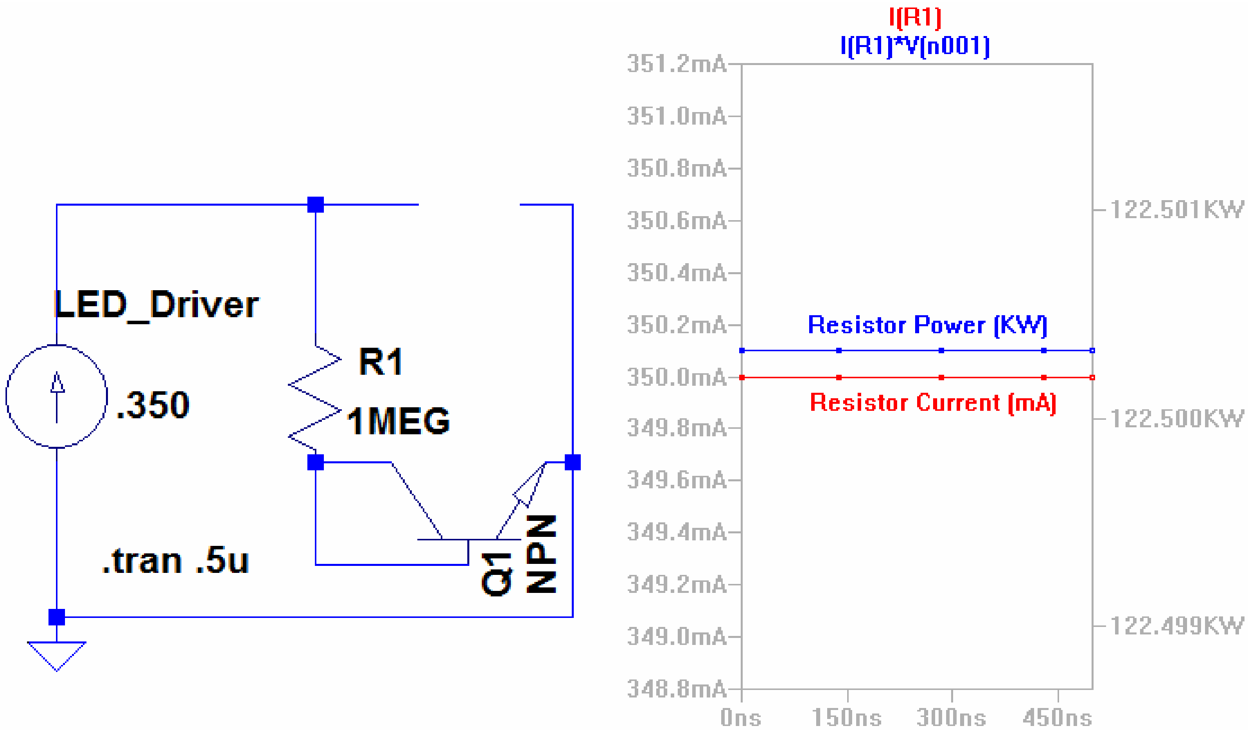


Figure 6. 1MΩ resistor dissipating 122.5kW in the open case

With the fail-safe working properly, the only variable that needed tweaking was the resistor value since we did not know how high or low it could go without negatively affecting the LED's performance. So with that in mind, we chose the fail-safe design shown in Figure 5 as the design for testing.

We then researched the kinds of white LEDs that would be used in our design. After looking for an inexpensive but bright LED, we settled on the LXML-PWC1-0120 LED with a typical efficacy of 124 lm/W at 350 mA [8]. A photograph of the LED as used for testing purposes is shown in Figure 7. The red and yellow wired were soldered on to allow for easier attachment a breadboard.

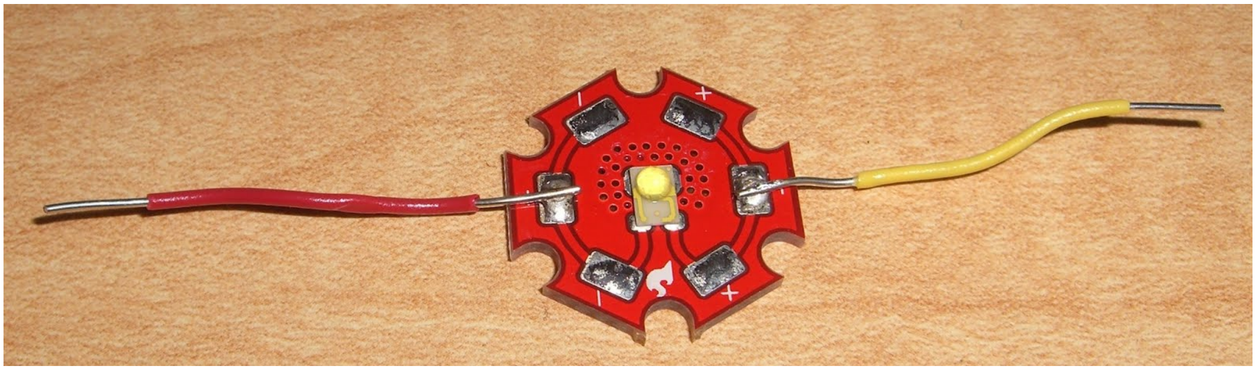


Figure 7. LXML-PWC1-0120 Cool-White LED

Next we would select appropriate resistor values to keep power dissipation levels low while having the resistance high enough so that the current does not bypass the LEDs by flowing through the resistors. After some testing, we observed that the LED would remain relatively bright when the resistance was somewhere between 20 - 30 ohms. We assumed a resistance of 25 ohms and incorporated that into our fail-safe design. The lower the resistance, the dimmer the LED and vice-versa. Figure 8 below shows our design for a single LED.

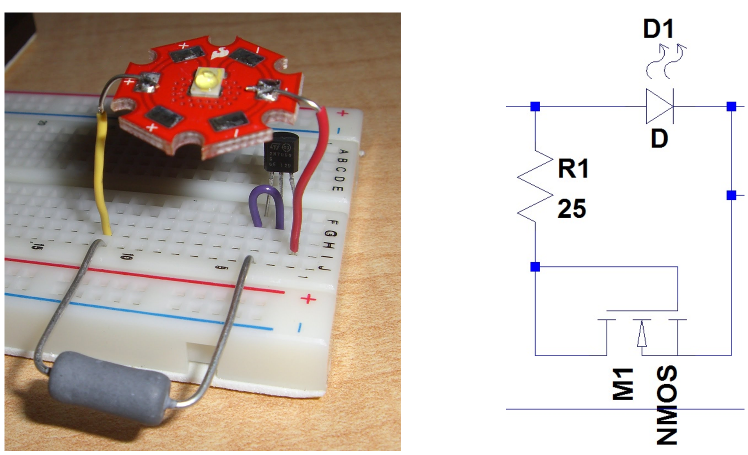


Figure 8. Final design of fail-safe for a single LED configured in drain-source

With the resistance value chosen, the next step was to test the fail-safe for several LEDs in series. With our circuit hooked directly to a +12V DC power supply, it was seen that after a certain number of LEDs was added to the circuit, there would be a massive drop in brightness. Because each LED had about 3V of forward voltage, the +12V DC power supply could only support up to four LEDs in series without serious degradation in brightness. Since our LEDs were to be driven at a specific current, we needed a constant current source rather than a constant voltage source. An LED driver was added to the circuit between the +12V DC power supply and the load. Difference in brightness was neglible and the current from the output of the LED driver was within 95% of 350 mA. Of that current, a small fraction flows through the resistor but has minimal impact on the brightness of LEDs.

The circuit has been tested for normal operation, with opens, and with shorts. With opens, we removed one LED from the circuit and found that the amount of power dissipated by the resistor was about 3W, thus making them very hot. So a resistor with a rating of at least 3W will be needed for the circuit. With shorts, nothing out of the ordinary happens as all the current travels through the short across the LED. The results showed that the fail-safe configuration works and the amount of power dissipated in each case were below 5W. Average power dissipation for the entire circuit as a whole was around 3.1W. The results concluded our testing of four LEDs using BJTs in the fail-safe.

Next we proceeded to test up to the maximum supplied voltage for the power supplies that were available to us at the time. About 23V DC was available for us to use and we were able to test up to seven LEDs without any degradation in lighting. Keeping the possibility of adding more LEDs to the load, we ordered a new LED driver that had higher input and output voltages. The RCD-48-0.35 LED driver can support up to 60V DC input and 56V DC output with an efficiency of 96% in 350mA output current. The only downside with this new LED driver was that it cannot be used to test single LEDs as the minimum input is 9V DC which is too high for the 3V forward voltage of our LEDs. From our testing's of the BJT, we noticed that power

dissipated from each LED was around 0.75W which was unexpected because theoretically our LEDs should be dissipating about 1W. About 250mA flows through the LED rather than 350mA as shown from our simulations shown in Figure 9 below.

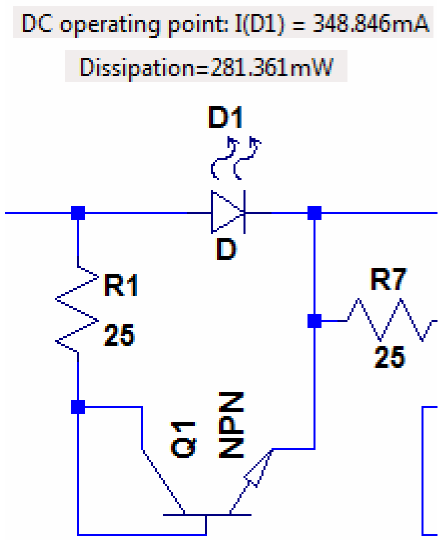


Figure 9. Simulation of BJT circuit showing current measured through LED

From testing and simulation, if the resistance in the fail-safe is increased, more current flows through the LED and less through the resistor. However the disadvantage of increasing resistance is that when there's an open, too much power gets dissipated by the resistor. Shown in Table 2 is the data collected for the BJT without any opens or shorts. Figure 10 shows the I-V variability for the BJT with 7 LEDs being used. For a typical diode, the I-V curve is rather steep. This is why we want to control the current and not the voltage. Adjusting the current allows for more control.

Table 2. Data for 7 LEDs using BJTs without opens/shorts

V-Power Supply (V)	I-Power Supply (mA)
22.80	330

7 LEDs (no shorts or open)				
LED#	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1	20.80	343.64	251.4	2.96
2	20.80	343.64	254.25	2.9
3	20.80	343.64	250.2	2.97
4	20.80	343.64	253.3	2.88
5	20.80	343.64	248.7	3
6	20.80	343.64	249.5	2.968
7	20.80	343.64	252.7	2.88
			Total Power (W)	5.168459

Resistors			BJT		
Current (mA)	Voltage(V)	Power(W)	Ic(mA)	Vce(V)	Power(W)
85.2	2.202	0.1876104	85.2	0.725	0.0617700
82.2	2.112	0.1736064	82.2	0.752	0.0618144
86.3	2.24	0.1933120	86.3	0.721	0.0622223
82.4	2.14	0.1763360	82.4	0.719	0.0592456
87.1	2.26	0.1968460	87.1	0.723	0.0629733
85.7	2.23	0.1911110	85.7	0.724	0.0620468
83.6	2.15	0.1797400	83.6	0.723	0.0604428
	Total Power (W)	1.2986		Total Power (W)	0.4305

Power In (W)	Total power LED (W)	Efficiency (%)
7.524	5.1685	68.69296917

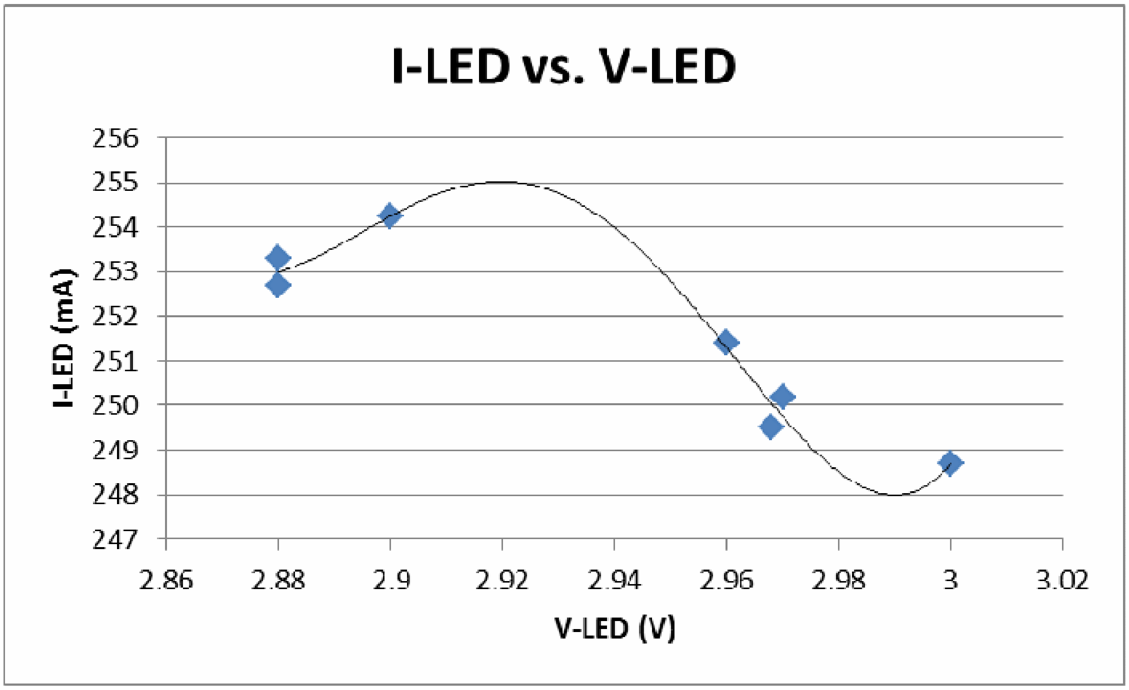


Figure 10. I-V variability for BJT data from Table 2

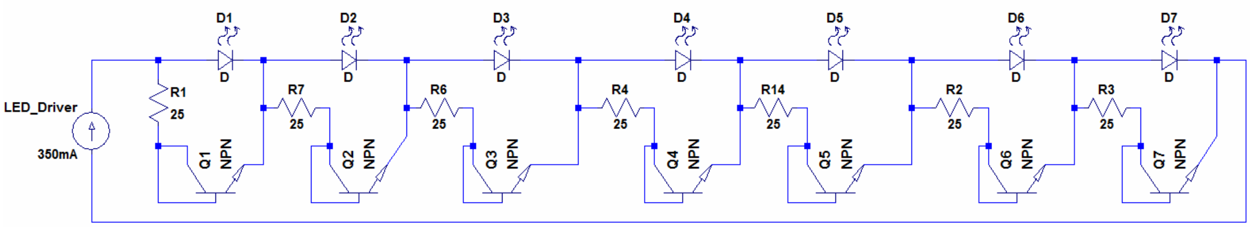


Figure 11. BJT circuit for Table 2

Other things we noticed while testing was that current measured through LED and through resistor was not constant when testing. Current would keep increasing by decimal increments through the LED and vice versa for the resistor. So what we did was extrapolate where the current would plateau or stabilize within a couple of milliamps the moment the power supply was turned on. This occurrence is probably due to the temperature of the LED rising, thus marginally increasing the amount of current in the LED. Not every terminal of the circuit

was measured so in our BJT data there is a couple of milliamps that are “missing”. These BJT and NMOS data for open and shorts cases will be shown at the end in Appendix B.

We also decided to test NMOS’s to see if it would make any difference in power consumption. We replaced the BJT with an NMOS and simulated the new configuration as shown in Figure 12 and Figure 13 below.

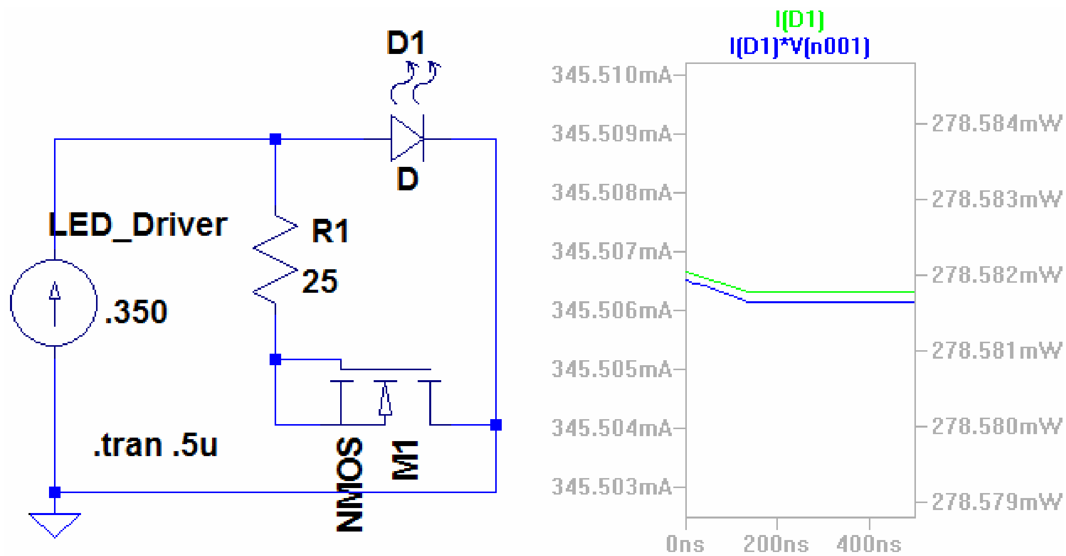


Figure 12. Simulated results for NMOS configured in Source-Drain

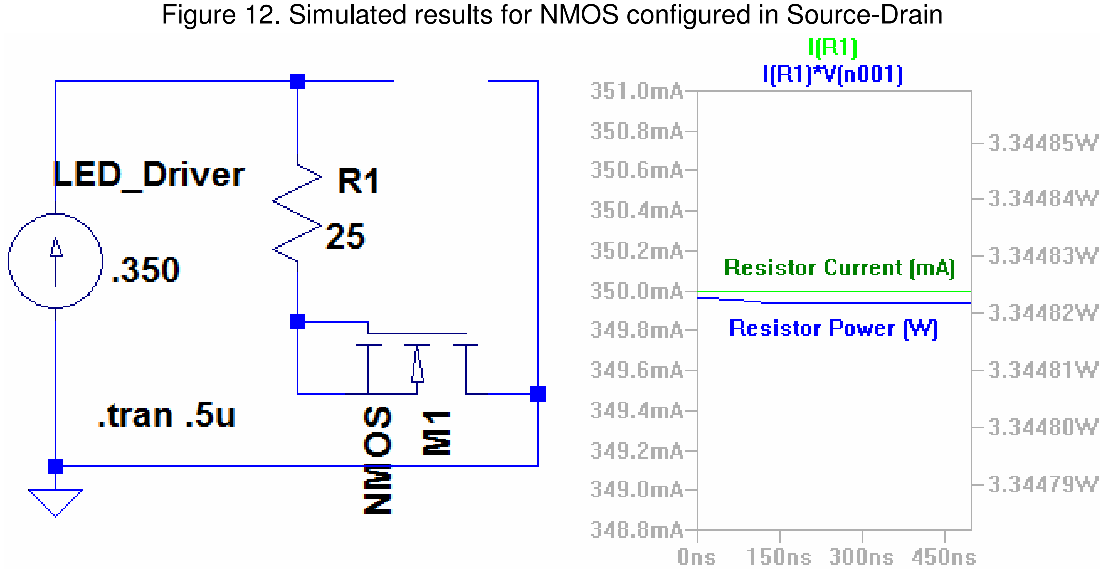


Figure 13. Open case for NMOS for resistor dissipating about 3.3448W

However when we tested the NMOS in source-drain configuration, the experimental data did not match up to the simulations. We switched the NMOS around into drain-source configuration and it seemed to have performed better by having more current flow through the LED as shown below in Figure 14.

Configured in Source-Drain				
7 LEDs (no shorts or open)				
LED#	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1	20.74	343.57	251.83	2.934

Configured in Drain-Source				
7 LEDs (no shorts or open)				
LED#	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1	21.20	343.6	328.19	3.004

Figure 14. Comparison of data of NMOS configurations

The same tests were done with the NMOS configured in drain-source as shown in Figure 16. For the NMOS data, we used Kirchhoff's Current Law (KCL) and found the current through the resistor. Table 3 and Figure 15 show the data for the circuit using NMOS transistors.

Table 3. Data for 7 LEDs using NMOSs without opens/shorts

V-Power Supply (V)	I-Power Supply (mA)
22.50	340

7 LEDs (no shorts or open)				
LED#	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1	21.20	343.6	328.19	3.004
2	21.20	343.6	330.5	2.94
3	21.20	343.6	330.3	3.01
4	21.20	343.6	329.9	2.91
5	21.20	343.6	322.5	3.03
6	21.20	343.6	326.8	2.99
7	21.20	343.6	327.5	2.907
			Total Power (W)	6.81811426

Resistors			NMOS		
Current (mA)	Voltage(V)	Power(W)	Id(mA)	Vds(V)	Power(W)
15.41	0.317	0.0048850	15.41	2.68	0.0412988
13.1	0.26	0.0034060	13.1	2.68	0.0351080
13.3	0.263	0.0034979	13.3	2.76	0.0367080
13.7	0.23	0.0031510	13.7	2.69	0.0368530
21.1	0.42	0.0088620	21.1	2.62	0.0552820
16.8	0.33	0.0055440	16.8	2.69	0.0451920
16.1	0.28	0.0045080	16.1	2.64	0.0425040
	Total Power	0.0339		Total Power (W)	0.2929458

Power In (W)	Total power LED (W)	Efficiency (%)
7.65	6.8181	89.1256766

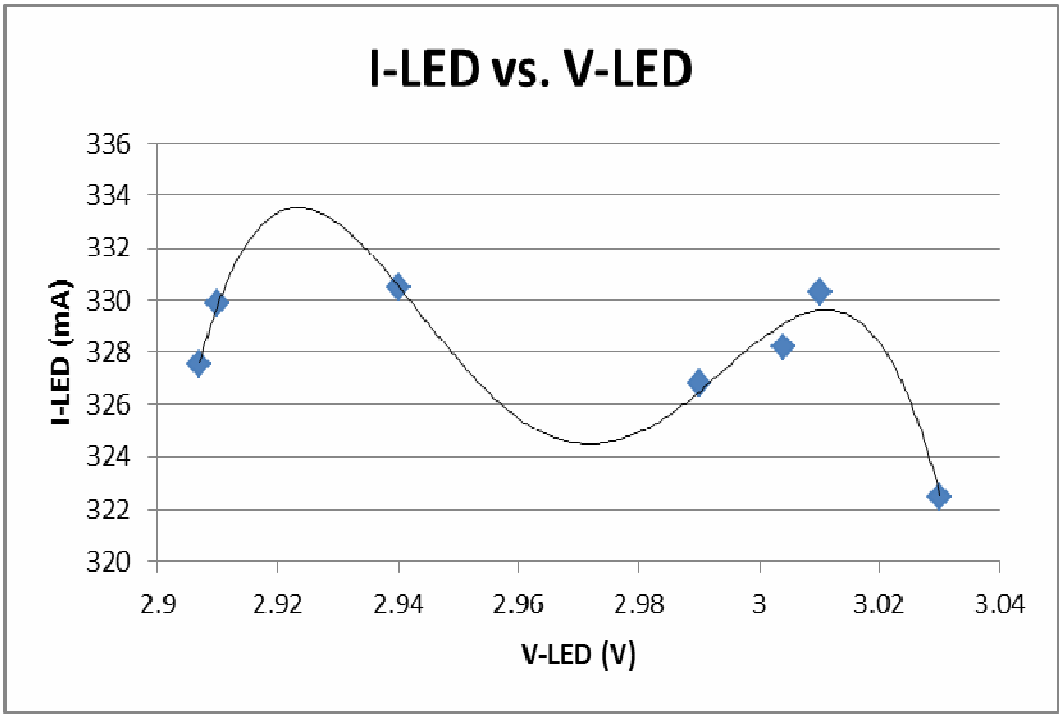


Figure 15. I-V variability curve for NMOS data from Table 3

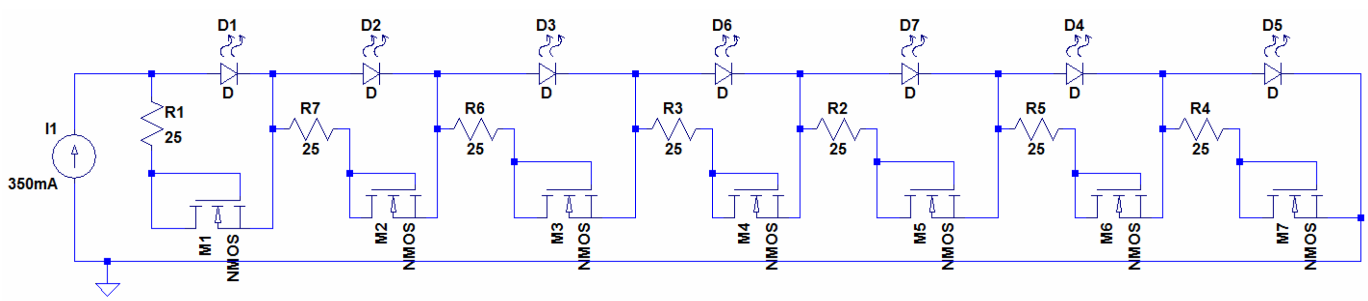


Figure 16. NMOS circuit configured in Drain-Source for Table 3

The current and power efficiency for the LEDs for the NMOS circuit is considerably higher than for the BJT. The NMOS data is similar to the BJT data in terms of power dissipated, however, there are also several big differences which will be discussed further in the next section.

NMOS vs. BJT

Based on the data collected, there are several noticeable differences between using a NMOS versus a BJT. From table 3, there is more current through the LEDs with the NMOS in normal operation, therefore providing more lighting. On average there is about 327.96 mA using the NMOS configuration compared with an average of 251.43 mA for the BJT. When one LED is shorted, there is also more current for the NMOS design as compared with the BJT. However, this is not the case when an LED is opened. The currents through the other LEDs are roughly the same, less than 10mA difference. The configuration with the highest power efficiency was the NMOS. From Tables 2 and 3, we can see that the efficiency for the LED in the BJT circuit is 68.69% while for the NMOS, the efficiency is 89.12%. Therefore, the recommended transistor for the circuit would be the NMOS.

12V vs. 48V

The main impact the use of different voltage levels is the amount of LEDs that can be supported. The higher the voltage supplied, the more LEDs and vice versa. As voltage supplied increases, so does power supplied and power dissipated when adding more LEDs to the load. If the load were to stay the same with four LEDs while supplied voltage is increased, the brightness of the LEDs would not be affected in anyway. However, when using a larger supply voltage, an appropriate constant current LED driver must be used to accommodate the increased voltage in order to avoid damaging the LED driver and the LEDs. Figure 17 shows a larger LED driver supporting up to 16 LEDs with 48V DC supply. The input voltage limits the amount of LEDs that can be configured in series. That amount of LEDs is approximately (Vsupply / 3) since each operating LED has a voltage of about 3V. Of course the intent of having higher supply voltages is mainly for bigger applications, such as the DC house which uses a 48V DC bus [11]. With 12V, it’s assumed that most applications would be for smaller lighting such as desktop lamps, a hefty flashlight, aquarium lighting, etc.

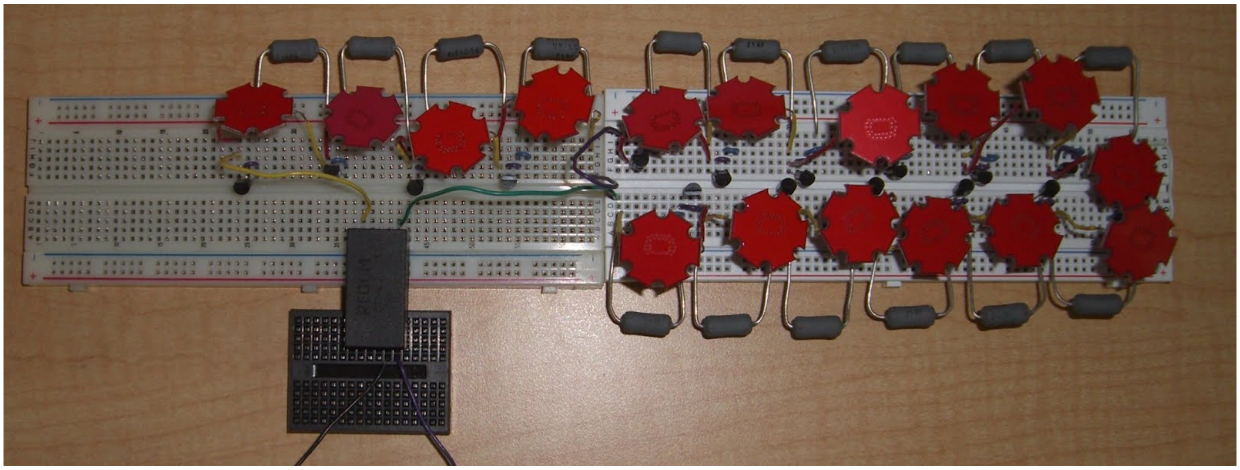


Figure 17. Test setup for 16 LEDs using 48VDC input with NMOS configured in source-drain

Final Design and Testing

Since the original specification of this project was to use a +12V DC supply, the final design for this project is going to be using 12V DC with a load of 4 LEDs configured in series. The smaller LED driver, VLD24-350, will be used in conjunction with 25 ohm resistors and NMOS's configured in drain-source. Below in Figure 18 is a schematic of the final circuit using 12V DC input into the LED driver.

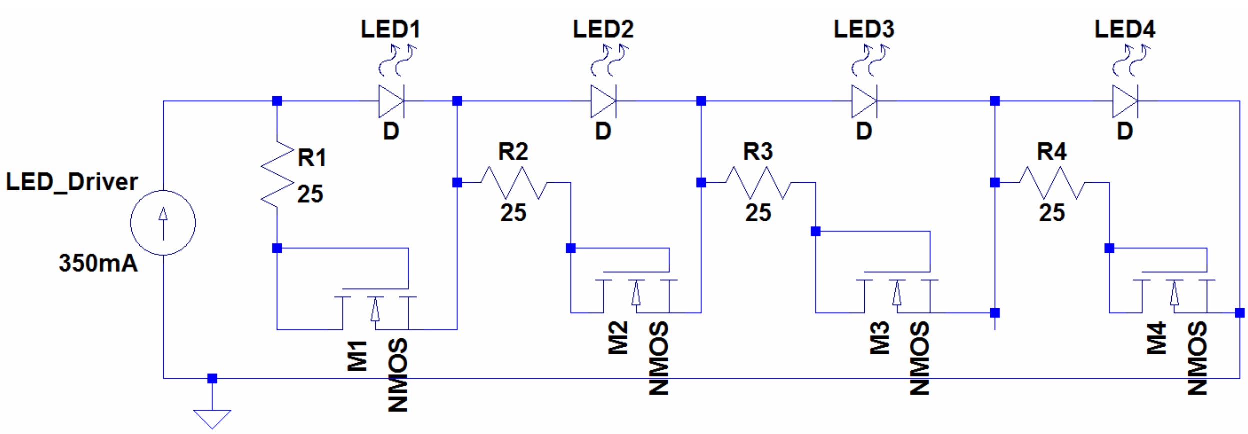


Figure 18. Schematic of LED fail-safe

Other Applications

The LED load used in our project can be used for various purposes other than as an application to the Cal Poly SuPER project. Some examples are DC House, outdoor/indoor lighting, solar integration, etc.

Cal Poly graduate student Kent Liang is currently working on a DC house as his master thesis and since power conservation is a big concern in the project, our white LED load would make a nice addition to the DC house as it's not as power consuming as traditional fluorescent/incandescent bulbs. Fluorescent and incandescent bulbs produce lumens in the range of 800-900 whereas our white LEDs can produce up to 1200 lumens with the same amount of power [9]. With solar panels installed onto the DC house, the project can be a self-sustaining unit as long as enough sunlight is absorbed. The specification for the DC house is the use of 48V. Using DC voltage for the distribution of LEDs with 350mA driving the LEDs, power consumed is similar to that of one fluorescent bulb.

Solar panels (or cells) can be integrated with white LEDs as well. The most widely use for this would probably be outdoor lighting such as street lamps or small lawn lamps. The technology is already out there but it's rather expensive at the moment. However, as technology progresses, the price for these solar LED lamps should drop. There is already a slow and gradual transition from the old fluorescent bulbs to LEDs in street lamps. The light emitted is much brighter and costs less in the long run. The lighting and lamp systems company OSRAM, predicts energy saving in the future may be as high as 80% as shown in Fig. 19 on the next page[10].

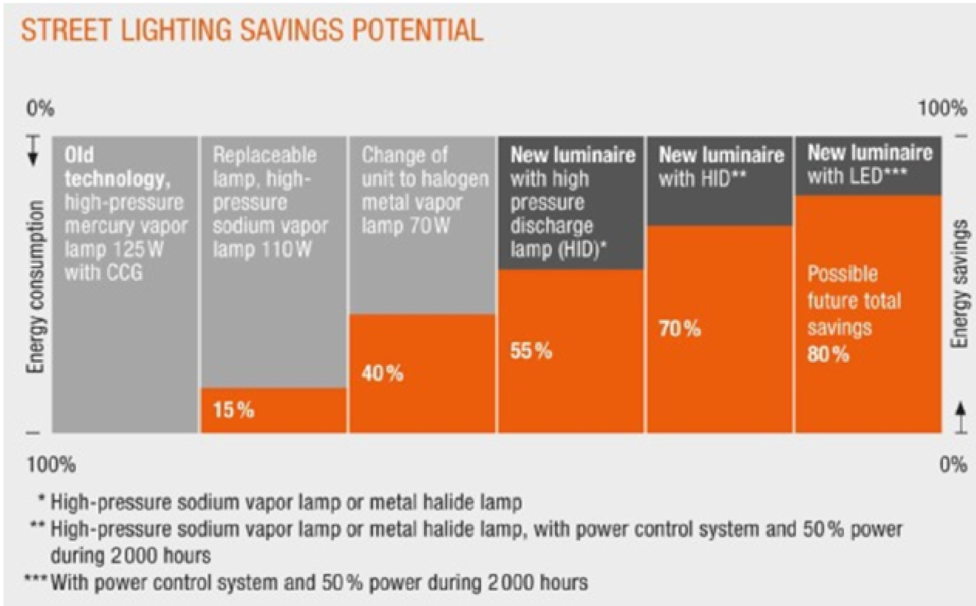


Figure 19. Predicted energy savings in the future

Since the newer white LEDs provide better lighting which can correlate to better safety, driving at night would be safer due to better lighting from the LEDs. Crimes would probably decrease as security cameras and witnesses would be able to capture images and videos of the crime in better quality due to the lighting of white LEDs.

Conclusions/Recommendations

Based on the results of testing, LEDs are proven to be a long-lasting efficient light source. The LED driver will take in an input voltage and deliver a constant current to the LEDs. The fail-safe make sure that in case of an open or short, current will continue to flow through the other LEDs. The amount of LEDs can be varied depending on the lighting required. Both BJT and NMOS have high power efficiency but it was determined that the NMOS transistors have higher efficiencies. The efficiencies for both cases are as follows: for the NMOS, 86.74% for short and 63.92% for open, and for the BJT, 68.27% for short and 36.2% for open.

This project has several aspects that could be improved or designed differently. The first and biggest recommendation to those deciding to further this project would to redesign the fail-safe so that the brightness of the LEDs would not be affected when there is an open, which is seen in both BJT and NMOS data. Another aspect is the dimming feature of the V-Infinity VLD24-350 LED driver which we did not expand on. On the VLD24-350 datasheet, there is a terminal for dimming the light via the resistance going into this dimming terminal. The lower the resistance, the brighter the LED and vice versa. That would most likely require additional circuitry like a potentiometer for easy control of the dimming feature, thus making the fail-safe bigger with the additional component. In an ideal circuit, the LED driver would be able to take in a very wide range of voltages and deliver the proper current to the LED load.

Our circuit is mainly comprised of through-hole components and although it's perfect for testing, actual implementation would leave the fail-safe rather large. The version of this circuit using surface-mount components instead would make the overall fail-safe smaller.

Another aspect could be to have a DC-DC boost converter incorporated into this LED circuit. That way if more LEDs were to be added on, the DC-DC boost converter would automatically accommodate for the increased load by increasing the supplied voltage. The DC-DC boost converter would eliminate the hassle of trying to set the right amount of voltages for the new load.

Bibliography

1. Zukowski, Joseph A.,"Implementation of High Powered LED Load into the SuPER System", Senior project, California Polytechnic State University San Luis Obispo, 2009. DigitalCommons@Calpoly. Web. 11 Jan. 2012. < http://courseware.ee.calpoly.edu/~jharris/research/super_project/jz_sp.pdf>
2. “Evaluating the Lifetime Behavior of LED Systems”, Philips Lumileds Lighting Company. Apr. 2012 <www.philipslumileds.com/uploads/167/WP15-pdf>
3. Hechfellner, Rudi, and Steve Landau. "Understanding LED Performance."*Philipslumileds.com*. 22 June 2011. Web. Apr. 2012 < http://www.philipslumileds.com/uploads/14/NA05-pdf>
4. "LUXEON Rebel General Purpose White Portfolio." *Philipslumileds.com*. Web. Jan. 2012. <http://www.philipslumileds.com/pdfs/DS64.pdf>.
5. "Colour Temperature Chart." *Colour Temperature Chart*. Web. Apr. 2012. <http://www.mediacollege.com/lighting/colour/colour-temperature.html>.
6. *Kandl LED*. Web. 2 May 2012. <http://www.kandiled.com/info.html>.
7. "LEDs Magazine." *LEDs Magazine*. Web. May 2012. <http://www.ledsmagazine.com/news/3/11/14/Acriche2>.
8. "LUXEON Rebel White LEDs." *Philips Lumileds LED Lighting*. Web. May 2012. <http://www.philipslumileds.com/products/luxeon-rebel/luxeon-rebel-white>.

9. Durda, Frank. "The Fluorescent Lighting System." *Fluorescent Lighting Energy Savings and Product Comparisons*. Web. Apr. 2012. <http://nemesis.lonestar.org/reference/electricity/fluorescent/efficiency.html>.

10. "White LEDs in Street Lighting - Functional, Safe and Efficient." *Trends & Knowledge|LED Home|LED Trends|Urban Safety|index*. Web. Mar. 2012. <http://www.osram.com/osram_com/trends-and-knowledge/led-home/led-trends/urban-safety/index.jsp>.

11. Chaidez, Jessica. *DC House Modeling and System Design*. Tech. Web. 18 May 2012. <http://www.calpoly.edu/~taufik/dchouse/download/Chaidez.pdf>.

Appendices

A. Parts List

Table A-1. List of the costs for the parts used in this project.

Component Name	Part Number/Description	Quantity	Cost
LED	Philips Rebel High Power LED	20	$107.20
LED Driver	V-Infinity VLD24-350	1	$10.52
LED Driver	RECOM RCD-48-0.35	1	$30.25
BJT	PN2222AFS	20	$3.33
MOSFET	2N7000	20	$3.81
Resistor (25 ohm)	UB5C-25RF1	20	$14.52
		Total Cost	$169.63

B. Design Test Data

Tested on April 3, 2012

Table B-1. Data for BJT tested with an LED shorted

V-Power Supply (V)	I-Power Supply (mA)				
23.30	280				
7 LEDs (with short)					
LED #1 shorted	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)	
1 (shorted)	17.77	343.64	0	0.00563	
2	17.77	343.64	253.7	2.988	
3	17.77	343.64	249.9	2.975	
4	17.77	343.64	253.4	2.884	
5	17.77	343.64	248.7	3.004	
6	17.77	343.64	251.3	2.969	
7	17.77	343.64	252.3	2.888	
			Total Power (W)	4.4541606	

Resistors			BJT		
Current (mA)	Voltage(V)	Power(W)	Ic(mA)	Vce(V)	Power(W)
0	0	0.0000000	0	0.00589	0.0000000
82.4	2.116	0.1743584	82.4	0.751	0.0618824
86.1	2.235	0.1924335	86.1	0.719	0.0619059
82.4	2.14	0.1763360	82.4	0.714	0.0588336
87.2	2.267	0.1976824	87.2	0.719	0.0626968
85.4	2.234	0.1907836	85.4	0.722	0.0616588
83.3	2.163	0.1801779	83.3	0.721	0.0600593
	Total Power	1.1118		Total Power (W)	0.3670

Power In (W)	Total power LED (W)	Efficiency (%)
6.524	4.4542	68.27346107

Tested on April 3, 2012

Table B-2. Data for BJT tested with an LED opened

V-Power Supply (V)	I-Power Supply (mA)
23.20	190

7 LEDs (with open)				
LED #1 open	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1 (open)	22.43	193.84	0	0
2	22.43	193.84	96.53	2.763
3	22.43	193.84	93.6	2.844
4	22.43	193.84	96.2	2.773
5	22.43	193.84	91.9	2.867
6	22.43	193.84	93.7	2.848
7	22.43	193.84	95.6	2.783
			Total Power (W)	1.59606309

Resistors			BJT		
Current (mA)	Voltage(V)	Power(W)	Ic(mA)	Vce(V)	Power(W)
184.8	4.731	0.8742888	184.8	0.761	0.1406328
77.43	2.0173	0.1561995	77.43	0.749	0.0579951
81.38	2.1283	0.1732011	81.38	0.7185	0.0584715
78.43	2.056	0.1612521	78.43	0.7168	0.0562186
81.965	2.15	0.1762248	81.965	0.7196	0.0589820
81.06	2.127	0.1724146	81.06	0.726	0.0588496
79.31	2.067	0.1639338	79.31	0.7225	0.0573015
	Total Power (W)	1.8775		Total Power (W)	0.4885

Power In (W)	Total power LED (W)	Efficiency (%)
4.408	1.5961	36.20832781

Tested on April 24, 2012

Table B-3. Data for NMOS tested with an LED shorted

V-Power Supply (V)	I-Power Supply (mA)
22.50	300

7 LEDs (with short)				
LED #1 shorted	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1 (shorted)	18.40	343.5	0	0.000
2	18.40	343.5	330.3	2.970
3	18.40	343.5	329.6	3.020
4	18.40	343.5	330.4	2.920
5	18.40	343.5	322.9	3.040
6	18.40	343.5	327.1	3.000
7	18.40	343.5	326.7	2.910
			Total Power (W)	5.854764

Resistors			NMOS		
Current (mA)	Voltage(V)	Power(W)	Id(mA)	Vds(V)	Power(W)
0	0	0.0000000	0	0.009	0.0000000
13.2	0.249	0.0032868	13.2	2.67	0.0352440
13.9	0.256	0.0035584	13.9	2.76	0.0383640
13.1	0.231	0.0030261	13.1	2.68	0.0351080
20.6	0.424	0.0087344	20.6	2.62	0.0539720
16.4	0.317	0.0051988	16.4	2.69	0.0441160
16.8	0.292	0.0049056	16.8	2.64	0.0443520
	Total Power (W)	0.0287		Total Power (W)	0.2512

Power In (W)	Total power LED (W)	Efficiency (%)
6.75	5.8548	86.73724444

Tested on April 24, 2012

Table B-4. Data for NMOS tested with an LED opened

V-Power Supply (V)	I-Power Supply (mA)
23.30	110

7 LEDs (with open)				
LED #1 open	V-LED driver (V)	I-LED driver(mA)	I-led (mA)	V-led (V)
1 (open)	23.06	107.9	0	0
2	23.06	107.9	97.4	2.782
3	23.06	107.9	94.8	2.861
4	23.06	107.9	97.6	2.798
5	23.06	107.9	96.6	2.88
6	23.06	107.9	94.8	2.862
7	23.06	107.9	97.9	2.793
			Total Power (W)	1.6382347

Resistors			NMOS		
Current (mA)	Voltage(V)	Power(W)	Id(mA)	Vds(V)	Power(W)
107.9	2.779	0.2998541	107.9	3.246	0.3502434
10.5	0.147	0.0015435	10.5	2.661	0.0279405
13.1	0.2353	0.0030824	13.1	2.623	0.0343613
10.3	0.1716	0.0017675	10.3	2.618	0.0269654
11.3	0.226	0.0025538	11.3	2.69	0.0303970
13.1	0.283	0.0037073	13.1	2.572	0.0336932
10	0.178	0.0017800	10	2.615	0.0261500
	Total Power (W)	0.3143		Total Power (W)	0.5298

Power In (W)	Total power LED (W)	Efficiency (%)
2.563	1.6382	63.91863831

For both open and short cases, the NMOS has higher efficiencies. In the open case, efficiency is much higher (63.92% compared to 36.2%). In the short case, efficiency is much higher (86.74% compared to 68.27%).

Senior Project Analysis

Project Title:

Student's Names: ___________________ Signatures: _____________________

___________________ _____________________

Advisor's Name: ___________________ Initials: ______ Date: ___________

- Summary of Functional Requirements

This senior project will be incorporated into the Cal Poly SuPER System. It uses a design of a series implementation of LEDs with a fail-safe mechanism. A DC battery voltage source will supply power to the circuit through a LED driver. The LED driver will deliver and control the amount of current that will flow through the LEDs.

- Primary Constraints

When designing the fail-safe portion of the circuit, it took some time to find the appropriate resistor value. The reason was because if the resistance was too low, too much current would flow through the resistor rather than the LED. If the resistance was too high, there would be a high voltage drop across the resistor. During the testing phase, we had difficulties accessing the lab that housed a power supply that would meet the needs that would allow us to test more than about seven LEDs at a time.

- Economic

The total cost of parts used for this project is $169.63 with the majority of the cost going towards the Philips Rebel High Power LEDs. We purchased 20 LEDs in case of any malfunction and it is nice to have spares around. When we researched DC-DC converters and transformers,

we discovered that there were LED drivers that were available that performed the function that we needed. The V-Infinity VLD24-350 was our first choice and we found that it was able to provide the correct current for a limited amount of LEDs. The RECOM RCD-48-0.35 was able to handle a larger input voltage and load so we used it to test the circuit with 16 LEDs. There will be large savings over time by using LEDs as a lighting source over today's conventional light bulbs, enabling many to benefit.

- Environmental

This project, as part of the SuPER project, will draw power from a photovoltaic source. Due to the efficiency and low power consumption of LEDs, this project will help the environment.

- Manufacturability

All of the components of the circuit were readily available online to be purchased. If the entire system was to be manufactured, there would need to be a very precise method that would need to be designed from the ground up. This method would have to ensure that every component is where it's supposed to be. Since the amount of LEDs can be varied, the manufacturing process will need to take this into account.

- Sustainability

As stated in the background section, the average life cycle for LED's is an average of 50,000 hours, which is a significant increase compared to the light bulbs that are being used today. Also, as advancements in LED technology continue to be made, the life cycle will increase even more. In order to improve the design of the project, a different LED driver could be used that would be able to handle various amounts of LEDs, depending on the desired need.

- Ethical

This project will be used to provide efficient lighting and will be difficult to misuse.

- Health and Safety

The LEDs can be very bright if someone gets too close and stares at the bulb for long periods of time. This is not recommended as it can damage one's eyesight permanently. During testing, sunglasses and shades were used when collecting data since we had to be up close to the LEDs to take measurements.

- Social and Political

LEDs are fast becoming the new lighting solution for many applications. As a result, any location that utilizes the LEDs will benefit with better visibility and economic savings due to better power efficiencies. Stakeholders in companies that manufacture LEDs will see their investments as worthwhile and will not create inequities.

- Development

Use of simulation software such as PSpice and LTSpice were used early in the design process so that appropriate components were chosen. All tools and techniques used for this project were based on those learned in the classroom.