Electrical Engineering Department
California Polytechnic State University

Senior Project Final Report

DC House Smart Pathway Lighting System

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Abstract

The Student Experimental Farm (SEF) is a two-acre site where students are able to create projects and experiments. It is also the location of the DC House project, a house with electricity provided by DC power as opposed to the traditional AC power. The motive of the DC house project is to provide affordable and renewable electricity for people living in remote areas where ac power grids are not available. Currently, the SEF does not have any lighting, so students would have to work in the dark after the sun sets. By creating a smart lighting system for the pathway towards the DC House, students working at the DC House will be able to work on their projects beyond daytime hours. The system will utilize DC power and turn on automatically when motion is detected. This lighting method will then save energy as the lights will only turn on momentarily as students pass by. With the ideals of the DC House in mind, the smart pathway lighting system not only saves energy, but it also will show the capabilities of a DC system providing proper lighting for communities with no access to an AC grid. The system was successfully implemented and installed. With expected conditions, power consumption requirements were met when system was both off and on.

Chapter 1. Introduction

In our world today, the demand for electricity has been rising along with the growing age for technology. Most households have access to government regulated power grid and many users take advantage of it. However, there are still many communities today that still do not have access to a power grid. According to the world-bank data, only 87% of the entire world population has access to AC power [1]. This is mostly because the expense to install, run, and maintain an AC power grid costs too much for many governments to regulate.

Located on campus at the Student ExperimentΩal Farm, the DC House Project started with the intention to provide power to a system from only direct current electricity. This idea best benefits communities in third world countries specifically those without access to any alternating current grid. Along with providing an alternative energy solution, the projects created at the DC House provides solutions for cost-efficient energy usage.

Current consumer lighting systems typically are powered off of AC systems connected to the grid. These are often efficient systems in modernized countries. However, the 13% of the world without access to AC power does not have the ability to use such a lighting system. Outdoor lighting is still important for these countries to provide safety and accessibility for citizens, so there needs to be a way for every person to have access to a lighting system.

Another important concern in the world of power electronics is efficiency and longevity. Especially in the intended field environment of a third world country, an efficient power system is necessary to provide the most appropriate cost-benefit and provide for the best environmental concerns. By saving more energy, consumers will be able to save money while still being able to access electricity. Many alternative lighting systems can be powered by batteries, many are disposable. However, many third world countries who do have access to these batteries will still face challenges for powering their lighting systems as these batteries may not last long, making lighting systems difficult to construct. With a stable efficient rechargeable battery, lighting systems can become more sustainable in the long run. This is ideal for third world market because of the limited amount of power resources available for these countries, especially in the rural areas.

Chapter 2. Background

The DC House project started in 2010 with the overall goal is to develop the technology to distribute electrical power to a house using DC electricity while incorporating multiple small-scale renewable energy sources. There have been many students participated and conducted projects on the DC House looking into the various aspects of the system which includes the source, the interface, and the load. However, there is one aspect of the project that would add an important feature of the DC House system, namely efficient lighting system. Since DC House makes use of small scale energy sources, therefore it is important to design a system that can conserve energy as much as possible. The efficient lighting is good example of such a system since it will automatically turn on with the presence of a person nearby, but then immediately turning off once the person leaves or walks away from the lighting.

Besides the ability to conserve energy when energy is scarce, the concept of a street or pathway lighting system in general has many purposes. First is to provide night-time lighting aimed mainly for providing safety for communities and road users, minimizing crime, and providing public lighting for safe traveling for night activities.

Secondly, as a source of light especially for night time, the lighting system may have direct social impact for many communities around the world. In many third world countries for example, crime is both the cause and consequence of poverty, insecurity, and underdevelopment [2]. Studies show that a well-designed street lighting system can actually reduce crime by twenty-percent [3] due to the fact that lighting systems will help with surveillance and decreased criminal opportunities. Although there are many different aspects of decreasing crimes in third-world countries, a well-designed lighting pathway system can help make an impact in reducing crime.

Additionally, having a lighting system may promote a safer environment for many communities. In one article [4], it is stated that many women are instilled with fear as they do not feel a place of belonging in the dark. Children could also benefit from the provision of street lighting since families will want their children to walk safely on the streets without having to worry that they may get because it is difficult to walk in the dark. Street and pathway lightings would help eliminate this problem by providing sufficient lighting in poorly lit locations.

The pathway lighting system presented in this report utilizes DC LED light bulbs which has direct impact on health, again especially in rural areas in third world countries. To date there are more than 1.6 billion people around the world who live without access to electricity. For many of these people, lighting is provided by kerosene lanterns in their homes and torches when they are traveling. Kerosene provides dim and inefficient light while releasing toxic smoke and producing CO_2. Because of this, kerosene also poses serious health hazards such as respiratory and eye problems and contributes to global warming. Solar powered DC LED light bulbs are a clean and affordable replacement to kerosene lanterns. LED lights provide reduced spending by poor families because they are cheaper than kerosene, improved studying conditions for children, and reduced air pollution. As one article mentioned, "Use of solar-powered white LEDs significantly reduces power consumption, no environment contamination by mercury, and increases monthly savings by up to 70%." [5].

Additionally, car usage is increasing in developing countries [6]. With the use of cars, there is a new trend for people to start moving into cities [7]. This creates more urbanization in third world country with more people grouping together. With these two factors, there has been an increasing need for lighting systems in third world countries to increase safety. Since street lighting reduces traffic accidents by an average of 30% [8], street lighting will be beneficial for the safety of drivers and pedestrians at night.

After conducting research on the methods to conserve energy in lighting system, we came across one project that attempted to create a “fade-out” circuit so that a light bulb would dim over time after it was turned on. This project provided the outdoor base setup for the physical system and the basic circuit design developed on a breadboard. This setup did not work well and needed further improvements to complete [9]. One of the issues dealt with wiring problem that caused the system to fail. The project also used a microcontroller for every three light bulbs which raised the overall system cost. In order to complete this project, changes for the circuit design along with the corresponding components are necessary. Therefore, the goal of the current project is to develop a functional pathway lighting system that is cost-efficient while utilizing the fade out feature to conserve more energy.

Chapter 3. Design Requirements

The general concept of the proposed system is shown in Figure 3-1. The process is as follows: every circuit is powered by the DC House which will also power the LED light bulb. If there is motion but there is sunlight detected, the device will not activate the light bulb. If there is no motion and no sunlight detected, the device will still not activate the light bulb. If and only if there is motion and no sunlight, the device will activate the light bulb and leave the light bulb on for about two seconds if no further motion is detected. With this simple concept, the main purpose of the system is to save energy by turning the light bulb only when it is necessary.

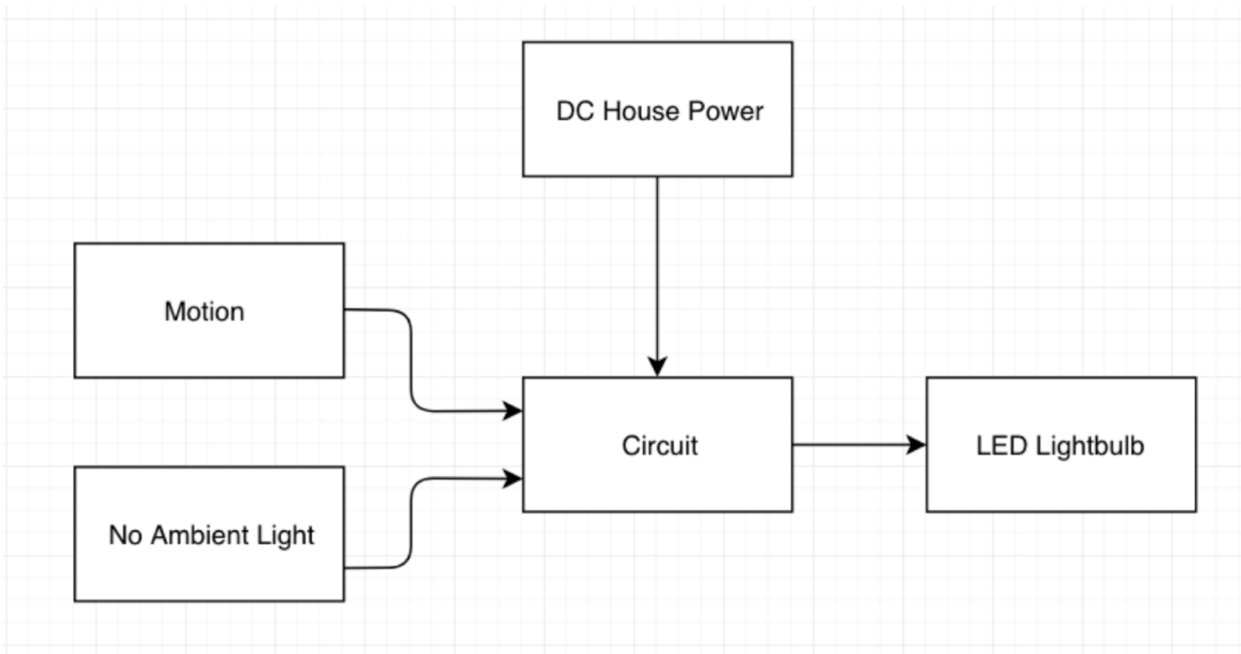

Figure 3-1: Project Level 0 Block Diagram

Technical Design Requirements:

Table 3-1: Technical Design Requirements

	Requirement	Justification
1	The system shall run on 48 V DC Power	System uses 48 V from DC House. By using DC power directly, there will be less power loss.
2	The system shall be fully autonomous.	The system must run by itself with no input, and minimal maintenance needed once system is installed.
3	The system should be as power efficient as possible.	System must use minimal power so that it doesn't use up battery quickly and to be more cost efficient. Projected goal is at least 90% efficiency.
4	The system shall sense movement and light	Lights will turn on only if it is dark enough, and if the system tracks movement nearby at most 3 meters away.
6	The system shall be well protected.	System will be weatherproof to promote longevity. The components must be protected from rain, wind, snow, heat, etc. IP67 enclosure rating is desired.

To go further, Figure 3-2 shows the design of our circuit. With the engineering requirement of having 48V DC we require a buck converter in order to step down our voltage in order for our electronic components to function. We desire to have the buck converter step down our 48V DC to 5V DC as most components only operate in a voltage region between 3.3 to 6V DC making 5V DC a safe nominal voltage to operate. Once the DC voltage is converted, it will power the motion sensor. The motion sensor will have two conditions: If motion is detected, then 5V will be outputted. If no motion is detected, then 0V will be outputted. The output of the motion sensor will then send a signal to the triple OR Gate. The triple OR gate will receive three different signals all from different lighting stations on the lighting pathway. One from the left of the lighting station, one from the current lighting station, and one from the right of the lighting station. This would then make the user have 3 light bulbs at most so that the user can have light in front of them and one behind them. The output of the triple or-gate would then go to the delay circuit which we would like to have a run time of 3 seconds. This delay acts as a fade-out so the brightness of the LED dampens over the 3 seconds. The output of the delay circuit would be connected to the gate of the MOSFET. The MOSFET will then act as a switch for our LED light bulb to turn on only if it receives the 5V signal at its gate. Additionally, the LED light bulb will still use the 48V DC to turn on in order to provide more power to be bright. The brightness depends on the factor of how the LED is manufactured. Studies have shown that an optimum luminosity for a lighting pathway should be around 10 lux, which when converted to an area of 1 square meter all around it results in brightness value of 100-150 lumens [10]. To better understand each individual component and its design requirements, Tables 3-2 through 3-7 list and describe the various specific electrical components of the proposed system along with their requirements, functionality, and brief descriptions.

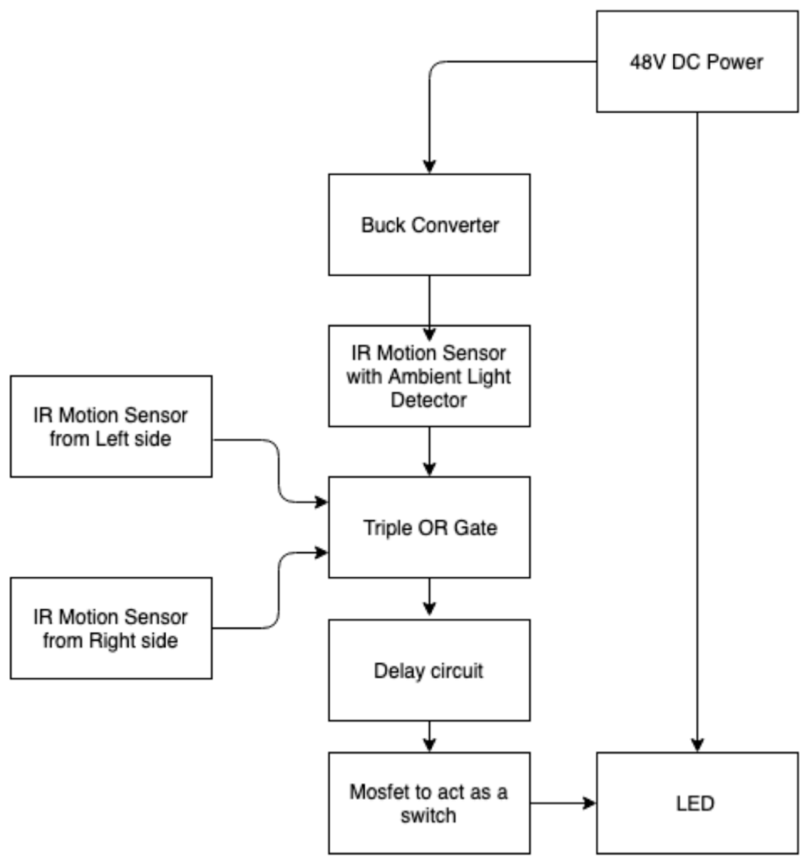

Figure 3-2: Level 1 Block Diagram

<u>Electrical Specifications:</u>

Table 3-2: Level 1 Buck Converter

Module	Buck Converter
Input	48V (DC) from DC House
Output	5V (DC)

Design Requirements	● Vin 48V ± 2V ● Vout 5V ± 10% ● Line Regulation < 20% The input voltage will usually be 48V ± 2V depending on energy stored in the battery from the DC House. The buck converter must have a proper line regulation as input voltage would fluctuate depending on energy stored in the battery. The line regulation should be under 20% as our nominal voltage would be 5V and expected minimum voltage should be 4.2V and expected maximum voltage should be 5.2V. The line regulation is very flexible as most of our circuitry will have a big safe operating region (3.3V to 6Vdc) and output current should be enough to drive the N-MOSFET to operate in the linear region to make it act as a switch.
Functionality	The buck converter is a DC-DC converter that brings a higher voltage down to a lower voltage, usually specified for the user. In our case, we would like 5Vdc for our nominal voltage in order to operate our electronic components which vary in the voltage operating region of 3.3V to 6Vdc.

Table 3-3: Level 1 Motion Sensor with ambient light detector

Module	Motion Sensor with ambient light detector
Input	An infrared sensor detects motion along with a specified low ambient light detection. Will be powered by a 5Vdc signal (Input voltage ranges from 3.3 to 6Vdc)
Output	Depending on the input, if a signal is detected, it will send out a high 5V output. If no signal is detected, it will sound out a low 0V output

Design Requirements	● Voltage operating region (3.3V-6Vdc) ● Detects ambient light ● Detects motion without lighting ● At least 2 meters range in front of the sensor The IR motion sensor should operate in the voltage region between 3.3V to 6V as it will be powered by the previous buck. Additionally, it should be able to measure ambient light and detect motion in order to send out the proper signal when motion is detected and when it reaches a certain ambient brightness to turn on the LED's when it is no longer bright outside. We also want the sensor to be able to sense movement at least 2 meters away as the distance from the lighting station to the lighting path is approximately that long.
Functionality	This is a sensor that is both a light sensor and a motion detector that requires both conditions to be met in order to send out a signal on its output.

Table 3-4: Level 1 Triple OR Gate

Module	Triple OR Gate
Input	The Triple OR gate will be receiving 3 inputs from the outputs of the IR sensors to the left, to the middle, and to the right of the lighting station it is at. These will all be 5V signals (Vin limitation is minimum 1V and maximum 5V).
Output	The output of the Triple OR Gate would then connect to the delay circuit

Design Requirements	● Voltage operating region (3.3V-6Vdc) ● 3 inputs and 1 output The triple OR-gate should operate in the voltage region between 3.3V and 6V as it will be powered by the output of the buck. Three inputs are required in order to read the signals from a person in front of the person, where the person is currently at, and behind the person. This would create proper lighting for the person to walk safely as the person can see ahead of the path in front and behind in case the person desires to walk backward.
Functionality	This triple OR Gate would be acting as a MISO where it receives 3 different inputs and sends out a single output when the IR sensor detects motion so that it can turn on the LED's at the specified locations.

Table 3-5: Level 1 Fade-out Circuit

Module	Delay Circuit
Input	The input of this circuitry will be from the output of the triple OR gate giving a 5V signal with at least a 10mA current to be able to charge the RC circuit.
Output	The output of this circuit connects to the gate of the NMOS which should drive the MOSFET to operate in the linear region to act as a switch. It should be a 5V signal with a minimum 10mA current to drive the NMOS as a switch

Design Requirements	● Voltage operating region (3.3V-6Vdc) ● Fade-out time of at least 3 seconds before fading out ● Minimum input current of 10mA The design of the delay circuit is mostly focused on the timing of how fast a user would walk past a lighting station. With many people walking at different speeds, a minimum of 3 seconds would be optimal for users to walk past a lighting station and reach the next one before having the light behind the user turn off fully. Because this circuit is before the NMOS switch, it should still operate in the 3.3-6Vdc region and should discharge voltage through the gate properly before fully turning off the LED. It needs a minimum of 10mA to be able to charge the RC constant and drive the NMOS enough to operate in the linear region.
Functionality	The delay circuit will be acting as our light fade out. In order to prevent the light from turning off abruptly and scaring users, the delay circuit to allow users to walk away from the lighting post before fully turning off. This would then conserve energy instead of fully being on all the time or for a set time and not scare users if it turns off abruptly.

Table 3-6: Level 1 MOSFET

Module	N-MOSFET
Input	The Gate will be receiving the signal from the motion sensor either a 0V or 5V signal. The Drain will be connected to the cathode of the LED. The drain will be tied to ground
Output	The output of the MOSFET is a current with a proper signal is received through the gate

Design Requirements	● Voltage operating region for gate (3.3V-6V DC) ● Vdrain max 50V DC ● Maximum drain to source Current 0.5A A specific NMOS needs to be chosen for this application. With the drain having a nominal voltage of 48V and the gate nominal voltage of 5V, the MOSFET needs to be able to have a maximum drain voltage well above 48V for the drain will be connected directly to the LED which is connected directly to the DC House 48V power line. Additionally, a maximum drain to source current of 0.5A will be required as depending on the power consumption of the light bulb, enough current needs to drive the LED to reach its expected brightness as well as not burn the MOSFET when current is running through the MOSFET.
Functionality	This MOSFET will be acting like a switch. If a 5V signal is sent into the gate of the MOSFET, then current will run through the LED and it will activate the light bulb to turn on.

Table 3-7: Level 1 LED

Module	9W consumption LED (60W rated LED)
Input	The input is the anode of the diode which will receive the 48V voltage from the DC House
Output	The output is the cathode of the LED which is connected to the gate of the MOSFET. We would expect brightness output of 100-200 lumens from the source.

Design Requirements	● Brightness output of 100-200 lumens from source ● 60W rated (to withstand the 48V input voltage and driving current) ● Power Consumed should not exceed 10W The LED should be able to have enough brightness to light up the lighting pathway for users to be able to see the pathway and walk safely. Based on references, 600-800 lumens should be our expected brightness to properly light the pathway. Additionally, the LED's power rating should be high enough that we would not be able to burn out the LED. At the same time, we do not want the LED's to consume too much power in order to not drain the battery at the DC House.
Functionality	The LED will turn on only if the circuit receives proper current through it. It will only receive the current if the MOSFET switch turns on.

Mechanical Specifications:

All wiring is already installed underground at the site where the proposed system will be implemented. The wiring system is encased in PVC pipes in order to protect the wires. The PVC pipes will also be used to mount the lighting system and the circuit will be encased in a plastic box in order to protect it from any weather damage. Additionally, the light bulb will be protected by a glass encasing in order to protect it from any weather condition while providing the necessary brightness for the pathway. Figure 3-3 shows the general layout of the lighting systems along with the pathway. The entire pathway is approximately 52 meters long and 1 meter wide with a spacing of around 3 meters between each lighting station.

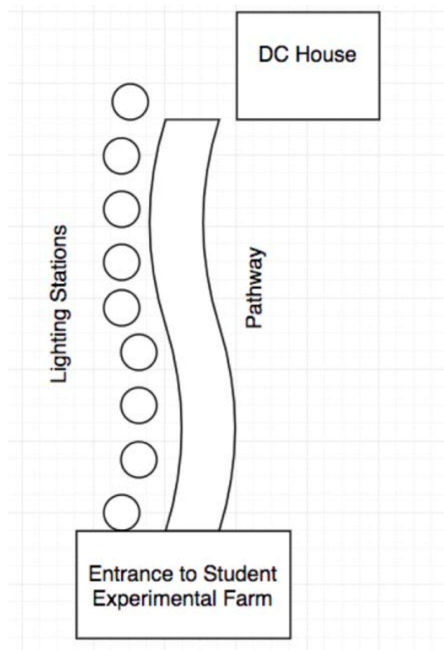

Figure 3-3: General layout of smart lighting systems

Figure 3-4 shows a complete diagram of the design of the proposed lighting system. The proposed lighting system employs two weatherproof enclosures that protect both the circuit and the light bulb itself. The light bulb encasing will be made of glass, as it will be more reliable than plastic and easier to clean in the case of any dirt or rain residue that gets stuck on it. Additionally, the encasing will most likely be made of thick plastic similar to that of a PVC pipe material that can be viable in hot or cold and sunny or stormy conditions. The PVC pipe attached to the box will hold all the DC wires provided from the DC House. There will be a small opening in front of the encasing in order for the motion sensor to read a motion along the path. Overall, the design of our product will be reliable, low-cost, and sturdy in order for rural communities to be able to afford the system, and it will also require less maintenance in the future.

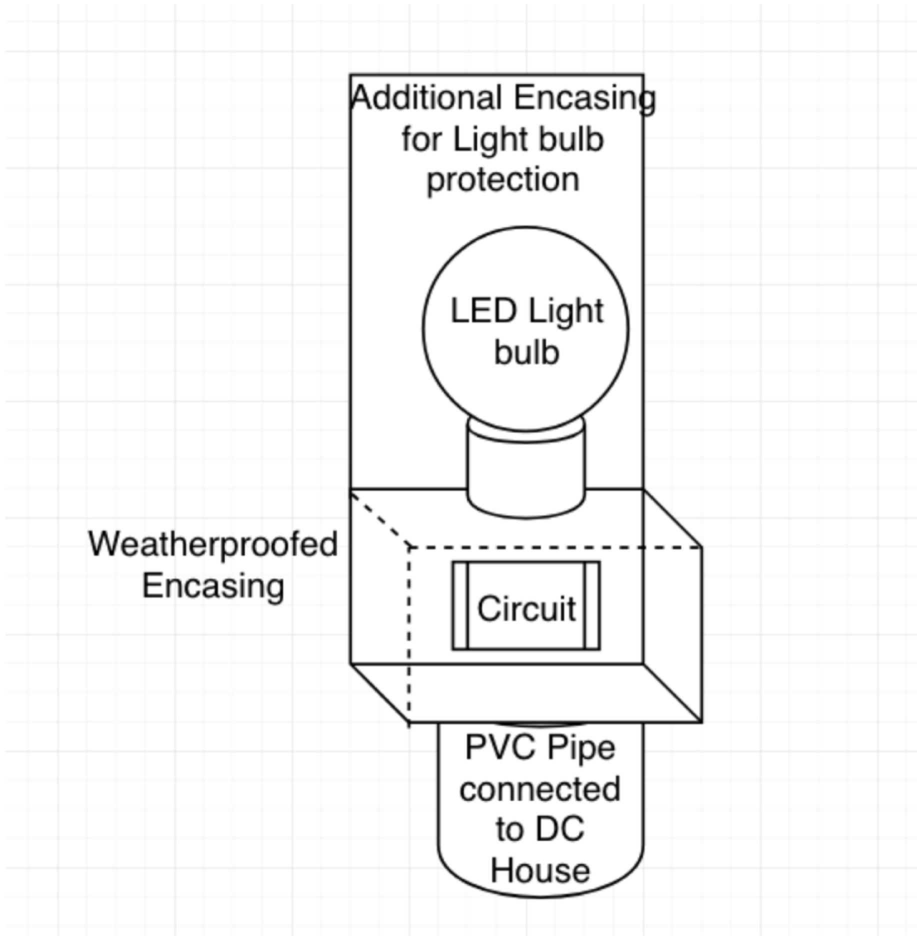

Figure 3-4: Project Concept Design

For the physical aspect of the design, there are many factors to consider: physical dimensions, electrical connection, wiring, enclosure, etc. In order to account for all these different parameters, Table 3-8 through 3-13 list the different mechanical design components of the proposed system, detailing their functionality, technical specifications, and justifications. Table 3-14 provides the summary of the electrical and mechanical design specifications of the proposed lighting system.

Table 3-8: Underground PVC Pipe

Module	¾ inch PVC Pipe
Specification	● ¾ inch pipe in order to allow at least 4 wires through ● Must act as a housing in order to prevent any water from getting in ● Requires 170 feet to run entire length of pathway
Functionality	This pipe is already installed underground with wires within it. This will function as the housing for the electrical wires that run from the DC House all throughout the entire pathway.

Table 3-9: Standing PVC Pipe

Module	¾ inch PVC Pipe
Specification	● ¾ inch pipe in order to allow at least 4 wires through ● Must act as a housing in order to prevent any water from getting in ● Requires 40 feet in order to have lighting station be at least 3 feet above the ground
Functionality	This pipe is already installed with wires within it. This will function as the housing for the electrical wires but also to hold the LED light bulb and its enclosure.

Table 3-10: Weatherproof encasing

Module	Standard Junction Box
Specification	● Junction box used to house the circuit and connect wires ● Housing dimensions are 4.25in x 2.75in x 3.25in (width x height x depth) or 18 cubic inches ● Requires a ¾ inch hole at the bottom to connect PVC pipe ● Requires a ½ inch hole at the top to provide a mount for the LED ● Requires a 0.025 inch square hole in the front for the sensor
Functionality	This box will be used to house the circuit and protect it from the environment. It will also mechanically hold the LED light bulb in place so that it does not move.

Table 3-11: Light Bulb Encasing

Module	Glass Mason Jar
Specification	● Must have a diameter greater than 2 ⅜in and height greater than 4 ⅜ inch (size of LED light bulb) ● Must be clear in order to not lose lumens
Functionality	This will serve as a weatherproof encasing for the LED light bulb to ensure that no rain touches the circuit. Additionally, it will protect the LED light bulb from getting any debris on it.

Table 3-12: Wires

Module	Power Wires (14-Gauge)
Specification	● Must be able to sustain around 3.5 Amps ● Requires around 220 feet of wire to run entire lighting pathway and into lighting stations
Functionality	This wire is already installed in the PVC pipes. These wires will carry the voltage from the DC House to the entire lighting pathway system. 14-gauge wire will suffice as total current for 10 stations will not exceed 3.5Amps.

Table 3-13: Printed Circuit Board

Module	PCB
Specification	● Must not exceed dimensions of 3.75in x 2.25in (width x height) ● Should have place on the board to attach 6 input or outputs for 14-gauge wires to connect to ● Must have a logical path of inputs and outputs ● Must have a large trace ground
Functionality	This board will be where all the circuitry would connect to.

Table 3-14: Summary of Parameters

Module	Specifications
Buck Converter	● Vin 48V ± 2V ● Vout 5V ± 10% ● Line Regulation < 20%
Motion Sensor	● Voltage operating region (3.3V-6Vdc) ● Detects ambient light ● Detects motion without lighting ● At least 2 meters range in front of the sensor
Triple OR Gate	● Voltage operating region (3.3V-6Vdc) ● 3 inputs and 1 output
Delay Circuit	● Voltage operating region (3.3V-6Vdc) ● Time delay of at least 3 seconds before fading out ● Minimum input current of 10mA
LED Light Bulb	● Brightness output of 100-200lumens from source ● 60W rated (to withstand the 48V input voltage and driving current) ● Power Consumed should not exceed 10W
Underground PVC Pipe	● ¾ inch pipe in order to allow at least 4 wires through ● Must act as a housing in order to prevent any water from getting in ● Requires 170 feet to run entire length of pathway

Standing PVC Pipe	● ¾ inch pipe in order to allow at least 4 wires through ● Must act as a housing in order to prevent any water from getting in ● Requires 40 feet in order to have lighting station be at least 3 feet above the ground
Weatherproof Encasing	● Junction box used to house the circuit and connect wires ● Housing dimensions are 4.25in x 2.75in x 3.25in (width x height x depth) or 18 cubic inches ● Requires a ¾ inch hole at the bottom to connect PVC pipe ● Requires a ½ inch hole at the top to provide a mount for the LED ● Requires a 0.025 inch square hole in the front for the sensor
Light Bulb Encasing	● Must have a diameter greater than 2 ⅜in and height greater than 4 ⅜ inch (size of LED light bulb) ● Must be clear in order to not lose lumens
Wires	● Must be able to sustain around 3.5 Amps ● Requires around 220 feet of wire to run entire lighting pathway and into lighting stations
PCB	● Must not exceed dimensions of 3.75in x 2.25in (width x height) ● Should have place on the board to attach 6 input or outputs for 14-gauge wires to connect to ● Must have a logical path of inputs and outputs ● Must have a large trace ground

Chapter 4. Design and Simulation Results

The lighting pathway system allows for less energy and maintenance cost due to the system only being turned on when a person walks passed it and triggering its sensor. If we assume that the LED is only on for 5% of the time, a lot of energy consumption is saved compared to a system with a long run time, such as a street light. The LED will only consume 9W for a few seconds and using the equation I = P/V, the maximum current consumed is I = 9W/48V = 0.187A, which decreases as the LED fades. This current would not drain the battery as fast when connected to the DC House. Additionally, the only parts that are constantly on are the linear regulator and Infrared sensor, which only consumes 1mA as stated from the datasheet. Furthermore, considering the fade circuit which in simulation consumes 18mA every time the LED is on, a lot of power is not being consumed. The following Figure 4-1 shows the circuit schematic of the fade circuit while Figure 4-2 shows the results.

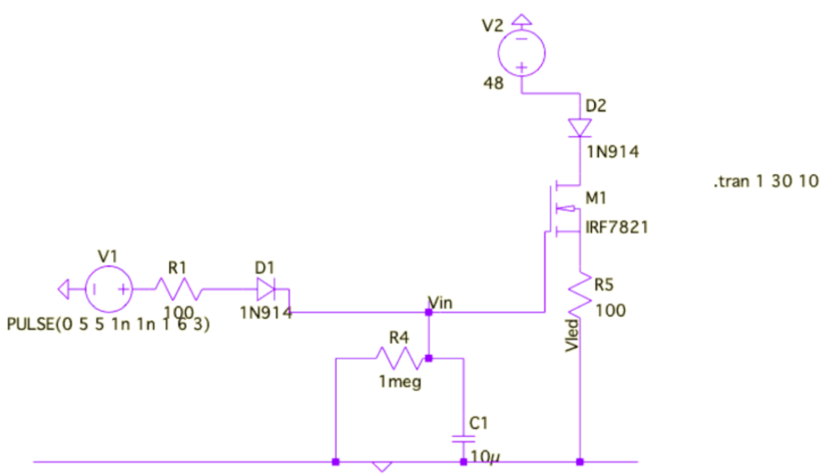

Figure 4-1: Circuit Schematic of the fade circuit in LTSpice

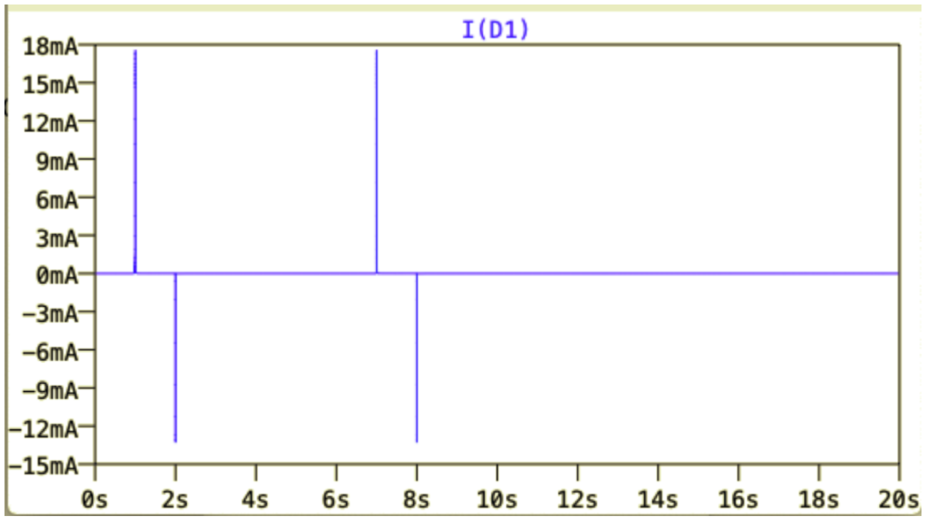

Figure 4-2: Current consumed by fade circuit when a person walks by

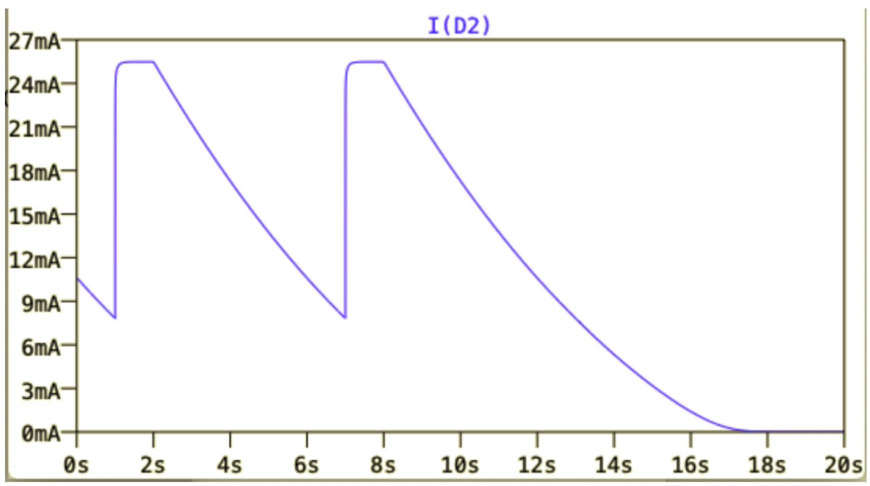

Figure 4-3: Current running through the LED with fader delay (two pulses occur until fade away)

In Figure 4-1, the voltage source represents the output of the triple OR gate which is powered by the IR sensor, which outputs a 5V pulse or square waveform when it detects motion and no ambient lighting. This gets fed into resistor R1 that limits the current through fade circuit. The current then flows through diode D1 that prevents any current from flowing back into the IR sensor. The current then drives the NMOS to turn on and charges the 10mF capacitor. Once the NMOS turns on, current runs through the LED D1 from the 48V battery source, turning on the

LED. However, once the IR sensor does not detect anything, no output is given which results in V1 in the schematic going to 0V. This further results in no current going through R1 and D1, but current still flows through the NMOS as the capacitor C1 discharges its energy through the resistor R4. This causes less current/voltage driving from the gate through R5 degenerate resistor, making a fade for the LED. Once the capacitor loses all its charge or falls below the turn on voltage for V_{GS} (which is 0.5V minimum), the NMOS will turn off causing the LED to turn off. Figure 4-3 shows the current running through the LED as two pulses runs through it. As seen in the second pulse, after about 10 seconds the LED will reach 0A current; however, the LED will stop shining when it reaches 0.5V minimum on the VGS. In order to time the delay, real components must be tested as VGS may vary and other parasitic capacitances and uncalculated resistances may affect the timing when compared to the theoretical assumptions. With this design, minimal current and power are consumed which prevent the lighting pathway system from heavily draining the battery for the DC House. This allows the battery to power other loads at the DC House.

The following calculation shows the entire power/energy usage:

Total Power when a person passes by all 10 lighting stations, but only with 3 of the 10 LED's always being on:

Power consumed when 3 LED's are on:

P = 3 * [IledVled + IdelayVdelay]}

P = 3 * [(0.187A)*48V +(18mA)*5V]= 81.054W= 0.081kW

Power consumed by 10 lighting stations with IR sensors that consume 1mA constantly along with power loss through the linear regulator, which is the current consumed multiplied by the voltage difference:

$P = 10* [I_{ir}V_{ir} + I_{linreg}V_{linreg} + I_{delay}V_{delay}]$

$P = 10 *[(2mA)* 5V + (2mA) * (48-5V)]$

$P = 10mW + 86mW$

$P = 96mW = 0.000096kW$

After calculating for the power consumption, we also want to calculate how much energy would be consumed in one day. Assuming the average day is 24 hours, and the usual timeframe that an ambient lighting is not present is between 6am to 8am and 6pm to 12am, it can be estimated that the LEDs would potentially be on only 8 hours in the day.

Assuming that the LEDs are constantly on 8 hours in the day the total energy used can be shown in the calculation. This would be the worst case scenario when people are constantly moving along the lighting pathway.

$E = Pt$

$E = (0.081kW) * 8 \text{ hours} + (0.000096kW) * (24\text{hours}) = 0.6503kWh$

However, if we assume that the LED pathway is only on for 5% of the time we can see that there is significantly less energy consumed:

$E = Pt$

$E = (0.081kW) * 8 \text{ hours} * 0.05 + (0.000096kW) * (24\text{hours}) = 0.0347kWh$

Comparing this to a standard street light that consumes 77W constantly we can see the difference in energy consumption (for 3 lights) [11].

$E = Pt$

$E = (0.077kW)*3 * 8 \text{ hours}) = 1.848kWh$

As we can see the worst case scenario of the lighting pathway scenario consumes 64.8% less than a standard street light. While the ideal scenario consumes 98% less power than the standard street light. Obviously, there is a lumens/Watt difference that must be consider as well, but simply changing the energy consumption of the LED light bulb will still show a difference of energy consumption.

Furthermore, a lot of maintenance and longevity costs can be reduced. With the LED having an average lifetime of being operating for 10,000 hours, its lifetime can be extended as it will not be constantly operating. This then also reduces maintenance costs assuming that the LED does not break. This applies not only for the LED, but also for the entire system. As only the linear regulator and IR sensor are constantly on, the other circuitry will also last longer as they are also only on the same time the LED will be on.

The general concept design can be shown in Figure 4-4. The circuit shows 2 lighting stations and its general circuitry. It starts with a 48V from the DC House connected to a linear regulator that steps down the voltage down to 5V. This signal gets sent to the IR sensor and if the sensor senses a signal it will output a 5V signal to the triple OR Gate. The Triple OR Gate would then output to the delay circuit and the gate of the MOSFET turning on the LED. Figure 4-5 depicts the further in depth view of the entire circuit. Figure 4-5 shows the in depth connections that are to be made with specified components that can be shown in the BOM.

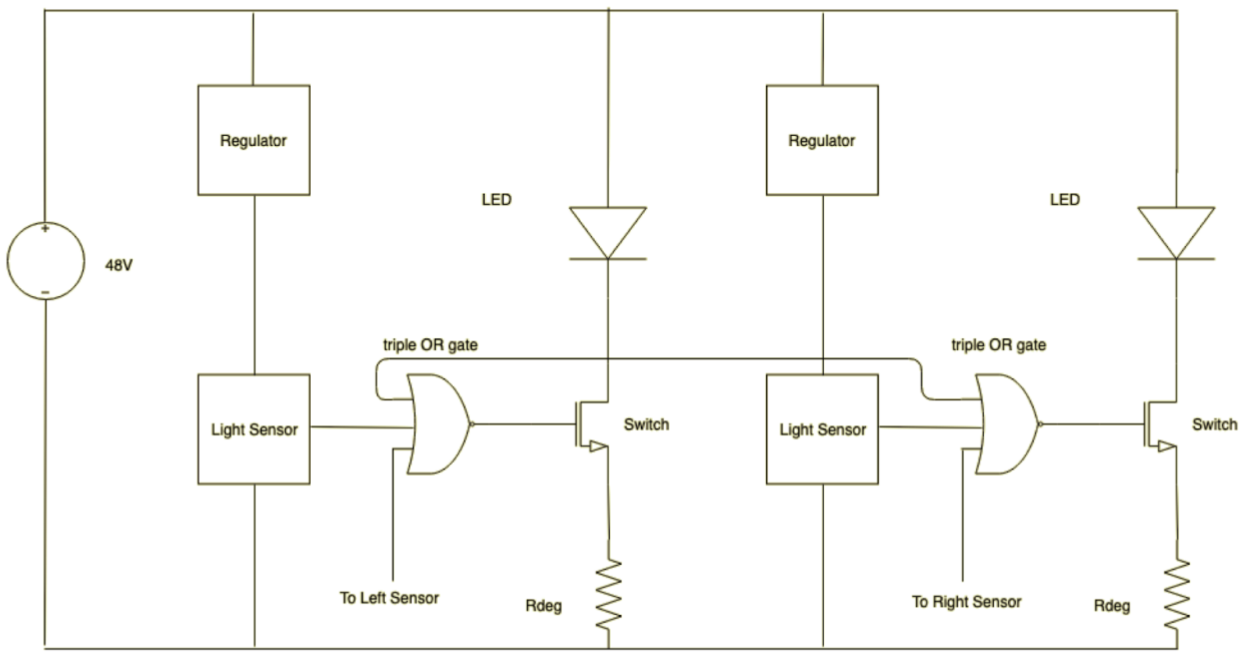

Figure 4-4: Circuit Schematic Idea

Previous designs required microcontrollers to generate the time delay of the LED. However, this requires coding costs and microcontroller costs. Instead of using a microcontroller, implementing a digital logic gate (Triple OR Gate) is more cost effective making circuit completely analog, with no coding required. With this concept, the goal to reduce costs is achieved by saving money on not buying microcontrollers, as well as the time and money needed to code each microcontroller.

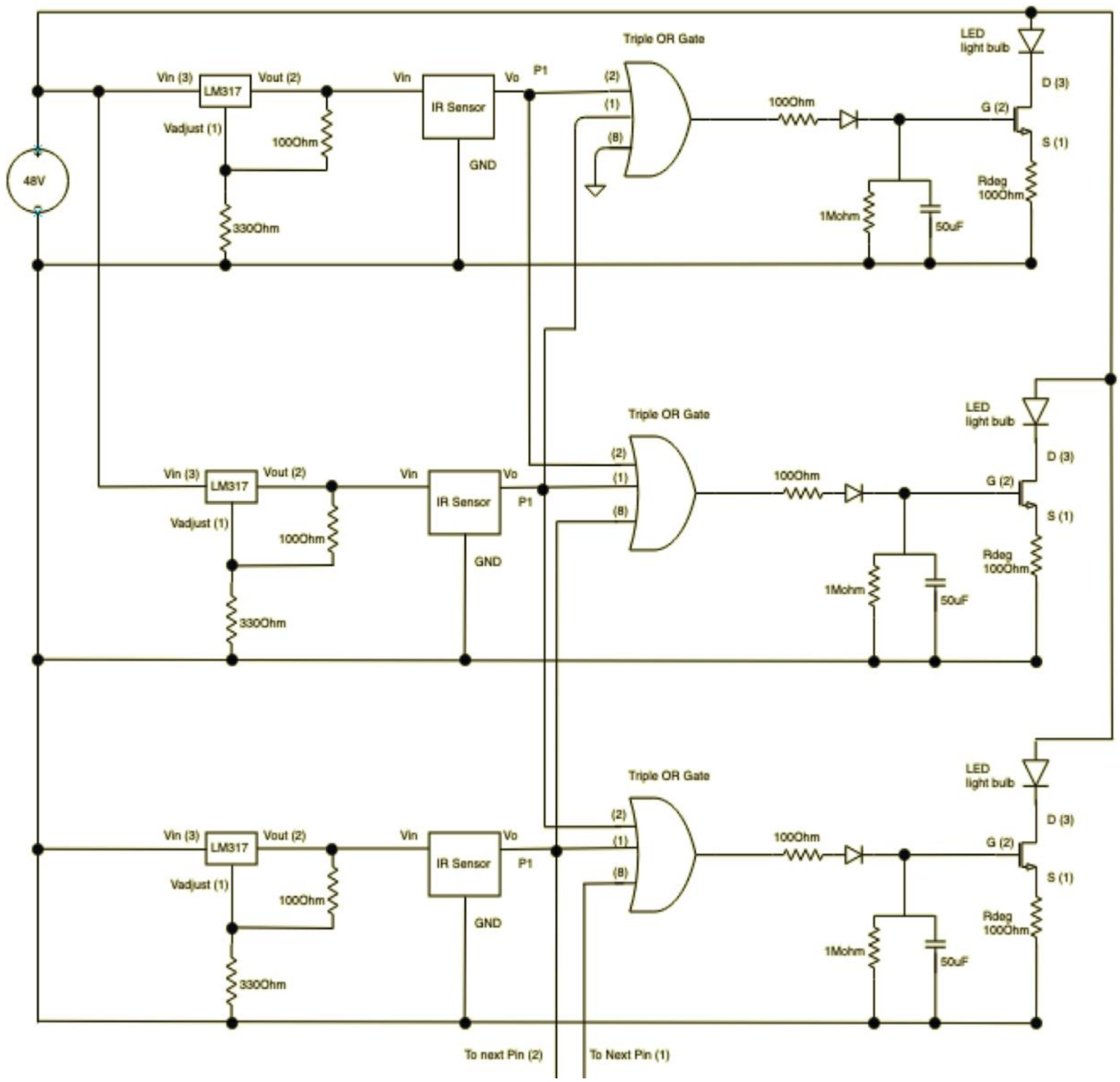

Figure 4-5: Circuit Schematic Design with pin connections to specific parts

Chapter 5. Hardware Test and Results

The hardware portion of this project consisted of constructing the PCB and installing it into the current lighting stations at the Student Experimental Farm (SEF). The previous senior project built the lighting stations with an 18 inch deep conduit that runs from the DC House along the pathway. Because of how they previously installed the conduit and wiring, our hardware was limited. Inside the conduit contains a single 14-gauge power line connected that runs the 48V DC rail through all the lighting stations and 4 additional 14 gauge wires that run in series from one station to the adjacent stations. At each lighting station there is a housing for the circuit to be installed.

Before installing the circuit at the SEF, the circuit needed to be constructed, soldered, and tested in a laboratory setting. Figure 5-1 shows a picture of our finished PCB without any components installed. This is a double sided PCB for through hole components with all the traces are on the top side with the ground node running at the outer edge of each corner. In order to improve efficiency when soldering, two members focused on soldering components while another member focused on checking for continuity to ensure that no shorts were created between pins and components. All components were soldered onto the board except for the IR sensor, which had to be soldered onto wires in order to have flexibility on adjusting it to an angle that is appropriate when installed at the SEF. This also allows for the sensor to be placed in the most optimal position, customized to each individual circuit housing. An adhesive was added to the place where the sensor was soldered in order to prevent any shorts from the pins accidentally touching each other or to prevent any other mechanical issues. Additionally, wires had to be soldered on pins Vin, GND, LEDin, LEDout, Pin 2, Pin 8, and two wires at the output of the sensor. These wires would then connect to the wires currently installed in the housing box at the SEF via electrical nuts. Once everything was soldered and no shorts were detected, the extra lead lengths were clipped in order to prevent any shorts during testing. The completed circuit can be seen in Figure 5-2. The installation of the circuit to the circuit housing at the DC house can be seen in Figure 5-3. The housing provides protection for the circuit from weather while still allowing for the sensor to perform.

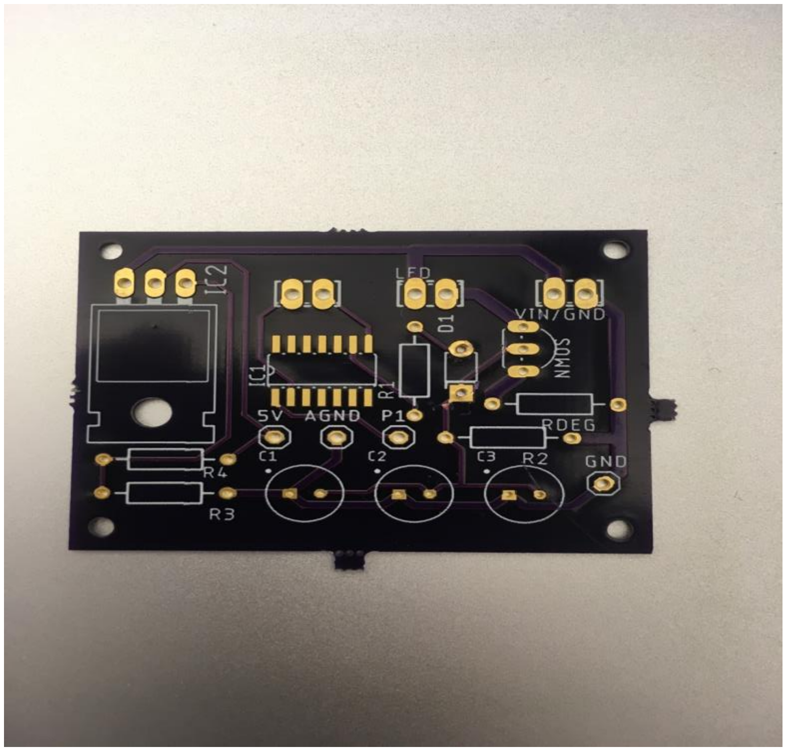

Figure 5-1: Picture of our PCB without any components added.

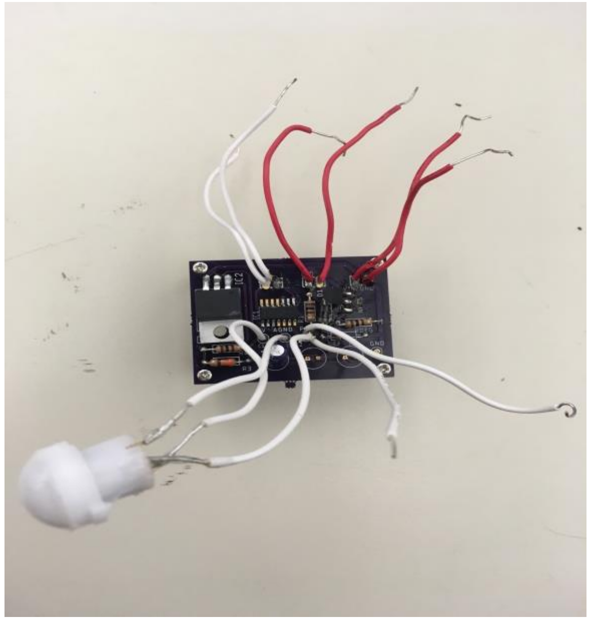

Figure 5-2: Soldered circuit with wire connections used to connect individual circuits to the circuit housings located at the DC house.

Figure 5-3: Installed circuits into circuit housing located at the DC house.

In order to test the circuit, the equipment needed consists of a 48V power supply (running at constant voltage mode), the finished constructed circuit, a LED light bulb, two banana to grabbers for the power supply input, and an oscilloscope. A block diagram of this test setup can be seen in Figure 5-4. The first setup is constructed to ensure that the circuit can turn on the LED light bulb and fade properly. This test was repeated for all circuits to ensure that no shorts were present and the circuit is functioning properly by itself. Table 5-1 shows the power consumption of each individual circuit both with LED on and off. Figure 5-5 shows the LED fade out as displayed by the oscilloscope where the scope probe was measuring the output voltage of the diode connected to the gate of the N-MOSFET. As shown in the oscilloscope drawing, it takes around 3.8 seconds for the LED to completely fade off. The scope shot also demonstrates that the LED slowly fades to turning off when no movement is experienced by the sensor. When the sensor does experience movement again, the LED lights up again, as indicated by the voltage spike.

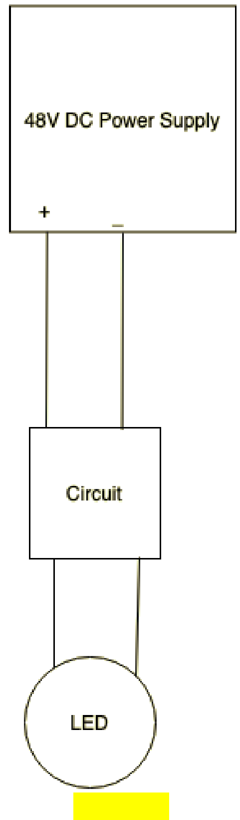

Figure 5-4: First test circuit measuring power when LED is on and power when LED is off.

Table 5-1: Data measurements for a single circuit powered but on DC power supply and not connected to any other circuits

Calculated Power when LED is on (W)	Output Current when LED on (A)	Output Current when LED off (A)	Time for LED to turn off (s)	Voltage input (V)
1.443	0.03	0.013	~3.8	48.1

Figure 5-5: Oscilloscope capture of the fade-out experienced when the LED turns off.

Once the first test was completed, the next test was conducted by powering three circuits in parallel to simulate how the circuit would behave when installed for the lighting pathway at the SEF. Initially, the lightbulb of each circuit was lit up. The sensor of each circuit was covered to simulate no movement noticed by the sensors. If the circuits were working correctly, the lights would all begin to fade out and eventually turn off. Then, one sensor would be uncovered to test if the correct LEDs would turned on. The sensor would then be covered again to fade the LEDs out again. This was then repeated for the other sensors. The test set up can be seen in Figure 5-6 where all three circuits were connected to a single power supply and only circuit #2 was connected to an LED.

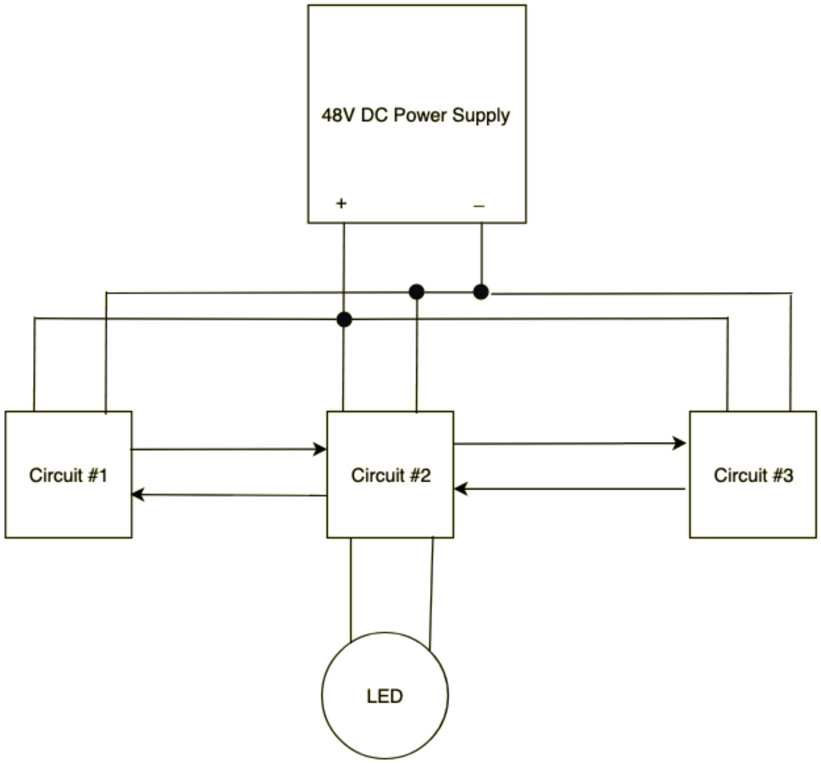

Figure 5-6: Block Diagram of Lab test setup for only 3 circuits.

The laboratory testing of the constructed LED lighting system was recorded and can be viewed from the following link:

Video of Lab Test: https://youtu.be/xJMDy_G2Isc

The video shows three circuits connected to each other. Sensors of the right and left circuit are connected to the OR gate of the middle sensor. The middle circuit is the only one connected to the LED. Video shows the successful operation of the LED system, which demonstrates that if one sensor from any of the three circuits detects motion, then the LED is turned on. When all three sensors are covered (not detecting motion), the LED slowly fades and turns off. Additionally, when tested with the DC power supply, it can be seen that the current drawn differs on where the LED is. As presented in Table 5-2, larger current is drawn from the point at where the LED is placed, making the LED brighter when a motion is detected directly in front of place of detected motion. If motion is detected from the adjacent circuits, the amount of current drawn is less resulting in less brightness. This provides the benefit of energy saving as majority of power is only consumed from the place where motion is directly being detected, and less amount is needed from adjacent circuits. Although, some light intensity is lost when motion is detected from adjacent circuits, users will still be able to see the surroundings but will have a brighter light at the place the user is actively moving.

Table 5-2: Data measurements for a three circuit setup test design connected to a single DC power supply

Output Current when motion in circuit #1 (A)	Output Current when motion in circuit #2 (A)	Output Current when motion in circuit #3 (A)
0.057	0.074	0.057

After the system was tested in the lab, circuits were installed at the Student Experiment Farm. A DC power supply was required since the DC house is currently vacated with no power. Eight banana to grabbers and three multimeters were used to help with the testing. First, each LED was tested by directly connecting it to the power supply. Five of the LEDs were found to be malfunctioning. This might be due to water damage, so the mason jars might not be adequate protection as some rainwater was found to be within the housing (because some of the mason jars were not properly mounted onto the housing fixture). With the working LEDs, the circuits were installed to the lighting stations as shown in Figure 5-7. The setup was similar to the lab test setup shown in Figure 5-6. Testing was done during the day time since working at the SEF would be very difficult at night. This made it slightly difficult to see the LEDs turning on and fading out. Multimeters were connected to the output of the diodes of the RC circuit or the gate of the N-MOSFET, so that the drop in voltage during the fade out was visible. The lighting stations were connected to the power supply. To test the fade out, sensors were manually covered. The system worked as expected with the installed circuits and LEDs.

Figure 5-7: Installed circuits with LED and mason jar to protect the light bulb from weather conditions and ecosystem around the lighting pathway

Although the system worked as expected, a problem occurred with the ambient light sensor where the circuit would still turn on even when ambient light is present. After retesting this, it was found that the ambient light sensor was not functioning as expected. Because of this problem, an alternative solution was constructed. This alternate solution uses a single ambient light sensor that is connected to a 5V source and will send out an analog output that is relative to how much light is detected. This analog output will feed into the gate of one of our N-MOSFETs that has its drain and source pin connected to the 48V line. This will then allow current and voltage to flow through the entire smart lighting pathway system only if ambient light is not detected. A circuit diagram of this circuit can be seen in Figure 5-8.

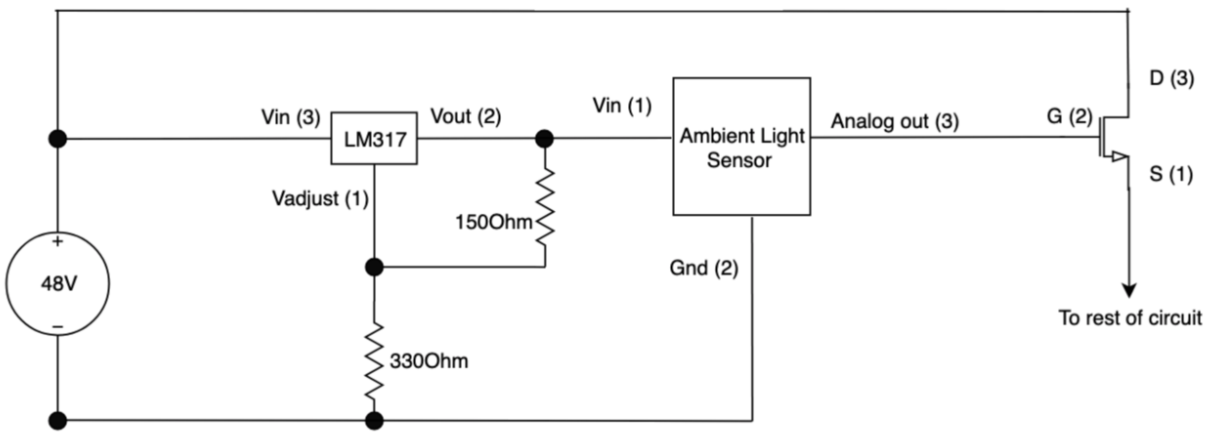

Figure 5-8: Circuit Schematic of ambient lighting

Before installing the circuit at the SEF, the circuit was tested in lab in order to ensure that the circuit properly works. Figure 5-9 shows the block diagram of the lab test setup. It was seen that the output of the LM317 was 4V as expected in the equation for the LM317 voltage regulator: Vout = 1.25 * (1+(330/150)). Additionally, the output voltage of analog out when there is no ambient light detected was measured to be 3.6V, having a 0.4V voltage drop across the sensor. Figure 5-10 displays an oscilloscope shot of the measured 3.6V when the sensor was covered and approximately 0V when the sensor was uncovered. It can be shown that the sensor has a lot of noise around 0V and when zoomed in and has a frequency of 60Hz noise which was assumed to be the frequency of the fluorescent lighting when testing in the laboratory. When this voltage was sent to the gate of the NMOS, it was found that the source voltage matched that of the drain voltage of 48V. Thus the circuit worked as expected. A close up of the finished circuit can be seen in Figure 5-11. Table 5-3 lists the measured values from the ambient light sensor circuit.

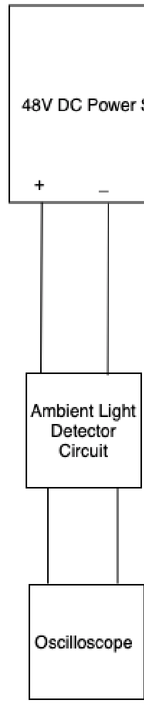

Figure 5-9: Block Diagram test setup of ambient lighting

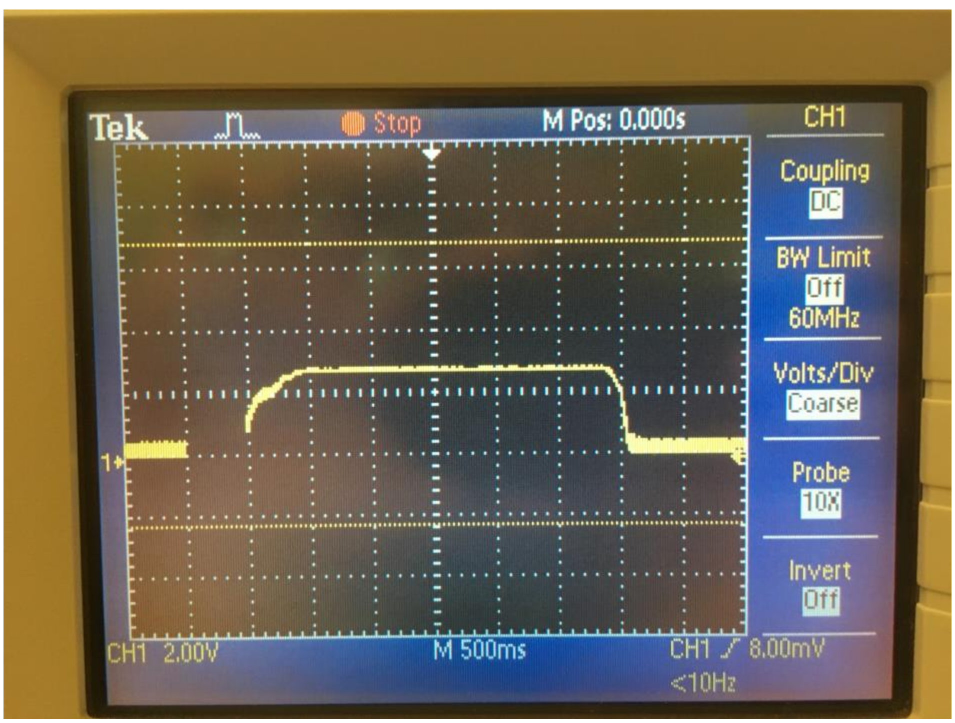

Figure 5-10: Oscilloscope capture of the ambient light sensor outputting 3.6V

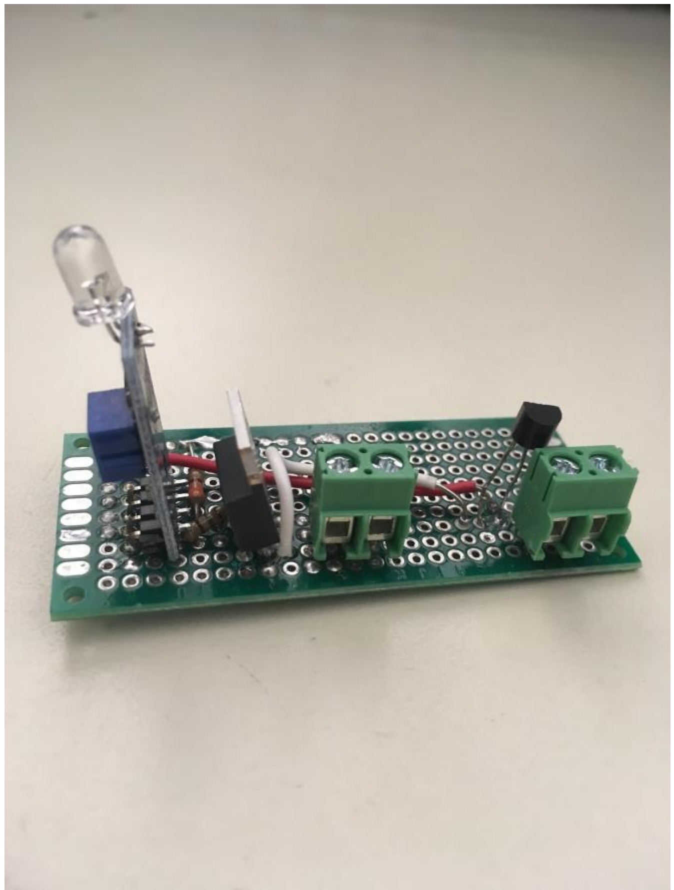

Figure 5-11: Soldered ambient light sensor on to protoboard

Table 5-3: Data measurements for ambient light sensor

Total Current supplied to circuit (A)	Output Voltage of LM317 (V)	Input Voltage (V)	Output Voltage of ambient light sensor (V)
0.014	4	48.1	3.6

This circuit was installed in series to the testing power supply to see whether the lighting stations would still turn on. The circuit can be seen in Figure 5-12. After confirming that the lighting station does not turn on when ambient light is detected, the sensor was then covered to simulate no ambient light to ensure that the lighting pathway still works. This confirms our system works properly.

Figure 5-12: Installed ambient lighting circuit

Chapter 6. Conclusion and Further Improvements

The Student Experimental Farm is a great resource for students to test projects in a real world scenario. With the installation of the DC House Smart Lighting Pathway System, students are able to navigate the pathway of the SEF at night easier. The purpose of this project was to provide a safe method for students to work on the farm at night. It also helped test the feasibility of having an outdoor DC lighting system for users of the DC House. With the results, it can be shown that using LED light bulbs help reduce power consumption and with the idea of fade away lighting and motion sensor lighting, energy consumption from the battery in the DC House can be greatly reduced. The improvement of switching from a digital microcontroller to strictly analog signals, helped greatly reduce costs and a less complex system for users to understand easier.

The main goal of the project was to improve and complete an already existing design on smart pathway lighting from a previous senior project. The previous senior project designed a microcontroller based circuit for the lighting system, but in order to reduce costs on buying microcontrollers, an analog design was preferred. In this project, the design also incorporated a PCB for the circuit. This is an improvement from the previous design since having the circuitry on a PCB makes it easy to install into the current lighting set up at the DC house. The PCB design and Bill of Materials are also provided in this report for future groups to be able to install this design in other sites. Another improvement from the previous project was done by creating a way to add a version of dynamic lighting to the LED where the LED is able to fade out after immediately turning on. This allows a person to walk through the lit up pathway while still saving energy because the circuit consumes less power while the LEDs are fading out. This improves the previous design of constant power consumption due to the LEDs being turned on at peak voltage for a period of time based on the timing of a microcontroller. There is more dependability in this circuit as well due to not having a microcontroller and only being controlled by hardware. There were still issues that occurred while creating and installing this project. One of the main issues that was encountered was the previous installation of the wiring at the DC house was difficult to work with. In order to install our circuit to the wiring, wire nuts were used to connect our 26 gauge wire to the previously installed 14 gauge wire. This proved to be difficult because the wires would sometimes become undone. Another issue is that many insects and spiders had made their way into the circuit housing and had to be removed before circuits could actually be installed. Water had also infiltrated the LEDs that were installed in the LED housing, causing half of the LEDs to stop functioning.

Many of these issues are things that can be easily improved. We recommend that the circuit housing be improved by increasing the water proofing for the LEDs by using a waterproof seal. The PVC pipes raising can be sealed up so that insects are unable to move from the ground into the circuit housing. The increased water proofing would also help keep insects out. The circuit could be improved by adding more connectors to allow for 14 gauge wire to be inserted into it. This would improve connectability and allow for even faster installation. If more installations are required to light up a larger area, using a buck converter to improve efficiency for many circuits should be used instead of the linear regulator. Additionally, a protection diode could be fixed at the beginning of the circuit to help prevent the circuit from burning up in case of a battery or DC power supply failure. Lastly, to improve cost efficiency, a cheaper PIR sensor is recommended as the current sensor costs $10 each.

Even though this circuit was specifically designed for the DC House, the concept of having DC faded lighting may be used in first world countries as well. With many street lights being on when users are not present at every second of the day, a lot of energy is wasted through lights drawing power. Having a motion sensor may lessen electricity costs and a slow fade instead of instantaneous turn-off will still help users be safe on the streets.

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Appendix A -Analysis of Senior Project

Project Title: Smart Pathway Lighting System
Students: Rafael Santiago, Brendan Schoemehl, Benjamin Tan
Advisor: Taufik

1. Summary of Functional Requirements

The project will provide sufficient lighting for the the pathway from the entrance of the Student Experimental Farm to the DC House. The system consists of 10 light units that have motion and light sensors attached. The entire system is powered from the DC House which currently uses solar panels to provide a 48 V DC power source. The sensors allow the lightbulbs to turn on only when a person is nearby.

2. Primary Constraints

The first constraint for this project will be time. With only twenty weeks to complete a PCB design with the correct parts and testing, there is not a lot of room for error if something goes wrong. To combat this, the entire schedule plan is laid out and we plan to stick to this schedule as best as possible. If the group is able to stay on schedule, we believe the project will be finished by June 2019.

In designing the PCB for the system, there will be a physical size constraint that will have to be followed. The size of the PCB will have to be less than 3 inches by 2.5inches to fit within the weatherproofing box. It is important to keep the physical unit as small as possible so that it could be shipped or moved easily.

3. Economic

What economic impacts result?

- *Human Capital:* The product could potentially create jobs in engineering, construction, manufacturing, sales, and marketing.
- *Financial Capital:* This product will create profit for investors. Customers could save money in the long run from the system's energy efficiency.
- *Manufactured or Real Capital:* An inventory of the product would be created and become manufactured capital.
- *Natural Capital:* Natural resources will be used to create the enclosures, the components, the PCBs, and the lightbulbs.

Design and manufacturing stages of the project lifecycle will be accumulate a large portion of the cost of the project due to cost of materials, labor, and time spent on research and development. Benefits will be seen upon project completion and until the system stops working. However, the research accrued from the project is also a valuable benefit.

The estimated cost of the project is $212.06 according to the Bill of Materials from Table 7. The EE provides $200 per person for senior project. If manufactured commercially, profit from sales would cover the accrued costs.

4. <u>If manufactured on a commercial basis:</u>

If this project was manufactured on a commercial basis, it would be used in conjunction with a previously set up DC powered system. The customer would have to be aware of this fact, otherwise it would not be usable for an AC powered system. The product would have to be labelled so that it is clear how it is intended to be used.

By creating a PCB, the product could easily be mass produced by printing the same circuit board for every product. This would make manufacturing easy and cheap, further reducing the cost and making it easier for the intended customers to purchase.

Below are the estimated statistics for manufacturing and costs:
Estimated number of devices sold per year: 5000 units
Estimated manufacturing cost for each device: $20
Estimated Purchase price for each device: $25
Estimated profit per year: $25,000
Estimated cost for user to operate device: ~$0.01/Hr (rough estimate of electricity cost)

5. <u>Environmental</u>

There are potentially wildlife that use the area of the SEF for their homes. Some of these animals burrow holes such as gophers, snakes, and squirrels. The project might need trenches as deep as 18 inches. The trenches can also affect the roots of the nearby trees. There are also environmental impacts due to e-waste from the fabrication of the circuits and lightbulbs.

The system’s main feature is it’s efficiency and use of the renewable energy. The project does not use any fossil fuels, so the system is very clean in terms of energy use.

6. <u>Manufacturability</u>

There are not many challenges expected for the manufacturing of the the system. All of the components should be available from manufacturers in the US and China. The design is relatively simple since it’s mostly wiring of the light bulbs and PCBs. The only challenge might be the physical setup of the system as ditches might have to be dug out.

7. <u>Sustainability</u>

The DC house itself uses solar powered energy. The lights will power off some of this power so the lighting system uses sustainable energy. Since the lights are only powered on for a few seconds at a time, there is little concern for a lack of power from the solar panels. The lighting system will not use its own set of solar panels to save cost and materials.

The lighting system will be weatherproof to add to the longevity of the system. This system should be reliable and able to work in any weather condition. This way, users of the lighting system will never have to worry about finding their way to the front door of their house.

The system will also have replaceable parts in case of breakage. If one part breaks, it should be able to be easily replaced so that anybody could fix the issue. This makes the entire system more sustainable because the users or customers would not have to buy an entire light system to replace the broke one if there is minor damage that can be replaced with only one or a few parts instead.

8. Ethical

An auto brightness functionality can save power if implemented in things like street lamps. However, if the auto brightness fails or breaks, it can potentially cause an accident. Most of the customers won't know how to fix the system especially if it's an internal problem (PCB board). With more tech running by themselves, designers will feel more comfortable leaving the technology unattended. When a small part of a large system fails such as one streetlight in a whole city, it may be hard to notice. Such cases can be solved by creating a system that is able to monitor failures and alert the designer. Ultimately, the benefits of an automatic system far outweigh the costs. It is just up to the designer to create a reliable system that is updated and tuned frequently.

With our product that is primarily being made for third world countries, a cheap and easy to maintain product would be beneficial to this market. An easy to assemble or disassemble product will be emphasized with PCBs that can be connected and disconnected with ease. By making a product that can be mass produced with environmentally friendly materials, the product should be easily available and easy to maintain. A weather-proofed design will create a product with longevity.

Concerns that may arise with our product may be with costs and longevity. With our system requiring an actual DC House to run, there are indirect costs users need to pay in order to operate the smart lighting pathway system. Although it may be a price to pay initially, users will have access to so many different ways of using the DC House energy for all their other appliances that they can operate on.

9. Health and Safety

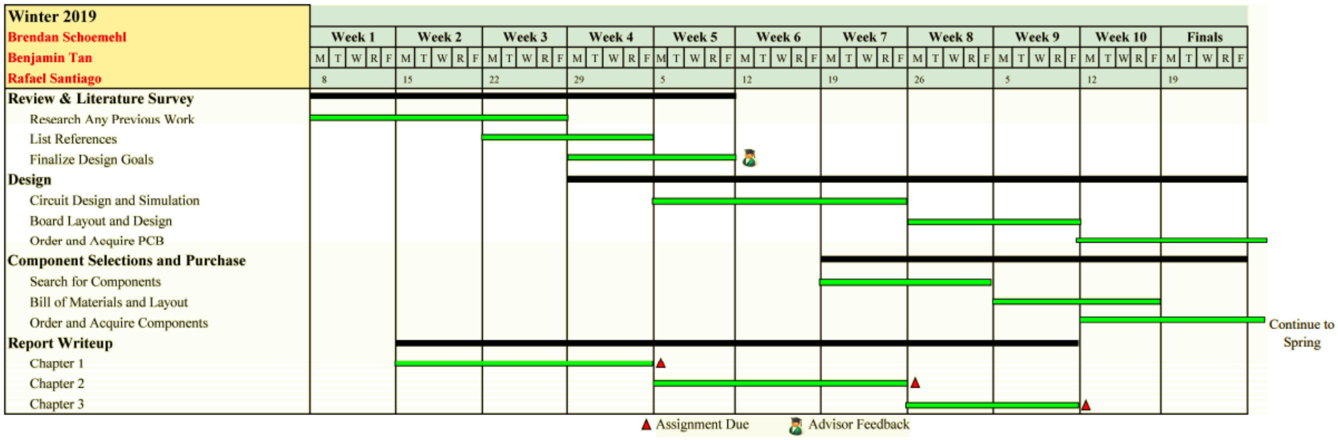
Major health and safety concerns involve the usage of DC voltage at 48V. This is potentially harmful and dangerous because it is high voltage. Precautions will be taken to prevent electrocution and electric fires through the use of insulated wires. Circuitry and enclosure will take precautions as well to prevent electrocution and fire risk.

10. Social and Political

Social issues with this product is that certain communities may benefit more than others. Areas with little sunlight cannot use the system to its full potential. For example, there are areas in the north that experience longer hours of darkness due to the tilt of the Earth relative to its orbit around the sun.

This product is marketed towards lower income communities. The communities may not be the ones the buy the product directly. Social welfare programs and charities would probably be the ones that invest in the product.

Appendix B- Timeline of Tasks and Milestones



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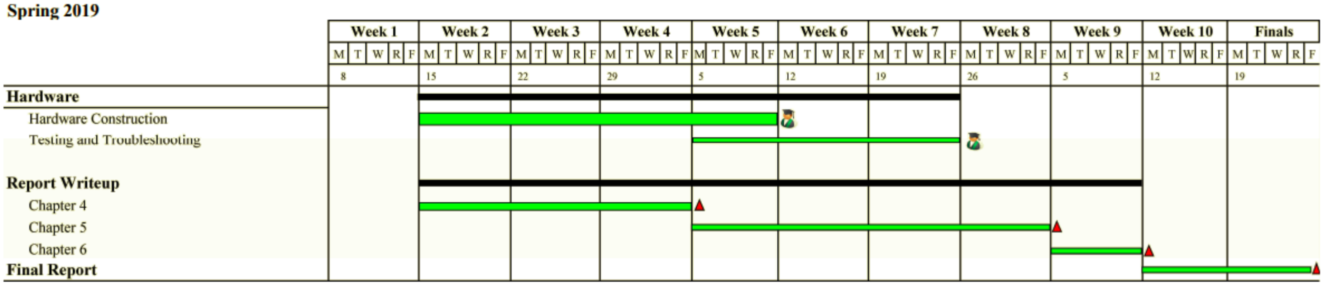


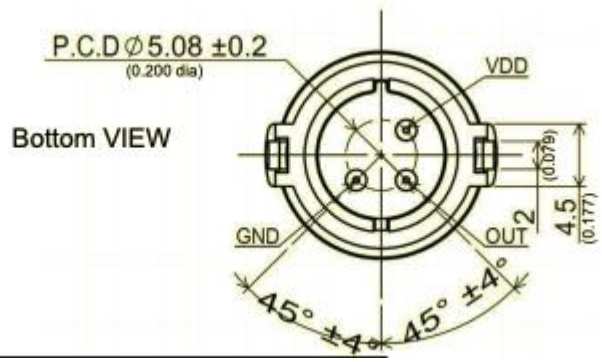
Appendix C- Bill of Materials

Count	Description	Part Number	Size	Manufacturer	Per Unit Cost	Total item cost
15	SENSOR MOTION PIR STD PEARL LENS	255-5424-ND	0.587in diameter	Panasonic	9.518	142.77
15	MOSFET N-CH 20V 530MA TO92-3	TN0702N3-G-ND	TO-92-3	Microchip Technology	1.09	16.35
15	DIODE SCHOTTKY 20V 1A DO41	1N5817FSCT-ND	Axial	ON Semiconductor	0.355	5.33
20	50uF Electrolytic Capacitor	P10425CT-ND	0.197" Dia (5.00mm)	Panasonic	0.147	2.94
15	IC GATE OR 3CH 3-INP 14SOIC	296-14279-5-ND	14-SOIC (0.154", 3.90mm Width)	Texas Instruments	0.42	6.3
50	TERM BLK 2POS SIDE ENTRY 5MM PCB	277-1667-ND	0.197" (5.00mm)	Phoenix Contact	0.411	19.64
25	100Ohm 1/4W AXIAL resistor	CF14JT100RCT-ND	0.091" Dia x 0.236" L (2.30mm x 6.00mm)	Stackpole Electronics	0.0292	0.73
25	1MOhm 1/4 AXIAL resistor	CF18JT1M00CT-ND	0.091" Dia x 0.236" L (2.30mm x 6.00mm)	Stackpole Electronics	0.036	0.9
25	330Ohm 1/4W AXIAL resistor	CF14JT330RCT-ND	0.091" Dia x 0.236" L (2.30mm x 6.00mm)	Stackpole Electronics	0.0292	0.73
25	150Ohm 1/4W AXIAL resistor	CF14JT150RCT-ND	0.091" Dia x 0.236" L (2.30mm x 6.00mm)	Stackpole Electronics	0.0292	0.73
10	100Ohm 1/2W AXial resistor	S100HCT-ND	0.091" Dia x 0.256" L (2.30mm x 6.50mm)	Stackpole Eletronics	0.043	1.09
15	PCB	U32JY2w4	1.90 x 1.44 inches (48.3 x 36.5 mm)	OSHPARK	4.43	66.5
1	PCB mounting for raspberry pi	43398-16606	2.5mm inner diameter	Geekworm	9.95	9.95
15	LM317HVT/NOPB-ND	LM317HVT/NOPB	TO-220-3	Texas Instruments	2.215	33.23
2	HOOK-UP SOLID 22AWG 300V	1528-1761-ND	22AWG	Adafruit	2.95	5.9

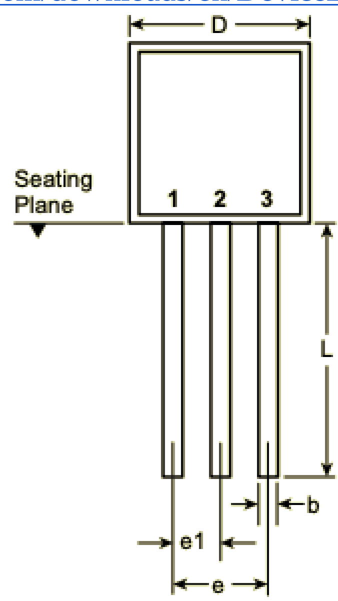
1	LED XLAMP COOL WHITE 6500K	MLCAWT-A1-0000-000XE1CT	3.50mm x 3.15mm	Cree Inc.	0.365	3.65
1	Light Sensitive Photodiode	200033	3.2cm * 1.4cm	DROK	5.68	5.68
1	8.8W A19 DIM LED	17801154405	A19	Geekworm	2.97	2.97
150	71B WIrenut	783250681150	71B	American Wires	6.27	6.27
1	Epoxy Glue E6000	76818364139	n/a	ADH	4.29	4.29
					Shipping cost:	17.98
					Total Tax:	20.12
					Total cost:	**374.05**

Appendix D - IC Pin layout

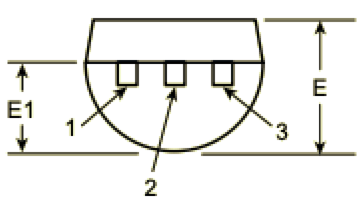
1. IR Sensor Pin Layout Reference: https://media.digikey.com/pdf/Data%20Sheets/Panasonic%20Electric%20Works%20PDFs/EKMC169311_Spec.pdf



2. NMOS TN0702 Pin Layout Reference: http://ww1.microchip.com/downloads/en/DeviceDoc/TN0702%20C080813.pdf

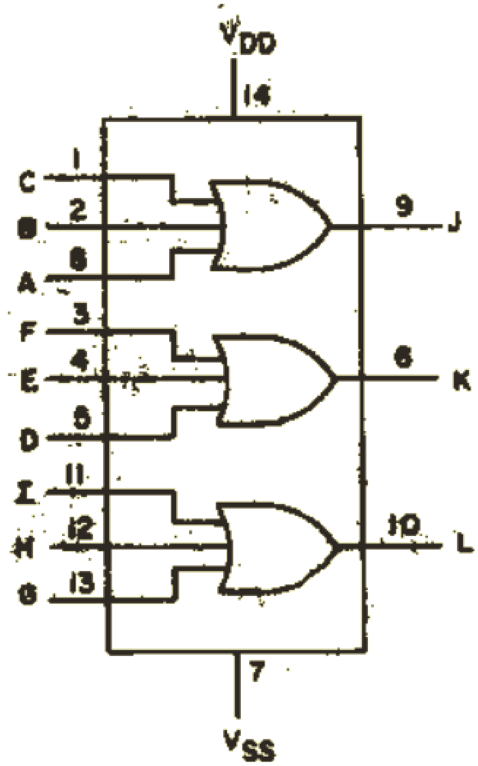


Front View



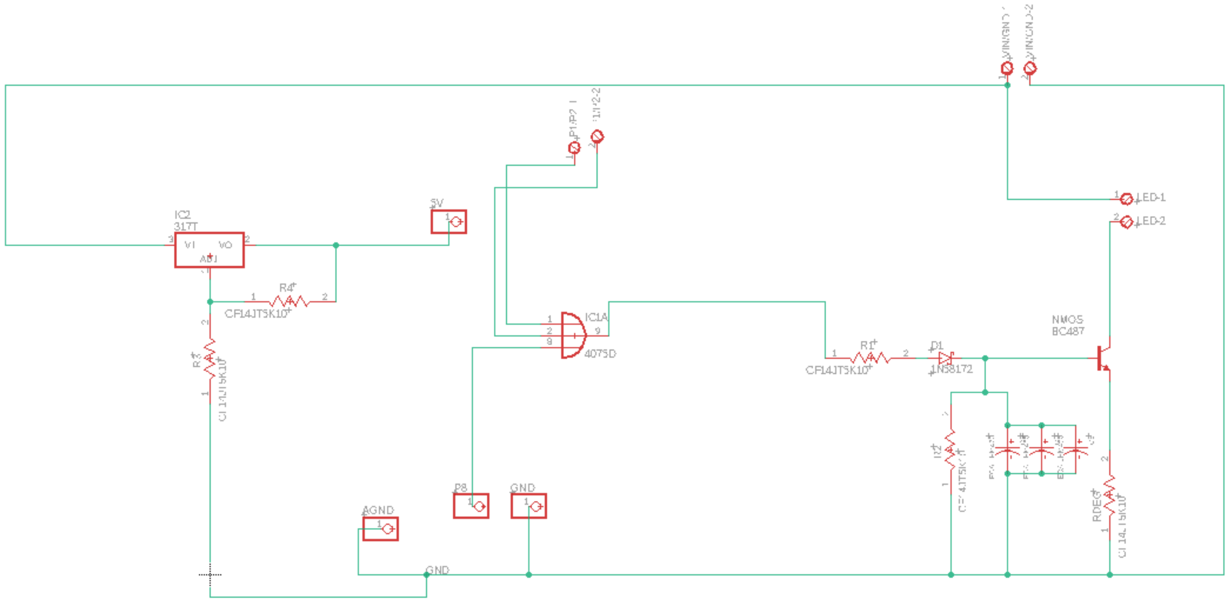
Bottom View

3. Triple OR Gate CD4075B Pin Layout Reference:
   http://www.ti.com/lit/ds/symlink/cd4071b.pdf

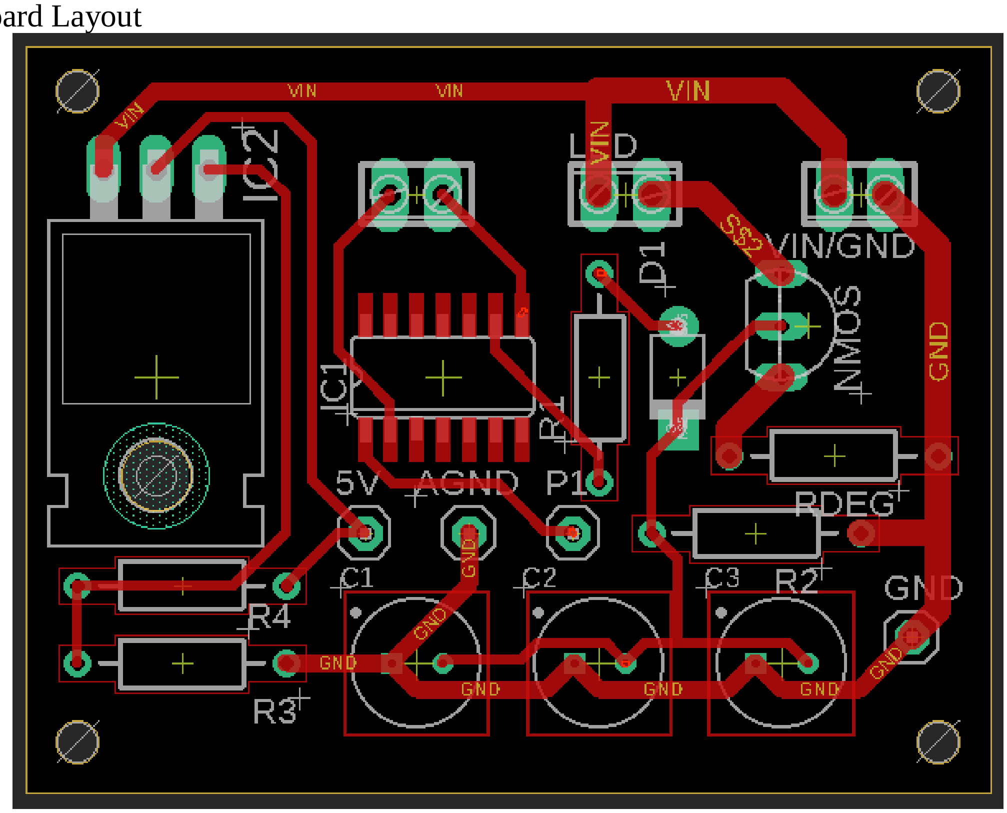


Appendix E - PCB Layout

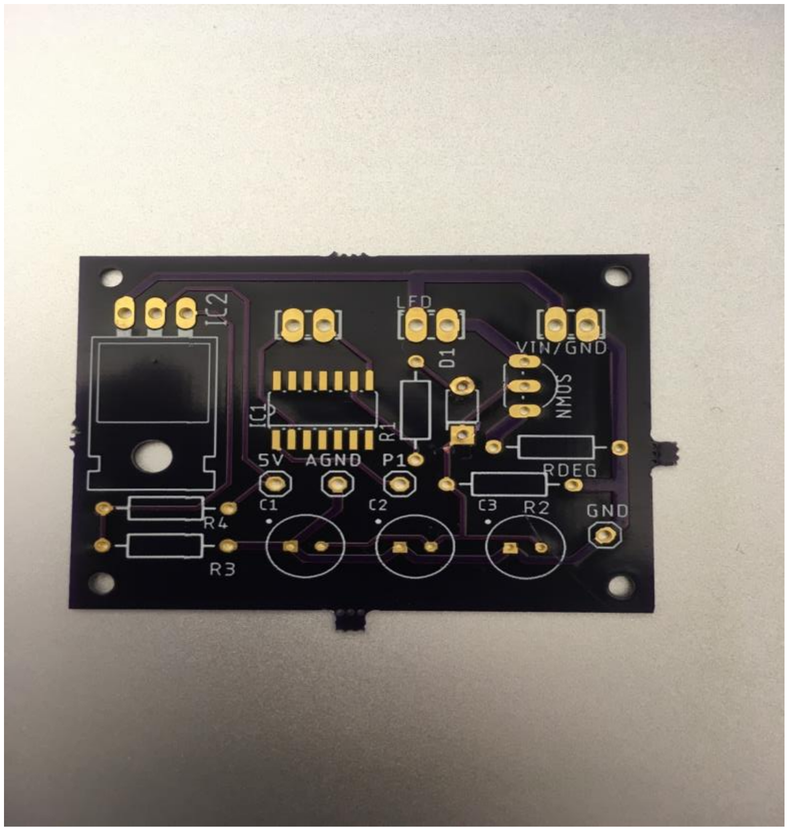
Eagle Circuit Schematic



Eagle Board Layout



Printed Circuit Board from OSHPark


IC2
LED
D1
VIN/GND
NMOS
IC1
R1
5V
AGND
P1
RDEG
C1
C2
C3
R2
GND
R4
R3