Solar-Powered Traffic Light

ECE 445 Design Document - Spring 2022

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Team 20

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1 Introduction

1.1 Problem

Traffic lights are integral to our society, despite their relative lack of innovation over the years. The most significant change has been the switch from incandescent bulbs to LEDs in an attempt to reduce the power consumption of this necessary device. However, this has also led to an increase of light pollution due to the cooler, more intense light emitted by LEDs.They can cause extreme glare and pose a danger to drivers at night. Additionally, the issue of bicyclists and vehicles sharing the road can create many awkward or dangerous situations due to the lack of separation.

1.2 Solution

We propose a solar-powered traffic light system that will reduce light pollution and solve the issues of drivers and bicyclists sharing the intersection. The system will be solar powered to minimize utility power used during the day. Connection to the grid will be necessary for operation at night or when solar conditions are suboptimal. At night, PWM circuitry will dim the LED modules. This not only reduces light pollution, but also lowers utility consumption at night. In the case of adverse weather conditions, the system will not dim the lights to ensure proper visibility.

1.3 Visual Aid

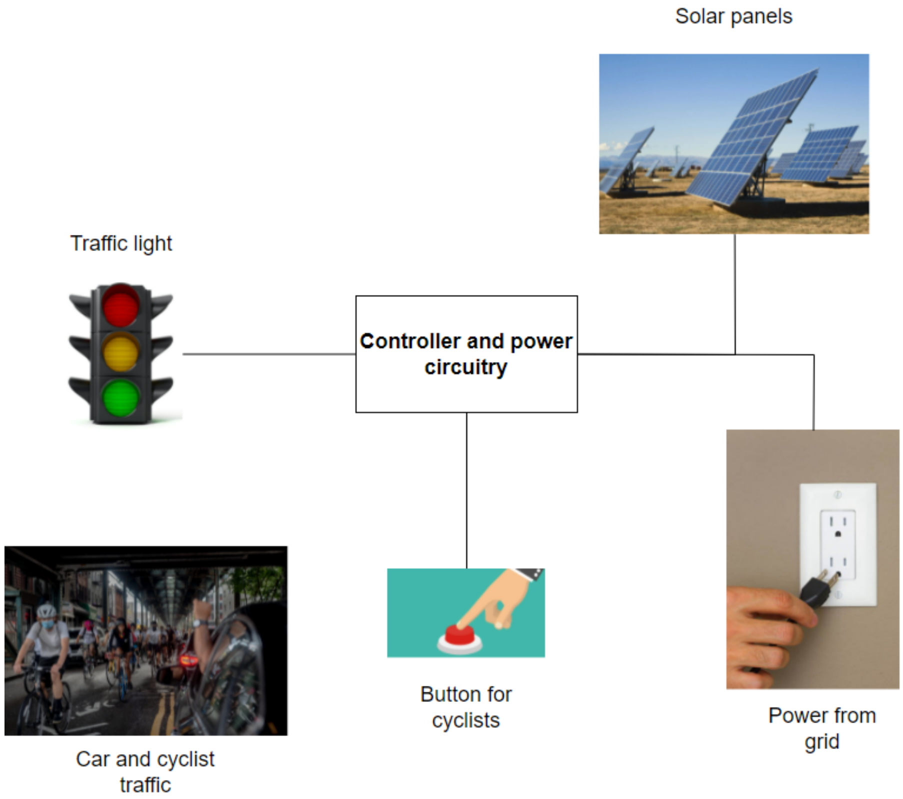

Figure 1: Visual Aid

1.4 High-level Requirements List

- A single traffic light bulb uses about 15 watts of power [1]. In order to limit light pollution and reduce consumption of utility power, the light modules must operate with less power when it is sufficiently dark outside (assuming clear weather). Should the power saved over an expected lifespan of about 20 years be non-negligible (and the other two requirements are met), we can conclude that this system is a success.
- The system must be able to switch between solar and utility power without causing a power failure. This is especially important when switching to utility power at night. Maximum voltage transients and switching time must not exceed 2.4V and 20ms respectively. This can be tested using an oscilloscope in the lab.
- The system must be able to efficiently adjust the light patterns and lengths of operation to increase the efficiency of traffic. Bicyclists and pedestrians will be able to press one of two buttons to trigger the bicycle and walk signs for them to safely cross the intersection. For example, assuming a walking pace of 3 miles an hour and a lane width of 20 feet [2], the walk signal must be on for a minimum of 15 seconds to ensure everyone crosses.

2 Design

2.1 Block Diagram

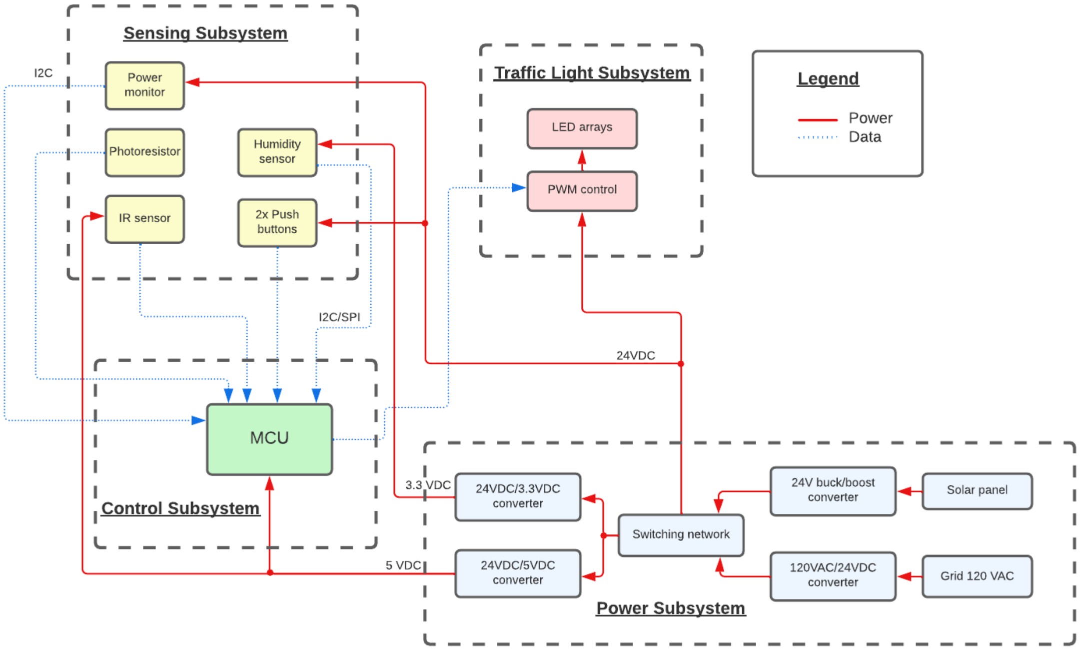

Figure 2: Block Diagram

2.2 Physical Design

A physical diagram of the project indicating things such as mechanical dimensions or placement of sensors and actuators. The physical diagram should also be accompanied by a brief one paragraph description.

2.3 General System

Requirements	**Verification**
The system enclosure must be rainproof, up to about 3.5 inches monthly - the average precipitation based on the 1981 to 2010 averaging period [3].	1. We can simulate this by assuming our enclosure area to be 1ft x 3ft x 1ft(w x h x d), and spray approximately 2 gallons of water on it

2.4 Power Subsystem

Solar Panel

Main power will be supplied by a solar panel with an output voltage of 18V

Requirements	**Verification**
The solar panel must provide up to 100W.	1. Use two multimeters and connect one in series to a power resistor and one in parallel across the power resistor to measure current and voltage, respectively 2. Multiply current and voltage readings to get power output
In full sunlight, the panel must generate 18V±5% when loaded.	1. Use a multimeter to take a voltage reading across the solar panel terminals and verify it remains within desired bounds

Switching Network

This system will switch the power input seamlessly between solar and utility. It will prioritize using solar power, and will switch to utility power if solar power drops below a threshold of 20W.

Requirements	**Verification**

Switching between the two sources must not interrupt normal operations.	1. Program the microcontroller to switch between power sources every 10 seconds and a counter 2. Use an oscilloscope to verify that the 24V, 5V, and 3.3V rails remain within tolerance levels 3. Visually monitor lights and ensure no flickering occurs 4. Check to make sure counter does not reset after any switches. If it does, the microcontroller might have gotten power cycled
Switching transients must not exceed 2.4V.	1. Measure output voltage using an oscilloscope to ensure that it stays within 10% of 24V every time the input switches.
Switching time must not exceed 20ms.	1. Hook up an oscilloscope to both LTC4359's shutdown pins and verify that the time between turning one IC off and turning the other on and vice versa is below 20ms.

Power Converters

Various converters will be utilized to ensure proper voltage levels for the lights, microcontroller, and sensors. The solar panel's output will be regulated to 24V with a step-up/step-down DC-DC converter. 120VAC utility power will be converted to 24VDC, which will further be stepped down to 5V and 3.3V.

Requirements	**Verification**
The buck boost converter at the solar output must provide 24V±10% at up to 3A output current.	1. Use an oscilloscope and a multimeter to check that the output is 24V±10% and up to 3A, respectively

The AC-DC converter at the grid output must convert 120V±10% to 24V±10% at up to 3A output current.	1. Use power supply to vary the input from 108VAC to 132AC and use a multimeter to ensure output remains within desired bounds
The 24V to 5V converter must provide 5V±5% at up to 500mA output current.	1. Use power supply to vary the input from 21.6V to 26.4V and use a multimeter to ensure output remains within desired bounds
The 24V to 3.3V converter must provide 3.3V±5% at up to 500mA output current.	1. Use power supply to vary the input from 21.6V to 26.4V and use a multimeter to ensure output remains within desired bounds

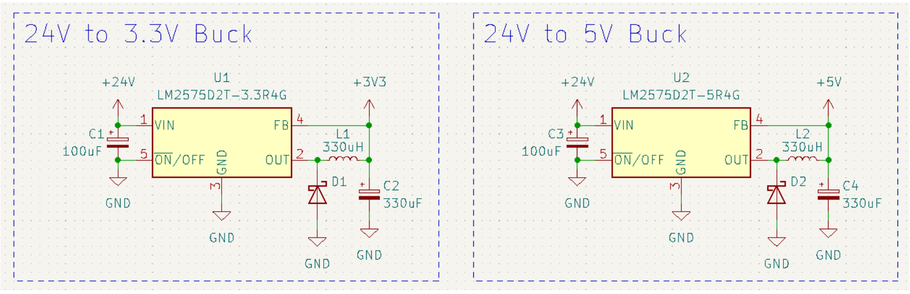

Figure 3: 3.3V and 5V buck converter schematic

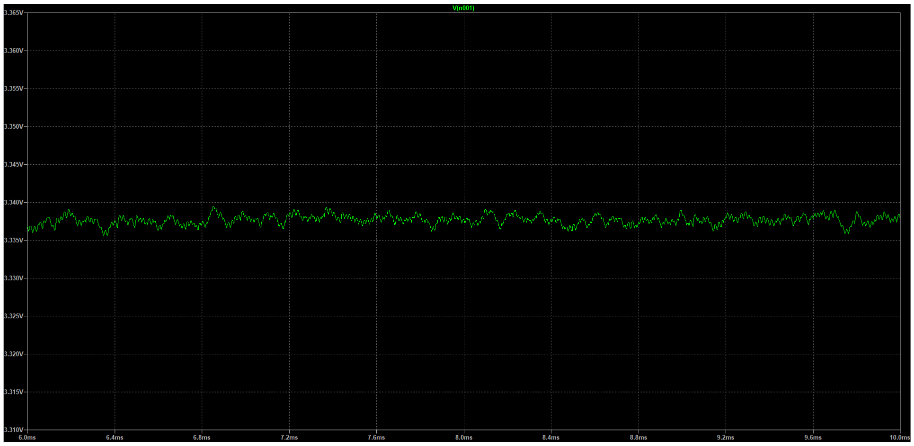

Figure 4: 3.3V buck converter simulation

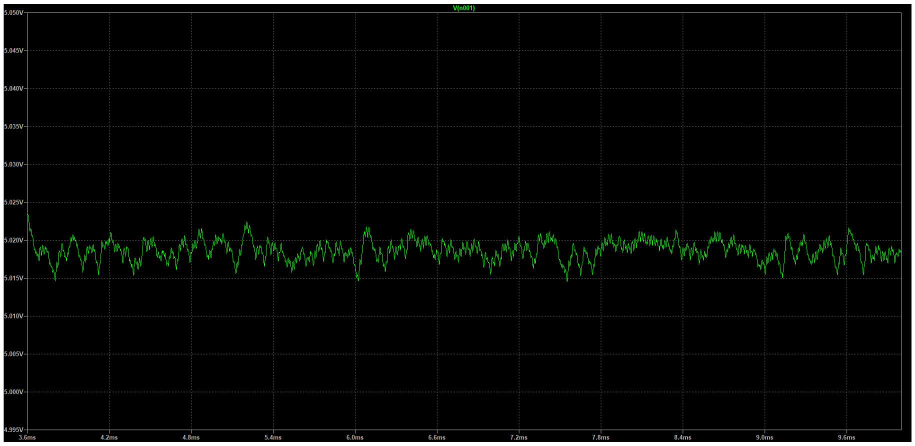

Figure 5: 5V buck converter simulation

2.5 Sensing Subsystem

The sensing subsystem is composed of all the sensors used in the system: one for power monitoring and the rest for the traffic lights. A current/voltage sensor is used to determine the output power of the solar panel. The power value is sent to the control subsystem using the I2C protocol. If the solar panel is disconnected, its power can still be measured through a dummy power resistor.

The traffic light sensors include two buttons, a light dependent resistor (LDR), a humidity sensor, and an infrared sensor. The buttons will be used to determine if there are bikes or pedestrians waiting to cross the street. Realistically, the wires carrying the button signals would be 20+ feet long, so a 24V signal will be used to reduce noise interference from voltage drops and ensure signal integrity. An opto-isolator circuit will be used to transmit the 24V signal to the microcontroller. The LDR is responsible for detecting the presence of sunlight and sending a signal to the MCU. Its resistance can range from a few hundred ohms in a bright environment to over one mega ohm in complete darkness. A simple voltage divider circuit will be used to correlate the light level to voltage level. The humidity sensor is used to detect adverse weather conditions and turn off the PWM light dimming if it is on. This ensures proper visibility of the traffic lights. The infrared sensor is used to detect vehicles and send a signal to the microcontroller.

Requirements	**Verification**
1. The power monitor must be accurate to ±10% of the actual wattage. 2. The power resistor must not overheat while dissipating power.	1. Use two multimeters and connect one in series to the power resistor and one in parallel across the power resistor to measure current and voltage, respectively. Multiply values to compute power 2. Check the temperature of the resistor using a laser thermometer while operating to see if there is any overheating
1. The buttons must not shock anyone who touches it.	1. Use an multimeter to ensure the enclosures and buttons themselves are properly grounded. All wires must be insulated and not exposed
1. The LDR must be able to differentiate between various light intensities.	1. Measure the voltage divider output voltage when the system is exposed to the sun at noon, complete darkness, and in a dimly lit room
1. The IR sensor must be able to detect the presence of a vehicle from a distance of at least 10ft.	1. Position the sensor 10ft and 18ft (maximum range) away from a vehicle and measure output voltages 2. Position the sensor such that there are no obstacles within its sight range and measure output voltage 3. Compare the voltage levels from both tests and establish a lower and upper boundary 4. Program the microcontroller with a test program to indicate if the voltage is within the boundary (i.e. car detected)

2.6 Control Subsystem

Control Flow

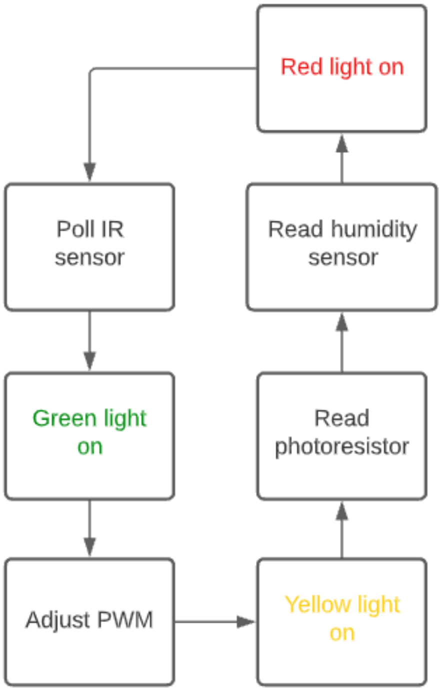

Figure 6: Main control flow

In addition to the main control flow when the biker/pedestrian button is pressed it will generate an interrupt. At this time the state of the lights will be checked and the lights will begin to change red or stay red and allow the biker/pedestrian to cross.

Microcontroller

The microcontroller will take data from the various sensors and control the PWM as well as the timing for the traffic lights.

Requirements	Verification
Microcontroller must respond to button interrupts.	1. When the biker/pedestrian button is pressed the lights should begin to switch to red or stay red

Microcontroller maintains state information and responds with appropriate control signals.	1. Use an oscilloscope on the PWM pin and change lighting conditions or humidity. We should see either an increase or decrease of the duty cycle

2.7 Traffic Light Subsystem

For our traffic light system we will be constructing them out of high power LEDs, which we will have to design an additional PCB board for or get a sample of real traffic lights to use in our project

Requirements	**Verification**
1. The LEDs must be visible from 150ft for drivers to see them in bright conditions. Most modern traffic lights are 400-1000 lumens so we aim to be in this range [4]. 2. Bike/pedestrian light turns on when it is safe for pedestrians/bikes to cross. 3. Push-button interaction 4. The LEDs should have multiple dimming levels (i.e. 40%, 60%, 80%, and 100% of full brightness), achieved by sending the 24V input in pulses. 5. The frequency at which the LEDs are turned on and off must be beyond frequencies visible to humans.	1. Standing 150 ft away we will see if the lights are visible. Use a light meter to measure lumen output 2. When lights are red and it is safe to cross, the bike/pedestrian light turns on. There is an adequate amount of time to cross the intersection 3. A biker is able to reach the button or pedestrian is able to walk up to the button and press it to turn the lights red and cross intersection 4. Use an oscilloscope to ensure the PWM duty cycle is being changed. Visually inspect the brightness difference 5. Use an oscilloscope to verify that the PWM circuit is behaving properly. There should not be any noticeable flickering to the human eye

2.8 Tolerance Analysis

The main issue we will run into for this project is creating a 24V switching network. We will need to ensure there is no delay/outage in our traffic lights when switching between grid power and solar power. Specifically, we aim to minimize the transient voltage to below 2.4V and switching speed below 20ms. For this, we will use an LTC4359, which can be used to OR power sources. If the output voltage transient is above the threshold, we can use capacitors to smooth the waveform.

The simulation in Figure 8 uses two voltage-controlled switches to toggle the shutdown pins on the

LTC4359. The 0.5ms periods where both of the ICs are off (Figure 10) only causes the voltage to drop to about 23.89V, as shown in Figure 9. From the ATmega328 datasheet [5], the maximum rise/fall time of any pin is 1600ns. This means that the switching network can successfully switch between solar and grid power while reducing transients and switching speed.

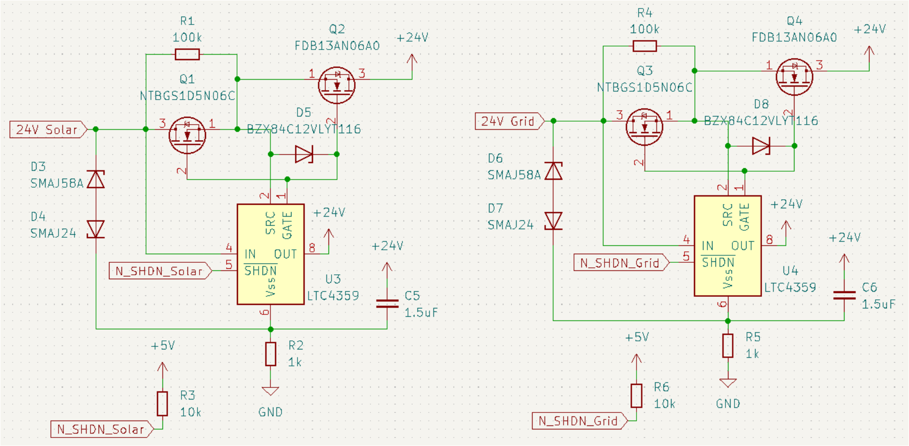

Figure 7: Switching network schematic

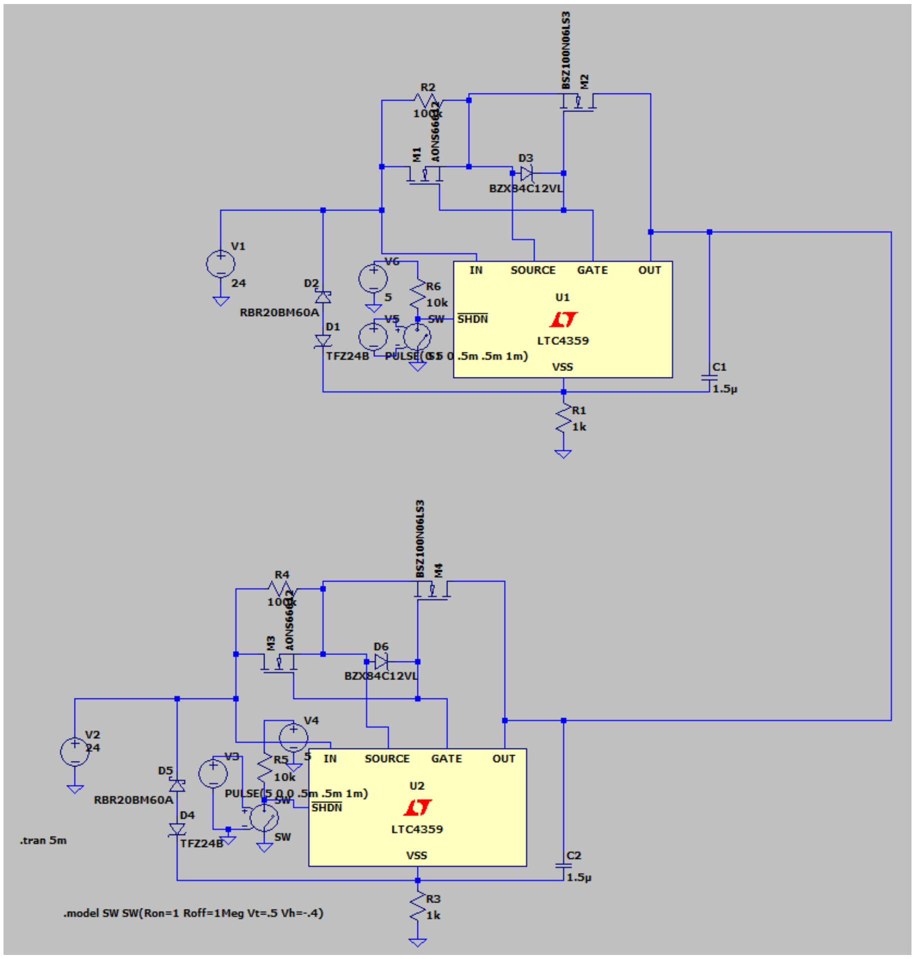

Figure 8: LTspice circuit using Spice model of LTC4359

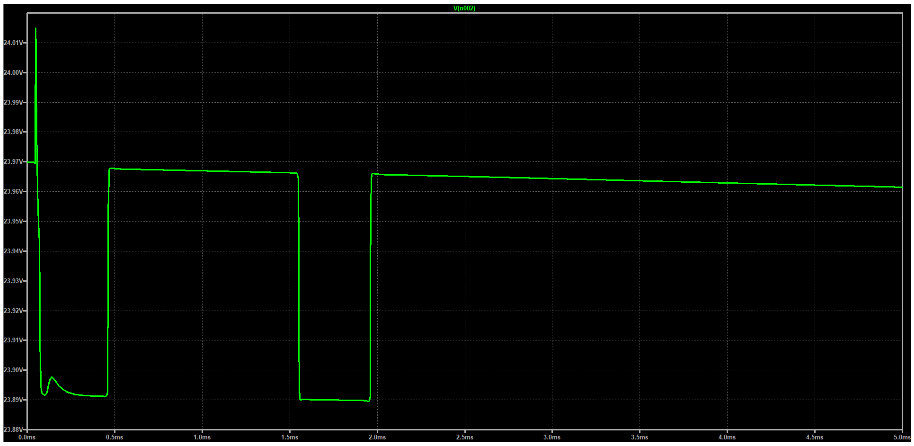

Figure 9: 24V switching network simulation

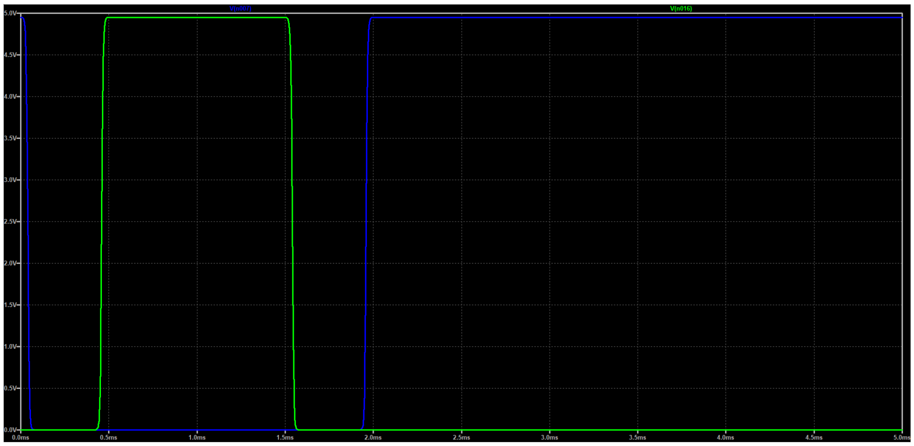

Figure 10: Shutdown signal on LTC4359s (Blue = Solar SHDN, Green = Grid SHDN)

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

Our team consists of two electrical engineering majors and one computer engineering major. From the 2019-2020 annual Illini Success Report, electrical engineers make an average of $76,129 and computer engineers make an average of $99,145 [6]. There are 9 weeks left in the semester, and we will work approximately 10 hours per week. This will total 90 hours.

Name	Bowen Xiao	Richard Przybek	Colin Tarkowski
Rate	$38.06	$49.57	$38.06
Hours worked	90	90	90
Total Cost	$3425.4	$4461.3	$3425.4

3.1.2 Parts

Following is a table of all the parts required for the project and their associated costs.

Component	**Part #**	**Retail Cost**
Photoresistor	161	$0.95
Humidity sensor	DHT20	$6.50
IR sensor	GP2Y0A710K0F	$21.21
MCU	ATMEGA328-PU	$2.58
3.3V buck IC	LM2575D2T-3.3R4G	$2.26
Schottky diode	VS-30WQ04FNTR-M3	$0.68
100uF cap	ESY107M050AG3AA	$0.44
300uH inductor	HCTI-330-5.2	$2.99
330uF cap	ESY337M025AG8AA	$0.45
5V buck IC	LM2575D2T-5R4G	$2.84
140W (33 Ohm) Resistor	TEH140M33R0FE	$15.20
45W AC/DC Converter	MPM-45-24	$28.31
Power Monitor (I2C)	LTC4151IMS-1#TRPBF	$8.40
Optoisolator	MOCD207M	$1.30
Sense Resistor	ERJ-3BWFR020V	$0.45
30 W DC-DC Converter	PYBE30-Q24-S24	$32.23
	Total Cost	**$126.79**

3.2 Schedule

Week	Bowen	Richard	Colin
2/21	Complete design document Design document review	Complete design document Design document review Follow up on Leotek samples	Complete design document Design document review
2/28	Work on getting PCB board approved	Put together list of parts for ordering Submit order for parts from machine shop	Work on getting PCB board approved
3/7	Work on physical design of lighting enclosure Work on programming the MCU	Work on physical design of the lighting enclosure Work on programming the MCU	Work on physical design of the lighting enclosure Talk to machine shop and have them start to make it
3/21	Start assembling and soldering PCB board and debug any subsystems/issues Design and submit LED PCB (if we are unable to attain Leotek sample)	Complete software for the MCU and begin testing Integrate the MCU with the rest of the hardware Design and submit LED PCB (if we are unable to attain Leotek sample)	Start assembling and soldering PCB board and debug any subsystems/issues Design and submit LED PCB (if we are unable to attain Leotek sample)
3/28	Complete individual progress report Perform overall testing of the system	Complete individual progress report Perform overall testing of the system	Complete individual progress report Perform overall testing of the system
4/4	Create mock demo	Create mock demo	Create mock demo
4/11	Create mock demo. Start working on final paper.	Create mock demo. Start working on final paper.	Create mock demo. Start working on final paper.
4/18	Mock demo. Begin working on final demo	Mock demo. Begin working on final demo	Mock demo. Begin working on final demo
4/25	Final demo. Create mock presentation.	Final demo. Create mock presentation	Final demo. Create mock presentation.
5/2	Final presentation. Submit final paper and lab notebook.	Final presentation. Submit final paper and lab notebook.	Final Presentation. Submit final paper and lab notebook.

4 Discussion of Ethics and Safety

The team will strive to adhere to the IEEE Code of Ethics. Since we are designing a product for use in traffic, we must ensure "the safety, health, and welfare of the public" and to "disclose promptly factors that might endanger the public or the environment." [7]

One of the dangers to this project is the bike and pedestrian buttons. Since they will be using 24V to transfer signals, the enclosure must be properly grounded or insulated to minimize risk of electric shock. Additionally, only the ground wire will be extended to the physical switch so that no accidental short circuits will occur.

We will also follow Section 4.1.1 "Relationship between Signal Timing and Traffic Control Design" of the U.S. Department of Transportation's guidelines for the traffic signal design process [8]. In order to provide the highest level of service to its users, the team will tune the system. Visibility, vehicle detector position, and minimum green time are some of the parameters that we will experiment with.

5 References

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