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1. Executive Summary

Riding a bike has been one of the main modes of transportation ever since the mid 1800s and has revolutionized the transportation industry. With technology rapidly advancing, the modern era has sought after motorizing bicycles so that older technologies can keep up with modern life for beneficial updates and modifications. This allows bikes to be a cheaper and more green and efficient alternative to cars that can be expensive to up keep and have a mid to high range of Carbon Monoxide since Electric Bikes are practically emission-free. Electric Bikes are also highly sought after for is for their efficiency of tackling jobs that are hard for the user to do on their own. Electric bikes can aid the user in climbing hills, fighting the wind, and giving the rider a longer range to travel on. Another way that an Electric Bike helps the user if the user suffers from joint pain in the knees are just are not able to peddle and operate a bike alone, this would give them the joy and experience of a typical rider without the obstacle of peddling.

There are two main disadvantages to Electric Bikes, one being that they are expensive for the average consumer to purchase, and the other that they would have to purchase a whole other bike that isn't the one that they are comfortable riding. We are wanting to create a system that is cheaper than the alternative conversion kits that can be purchased and easily mountable to an existing bike. This system would include features that would aid and inform the user with each operation. These features include a liquid crystal display (LCD) to promptly display the speed and other information about the bike/system, a motor that would drive the rear wheel of the bike for no peddle operation, thumb throttle control on the handle bars, and solar charging for the system battery for total green power efficiency. The LCD Interface will have easy to read information and will even be user friendly and personal to the user. This system would be designed to fit on most bike configurations.

One of the crucial tasks of the system is to produce a pulse width modulation that would drive the MOSFETs that control the flow of current through the motor. The motor will see these digital pulses as an analog voltage average which allows the motor to rotate.

The Solar Bike is an excellent alternative to other types of conversion kits and motorized bicycles since it can be green and efficient way of riding all with the benefit of using your favorite bike.

2. Project Description

2.1 Project Background

In large metropolitan cities, such as New York, many people use bicycles as an alternative form of transportation. This is because traveling by car in a densely-populated area is time consuming and inefficient. Traveling long distances is especially straining to cyclist's bodies over time. Many are also trying to get from point A to point B as quickly as possible. For these reasons, cyclists often turn to electrically operated bicycles.

An electrically operated bicycle allows the user to achieve speeds of up to 20 miles per hour, while maintaining control and the luxury of pedaling when they find it convenient. The bike usually consists of a custom bicycle frame and an electric motor, in the form of a hub motor, mid-drive motor or belt drive connected to the rear wheel, although some designs also include a front wheel design.

Electric bicycles most commonly use lithium ion batteries. The problem with this system is that it uses a lot of power so the battery must be constantly charged every day for use. This is one of the costs associated with electrical bike travel.

In this project, we want to be able to convert anyone's bike at home into an electric bike at a low cost compared to most conversion kits. This will help more people see that there is a cheaper alternative to buying a manufactured electric bike and that they can use the bike that they've used before.

Some of the features that will be implemented with this are an HUD LCD that will show the operators current speed when in the motor operation mode displayed between the handle bars for easy viewing. Another feature will be variable speed control for the users' convenience using a throttle that will be mounted on the handle bars, as well.

2.2 Objectives

2.2.1 Motivation

The motivation for this project is to demonstrate our knowledge and apply what we have learned at the University of Central Florida. As well as the knowledge gained thus far, the opportunity to work in a group, experience that can be applied towards future career paths, is introduced. The challenges and advantages associated with working with a group are very valuable and necessary experiences to be introduced before degree completion at the University of Central Florida.

2.2.2 Design A

To design an electric bicycle that integrates solar panels to charge the main battery powering the bicycle motor.

To design two different power systems:

- A main power system comprised of solar cell conversion, a 48V+ lithium ion battery that powers the bicycle's motor, and homeport charging option

- A secondary power system, low voltage, used to power electronics on the bicycles handle bars

2.2.3 Design B

To design an electric bicycle that integrates solar panels to charge a secondary battery powering electronics mounted onto the bicycle.

To design two different power systems:

- A main power system a 48V+ lithium ion battery that powers the bicycle's motor, and homeport charging option
- A secondary power system, low voltage, supported by solar cells conversion to charge the battery used to power electronics on the bicycles handle bars

2.3 Requirements Specifications

*** "**The system" refers to the bike and all accessories and/or attachments

- The system shall be no taller than 3.333 ft.
- The system shall be no longer than 6 ft.
- The system shall not weigh more than 125 lbs.
- The system shall contain a bike, battery, solar panel(s), motor, and sensor control
- The system shall be able to be transferred or mounted to a range of different bicycle styles
- The solar panels shall not exceed 8 cubic feet
- The solar charge regulator will have overcharge protection which limits the current when the battery is fully charged
- The power system shall have current leakage protection
- The power system shall be capable of delivering at least 24 volts DC
- The secondary battery shall be capable of charge via solar panels and/or wall plug
- The power supply shall be capable of powering multiple sensors and accessories
- The power supply shall be capable of powering the DC motor
- The bicycle shall be able to reach speeds of 12 miles per hour via electrical operation
- The battery shall have a full charge time of at most 12 hours
- The system shall be capable of variable speed operation
- The total cost of the system shall not exceed $1000
- The microprocessor shall be capable of pulse width modulation
- The motor shall be driven by use of pulse width modulation
- The bike must be blue (sponsor requirement)
- The battery connected to the solar panel shall have a capacity of 5 Ah or greater
- The output current of the solar panel shall be, at a minimum, one tenth of the battery capacity
- The output voltage of the solar charge regulator shall be within the range of 12.6 V to 13.7 V while the solar panel is receiving energy (light)
- The output current of the 12 V to 5 V voltage regulator shall not exceed 1.9A

- The output voltage of the 12 V to 5 V voltage regulator must stay constant with respect to the varying input voltage from the battery, within 2 mV
- The secondary battery shall weigh no more than 4.1 pounds
- In order to claim conformance to any of the included standards, requirements shall be stated and adequate proof provided confirming conformance is met
- The microcontroller must be able produce a PWM signal that has the amplitude of 5V max and a minimum of 0V
- The frequency that the microcontroller must produce on the PWM signal must be able to operate on a range of 1kHz up to 25 kHz (typical frequency range for common motors).
- The minimum operation voltage of the microcontroller must be at least 5V and a maximum of 20V
- The MOSFETs must be able to be driven by a MOSFET driver with an output of at least 12V
- The USB, that may be implemented, must be able to output a 5V / 200mA power output to successfully charge devices, such as a modern cell phone
- The LCD of the HUD must not exceed a volume of 4.2 x 3 x 3 inches (LxWxH)
- The bike must be able to be manually powered by peddling when the system is not in use
- The center of mass of the bike system must not exceed 3 inches out to the side from the parallel center of the bike
- The program of the system must be able to compile and correctly output the speed of the bike in miles per hour (MPH)
- The components included in the system shall be designed or chosen such that they do not interfere with the motion of the rider
- The system shall have weather proof protection on all electrical components
- The system shall inform the rider that helmets are required for safety
- The system shall include adequate heat sinks, where necessary, to ensure both rider and device protection

2.4 Marketing and Engineering Requirements

Table 1: Marketing and Engineering Requirements

		Ease Of use	High Performance	Energy Cost	Quality	Speed	Target*
		+	+	-	+	+	
Efficiency	+	↓	⇑	⇑	⇑	⇑	>70%
Weight	-	↓	⇑	↓	⇑	⇑	<300lbs
Quality	+	⇑	⇑	↓		↑	>70%
Dimensions	-	↓	↑	↓	↓	↓	<2x2m
Cost	-	⇑	⇑	⇑	⇑	⇑	<$1000

Engineering Marketing

↑= Positive correlation

⇑= Strong positive correlation

↓= Negative correlation

⇓= Strong negative correlation

+ = Increases the requirements

- = Decreases the requirement

3. Research related to Project Definition

3.1 Existing Projects and Products

As with many of today's technology, innovation plays a key role. Expanding on designs that have been laid out before is a basis of all modern engineering. There are existing technologies that incorporate solar power and electric bicycles, but with very different designs and approaches of integration.

3.1.1 Solar Cell Design

There are many designs associated with the integration of solar panels to an electric bicycle. Because of this, we know that the power consumption of electric bicycles are high, propelling weight up to and over hundreds of pounds. This section covers the most common designs, integrating solar panels and bicycles together to more efficiently provide charging power to the motor's battery.

Figure 1: Existing solar bike design

Figure 1 shows an electric bicycle design that incorporates photovoltaic cells on the tires themselves. This allows the battery that is driving the motor to be charged while the bike is left in the sun, and discharged when the bike is in use, not actually driven by the solar cells themselves. A bicycle like the one shown can go up to speeds of 19 miles per hour, driven by a 500-watt motor. The motor is powered by a “water bottle” battery design. The battery is more than 45 volts and is shaped like a water bottle to more readily fit the bike and application. From figure 1 we can see that the throttle is located on the left side handlebar, allowing the user to control the speed at which the motor drives the bicycle.

Figure 2: Existing solar bike design

Another popular design is shown in *Figure 3.2*. This integration has the solar panels arched over the back tire, facing in opposite directions. According to the article's source, it takes roughly 6 hours to charge its main battery while in direct sunlight using two 25 watt solar modules.

3.1.2 Accessories

Figure 3: Existing bike accessory

Figure 3.3 shows a speedometer for a bicycle which uses magnets on the spokes to accurately read the speed. This is similar to our objective to provide the user with accessories such as a speedometer, reading the bicyclists current speed, timer which records the amount of time the user has been riding, and potentially feedback for current weather conditions.

We want to give our user the luxury and total control of their cruising experience. This total control comes from having the knowledge of their speed, cruise time, and distance traveled at the touch of their fingertips.

3.1.3 Throttle Design

There are many existing designs for throttles, each one with its own application. These designs have advantages and disadvantages when it comes to certain applications. This section will cover common designs for throttles used to control motor speed.

Potentiometer Controlled Throttle

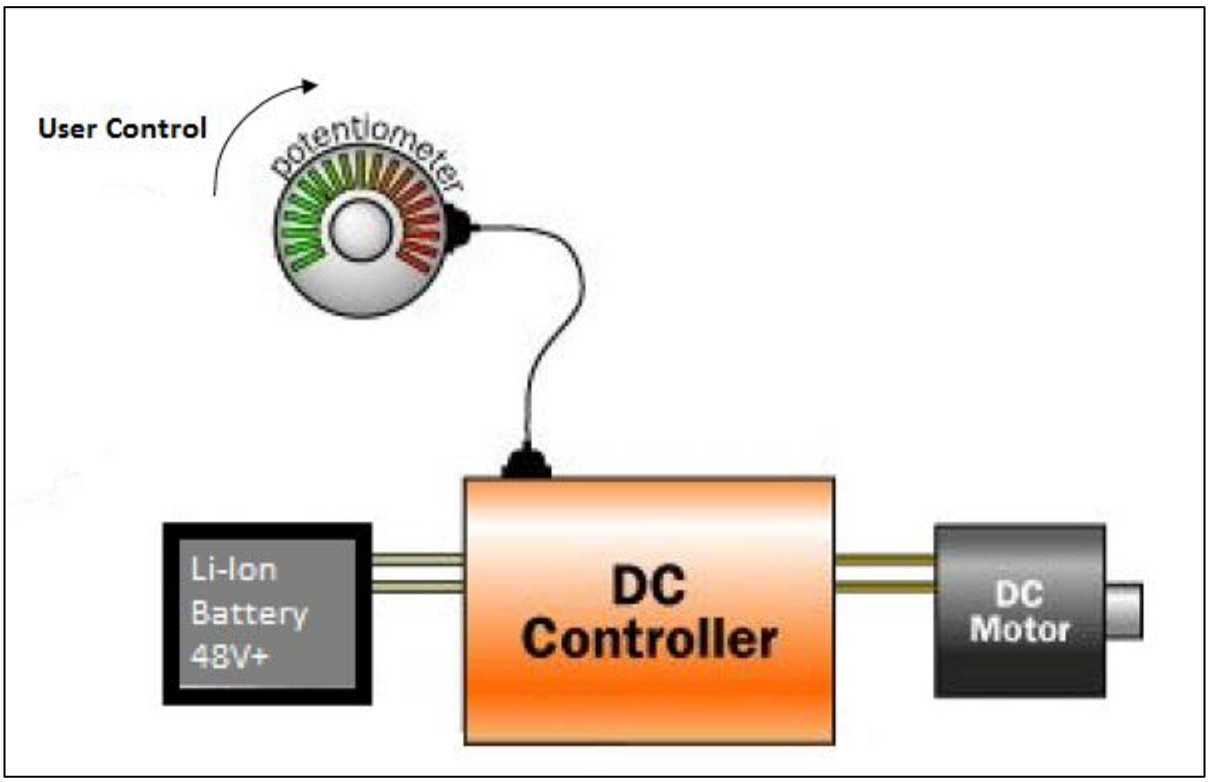


Figure 4: Potentiometer controlled throttle design

This throttle control design is one of the simplest and most well-known. As shown in *Figure 4*, it involves an external user controlled potentiometer. A potentiometer is an adjustable resistor, having contacts that moves across a resistive element. The user controls the resistance given off by the potentiometer, and that is fed back to the DC controller. The DC controller then regulates the amount of voltage to send to the motor depending on the input from the user controlled potentiometer. The advantage of this design is that it is relatively simple and low cost. In turn, you sacrifice the longevity of the design, as the average life cycle is very low, as most only last a couple of thousand rotations before the material wears out. Potentiometer based throttles are also limited in the power they can handle, as they can only dissipate a few watts of power at most and to handle more power they become bulky and expensive.

Hall Effect Sensor Throttle

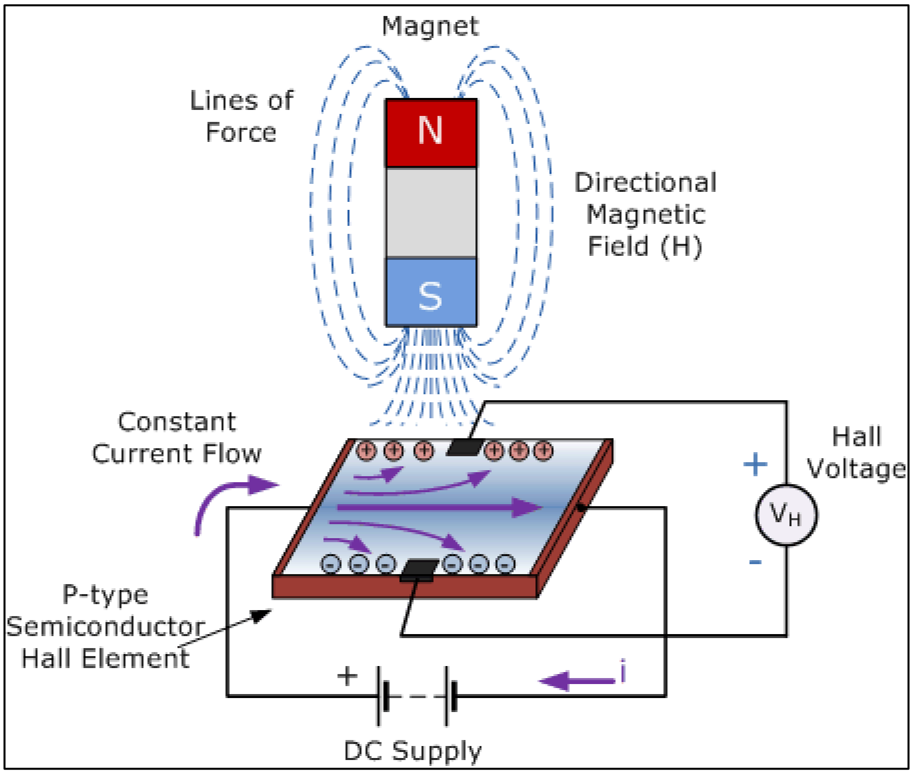


Figure 5: Hall Effect

The Hall Effect sensor throttle works similarly to a potentiometer except rather than turning a manual dial, you move a magnet closer to a hall sensor. A hall sensor is a transducer that varies its output voltage in response to a magnetic field. It is a common sensor known as a magnetic sensor because it converts magnetic or magnetically encoded information into electrical signals for processing by electronic circuits. Magnetic sensors, such as the Hall Effect sensor used for throttling, make it ideal for applications where the use causes wear and tear. This is because the Hall Effect sensor is non-contact wear free operation with low maintenance and a robust design. The sealed Hall Effect devices are immune to outside disturbances, such as vibration, dust, and water.

Figure 5 above shows the general nature of a hall effect, generating voltage by use of a magnetic field. The DC supply provides the constant current flow. When the magnetic field is moved closer to the sensor, it allows current to flow through, resulting in the Hall voltage, V_H, the voltage output directly proportional to the strength of the magnetic field passing through the semiconductor material. This nature of the Hall Effect is used for throttles, including many electric bicycle motor control. The throttle is equipped with a hall sensor and magnet. When the user turns the throttle, usually a hand twist or thumb push throttle, the magnet is brought closer to the sensor, increasing voltage flow to a main control board that dictates the main power going to the motor.

3.2 Relevant Technologies

3.2.1 Photovoltaic Cells

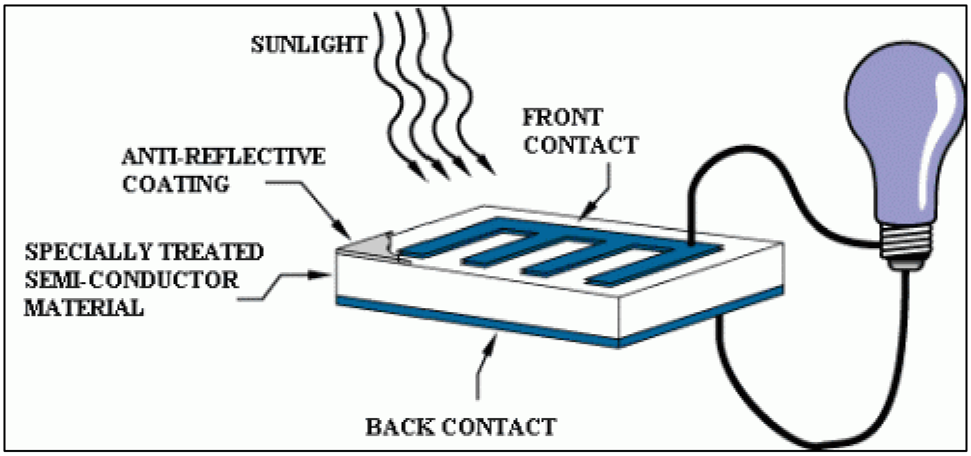


Figure 6: Photovoltaic Cell

Our design integrates photovoltaic cells, or solar panels to harness the energy from the sun and convert it into power we can use to charge the battery on the bicycle. The Sun radiates microscopic particles called photons. When these photons hit the surface of a semiconductor material, mainly a photovoltaic semiconductor, they indirectly transfer their energy to electrons in the outer shell, causing them to separate from the atom. The solar cell then guides these free electrons and create an electric current by methods of doping the semiconductor material. These electrons flow through the wire from the cells and into our load.

Uses of photovoltaic cells:

- Calculators, toys, watches
- Space rovers
- Emergency power
- Satellites
- Electric Fences
- Water pumping
- Remote lighting systems

There are many advantages that go along with the use of photovoltaic cells to power many of our electronics. Solar cells have no moving parts and, as a result, require little to no maintenance after installation. Photovoltaic cells are ideal for the environment, as they do not pollute their surrounds or burn fossil fuels in any way. It is a proven fact that solar cells can last longer and have a lower running costs than many other alternative energy sources, such as hydro, nuclear, wind etc.

3.2.2 Bicycle Motor

There are different types of motors used for electric bikes. These include Hub motors, mid drive, and friction drive.

Hub motors are electric motors that are housed inside the hub of either the front real wheel. They are the most common motor found in electric bikes.

Mid drive motors are powered through the drivetrain of the bike which enables the motor to help with long and steep climbs. These are less commonly used because of the strain it puts on internal components within the drivetrain.

Friction drive motors use a roller that sits on the bike wheel and uses friction to transfer the power from the roller wheel to the bike wheel. These motors do not perform well in wet weather and off road tires.

3.2.3 Throttle Control

The throttle for an electric bike controls the speed at which the motor drives the bicycle tire, resulting in the speed at which the user travels. There are three types of electric bike throttles: thumb throttles, half twitch throttles and full twist throttles. The throttle is controlled by the user using their hands and limits the amount of power being sent to the motor.

For a Hall Effect sensor throttle, the throttle interfaces directly with a controller or controller box. This controller box is only concerned with the output voltage from the throttle. The throttle takes an input voltage, usually around 5V

3.2.4 Bicycle Battery

The most commonly used battery for an electric bicycle is a lithium ion battery because they are rechargeable and have a higher current capacity than others. Depending on the motor driving the bicycle, this battery can have a different voltage rating commonly from 24 volts and higher. Because it takes a lot of power to drive a weighted bicycle, these batteries must have a power rating to drive the motors.

A smaller rechargeable battery may be used to power low power electronics mounted onto the bicycle. This battery will most likely be a lead-acid battery since it will be a better match to the solar panel.

3.2.5 Pulse Width Modulation Control

This section will provide a brief overview of pulse width modulation (PWM), common applications, and integration into the solar bike design.

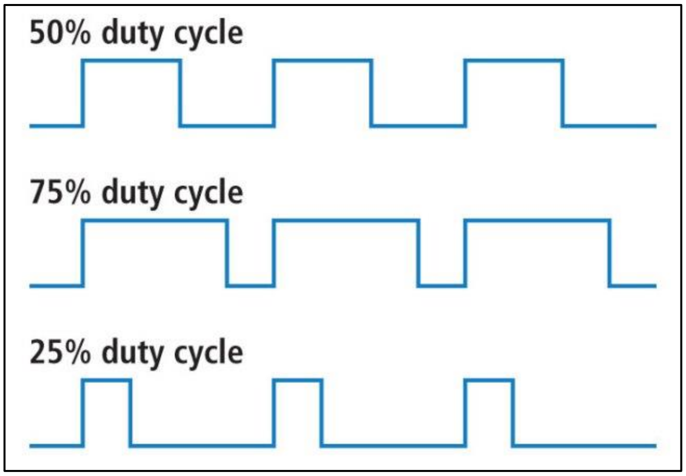


Figure 7: PWM Duty Cycle Comparison

Pulse width modulation is a method for generating an analog signal using a digital source. A PWM signal has two defining characteristics: duty cycle and frequency. The duty cycle represents the amount of time the signal is in an “ON” state or “HIGH” level and is given as a percentage of the total time it takes to complete one cycle. For example, 500Hz, would be 500 cycles per second, the rate at which is switches between “ON” and “OFF” states. It is important to note that these “ON” and “OFF” states are representative of voltage levels. “ON” being characterized by a certain voltage level in which the signal is seen as “HIGH.” “OFF” being characterized by a voltage that is lower than the preset “ON” voltage.

By using a digital PWM, at a certain frequency and with a certain duty cycle, we can create constant voltage analog signals used to power a wide array of devices. For example, a certain PWM signal has a amplitude of 5V and a positive duty cycle of 10%, the analog signal will be of 0.5V since the load will see the average of the PWM digital signal as a constant analog. This relationship between the digital input and the analog output that the load sees can be visualized in Figure X below.

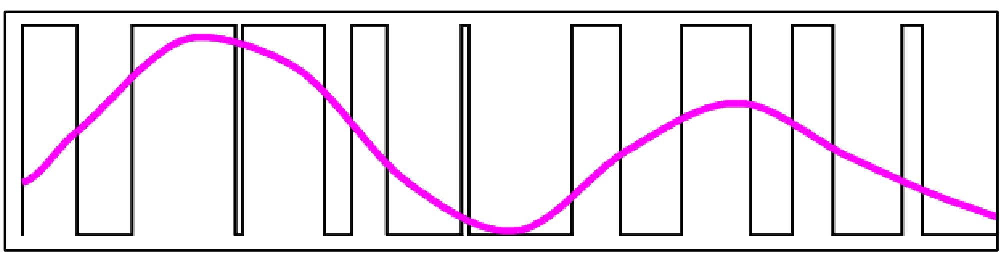


Figure 8: PWM Digital/Analog Comparison

As observed above, when the duty cycle of the PWM signal reaches near 100%, the amplitude of the analog output is close to the full 100% voltage of the PWM signal amplitude. On the contrary, as the positive width of the signal becomes smaller, closer to a 0% duty cycle, the analog output voltage gets closer to 0V. This variation in duty cycle can be controlled using digital control through the means of programming or through analog inputs like throttles or potentiometers.

The main use of PWM is to control DC motors, a direct application of what we are doing here, but is also used to control valves, pumps, hydraulics, and many other mechanical parts which require controlled analog voltage. In this project, a PWM will be used to control the motor speed output. This will be done by changing the duty cycle from near 0% up to near 100%. The throttle will be used to control the duty cycle change.

3.2.6 Voltage Regulator

Every electronic circuit is designed to operate at a certain voltage, or voltage range. A voltage regulator provides this constant DC source while holding the voltage constant, regardless of varying input voltage and load current pull. A voltage regulator takes an input voltage and creates a regulated output voltage. This automatic regulation of output voltage level is handles by various feedback techniques that can improve performance, reliability, and efficiency. There are two main types of voltage regulators, linear and switching.

3.2.6.1 Linear Voltage Regulator

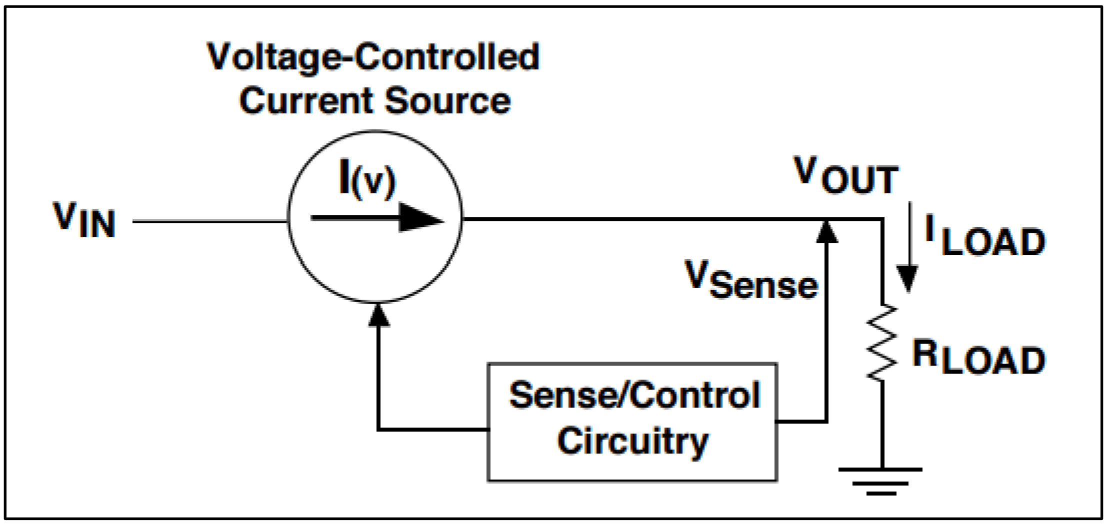


Figure 9: Linear Voltage Regulator Architecture

Figure 9 shows the basic architecture for a linear voltage regulator. A linear voltage regulator uses a voltage-controlled current source to force a fixed voltage to appear at the output of the regulator. From above, the sense/control circuitry must quickly monitor the output voltage, constantly adjusting the current source in order to hold a fixed output voltage at some pre-determined value. Linear voltage regulators have a limit to the amount of current they can source while still maintaining the desired voltage regulation. This design limit is defined by the current source, controlled by using a feedback loop, integrating some type of compensation to assure loop stability.

Feedback Control Loop

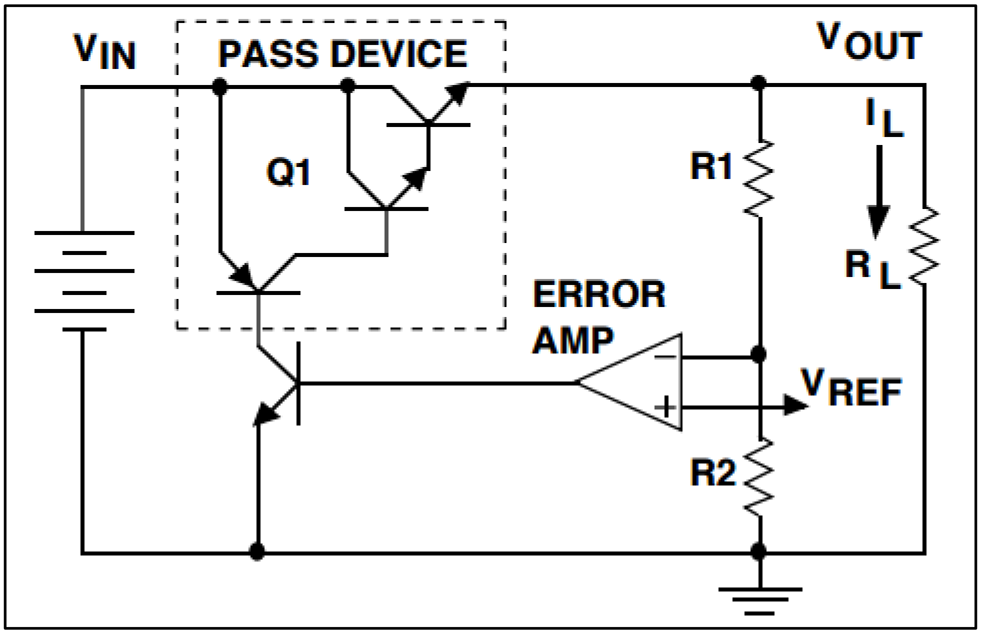


Figure 10: Linear Voltage Regulator Feedback Control Loop

Figure 10 shows a diagram for a typical linear voltage regulator. Many linear voltage regulators use a power transistor to act as a voltage divider network, in combination with resistors. The output from the voltage divider is used as feedback, sourcing the power transistor in order to maintain a constant output voltage. Another common characteristic of linear voltage regulators, and sometimes a disadvantage, is the amount of time it requires to "correct" the output. Since it is using a feedback controlled system, the output voltage will constantly try to change when the current pull from the load varies. This is often referred to as the transient response, measuring the speed at which the regulator can output the required steady voltage after a change in load characteristics.

Because the process of regulating voltage requires power manipulation, there are times where the energy lost due to heat can be very high, demanding good heatsinks and airflow within the design for efficient heat dissipation. The total power converted to heat is equal to the voltage drop between the input and output voltages multiplied by the current supplied to the load.

Linear Voltage Regulator Types

Types of linear voltage regulators include, low dropout(LDO), Standard, and Quasi-LDO. We will briefly cover those that directly impact this project.

Standard

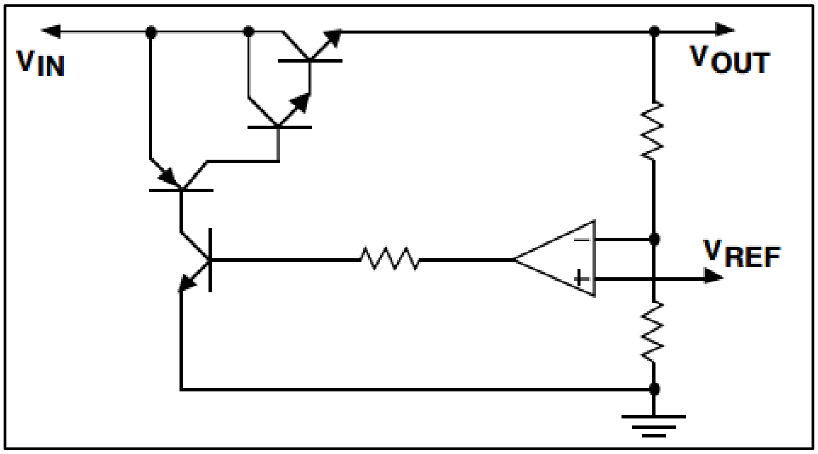


Figure 11: Standard Voltage Regulator Configuration

A Standard voltage regulator makes use of a NPN Darlington pair configuration as shown in *Figure 11* shown above. An important characteristic of a Standard voltage regulator is that there is a minimum voltage required to maintain output regulation.

$$V_{D(MIN)} = 2\ V_{BE} + V_{CE} \qquad \text{(Standard Regulator)}$$

This is usually set to 2.5 to 3V by the manufacturer to guarantee specified performance. The voltage where the output from the regulator falls out of regulation is most commonly called the dropout voltage and will be somewhere between 1.5V and 2.2V for Standard regulators.

Low-Dropout (LDO) Regulator

The Low-dropout (LDO) voltage regulators differ from other regulators because they are only made up of a single PNP transistor as shown in *Figure 12*.

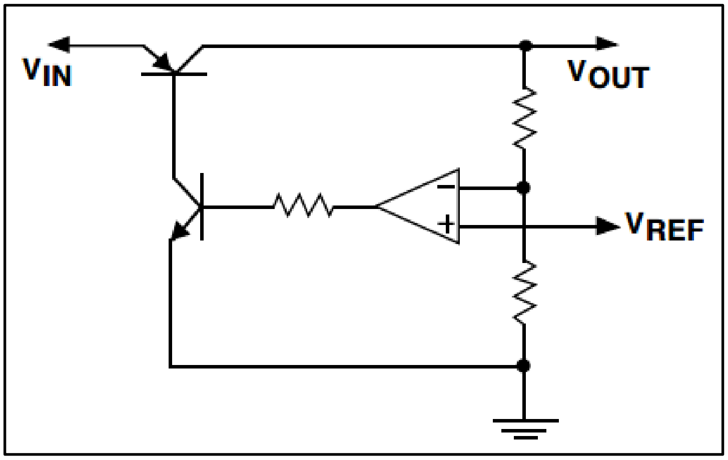


Figure 12: LDO Configuration

The most important characteristic for an LDO voltage regulator is its ability maintain regulation at low voltages, where the voltage required is just the voltage drop across the transistor and is usually around 0.7 to 0.8 at full current. LDO voltage regulators dominate the electronics markets which primarily operate on battery-power. This is because they maximize the available input voltage, resulting in much higher efficiency.

3.2.6.2 Switching Voltage Regulators

Linear voltage regulators provide solutions to low power applications where there is primarily a small budget and where the voltage difference between the input and output is low, but they aren't the common choice is higher power applications. This is because linear regulators aren't very efficient, with many regulators below 50% efficient, dissipating much of the power as heat. This is where switching voltage regulators are used, when applications require a wide range of input voltages and power efficiency needs to be 85% or above.

Types of Switching Voltage Regulators

The types of switching voltage regulators we will cover include buck (step down) and boost (step up), although many more exist with varying applications and topologies.

Buck Converter

A buck converter steps down a higher voltage to a lower voltage. It is a DC-to-DC power converter, stepping up the current, while in turn proving a lower output voltage necessary for the designer's specifications. A buck convert is a type of switch mode power supply. Switch mode power supplies usually contain at least two semiconductors, a diode and a transistor, and at least one energy storage element, a capacitor, inductor, or the two in combination. Capacitor filters are integrated into these switch mode power supplies in order to reduce the ripple voltage and are typically added to such a converter's output (load-side filter) and input (supply-side filter).

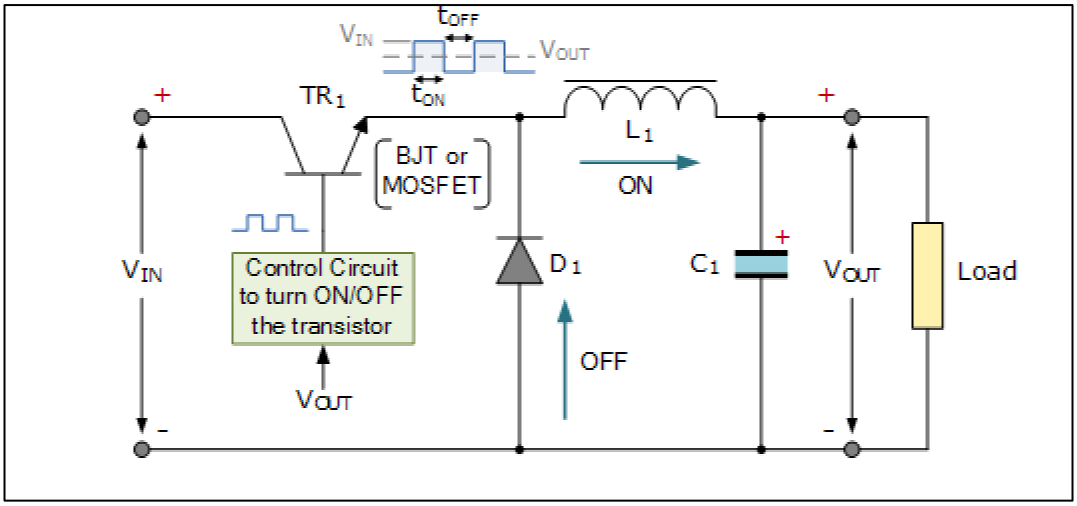


Figure 13: Basic Buck Converter (step down)

Switch mode power supplies, such as the buck converter, are much more efficient as DC-to-DC power converters versus a linear voltage regulator. Comparing, linear voltage regulators are less complex circuits that lower voltages by dissipating power as heat and do not provide a higher current output.

Buck converters can be remarkably efficient (often higher than 90%), making them useful for tasks such as converting a computer's main supply voltages of 12 volts or more, down to lower voltages needed by USB, DRAM, the CPU, which can be 1.8 volts or less depending on the application.

Boost Converter (step up)

A boost converter is another switch mode power supply which outputs a voltage greater than the input voltage. It is a DC-to-DC converter which also lowers the output current. Another name for this is the step-up converter as it is commonly called. We retain the conservation of energy, where the input power must be equal to the output power and we assume no losses in the circuit. This is achieved through the lowering of the output current because the output voltage is taken to a value above the input voltage.

The main functionality of a boost convert is that the internal inductor of the input circuit resists sudden variations in input current. The inductor stores magnetic energy when the input is OFF and discharges when the switch closes. The output circuit had a capacitor large enough to assume the RC time constant in the output stage is high. This results in a constant output voltage, as the large RC time constant is weighed verses the switching period.

3.2.7 MOSFETs

Metal-oxide-semiconductor field-effect transistors (MOSFET) are the building blocks of modern VLSI circuits with the areas of applications that include: microprocessors, dynamic memories, switching, regulating, and many more. We will cover two kinds of MOSFETs, the N channel MOSFET and the P channel MOSFET. While both are closely related, they have very different functions and characteristics.

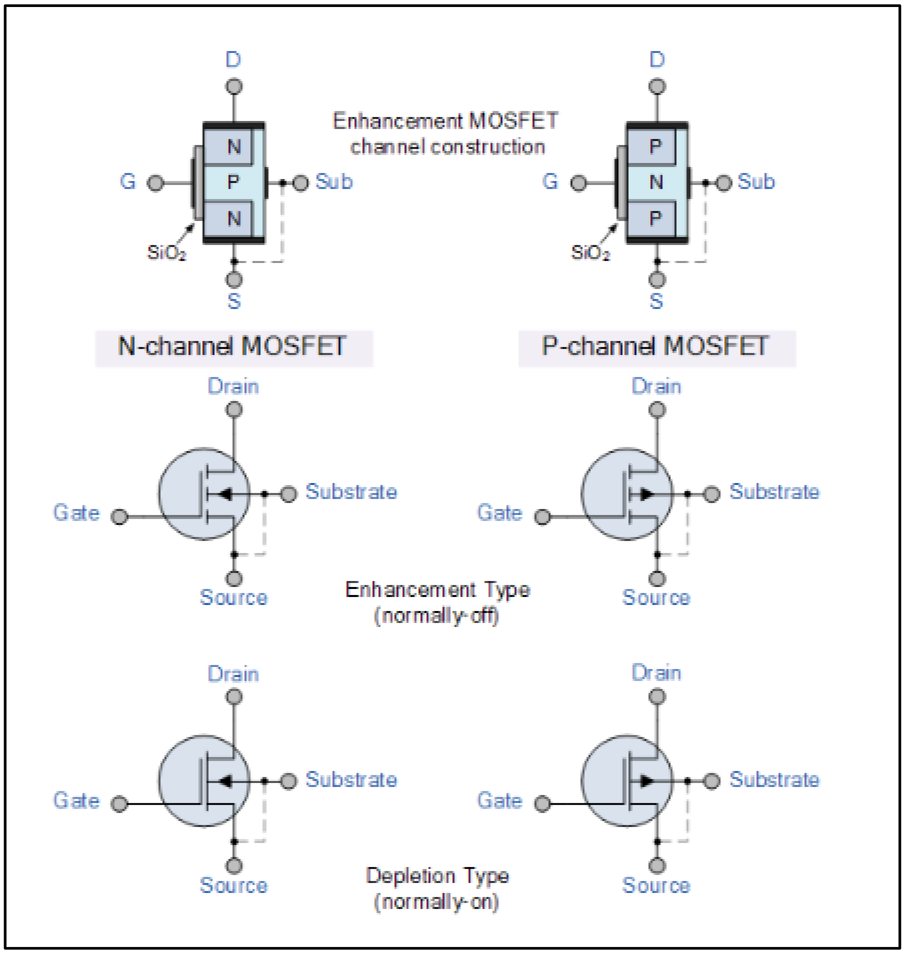


Figure 14: MOSFET Symbol Comparison

Figure 14 shows the basic construction and configurations of the N-channel and P-channel MOSFETs.

The Metal Oxide Semiconductor Field Effect Transistor, or MOSFET for short, has an extremely high input gate resistance with the current flowing through the channel between the source and drain being controlled by the gate voltage. Because of this high input impedance and gain, MOSFETs can be easily damaged by static electricity if not carefully protected or handled.

MOSFETs are ideal for use as electronic switches or as common-source amplifiers as their power consumption is very small. Typical applications for metal oxide semiconductor field effect transistors are in Microprocessors, Memories, Calculators and Logic CMOS Gates etc.

MOSFET Quiescent current: A MOSFET's quiescent current is the measure of the current that the MOSFET consumes when it is in standby mode, or seen as OFF in a switching application. This current consumption is usually very low, which is why MOSFETs are popular in many applications and their use is evident in every day technology.

MOSFET type	V_{GS} = +ve	V_{GS} = 0	V_{GS} = −ve
N-Channel Depletion	ON	ON	OFF
N-Channel Enhancement	ON	OFF	OFF
P-Channel Depletion	OFF	ON	ON
P-Channel Enhancement	OFF	OFF	ON

Figure 15: Switching characteristics

For the N-Channel MOSFET, a positive gate voltage will turn the transistor ON while a zero-gate voltage will put the transistor OFF. For a p-channel enhancement type MOSFET, a negative gate voltage will turn "ON" the transistor and with zero gate voltage, the transistor will be "OFF". The threshold voltage determines the voltage point at which the MOSFET will start the flow of current. The switching characteristics for each MOSFET determines their application specific nature. Both MOSFETs are commonly used in switching applications either together or separately. The N-Channel MOSFET is the more common in standard switching, while the P-Channel MOSFET is highly used in areas of power applications or high power control.

3.2.8 MOSFET Drivers

In applications that require the use of a microcontroller, many will find that the output pins can only drive so much voltage or current. This low voltage/current combination results in a scattering of logic, especially when dealing with transistor to transistor logic(TTL), where the high side voltage onto the base is more than what a microcontroller can source. Because of this, drivers are needed. Drivers are chips that "drive" the output of the microcontroller, or any output generally speaking, with the goal of producing a higher output, compatible to the needs of a user or application. For MOSFET drivers, the typical use is to drive a high enough voltage onto the gate, turning the MOSFET on or off. This is especially important when dealing with switching speeds that need to be very fast. Applications include: switch mode power supplies, motor controls, pulse transformer drivers, switching amplifiers, pulse generators and more.

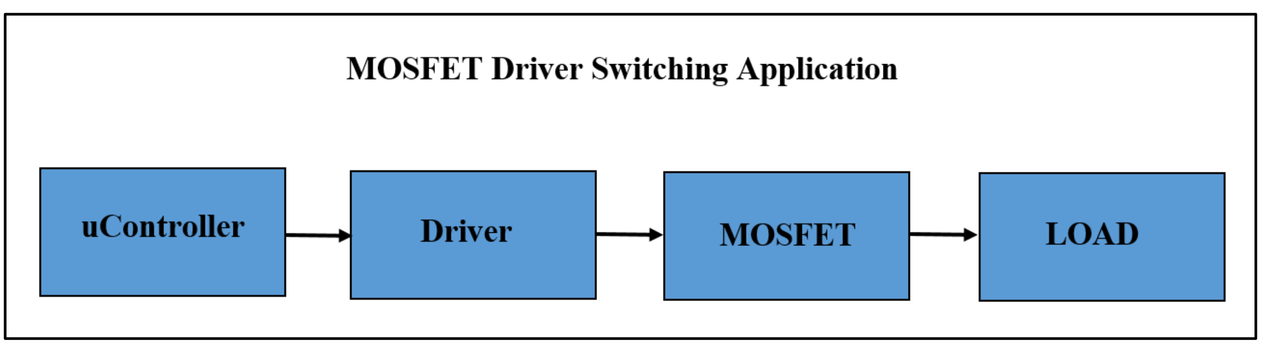


Figure 16: MOSFET Driver Switching Application

Figure 16 shows the general layout and use of a MOSFET driver used to drive the output from a microcontroller. This specific application is switching for some type of load from the MOSFET, although the general use is the same.

3.3 Strategic Components and Part Selections

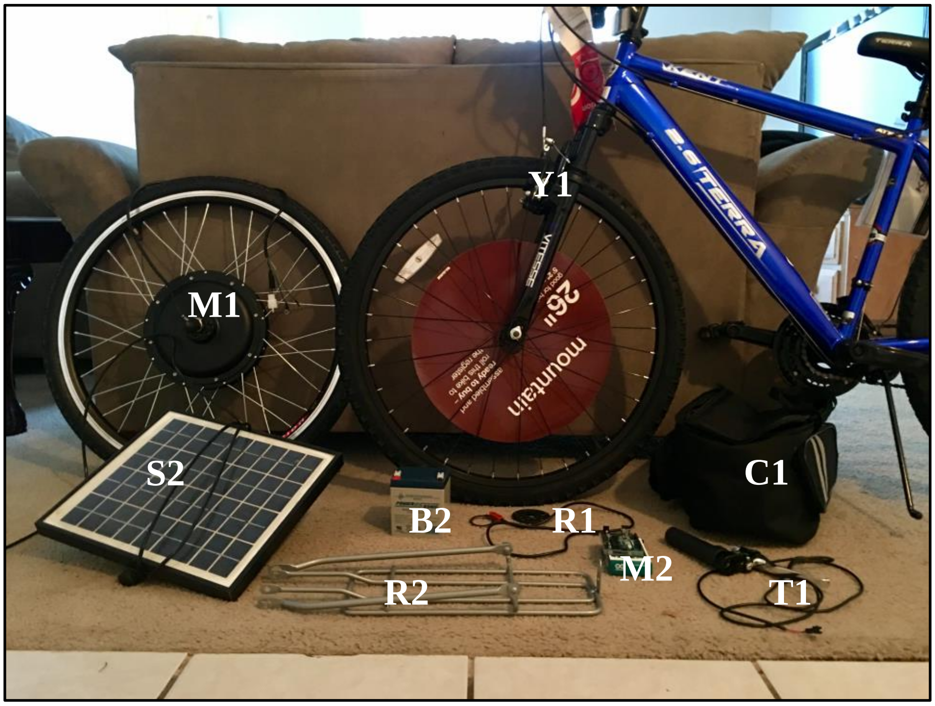


Figure 17.1: System Parts Collection

Table 2: Parts List

Reference	Part Name
M1	Aosom 26” Rear Wheel 48V 1000W Electric Battery Powered Bicycle Motor
S2	Gates That Open, LLC Solar Panel (10W)
Y1	Kent Terra 2.6 - 26” Mountain Bike
B2	UPG UB1250 Sealed Lead Acid Battery (12V)
R1	Magnetic 5 Spoke Reed Sensor
M2	ATmega328 (Arduino Uno)
R2	Rear mounting bar
C1	Rear Circuitry Case
T1	Throttle

3.3.1 Motor

When selecting the motor for this project, we set out some parameters to help us choose. These parameters include power output, size, weight, orientation, and cost. We wanted to find a motor that had power behind it so we determined that we needed a motor that would output roughly 24-

48V, 500-1000W. Ideally, we would like to have a motor that can be operational just off of 24V to help with reducing the amount of batteries powering the motor which leads to less weight on the bike. The size of the motor was the least important parameter since most motors were relatively small when compared to the bike. Weight of the motor was high priority parameter since the weight of the motor contributes greatly to the weight of the bike. Depending on orientation, the weight of the motor could through the bike off balance in normal operation if the motor was on the heavier side. Knowing this, we set the motor weight limit to no more than 30lb. The orientation of the motor was a tremendous consideration when researching motors. There are two different types of orientations that we had to choose from, the first being a side-mounted motor, which has the motor mounted to the side of the wheel for ease of removal, and the wheel mounted motor, which has the motor built into the wheel of the bike. We strived to find a motor that was wheel-mounted since there would be more stability in operation for a more enjoyable ride for the user. The cost played a subtle role in our decision since most motors were vastly varied in price like how side-mounted motors are typically cheaper than wheel-mounted motors and that motors that have a high-power output tend to be more expensive. So we put our budget range from $90 - $300 as a rough estimate. We also kept in mind of the budget given to us since we knew that the motor would most likely be the most expensive part of the project. Knowing all these parameters that were set, we came down to 3 different motor contenders that met most of the parameters that we set to strive for.

Aosom 26” Rear Wheel 48V 1000W Electric Battery Powered Bicycle Motor

This motor is at the threshold for the power output that we wanted. The weight of this motor is roughly around 28.7 lb. which falls within the chosen weight range. This motor is a wheel mounted brushless hub motor that has a wheel radius of 26” which is the preferred choice in motor selection. The max speed is advertised as 28 mph, which would also meet our requirement specification of at least 20mph. The cost of the motor is $239.95 off Amazon which is below our $300 limit. Overall this is a perfect candidate for our project. This is motor we ended up selecting for this project since our sponsor wants the best quality that meets our parameters.

24V 350W MY1016Z3 Electrical Motorized E-Biker Bicycle Motor

This motor is a single phase permanent magnet DC Brush motor that has a sufficient voltage of 24V, a rate power consumption of 350W, and a rated current of 18.7A. Thus, the specifications for this motor rated the maximum speed to be between 15 and 18 miles per hour, falling within our requirement specification of at least 12 miles per hour. The rated load RPM for this motor is 3000 which is decent since its no load RPM is 3850 giving it a 78% efficiency rating. The weight of this motor was the lightest, weighing in at 11.02 pounds (US) which easily fell within our weight parameter. This motor is a side-mounted motor which was not preferred but since it had light weight, we figured that stability within operation could still be achieved. Since it is a side-mounted, this motor will be directly connected to the chain of the rear wheel instead of having to replace the rear wheel, like how a wheel-mounted motor would require. The cost of this motor was the cheapest of our options with a price tag of $94.99. This price is on the lower spectrum for bicycle motors, making it perfect for budget conscience projects.

3.3.2 Microcontroller

The role of the microcontroller is split into two major tasks. to measure the time the wheel takes to rotate one full rotation, through the use of a magnetic reed sensor, and convert that into a speed measured in the units miles per hour (MPH). This speed would then be output onto an LCD. In our choice for a microcontroller, we kept this task in mind of what processor would be the best choice for this project. Another though considered would be the language that the processor would understand, and that we would strive for a language that is familiar to our programmer.

In addition, the MCU will be taking in throttle input that will be used to edit the produced a high frequency PWM signal for motor control. We would need a MCU with a high processing speed that is capable of producing such a signal. We also would want to find a microcontroller that is powerful enough to take on the task while keeping the cost within reason.

ATMEL ATmega328

The two microcontrollers we considered as candidates for this project are the Atmel ATmega328 and the Texas Instruments MSP430G2x53 series. The ATmega328 is a typical and popular choice in microcontroller for most projects since they are, for the most part, user friendly. The positives about the Arduino is that there’s not a heavy setup for the processor, code-wise, and that taking analog inputs is much easier to program than most other boards. The ATmega328 runs on a processing speed of 16MHz and has an operating voltage of 5V which is a low voltage that the solar panel can supply. The ATmega328 also has a more understandable logic when interfacing with an LCD screen for UI output. The cost of the ATmega328 doesn’t dig deep into our budget since most websites sell it for a low cost of just $16. The negative to the Arduino is that for the programmer, the language is not as familiar compared to the language taught on the MSP430, which will have to be an obstacle to overcome with more experience. On a side note, we considered getting a starter kit for the Arduino to have access to other sensors and take advantage of the included LCD that we would need. We decided against this since we felt that it would be a waste of finances to our sponsor. In the end, we chose the Arduino UNO as our microcontroller of choice.

MSP430G2553

The other choice for a microcontroller is the MSP430G2553. This is a familiar microcontroller that we have used in the classes. The positives for this processor is that it has a familiar language that our programmer knows well, low costing (roughly $10), runs at 16MHz with 16 kB of flash, a 5V input. The negatives for this board are that it requires more coding to properly use an LCD, take in analog inputs, and for the initial setup than the Arduino, and also that the IDE for the MSP430G2553 is not supported for Mac or Linux environments.

Broadcom BCM2837 SoC

The third MCU in consideration would be the Broadcom BCM2837 SoC. This MCU is typically used in various types of projects in communities from education, home automation, and in commercial products from digital media players, vending machines, and wireless transceivers. This MCU is typically on the Raspberry Pi 3 boards, which is used in such projects.

The BCM2837 is an ARM Cortex-A53 processor that has a processing speed of 1.2GHz. The architecture of this MCU is a quad-core 64-bit with 512 KB L2 Cache memory. This chip does have PWM support through the use of pwmWrite(,) function and analog input for control. These specs for this project are a way over necessity and too powerful for what is needed.

Below is a table comparing the specifications of each microcontroller.

Table 3: MCU Comparison

Feature	ATmega328	MSP430G2553	BCM2837
Operating Voltage	1.8 – 5.5V	1.8 – 3.6V	2.5 – 6.0V
Temperature Range	-40°C to 85°C	-40°C to 85°C	-25°C to 80°C
Max Clock Frequency	20 MHz	16 MHz	1.2 GHz
Memory	32 KB Flash, 1 KB EEPROM, 2 KB SRAM	16 KB Flash, 0.5 SRAM	512 KB L2 Cache
Analog I/O	Input Only	Both	Both
Digital I/O	Both	Both	Both
GPIO Pin Count	20	24	40
Bit count	8-bit	16-bit	64-bit
Low Power	Yes	Yes	Yes
Power Consumption	Active Mode: 200µA@1MHz Off Mode: 0.1µA	Active Mode: 330µA@1MHz Off Mode: 0.1µA	Active Mode: 3500mW minimum
Board Price	$16.06	$19.83	$35.99

Analyzing this table, are needs for this project are met with using the ATmega328. The main reason is that the MSP430 and the BCM2837 have too many features that are just extra and unnecessary for the design of the project. One instance is that the design will not be sending any analog outputs to any part of the board and therefore having both analog I/Os would be nice, it would not be utilized in this design. Another reason is that the ATmega328, by comparison, is a more powerful than its competitor with a 20 MHz processing speed. We also kept in mind that the design of power system that will be supplying the MCU will be a 12V battery, and keeping that in mind we would want a MCU that can be operated at higher supply voltages so that power waste is at a minimum. Overall each MCU could get the task completed, but ultimately chose the ATmega328 in our design.

3.3.3 Magnetic Reed Sensor

A magnetic reed sensor will be used as a sensor to send a signal to the microcontroller for speed measurement. The way that the reed will work is that the positive terminal will be connected to the supply voltage of the microcontroller (this supply voltage can be output from the Vcc pin on the Arduino board or directly from the battery). The output terminal will be connected to the analog INPUT pin on the Arduino board. When the magnets connected that are connected to the axle of the wheel hover over the magnetic reed, the magnetic switch in the relay will close and allow the INPUT and Vcc to connect to read in a HI signal. This signal will be used by the Arduino to calculate the speed of the bike. The last terminal of the reed is the ground pin which be connected to ground. There will be 5 magnets on the magnet hover disk that will close the reed. This means that the reed will close 5 times within 1 full wheel rotation.

The magnetic reed that we will be using for the bike will be the one provided with the Aosom 26”Rear Wheel 1000W Electric Battery Powered Bicycle Motor. Using this reed compared to others would save us money as time since this reed also has a metal loop attached for easy installation on the wheel axle.

3.3.4 Throttle

Table 4: Throttle Selection Comparison

Part #	GB-53140/66-XXF-9000	THR-38	AS019
Manufacturer	Bikeberry	Electricscooterparts	Wuxing
Size	22mm	22mm	22mm
Voltage Rating	12-48V	36V	48V
Type	Throttle Grip	Thumb	Thumb
Cable Length (inches)	49	60	78.74
Interface	3 pin JST	3 pin	6pin
Cost	$19.95	$19.95	$14.95

Size: The size for the throttle needed to fit our chosen bicycle. We opted to consider only throttles with a diameter size of 22mm, as this fit our bicycle handle bar properly.

Voltage Rating: The voltage rating for the throttle defines the designed input voltage from the battery. From the above table, we can see that we have varying voltages. This is because we considered multiple options before deciding that we needed to run the motor off of a 48V battery in order to get the performance we desired.

Type: There are many types of throttles, as covered in the relevant technologies section of this report. We considered the throttle grip, and two thumb throttles as they were common types for throttles and were similar in other areas of consideration.

Cable Length: This factor was very important in consideration of the throttle because our design calls for the control box and/or battery to be rested behind the user, above the rear tire. This means we needed a long cable for the throttle to reach the handle bars. For

Interface: The interface for the throttle defines the amount of pins, inputs and outputs, and any additional features restricted to the throttle, such as an on/off switch. We found that the AS019 has an on/off switch resulting in more pins on the interface, while the other two had standard 3 pin interface with voltage in, ground, and voltage out.

Cost: The cost for the throttle was very important. We wanted to stay with a low budget throttle that would still allow for a rigid mechanical functionality, imploring isolation from outside disturbances.

It is important to note that these three considerations for throttles were all Hall Effect sensor throttles. Please refer to section 3.1.3. We chose to go with a Hall Effect sensor integrated throttle because it has a more robust design, isolated from weather hazards, vibration, and dust, and had the output voltage characteristic we needed to work with the microcontroller's duty cycle varying code. The AS019 from Wuxing met all our specification goals with the lowest price point of all considered throttles. The AS019 was the throttle we ultimately chose and integrated in our purchase of the motor and speed sensor.

3.3.5 MOSFETs

This section will cover the various MOSFETs we considered for our projects, including different applications within separate subsystems.

3.3.5.1 Pulse Width Modulation Control

In order to drive the motor from the pulse width modulation produced by the microcontroller, we needed high power MOSFETs that could source a lot of current while having a high input drain to source voltage, commonly called Vdss since our main battery will be 48+volts. Below is a comparison of three different types of MOSFETs we considered, their strengths and weaknesses and optimal parts selection basing.

Table 5: MOSFET Key Parameter Comparison

	Part #		
	2N7000	**HY1707**	**IRFP4468**
Max Voltage	60V	70V	100V
Max Current(continuous)	200mA	80V	290A
Rds(on)-typical	5ohm	6mohm	2mohm
Manufacturer	Fairchild	Hooyi	International Rectifiers
Package options	TO-92	TO-220FB-3L TO-220FB-3S TO-262-3L TO-220MF-3L TO-3PS-3L TO-3PS-3M	TO-247AC
Gate leakage current	10nA	100nA	100nA
Max power dissipation (25 C)	350mW	178 W	520 Watts
Single Price (digi-key)	0.38000	7.21	7.33

Maximum Voltage: Dealing with voltages of up to 50V, we needed a device that could handle that voltage and more, for safety reasons.

Maximum continuous current: These MOSFETS are used to source the switching/PWM from the microcontroller to the motor. As a result, they need to be able to source a large amount of current because the motor is acting as a load, pulling the current it needs to drive the bicycle forward from the main power source, the 48V battery.

Rds(on): This parameter is important when choosing any field effect transistor. It describes the resistance between the drain and the source when the MOSFET is seen as ON. It is important because a high Rds(on) results in power lost, and heat dissipated.

Manufacturer: Looking into providers for components, it’s very important that we consider companies that have a proven track record for success. Great components come from great sources and proper research into a company can tell a lot about the quality of their devices.

Package Options: This parameter wasn’t as important as others, as we have some flexibility. Of course we would like to keep our PCB as small as possible, but these power components have very similar package sizes.

Gate leakage current: This parameter describes the amount of voltage that leaks from the channel to the gate. We wanted a very low gate leakage current in order to improve standby power efficiency. Effectively, while the bike is not using its motor, but still on and in standby, the power lost from the battery because of the leakage results in a shorter battery life and inefficient energy use.

Max power dissipation (25 C): This is the maximum allowable power dissipation that will raise the die temperature to the maximum allowable when the case temperature is held at 25 degrees Celsius. Because we are dealing with high voltage batteries, we wanted the power dissipation to be well above what we expect and need for safety and efficiency reasons.

We ultimately selected the IRFP4468 because it gave us a max voltage handling more than twice what was needed. This is strictly for safety and reliability concerns. The current sourcing capabilities were also the best out of the MOSFETs we considered, while the same can be said for the power dissipation. The price was justified through research, finding that many high power MOSFETs require spending a little more for efficiency and application specific use.

3.3.6 LCD

Table 6: LCD Key Parameter Comparison

	Part #		
	A13071200ux0781	**RRLCD204WB**	**27977**
Manufacturer	uxcell	RioRand	Parallax
Construction	16x2	20x4	16x2
Backlit	YES	YES	YES
Dimensions(inches)	3.7 x 1.2 x 2.4	0.6 x 0.3 x 0.3	1.42 x 3.15
Current Draw(typical)	50mA	60mA	80mA
Power(VDD)	5V	5V	5V
Interface	I2C	I2C	I2C
Cost	$6.56	$10.99	$21.95

When selecting an LCD that would pair with our microcontroller, there were various parameters that we felt were very import. These include:

Manufacturer: We wanted a brand that was well known for quality and performance, as well as having a proven track record for successful hardware.

Construction: The construction of the LCD provides us with the number of lines the LCD can hold and the number of characters in each line. 16x2 can hold 2 lines with each line holding a maximum of 16 characters. We wanted enough characters to fully display speed, time, and other user friendly messages. Because this is breadboarding and prototyping phase, we didn’t want something that would be too costly, as we may change selections to meet our needs more readily in the future.

Current draw: This is the most important characteristic we looked for when comparing LCDs. This is because we wanted a very low current draw from the LCD, both in standy, backlight on and backlight off. We need to conserve as much of the battery as possible. Opting for a low current LCD will make long battery life more possible, allocating power more efficiently to other sources.

Power(VDD): When selecting an LCD, we needed one that could run off of 5V, to keep the power used to a minimum and also to keep the design compact. Since we are already regulating voltage down to 5V, we needed to make sure any LCD we chose could run off of 5V.

Interface: The interface for LCD to microcontroller needed to compatible with the ATmega328.

Cost: This was an important factor to consider, mainly because we are in the breadboarding and development stage. We didn't need an LCD that was fancy, or had so many characters because we first wanted to make sure we could interface with the microcontroller properly.

Considering all these important parameters and constraints, we ultimately decided to go with the A13071200ux0781 16x2 LCD by UxCell. This is a budget LCD, perfect for breadboarding and testing development specifications. It also had a very low current draw, enabling us to save as much power as possible, while still providing the user with a backlit display.

3.3.7 Solar Panels

These are the solar panel modules we considered. These solar panels are comprised of many individual solar cells linked together for a greater output power.

Table 7: Key Solar Panel Parameter Comparison

Part #	**RB510**	**RB507**	**SP25W12V**	**HY025-12PS**
Manufacturer	Gates That Open	Gates That Open	Aleko	ACOPOWER
Power Rating(Watt)	5	10	25	25
Dimensions(inches)	23 x 12 x 2.3	15 x 11.6 x 3.9	22 x 15 x 3	14.6 x 14.2 x 0.7
Weight(lbs.)	5.5	4.9	6	5.8
Power Max Current(A)	0.22	0.57	1.35	1.43

Power Rating: This describes the power output and rating for the solar panel. We need a power rating of at least 10W to charge our secondary 12V battery. We considered a wide variety of different power ratings. This is because you sacrifice size when to get more power.

Dimensions: These dimensions characterize the power performance you sacrifice when getting a smaller size. We considered these options because they had the best size versus power output ratio.

Weight: To meet our requirement specification, we had to consider low weight solar cell modules. This is to keep the bike as light weight as possible, allowing for better performance and speed.

Power Max Current: This is the maximum current output the solar without a load. This is important when considering picking a solar cell module because we need a minimum recommended output current in order to charge our secondary 12V battery.

Because we already had RB510 and RB507, we chose to use these solar panels in order to reduce the cost of breadboarding and prototyping. These solar panels can be linked in series, giving a greater power output and increasing the spectrum of their application.

3.3.8 MOSFET Driver

The MOSFET driver is the component that takes the PWM signal from the microcontroller and "drives" it to the gate of our MOSFETs which will handle the switching of the PWM signal.

Table 8: MOSFET Driver Comparison

Part #	MIC4451	MCP1401
Manufacturer	MICREL	Microchip
Operating Voltage	4.5-18V	4.5-18V
Output Current(Max)	12A	500mA
Packages	8pin DIP 8pin SOIC 5pin TO-220	SOT23
Delay Time	30ns	35ns
Cost	$2.06	$0.62

From table 7, we see that the two MOSFET drivers considered had comparable aspects. The important aspects to consider are output current maximum, which tells us how much these components can source. Since we are dealing with a high power motor, we wanted something that could source a lot of current. We considered the MCP1401 because for breadboarding the cost was very efficient. The MIC4451 gives us more package options, which may become crucial when finalizing our PCB layout, decreasing the size and overall cost. Since we are using the driver for switching the PWM output from the microcontroller, the delay time was a very important factor, with the MIC4451 giving a better delay time.

We chose the MIC4451 for our design mainly because of its great current sourcing capabilities and the different package options. We needed to go with something more robust, even for the earlier testing cycles to ensure that we were getting the performance we needed and wanted. The MIC4451 will allow us to work with freedom and safety of knowing that we are within the limits of the device.

3.4 Possible Designs and Related Diagrams

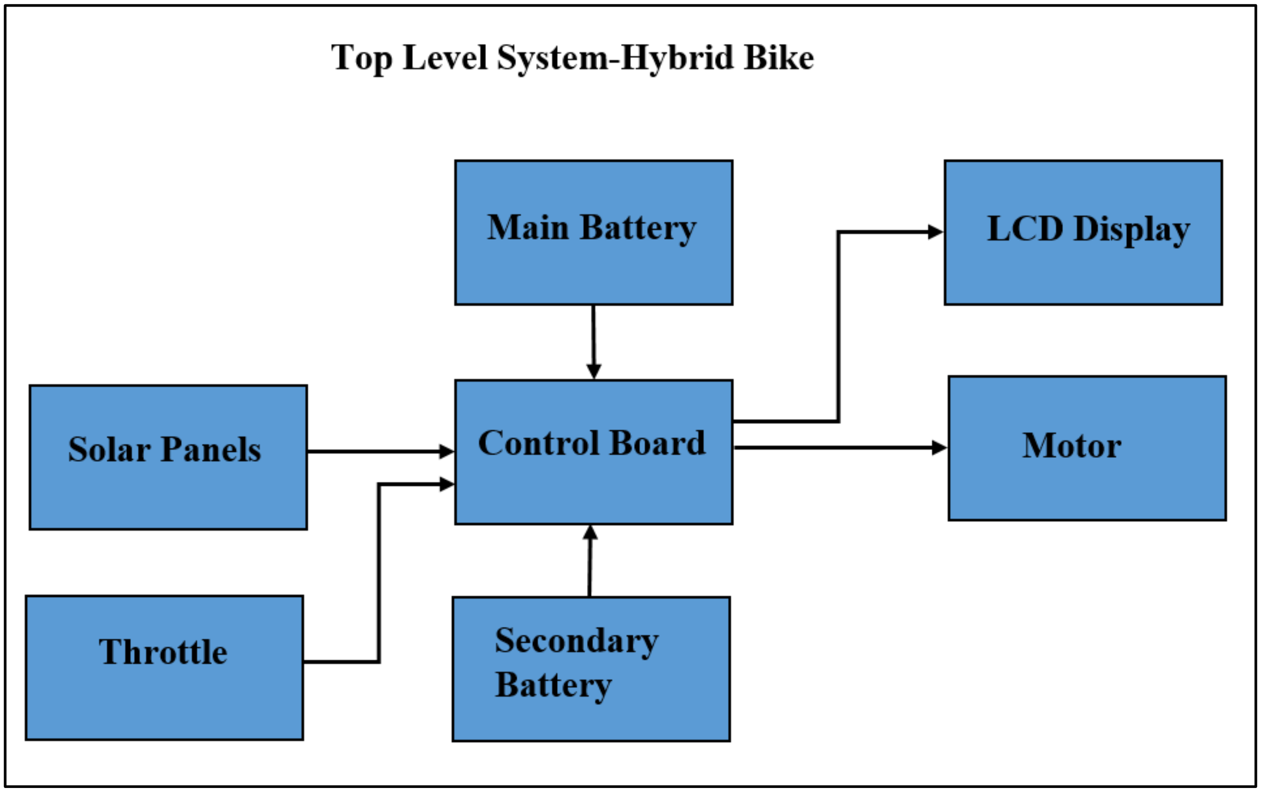


Figure 18.2: Top Level System

A possible design for the Solar Bike makes use of two separate power systems. One high capacity battery to power the bike motor and one to power the bicycle display and accessories. The solar panels mounted onto the bike will be used to charge the smaller capacity battery. The throttle for the motor will be designed using a magnet which is moved closer or farther from the sensor to increase or decrease speed, respectively. This is commonly called a hall effect sensor and is used in a lot of throttle designs for various applications.

The motor in this bike is powered by a high voltage Pulse Width Modulator (PWM) in order to run. This calls for the design of a PWM that can output high voltage amplitudes. One design that we have considered is having the microcontroller generate a PWM that can have a duty cycle that can be controlled through additional input. This signal will then be amplified through the amplifying circuit that would connect to the motor inputs. The generation of the PWM in the Arduino will be fully programmable which would lead to less error in the signal. For the amplifying circuit, we would use a series of operational amplifiers that are rated for supplies voltages higher than +50V, since the negative rail will be adjusted to 0V or GND since there is no negative values in the signal that needs to be generated. These outputs will then be connected accordingly to the corresponding motor terminals.

The other design considered would be designing an analog PWM that would be attuned to high voltage amplification. This would implement the use of a 555 Timer to create a pulse

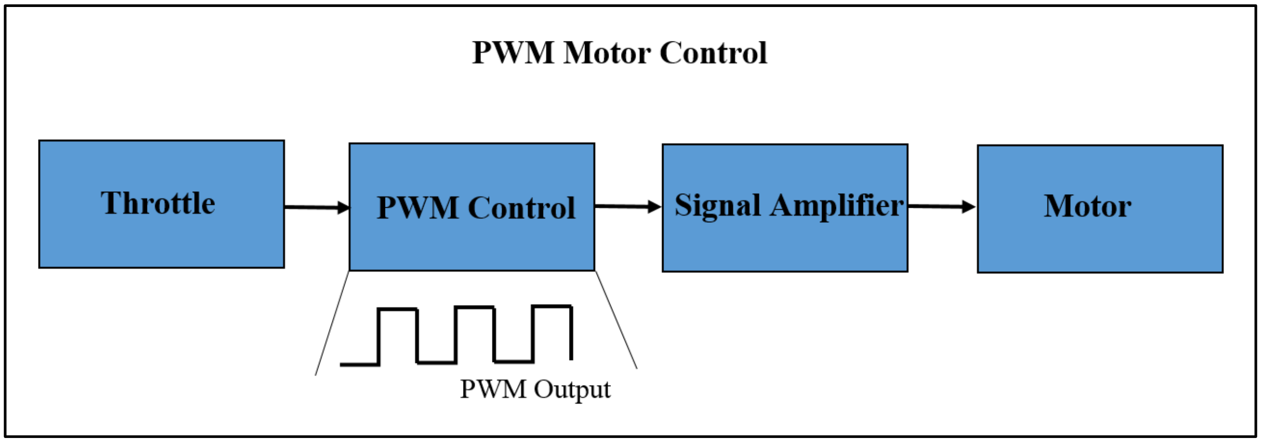


Figure 19: PWM Motor Control

3.5 Parts Selection Overview

Table 7 below, gives an overview of all major parts selected for our application. More details can be found within their respective strategic parts selection subsection located in 3.3.

Table 9.1: Parts Selection Overview

Item	Part #	Manufacturer	Cost (USD)
Motor	B00GIXZKP8 B4-0076	Aosom	$239*
Microcontroller	ATmega328	Atmel	$3.28
Reed Sensor	*	*	*Included cost
Throttle	AS019	Wuxing	*Included cost
MOSFET Driver	MIC4468		
MOSFETs (PWM)	IRFP4468	International Rectifiers	$7.33
LCD	A13071200ux0781	UxCell	$6.66
Solar Panel Modules	RB510(5W) RB507(10W)	Gates That Open	-

4. Related Standards and Realistic Design Constraints

This section discusses standards which are applicable to our Solar Bike design, as well as realistic design constraints of the project.

4.1 Related Standards

Standards are one of the most important parts of any design. There are many different standards relating to our Solar Bike design. These standards will be gathered from IEEE Standards Association. There are many other organizations which provide standards, which includes the *NSSN: A National Resource for Global Standards.* The American National Standards Institute (ANSI), "a private non-profit organization whose mission is to enhance U.S. global competitiveness and the American quality of life by promoting, facilitating, and safeguarding the integrity of the voluntary standardization and conformity assessment system," administers the NSSN [C1]. Certain standards provide a set of requirements which aid in the compatibility of one system to another. An example of this is the micro USB charger. The micro USB charger can be used in charging a variety of different phone types as well as many other electronics. The use of this standard for the micro USB enables a single cord to charge or power a wide range of different devices.

Another consideration to standards which are related to the design of the Solar Bike is IPC standards. IPC is an organization which develops standards and is referred to as an "Association Connecting Electronic Industries" [C5]. IPC is accredited by the American National Standards Institute (ANSI) and is known around the world. They are known for their most widely accepted standards in the electronics industry. IPC provides industry standards on assembly, design, printed circuit boards, and many others. Each of the previously mentioned standards IPC provides are split up into different sections, covering nearly all aspects of the electronics industry. While many of the standards provided will not directly apply to our design, they will apply to the manufacturer of components included in our design. Without standards in place for the manufacturer, components needed for this design may not be available or may not function as they are supposed to. Therefore, these standards, while not directly related to our design, are critical standards associated with our Solar Bike design.

A joint technical committee operated by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC), make up the ISO/IEC Information Centre [C9]. The committee provides information about standardization, standards and related matter to its stakeholders [C9].

Committees and organizations, described above, which are responsible for the creation of the standards related to the Solar Bike's design, included in the following subsections, make up only a small fraction of all the organizations dedicated to providing standards. Standards can be accepted internationally, nationally, or even on a company level, which is why there are so many different organizations dedicated to the creation of different standards.

4.1.1 Battery Standard

IEEE Std 1013™-2007 is a standard which explains the "IEEE recommended practice for sizing lead-acid batteries for stand-alone photovoltaic (PV) systems" [C2]. In use of this standard, knowledge of the different types of lead-acid batteries as well as which to choose for safety and efficiency will be acquired. It is first stated that there are two different types of lead-acid batteries, vented and valve-regulated, both of which sizing will be explained. The term stand-alone photovoltaic (PV) system is referring to a solar power device such as a solar panel which by itself produces an output voltage and current. The standard explains that the use of a battery in this system is required for the case where the system load exceeds the output of the solar panel, or PV array. As well as for this reason, the battery will serve a role in our design for the times when the user is riding the bike at night or on a shaded day when the solar panel is not producing enough power to turn on the accessories.

The battery being used when the panel is not outputting power is named in the *Autonomy* clause in the standard. This clause describes it as “the length of time that the stand-alone PV system’s load should be supported solely its fully charged battery, [which] is established by the system design requirements” [C2]. There are several different factors included in this section which are to be considered. These factors include: system application, system availability, solar irradiance variability, predictability of load, recharge capability, and accessibility of site.

As well as the length of time that the system will be running solely from battery power, it is also required to know the load that the battery will have to support during that period. The load that the battery will have to support is essentially referring to the dc load current that will be drawn from the battery for the amount of time determined in the previous consideration. The maximum daily load is used to compare to different battery sizes in order to ensure that the battery can sustain these loads. Starting current, that is when the system is first turned on, as well as its running current should be considered. Parasitic currents losses resulting from inverters or charge controllers should also be considered. As well as the current, the minimum and maximum voltage required for proper operation of the system should be considered.

The results of the load calculations gathered will assist in determination of battery capacity and functional-hour rate. “Battery manufacturers rate lead-acid cells for maximum depth of discharge (MDOD), maximum daily depth of discharge (MDDOD), and end-of-life (EOL) capacity” [C2]. The greatest of these three capacities will satisfy the adjustments required for the group. Another factor to keep in mind is the temperature at which the system will be operating. The “cell capacity ratings are generally standardized at 25 °C”, which means that for temperatures other than the standardized, the capacity will vary. An increase in temperature results in an increase in capacity and a decrease results in a smaller capacity.

Therefore, the steps designed in this standard allow for the efficient and safe sizing of a lead-acid battery in a stand-alone PV system. A summary of the steps include first understanding how often and how long the battery will be used solely for powering the load. Next is to understand how much current that is to be supplied by the battery over a certain period of time, which determines battery capacity and discharge rate. After, the number of series connected cells is to be determined, which is set by the system’s voltage limits. Once all of these factors have been taken into account it is then that the battery should be chosen.

4.1.2 Design Impact of Battery Standard

The battery is the basis to the Solar Bike design in each of the subsystems. Without the battery attached to the motor, the motor would not run. If the solar system lacks a battery, the system would only function during well-lit days. For these reasons it can be said that the battery is the base to each of the subsystems. With that being said, the need for a well matched battery in each of the subsystems is of great concern. Matching the batteries correctly results in greater efficiency of each of the systems. The battery standard introduced above is applied to the solar subsystem, but can also provide some insight on the determination of the battery needed for the motor.

For the Solar Bike design, the valve-regulated lead-acid battery will be used. The vented lead-acid battery requires water levels to be replenished, which introduces an extra maintenance step that the consumer may not desire. The valve-regulated lead-acid battery does not need water levels to be replenished due to the fact that it is sealed and water is only released in extreme overcharge cases. The risk of water loss in the solar system battery should not be of concern due to the charge regulator that will protect against overcharging the battery.

4.1.3 Standard SystemC® Language Reference Manual Standard

IEEE Std 1666™-2011 is a standard which defines SystemC®. The standard describes "SystemC [as] an ANSI standard C++ class library for system and hardware design for use by designers and architects who need to address complex systems that are a hybrid between hardware and software" [C3]. Through the use of this standard, the SystemC® implementation can be achieved, without the need of further reference of any other source. The importance of this standard is that many traditional HDL (hardware descriptive languages) are not capable of achieving the same results as of those obtained through the use of SystemC®. In the Solar Bike design that is being created, this standard will be very helpful in the software section of this report. The Arduino will be programmed using C/C++ programming languages, which directly relates to the C++ class library included in this standard.

4.1.4 Design Impact of Standard SystemC® Language Reference Manual Standard

The use of this standard will allow for more advance code to be written in the case that a complex system, which incorporates any of the contents of this standard, is used. The impacts on our design related to this standard will in no way limit design software. The standard will, instead, allow for expansion of code and introduce possibilities to include complex systems in our design. Possibilities that, otherwise may not be obtainable without the use of SystemC® language.

4.1.5 Software and Systems Engineering – Software Testing Standard

The standard, ISO/IEC/IEEE 29119, is a combination of software testing standards. The use of this standard is designed to "define an internationally-agreed set of standards for software testing that can be used by any organization when performing any form of software testing" [C6]. The contents of this standard are used as an aid to ensure proper testing processes, techniques and documentation of software. Direct reference to this standard will allow for software development that not only meets this industry standard, but also is properly tested to ensure functionality.

There are currently four different parts included in this standard, which work being done to include a fifth part in the future. The second and fourth part of this standard will be explained and related to the software portion of the Solar Bike's design.

Part 2: Test Process

ISO/IEC/IEEE 29119-2 is a section of the standard which "specifies test processes that can be used to govern, manage and implement software testing" [C6]. The test process is split up into three separate groups, organizational test process, test management processes, and dynamic test processes.

The organizational test process section is made up of procedures for the creation, maintenance and review of the organizational test specifications. In terms of this project, the organizational test process refers to the three group members as the organization, since the project performed is a group based project, and not included in an actual organization.

Test management process is broken up into three separate processes, test planning, test monitoring and control, and finally, test completion. There may be several different test plans, such as a reliability test plan, system test plan, and acceptance test plan. These test plans may be tested separately or combined into one overall test, the following procedure will remain unchanged regardless of the decision regarding test plans. After a test plan is established and testing begins, test monitoring and control will allow for any unplanned results that may arise to be addressed, and used to alter the original test plan. The test plan should meet organizational test process guidelines and be evaluated to ensure all criteria is met. Once the test plan is altered as to account for all unplanned results, the group may move to the test completion process.

Incorporated into the test completion process is the dynamic test process, which includes test processes related to test design and implementation, test environment set-up and maintenance, test execution, and test incident reporting. The role of this process is to ensure that the test completion process is performed correctly and all contributing members are aware of testing results with respect to the set guidelines of the process and final result.

A summary of the three test processes included in standard ISO/IEC/IEEE 29119-2 and the relationships between them are included in *Figure 19*, below. *Figure 19* is contained in the standard and is copied here to display the overall guidelines to this section of the standard.

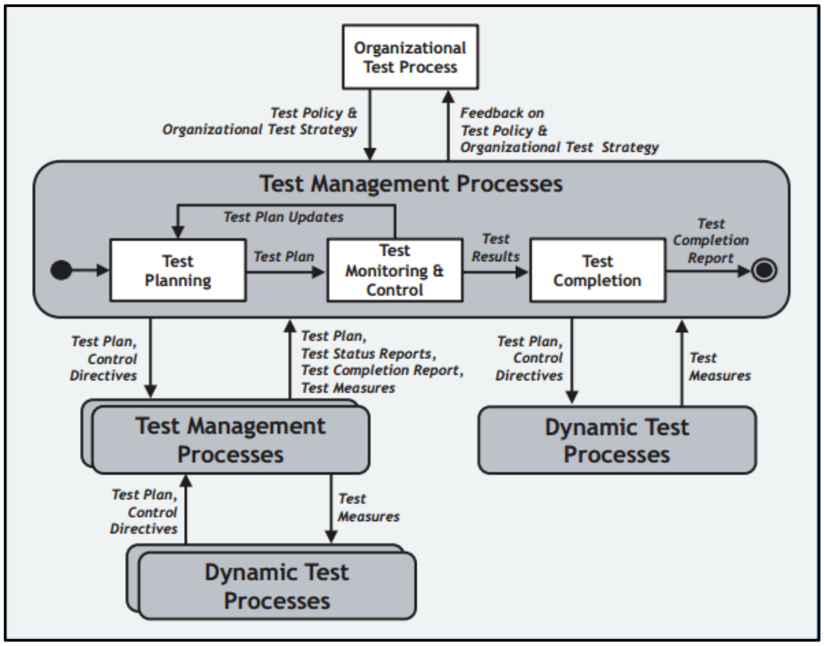


Figure 20: Overview of relationship between various test processes

Part 4: Test Techniques

ISO/IEC/IEEE 29119-4 is a section of the standard which "defines test design techniques that can be used during the test design and implementation process that is defined in" Part 2: Test Process [C7]. This section of the standard provides test design techniques for three separate classes of testing. These techniques are applied to specification-based testing, structure-based testing, and experience-based testing. Each of the three classes of testing include multiple different possibilities that may be applied in order to complete testing. Each case portrayed is defined in terms of derivation of test conditions, test coverage items and test cases.

Specification-based test design techniques primary source of information, to apply towards the test basis, is gathered from the requirements, specifications, models, or user preferences. The standard provides over ten different techniques that may be used to satisfy specification-based testing. Consideration to each of the techniques will allow for the best fit technique to be used.

Structure-based test design techniques primary source of information is gathered from source code or the actual structure of a model created. Again, there are multiple techniques which can be best fit towards the project in question.

Experience-based test design techniques are limited to the knowledge and experience of the tester, which is used as the basis of the test case design. A general guideline for experience-based testing is explained in this standard, however, due to varying experience levels, it cannot be limited to one definition. The standard applies error guessing as an experience-based testing technique, which requires a set of defect types to be determined by the tester. The tester uses previous experience to predict inputs to the item being tested that may cause failures. Each defect type considered is included as a test condition.

4.1.6 Design Impact of Software Testing Standard

Through consideration to standard *ISO/IEC/IEEE 29119*, there are several aspects of the Solar Bike design that will be impacted. Following this standard exactly and demonstrating that all requirements have been satisfied will allow for our group to claim full conformance to this standard. However, there are many techniques that are included in this standard which are not necessary to the Solar Bike design, and for that reason tailored conformance can be claimed. Tailored conformance can be claimed by demonstrating that the requirements chosen by our group have been satisfied.

Organizational test processes will impact the design of software in the sense that each group member will have to review and approve the coding. Since the organization is essentially the three group members, the organizational test policy and strategy will be created and applied by the group.

Test techniques will follow requirements set by the standard as well as those defined by the group itself. In order to assure that all testing is performed adequately, the testing techniques which are specified will be applied to each set of testing that is performed.

4.1.7 Programming Languages – C Standard

ISO/IEC 9899 is an International Standard which "specifies the form and establishes the interpretation of programs written in the C programming language" [C8]. The standard covers several very important aspects which are related to the software section of the Solar Bike design. Coverage includes: representation of C programs, semantic rules for interpreting C programs, and representation of input/output data processed/produced by C programs, as well as, the syntax and constraints of the C language. While the standard, in its entirety, applies to the software design, the aspects of the standard which most closely relate to the software section of the Solar Bike design are summarized below.

As with any language, there are definitions, notations, concepts, conversions, and many other contributions which construct the language. Notations described in the standard include the italic type, which represent the nonterminals, and the bold type, which portrays the terminals. A colon which follows a nonterminal introduces its definition. In the main text, syntactic categories are not italicized and spaces are used in place of hyphens. An overall summary of the language syntax is included in annex A of the standard [C8].

Included in the concepts section of the standard are the scopes of identifiers, types and their representations. "An identifier can denote an object; a function; a tag or a member of a structure, union, or enumeration; a typedef name; a label name; a macro name; or a macro parameter" [C8]. The identifier can only be used within the its scope of the program. A scope can be categorized into four different types: function, file, block, and function prototype. The standard explains how each of these scopes are to be used and what may be applied to them. The type of expression used creates a value which will be stored as a result. The type refers to integer type, character type, Boolean type, floating types, array structure types, and pointer types. Each type is categorized into a group with which the types share common characteristics.

4.1.8 Design Impact of Programming Languages – C Standard

There are several impacts that this standard will have on the software design of the Solar Bike. Code which is written by members of the group will be reviewed and compared to the various shall statements included in the standard. “Shall” statements are a list of requirements or guidelines that must be met in order to claim conformance to this standard.

As well as guidelines that need to be met, associating this standard to our design will allow for definitions as well as coding to be incorporated into the design which may have previously been unknown to the software designer(s). While the C language is not taught throughout this standard, with use of information previously acquired on how to implement the language, new programming techniques can be learned. There are several different sections which explain the priority, or rank, that one type may have over the other. This is important to keep in mind and will impact the structure of the software designed, in order to meet requirements.

The software that is to be implemented in the Solar Bike design is very heavy on arithmetic. Calculations must be performed to produce delays, for example in Pulse Width Modulation, which rely on arithmetic to be performed. Using the incorrect method of arithmetic or loop structure may result in undesired results and very inefficient software. For this reason, the standard on C language will be very beneficial in order to use correct arithmetic techniques and program structure. Included in arithmetic are the integer types which make up the numbers used for calculations. The use of the correct integer type is also very important, due to rounding errors, as well as, format errors in which two different types may not be compatible. As previously explained, different types included in a main group will have rank or priority assigned to each of the included types. Using the integer type as an example, if two different integer types are used together in arithmetic, the result will be of the integer type with higher rank. Therefore, it is important to realize which type to use for each application and to match operands accordingly.

Overall, all aspects of the software design implemented in the Solar Bike, which relate to the C language, are impacted by this standard.

4.2 Realistic Design Constraints

Every system requires realistic design constraints in order to successfully implement the design. The content below will consider many different constraints that are associated with the design and production of the Solar bike. Each constraint is first considered individually, then after all have been examined, the complete set of constraints are applied to the design. All constraints must be realistic in order for the complete set to be considered in the design. Each constraint must consider various other constraints in order to be valid and realistic.

4.2.1 Economic and Time constraints

Economic constraints will limit the parts selection which will be used in the design. Certain technologies or components which are desired in the design may not be able to be included due to a limited budget. The budget of the Solar bike, which is provided by our sponsor, *4F Structural Concrete & Masonry, LLC,* is $1,000. Considering the cost of the bike, the motor, and various batteries included in the design will reduce our budget left for components by a large fraction. The most advanced technology in component selection may not be obtainable due to economic constraints, in some cases less technologically advanced components must be selected.

As well as economic constraints, there are time restrictions that should be kept in mind. Time constraints will create a template for when each part of the design should be completed. The research and testing of the design should be completed by December 6, 2016. After research and testing are completed the manufacturing of the Solar bike will begin. The completed Solar bike will be presented at the end of the spring 17’ semester, which will be in May of 2017. Completion of part selection and circuit design by December 6, 2016 will allow for ample time to manufacture and correct any flaws in the design process. It is important to realistically consider time constraints in the sense that if one method, which might create a better result, exceeds the time constraints, another method should be chosen to meet deadlines.

4.2.2 Environmental, Social, and Political constraint

There are countless different electric bike designs and manufacturers. Social and political constraints will include features which may not be available in other bikes of the same category. The solar design will eliminate the need of charging the battery connected to the accessories. Also, the design will give the user the option to remove the motor and replace it with a normal bicycle wheel, which is included, to use the bike solely with the accessories, reducing the weight of the bike. The differences in our design compared to others will satisfy social and political constraints to give the user an option different from the rest.

4.2.3 Ethical, Health, and Safety constraints

Riding a bicycle can be dangerous, incorporating a motor can make it even more unsafe. For that reason, it will be visually advised to the rider that a helmet should be worn at all times. In addition to rider error the design should be created so that the components do not interfere with the rider in any way. All electrical contact points are to be covered and insulated to prevent possible electrocution. Also, batteries and other components should be centered on the bike to avoid any unbalance to the rider. There should be ample room between the legs when pedaling to avoid legs coming in contact with the attached accessories. Another important factor to consider is the all electrical components are properly grounded.

4.2.4 Manufacturability and Sustainability constraints

Manufacturability constraints restrict the components of a design to something that is able to be manufactured. In our case the manufacturing will be limited to services that are available to us. Sustainability constraints are especially important to our design because the Solar bike is meant to be ridden outdoors, which exposes it to the elements. Manufacturability and sustainability constraints may either complement or oppose each other. In a case where manufacturing of a selected part improves the sustainability would be considered a positive correspondence. However, in many applications the opposite is true and the manufacturability and sustainability constraints oppose each other. This is the case for throttle control.

There are two types of throttle controls which will be assessed. The first type utilizes a potentiometer in order to vary the voltage applied to the motor. The second applies the properties of a Hall effect sensor in order to regulate the voltage supplied to the motor. When considering the two separate throttle designs, the sustainability and manufacturability of both should be considered. In consideration of the manufacturability constraints, the potentiometer throttle design would be the better choice. However, taking the sustainability constraints into consideration, the Hall effect sensor throttle should be selected. The potentiometer throttle requires physical connection between components, while in the Hall effect sensor throttle the sensor does not come in contact with any of the components. For this reason, the sustainability of the Hall effect sensor throttle is much greater than the potentiometer throttle, which has a much greater potential to wear down and become ineffective. The manufacturing of a Hall effect sensor throttle requires the ability to move a magnet closer or farther from the Hall effect sensor, at a pre-set distance, in order to achieve the desired effects. The issue with this is creating a device that will allow this action, and be convenient for the user. However, a potentiometer can easily be converted into a throttle control that is convenient for the user, which better fits into our manufacturability constraints. In this case, other factors will be considered in the selection of throttle type.

As mentioned previously, sustainability requirements are very important to our design due to the outdoor application of the Solar bike. As with any electric device designed to be used outdoors, ample consideration should be made on manufacturability and sustainability constraints. Weather proof cases must be made for all uninsulated electrical components or covered well enough that moisture will not reach any of the connections. As well as moisture, dust and debris can also damage electrical equipment.

5. Project Hardware Design Details

Hardware refers to the physical components that will be used to power and control the Solar bike. This section will display information pertaining to each of the subsystems hardware design.

5.1 Initial Design Architectures and Related Diagrams

To begin the semester and the creation of the Solar Bike design, one of the first tasks was to create a document called 'Divide and Conquer'. In this document, an initial design flow diagram, *Figure 21*, was created. The purpose of the 'Divide and Conquer" document was to layout the know aspects of the design to begin bringing the project together. With little research performed, this diagram shows the idea in which became the Solar Bike.

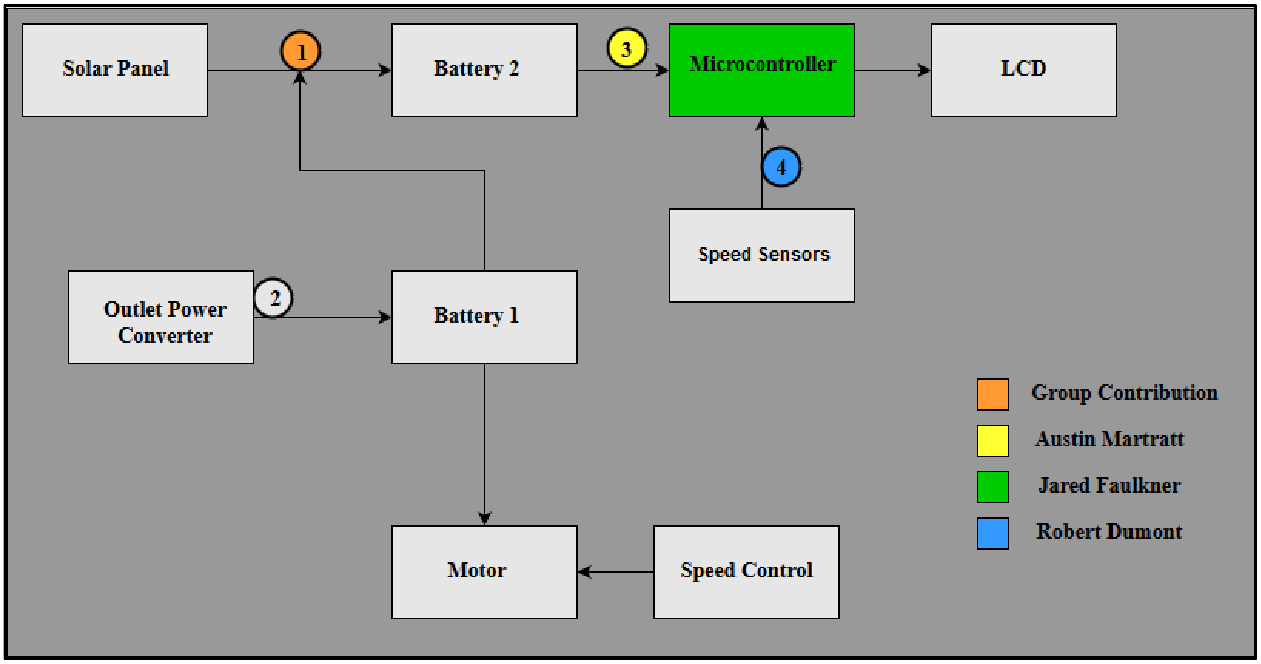


Figure 21: Initial design flow diagram

A key starting point to the design process of the solar bike are the initial ideas, which allow design to begin. The figure above shows the initial idea of the Solar Bike design. Testing and further research on different aspects related to the design may alter the initial design idea either slightly or dramatically. As well as the design subject to change, the responsibilities assigned to each of the group members may change as well.

The initial design may or may not resemble the final design at all. However, regardless of the similarities, one of the most important figures displayed in this document is the initial hardware design. Most of the research performed, deciding whether the design will work as expected, what to place between different components, how to distribute the workload, and many other factors of the design processes all began through one figure alone. Without the initial design in place it would be very hard to start planning and to understand exactly what the desired outcome of this design is.

Included in the following sections are design aspects related to the hardware section of the Solar Bike design, which will lead to the final design layout, resulting from research and testing on the different components chosen to be included in this design.

5.2 First Subsystem - Bike Motor and Throttle Control

The first subsystem of the Solar bike is related to the motor, battery and throttle control. The motor is a brushless hub motor, which is purchased from Aosom Direct. The initial thought was that the ground wire from the brushless hub motor will be directly connected to the negative terminal of the battery. The power wire will be connected to our designed throttle control, where it will then lead back to the positive terminal of the chosen battery. The throttle control will consist of a Hall effect sensor and a magnet which is moved closer or farther from the sensor to increase or decrease speed, respectively. However, this design has been reconsidered after the motor was received and testing was done that confirmed the motor was not a simple DC motor with a power and ground wire attached. The conclusions of motor testing are included below.

5.2.1 Motor Design

The first step of determining the hardware selection required for the motor controlling circuit is to run tests on the motor to determine what type of technology is needed to efficiently and effectively power the motor. The reason for this testing is that unfortunately the motor did not come with a datasheet and the manufacturer would not provide one upon request. As explained in section 3 of this report, there are many different types of motors and various powering methods used to drive these motors. The motor purchased, an Aosom 26” Rear Wheel 48V 1000W Electric Battery Powered Bicycle Motor, comes with a control board which provides connections to many different accessories. The accessories included that were used during testing include the throttle control and the brakes. There were other accessories included but were not necessary for testing. The control board also contains connections for other accessories, which can be purchased separately, but were not tested because they will not be used.

The testing performed included several main objectives. The first objective was to determine the supplied voltage which would allow the motor to spin. The testing began by using the Agilent E3630A Triple Output DC Power Supply, provided in the laboratory, to supply a DC voltage to the motor, which was equal to 24V. Keeping the throttle in the fully on position, the voltage was then incremented until the point at which the motor began to spin. Once the voltage reached 36V, the motor started to rotate, however it was not a steady rotation, instead it would pulse on and off. This proved that the motor, which is rated for 48V can be supplied as little as 36V, however would run inefficiently. The main goal of this test was to determine the minimum voltage that could be supplied to the motor, or in other words, the voltage the battery would be able to decrease to until the motor would turn off.

Finally, the technology used to power the motor was tested. Again, the motor was supplied a DC voltage of 48V, but this time the throttle was turned on only slightly. Each of the three power wires going into the motor were connected to the Tektronix MSO 4034B Digital Mixed Signal Oscilloscope. The initial thought was that the motor was using three phase technology, due to the three power wires. The results on the oscilloscope portrayed a square wave signal with a low duty cycle for the case were the throttle was in a low position. As the throttle was opened further, the duty cycle of the waveform was then increased. When the throttle was in the fully on position, the waveform showed a duty cycle of nearly 100%. *Figure 21*, below shows a result of one of the waveforms.

Figure 22: Voltage supplied to one terminal of the motor

When all waveforms are displayed, the results show that they all contain the same duty cycle and have a peak at 48V, however they are each 120-degrees out of phase. Conclusion of testing the technology used to power the motor provided insight that the motor contains three phases, with constant duty cycles, which are increased as the throttle is opened, and have a 120-degree phase margin. Further research provided knowledge that the technology which is being used is also used in three phase induction motors, which is done using pulse width modulation (PWM). With this information, the design of pulse width modulators can be used to create our own circuit which will power the motor.

5.2.3 Throttle Design

In order to understand the design of the throttle, the first step was to determine which wires are associated with what function. Again, the reason for testing is that there was not a datasheet included with the motor and its accessories. *Figure 22* shows the pin assignment for each of the wires entering the wire harness attached to the throttle.

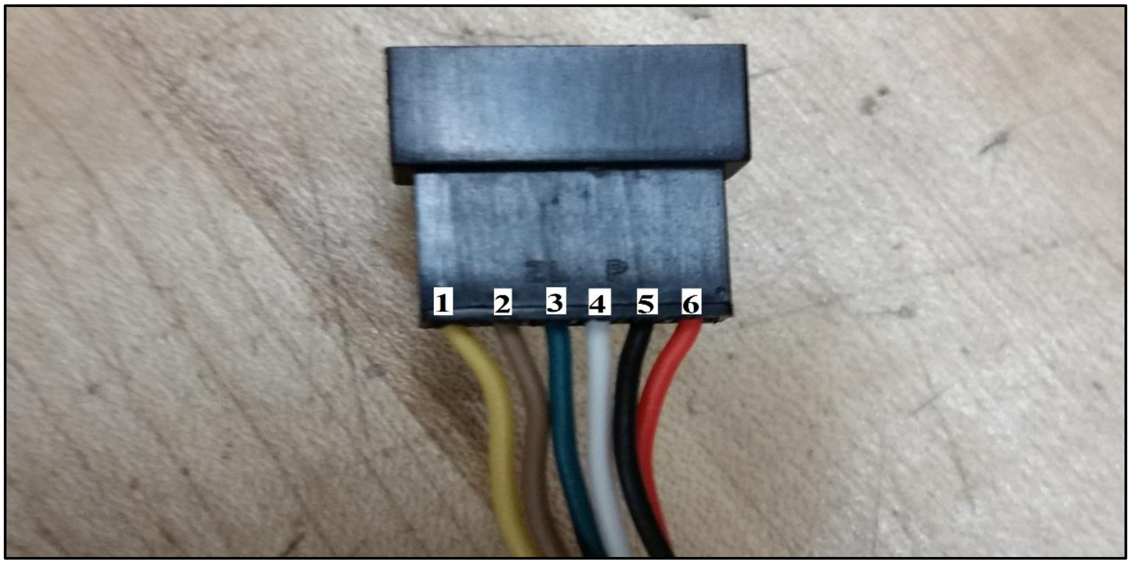


Figure 23: Pin assignment for throttle control harness

To test the functionality of each wire contained in the wire harness, all tests were initially performed without any voltage applied to the pins. Damage could occur from applying voltage across a wrong set of pins, and since wire functions were initially unknown, this was the safest way.

The objective of the first test was to test which two wires correspond to the switch. When a switch is turned OFF, the circuit is opened and current is restricted from flowing. A switch that is turned ON will short the circuit and allow current to flow through. To test whether the switch is opened or closed, the Tektronix DMM 4050 6 ½ Digit Precision Multi-meter provided in the lab was set to test resistance. The resistance of an open circuit is equivalent to an infinite resistance, which is displayed as “OVERLOAD” on the display. The resistance of a shorted (or closed) circuit will be very low, measuring only the resistance of the wire itself. Using the knowledge previously explained, the test was first performed with the switch turned to the ON position. Each pin was tested to all other pins and the lowest resistance pin combinations were recorded. The lowest resistance was found between Pin 1 (yellow wire) and Pin 2 (brown wire). The next step was to turn the switch OFF and test to see if the resistance between the pins displayed “OVERLOAD” on the multi-meter’s display. The only pin combination that was altered was the Pin 1 and Pin 2 combination, which resistance displayed infinite resistance. Therefore, it was determined that Pin 1 and Pin 2 correspond to the wires leading to the switch.

With the function of two of the wires resolved, the remaining four wires were to be determined. The remaining four wires would have to be used for the hall sensor and the battery level sensor. Knowledge of hall sensor layout led to believing that three of the wires were to the hall sensor, one wire which is the input voltage of the hall sensor, the ground, and the output wire which will output a voltage that corresponds to the position of the magnet with respect to the sensor. *Figure 22* was created to aid in the explanation of the pins on a typical hall sensor. Using general background of wiring circuits and hall sensors, the red wire was assumed to be the input voltage and the black wire to be ground. This left the white wire and the green wire remaining. Again, using wiring background the green wire was assumed to be a ground as well (likely used in the battery sensor), which left the white wire to be the output voltage of the hall sensor.

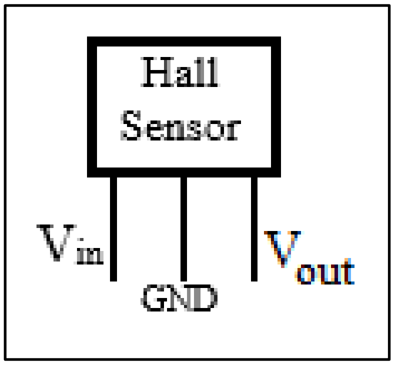


Figure 24: Hall sensor pin reference

Using the assumptions made above pertaining to wire color; Pin 6 was provided an input voltage equal to 5V, Pin 5 was brought to ground, and Pin 4 was connected to the positive lead of the multi-meter. Testing to confirm the correct assumption of wire colors was confirmed by altering the throttle position and the output voltage increasing. The results of output voltage from the throttle are included in *Section 7.2*, *Table 18***:** *Throttle percentage ON versus Hall sensor output*. Therefore, testing for throttle design was completed and the results are displayed in *Table 8*, below. The pin numbers reference the labeled pins on the wire harness portrayed in *Figure 19***:** *Pin assignment for throttle control harness*.

Table 10: Tested throttle control wire descriptions

Wire Color	Pin Number	Description
Yellow	1	ON/OFF Switch
Brown	2	ON/OFF Switch
Green	3	Ground or Reference (Battery Level Display)
White	4	Hall Sensor Signal (Output)
Black	5	Hall Sensor Ground
Red	6	Hall Sensor Input

Results shown in the table above are not necessarily the correct representations of each pin. Instead, results are, based on testing, the logically determined representations of the pin configuration. After testing of the throttle in order to determine the pin configuration, Pin 3, associated with the green wire is still not certain with its functionality. Assuming that the pin is associated with ground, it arises a question on what is used for the reference voltage of the battery level display. If not, the other option would be that Pin 3 is the reference voltage to the battery level display and the ground used for the hall sensor is a common ground between the Hall sensor and the battery level display.

Upon further research, a pin out was found for the throttle control sensor. The results gathered from testing are compared to this new-found information. The tested results of the throttle pin configuration are confirmed to match up exactly with the pin configuration found for the throttle. The only difference between the results gathered from testing of the throttle to determine the functionality of each wire and the results found from research is Pin 3 is confirmed to be the reference voltage equal to 48 volts.

Testing was then performed to determine the input voltage which would correspond to the battery level displaying FULL, HALF, EMPTY, and the voltage at which it does not display anything.

5.2.3 Microcontroller Design

To test on the breadboard, the previously shown schematic will be implemented using said components. This test will determine if the schematic will produce a Pulse Width Modulation waveform and to see if the motor will operate with the configuration.

<u>Schematics:</u>

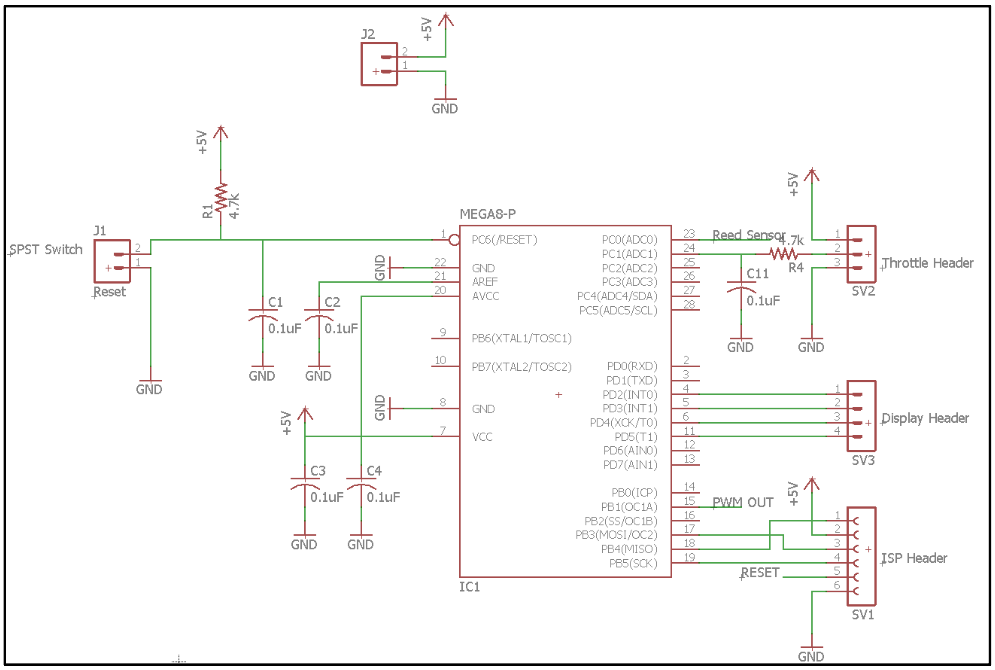


Figure 25: Microcontroller schematic

The above figure shows the microcontroller PCB schematic with headers used for ISP programming, speed control from the reed sensor, throttle control input, and the LCD display output.

Table 11: Component selection for microcontroller design

Reference Designator	Value	Part Number	Type
C1,C2,C3,C4,C11	100µF 25V	3M0802	Capacitor, Electrolytic
IC1	-	ATmega328	28 pin
R1	4.7kΩ	Supplied In Lab	Resistor, Carbon Composite
R4	4.7kΩ	Supplied In Lab	Resistor, Carbon Composite
J1,J2	-	KF350-2P	Block Terminal 2 jack
SV1	-		ISP 6 pin
SV2	-		Header 3 pin female
SV3	-		Header 4 pin female

An alternate design to the MCU circuit controlling the PWM signal can be implemented using 555-Timers PWM circuit. This signal will then be connected to the gate terminal of a NPN MOSFET that will control the motor negative terminal going to ground. The positive lead of the motor will be connected to the battery via manual switch. The 555 timer will be controlled by using the throttle. The 555 timer will be supplied by a 6V input that will come from the secondary battery.

In the condition that the PWM cannot be designed up to specifications, either through the MCU (ATmega328) or the 555-Timer circuit, then the provided controller that came with the wheel motor will be used to control the motor speed.

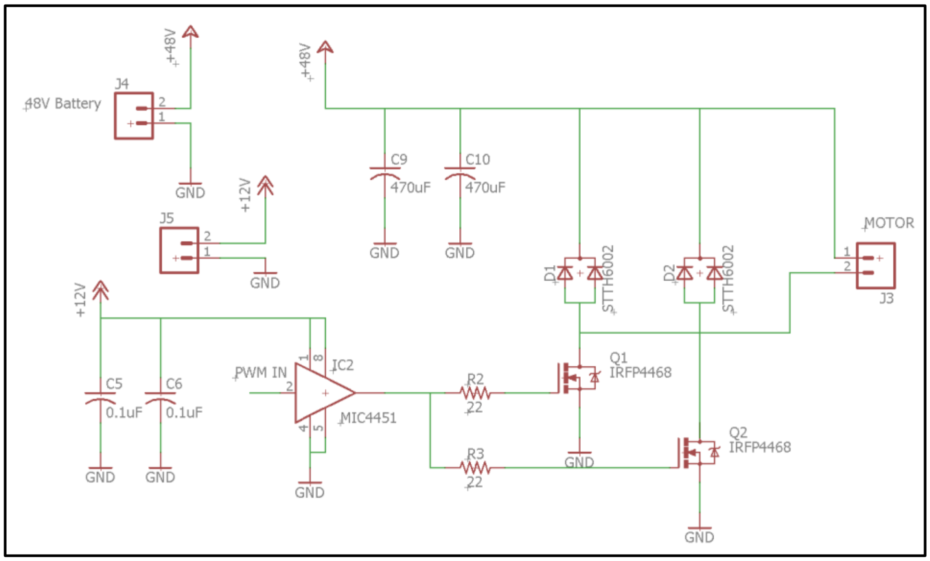


Figure 26: PWM driver schematic

The above figure shows the PWM driver that takes the PWM output from the microcontroller and drives the MOSFETs, producing the high voltage PWM we need to run the motor.

Table 12: Component selection for PWM driver design

Reference Designator	Value	Part Number	Type
C5,C6	0.1µF 25V	3M0802	Capacitor, Electrolytic
C9,C10	470µF 25V	3M0802	Capacitor, Electrolytic
IC2	-	MIC4451	8 pin DIP
R2	22Ω	Supplied In Lab	Resistor, Carbon Composite
R3	22Ω	Supplied In Lab	Resistor, Carbon Composite
J3,J4,J5	-	KF350-2P	Block Terminal 2 jack
D1,D2	-	STTH6002	Diode
Q1,Q2	100V 290A	IRFP4468	N-Channel MOSFET

PCB Layout:

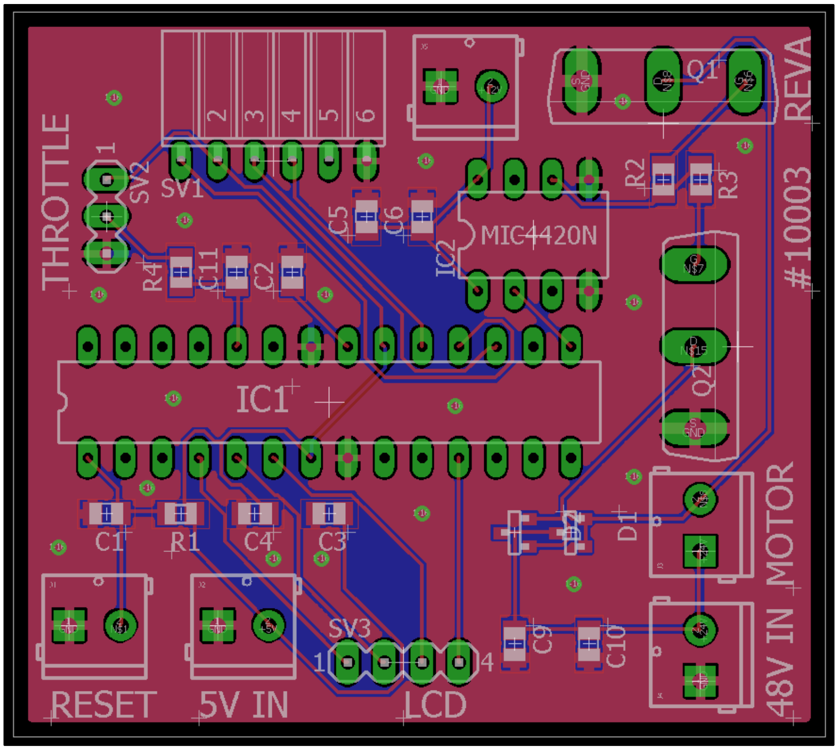


Figure 27: PWM Driver PCB Layout

The above figure shows the PCB layout as designed in EAGLE PCB software. Notice, that the bottom and top layers are both designated as ground. This helps to simplify the design of the board, keeping traces minimal length and reducing the amount of vias needed. Multiple vias are placed throughout the board, connecting the top and bottom layers of GND, ensuring there is a stable ground connection all throughout the board. This is common practice when designing PCBs for any application. We put the microcontroller near the middle of the board because it has the most input/outputs. This makes it easier to brand traces off from the microcontroller, keeping everything looking clean. As you can see, we also kept the capacitors as close to their nodes as possible. This is to reduce the inductance from the trace length. The smaller the capacitance, the more crucial this layout characteristic becomes. This board has multiple voltages, or supply nets, and as a result we needed to keep those voltages on separate parts of the board. This allows us to keep cost low by staying with a 2 layer board, whereas boards that have multiple supply nets may commonly need three or more layers to keep signals from interfering with each other. Because we are in the breadboarding and prototyping phase, we wanted to keep the PCB design as preliminary as possible. This is to say that we want to first breadboard each subsystem to ensure it works, even on the PCB. By keeping each subsystem to their own board, we can more readily isolate problems or disturbances that we may face in the future. Ultimately, the end design will have all subsystems placed onto one main controller board when we are confident in the final design and layout of the system.

5.3 Second Subsystem - Solar Power (Solar Panel to Accessories)

The second subsystem of the Solar bike is the system which contains the solar panel and the bikes accessories. The solar panel will charge a battery which is separate from the battery used in the throttle control system. The only charging source associated with this subsystem is the solar panel. A 12V lead-acid battery will be chosen with reference to the battery standard discussed in Section 4.1.1. Between the solar panel and battery is a charge controller/regulator which will prevent overcharging the battery and maintain a constant charge to the battery while the solar panel is exposed to sunlight. From the battery, power will then be supplied to the Arduino microcontroller, which is regulated by a voltage regulator/voltage step-down component. The microcontroller will be responsible for powering the LCD display which will display the speed of the bike as well as other included displays.

5.3.1 Voltage Regulator Design: Battery to Microcontroller

The use of a 12V battery will require a step-down voltage regulator to provide a constant DC voltage, which is reduced down to the required input voltage of the Arduino microcontroller. The regulator will step-down the voltage to 5 volts, which is required by the ATmega328 chip contained in the Arduino. The reason for designing a voltage to meet requirements of the ATmega328 is that after testing of the Arduino, we will be transferring the chip onto our PCB design. Transferring only the chip to our PCB means that we will no longer need the required input voltage of the Arduino microcontroller itself, instead the need is only for the ATmega328, itself.

5.3.1.1 Linear Voltage Regulator

The first consideration for a step-down voltage regulator is a linear regulator, the schematic of which is shown in *Figure 27*, below. This schematic is followed by *Figure 27*, which shows the linear regulator implemented on a breadboard. This is a simple, yet effective design which uses a TL084 Op-amp and a 2N5458 JFET, n-channel transistor. The section of the circuit contained between the two capacitors, C1 and C2, is essentially what is contained in the LM7805, however the resistance values have been altered in order to produce an output equal to 7 volts, versus the designed 5-volt output. A wide variety of different Op-amps and transistors can be substituted in this circuit, and tests will be done to find the best combination of these components if this linear regulator is chosen.

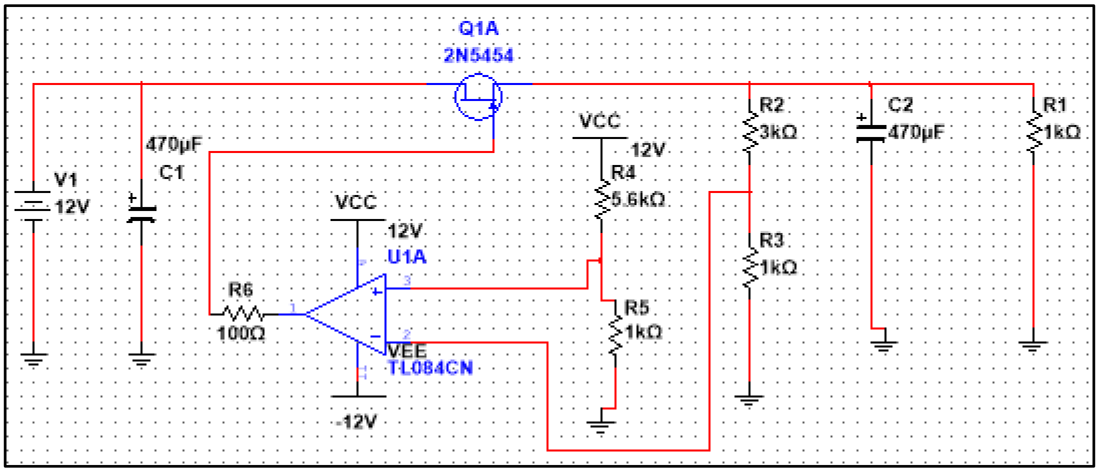


Figure 28: Linear voltage regulator schematic

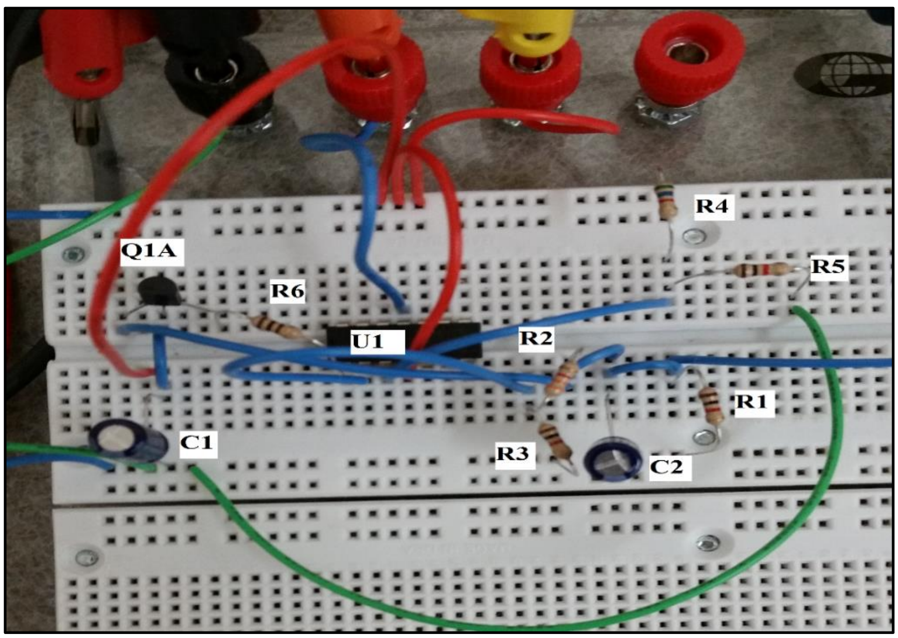


Figure 29: Linear voltage regulator breadboard test

Testing was performed and the results are as follows: with an input voltage equal to 12 volts, the corresponding output voltage is equal to 7.2 volts. The input voltage for the Arduino Uno is limited to the range of 6V – 20V, however it is recommended to use a voltage between 7V – 12V. It is desired to stay as close to the minimum recommended input voltage as possible. Achieving an output voltage of 7V will allow for the least battery consumption while staying inside the recommended input voltage range.

Of course, a battery will not always produce a steady 12 volts, instead it will output between 11.5 to 12.7 volts, depending on charge level. The voltage range considered may vary depending on battery type. However, it must be realized that the linear voltage regulator is just that, linear. This means that as the input increases or decreases, the output will increase or decrease, respectively. The design shown in *Figure 27* has a linear slope which is equal to 0.606, that is, as the input is raised by 1 volt, the output increases by 0.606 volts. Although the output is not a constant voltage, the range at which it will vary is still in the input range of the Arduino Uno, which will work for our design. Results listed above will aid in the decision of which voltage regulator will be used.

The design specifications have been changed after this section on linear regulators was written. However, the knowledge gained through testing the 12V to 7V voltage regulator can still be applied to future testing and is therefore still relevant to the hardware section of this report. The required output voltage of the regulator is desired to be 5V.

5.3.1.2 Switching Voltage Regulator

Further research has been conducted and the results confirmed that the linear voltage regulator, while a reliable regulator is not very efficient. Instead, we have chosen to use the LM 2576 switching regulator which, per the datasheet produces 77% efficiency [B2]. The linear regulator previously discussed has an efficiency that is much less, which is around 40%. Displayed in *Table 11*, below, is a comparison of the popular LM7805 linear regulator compared to the LM2576 switching regulator, when both are used as a 12V to 5V voltage regulator. The results are gathered from Texas Instruments datasheets provided for the LM7805 [B3] and LM2576 [B2].

Table 13 LM2576 switching regulator vs. LM7805 linear regulator

Feature	LM2576	LM7805
Operating Voltage	4 – 40 V	7.5 – 35 V
Max. Output Current	3.0 A	1.5 A
Output Options	Adjustable	Fixed
Operating Temp	-40 – 125 °C	0 – 125 °C
Efficiency	77%	~ 41%
Switching Frequency	42 – 63 kHz	N/A
Unit Price	$1.19	$0.46

The comparison between the linear versus the switching regulator shows that, although the cost is more than double for the switching regulator, the efficiency is almost twice what it is of the linear regulator. Due to relatively low costs of both technologies, the price difference is not very heavily considered. The range of operating voltage and temperature are much greater for the switching regulator than that of the linear regulator, which allows for greater possibilities. However, the efficiency is the greatest concern here due to the relatively small range of temperatures and voltages that will become of the Solar Bike.

The fixed output voltage version of the general use circuit portrayed in the LM2576 datasheet is shown in *Figure 29*, below. This circuit is the basis of the switching voltage regulator circuit that will be used in our design. The output voltage is set at a constant voltage of 5V with a 12V input. There is another version of this design which will allow for a variable output voltage, but for the needs of the Solar Bike design, it is unnecessary. The adjustable version also requires two extra components (resistors), which will add space to the PCB layout and increase the cost of fabrication. However, the adjustable version will be sufficient for breadboard testing.

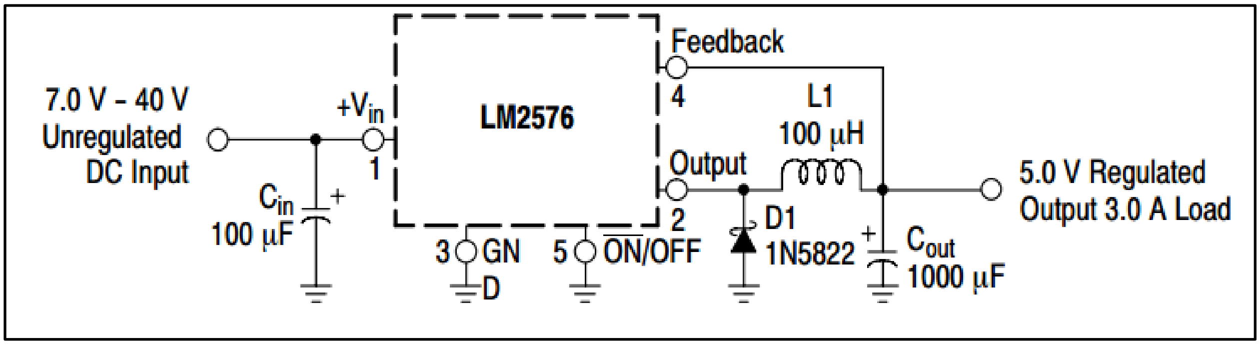


Figure 30: Fixed output voltage version of LM2576 from datasheet

One key factor of this design is that the maximum load current can be altered, by varying the inductance value of L1. The general circuit will produce an output of 5 volts with a maximum load current of 3 amperes. The specifications for the Arduino Uno require a maximum input current equal to 2 amps. Therefore, a maximum load current of three amps is unnecessary and can be reduced, with slight increases to the overall efficiency of the circuit.

The circuit, designed to serve as a voltage regulator between the battery and the ATmega328, will look the same as that shown in the figure above, with varying component values. Considering the case of the Solar Bike design, where the input voltage (from the battery) will be relatively constant, the replacement of the inductor L1 with greater inductance values will reduce the maximum load current associated with the output. Reducing the inductance will essentially place the maximum load current stationary at 3 A.

Note that the initial testing of the ATmega328 will be done using the Arduino Uno, however the goal is to include the ATmega328 on our PCB, where the voltage regulator will be used to power the ATmega328. This consideration is important to keep in mind for the fact that the input voltage to the Arduino Uno is higher than that of the ATmega328.

The schematic designed for the 12V to 5V switching regulator is shown below in *Figure 30*. The schematic was created in Eagle and used to create the Eagle PCB design for the switching voltage regulator, shown in *Figure 30*. The PCB Fab Top View is shown as the product that will be received from our vendor, OSH Park.

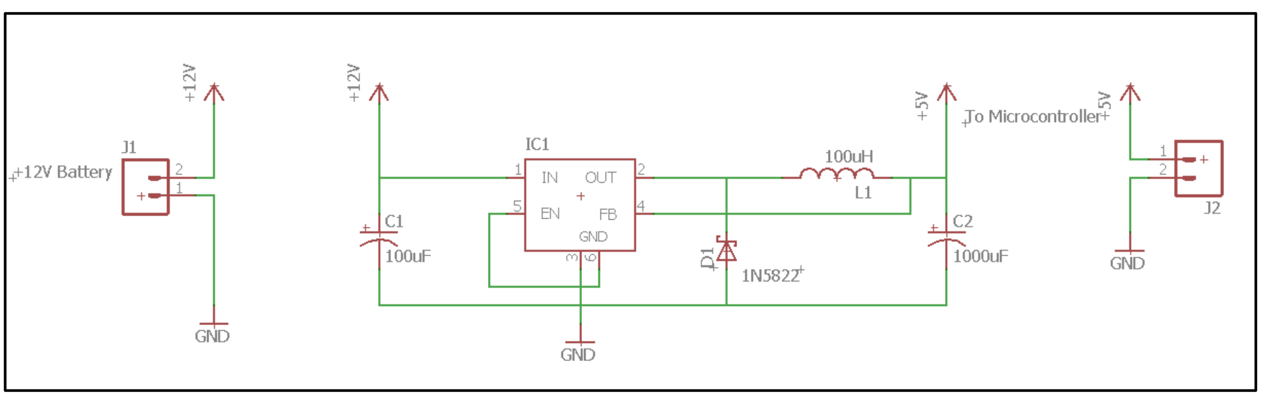


Figure 31: Schematic of switching voltage regulator design

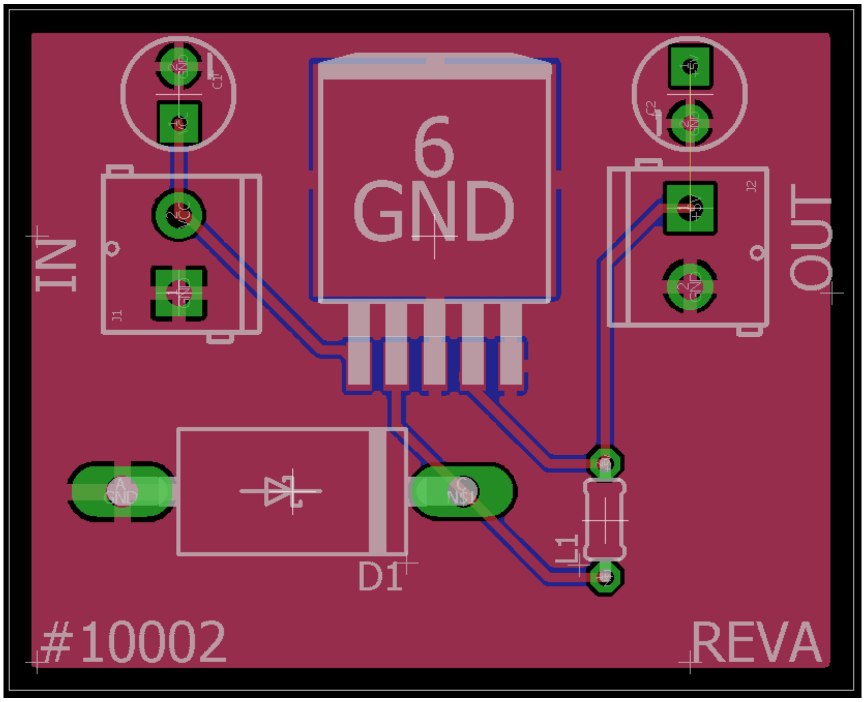


Figure 32: Eagle PCB design of switching voltage regulator

The PCB designed is created with the entire top surface designated as ground. The main block of the LM2576 surface mount chip is designated as ground and is therefore beneficial to place ground at the surface of the PCB. With the intentions to create a board that is as small as possible, surface mount devices can be used in place of the currently shown through hole device slots. In terms of size, the current PCB, with through hole devices, measures 1.5 inches by 1.2 inches, which is relatively small. The use of surface mount devices will further decrease the size of the PCB.

Breadboard test:

An important factor considered during breadboard testing was the need for a single point ground. Grounding in locations other than a single point can allow for ground loops, which allow noise obtained between the separate grounds to be gathered and, since the internal components of the LM2576 contain several op-amps, become amplified. This amplification of disturbances to the circuit can result in undesired voltage transients, which is why single point grounding was emphasized. The base of capacitor C_{in}, Pin 3, D1, and C_{out} should all be brought to a single point ground, as shown in the breadboard test *Figure 32*, below.

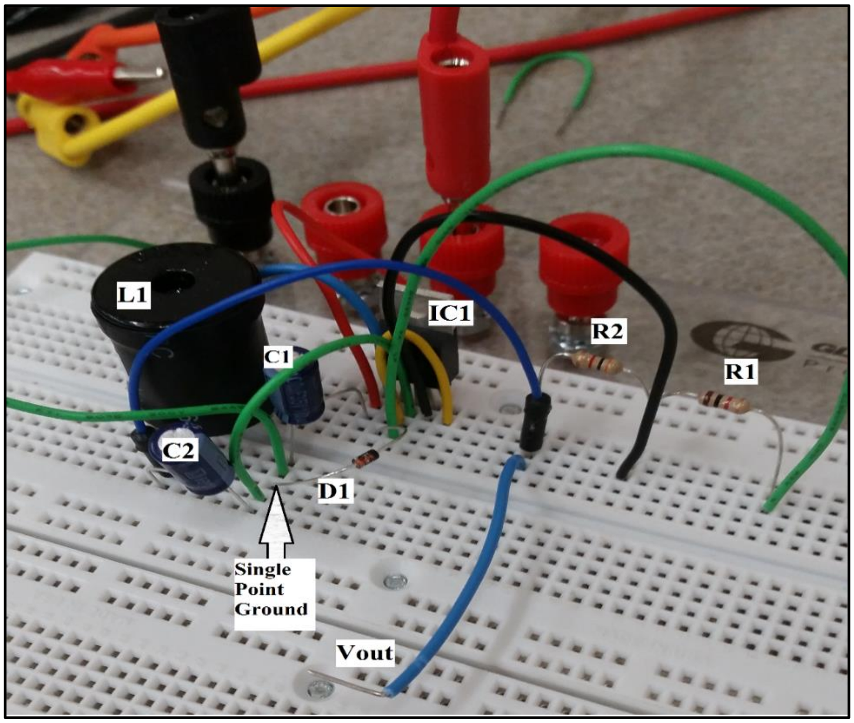


Figure 33: Switching regulator breadboard test

Breadboard testing was completed to determine if the design of this circuit will meet the requirements expected and serve as the voltage regulator. The circuit displayed above uses the adjustable version of the LM2576, however the resistor values chosen will provide the same results as that of the fixed output version, making this an acceptable alternative to the fixed output LM2576 chosen for the switching regulator design.

There are two main requirements that this circuit must meet. The first requirement includes providing an output voltage which is held constant for an input voltage which may vary from 10.5 volts to 12.6 volts, which are the minimum and maximum voltages which may be provided by the battery, depending on the battery charge level. Testing was performed using varying input voltages from 10.5 volts up to 20 volts and the results are displayed in *Section 7.2 Table 21: Input vs. output voltage- switching regulator* located under Section 7.1 of this report. Results display that the voltage is held constant within a few millivolts, which is considered acceptable. With the first requirement met, testing was performed for the second requirement.

The second requirement to be met is that the output current is held below two amperes, which is the maximum input current tolerated by the ATmega328. Power was supplied to the circuit using the Agilent E3630A Triple Output DC Power Supply, which resulted in the unloaded circuit output current equal to 1.25 mA. However, it must be realized that, once loaded, the current will vary depending on the impedance of the load attached to the circuit. Further testing upon completion of the system will be required to determine the current that will be supplied.

Therefore, testing of the switching regulator has provided sufficient evidence that the circuit will serve well as the voltage regulator in our design. The components which were used in breadboard testing are provided in *Table 12*, below.

Table 14: Components used for breadboard switching regulator design

Reference Designator	Value	Part Number	Type
C1 & C2	100µF 25V	3M0802	Capacitor, Electrolytic
D1	-	1N4148	Diode, Small Signal Switching
L1	100µH	RENCO RL-24444	Inductor,
IC1	-	LM2576T-ADJ	Transistor, NPN Epitaxial Silicon
R1	3kΩ	Supplied In Lab	Resistor, Carbon Composite
R2	1kΩ	Supplied In Lab	Resistor, Carbon Composite
J1 & J2	2 pin	KF350-2P	Terminal Block Connector

The components contained in the table above will vary from the components used in the PCB design. The main reason for testing with components different than that of the final design is the use of surface mount devices will be used, as possible, in PCB design to reduce size. Through hole devices are used in breadboard testing to place components into the breadboard.

Overall, the switching voltage regulator design has proved to be the superior option in voltage regulators portrayed in this section. Therefore, it has been decided to use the switching voltage regulator to regulate and step-down the 12 volts provided by the battery, to the 5 volts received by the ATmega328.

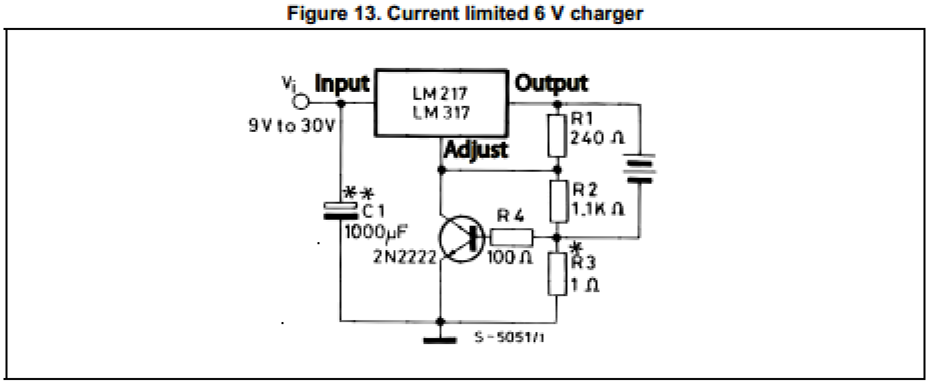
5.3.2 Charge Regulator Design: Solar Panel to Battery

A lead-acid battery has charging requirements that must be controlled to charge efficiently and protect the battery. Overcharging can damage and reduce the life of the battery. Characteristics of the chosen battery will provide requirements of the charge regulator to maximize charging efficiency. Another consideration taken into account is that when a solar panel is turned off, the cells will discharge the battery. Therefore, the charge regulator will also incorporate discharge protection to avoid battery drainage from the solar panel.

A solar panel in itself is a reputable source of power, however the voltage provided is far from constant. This is due to various factors, which include, but are not limited to, cloud cover, position of the sun with respect to the panel, and temperature. This constant change in voltage can be very harmful to the battery, which creates the need for a charge regulating circuit connected between the solar panel and the battery that it will be charging. The desire is to create a voltage regulator that will also limit the amount of current passed to the battery to avoid damage to the battery. A device that will do just this is explained below.

The following information is gathered from the LM317's datasheet [B1]. The LM317 is a monolithic integrated circuit that is most generally used as a positive adjustable voltage regulator. The circuit contained inside is design to supply an output voltage that is adjustable between 1.2 to 37 V, at a load current able to rise above 1.5 A. The design shown in *Figure 33***,** below is the recommended circuit design contained in the datasheet for a current limited 6V charger. This will be the basis for the charge design that will be implemented.

Figure 13. Current limited 6 V charger



* R3 sets peak current (0.6 A for 1 Ω).

** C1 recommended to filter out input transients.

Figure 34: Current limited charger design from LM317 datasheet [B1]

The battery that we will be charging is a 12V battery so it is obvious that the circuit above must be modified in order to meet the needs of our design. There is a reason that this circuit was chosen, however, instead of the 12V charger circuit also contained in the datasheet. The reason for this is the current limiting properties that the circuit provides. The goal is to charge the battery at about one tenth of the batteries amperage capacity. That is, the battery that we will be charging is rated for 5 Ah, which means a charge rate of 0.5A is desired.

5.3.2.1 Schematics

Resistors R3 and R4 main purpose is to vary the regulated output voltage, the values of which have been calculated to meet our needs. A variable resistor (or trim pot) will be used, adding to the resistance of resistor R4, to determine the exact resistance needed through breadboard testing. After testing was performed, the resistance value is found to be very sensitive to the output voltage which is desired. In that sense, the trim pot will be included in the PCB design and will be soldered to stay at the position required, to meet output voltage requirements precisely. The NPN transistor is responsible for sinking the excess current and the current sunk is controlled by resistor R2. The result of these changes to the circuit, included in the LM317 datasheet, is shown in the schematic contained in *Figure 34*, below. This schematic will serve as the basis to our solar charge regulator.

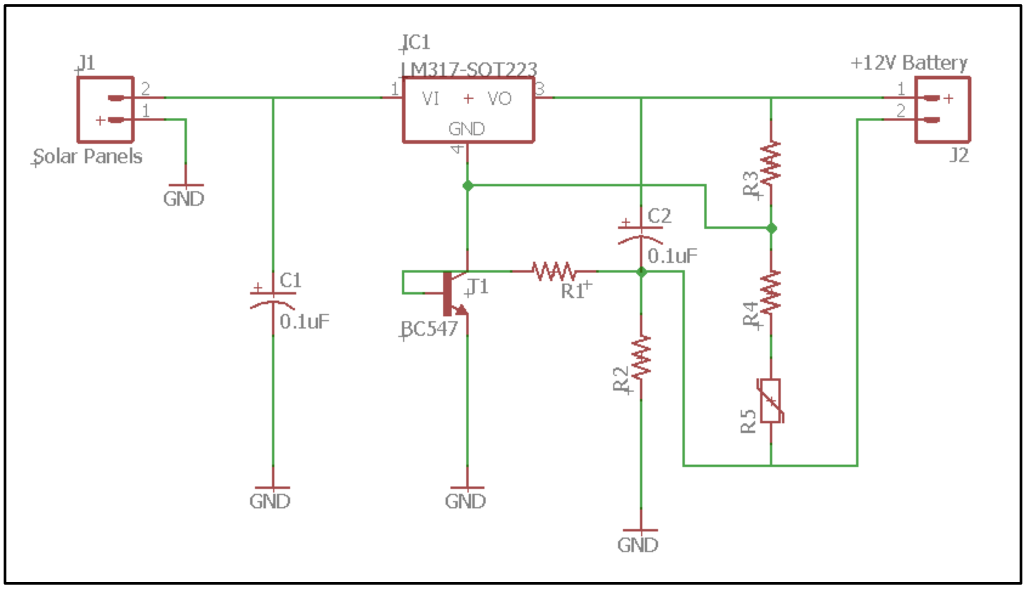


Figure 35: Schematic of designed solar charge regulator

5.3.2.2 Breadboard Test

Bread board testing was performed to verify functionality of the solar charge regulator. The result of the layout for breadboard testing is included in *Figure 35*, below.

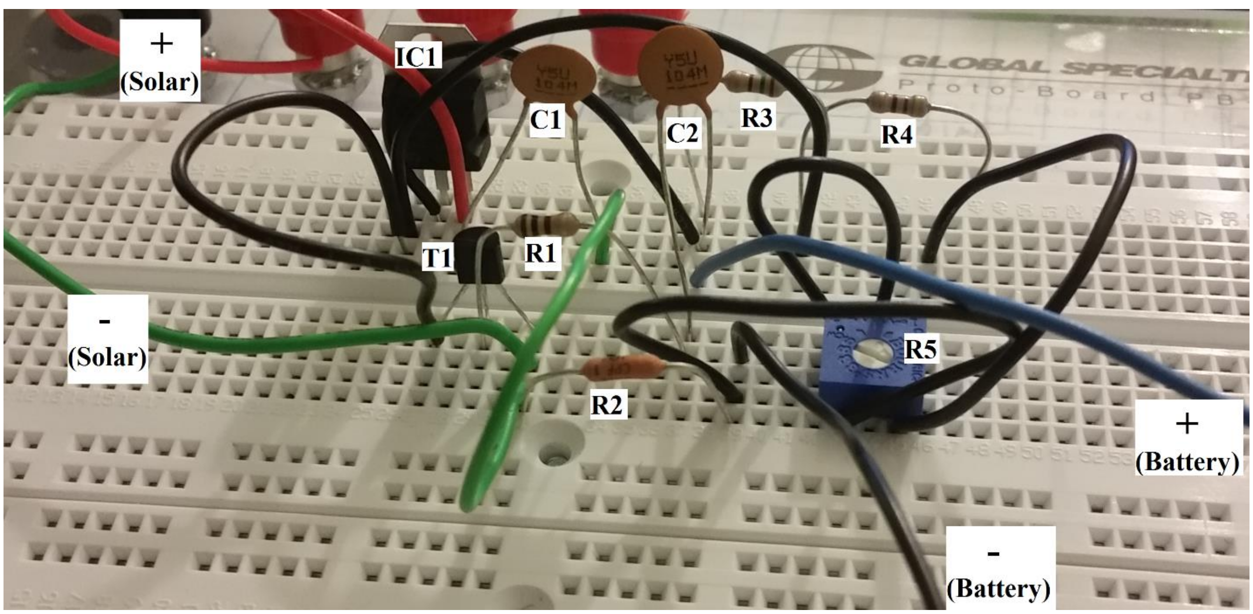


Figure 36: Breadboard test of solar charge regulator

Testing will be done in order to confirm if solar panels have diodes in place, if not a diode will be placed between the positive terminal of the solar panel and the input of the LM317.

5.3.2.3 PCB Layout

The circuit for our designed solar charge regulator is then transferred to a PCB board layout, generated in Eagle. The result of the layout is shown in *Figure 36*. The PCB is relatively small, which is desired in order to allow for easy placement on the bicycle itself. The PCB is a two-layer design with a length of just over an inch and a half and a width of just under an inch. Something that can be easily mounted and will remain out of the path of motion of the rider.

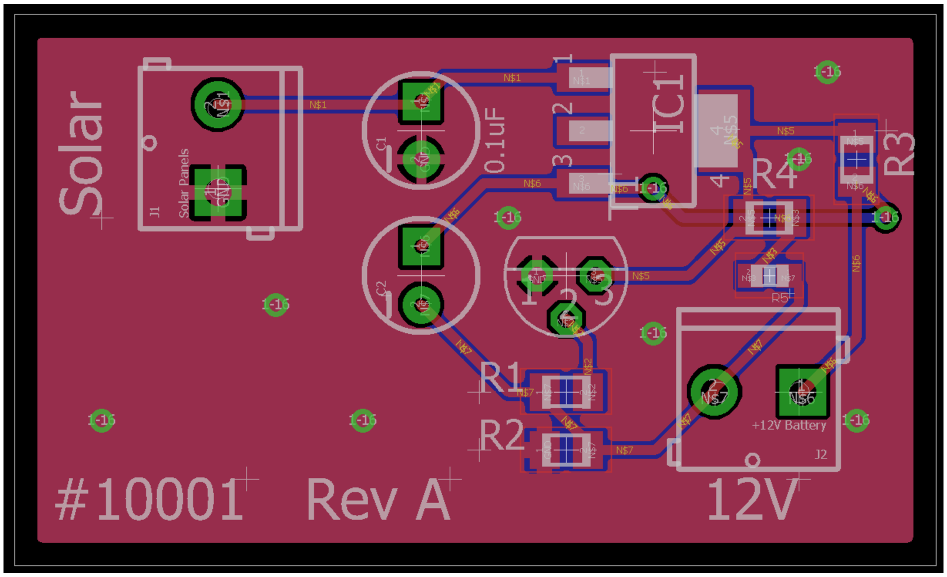


Figure 37: Eagle PCB layout of solar charge regulator

The components of this charging regulator will need to be chosen with careful consideration. The reason being that we would want to choose components that can handle the power load to avoid heat buildup and have low failure rates to ensure reliability of the boards. *Table 13* displays a list of components that we have chosen.

Table 15: Selected parts for solar charge regulator sub-system

Reference Designator	Value	Part Number	Type
C1 & C2	0.1μF	Y5U104M	Capacitor, Ceramic
R1	100Ω	Supplied In Lab	Resistor, Carbon Composite
R2	1Ω	CPF11R0000FKEE6	Resistor, Metal Film
R3	150 Ω	Supplied In Lab	Resistor, Carbon Composite
R4	470 Ω	Supplied In Lab	Resistor, Carbon Composite
R5	5kΩ	3386F-1-502LF	Trimming Potentiometer, Cermet
J1 & J2	-	KF350-2P	Terminal Block Connector
IC1	1.2V - 37V	LM317-SOT223	Voltage Regulator, Adjustable
T1	-	BC547	Transistor, NPN Epitaxial Silicon

Surface mount components will be used in place of the current through hole devices included in the above table. Price differences between each component, whether through hole or surface mount will be considered, as well as the amount of space that will be saved.

5.4 Bike Chassis Configuration

The bike chassis that we will be chosen to have each system implemented on will a 26” wheel Mountain bike. This bike has a wheel diameter of 26” which is the same size as the in-wheel 3 phase induction motor that we have acquired. Because of this, installation should be quick with a minimal amount of work. The bike has a 21-speed gear shift option which is technically irrelevant for the design that we have its own 6-speed gear ratios that are already built on the side of the motor since this will give the operator the option for higher gears when in manual peddling mode. There will be testing that will determine how much the higher gears will affect the speed. The frame of the bike chassis is made of a 4-bar linkage aluminum dual-suspension allowing for a smoother ride for the user when operated on rough terrain.

Assembly of the system of the bike will be referenced from *Figure 37* and as follows. The Motor of the bike (M1) will be placed between the rear wheel and the peddles of the bike so that it can be attached to the chain. This will provide rotation to the rear wheel when powered on and connected to the chain of the bike. The reed sensor (S1) will be attached to the axle of the rear wheel to provide information of how many rotations will accumulate in a certain amount of time. The LCD display (L1) will be mounted between the handle bars of the bike and angled for a direct HUD for the operator. Another place that we have considered putting the LCD would be on the opposite handle bar of where the throttle (T1) will be. This would provide more of a less angled down view for the user to see but at the cost of the LCD not being centered. The throttle (T1) will be situated on the right handle bar of the bike for the thumb control for ease of access. If the user is left handed or prefers the throttle on the left, then throttle (T1) will be adjusted to fit the other side. The control / power system (C1) will be the carrying case that will hold the MCU, Motor controls, secondary battery, and the solar power charge regulator circuits. This will be mounted using a rear bike case bar that can be attached and secured above the rear wheel. The solar panel (S2) will be assembled and configured at an optimal angle for the most efficient sun exposure. This will also be attached by a bar that would be mounted on the end of the bike case bar. The main battery for motor power (B1) will secured on the bike frame and have wires running from it to the motor drivers in the control system housing (C1).

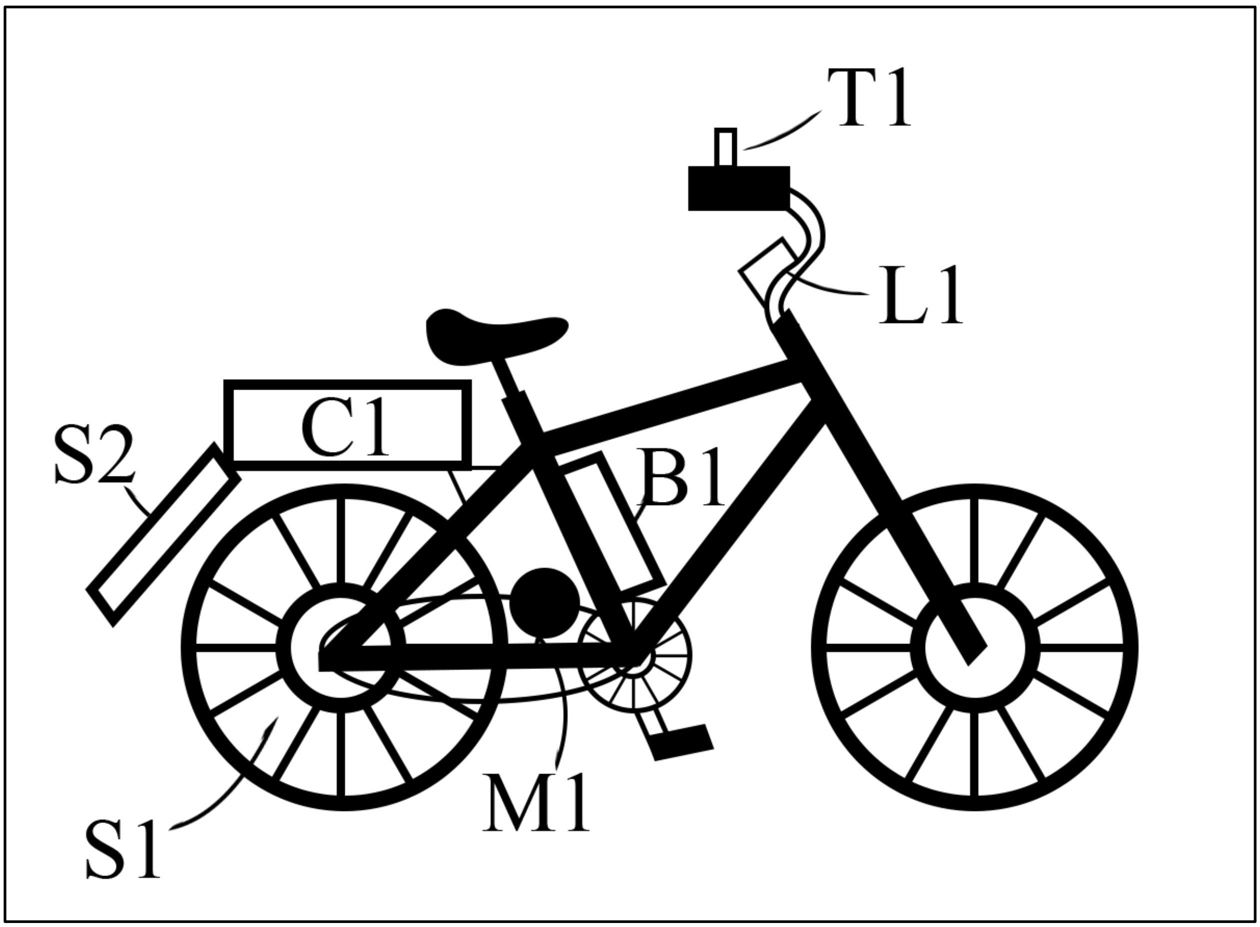


Figure 38: Bike System Placement

5.5 Additional Hardware Features

There are some additional features that we have thought to add to the hardware of this project. Some of these features can be implemented by adding different components and additions to the PCBs as well as completely new additions to the system. These features will add benefit to the operator of the bike while most will be more of an informative feature. These features will not be counted as the expected features to include in the final design. These additional features will only be added to the final if seen fit to add and the team has the available time to add said features before the final presentation of the project at the end of Senior Design 2.

5.5.1 Headlights

Like most vehicles, headlights are major key to the visibility and safety to the operator. Headlights will be beneficial to the user by providing sight when the environment outside becomes too dark for the operators eyes to see. They are also beneficial to other vehicle operators as well as pedestrians to ensure that they see the operator of this bike to avoid collision and/or possibly serious injury.

The headlights in this project will be a simple design with a control switch that would provide or cut off power to a headlight beam. This head light beam will take in voltage from the battery with the use of a stepdown voltage circuit that would provide the require current and voltage to sustain a light that will have enough lumens to increase visibility by at least 10 meters. This would be a simple and effective addition to the project

5.5.2 Taillights/Blinkers

Taillights, like headlights, are a valuable and common feature to vehicles especially at nighttime/dark operations. The main purpose of taillights and blinkers is to provide information to other operators on the road or bike lane behind the user of the bike of when they brake for stopping and to signal which direction the user plans to turn to. These can also be used to provide constant illumination to inform others near the bike that they are in the vicinity, in turn increasing the safety of the operator.

The taillights/ blinkers in this project will be fully analog. They would be implemented using a 555-timer pulse circuit that will send pulses to the taillights depending on the user input. This circuit would include a 555-timer IC for the main generator of a pulse. This pulse would be determined by the capacitance of the capacitor that would connect to the Trigger of the 555-timer. A prototype circuit is shown below to help show what such a blinker circuit would be designed.

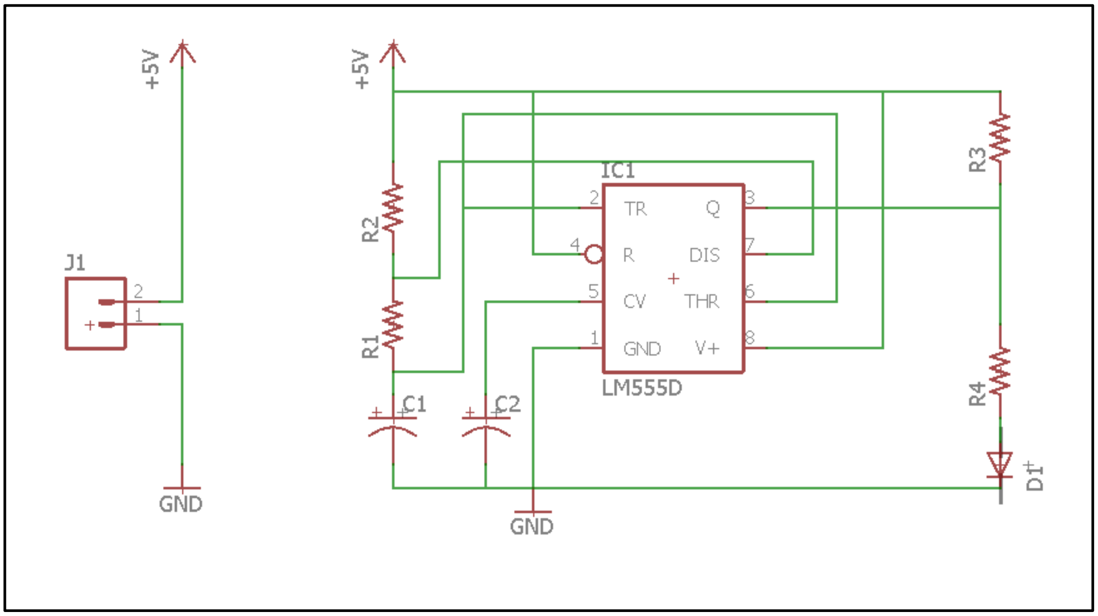


Figure 39: 555-Timer Blinker Circuit

5.5.3 System Housing

One feature that we are strongly considering adding to the bike is a housing for all the components. One idea that we plan to use would be a carrying case that would mount on to the back of the bike over the rear wheel. This would be held up by a bar that would be mounted on the back over the rear wheel. The carrying case would be placed upon it and strapped down on the bar. This carrying case would hold the batteries and the circuit boards. There would be outlet holes that would be for the wires to go through to their corresponding ends. This case would be waterproof to avoid any water damage on the components.

In addition to the case, there would be individual housing for each circuit board and the LCD and switch controls. This would provide protection to the circuit boards from water, dents, ESD, and direct sunlight. A housing case would be designed by means of software, like AutoCAD, in a box shape with outlets for connecters that would match up with the circuit boards. For the LCD, there would be a second housing that would be mounted on the handle bars of the bike. This housing, like the housing for the circuit boards, will be designed to withstand weather and most environments, but the LCD housing would be designed to withstand more since it will be directly exposed to the outside environment. This LCD housing will include cutouts for the LCD to be shown and also for the buttons and switches associated with the ATmega MCU.

The material that would make up the designed housing would be chosen carefully. There are two options that would be considered, wood or plastic. Wood would make designing a housing very simple since it would easy to manufacture and customize. The con to using wood would be that there is has a higher chance of burning since wood is easily custom to burning when heat is applied at a certain temperature, and that it would be prone to mold by when exposed to the weather over time. This could be treated by using a sealant that would cover the external and internal of the housing, but this would not be a permanent fix. The other option would be durable plastic that would withstand harsh weather. This plastic would be the preferred choice since the design and functionality would be pristine. The down fall to using a plastic design is that it would be costlier to manufacture and has more environmental standards that would need to be followed (depending on the type of plastic that would be used).

5.5.4 USB Charging Port

A convenient and useful addition to the hardware of system would be a USB charger. This would be driven by the secondary 12V battery through another voltage regulator. The output of this USB to power a device would be the typical 5v / 200mA power output without the option of having a data I/O pins in use. We would design this on to the microcontroller circuit as an external output by attaching a female USB 2.0 head and sending +5V to the corresponding pin and connecting the ground to the corresponding pin on the USB pins. We would match these pins up to the standard USB configuration shown below in *Figure 39*.

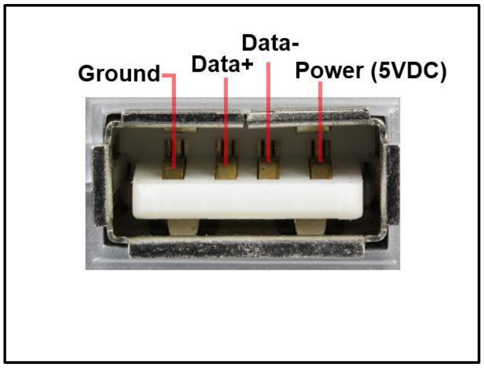


Figure 40: USB Pinout

This USB would have the considered option to have data input that would be used to program and modify the existing code on the ATmega. The Data+ and Data- that are shown above would be connected to the RxD and TxD (pins 2 and 3, respectively) which will transmit and receive the data from a computer for serial communication. This would be useful for the addition and modification of any feature that we would ever wish to add on the system later. This would also serve as a maintenance port for troubleshooting and debugging the code, if any errors were to be given.

5.5.5 Brake Design

Next, the functionality of the brakes was tested. The motor was supplied a DC voltage equal to 48V and the throttle was opened fully. Once the motor began rotating at a constant speed, the brake was pulled, resulting in the motor no longer receiving power. The result of this testing produced knowledge that the function of the brakes was simply to cut off the voltage supplied to the motor, at there are no internal braking components. This is in the addition of the mechanical brakes that are already applied on the bike chassis.

5.6 Summary of Hardware Design

Throughout the previous subsections included in Section 5 the hardware design has been added to and modified from the original design diagram, created during the start of the project. Each design aspect has been researched, tested and discussed, throughout. The result of research, design, and testing has created the final design diagram shown in *Figure 40*, below.

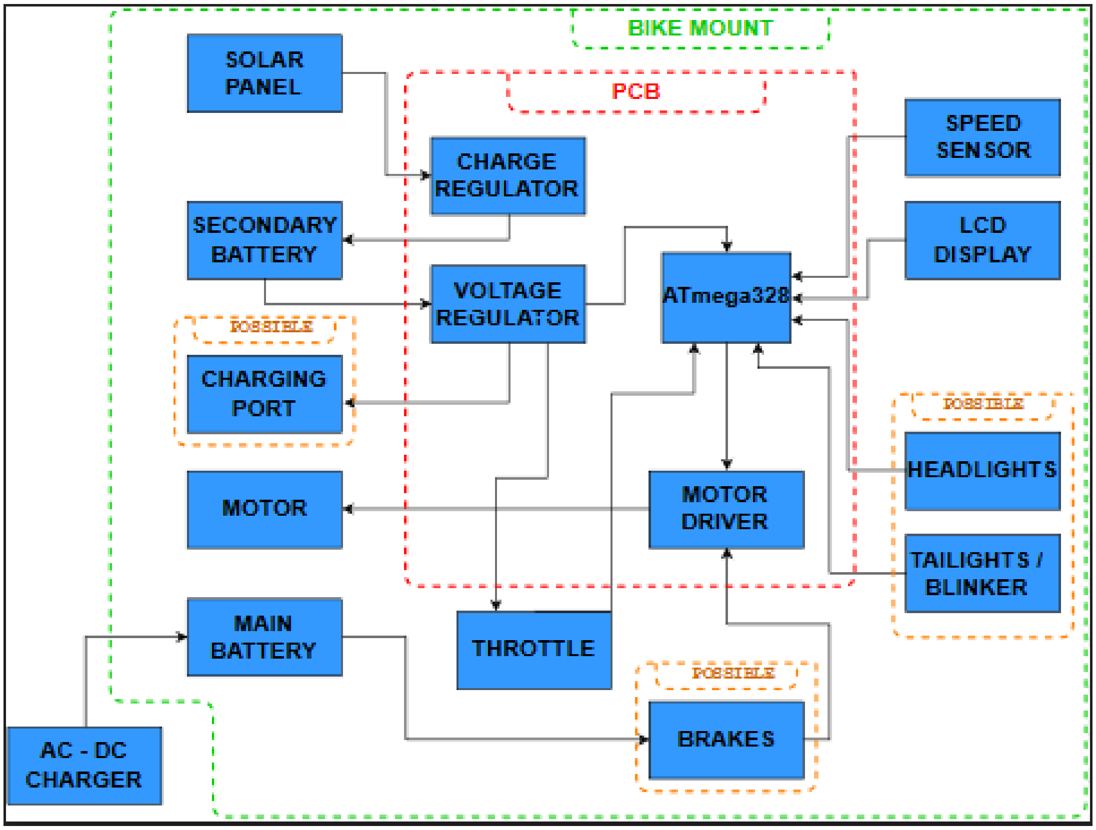


Figure 41: Final hardware design diagram

Referring to the above diagram, there are several blocks which are outlined and shown to be possible. These blocks are extra features which may be added to the design, as long as time permits. The main objectives are those not included under the possible design hardware, and therefore, will take priority. Not included in the final hardware design diagram is the location of the power switch which will be placed between the throttle and the ATmega328. The power switch is included with the throttle design, which is why a power switch is not displayed.

Overall, the hardware design, which was once a very simple design, has been modified to meet requirement specifications and design constraints. All components, excluding the AC to DC charger used to charge the main battery, shall be mounted to the bike chassis. The bike chassis is only to be considered in hardware design in that it is the source which hold all other components included in the design. Otherwise, the focus of the Solar Bike design is on the system which makes up the power, drive, and accessories associated. At the center of the hardware design lays the PCB, which associates all other hardware into one system. The motor, throttle, and main battery are considered to be one system, and the remaining hardware to be the other. However, through one common PCB, the two systems become one. Objectively, the Solar Bike design is to be produced with the ability to apply the hardware associated in the system to many other bike chassis styles, not just the chassis purchased by our group.

6. Project Software Design Details

The software portion of the Solar bike will be implemented on the ATMega328 microprocessor which will take in INPUTs and produce OUTPUTs that will be used within the code. The code will have three main tasks to carry out: producing a pulse width modulation signal to control the pulses going the motor, take in sensor input from the reed to calculate speed, and display the speed on to the LCD.

6.1 Software Functionality

The purpose of the software is broken down into two main tasks: reading/displaying information to the user and controlling the motor. This is done through three functions that are implemented into the ATmega328. The software environment that will be used to compile and transmit the code will be the Arduino Integrated Development Environment (IDE).

6.1.1 Sensor Input Calculation

The function of this task is to calculate the speed of the bike that is read from the magnetic reed sensor. The ATMega328 will take in the input read by the reed by using the “pinMode(reed, INPUT)” function. The reed will first need to be defined in the initial setup by connecting it to one of the analog input terminals and using #define. All constants like the circumference, the maximum reed count, and the timer setup will be defined. All timer interrupts including TCCR1A, TCCR1B, TCNT1will be set to 0.

The next part will be the function that calculates the speed. This function will be under the timer interrupt function ISR(TIMER1_COMPA_vect) for continuous processing. This will need to be continuous since the speed will need to be continuously updated. The reed value will be read in as a digital HI or digital LO using the digitalRead(). The function will then determine if the digital reed signal is either HI or LO and perform certain tasks. If the digital reed value is HI, the mph will be calculated by using the timer time as the variable or if the counter is not zero and is a positive value, then the reed count will decrement. If the digital reed value is LO, the timer will just increment in value unless the timer value is greater than 2000, then the mph will be set to be zero.

6.1.2 LCD Display

The function of this task is to display the values of speed that are calculated in the previously mentioned task. This will be a relatively simple function to create since it will be mainly formatting on to the LCD. The functions for formatting the LCD characters will be:

Table 16: Serial.write functions

Function	Reason
Serial.write(12)	This function clears the LCD
Serial.write(13)	This function moves down to the next line of the LCD
Serial.wirte("String")	This function will print a desired string on the LCD

The desired output on the LCD will be in a format similar to the below lines

Odometer Speed = 12.3 MPH
Battery: Charged

The first line will display the speed of the bike from the Sensor Input Calculation task. The phrase "Odometer Speed = " will be used to identify that this is where the user should look for the speed of the bike with the unit of miles per hour (MPH) of the speed following. The second line will be used for extra possible features such as battery status to inform the user the level of the battery being either "Charged" or "Low".

6.1.3 Pulse Width Modulation Motor Control

The last main task for the ATMega328 to execute is to generate a 3 Phase PWM that will control the motor. Referring to the PWM section of the Hardware Design, a 3 phase PWM will be used to control each phase that operates the gates to the N Channel MOSFETs. This signal will need to operate at a frequency of at least 10kHz. This frequency can be modified by using the function setPwmFrequency(pin, divisor). This divisor is determined by modifying the base frequency of each PWM pin. These pins include, 3, 5, 6, 9, 10, and 11. The base frequencies differ on each pin. For pins 3, 9, 10, 11 have a base frequency of 31250 Hz while the base frequency for pins 5 and 6 is 62500 Hz. To set a desired frequency is to divide the base frequency of the pin by the desired frequency and this will give you the divisor. Unfortunately, the divisor can only be specific values. For pins 9, and 10 the available divisors are 1, 8, 64, 256, and 1024 yielding the frequencies 31250Hz, 3906.25Hz, 488Hz, 122.Hz, and 31Hz, respectively. The Table X below shows the frequency for each divisor with respect to the corresponding pin.

Table 17: setPwmFrequency Divisor Frequencies

	Divisor						
Pins	1	8	32	64	128	256	1024
9 & 10	31250 Hz	3906 Hz	N/A	488 Hz	N/A	122 Hz	31 Hz
5 & 6	62500 Hz	7812 Hz	N/A	976 Hz	N/A	244 Hz	62 Hz
3 & 11	31250 Hz	3906 Hz	977 Hz	488 Hz	244 Hz	122 Hz	31 Hz

**One thing to mention about setting the pin output frequency is that this alters the frequency of the ATMega328s timers. This will mess up functions such as delay(), millis(), and the Servo library. This will be kept in mind when calculating the speed of the bike.

Since the desired frequency for the motor is roughly 8 kHz, we plan to use pins 5 or 6 to send the PWM signal out since the frequency with the divisor 8 is the closest value to our desired frequency (7812 Hz).

To generate the pulse width signal, a special, yet simple function will be used: AnalogWrite(). AnalogWrite sends a pulse to a desired pin. The value that goes into this function will be between 0 and 255; 0 being 0% of the duty cycle (always off) and 255 being 100% of the duty cycle (always on). This duty cycle can be modified depending on the value addressed in the function.

Another way of creating a PWM signal is to “manually” implement a PWM signal by repeatedly turning the pin Hi and Lo with delay in between each toggle. This delay can be made by using the “delayMicroseconds() function which will create a delay of how many microseconds the value in the function is, in other words, the value inside of the function is how many milliseconds the delay will delay for. These values that go into each delay function can determine the frequency and the positive pulse width of the pulse wave signal. The positive pulse width will be the duty cycle / frequency. The frequency can be calculated by adding both the Positive pulse width and the LO pulse width and taking the inverse of this number.

If this frequency is too low for the motor to run smoothly on without any jerks, then other alternatives to will be explored to generate a more consistent frequency and pulse. For example we would use the provided DC motor controller that came with the motor.

6.2 Algorithm Description

The code will be implemented in three different sections that will carry out each of the three tasks. With each task, all constants and variables will be defined. All initial setups for INPUTs and OUTPUTs and any library and headers that will be used will be initialized in the start of the code. Each task will be will be broken down and have its procedure listed to show what the processor will be compiling in order.

6.2.1 Speed Calculation

Purpose: To continuously read and calculate the speed using ISR(TIMER1_COMPA_vect) function.

- START
- Read in the digital reed signal
- If there is a voltage coming from the reed sensor
  - If the counter is equal to 0, the calculate the mph and reset the timer back to 0 and reset the counter back to max value Else if the counter is greater than 0, decrement the counter
- If the timer is greater than 2000, set the mph to 0
- Else increment the timer
- END

6.2.2 Display Function

Purpose: To display the information to the user.

- START
- Clear what is on the display
- Print the Odometer phrase
- Print the speed that was calculated in the first function
- END

6.2.3 PWM Control Function

Purpose: To generate and transmit a throttle controlled PWM signal to the motor driver.

- START
- Read in the analog throttle voltage value and convert it into a digital and return the digital value
- Jump to the loop and enable the digital output pin to be HI and the create a delay using the delay microsecond function and have the value be the pulse width multiplied by the input of the throttle over the maximum throttle value
- Set the digital output of the PWM pin to be LO and use the delay microsecond function with the value of the value put in the first delay subtracted from the inverse of the frequency. This would achieve our LO duty cycle time
- The function will just need to repeat itself until an interrupt halts it.
- END

6.3 Coded Flow Chart

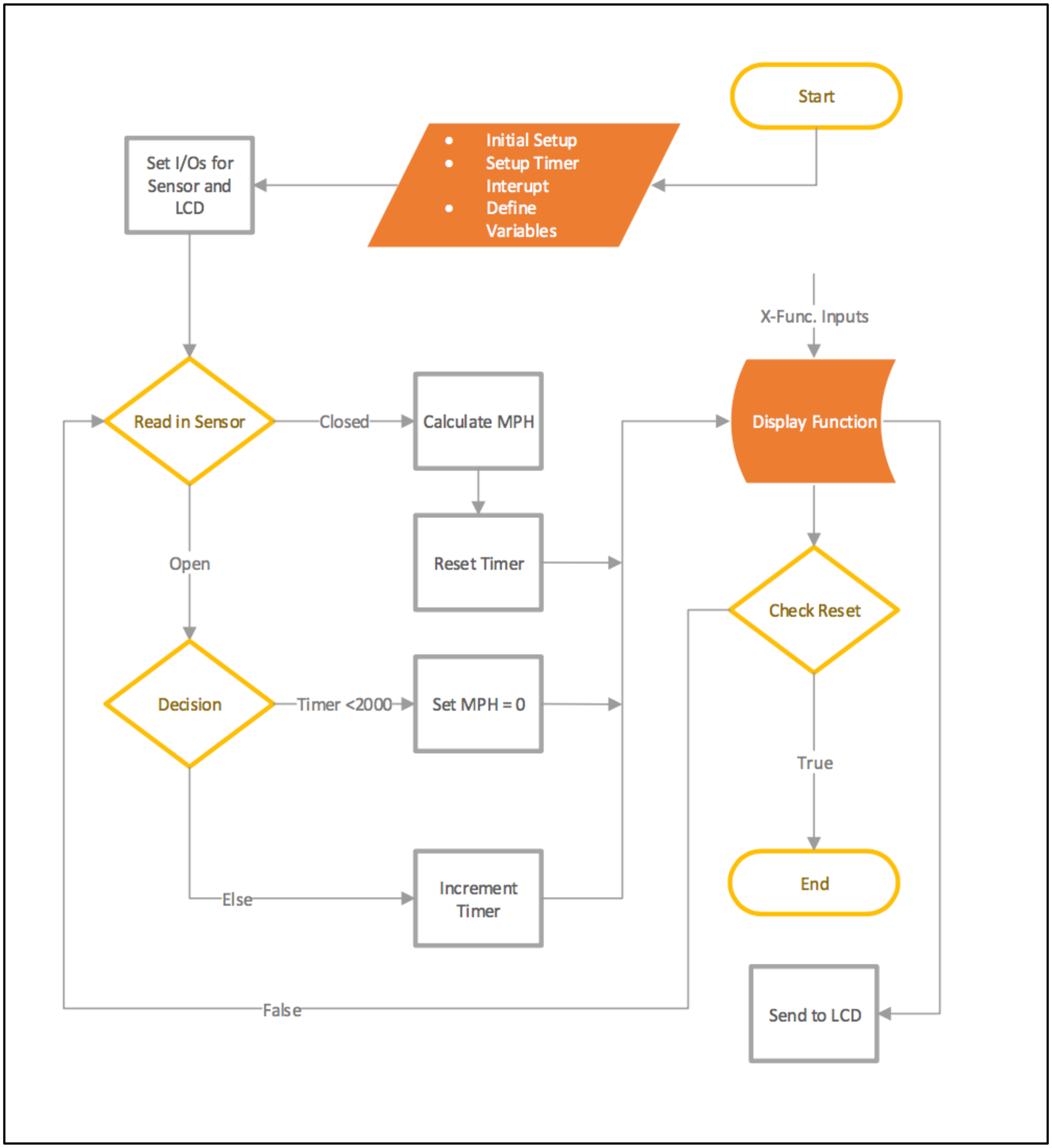


Figure 42: Speed Calculation Flow Chart

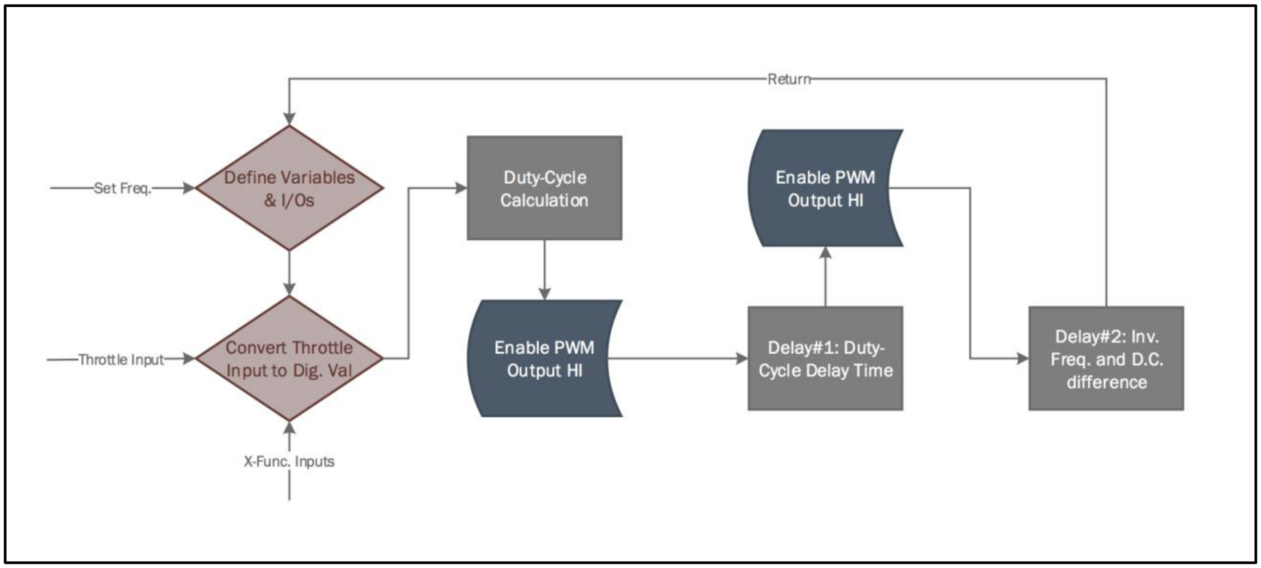


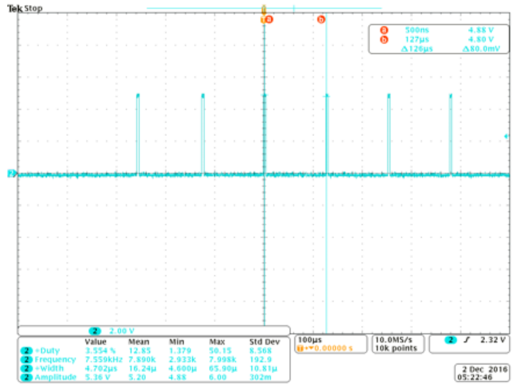
Figure 43: PWM Generation Flow Chart

6.4 Control Signal Testing

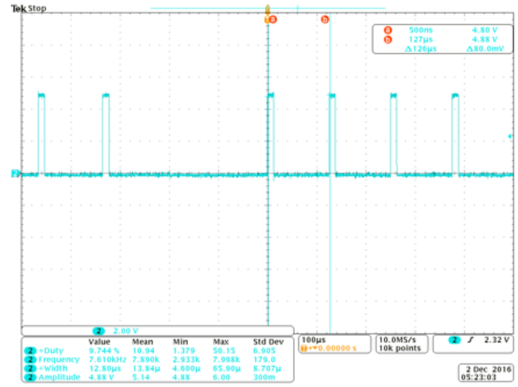
Like the hardware, testing on the software functionality is necessary to ensure that the tasks of the programming is carried out correctly. For this testing, the ATmega328 will be used in this for testing, but on the Arduino UNO board for testing purposes. Note that the Arduino board will not be used in the final design of the project.

6.4.1 PWM Throttle Control

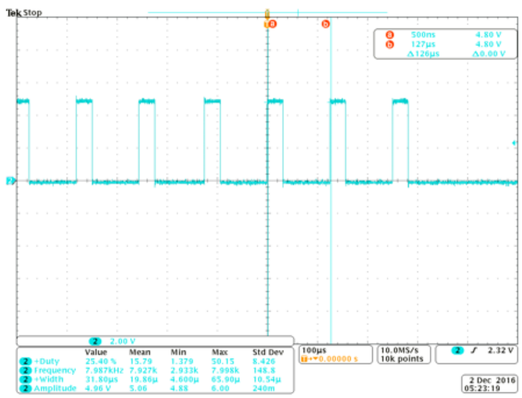
The first test to perform is to make sure that the PWM signal being generated from the MCU is being properly produced and able to be controlled by a throttle. To simulate a throttle, an adjustable DC voltage source will be connected to the corresponding throttle analog input. An Oscilloscope will be used to analyze the output of the digital output terminal where the PWM signal has been assigned. Initially, the throttle will not be used and will have a set digital throttle by coding in the throttle values. This will test to see if a PWM signal can be produced. The digital throttle values will be set to have the duty cycle set to 5%, 10% 25%, 50%, and 95%. These values will represent zero speed, low speed, medium speed, high speed, and top speed, respectively. Another parameter to check would be the frequency of the pulses, for this, we are using 8000 Hz as the set frequency. Below are waveforms of each duty cycle value.



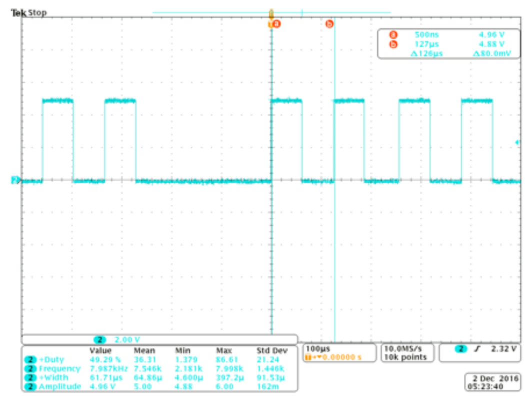
PWM 5% Duty Cycle



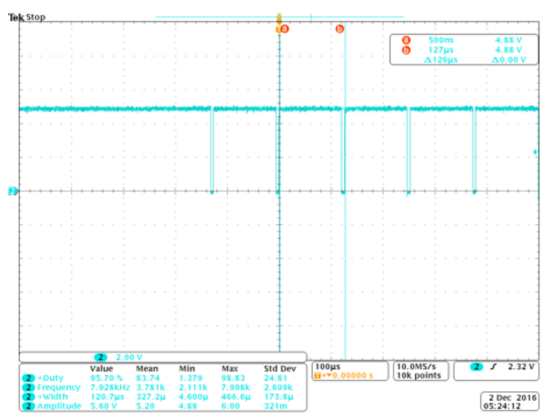
PWM 10% Duty Cycle



PWM 25% Duty Cycle



PWM 50% Duty Cycle



PWM 95% Duty Cycle

Figure 44: PWM Duty-Cycle Oscilloscope Readings

As shown, the duty cycle should relate to the waveform where the smaller the duty cycle percentage, the shorter the positive HI signal should be and the longer the LO signal should be. These waveforms show that the programming for the MCU is performing correctly. The next test will be throttle testing, which for testing purposes, will be an adjustable DC supply. This DC voltage will be varied between values from 0V to 5V, the same parameters as the analog throttle. The positive terminal of the supply will be connected to the define analog input terminal on the

Arduino UNO board while the negative terminal will be connected to the common GND of the board. A modified version of the code with the throttle control additions will be compiled and uploaded to the board. Adjusting the voltage from 0V to 5V should show an increase in the positive pulse width on the oscilloscope while keeping the same frequency. Note that the voltage of the supply when reaching 5V could cause distortion in the PWM signal. To counter this, if it may occur, is to increase the throttle divider within the code by a small factor (roughly 10 but no more than 15) so that the equations in the code do not read a full 100% duty cycle.

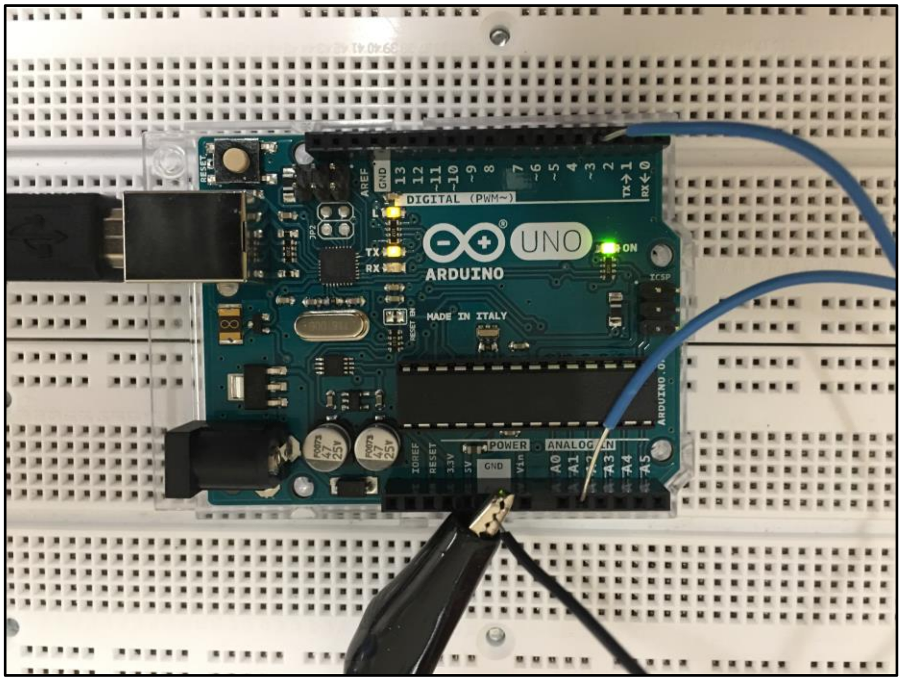


Figure 45: Arduino Throttle Testing Setup

When setting the pseudo throttle DC supply to 0V, after running the code, the oscilloscope waveform should show a PWM signal with a duty cycle of near zero, in other words, there should be a slight pulse with a small pulse width. Adjusting the voltage, the pulse width should be getting larger as the throttle voltage increases. When nearing 5V, the pulse should be nearly max at a full 125 microseconds (assuming the frequency in the code is set to 8 kHz). This shows that the throttle code works efficiently.

One of the issues ran into while testing the throttle input was that the oscilloscope was reading a different value for frequency then what was set in code. After some changes and experimenting, we realized that the processing time for the loop was being lagged since the duty-cycle calculation was done within the loop for the PWM generation. This was causing the processor more time between enabling the HI for the output digital signal when looping back after enabling the LO signal. This delay produced a 5 kHz frequency on the output signal, and also did not allow the duty-cycle to reach the full 95%. This would have been a major issue in actual operation since the average of the analog voltage being read by the motor to be lower than commanded to be causing the operator not to be able to reach the max speed of the bike. This has been corrected by removing the duty-cycle calculation from the loop and placing it within initial setup phase of the code. After testing again, the frequency was reading the correct 8 kHz that the code has set it to.

6.4.2 LCD Testing

Testing the LCD for is key to allow the user to be able to see the correct speed that the bike is traveling at. This is done through calculation that are in the programming of the board. To test if the LCD is properly connected, a Serial.write("Hello") will be needed to be programmed to see if the LCD is properly written to. The LCD should display "Hello" showing that the LCD is properly connected and functioning within the program.

6.4.3 Reed Sensor Testing

In order for the MCU to display the correct speed of the bike, an input from the reed sensor is necessary to show the time interval between each full rotation. This time is used to calculate the speed. To test for the reed sensor, a simple code is needed to measure the value of the reed signal by the analogRead() function and display the value by printing it. This value that should be printed is roughly 1023. If this value is read, then the reed is being properly sensed by the program.

6.4.4 Frequency Testing

The motor that will be used will have a certain threshold frequency for smooth operation. If the frequency is too low, then the motor will jerk the and only rotate in a pulse-like manner. If the frequency is too high, then the motor will either always run at full throttle since the HIGH duty cycle will always be read and ignore the pulse width or it will just not run at all. So finding the right frequency is necessary to ensure that the motor will run and have a consistently smooth operation.

When the PWM is being generated from the ATmega, the set frequency is not the same is what is being outputted. This is believed to be caused by the processing time of the other functions in the code that are simultaneously compiled with the PWM code. Typically, the frequency outputted in the PWM will be lower to a degree than what was set in the code. To compensate for this, the frequency declared in the code will need to be higher to achieve the desired frequency on the output. This test will show the output frequencies of the PWM signal compared to the set frequencies in the code.

Table 18: Programmed Freq. vs Output Freq.

Programmed Frequency (Hz)	**Output Frequency (Hz)**	**Output vs Programmed (Hz/Hz)**
1200	820	0.6833
2000	1400	0.7000
3000	2900	0.9667
4000	3820	0.9550
5000	4800	0.9600
6000	5740	0.9567
7000	6650	0.9500
8000	7540	0.9425
9000	8400	0.9333
10000	9300	0.9300
11000	10200	0.9273
12000	10980	0.9150
13000	11800	0.9077
14000	12620	0.9014
15000	13480	0.8987
16000	14250	0.8906
17000	15100	0.8882
18000	15800	0.8778
19000	16600	0.8737
20000	17190	0.8595
21000	18100	0.8619
22000	18800	0.8545
23000	19500	0.8478
24000	20300	0.8458
25000	20750	0.8300

As observed, the higher the frequency, the larger the difference between the frequencies becomes. The trend on graph *Figure 45* below is a linear trend line with a slope of 0.8363 Hz/Hz. This means that on average, the ratio between the programmed frequency and the output frequency is roughly 0.8363. This will be useful information since when we determine the motors operational frequency, we know what multiplier will give us a rough estimate on what to set the frequency to within the code.

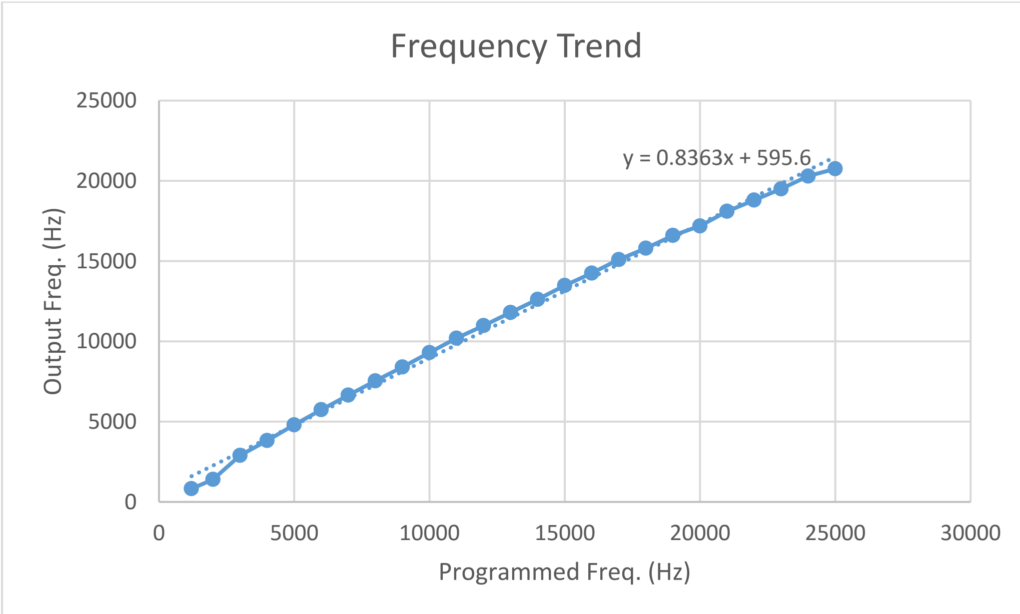


Figure 46: Frequency Trend Graph

6.5 Additional Software Features

There are some additional features that we have thought to add to the project. Some of these features can be implemented by adding different functions and additions to the set code on the MCU. These features will add benefit to the operator of the bike while most will be more of an informative feature. These features will not be counted as the expected features to include in the final design. These additional features will only be added to the final if seen fit to add and the team has the available time to add said features before the final presentation of the project at the end of Senior Design 2.

6.5.1 Battery/Solar Voltage Monitoring

Battery sensing is a typical feature that most machines/vehicles offer. This notifies the user whenever the battery is at a level that is too low for the motor or any other circuitry or equipment on the system to run properly one. For voltage sensing on the solar panel, the user would need to know if the solar panel is producing a sufficient voltage to charge the battery that the MCU is being powered by. This would inform the user if any failures on the solar panel occur.

How we would implement voltage monitoring in this system would nearly be all software modification. There would be the need of a lead lines from the battery or solar panel to one of the analog inputs of the MCU by dividing the voltage with a resistor series to avoid overloading the MCU analog pin with too high of a voltage. This voltage will then be read into the MCU by using the analogRead() function, converting it to a percentage, and then multiply it by the 100% Vcc value. This value can either be directly sent and displayed on the LCD or used as a case variable to either show on the LCD “FULL” or “LOW BATTERY” on the LCD screen through the display function that is already implemented.

6.5.2 Distance Traveled

One feature that most people when traveling or riding a bike wonder about is 'how far have I traveled?' On nearly every vehicle that is on the roads today will have some sort of odometer, whether it be digital or analog controlled, to measure the distance traveled by the car. This measurement usually has a reset button so that the operator can set the start of a trip to be informed of how much distance was traveled when reached the destination. This is a great alternative to using applications on phones that use GPS to determine how far the phone has traveled (i.e. GoogleMaps). This feature would ultimately reduce the data use and elongate the battery life of the user's cell phone since this feature will not use a data from GPS at all and will be determined by the reed sensor input digitally.

This would be a feature that we would consider adding on to the bike since it would be a very simple addition. Adding it would be fully software and require minimum algorithm modification. It would be a simply count of each wheel rotation, through reading the reed signal input, and multiplying it by the wheel circumference. This calculation would consistently be updating to have real time distance updates that would be displayed on the LCD by using the Display function defined before.

6.5.3 BIST

Built-In Self-Tests (BIST) is testing to see if there is any program runtime error. The purpose of BISTs is to reduce the complexity, which in turn decreases the cost and reduce reliance upon external testing for program errors. This can improve the systems reliability and can lower the repair the cycle times. BIST can also increase the safety of a vehicle by providing the operator with failure analysis of if a wire is broken, a light is out, the motor is malfunctioning, the battery is low of voltage, and many more failures that can occur over time with use of the vehicle.

In this project, the BIST that are considered in being added as an additional feature will be a program runtime error indicator. This indicator will be fully code generated to give an error message if anywhere in the code does not compile correctly or if the algorithm is stopped for any given reason. These errors would then be informed to the user through use of displaying on to the LCD.

6.5.4 Cruise Control

One of the most prominent features on any motorized vehicle is the option for speed control. Speed control is a luxury feature designed to operate automatically, under certain conditions, keep the speed of the motor at a predetermined rate. This would be done ultimately through coding with the addition of an external button that would have to be added to the hardware design. This button would act as the enable/disable control for the cruise control operation. This button will be realized as an analog input to the ATMega MCU and will be powered by the 5V input powering the MCU.

The software for this feature will include two if cases that will be determined by a Boolean parameter. This Boolean parameter will be determined by if the control signal for cruise control has already been enabled or disabled. If the Boolean cruise control value hasn't been enabled but the button is pressed, then the MCU will run an if case algorithm that will take the current duty cycle value from the PWM generator function and keep that value stagnant, disable the throttle variation from the duty cycle function, and then set the Boolean cruise control value to enabled. If the Boolean cruise control signal has been enabled but the button is pressed, then the MCU will run another if case algorithm that will reset the duty cycle value to have throttle variation calculated in, and set the cruise control Boolean value to disabled. In lighter terms, the button will enable or disable cruise control with every other push of the button.

7. Project Testing and Prototype Construction

The intent of prototyping is to create a real-life model of the system to be tested upon for functionality. These tests would be conducted on the hardware as well as the software portion of this project.

7.1 Prototype PCBs

Table 19: Prototype PCB Overview

Part #	10003	10002	10001
Manufacturer	OSH Park	OSH Park	OSH Park
Dimensions(inches)	2.187 x 1.949	1.487 x 1.2	1.58 x 0.949
Cost (3 boards)	$21.30	$8.90	$7.50

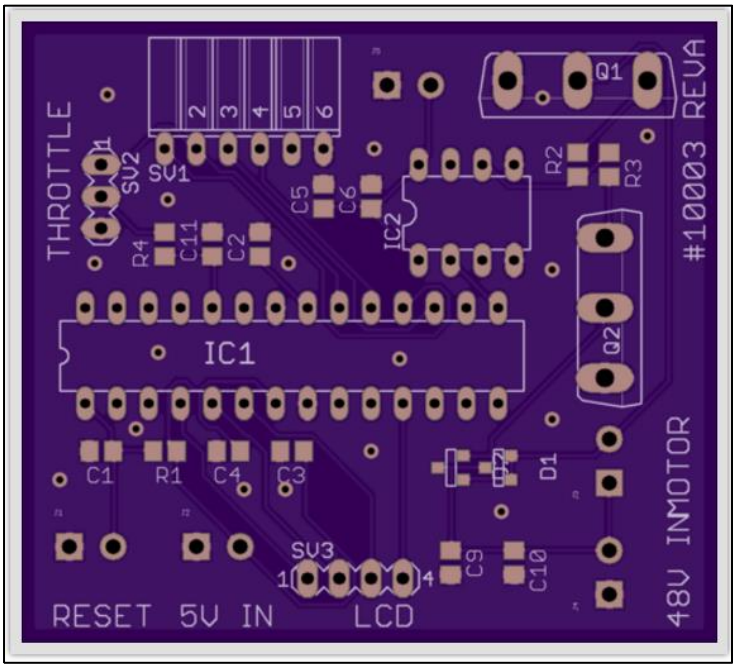


Figure 47: MCU and PWM PCB Prototype

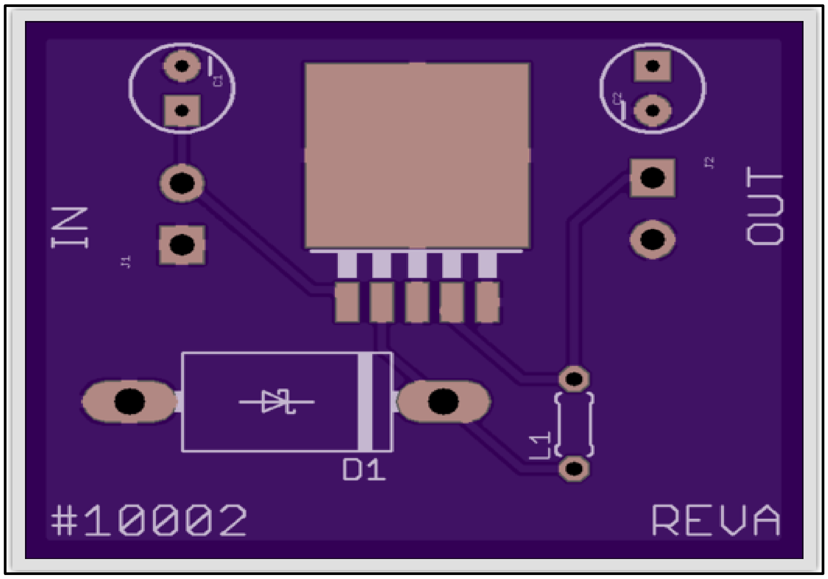


Figure 48: Switching Voltage Regulator PCB Prototype

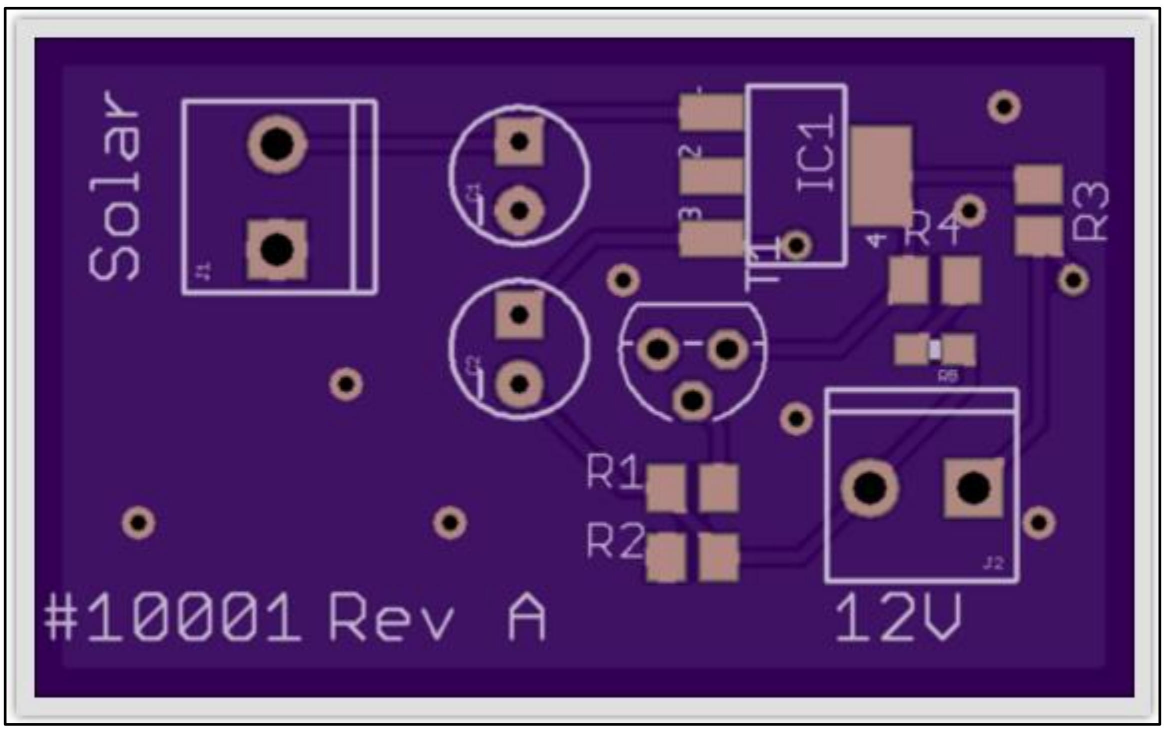


Figure 49: Solar Panel Charge Regulator PCB Prototype

7.2 Hardware Testing

Hardware testing of the motorized subsystem will ensure the motor is working properly. All hardware testing will first be simulated in a circuit simulation software, such as Multisim™. Simulation will display any unseen errors in circuit design and allow for correction before physical testing of hardware, which avoids potential damage to hardware components.

Hardware testing of the solar panel will be limited to outdoor testing and will be tested on various days to record characteristics of cloud cover and shadow castings. Results obtained from outdoor testing will be used indoors and modeled to the circuit using the DC power supply provided in the laboratory.

Motor Testing

Objective: The objective of testing the hardware is to ensure that the hardware on the bike is working properly for safe use. This test will require that the user to use a Digital Multimeter with a 20V setting with the positive probe in the VOhmHZ terminal and the negative terminal is connected to the Common terminal.

Environment: A majority of hardware testing will be performed at UCF's Senior Design Laboratory located in Engineering 1, Room 456. The laboratory equipment provided at each station of the lab includes:

- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator, 25 MHz
- Tektronix DMM 4050 6 ½ Digit Precision Multi-meter
- Agilent E3630A Triple Output DC Power Supply

Procedure: To test the hardware portion of the Solar bike, procedural steps will be as followed:

1. Check to ensure that all connections are connected to the correct connector/terminal and are not free or loose.
2. Use the multimeter to measure the battery with the positive lead on the positive terminal of the battery and the Common lead on the negative terminal of the battery. The meter should read a value of somewhere close to 24V. If the voltage is under 12V, the batteries will need to be charged.
3. Connect the oscilloscope probe to the positive terminal leading to the motor. Connect the corresponding ground to the RTN line of the battery or to the negative end of the motor.
4. Steadily, increase the throttle until the motor starts to move. Keep the throttle at this point to achieve a steady and low speed. The oscilloscope wave forms should all be a Pulse Width Modulation and should all read a max voltage of near 24V and a duty cycle of near 5-10%. The width of each pulse should read somewhere around 6 to 13 microseconds. This is the low speed signal.
5. Increase the throttle close to full throttle to generate a high speed on the wheel. The oscilloscope should be reading a duty cycle in the range of 80-90% with a pulse width near 125 microseconds. This is the high speed signal.

Conclusion: If the readings on the oscilloscope match near the procedure, then the motor should work as intended. If any ready is off, then error may exist.

Throttle Testing

The first contribution to testing of the throttle included testing related to the hall sensor output. As shown in *Figure 49*, below, testing was performed by connecting a positive five-volt source to Pin 6 and connecting Pin 5 to ground. The output of the hall sensor was measured between the output terminal of the hall sensor (Pin 4) and ground (Pin 5).

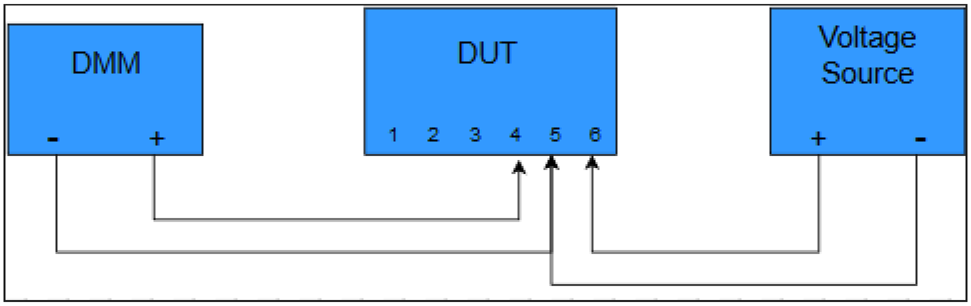


Figure 50: Device Under Test diagram for Hall sensor testing

Table 18, below uses the pin numbers assigned in *Figure 22**:** Pin assignment for throttle control harness* to portray the output voltage of the hall sensor throttle with respect to the percentage the throttle is turned towards the fully ON position. Testing was performed by first recording the angle created between the throttle fully OFF and the throttle fully ON. The angle was then split into 4 sections, each of which corresponded to an additional 25% of the throttle percentage ON. Of course these percentages are estimated, however still serve as reputable data points. Reference can be made to Section 5.1 under the Throttle subsection to further understand how throttle testing was performed.

Table 20: Throttle percentage ON versus Hall sensor output

Throttle Percentage ON	Pin 4 (Output)	Pin 5 (Ground)	Pin 6 (Input)
0%	0.85 V	0 V	4.98 V
25%	2.18 V	0 V	4.98 V
50%	2.45 V	0 V	4.98 V
75%	2.75 V	0 V	4.98 V
100%	4.21 V	0 V	4.98 V

Next, testing for the battery level display, included on the throttle, was performed. *Figure 50* displays the testing set-up for the battery level display. A varying voltage was supplied to Pin 3 as the reference voltage for the battery level display and Pin 5 was connected to ground. The illumination of the corresponding LEDs on the battery level display indicated which input voltage resulted in various battery levels.

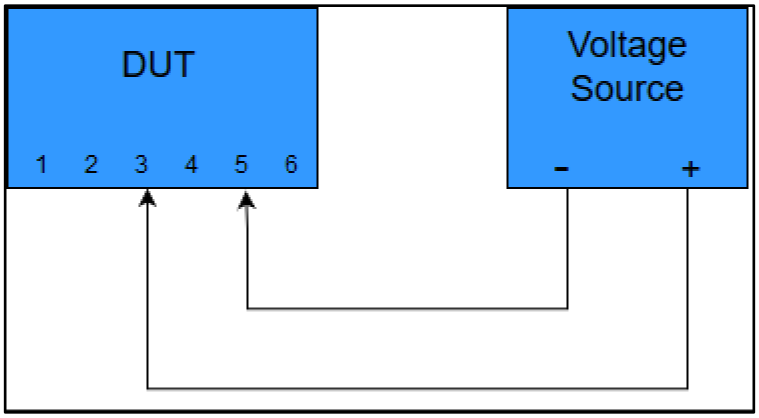


Figure 51: Device Under Test diagram for battery level display testing

Table X displays the voltages at which the LED corresponding to each of the battery states (EMPTY, HALF, and FULL) are illuminated. The voltage associated with the EMPTY state of the battery level display is the point at which the LED is dimmed until it is finally shut off, however at this point the motor will no longer run. As previously tested, the motor requires a minimum of 36 V to rotate. Therefore, the minimum voltage required to illuminate the EMPTY state LED on the display is only for reference, and it should be noted that the motor will not run while the EMPTY state LED is starting to dim.

Table 21: Battery level display output versus reference voltage input

Battery Level Display	Minimum Voltage Required
None	0 V
EMPTY	29.85 V
HALF	46.87 V
FULL	49.89 V

Solar Panel

Table 20 below shows the voltages and currents of the output by the solar panel. In this test, two solar panels will be measured in various conditions that could be applied during operation of the bike. These conditions will be the time of the day with the two to compare will be both manufactured by Gates That Open, LLC, Part numbers: RB510 (5W) and RB507 (10W). The currents and voltages will be measured with no load. Temperature is measured in Fahrenheit.

Table 22: Solar Panel Voltages/Currents

Conditions	Morning (≅68° Little Nat. Light)	Midday (≅79° Full Nat. Light)	Evening (≅75° Little Nat. Light)	Night (≅72° No Nat. Light)
RB510 (5W)	19.28V 0.02A	21.50V 0.13A	13.6V 0.00A	-0.04V -0.0502A
RB507 (10W)	20.26V 0.02A	20.5V 0.27A	14.8V 0.00A	-2.02V -0.0702A

<u>Switching Regulator</u>

Testing performed for the switching voltage regulator, located between the secondary battery and the ATmega328, is outlined in *Figure 51*, below. The voltage source used during testing is set to model the battery which will be used in the final design, and the DMM is used to read the output voltage that will be seen by the ATmega328 upon finalization.

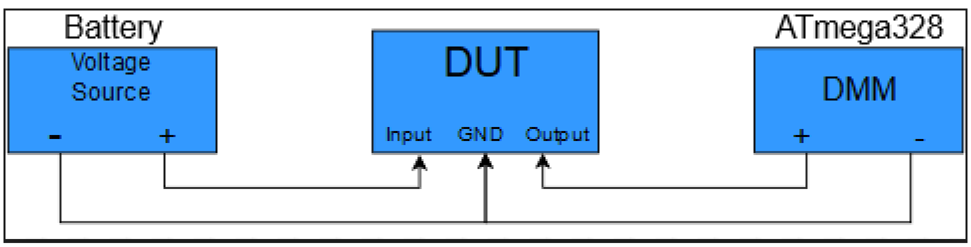


Figure 52: Device Under Test diagram for switching regulator testing

As stated in Section 5 as well as in the requirement specifications of this report, the objective of testing is to ensure that the five-volt output of the voltage regulator is at a minimum of five volts, and stays within a 2 mV differential as the input voltage is varied from each extreme of the battery's output voltage. *Table 21*, below, displays the output voltage of the switching voltage regulator, with respect to the varied input voltage. A fully charged battery will output around 12.6 volts, which is the maximum voltage the regulator shall see. When the battery is completely discharged, the resulting output voltage of the battery will be near 10.5 volts. The variance of the output voltage of the switching voltage regulator is measured between the two extremes, 12.6 volts and 10.5 volts. The result is a fluctuation of 1.7 mV, which falls inside of the requirement to be less than 2 mV variance in output voltage.

Table 23: Input vs. output voltage- switching regulator

Input Voltage	Output Voltage
20 V	5.0367 V
12.6 V	5.0356 V
12 V	5.0354 V
10.5 V	5.0349 V

Solar Charge Regulator:

The testing setup related to the solar charge regulator is shown in *Figure 52*, below. Since the testing was performed indoors, the Agilent E3630A Triple Output DC Power Supply was used in place of the solar panel in order to simulate the variance of output voltage associated with the solar panel. The output voltage, which would be seen by the battery, was recorded using the Tektronix DMM 4050 6 ½ Digit Precision Multi-meter. If time permits, further testing will be conducted with the physical battery in place of the DMM, and possibly with the solar panel connected as an input.

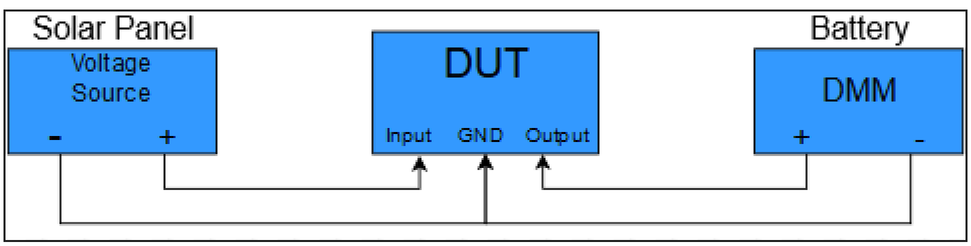


Figure 53: Device Under Test diagram for solar charge regulator

The objective of testing performed on the solar charge regulator is to ensure that the output voltage of the solar panel does not exceed 13.6 volts, as well as limits the current that is provided to the battery after a charged voltage of 12.6 volts is achieved. *Table 22*, below, displays the output voltage associated with the various input voltages that may be applied by the solar panel, depending on conditions.

Once the circuit was set up, two conditions were tested. The first test performed was assuming that a single 12-volt solar panel will be used as the input source. The second, performed as if the input source is two 12-volt solar panels in series, which would imitate a 24-volt panel.

Initial input voltage equal to 48 volts was applied to the input of the solar charge regulator. The reason for such a high initial voltage is that to set the trim pot resistance, a voltage much higher than required will allow for setting of the maximum output voltage allowed. The resistance of the trim pot was measured after the desired results, of a maximum output voltage equal to 13.6 volts, were displayed. The value of the trim pot measured to be equal to 997 **Ω**. It is shown in *Figure*

52 below that as the voltage is varied from 48 volts down to 15.5 volt, the output stays constant at the desired voltage.

Assuming that the final design incorporates the use of two 12 volt solar panels in series, the results shown between the input voltages between 24 volts and 48 volts confirm that the charge regulator design will meet requirements, as far as charging voltage requirements. Current requirements cannot be confirmed until testing is done using the physical solar panel as an input.

If a single 12-volt solar panel is used in the final design, results included between 17 volts and 13.6 volts will be used. The maximum voltage that may be produced by a single 12-volt solar panel is approximately 17 volts, however higher voltages were tested in the case that voltage rises above this approximate value. For input voltages between 17 volts and 14.2 volts, the solar charge regulating circuit will produce output voltages capable of charging the battery. However, as voltage drops below 14.2 volts, the output voltage drops below the required minimum voltage to charge the battery chosen. Therefore, a comparator circuit must be introduced, which will allow the solar charge regulator to perform charging at input voltages of 14.2 volts, or higher. At voltages lower than 14.2 volts, the comparator circuit will bypass the charge regulator circuit and directly charge the battery through solar panel voltage.

Overall, testing of the solar charge regulator has been successful and confirmed that output voltages are as expected for the case where two solar panels are wired in series. Testing performed assuming a single solar panel input has proven to require modification in order to meet expectations.

Table 24: Input vs. output voltage - solar charge regulator

Input Voltage	Output Voltage
48 V	13.65 V
23 V	13.65 V
17 V	13.65 V
16.5 V	13.65 V
16 V	13.65 V
15.5 V	13.65 V
15 V	13.42 V
14.5 V	12.9 V
14.2 V	12.6 V
13.6 V	12 V

MOSEFT Driver

This test is to determine if the MOSFETs will match the frequency and duty-cycle of the outputted PWM signal generate by the ATmega microcontroller. In this test, we will be using a 1 kOhm resistor to simulate the motor impedance and the DC supply for this will be tested at 20V. An oscilloscope will be used to measure the amplitude, duty-cycle, positive pulse width, and frequency of both the output of the MCU and across the 1 kOhm motor impedance resistor. FigureX below is a rendering of the setup for this test.

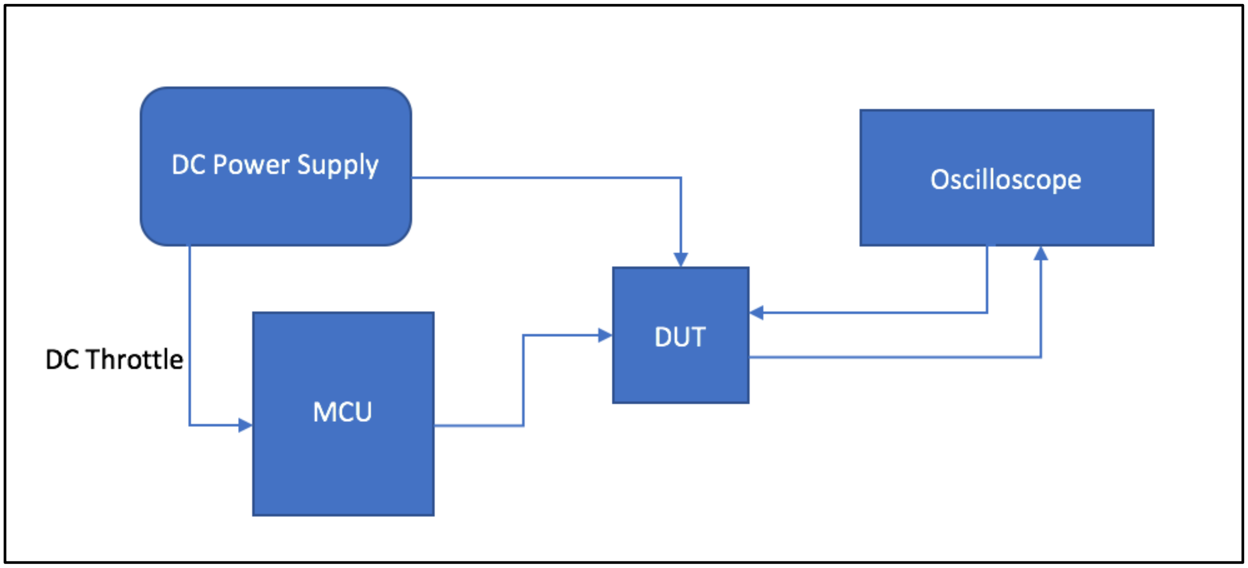


Figure 54: MOSFET Test Setup

In this test, we will be varying the input throttle via a DC supply source to simulate the throttle. We will be taking the measurements off the oscilloscope for comparison between the two outputs.

Table 25: ATmega Signal MOSFET

ATmega Signal	Throttle Voltage	Frequency	Positive Pulse Width	Duty-Cycle	Amplitude
No speed	0V	7.998 kHz	4.714 usec	3.727%	5.80V
Low Speed	1.06V	7.998 kHz	31.80 usec	24.14%	5.00V
Medium Speed	2.10V	7.998 kHz	59.80 usec	47.57%	5.00V
High Speed	3.44V	7.998 kHz	94.37 usec	77.34%	5.00V
Full Speed	4.21V	7.998 kHz	115.30 usec	97.94%	6.00V

Table 26: Motor Signal MOSFET

Motor Signal	Throttle Voltage	Frequency	Positive Pulse Width	Duty-Cycle	Amplitude
No speed	0V	7.988 kHz	4.352 usec	3.347%	20.00V
Low Speed	1.06V	7.968 kHz	32.10 usec	25.16%	20.00V
Medium Speed	2.10V	7.999 kHz	59.93 usec	47.83%	20.00V
High Speed	3.44V	7.968 kHz	92.78 usec	75.26%	20.00V
Full Speed	4.21V	7.968 kHz	113.30 usec	96.51%	20.00V

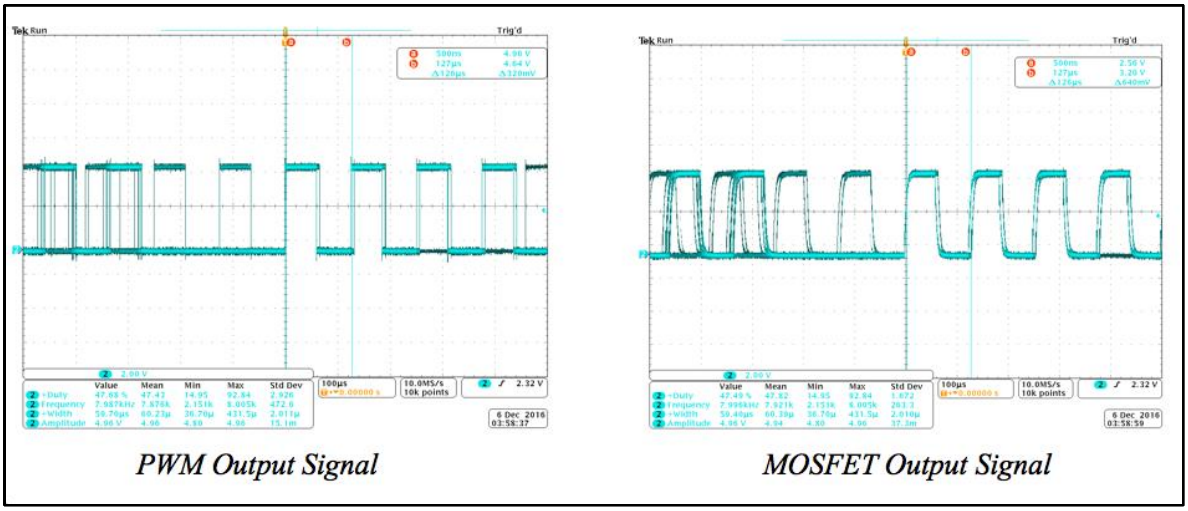


Figure 55: PWM & MOSFET Output Waveforms

7.3 Software Testing

Testing the software is crucial to ensuring the system will perform and measure properly. The system will need to be able to power on correctly, be able to read in the sensor signal, and precisely give the delta time between each sensor signal. The processor will also need to be able to correctly display the calculated speed on the LCD display, and the MCU will need to correctly generate a PWM signal that matches the desired frequency. In addition, the PBITs will need to correctly display any errors that occur, if they were to, on the LCD display.

Objective: The objective of this test is to ensure that the software is completing and processing the coded task successfully.

Environment: Most of the testing for the software portion of the prototyping will be at UCF's Senior Design Laboratory. Personal computers (Mac or PC) running the Arduino IDE will be used to monitor and edit the program code of implemented on the microcontroller.

Procedure: To test the software portion of the Solar bike, procedural steps will be as followed:

1. Power on the processor and wait for display to show the correct display of characters. The first display shown should read "Hello".
2. Check to see if the display turns off and sets up the MPH display on the first line and any additional features on the second line.

3. Keeping the bike stationary, the display should read “MPH = 0”
4. Line the sensor on the wheel with the one on the chassis and turn the wheel 5 complete turns and record the time.
5. Convert this time using mph = (284*circumference)/(delta time) and compare to the speed displayed on the LCD.
6. If these speeds match up, then the algorithm is properly measuring the delta time. In the case that these speeds do not match within a 5% tolerance, then the test may need to be ran again or further investigation within the code needs to be taken.

PWM Testing

1. Using a test PWM function, connect the oscilloscope to the desired output terminal where the PWM signal will be generated.
2. Set the frequency of the PWM (within the code) to 8 kHz and set the positive duty cycle to 50%.
3. Observe the waveform on the oscilloscope. This waveform should be a PWM with a HI 5V amplitude for roughly 62.5 microseconds and a LO 0V amplitude for 62.5 microseconds.
4. Make sure to measure the frequency of the waveform to match closely to 8 kHz.

Conclusion: If any of these waveforms or displays do not generate what is expected, further troubleshooting within the code will be needed. Assuming all procedures are done correctly, operation of the bike should be acceptable.

8. Administrative Content

This section of the document will be to show how well the team can manage their time and budget on this project. The time and due dates for each milestone will be spread from the Initial Document to the Final Presentation time. The budget will be decided by our sponsor and will be listed to show each expense that makes up the Solar bike.

8.1 Milestone Discussion

This section will break down the milestone completion of the project. It will show the start from the initial idea stage during Senior Design 1 in the Fall2016 semester down to the final project presentation at the end of Senior Design 2 in the Spring2016 semester.

Table 27: Project Milestone

Number	*Task*	*Start*
Senior Design 1		
1	**Idea**	8/22/2016
2	**Project Selection & Role Assignments**	8/29/2016
3	**Project Report**	
4	Initial Document – Divide & Conquer	9/9/2016
5	Table of Contents	19/3/2016
6	First Draft	10/10/2016
7	**Research, Documentation, and Design**	
8	Solar Panel	9/10/2016
9	DC Motor	9/10/2016
10	Micro Controller	9/10/2016
11	PCB Design	9/30/2016
12	Power Supply	10/1/2016
13	**Document Review Meeting (w/ Dr. Wei)**	11/16/2016
14	**Order Parts**	11/16/2016
15	**Final Document Due**	12/6/2016
Senior Design 2		
16	**Assemble Prototype**	1/16/2017
17	**Testing and Redesign**	TBD
18	**Finalize Prototype**	TBD
19	**Peer Report**	TBD
20	**Final Documentation**	TBD
21	**Final Presentation**	TBD

8.2 PCB Vendor

Choosing a vendor to construct our design on to a PCB is a careful consideration. They must have a great, reliable reputation as well as above acceptable quality products that can be produced within a timely manner and at reasonable cost. Keeping this in mind, the PCB vendor that will take on designing our board will be OSH Park. We believe that they are a reputable choice because of our own experience with using them to create extracurricular PCB designs. With the outstanding production of these extracurricular boards, we knew that we could entrust OSH Park to design our boards for our project.

The prices for producing PCBs from OSH Park are as follows:

- The Standard 2 Layer Order - $5 per square inch
    - Includes three copies of the design; order is in multiples of three
    - Ships within 12 calendar days
    - Board Thickness: 63mill (1.6mm)
    - Copper Weight: 1 oz
- The Standard 4 Layer Order - $10 per square inch
    - Includes three copies of the design; order is in multiples of three
    - Ships within 2-3 Weeks
    - Board Thickness: 63mill (1.6mm)
    - Copper Weight: 1 oz (outer), 0.5 oz (inner)

*OSH Park does give the option for Super Swift Service for the Standard 2 Layer boards at a price for $89 extra. This would have the boards shipped within 5 business days opposed to the standard 12 calendar days. Otherwise, all shipping cost would be $0 unless opted for sooner delivery time at expedient rates.

Specifications:

- All 2 layer boards are FR4 170Tg/290Td which are suitable for lead-free processes and temperature
- 4 Layer boards are now FR408 (180Tg)
- They have ENIG (gold) finish for superior solderability and environmental resistance
- They’re 1.6mm thick (0.063 inches) with 1 ounce copper on both sides. For four layer boards, the internal copper is 0.5 ounce
- The minimum specs for 2 layer orders are 6 mil traces with 6 mil spacing, and 13 mil drills with 7 mil annular rings
- The minimum specs for 4 layer orders are 5 mil traces with 5 mil spacing, and 10 mil drills with 4 mil annular rings
- Internal cutouts are allowed and supported. Draw them on your board outline layer
- Plated slots aren’t supported

Assembly of the boards will require us to solder on the boards with the electrical components that we designed in the schematics. We will personally piece the components on the board since we have personal experience with soldering from extracurricular projects and on-the-job experience through internships. All PCBs will be connected using connector cables that we will design ourselves.

8.3 Budget and Finance Discussion

Kevin Faulkner, president of 4F Structural Concrete & Masonry, LLC, will be sponsoring this project on behalf of the company. Researching, we considered we should have a lower cost than other models of electric bikes that had the price range from $1066.98 to $1252.95 into our budget. Compiling a list of necessary parts for this project, we calculated that the estimated cost of materials will reach $800. This budget was approved by our sponsor since it falls within the $1000 budget 4F Structural Concrete & Masonry, LLC will be financing.

Table 28: Estimated Cost Table

Subsystem	Item	Quantity	Vendor	Estimated Cost
Bike Chassis	26" Men's Genesis V2100 Mountain Bike	1	Generic (Walmart)	$106
Processor/Solar Subsystem	Solar Panel (12V)	1	Gates That Open, LLC	$0.00 ($139.00)
	ATmega328 MCU (Arduino UNO)	1	Atmel (Amazon)	$16.06
	Subsystem#2 PCB (MCU Config and Solar Charge Regulator)	2	OSH Park	$15
	UPG UB1250 Lead Acid Battery (12V)	1	Beiter DC Power (Amazon)	$14.98
	16 x 2 Character Blue Backlight LCD	1	Uxcell (Amazon)	$5.58
	Miscellaneous (Resistors, chips, Capacitors, etc.)	-		$10 EST

Subsystem	Item	Quantity	Vendor	Estimated Cost
Motor Subsystem	Alvey 24V-350W MY1016Z3 Electric Motor (Single Phase)	1	MonsterScooterParts (Amazon)	$94.99
	Aosom 48V-1000W DC Motor Conversion Kit (Three phase Induction Motor)	1	Aosom (Amazon)	$239.95
	Lithium Ion Battery (24V – 11Ah)	1	BiXNET (Amazon)	$266.95
	Subsystem #1 PCB (Motor MOSFET Config with driver)	1	OSH Park	$7.50
	Miscellaneous (Resistors, chips, Capacitors, etc.)	-		$10 EST
Total Estimated Cost				$787.01

The budget outlined above shows every component that has been ordered and plan to be used in our project design. Note that some components on here are on here for an original design and will ultimately not be used in the final prototype i.e. the Aosom 48V 1000W DC Motor Conversion Kit (Three phase Induction Motor) has been used as the original design but will most likely be replaced by the Alvey 24V-350W MY1016Z3 Electric Motor (Single Phase). This will also reduce the total cost of the project to significantly lower.

Budget is very important to our project since most other models can be out of price range for most consumers, and that 4F Structural Concrete & Masonry, LLC is entrusting us that this project can be created under budget. Keeping track of all of our expenses was key to our sponsor so that we can show them each and every component that went into this project, and to show that we spent their money responsibly and met their expense requirements. This also gives them the opportunity to interject whether a specific part or component is too expensive or too cheap.

8.4 Project Design Problems

As with nearly all design processes, several problems occurred during the creation of the Solar Bike design. Problems which have become of the project have been recorded in order to understand the issues which created these problems and learn from previous mistakes.

8.4.1 Charge Regulator Problem

The charge regulator is designed to limit the voltage to a maximum of 13.6V when the solar panel is at a maximum output voltage. As the input is lowered towards 12V, which is the output of the solar panel in unfavorable conditions, the charge regulator does not stay constant and drops below the required charging voltage. To solve this problem, it is possible to use a comparator circuit which will allow the lower voltage produced by the solar panel to pass directly to the battery, only limiting the higher voltage output of the solar panel. Another option is to include two solar panels in series, which will output a minimum of 24V and a maximum of approximately 34V. This alternative will eliminate the need for the comparator circuit and will hold the charge voltage steady at maximum charge voltage. The functionality of the charge regulator, which limits the amount of current applied to the battery at full charge level, will still hold true in this case.

The need of additional testing arises from the design error associated with the charge regulator. One of the first considerations to additional testing includes the contribution of a comparator circuit to input of the charge regulator circuit. The second will include linking two solar panels in series and determining the effects on output current as well as voltage. Both considerations will be tested and compared in order to confirm which is the better option. As well as these two possibilities, other alternatives to a solution will be considered.

8.4.2 Throttle Problem

As previously mentioned, in Section 5 of this report, the bike motor and accessories included did not come with any form of datasheets or wiring configurations. Therefore, testing was required to gain knowledge of the design of each component planned to be included in the Solar Bike design. Initial testing of the throttle was performed successfully, with assumed wiring configurations. However, after searching to find a pin out for the throttles harness, a source was found which claimed that the assumed wiring configuration was not completely correct. The black wire (Pin 5), according to the information found on the throttle, was said to be connected to a voltage equal to negative five volts. Originally, when testing was successful, this pin was connected to ground. In order to test the found configuration, testing was repeated, but this time with Pin 5 connected to negative voltage. The result of this testing burned out the hall sensor in the throttle, resulting in a throttle that no longer functions.

As a result of this testing, it was learned that thorough research of the manufacturers specifications for the outlining mechanism functionally of the part that we have chosen is essential. This knowledge will be used to apply our understanding of our projects design goal.

8.4.3 Software Frequency Issue

Previously mentioned in Section 6.4.1 PWM Throttle Control, an issue where the output frequency was not matching the declared frequency that was programmed on to the ATmega.