UCF Senior Design 2

Department of Electrical and Computer Engineering

Phone Energizing Device and Lights Bike
(PEDAL Bike)

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Group 32

Roxanna Cruz - EE Power track
Elizabeth Curcio - CpE
Dexter Mayorga - EE Power track
Melvin Vicente - EE Power track

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1. Executive Summary

Growing up, riding a bicycle was always so enjoyable, wasn't it? Whether we still ride them or not to this day, there's no denying that irrefutable fact. But nowadays, the average bike rider may stop and wonder, is there any way to get more out of this bicycle? Plus, when it comes to reducing carbon emissions and helping the planet, there's really no better way to be green than to ride a bicycle is there? Well unfortunately, in the middle of thinking about these questions, it turns out that your phone just ran out of battery. If only there were some way to improve a beloved bike, care even more for the Earth, and charge this essential device all in one convenient package…

Luckily, there's a way to get more enjoyment out of a bicycle and answer all of these questions with the help of the PEDAL Bike. The goal here is to be able to charge your trusty device not only with solar power, but also with mechanical power generated from a simple bike ride down the street. This is a system that attaches to a bike in order to truly upgrade it and give it another use besides transportation. In the process, charging a device with energy generated from the sun and movement will further help the environment than a bicycle alone will, through reducing the use of conventional electricity.

By providing both a means of transportation and a charger with no need for outlets, the way cyclists lead their lives will no doubt improve for the better. Hikers will no longer need to carry portable chargers because they *are* their own charger. People working in delivery can make their runs without worrying about a dead phone all day if necessary. Even the average bike owner can find some use out of the PEDAL Bike, because when people have broken chargers or lack outlets in a pinch, they'll be glad they brought their bike with them.

With dependable solar panels that work for 20+ years, lithium ion batteries, chargers with heat and overcharge protection, and a generator that is waterproof and made to last, this system can be very sustainable, not to mention extremely safe. The system aims to be usable in many different scenarios, as all bikes should be, so the necessary components will be protected against rain and other weather conditions. Not only that, but the components and attachments involved will pose little to no inconvenience for daily bike usage.

2. Project Description

This section will give a broad overview of what the project will encompass and the motivation behind the project. The objectives of the project will be provided alongside a block diagram showing a generalized breakdown of the main goals and flow of how objectives will be completed.

2.1 Project Motivation and Goals

The project serves as a way of charging a phone or device with only a bicycle, which could be useful for hikers, Doordash riders, and commuters, just to name a few. It would harness energy from the rotation of the wheels and a solar panel attachment. Since it is more likely for bikers to be outdoors during the day, it makes sense to integrate solar panels. This allows for efficiency in harnessing more power in a shorter amount of time, while also making use of a renewable energy source.

Having two sources of energy charging a storage battery instead of directly charging a phone will eliminate the need of having to bike at high speeds for extended periods of time, since charging directly to the phone requires certain speeds to enable stable charging. It would also help bikers in metropolitan cities where they deal with constant stop-and-go traffic. More traffic means fewer full rotations of the tires, and this will harness less energy versus at constant higher speeds. Solar panels can be added to contribute to charging the battery and make up for traveling at those lower speeds.

When riding a bicycle and using a map application, the location services from the app are constantly sending signals between satellites trying to pinpoint your location which drains your battery a lot faster than other simple functions would. Being in a place with a weak signal will drain your battery life even quicker due to the longer period of time required to send signals and pin locations. To avoid the battery life from being completely depleted, we can harness the energy from the rotational movement of the wheels along with solar energy to a battery. This will allow bikers in remote places and in the city to charge their phone no matter how fast or slow they pedal.

2.2 Objectives

The bicycle will integrate two sources of energy, solar and mechanical, to charge a battery which can then be used to charge small devices. By using only renewable energy, the project will be inherently eco-friendly. Because the device is meant to be attached to a bicycle, it must be portable as well. Since our intended audience are people like hikers and commuters, the project should be easy to use and understand so that the average layperson can operate it. It should also be able to withstand some weather associated with using a bicycle outside, some rain or temperature changes. To achieve this, most of the components will likely be housed within a lidded basket attached to the bicycle. Except for the two energy sources which will have to be outside the basket to function; the solar panels likely attached on top of the basket lid and the mechanical bicycle generator attached to some part of the wheel.

After some investigation, similar products were found to identify features. The PedalCell uses a fork-mounted rim generator with maximum power output of 15-20W and a smart power hub, built using a super capacitor instead of a battery, that includes two USB-C ports, one outputting 3W max and one 12W max. The use of the supercapacitor makes the device able to withstand a much larger range of temperatures and can deliver energy much faster when compared to a battery. On the other hand a battery can hold more power for much longer periods of time. Other similar products include various dynamo that take advantage of the mechanical energy related to the motion of different parts of a bicycle and convert it to electrical energy. Using these existing products we can get inspiration for how our project should function and what our potential limitations may be.

Other features of the project include a headlight and taillight that will be powered by the same battery as the phone or small device. This will improve the safety of users while biking at night especially. The lights can be automatic, detecting ambient brightness with a photoresistor, or manually operated so the user can choose when to turn lights on. A digital display will be able to display various statistics including the voltage being generated, velocity of the bicycle, ambient temperature, the time, and charge remaining on the battery. The digital display will have at least three modes that can be selected: off mode to prevent draining the battery when it is not in use, and modes that will display various sensor readings split into categories.

2.3 Requirements Specifications

Parameter	**Specification**
Portable / Lightweight	< 5Lbs
Low cost	< $250
Output to phone	>=5V

Water resistance	IP34
Voltage regulator efficiencies	>80%

Table 2.3 Requirements and Specifications

2.4 House of Quality Analysis

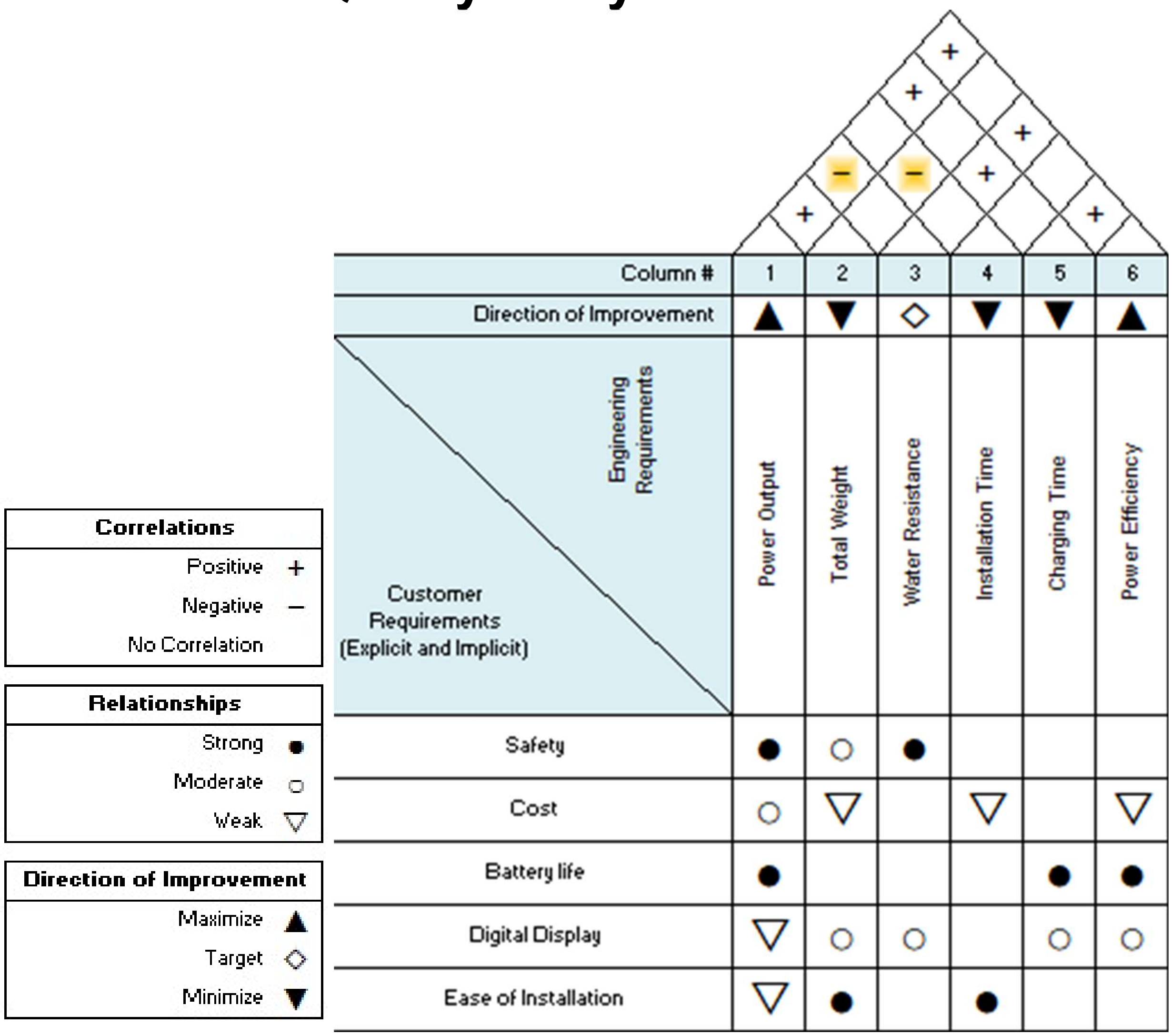


Figure 2.4 House of Quality

Our House of Quality diagram depicts our customer requirements and our engineering requirements in relation to each other. Each engineering requirement is assigned a direction of improvement, showing whether this feature should be maximized or minimized. The relationships between the customer and engineering requirements are characterized as strong, moderate, and weak, depending on how they affect each other. Finally, each engineering requirement's relationship to each other is assessed by assigning a correlation, either positive, negative, or none.

The first customer requirement, safety, has a strong relationship with both power output and water resistance. We do not want the user to be harmed by an issue caused by water coming into contact with the electrical components, or an improper power output. The total weight has a moderate relationship with safety as making the system safer is likely to make it more bulky and weigh more.

Cost is the second customer requirement, and it has a moderate relationship with power output since getting more power output would likely require more expensive parts, therefore increasing the cost to the consumer. Similarly, it has a weak relationship with power efficiency for many of the same reasons that it is related to power output. It also has a weak relationship with total weight, since making the design smaller would cost more money. Installation time has a weak relationship with cost as well; spending more money on the project and raising the cost to the customer could make it easier to install on the bicycle.

Battery life is another important customer requirement, as users will want to charge their device for as long as possible. This has a strong relationship with power output. Having less power output will extend the battery life. Charging time is directly related to battery life since a faster charge will take up more of the battery life on the battery. Of course, it is also related to power efficiency because higher efficiency will lead to better overall battery life.

The digital display is a valuable consumer requirement that will show the bicycle rider information about their environment and battery charging statistics. Since the screen will draw power from the battery, it has a weak negative relationship with power output. In a related vein, it will also affect power efficiency and charging time because it draws power. It has a weak relationship with weight by adding a small amount of weight to the overall system, and a weak relationship with water resistance as it is another component that will need to be made water resistant.

The final consumer requirement is ease of installation. Your average layperson does not want to spend hours figuring out how to properly hook the system up to the bicycle, so we will have to make it as easy as possible. This has a strong relationship with weight since the bigger the system gets, the harder it will generally be to install. Ease of installation is obviously directly positively correlated with the installation time. There is also a weak relationship to power output from a bigger system leading to greater power output leading to a more complicated install.

In the engineering requirements section, we are targeting a water resistant system, maximizing power output and power efficiency, and minimizing total weight, installation time, and charging time. Water resistance and power output will be negatively correlated.

Adding more power output will make it harder to be water resistant. All of our other engineering requirements as can be seen in the house of quality are either positively correlated or not correlated, putting us in a good position.

2.5 Overview Block Diagram

2.5.1 Initial Design

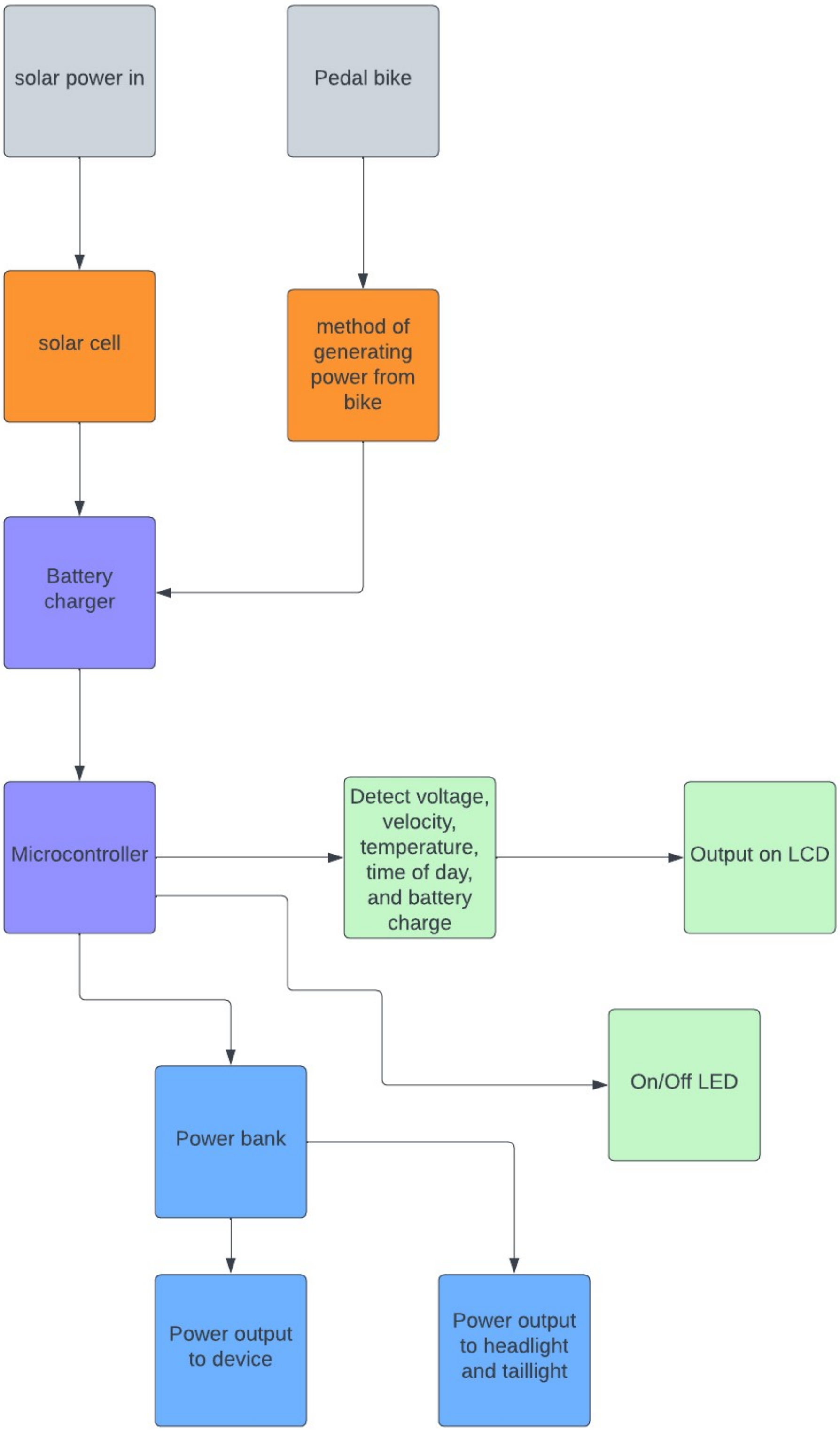


Figure 2.5.1 Initial Block diagram

Pictured above is our initial project block diagram. It details our system as we initially planned to design it. It takes both the sun's energy and motion generated from pedaling a bicycle as inputs. Then, the energy from the sun is passed through a solar panel and the motion from the pedals goes into a mechanical generator. Both energy sources are passed into the battery and charge it up. The battery will then power the microcontroller, which will output information gathered from sensors onto the LCD and also power an LED indicating whether the system is on or off. After going to the microcontroller, the power will be passed into a power bank or supercapacitor, where it will directly power both the phone that is plugged in as well as headlights and tail lights on the bicycle. We have tentatively assigned roles based on the diagram to each member of the group. Roxanna is orange, Dexter is purple, Elizabeth is green, and Melvin is blue.

2.5.2 Implemented Design

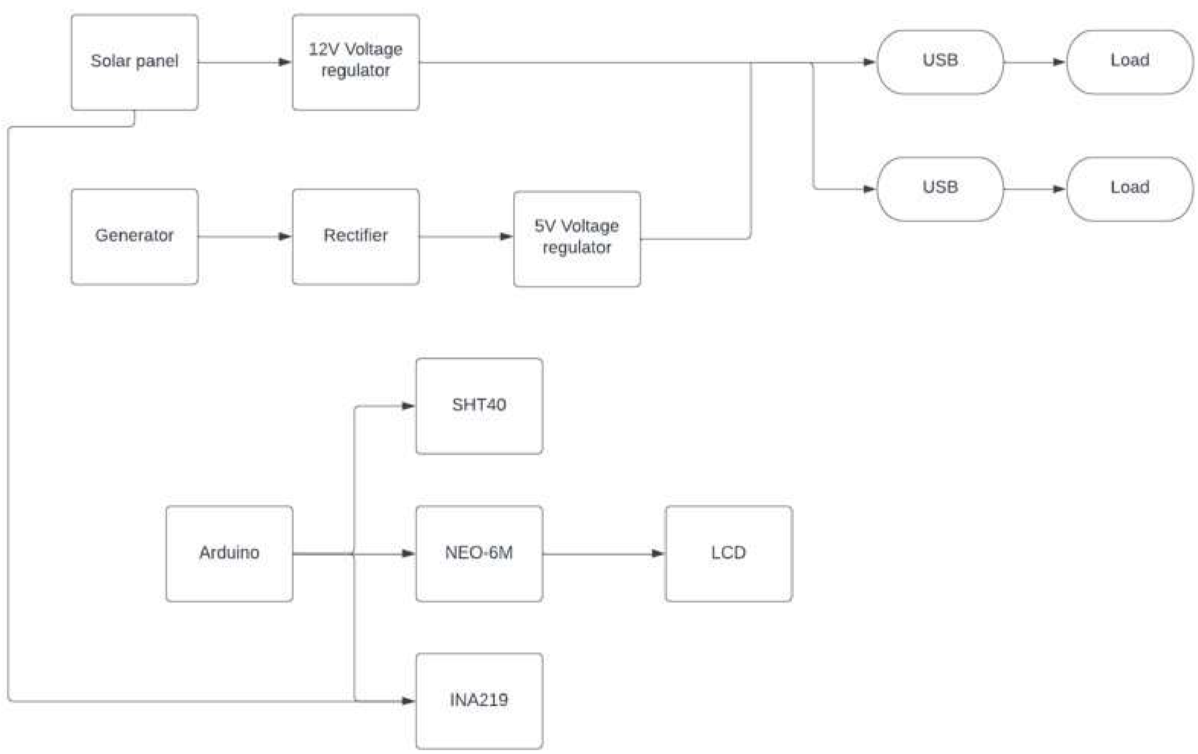


Figure 2.5.2 Implemented Block diagram

Pictured above is the block diagram for our final implemented design. It takes both the sun's energy and motion generated from pedaling a bicycle as inputs. Then, the energy from the sun is passed through a solar panel and the motion from the pedals goes into a mechanical generator. The generator produces AC power which then goes through a rectifier in order to convert it to DC power. After rectification both energy sources are independently passed through separate voltage regulators. To have both outputs of the regulators be used for either of the two USB port loads, both positive outputs of the 5V and 12V regulators were connected together and then connected to the positive terminal of the USB connectors. Likewise the ground terminals of both voltage regulators were connected to the ground terminals of the usb connectors. This allowed for the generation source with the largest voltage output to supply the loads with power.

The solar panel is also directly connected to the INA219 sensor to supply it with voltage level data, this sensor is measuring the voltage and power produced by the solar panel before any regulation. In the sensor and display subsystem the arduino controls the sensors and takes their measured data and displays it out on an LCD. Ideally this subsystem would be one of the two loads of our power subsystem, but the variable nature of our sources was not suitable for the display, and the sensor subsystem was not working this way. In our initial design the battery charger would have allowed us to charge and discharge a battery from the sources and to the loads respectively, but unfortunately the initial charger did not work for us. If we had more time we would have implemented a new charger circuit that would have allowed us to utilize our battery to output a more steady supply of power to our loads.

3. Technology Investigation and Part Selection

Throughout this section we will explore existing technologies that may help us implement our project. We will look at commercial products on the market that are similar to our project and we will explore components that we will need to incorporate into our project. For each component we will investigate the science behind the technology and consider different options in order to select the best option for our project. Finally we will choose specific parts for each of the components that will be necessary in our project.

3.1 Existing Similar Projects and Products

This section examines products that are already on the market that bear similarities to our project concept. While we are not working on this project for a company, this step is very important in research and design. It allows one to see if there is a space in the market for their product. For our team, looking at other similar designs can help us figure out how we should construct our design. Of course, this is all within reason. We obviously don't want to copy any design, just find inspiration and examine the options we have for our own project.

3.1.1 PedalCell

PedalCell is a bicycle power source that consists of a generator and smart power hub rubber mount. The proprietary generator attaches to the front fork of the bicycle and, like dynamo generators, convert mechanical energy from the rotation of the tires into electrical energy. PedalCell's generator has a maximum power output of 15-20 W. This gives them a 2-3 times faster charging rate than other dynamo generators such as the Igario D2 SON

28 and Sinewave SON28. Working alongside PedalCell's generator is the smart power hub that includes 2 USB-C ports; one safety prioritized and one high-power, and they implement their patented CadenceX technology. Their high generator power output allows for more energy to be available at lower speed, which allows users to charge their phones faster at fast or, more importantly, slower speeds.
PedalCell uses a bank of supercapacitors that have high charging efficiency, long lifespans, and optimal for a wide range of temperatures to help with charging stability. These supercapacitors load share with the generator to allow for faster charging at slower speeds, which can be anything from slowing down for turns or riding uphill. They also help in making power available at sudden and short stops. Efficiency characteristics include providing power only when needed (less power output when device is fully charged), and eliminating mechanical drag by decoupling from the rim when not needed.

Figure 3.1.1 PedalCell Device. Permission pending. Reprinted from https://pedalcell.com/

3.1.2 UpCycle

The UpCycle Ecocharger is another project that takes energy created from pedaling on a bicycle and converting it to electricity to be used or stored. The generator collects energy from the rear tire on the bicycle, then converts DC electricity to AC via an inverter and then can either be stored if connected to a battery or sent back in the grid by connecting into a wall outlet. Unlike the PedalCell, the UpCycle Ecocharger requires someone to pedal on a stationary bicycle and pedal at a consistent speed to get the correct voltage and amperage that will begin charging the battery without overcharging it. Riding on a stationary bike gives the ability to pedal for a certain speed for an extended period of time because the rider does not have to deal with other bike riders, pedestrians, or oncoming traffic.

Another aspect instead of charging a battery is to send the produced electricity directly into the grid. This can be achieved by connecting the Ecocharger into a simple wall outlet and sending the electricity directly into the building to be used by other products such as the television or coffee machine. According to the UpCycle Ecocharger website, the average human is able to produce between 50 and 150 watts continuously, which is enough to power devices such as a phone, but not enough to make a big enough dent in the electricity bill. Sending energy back into the grid has raised speculation. There are some that believe there should be some reimbursement for providing energy that does not come from the local utility market. This is where it can be seen that the creator of Upcycle has created the project to raise awareness. Tthe main goal of this project is to encourage people to participate in not only staying in shape, but also producing energy at the same time, and understand what it takes to produce 50-150 watts to hopefully encourage them to conserve energy in their own home more often.

Figure 3.1.2 Upcycle Eco Charger. Permission pending. Reprinted from https://www.thegreenmicrogym.com/setup/

3.2 Solar

There are two main types of solar power generation: photovoltaic and concentrated.

In concentrated solar power systems electricity is generated by using a series of strategically placed mirrors to concentrate the sun's light hitting a wide area into a singlepoint, the receiver. Light energy is converted to heat energy at the receiver and either powers a chemical reaction or is connected to a heat engine driven electrical generator. This type of solar power generation is not compatible with our project because it requires a large area to function properly and this is incompatible with our project goal of portability. As such concentrated solar power generation will not be further discussed.

In photovoltaic (PV) solar power systems semiconducting materials are used to turn light energy into electric energy through the photovoltaic effect. This is a chemical phenomenon where absorbed light causes excitation of electrons in the semiconductor material to move into a higher energy state, the valence shell of an atom, and from there they come free of the atom and flow through a wire connected to the solar cell, producing electricity. Solar modules, or panels, are made up of solar cells (made of semiconductor material) packed closely in the modules to protect cells from environmental factors like rain and dust. Solar panels are made in various sizes and voltage levels, so there will be many options that meet our goal of portability.

PV systems produce electricity through the absorption of light, but light can also pass through the panel, or be reflected by the panel. Current is directly proportional to the amount of light absorbed by the panel. Higher temperatures can affect a solar panel's capacity to generate power. A solar panel’s temperature coefficient measures the panel’s decrease in power output for every 1°C rise over 25°C (for example a temperature coefficient of -0.4% means that the solar panel’s efficiency decreases by 0.4% for every 1°C above 25°C). There are three types of solar panels with varying levels of absorbency, efficiency, and cost. The three types of solar panels are monocrystalline, polycrystalline, and thin film.

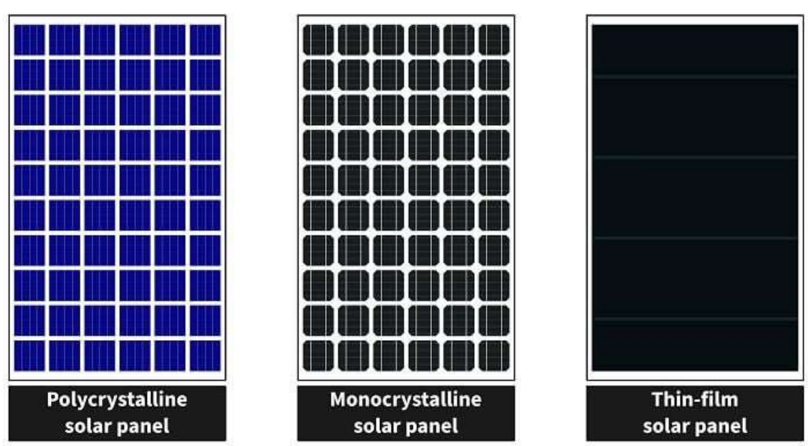


Figure 3.2: Three main types of solar panels. Permission pending. Reprinted from https://www.theecoexperts.co.uk/solar-panels/solar-panels-types

3.2.1 Monocrystalline

Monocrystalline solar cells are the highest efficiency and highest cost type. They are made of a single continuous crystal structure, which is difficult, energy intensive, and expensive to produce. Upwards of 50% of silicon can be wasted in the manufacturing process of these continuous crystal structures, increasing the price of manufacturing. They are the oldest of the three types and as a result, the most developed of the three as well. They also tend to have the longest lifespan and are the most space efficient. Monocrystalline solar panels typically come in standard sizes of 60, 72, and 96 cell panels.

The continuous crystalline structure of these panels results in more pure and more efficient solar cells. Monocrystalline panels have an efficiency rating over 20%. These cells also have the highest power capacity, with most monocrystalline panels generating up to 300w of power capacity. Monocrystalline panels have a temperature coefficient between -0.3% / °C to -0.5% / °C, making them more sensitive to temperature changes than thin film panels. Monocrystalline panels can suffer from light induced degradation (LID), a performance loss that occurs in the first few hours of exposure to sunlight. The sunlight reacts with oxygen traces within the panels, left over from the manufacturing process, which affects the silicon crystal structure. The LID loss is related to the quality of manufacturing and usually ranges from 1-3%.

3.2.1.1 PERC

Passivated Emitter and Rear Cell (PERC) solar panels are an improved modification of monocrystalline solar cells. These panels have an additional layer at the back of the panel that reflects light back into the solar cell that would have otherwise passed through a traditional monocrystalline panel, so more light is being absorbed by the cell. The additional layer also reflects back higher wavelengths of light that cannot be absorbed by the cell, but would otherwise heat the panel and decrease efficiency if they were allowed to pass through. PERC panels are slightly more expensive than traditional monocrystalline panels, but the increases in efficiency mean that they have a lower cost per watt. On average the additional passivation layer of PERC panels add an extra 5% of efficiency.

3.2.2 Polycrystalline

Polycrystalline solar cells are less efficient and expensive than monocrystalline but more efficient and expensive than thin film solar cells. They are made of fragments of silicon crystals melted together and then cut out; which is a simpler, less expensive manufacturing process. In fact wasted silicon fragments from the manufacturing process of monocrystalline cells are sometimes used in the manufacturing of polycrystalline cells, making them cheaper to produce. This structure makes polycrystalline solar cells less efficient both in energy conversion and space, because the silicon is less pure than the cells of monocrystalline panels. They are also less efficient in higher temperature environments. Like monocrystalline solar panels, polycrystalline panels typically come in standard sizes of 60, 72, and 96 cells per panel.

Polycrystalline panels typically have an efficiency rating of 15-17%. The power capacity of these panels is close to that of monocrystalline panels, producing between 240-300w, but with a lower power capacity per cell than monocrystalline. Similar to monocrystalline panels, polycrystalline panels have a typical temperature coefficient of -0.3% / °C to -0.5% / °C; and polycrystalline panels can also be affected by LID performance loss due to its crystalline structure.

3.2.3 Thin Film

Thin film solar cells are the least efficient and least expensive of the three types. Because they are less efficient they often require a larger amount of surface area to produce a comparable amount of energy. However thin film is light weight, flexible, and tends to be more resistant to interference from shade or indirect sunlight. Unlike both monocrystalline and polycrystalline solar cells, which are both made of silicon wafers put into rows, thin film panels can be made from different materials including cadmium telluride (CdTe), amorphous silicon (a-Si), and copper indium gallium selenide (CIGS). A thin layer of one of these semi conducting materials is applied to a supporting material like glass or steel. Also unlike monocrystalline and polycrystalline panels, thin film panels are not limited to standard cell count sizes, they come in a larger variety of sizes that can be used for different settings. These panels do not have a very long lifespan compared to the other two types and will require regular replacing.

On average thin film panels are 2-3% less efficient than monocrystalline and polycrystalline silicon based panels. Unlike monocrystalline and polycrystalline panels, thin film panels don’t come in standardized sizes, there is no typical power capacity, capacity differs between thin film panels based on their physical size and composition. But in general, crystalline panels output more power than thin film panels of the same size. Among thin film solar panels, CIGS is the most expensive, then CdTe, and the cheapest is a-Si. Thin film panels have temperature coefficients closer to -0.2% / °C, so they experience less efficiency loss in hotter environments than monocrystalline and polycrystalline panels.

3.2.3.1 Cadmium telluride (CdTe)

CdTe solar panels are manufactured through a vapor deposition process that condenses CdTe onto a backing usually made of plastic or glass. These panels seem to have just one main manufacturer, First Solar. They have achieved high efficiency rates in a lab setting, but not necessarily in an uncontrolled setting. Cadmium is a toxic heavy metal that is a known carcinogen, so there can be risks in manufacturing and recycling of these panels. CdTe panels’ efficiency ranges between 9-11%.

3.2.3.2 Amorphous silicon (a-Si)

As the name suggests, a-Si panels lack shape, in contrast to the crystalline structures of the monocrystalline and polycrystalline panels (both crystalline types can also be described as c-Si, or crystalline silicon). This lack of structure means that a-SI panels require much less silicon to manufacture individual cells, bringing the manufacturing costs down, but the efficiency is also dramatically decreased. The low amounts of power produced by a-si panels make them suitable for applications like hand held calculators or light sensors. A-Si panels have the lowest efficiency range at 6-8%.

3.2.3.3 Copper indium gallium selenide (CIGS)

CIGS solar panels are manufactured by placing a thin layer of a solution made of copper, indium, gallium, and selenide onto a backing usually made of plastic or glass. These panels have a high absorption coefficient so they are thinner and more efficient than the other thin film panels, but still less efficient than the crystalline silicon panels. CIGS panels have an efficiency range of 13-15%.

3.2.4 Panel Type Comparison

In Table 3.2.4 below the solar panel characteristics discussed throughout section 3.2 are listed for monocrystalline, PERC, polycrystalline, CdTe, a-Si, and CIGS panels, to be more easily compared.

	Cost	**Efficiency**	**Temperature coefficient**	**Power Capacity**
Mono crystalline	Highest cost of three main types.	>20%	-0.3% / °C to -0.5% / °C	300w
PERC	More expensive than typical mono crystalline panels, but more cost efficient.	>20% +5%	-0.3% / °C to -0.5% / °C	-
Poly crystalline	Less expensive than mono crystalline but more expensive than thin film	15-17%	-0.3% / °C to -0.5% / °C	240-300w

	panels.			
Cadmium telluride	Least expensive of three main types.	9-11%	-0.2% / °C	-
Amorphous silicon		6-8%	-0.2% / °C	-
Copper indium gallium selenide		13-15%	-0.2% / °C	-

Table 3.2.4 Panel comparison

3.2.5 Panel Options and Selection

Because solar panels come in so many different sizes and power outputs, we will narrow down what we want out of a solar panel so we can narrow our search. The solar panel will be connected in parallel with the mechanical bicycle generator so they should have the same or similar output voltage. If they do not, one power source will overpower the other and some voltage will be wasted. So, because the generator will have an output of 12 Volt / 6 Watt / 0.5 Amps, we should aim for a solar panel that has an output voltage around 12V. Alternatively a solar panel with an output close to 6 Volt / 3 Watt / 0.5 Amp could also be paired with that configuration of sidewall generator. We also need to consider the physical size of the solar panel because it needs to be small enough to be able to attach onto a bicycle but not too small that it does not produce a significant amount of power. We estimate this size to be somewhere between 5in x 8in and 10in x 15in. From there we will try to maximize power and efficiency while minimizing price. All of the options considered are in stock and within our budget, except shipping costs are not being considered.

3.2.5.1 FIT0601

Maximum Current @ Maximum Power	1 A
Maximum Voltage @ Maximum Power	5 V
Maximum Output Power	6 W
Vendor	arrow.com
Price	$9.68
Type of Panel	Monocrystalline
Dimensions (mm)	275 x 160 x 2

Weight	90 g

Table 3.2.5.1: FIT0601 Solar Panel

This panel has a comparable voltage level to the 6 Volt / 3 Watt / 0.5 Amp generator configuration. But due to the current being higher it can reach the same wattage as the sidewall generator operating with 12V. It comes from an electronic components retailer, and has a datasheet readily available, making it a more credible choice. It is a monocrystalline panel so it is a higher quality of silicone making the panel more efficient. The dimensions are 275mm x 160mm which is approximately equivalent to 10.8268 in x 6.29921in, which falls within our estimated size range.

3.2.5.2 Fielect 6V 3W Polycrystalline Mini Solar Panel

Max work voltage	0.5 A
Max voltage	6 V
Max Power	3 W
Vendor	amazon
Price	$9.49
Type of Panel	Polycrystalline
Dimensions (mm)	145 x 145
Weight	90.7 g

Table 3.2.5.2: Fielect solar panel

This panel also has a comparable voltage level to the 6 Volt / 3 Watt / 0.5 Amp generator configuration. Unlike the previous panel option the current and power values also match the generator configuration. It comes from amazon, on which there are lots of third party retailers, so it is hard to know where your product is coming from, there is no datasheet available.. It is a polycrystalline panel so it is a medium quality of silicone. The dimensions are 145mm x 145mm which is approximately equivalent to 5.70866 in x 5.70866 in, which falls outside of our estimated size range, but not by too much and that was just an estimate of what we might need, not necessarily what we actually need.

3.2.5.3. Solar Panel 5W 12V

Short circuit current	180mA
Working voltage	12 V

Power	5 W
Vendor	eBay
Price	$7.99
Type of Panel	Polysilicon Epoxy Board
Dimensions (mm)	110 x 136
Weight	70 g

Table 3.2.5.3: 5W 12V solar panel

This solar panel is the first option that operates at 12 volts. It is similar to the 12 Volt / 6 Watt / 0.5 Amps generator configuration that we chose. The only difference being that it has a slightly lower current so the power is 5W instead of 6W. It is sold by an international vendor, ships from abroad and as a result has a very wide arrival window. Sometimes international shipping is not a problem in that sense, but in this case the end of the arrival window is February 23rd, which is probably later than we would need it. Like the previous panel option this is a polycrystalline panel made of medium quality silicone. The dimensions are 110 mm x 136 mm which is approximately equivalent to 4.33071 inches x 5.35433 inches, which is smaller than we had estimated, but again the estimate is not necessarily what we need, in this case however it seems the smaller size did result in a lower power value than we wanted.

3.2.5.4 Newpowa 10W(Watts) 12V(Volts) Monocrystalline Solar Panel

Current MPP Imp	0.69 A
Voltage MPP Vmp	17.37 V
Max Power Output	10 W
Vendor	amazon
Price	$25.49
Type of Panel	Monocrystalline
Dimensions (inches)	15.35 x 7.68 x 0.71
Weight	907.185 g

Table 3.2.5.4: Newpowa solar panel

This solar panel is unique among our options in that it is much higher power. It has a comparable voltage level to the 12 Volt / 6 Watt / 0.5 Amps generator configuration, or at least the name of the listing suggests this, but the actual maximum voltage is 17.37 V according to the specifications. For a panel with this power rating it is relatively cheap, and it is a monocrystalline panel, the higher quality of silicone, which also makes the panel more efficient. This panel is also much larger than the other panels at 15.35 inches x 7.68 inches, and much heavier as well. It is possible that this panel could be mounted on a bicycle carrier rack, but if the bicycle that we have does not already have a carrier rack attached to it, this will incur an additional cost onto the already more expensive cost of this panel when compared to the others.

3.2.5.5 Solar Panel Choice

Among these four options we are considering, two are 6V panels and two are 12V panels. The Newpowa panel and the FIT0601 are both monocrystalline panels, while the other two are polycrystalline. The Newpowa is an outlier among these because it is much bigger, has a higher power rating, and it is more expensive. This panel seemed worthwhile but we worried that it was too high power for the other circuit elements selected, and perhaps too large to be attached to the bicycle. We finally did choose the Newpowa panel. It ended up fitting on the bicycle perfectly and meeting our needs power wise.

3.3 Mechanical Generator

The second source of renewable energy our project will utilize is the mechanical energy generated by pedaling the bicycle itself. To harness this mechanical energy and convert it into usable electricity a generator will be needed. There are several types of bicycle attached generators on the market, with the main differences being where on the bicycle the generator is attached.

Most of these generators are commercially called dynamos but are not actually dynamo generators. Dynamo refers to a generator that produces direct current (DC) as opposed to alternating current (AC). A dynamo, like a simple AC generator, is constructed with rotating coils in a magnetic field, but as the coils rotate the current flowing switches direction producing AC power. To rectify the AC power to DC power, a dynamo uses a commutator, which acts as a rotary switch that disconnects the power during the reversed current part of the rotation cycle and connects to the other part of the coil that would be producing current in the desired direction at that time.

The brand Dynohub produced some of the first commercially successful bicycle mounted hub generators, and so the word dynamo has been used to refer to these generators even though they are not technically dynamo generators. Instead most of these bicycle mounted generators are magnetos. Magnetos are forms of alternators, with the distinction that a permanent magnet is used instead of a magnetic field. Throughout this section we will refer to the various types as generators rather than dynamos, except when referring to a specific product name.

Because AC power will be produced from these generators, we will likely need to convert to DC power to charge our battery. Some generators come with a rectifier integrated into the generator to do this. Otherwise we will need to implement a rectifier ourselves.

These bicycle attached generators enable a bicycle rider to travel without having to worry about keeping their bicycle lights or small device charged before going out or having to stop to charge them to ride safely. The solar panel in this project will provide more energy and help charge the rider's device faster, but the panels will not be able to provide energy all of the time, at night for example the panel will not function. The rechargeable battery allows our project to hold charge when not in motion. In systems where the battery is not rechargeable it requires replacing, which goes against our goal of sustainability, and rechargeable or not the rider needs to keep in mind when the battery will run out especially in times when the solar panels cannot provide energy. The mechanical generator ensures that there is always a way to keep the lights on and to keep a device charged if necessary.

There are some downsides to these generators. Depending on the bicycle placement some types of generators can be difficult and expensive to install. All different types impose an additional amount of drag on the rider, varying amounts depending on the type, but overall the effect of the drag is minimal. Most generators only increase drag by an equivalent of 6 to 20 feet per mile. Another downside is that these bicycle mounted generators do not produce a lot of power. Most of them produce between 3 watts and 6 watts of power at normal riding speeds. For phone charging, most modern smartphones require at least 2.5 watts for slow charging or 18 watts for fast charging. So these generators alone will likely not be enough to completely charge a smartphone in a short amount of time, but should be able to maintain a charge.

3.3.1 Sidewall generators

Sidewall generators, also called bottle generators due to their shape, are one of the oldest types of bicycle mounted generators, with newer models emerging as technology improves. These were the most common historically. Sidewall generators are generally attached to the fork of the front wheel, with a roller on the end that remains in contact with the sidewall of the tire, some tires having a special generator tread on the sidewall for this purpose. As the wheel of the bicycle turns, the roller turns as well, perpendicular to the wheel of the bicycle. The driving roller of the generator spins an axel connected to a permanent magnet. Instead of spinning coils in a magnetic field, as in a traditional alternator, these magneto generators rotate a permanent magnet in the presence of conductive coils.

For the sidewall generator to work the rollers need to rotate as the bicycle rotates without much slippage. The pressure of the roller against the tire is important to maintain rotation. The generator must be installed at an angle such that a straight line could be drawn through the center of the generator to the axis of the wheel, aligning the generator with the wheel's dropout. Sidewall generators along with some other types can be disengaged at will, without having to dismantle the bicycle, unlike hub generators.

Environmental conditions affect the likelihood that slippage will occur. For example, rain and snow, or dust and debris can get in between the roller and the bicycle wheel, increasing the chances of slipping and decreasing efficiency. So sidewall generators are not a very good option for riding a bicycle in very muddy or snowy conditions, as some off road bikers and mountain bikers would experience, but for the purposes of our project this should not be too much of an issue.

Drag can be more of an issue with this type of generator compared to the hub generator for example. And due to the likelihood of debris getting between the generator roller and the tire, and because of the consistent rolling on the tire, wear on the sidewall of the tire could be a concern, especially for lightweight or thinner tires. Correct alignment with the wheel minimizes the risk of drag and wear.

The installation process for a sidewall generator is much simpler than the process of hub generator installation and sidewall generators generally are one of the less expensive generator options. Sidewall generators typically fall in the price range of $15 to $40. They come in 12 Volt / 6 Watt / 0.5 Amps and 6 Volt / 3 Watt / 0.5 Amps power configurations. Both of these factors, ease of installation and lower costs makes a sidewall type of generator a good choice for our project.

The figures below provide an example of what a sidewall generator looks like, and a diagram of the internal construction of the generator, with the spinning permanent magnet generating a flow of current in the coils nearby.

Figure 3.3.1A: Soubitez dynamo on 1977 Jack Taylor Tandem. Permission pending. Reprinted from https://restoringvintagebicycles.com/tag/bottle-dynamo/

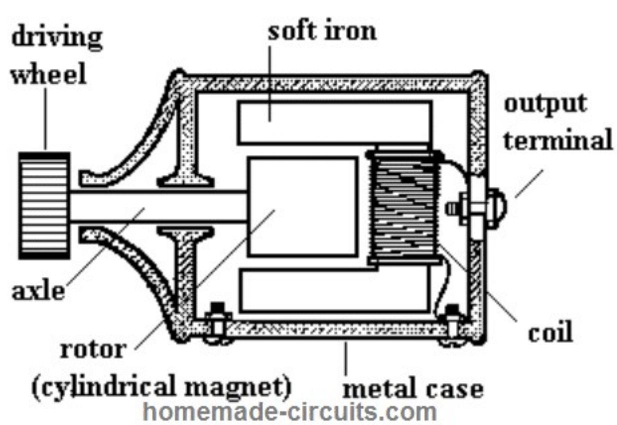


Figure 3.3.1B: sidewall generator construction. Permission pending. Reprinted from https://www.homemade-circuits.com/bicycle-dynamo-battery-charger-circuit/

3.3.2 Hub generators

Hub generators are installed on the hub, or axis of rotation, of the wheel. As the wheel of the bicycle spins, the generator spins causing a voltage to be induced on the internal stationary windings. A series of small magnets on the wall of the hub spin, as the wheel spins, around a stationary magnet and wire coil at the center of the hub. The movement of the magnetic field around the coil causes a current to flow through the wire. The faster the magnets spin the more power will be produced.

Hub generators require professional installation to thread the spokes of the wheel through the generator, or a custom made wheel or bicycle with the hub built in, because the generator replaces the regular hub of the front wheel of the bicycle instead of being attached to the regular hub. This is a more labor intensive installation process than the other generator types and can incur an additional installation fee of about $100. Because the generator is the hub of the wheel, it will always impose a degree of drag regardless of whether the lights are turned on or if a device is charging, hub generators cannot be easily disengaged like sidewall and rim generators can.

These are also regarded as the most reliable and efficient of the bicycle generators partly because their enclosed design protects the internal components from environmental conditions that might damage or produce unnecessary friction. This produces less drag and unlike sidewall and rim generators, hub generators will not suffer losses in efficiency due to slippage. Some even have a feature that prevents condensation of moisture inside of the hub.

High efficiency and difficult installation are both factors that increase the price of hub generators; hub generators are the most expensive of the bicycle generators. Lower end hub generators have a typical price range of $60-$100, while more expensive models can be around $400. The majority of hub generators come in a 6 Volt / 3 Watt / 0.5 Amps power configuration.

Figure 3.3.2: Bicycle hub generator. Permission pending. Reprinted from https://wheretheroadforks.com/are -dynamo-hubs-worth-it-pros-and-cons/

3.3.3 Bottom Bracket generators

Bottom bracket generators are similar to sidewall generators, in that they both rely on friction against the moving wheel of the bicycle to function. These generators are attached between the chainstays of a bicycle, behind the bottom bracket and the roller maintains contact with the top of the back tire, rolling against the tread of the tire.

Because they need to be in contact with the tread of the tire instead of the sidewall, the rollers of these generators have a larger surface area which enables the roller to maintain more friction with the tire and reduces slippage. However, more so than sidewall generators, these will be susceptible to interference from debris, snow, or mud getting between the roller and the wheel. As a result these generators only really work in clean conditions where little to no debris is getting on the tire. Because of their position, bottom bracket generators are not compatible with bicycles that have a kickstand also mounted on the bottom bracket.

Bottom bracket generators do not have the same risk of wear as sidewall generators because the tread of the tire is much more durable. Their position between the chainstays also provides more protection from accidental displacement from the bicycle falling or something knocking against it. Like sidewall generators, bottom bracket generators can be easily disengaged by separating the roller from the tire when their use is not necessary, and they impose no drag when they are not in use.

There do not seem to be any bottom bracket generators manufactured today. Pre-owned ones can still be found on resale sites like eBay, but hub and sidewall generators overtook bottom bracket generators in popularity to the point that they are no longer made. Sidewall and rim generators provide an easier installation and are less likely to experience slippage while hub generators provide a much more protected enclosure that prevents slippage altogether. For the purposes of our project a bottom bracket generator does not seem practical.

Figure 3.3.3: Bottom bracket generator Permission pending. Reprinted from user ricohman of https://www.bikeforums.net/classic-vintage/674468-bottom-bracket-dynamos.html

3.3.4 Chain generator

Chain generators seem to be a newer concept for a bicycle generator. These generators rely on the motion of the bicycle's chain to generate energy. Power from these generators is more unreliable because the chain of a bicycle does not move with the same predictability as a bicycle's wheel does. The chain can stop moving while the bicycle is still moving, and on some bicycles the chain moves side to side during gear shifting, and moves in non uniform ways based on the tension of the chain.

We could only find very limited information about chain generators, indicating that they are a newer and/or less popular type of bicycle mounted generator. The main sites where we could find any information about them were websites selling these generators, and there didn't seem to be a brand attached to any of these. The prices range from $30 to $60.

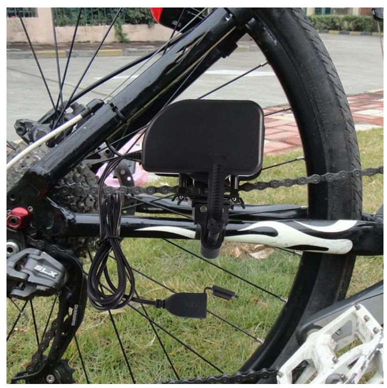


Figure 3.3.4: Chain generator. Permission pending. Reprinted from https://www.aliexpress.us/item/3256802712901697.html?gatewayAdapt=glo2usa4itemdapt&_randl_shipto=US

3.3.5 Wheel Mounted generators

These generators are mounted on an already existing bicycle hub either on the back or front wheel depending on the model. These generators have varying methods of installation such that part of the generator is attached to a stationary part of the bicycle and another part clasps onto the spokes or around the hub to rotate along with the bicycle wheel. Some models may interfere with disc brakes present on some bicycles.

Like chain generators, wheel mounted generators seem to be a newer concept in the bicycle generator space. There is a little more information available about wheel mounted generators however and there are several distinct brands manufacturing them. They are newer, as some of these wheel mounted generators were kickstarter projects, raising money through crowdfunding. These products generally come with a phone charging port, energy storage unit, lights, and/or other features, they are more of a complete product rather than just a power generator. All models that we could find were priced upwards of $100.

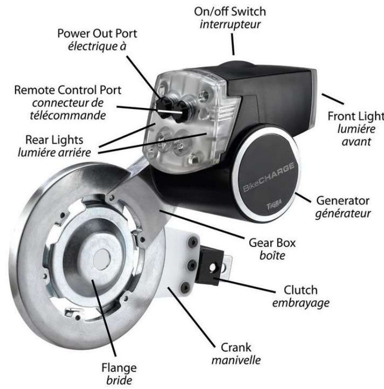


Figure 3.3.5: The Tigra Sport BikeCharge. Permission pending. Reprinted from https://www.tigrasport.com/power-solution/873-bike -charge-dynamo.html

3.3.6 Rim generators

Rim generators are very similar to sidewall generators, with the distinction that these generators make contact with the rim of the wheel instead of the sidewall of the tire. As a result they do not impose a risk of wear to the tire. They also seem to be a newer concept on the market. The PedalCell, a product investigated in section 3.1 Existing Similar Projects and Products, uses a rim generator.

Like sidewall generators and unlike hub generators, rim generators can be disengaged when not in use to avoid additional drag, and there is no need to have a rebuilt or custom wheel. They are significantly more lightweight than hub generators, and newer models can harvest 40-70% more power than hub dynamos, with 10-12% increased efficiency when compared to hub generators. Rim generators are susceptible to slippage and interference from debris. At high speeds, which cause the devices plugged in to draw a higher amount of power, they are especially prone to slippage.

Despite sharing a relatively simple design and installation process with sidewall generators, the price range of rim generators is more in line with that of hub generators, upwards of $100. This is likely because rim generators seem to be a newer product and there are not too many on the market, as well as their higher efficiency.

Figure 3.3.6: A Velogical rim generator. Permission pending. Reprinted from https://www.cyclingabout.com/rim-dynamos -can-now-generate-more -power-than-hub -dynamos/

3.3.7 Mechanical Generator Options and Selection

After considering the different types of bicycle attached generators that are available on the market, we will focus on finding a sidewall generator for our project. Sidewall generators tend to be lower cost, which meets our limited budget needs. They are abundant on the market and easy to find with many manufacturers producing them. They come in two different configurations of 12 Volt / 6 Watt / 0.5 Amps and 6 Volt / 3 Watt / 0.5 Amps. They have a simple installation process especially compared to hub generators which require a custom wheel or professional installation that would incur additional costs we would prefer to avoid.

In this section we will consider a few different specific sidewall generators that are available for us to purchase and use in our project. The factors we will be taking into consideration include size, cost, performance, and whether or not changes will need to be made to either install the generator or to make it work within our circuit.

Possible changes include needing an additional bracket and/or ring loop to attach the generator to the bicycle. Generally sidewall generators have a ring loop on the body of the generator that enables compatibility to the majority of brackets which are then used to attach to the bicycle. If a generator does not come with a ring loop or a bracket then they would have to be bought separately. Another possible change that may be needed is the implementation of a rectifier within our circuit to change an AC output to DC, which is what our circuit will need.

Some of these options will have less information than others available about how the generator functions and where it comes from, depending on where they are being sold. Where not noted an additional shipping cost may apply to some options where that information was not readily available.

3.3.7.1 Wai Danie Bicycle Dynamo Generator 12V 6W AC

Power configuration	12 Volt / 6 Watt / 0.5 Amps
Vendor	Amazon
Price	New $20.99 or used for $17.49
Ring loop / bracket included	Yes, both
Material of body	aluminum

Material of roller	metal
AC/DC	AC

Table 3.3.7.1: Wai Danie Bicycle Dynamo

This generator does not have any obvious branding on it so we rely on the name of the item to be accurate that the brand is Wai Danie, though generators with that name seem to only be sold on amazon. We found two listings on different websites that look visually identical with the same 6PC -12V6W inscription on them. The two listings are not named the same, but they are not branded at all in the photos, like the amazon listing, and sometimes retailers do not list products correctly. The first listing is from Walmart, it includes two sets of generators and brackets for $32.07 with free shipping, which comes to $16.04 per set. This is somewhat cheaper and could be useful to have more parts for redundancy purposes. The second listing is for one set of generator and bracket on ebay for $8.99 plus $6.71 shipping, which is cheaper.

3.3.7.2 Generator - 12v DC / 6 watts

Power configuration	12 Volt / 6 Watt / 0.5 Amps
Vendor	teachersource.com a site that sells educational materials for teachers
Price	$19.95 + $7.95 shipping
Ring loop / bracket included	No
Material of body	aluminum
Material of roller	metal
AC/DC	DC

Table 3.3.7.2: Generator - 12v DC / 6 watts

This generator is unique among the options we are considering in that it claims to have an integrated internal rectifier and as a result the generator outputs DC power. The inclusion of this rectifier means we would not need to implement our own rectifier. It also does not have a ring loop on the body of the generator. So in addition to a bracket we would have to find and purchase a separate ring loop and attach it to the generator. We could also find some other way of attaching the generator to the bicycle but that risks an unsecured attachment. This generator is unbranded but looks very similar to the Wai Danie generator, except that it does not have the ring loop nor the inscription on it.

3.3.7.3 AXA 8201

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	The AXA manufacturer, at their website axasecurity.com
Price	€ 15.95 recommended price by manufacturer, which is approximately equivalent to $16.73 On sale from ebay for $22.29 + $1.69
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	aluminum
Material of roller	steel
AC/DC	AC
Weight	180 gr

Table 3.3.7.3: AXA 8201

This is the first of the options that we are exploring that has a clear brand that is manufacturing the generators. Not mentioned in the table, but it also claims to have an internal diode that would protect components from overvoltage as a result of sudden current spikes. This diode is a requirement from German and French regulations. It does not however mention a rectifier, it still outputs AC power, so we would have to implement our own rectifier. And it does not come with a bracket so we would need to purchase that separately.

3.3.7.4 ANLUN Alu 2 dynamo

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	bigmart.com
Price	6,90 EUR recommended price by manufacturer On sale from bigmart for $35.99 + $12 shipping
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	aluminum
Material of roller	rubber
AC/DC	AC

Table 3.3.7.4: ANLUN Alu 2 dynamo

This generator also has a clear brand associated with it. It does not have an internal rectifier nor a bracket so we would have to implement those on our own because we need a DC output for our circuit and we need to attach the generator to the bicycle. This is the first option with a rubber roller. A rubber roller might achieve better friction with the tire when compared to a metal roller especially in rainy or wet conditions. But a rubber roller also has a risk of melting or faster wear after riding at high speeds or for extended periods of time. On the other hand a metal roller would be more likely to wear on the bicycle tire overtime, which is a risk especially for thinner tires. Rubber rollers may be a better option, especially when one compares the price of replacing a rubber roller versus the cost of replacing a worn out tire. Cost may be prohibitive for this option though as it is more expensive than other options we are considering.

3.3.7.5 Basta Dynamo Duo Overvoltage Protection Generator

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	ebay
Price	GBP 12.99 + shipping GBP 29.00 Which is approximately equivalent to $15.87 + shipping $35.43
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	plastic
Material of roller	rubber
AC/DC	AC

Table 3.3.7.5: Basta Dynamo Duo

This generator is made of plastic, which is a departure from the other options we have considered. A plastic generator body is likely not as durable as an aluminum one. It does not include a rectifier nor a bracket so we would have to implement those ourselves. Assuming that the name of the listing is accurate this generator also has an internal protection from overvoltage, likely a diode like the AXA generator has. Something unique to this generator is that it has double the connections, such that it could be connected to two loads instead of just one, with the intention being to use one connection with headlights and the other for rear bicycle lights. The product being sold in this listing is new old stock meaning that it is unused but was not manufactured recently. This may mean that the product was discontinued, but the age of the product should not have a large impact on performance, as there are examples of people using the same sidewall generator for decades. The higher cost of this generator may be prohibitive.

3.3.7.6 CONTEC Dynamo DL-150

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	hollandbikeshop.com
Price	12.95€ recommended price by manufacturer On sale from hollandbikeshop for £ 10.24, which is approximately equivalent to $12.48 + $36.67 shipping
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	aluminum
Material of roller	Rubber or plastic
AC/DC	AC
Weight	14 g

Table 3.3.7.6: CONTEC Dynamo DL-150

This generator does not include a rectifier nor a bracket so we would have to implement those ourselves. It also has an internal surge protection mechanism, likely a diode like the AXA generator has. The higher cost of this generator may be prohibitive.

3.3.7.7 UNION DYNAMO UN-4190 SIDE RUNNER

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	studiobrisant.com
Price	€9.80 + €9.50 international shipping Which is approximately equivalent to $10.28 + $9.97 shipping
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	Aluminum
Material of roller	steel
AC/DC	AC
Efficiency	~35%

Weight	202 g

Table 3.3.7.7: UNION DYNAMO UN-4190

This generator does not include a rectifier nor a bracket so we would have to implement those ourselves. The lower cost of this generator makes it possibly a good option for our project, but the international shipping may be a problem. This is also the first of our options that lists the efficiency, which may make it a more reliable source as it's more detailed compared to the other retailers.

3.3.7.8 BUSCH & MULLER DYMOTEC 6 SIDEWALL BOTTLE DYNAMO GENERATOR 6 volt 3w

Power configuration	6 Volt / 3 Watt / 0.5 Amps
Vendor	ebay
Price	GBP 17.99 + GBP 22.32 shipping Which is approximately equivalent to $21.98 + $27.27
Ring loop / bracket included	Yes ring loop but no bracket
Material of body	plastic
Material of roller	rubber
AC/DC	AC
Efficiency	~40%
Weight	185 g

Table 3.3.7.8: BUSCH & MULLER DYMOTEC 6

This generator does not include a rectifier nor a bracket so we would have to implement those ourselves. Dymotec sidewall dynamos are discontinued so this is likely new old stock like the Basta Dynamo. The Dymotec 6 is supposed to have a special feature that reduces drag. The higher cost of this generator may be prohibitive.

3.3.7.9 Generator choice

The information available about these generator options is limited because they are not being sold by electronic component shops, but more so by bicycle hobbyist websites or brands that market to bicycle hobbyists. The brands have an interest in keeping their designs secret for proprietary reasons and their audience does not necessarily care about more technical information. As a result we do not have access to something like a data sheet with more information. There are also some options that are not really associated with a brand name, so their specifications cannot be verified from the manufacturer's website, that combined with little information results in potentially incorrect values being used to sell the product and no way to know if they are accurate without testing the generator.

After eliminating the options that are likely too expensive for our budget, we are left with the Wai Danie Bicycle Dynamo, the generator from the teacher resources website, the AXA 8201, and the Union Dynamo UN-4190. Of these the Wai Danie Bicycle Dynamo and the teachersource generator offer higher outputs with 12 Volt / 6 Watt / 0.5 Amps power configurations, and these two are also shipped domestically so we could expect faster shipping times. On the other hand the AXA 8201, and the Union Dynamo UN-4190 are both from a specific brand which may be more credible. The lowest cost generator when we take shipping into account is the Wai Danie Bicycle Dynamo purchased through ebay, followed by the AXA 8201 and the Union Dynamo UN-4190 which are both close in price, and lastly the teachersource generator is the most expensive. The Wai Danie Bicycle Dynamo is the only one that includes a bracket to attach the generator to a bicycle, while the teacher source is the only option that does not have a ring loop which would make installation harder than the other options. The AXA 8201 and the Union Dynamo UN-4190 both have a ring loop but no bracket so we would need to purchase an additional bracket. The teachersource generator is the only option that mentions including a rectifier and has DC power output, which means that for the rest of the options we would have to implement our own rectifier. But the teachersource generator also had the least amount of information of all the options, maybe indicating that it is not a reliable source.

The Wai Danie Bicycle Dynamo seems to be the best of these choices. It ships domestically, includes a bracket, is the lowest cost, and has a higher output, the only negative is that it will require an external rectifier. After that the next best options would be the AXA 8201 and the Union Dynamo UN-4190 because they come from reliable sources and are only a little more expensive, but they ship internationally, have a lower power output and would require a bracket purchase and an external rectifier. Lastly is the teachersource generator because it is the most expensive, we would have to find a different way of attaching it to the bracket and purchase a bracket. The fact that it could come with an internal rectifier would be a big factor but because it's coming from a source with very little information and there is no brand from which we could verify that it may not be true.

We did end up choosing the Wai Danie Bicycle Dynamo and after testing we found that it worked as advertised. It worked well for our purposes.

3.4 Rectifier

Almost all devices we use require a direct current (DC) to operate. The issue with this is that power sources that supply DC are very limited and for the most part can only be found from outlets in homes. The power generated and sent to your home is an alternating current (AC) power source. To convert this power from AC to DC, we can use rectifiers.

Rectifiers are used to convert oscillating two-directional AC into a single-directional DC. Rectifiers are used daily since most devices run on DC power and the power grid supplies us with AC power. There are many different types of rectifiers, each having their advantages and purpose depending on the output needed for specific applications. The most widely used types of rectifiers are half-wave rectifiers, full-wave center tapped rectifiers, and full-wave bridge rectifiers.

3.4.1 Half-wave rectifiers

Half-wave rectifiers are the simplest form of available rectifiers on the market. The three main parts are a transformer, resistive load, and a diode. As the AC input on the primary side goes through the transformer and into the secondary side, the diode is forward biased during either the positive (or negative) half cycles of the AC input. This means that the current during the positive half cycles of the AC input is allowed through. The diode is then reverse-biased during the negative half cycles and does not let any current through (acts like an open). This process repeats and we can see in the image below how we only have positive half cycles as the DC output. Although we get a DC output, the pulsating DC output is not practical and must be smoothed out using a filter (capacitor or inductor). The advantages of the half-wave rectifier are how simple they are. Because of their simplicity, they are easy to construct and are cost effective. The disadvantages are that the negative half cycles (or positive cycles) that were not let through because of the reverse biased diode are wasted energy and contribute to a low voltage output. The output then needs to be further smoothed in order to be useful.

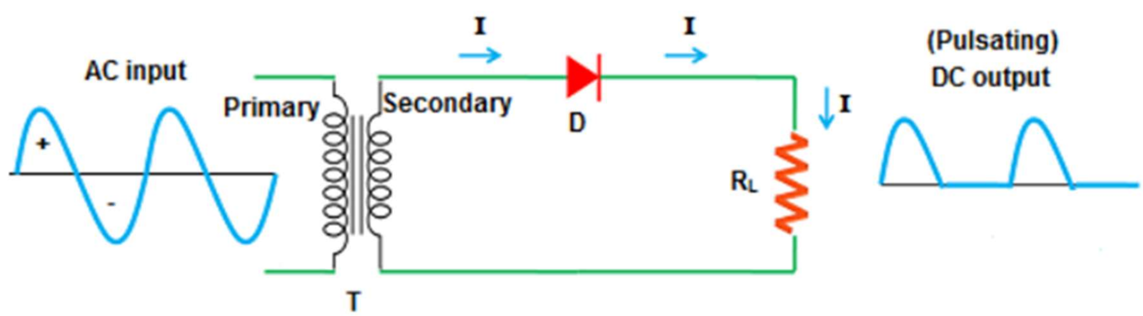


Figure 3.4.1 Half-wave rectifier. Permission pending. Reprinted from https://www.physics-and-radio-Figure 3.5.1 Series linear voltage regulatorelectronics.com/electronic-devices-and-circuits/rectifier/halfwaverectifier.html

3.4.2 Full-wave center tapped rectifier

Full-wave center tapped rectifiers are more widely used than half-wave rectifiers for their ability to output both half cycles as a DC output. This rectifier is made up of a few more components than the half-wave. Those components are a transformer, two diodes, a load resistor, and a center tap. The center tap is placed on the secondary side of the transformer exactly in the middle (at 0 volts) to divide the input AC signal into two parts.

The top part produces a positive voltage, and the bottom part produces a negative voltage. Although both the top and bottom voltages are equal in magnitude, they are 180 degrees out of phase of each other. As can be seen in the diagram below, diode D1 is forward biased and diode D2 is reverse biased during the positive cycle, which means there is only current flow in the top part. During the negative cycle, the opposite happens. From this, we can see we get double the DC output than a half-wave rectifier. This is one of the advantages of using this rectifier, a larger voltage output which means better efficiency. The biggest disadvantage is the high cost of using the center tap. Since the pulsating DC output is not practical for useful application, a filter needs to be used to smooth out the DC output. This can be done by placing a capacitor parallel to the load resistor.

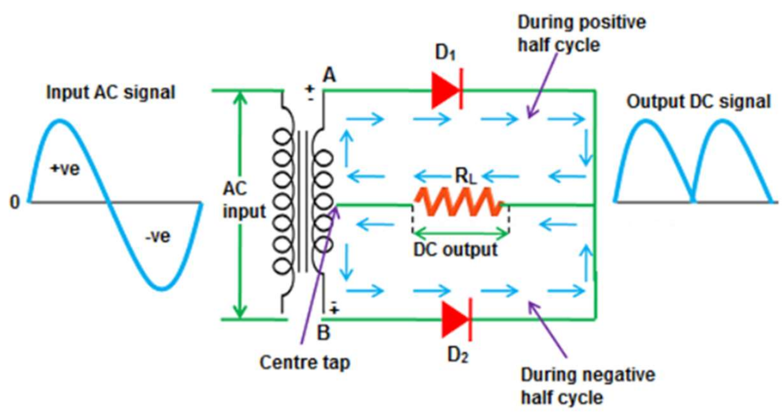


Figure 3.4.2 Full-wave rectifier. Permission pending. Reprinted from https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/rectifier/fullwaverectifier.html

3.4.3 Bridge rectifier

The bridge rectifier is more cost effective versus the center tapped rectifier since the center tap wire and the transformer are no longer needed. This also reduces the size. Instead, the bridge rectifier consists of 4 diodes and a load resistor. Similar to the center tapped rectifier, 2 diodes allow current to flow through during the positive half cycle and the other 2 diodes allow current to flow through the negative half cycles. This means that the DC output of this rectifier is almost identical to that of the center tapped. Advantages are that you get double the DC output than a half-wave rectifier while being cheaper than the center tapped rectifier. One of the biggest disadvantages is that since you have 4 diodes, it means more voltage drop. The complexity is higher compared to other rectifiers that use 1 or 2 diodes.

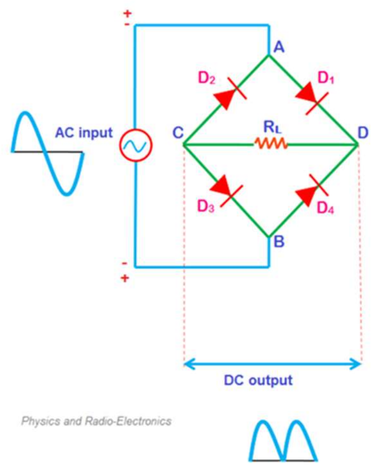


Figure 3.4.3 Bridge rectifier. Permission pending. Reprinted from https://www.physics-and-radio-electronics.com/electronic-devices-and-circuits/rectifier/bridgerectifier.html

3.4.4 Choosing the right rectifier

Integrating the correct rectifier into the circuit will be dependent on how much voltage you want as the output. Looking at the generator and the solar panel, they have max voltages of 12V and 17V, respectively. In order to produce these voltages, ideal conditions would be needed. That means long distance riding without any red lights or other obstructions, and sunny weather. Considering lower voltages will be achieved on average, choosing a half-wave rectifier would further cut on the amount of energy being transferred to the battery charger. Since the bridge rectifier can be built using only four diodes, and produces both the positive and negative half cycles of DC output, it is the better choice for efficiency and even cost. The full-wave center tapped rectifier also produces the positive and negative half cycles of the DC output, but the complexity increases and is more expensive due to the need of a transformer and center tap wire.

3.5 Voltage regulator

Voltage regulators are important since all electronic devices have specifications on which predetermined voltages they can function at. Most of the power supplied from the grid comes in the form of AC power. After AC is converted to the designated power form (AC-DC), the voltage regulator makes sure that a constant voltage source is being supplied to the load throughout all operating occurrences. More importantly, this means it will regulate voltage going to the load during power fluctuations and changes in the load consumption. Normally, a voltage regulator will take a higher voltage input and output a lower, more stable voltage. This also helps protect external devices and circuitry against voltage spikes that could go over devices' voltage rating and cause permanent damage. The most common type of active voltage regulators are integrated circuits that are made up of transistors and op-amps like linear regulators and switching regulators.

3.5.1 Linear Regulators

Linear voltage regulators maintain a specific voltage output regardless of changes to the input voltage and load conditions. This can be seen in the image below. The BJT is controlled by a high gain amplifier. Another big part is the voltage divider that can be seen made by R1 and R2. In order to keep a constant output voltage across the load resistor (RL), the resistance of the resistors R1 and R2 in the voltage divider are varied. The voltage from the voltage divider is compared to the voltage reference (Vref). This comparison will send a signal to the BJT, varying the voltage across it and therefore output voltage is kept constant. These are sometimes known as step down converter since some of the power is converted into heat to keep the output voltage constant. Its ease to implement and cost-effective characteristics make it sought after. This works great if you want your output voltage to be less than the input voltage, but makes it less efficient simultaneously.

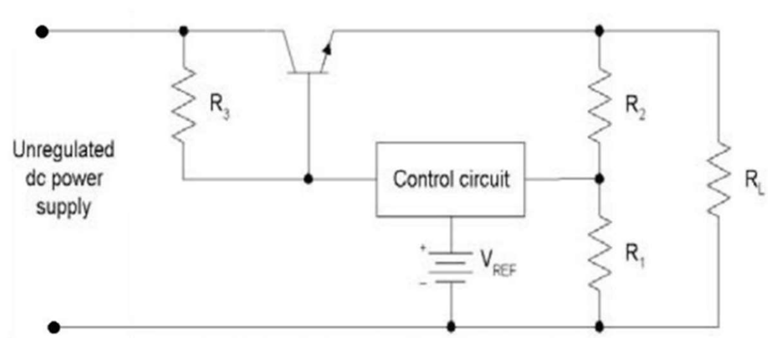


Figure 3.5.1 Series linear voltage regulator. Permission pending. Reprinted from https://how2electronics.com/linear-voltage-regulator-circuit-types-applications/#:~:text=A%20linear%20voltage%20regulator%20is,by%20a%20high%20gain%20amplifier

3.5.2 Switching Regulators

Switching voltage regulators use a switching element to convert the input voltage into a pulsing voltage which is then smoothed out using filters like capacitors and inductors. The switch will stay ON and pass power from the input to the output until the desired voltage is reached. Once it is reached, the switch goes OFF and no more power from the input is passed through. This keeps repeating and provides the pulsating voltage that is further smoothed by a capacitor as can be seen below before being the output voltage. advantages include higher efficiency and less heat generation. On the other hand, it is a more difficult design to implement and more parts are required which would increase the cost of the project.

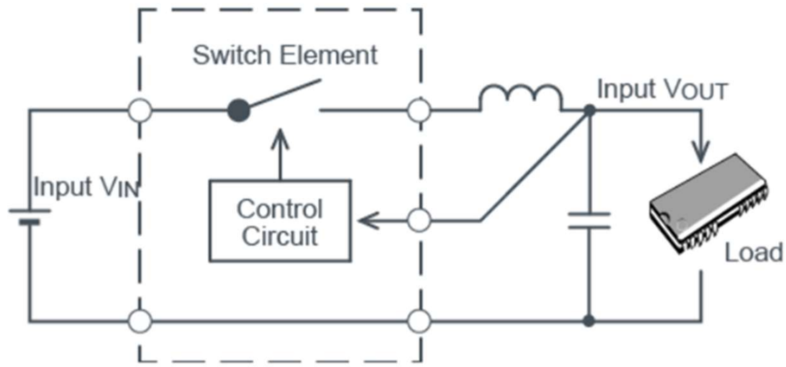


Figure 3.5.2 Switching regulator. Permission pending. Reprinted from https://www.rohm.com/electronics-basics/dc-dc-converters/linear-vs-switching-regulators

3.5.3 Buck converter

Later in the charger section of the document, it's briefly mentioned that a buck switch-mode charger contains a DC/DC buck converter, but how does it work exactly? In the buck switch-mode charger, there are two FET switches out of four that are used in conjunction as a DC/DC buck converter. Another name for the buck converter is a step down voltage regulator, and for good reason, as that is essentially what it does. Stepping down DC voltages allows for more efficient usage of power, while simultaneously stepping up current, and it's done by using an inductor and a few transistor switches. Converting a high voltage to a low voltage by stepping it down will allow for several more benefits than just more efficiency, as there will also be better performance in the transient phase along with reducing current requirements for the input capacitor.

The way a buck converter works is easily broken down into two steps. The first step consists of turning on the switch. Upon turning on, the switch lets current flow to the output capacitor, and therefore charging it in the process. The voltage across the capacitor won't rise instantly, and this voltage is not the full voltage available from the power source due to the inductor limiting the charging current.

Once the switch turns off, the inductor creates a voltage across the inductor because the current in an inductor is incapable of rapidly changing. Then this voltage can charge the capacitor, and when the switch is off, power the load through the diode and maintain an output current during the switching cycle. These two steps are repeated thousands of times rapidly within a second to give a continuous output.
The beneficial thing about a buck converter is that it can take a DC input directly from a DC source, like a battery for example, but it can also take in inputs from rectified AC sources.

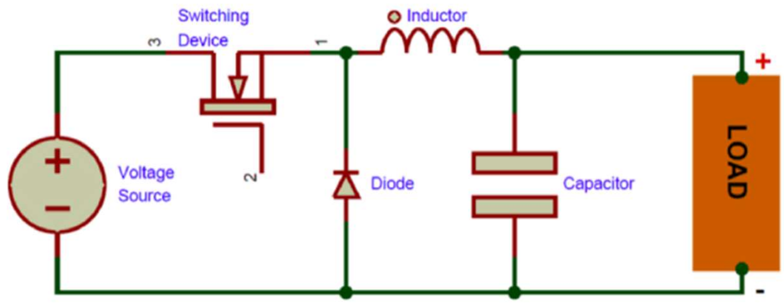


Figure 3.5.3: typical Buck Converter circuit

3.5.4 Voltage Regulators Used

Two voltage regulators, 7805T and 7812T were used for the sidewall mount generator and the solar panel respectively. The reason for using the 7812T regulator for the solar panel was that the solar panel had a larger voltage output than the sidewall mount generator. Since the solar panel, under a normal sunny day, would deliver more voltage than 12V, the regulator would always output a constant voltage. The same applied to the sidewall generator, where pedaling the bike generated more voltage than 5V, always allowing the 7805T regulator to output 5V. Being able to supply a steady voltage, even at the times the rider is not pedaling (because of the solar panel), allowed us to charge loads (cell phones) without having a battery as part of the system.

3.5.4.1 Generator voltage regulator

After being rectified into DC voltage the power from the generator goes through voltage regulation. The voltage regulator circuit that we utilized for the sidewall generator uses the 7805t part. This is a 5 volt regulator. The design also includes a 0.33uF capacitor and a 0.1uF capacitor. In our design we used three 0.1uF capacitors in parallel to combine up the 0.33uF capacitor needed. In the original design, a much too small surface mount regulator part was used. That option was no longer viable so we made our own, simpler, regulator circuit.

3.5.4.2 Solar panel voltage regulator

The voltage regulator circuit that we designed for the solar panel uses the 7812T part. This is a 12 volt regulator. Much like the voltage regulator for the generator, the voltage regulator circuit for the solar panel includes a 0.33uF capacitor and a 0.1uF capacitor, and we used 0.1uF capacitors in parallel to make the 0.33uF capacitor. The 12 voltage regulator allows us to take advantage of the solar panel's higher voltage rating of 17V when compared to the generator's 12V.

3.6 Battery Charger

To properly suit the bicycle, the team must find a charger that can receive two sources of power input due to the nature of the project. Of course, the battery chosen will be rechargeable for more convenience and less turmoil for the rider. Since specific solar batteries are not needed, the team will be more focused on just rechargeable batteries. With that being said, different battery chargers that were looked into are discussed below.

First and foremost, when it comes to selecting a charger, it’s important to keep in mind that the team would like to keep the battery safe, which means protecting the battery from overcharging; and the team wants to make the charger easy to implement, along with once again having a need for a charger that can handle two inputs. A charger with these three elements would let the team feel as comfortable as possible with the project.

There are also a large number of different kinds of battery chargers that need to be looked over. There are linear chargers, buck switch-mode chargers with and without three levels, direct chargers that consist of flash chargers and two-phase, switched-capacitor chargers (or 2:1 SC chargers for short), boost chargers, and last but certainly not least, buck-boost chargers.

3.6.1 Linear Chargers

Linear chargers consist of two blocking switches that can go in either direction and exist to isolate both the input and output terminals. The middle point of these two switches, referred to as the PMID, is what powers the system. Due to this, linear chargers allow the system voltage to range from input voltage down to battery voltage upon removing the input. This is further found in the following components in the feature known as Power Path management. Linear chargers are especially useful for their simplicity and ability to be used on even the smallest printed-circuit-boards of 12mm, along with their low quiescent current, that clocks in at the lowest of them all. This charger type also has the ability to have a highly accurate regulation accuracy at low currents, due to the lack of high frequency switching loops that end up keeping electromagnetic interference to a minimum. The main issue with this charger type, however, is the fact that its efficiency is lacking. This limits the charger to usually be used in appliances that require a current of 1A or lower, like small handhelds and most recently, wireless earbuds and fitness trackers.

3.6.2 Buck switch mode charger

The way that a buck switch-mode charger works is through the use of four switches. One that is referred to as the reverse blocking field-effect transistor, or FET, that functions as a way to prevent the battery from discharging into the input; another two switches that are also FETs and are used together as a DC/DC buck converter; and a FET battery that is used to allow for Power Path management. The buck charger does its job of powering the system through the buck converter when there’s an input, or through the battery when there’s no input. Buck chargers are far better than linear chargers when it comes to efficiency, as these chargers can ideally keep about 91% of efficiency, which can vary when other components and silicon within the charger are tweaked. It's worth mentioning that higher efficiency at higher currents comes through with a larger circuit area, which linear chargers aren't known to possess. Buck switch-mode chargers are very versatile for this reason, as they are quite popular and are used for a variety of modern day applications, like portable power-banks, hand-helds, and even video game controllers. A drawback of these devices is that there may be electromagnetic interference due to the high-frequency switching that buck converters use to convert voltage, so when it comes to interference, linear chargers are the better alternative, albeit a less powerful and versatile one.

3.6.3 Three-level buck switch-mode chargers

Three-level buck switch-mode chargers are different from their one level counterparts in that they include a flying capacitor that reduces the stress of voltage on switching FETs by an entire 50%. This in turn allows for much higher effective switching frequency, just about twice as much when compared to a regular buck charger. Not only that, but the peak ripple current is reduced to 25%, making the efficiency and power density much higher, which are hard to have both as a feature in buck switch-mode chargers. The inductance requirement of these chargers is lower as well, due to the flying capacitor that remains balanced at $V_{BUS,}$ which then leads to a smaller area and even more efficiency. The peak efficiency of three-level buck switch-mode chargers are about 95%, and they achieve these levels with smaller circuit areas than their counterparts. They also deal well with high charge currents due to their stellar handling of heat and of course, the high efficiency. All of these key features allow for this kind of charger to handle modern day smartphones.

3.6.4 Direct chargers

Direct chargers, while avoiding the use of circuitry to get their job done, most definitely still get the job done. Their efficiency can be up to 96% by offloading regulation to an external adapter and directly connecting the input to the charger's output. These direct chargers are in turn perfectly suitable for high charge currents in the range of 4A to 8A. Of course, like the other chargers, this one comes with its own downside. In this case, it's the fact that the cables required to make these chargers require high current thresholds, making the cables and chargers expensive in the process. However, these devices are incredibly useful for their adapters that have high regulation accuracy and their dedicated host that monitors the battery level at all times, while also being able to effectively communicate with the adapter for correct regulation.

Direct chargers come in two variants, the flash charger and the 2:1 switched-capacitor charger both mentioned above. The flash charger is able to achieve the lowest loss seen in a charger due to its use of two shorting FETs in the middle of VBUS and VBAT that charge the battery. This is the smaller variant of the two with the expensive cables. The other variant achieves the opposite by having high efficiency while reducing input current thresholds, rather than having higher requirements like the flash charger. However, the

SC charger has a need for a smart adapter that can double battery voltage, since the charger is an unregulated switching converter that works by halving input voltage and doubling input current. Therefore, this kind of charger can also utilize 8A of charge, which is the highest charge current.

3.6.5 Charger type comparison

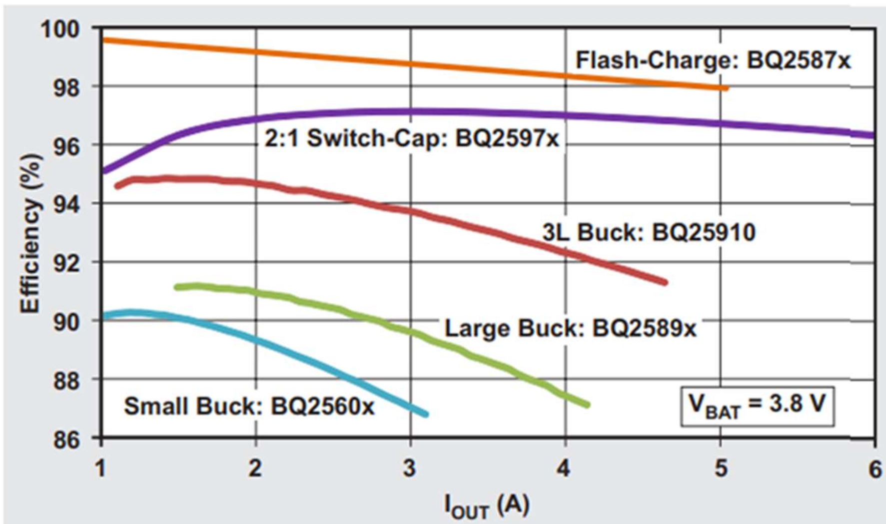


Figure 3.6.5: Levels of Efficiency for the different kinds of chargers discussed above. Permission pending. Reprinted from https://www.ti.com/lit/an/slyt769/slyt769.pdf?ts=1670219493886&ref_url=https%253A%252F%252Fwww.google.com%252F

	Linear	*Flash*	*2:1 SC*	*Buck*	*3 Level Buck*
Applications	Small handhelds, earbuds etc.	Electric grid and cars, aviation	High power density converters	Portable power banks, game controllers, handhelds	Modern smartphones
Benefits	Simple, high accuracy at low current, minimal EM interference, small size	Highest efficiency, smaller than SC	High efficiency, can use the highest current charge, less expensive than Flash	Very versatile yet simple, high compatibility , popular	Excellent heat and high current handling, much more efficient and smaller than buck

Drawbacks	Lowest efficiency	High cost	Needs to communicate with adapter	Risks Electromagn-etic Interference	

Table 3.6.5: Single-Cell battery charger overview

Earlier, boost chargers and buck-boost chargers were mentioned but these are a step above single-cell battery chargers, as they are dual chargers instead. Dual chargers are able to reach higher charge currents due to it being composed of two chargers in parallel. It functions by having a main charger that provides the charge current while supporting the system's load, and then including a parallel charger that gives highly efficient, additional charging current.

Boost chargers function like a reverse buck converter, meaning that they generate an output voltage higher than the input voltage to the system. Through this method, the charger can power devices that need high peak currents and/ or high voltage. The average boost charger can charge two lithium ion batteries from a 5V USB source. These chargers have been employed in smartphones for almost a decade already, and they're especially useful in printers, motors, and speakers.

The buck-boost charger has applications in drones, portable computers, and robot vacuum cleaners due to its flexible input voltage range. With a range of 3.5V to 24V, the buck-boost charger can be used with most common devices and has great compatibility with USB power delivery. The way it functions is through four switching FETs that can go from buck, boost, and buck-boost operating modes, which allow it to be used for just about any battery, not to mention one to four cells at a time.

Overall, discussing all of these charger types lets the team better understand which one is best suited for the project, whether it be a single-cell or multi-cell charger. At the moment, single-cell is the cheaper and smaller option, so that will most likely be the focus going forward.

3.6.6 Charger options

All of the chargers listed below have been shown to be less than $5, which is astonishingly cheap for such good products. Similar prices between all of these models means that it doesn't make much of a difference which is purchased when it comes to budgeting.

3.6.6.1 BQ24160 (1-cell)

The BQ24160 battery charger from Texas Instruments shares many characteristics with other similar models (24160A, 24161(B), 24163, 24168) but each has its own set of specifications that allow it to stand out from the other ever so slightly. These are all single-cell lithium-ion battery chargers that are targeted for small, portable appliances with batteries that have a high capacity. These models all check the three boxes mentioned earlier, as they contain overvoltage protection (OVP), meaning that a battery will not be at risk of overcharging; all of the models are able to use USB inputs of up to 6.5V and 1.5A, meaning that it's easy to implement; and finally, one of the main aspects of these models is that they all handle two inputs, with a regular IN input rating of 10.5V and 2.5A for the 24160(A), 24161, and 24163 models.

Along with having the team's desired qualities, the models mentioned above contain a variety of other useful features. The battery charger contains power path control, allowing for the system to instantly start even with a heavily discharged battery or no battery at all. The dual input OVP charger has a 20V input rating that not only allows for USB input, but also allows for a higher-power input supply, like an AC adapter or wireless charging input for instance.

Due to the component's layout and the I^2C interface, these two inputs are isolated from the other and allow for easy selection between them. Ideally, the components are for small, portable appliances, like handhelds, media players, equipment, and netbook or internet devices.
The accuracy of the component is a little lacking, but it is nonetheless safe at a 1% battery regulation accuracy and a 10% charge current accuracy.

The 24168 model alone has a voltage rating of 6.5V for a regular IN input, and an amperage rating of 2.5A, making it the weakest of the bunch, but it still contains one more feature than the 24161 model, the dual BAT temp thermistor monitoring, since it has both the JEITA profile and the hot/cold profile. JEITA just means that it's up to Japan's electronic standards, thus adding more compatibility. Every model except the 24161 model is JEITA compatible, which could be important when looking at overall compatibility. Ultimately, the 24160 and 24163 models are identical and the most ideal, as they contain both thermistor monitoring types along with IINDPM (Input current limit), Input OVP, Power Path, USB D+/D-/BC1.2 integrated, as some models are seemingly missing the last element.

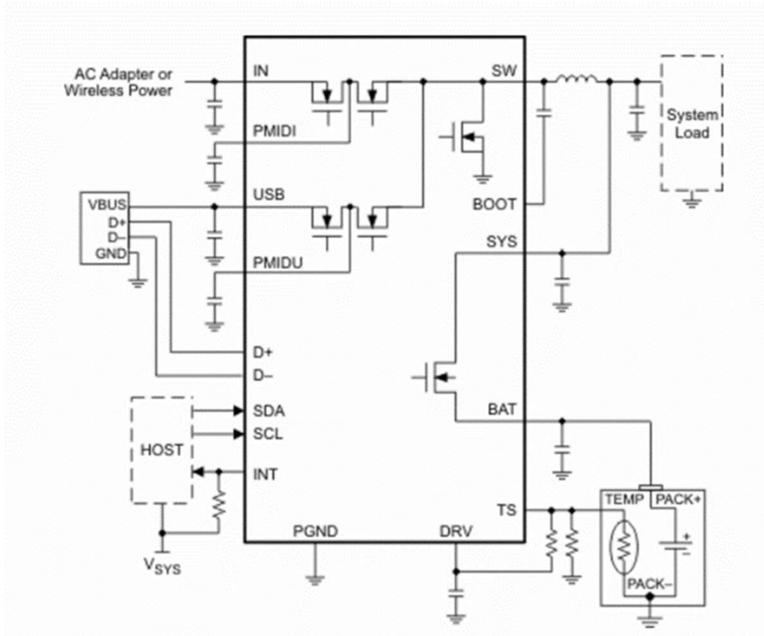


Figure 3.6.6.1: BQ24160 schematic. Permission pending. Reprinted from https://www.ti.com/lit/ds/symlink/bq24160.pdf?ts=1670389208209&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FBQ24160%253FkeyMatch%253DBQ24160

3.6.6.2 BQ24166 (1-cell)

These models of the BQ241xx are fairly similar to the earlier ones, but they have notable differences that should be considered when picking a battery charger. Although the BQ24165, 24166, and the 24167 were built for the same purpose in mind (charge small, portable devices), the specifications and features are still different.

These models are still made from lithium-ion, have USB ports, have thermistors to monitor battery temperature, utilize two inputs, and contain the same voltage and ampere ratings (for both USB and regular IN inputs) as the 24160 model, but have the added feature of VINDPM, which is a threshold on input voltage made to maximize an adaptor's power. Not only that, but with the Power Path feature, these models can make a GSM phone call without batteries or with a very heavily discharged battery. With GSM being the mobile phone standard, essentially, these models can function as decent phones and data transmitters. This is one of the key features of this model and for good reason, as this seems like a large step up from the others. Along with this, these models are also slightly more accurate with battery regulation accuracy: 0.5% compared to the 1% the others contain. The charge current accuracy remains the same at 10%.

More features added here are the low battery leakage current and BAT short-circuit protection, a soft start feature that reduces Inrush current, and a thermal shutdown protection feature. Overall, these models seem the most suited for safety precautions, which is a gigantic plus to the team and one of the critical aspects we're looking for. It's worth noting that the system will never drop below 3.5V, but the constant monitoring of battery current and the other features in place to terminate charging allow for a safe component. Power Path management and adjusting charge current are still easy as well across all models, and it seems that 24167 exists for more JEITA compatibility and not much else.

One difference that 24165 has from the others is the inclusion of a second Charge Enable input, meaning that that model can use this feature to enable and disable the charging process like the other models, along with changing battery and charge regulations. It sounds appealing, but that model also isn't explicitly stated or shown to use the Standard Temperature Range or be JEITA Compatible with a thermistor, which is strange since the Texas Instruments pages says it contains a thermistor that fulfills both roles. Upon looking at the pin configurations, it has no TS or thermistor pin. Typo or not, it seems to be in our best interest to pick the BQ24166 model out of these three, as a thermistor is more essential to the project.

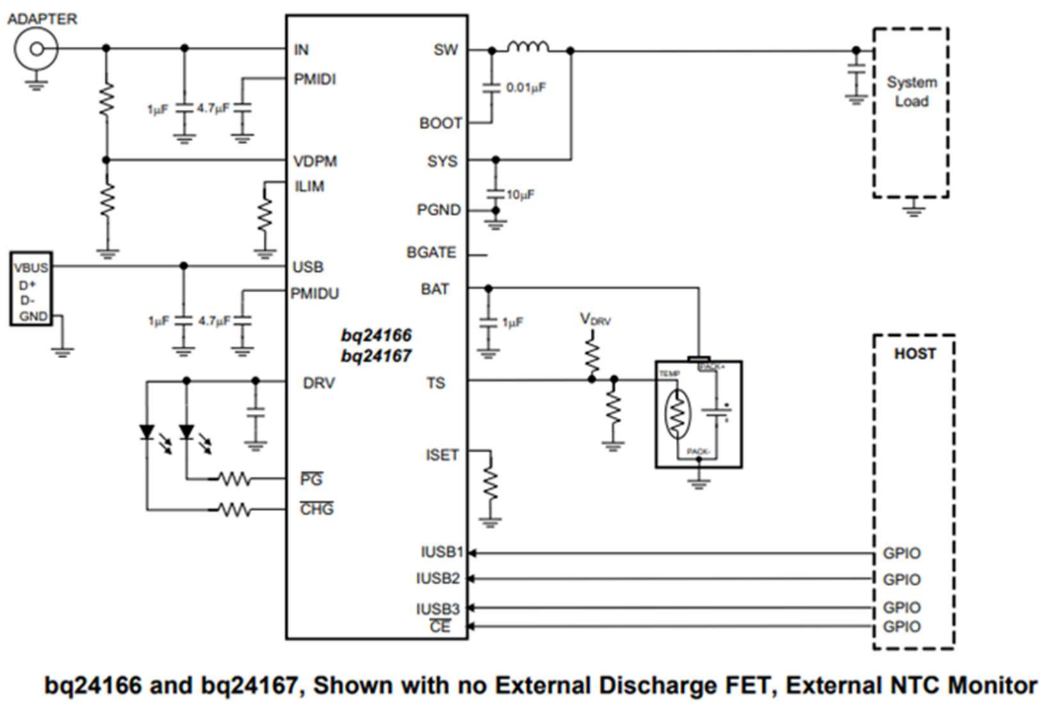


Figure 3.6.6.2: One possible application circuit with BQ24166. Permission pending. Reprinted from https://www.ti.com/lit/ds/symlink/bq24166.pdf?ts=1670323858360

3.6.6.3 BQ2407x (1-cell)

Developed once again by Texas Instruments and consisting of the models BQ24072, 24073, 24074, 24075, and 24079, these models are quite different from the ones mentioned before. Right off the bat, this charger's voltage ratings are quite high for what we need, and that allows for a more diverse variety of uses. It's commonly used for headphones and charging cases, IP network cameras, gaming accessories, asset tracking and fleet management, and of all things, portable medical devices, and video doorbells. This range of appliances implies that this is quite the versatile component, and that looks quite appealing to the team already.

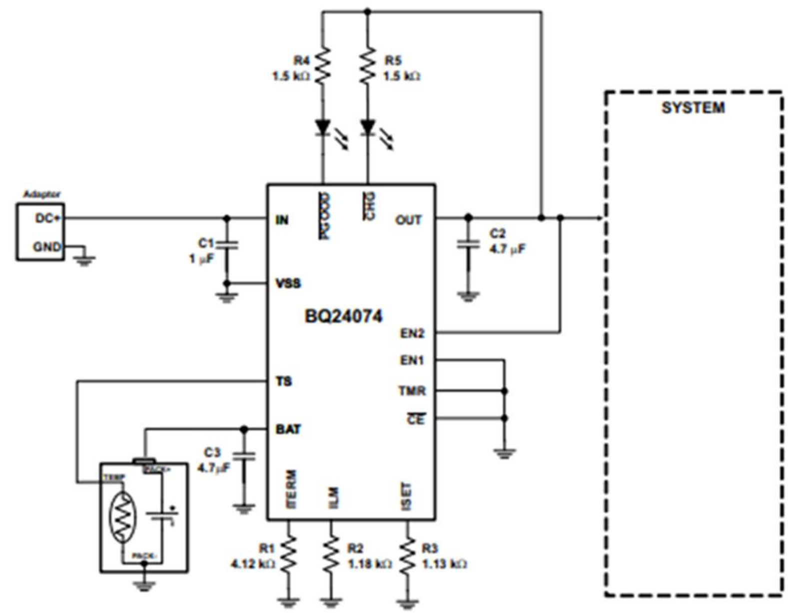
Luckily, the 28V input rating also comes with overvoltage protection, a key feature the team has been looking at to ensure full safety and no overcharging. Its fully compliant USB charger and protection against poor USB sources makes the component easily implemented into a design as well, checking another box in the team's requirements. The protection against poor sources could mean that the charger could connect to several different things, which only increases the charger's applications. For convenience, the USB charger can select between 100 mA and 500 mA max input current, and these models support up to 1.5A charge current with the ability to even monitor the current output. The ability to switch between the two input currents can let the team experiment with various inputs if the need arises, plus the added monitoring of current output allows it to be done safely.

Some other appealing features shared across the board are the ability to program pre-charge and fast-charge safety timers, limit inrush current, and show the status of the battery's charge. The pre-charge safety timer would allow the team to save time charging the battery, but of course the fast-charge timer is incredibly useful for a project like this, as the goal is to keep a phone charged efficiently and quickly if possible. Displaying the battery's charge status already without the need for more equipment gives much appreciated convenience to the team.

Incredibly enough, these models also have protection against reverse current, short-circuits, and heat, along with providing an NTC thermistor input. Since safety is a large factor in choosing components, the protection against short-circuits and heat are highly regarded, especially with the team wanting the project to be useful in many different weather conditions. Overall, the number of useful features provided by this charger is quite astonishing and definitely something to be considered in the team's design.

Different models come with several different features, and compared to the other BQ components above, there is far more of a difference between these models' features. The BQ24072 model's system output can track battery voltage, a pretty useful feature when it comes to keeping an eye on how the battery is doing. This, combined with the overvoltage protection, combine into a nice little bundle that allows for full monitoring of the battery with the charger alone and without any need for other outside instruments.

This seems to be a reoccurring theme with these models, and the team couldn't be happier. The BQ24074 comes with programmable termination current and is Functional Safety-Capable, which essentially means that this model in particular is especially safe and has met many rigorous safety requirements. The team doesn't expect to program termination current, but it's nonetheless a useful feature that should be mentioned. The fact that this model adheres to such a high safety standard is also very comforting if this one was to be picked by the team. The BQ24705 and BQ24079 both have a battery disconnect function due to their SYSOFF input, which could be useful during testing so that the battery doesn't have to be constantly disconnected and reconnected and could instead be dealt with at a moment's notice.



Using BQ24074 in a Standalone Charger Application

Figure 3.6.6.3: Example of BQ24074 Application. Permission pending. Reprinted from https://www.ti.com/lit/ds/symlink/bq24074.pdf?ts=1670340670517&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FBQ24074

3.6.6.4 BQ25672 (1-4 cell, 3.5Vin)

After looking extensively at single cell chargers, the team decided to take a look at what multi-cell chargers can offer. As discussed before in the main charger section, these powerful chargers can be applied to just about anything, so if the team needs an electrocardiogram feature for any reason, we should look no further. If time permits, having a feature dedicated to fitness would be perfect for the bike, and with this charger it would be very possible. Not only that, but these chargers allow for mobile POS usage, meaning that the user of the bike could use their phone to pay for something on the bike itself. This would be useful in a commercial setting where the bike has to be paid for before riding it, much like electric scooters found in college campuses.

Immediately the team can see that this kind of charger is incredibly efficient, sporting a rating of 96.5% efficiency and high power density as well. The accuracy is a little better than some of the components from before, since it's between -0.25% to 0.65%, making its accuracy 0.8% overall. Its regulation for charge and input are both -+5%, so it's about the same as the others. Where this charger excels however, is the range of input voltage. Due to it being from 3.6V to 24V with an absolute max of 30V, this will most certainly fit any situation thrown at it. In our case, this model is especially useful due to its compatibility with photovoltaic panels, as it's able to use its maximum power point tracking, or MPPT, to receive charge from it. Along with being compatible with solar power, it still contains the ability to receive adapters through USB. Among all of those features, it can also utilize dual-input and alternate between sources.

Even after all of these features, the component still has an emphasis on safety, with thermal regulation, thermal shutdown, input OVP, and a charging safety timer all being present. At every step, this component is looking more and more like it's the best of the bunch so far.

The component is overall just fantastic. In fact, it's so fantastic that it's unavailable and that's the only reason why it wasn't able to join our list of components. A typical application of the component is shown below, and it's plain to see that it can handle a great deal of attachments, which proves why the model is unfortunately unavailable.

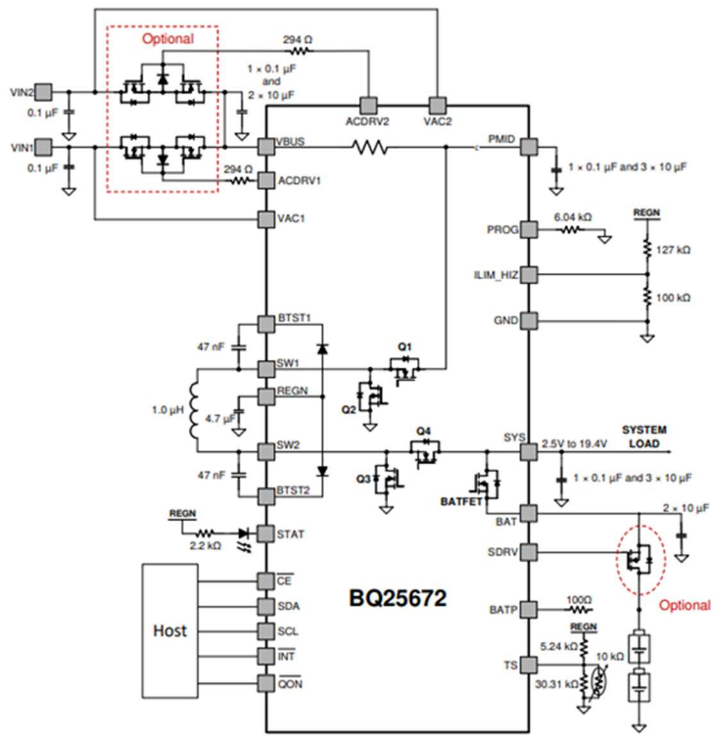


Figure 3.6.6.4: BQ25672 handling two input sources. Permission pending. Reprinted from https://www.ti.com/lit/ds/symlink/bq25672.pdf?ts=1670337314800&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FBQ25672

3.6.6.5 Battery charger used in initial design

In our initial design we used the BQ25672 RQMR part that was discussed in section 3.6.6.4. It was very small which likely led to shorts during soldering, and potential damage during resoldering, making it not usable. We didn't end up using a battery charger, and in fact didn't use a battery in our final design. With more time we would have implemented a new battery charging circuit that would have worked with our new design.

3.7 Battery

In order to harness and use the energy generated from the solar and mechanical generator sources, a battery will be used to power or charge electronic devices. Energy may be needed to be readily available, or it may be needed at later times when energy isn't being generated at a constant rate. Generally, a battery consists of two terminals, the anode (negative charge) and cathode (positive charge), that are separated by a chemical medium, the electrolyte. After a battery has been charged, the stored energy can be discharged as usable electricity. Considering that we want to make this as efficient and long lasting as possible, we will focus on rechargeable batteries since disposable batteries will only work in one direction, meaning that the chemical energy will be transformed to electrical energy, but not vice versa. This will not be convenient and increase cost over an extended period of time, and will defeat the purpose of harnessing renewable energy generated from the bicycle.

It should be mentioned that since the solar system is not large, we do not need to worry about using specific solar batteries. Solar batteries are different from regular batteries in that they are typically c10 rating. This means that they should not be fully discharged within 10 hours of charging the battery. Regular batteries are typically c20 rated. Being c10 rated benefits solar batteries as there are usually about 8-10 hours of direct sunlight when weather conditions are fair.

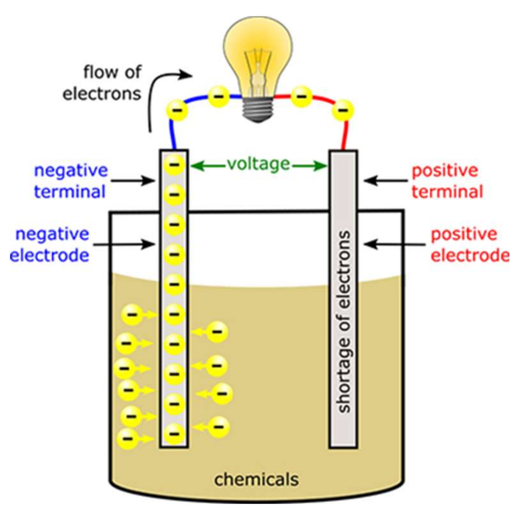


Figure 3.7 Battery. Permission pending. Reprinted from https://www.dummies.com/article/technology/electronics/general-electronics/how-batteries-work-138048/

After concluding that rechargeable batteries were the optimal option over non chargeable for this project, the next decision is on which type of rechargeable battery to use. The four options of batteries that were considered are lead-acid, Lithium-ion, Nickel-Cadmium, and Nickel-Metal Hydride. These 4 options were considered due to their availability with regards to recent pandemics around the world affecting market supply. They also have specifications that would make them possibilities for this project.

3.7.1 Lead Acid

The lead-acid battery is the oldest rechargeable battery on the market. Because these batteries are powerful, cheap, and last for a long time, they are still currently used in many applications today. These batteries are easily rechargeable and have high power output. One of the disadvantages of the lead acid battery is the lead they contain. This toxin can be very bad for the environment if the battery is not disposed of properly once replaced. Another disadvantage is their size. Lead-acid batteries tend to be bulky, heavy, and large in comparison to most other batteries on the market due their low energy density.

3.7.2 Lithium-Ion (Li-ion)

Lithium-ion batteries are the most common rechargeable batteries that are in use in small portable handheld devices today. They are favorable for small electronic devices because of their light and compact design. Lithium-ion batteries have a higher energy density than most rechargeable batteries which contributes to their long-lasting characteristic. Maintaining these batteries does not include having to do scheduled cycling as often as other batteries. They deliver more current and have a slow self-discharge rate which gives them a longer shelf life. All of this comes with disadvantages. One of the most important disadvantages is its safety. Since they contain a flammable electrolyte, they do pose a danger, like a fire (ex. Samsung Galaxy Note 7 fire). Therefore, having a safety circuit is important for these batteries. Being that this type of battery holds a charge the longest of the four battery options, they do come with a higher price tag.

3.7.3 Nickel-Cadmium (NiCd)

These batteries have been around for a long time, and being that they can supply a high current makes them a great use for devices that need lots of energy. An environmental advantage is that they are very hardy and can last 10-15 years or longer. Their low capacity can be both an advantage and a disadvantage. Their low capacity gives them the ability to reach a full charge in a short amount of time. This would make sense for an application that requires a lot of power in short increments, and then recharge again. The disadvantage of the low capacity is that the charge is not held for very long. Discarding them must be done appropriately since they do contain the toxin cadmium.

3.7.4 Nickel-Metal Hydride (NiMH)

Unlike Nickel-Cadmium batteries, Nickel-Metal Hydride batteries have better capacities, meaning they are superior in those areas compared to Nickel-Cadmium. One of the disadvantages would be its lifespan, where they on average last about 3 years maximum. As they go through repeated cycles of high load currents, the performance begins to deteriorate after only a couple hundred cycles. Another disadvantage would be the high self-discharge rate. Having a higher discharge rate than NiCd, they lose energy a lot faster when not actively used.

3.7.5 Choosing the right battery

After looking through all possible options of batteries, we have decided to choose a 3.7V rechargeable lithium-ion battery with a capacity of 6.27Ah. The reason for choosing a Lithium-ion battery is because of their compact design which would increase the options of mounting on different parts of a bicycle. The downside comes in the financial category. These batteries were the most expensive choice out of the four options, but considering the flexibility it gives on where we can mount it on the bicycle, in addition to its higher energy density and slow self-discharge rate, it is definitely worth spending the extra money for it. The standard charger for iPhones have an output of 5V and 1A. This gives 5W of energy used to charge an iphone. Because our intent is not to mimic the charging capability of a wall outlet, we do still want enough power to charge an iphone. Because of this, we chose a battery that has 3.7V rating and output constant charging current of 1.65A. This gives 6.105W of energy to charge the phone which is way more than a wall outlet. Realistically, it is not expected for the battery to always deliver 1.65A to the load. This is still acceptable because slow charging for an iphone requires 3W of energy. The battery also has a JST PH Connector termination which will help in the construction stage of the project. if there is a JST PH Connector at the other end, then you can simply connect it. If not, then cutting off the connector is an option and can be attached using extending wires.

3.7.6 Implemented Design

The biggest set back was not being able to include a battery in the system. The battery would act as a steady DC source of energy to the loads. Instead, two voltage regulators, 7805T and 7812T were used for the sidewall mount generator and the solar panel respectively. Being able to supply a steady voltage, even at the times the rider is not pedaling (because of the solar panel), allowed us to charge loads (cell phones) without having a battery as part of the system. Not having a battery as part of the system eliminated the need for the charging circuit. This turned out to be a positive since the battery charger that was initially ordered for the original design was a surface mount part and would be unusable on a perfboard, and parts to build a charging circuit from scratch was absent.

If we had more time we would have been able to implement a new charging circuit for our system and use the battery again. Though we would have also needed a battery with higher voltage than the one that we initially chose.

3.8 Microcontroller

The team doesn't expect much programming and computation to be necessary for this project, so our goal is to obtain a simple microcontroller that can be operational with little power.

3.8.1 MSP430FR6989

The Texas Instruments MSP430FR6989 microcontroller allows for a variety of uses, that of which includes on-board emulation for programming, debugging, and energy measurements. It contains two LEDs and buttons for user interaction, along with its own LCD, a display that can be customized with relative ease within Code Composer Studio. The microcontroller contains several modes, like a stopwatch and temperature sensing mode as well. Its USB connector allows it to connect to a PC effortlessly for configuration, as well as other sources of power if necessary. Not only that, but the board also sports both a digital input and a digital output.

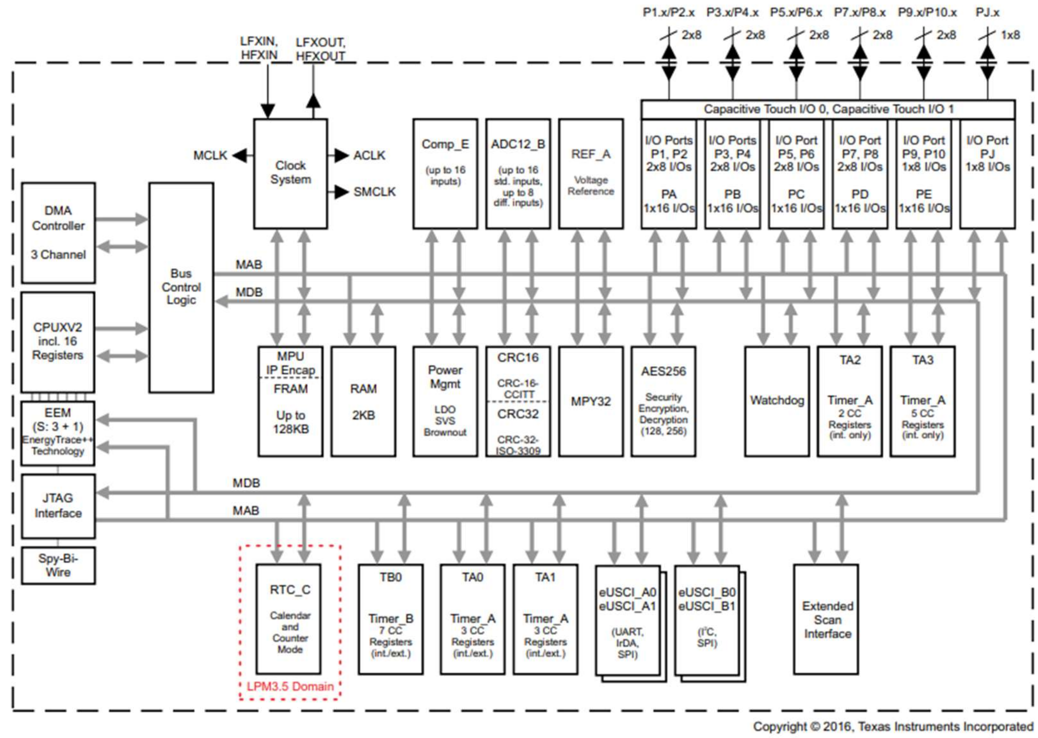
The microcontroller will need to have a decent number of pins in order to implement sensors and other planned features for the project, and this one in particular checks that box with a whopping 83 pins.

The board uses 16-bit RISC architecture, making it highly-optimized and efficient, while also being versatile. This is only strengthened further with the 128KB of flash memory, allowing the board to be viable and speedy even without an active power source. The operating temperature of -40°C – 85°C even allows the board to be used in the most outrageous environments.

One critical aspect of the MSP430FR6989 is the ability to greatly conserve power. It contains seven different low power modes, and in a project where the goal is to have as much charge as possible go towards a cellular device and away from the other components, this will no doubt be invaluable to the team. Minimizing and preventing wasted power is not only eco-friendly, but also vital to the project. With that being said, its operating voltage is 1.8V - 3.6V, with its power consumption being 100µA while on and 0.02µA when turned off.

This microcontroller has been used and acquired by several members of the team in the past due to a few courses requiring its use, so it has the added benefit of being familiar. This makes the MSP430FR6989 a likely candidate for the team's use. If the board were to require a replacement, the team would only need $20 and a visit to Texas Instruments' website, adding yet another pro to the list.

Looking at the block diagram below, it can easily be seen that this particular microcontroller has many useful components built in:



Functional Block Diagram – MSP430FR598x, MSP430FR598x1

Figure 3.8.1: the MSP430FR6989's block diagram. Permission pending. Reprinted from https://www.ti.com/lit/ds/symlink/msp430fr6989.pdf?ts=1670313827340&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252FMSP430FR6989

3.8.2 Arduino Uno R3

Arduino microcontrollers are not only abundant, but they're quite popular due to one of their main selling points: free open source software. While Texas Instruments microcontrollers have open source hardware and some open source software, Arduino offers a lot more in comparison. With a large amount of open source material, it would be easy to find designs for reference and implementations online without a hitch.

The board is created with beginners in mind, and many agree that using it is quite simple. However, the team isn't as familiar with this board as it is with the MSP430, so there would have to be some time allotted to figuring out the necessary features the Arduino holds. It uses its own programming software as well, instead of Code Composer Studio. The Arduino Software Integrated Development Environment still uses C/C++ and contains a variety of libraries for the user to look through and use though. Regardless, the board is used very often and is compatible with every common Operating System, making it valuable to any project.

The Arduino Uno R3 contains the ATmega328 microprocessor, which makes the board perform powerfully, quickly, and most importantly, conservatively. Although the board does not contain an LCD, we plan on using a separate LCD as seen below, so for this situation, it doesn't seem necessary. The board also uses a USB connection like the MSP, allowing for a convenient plug in to a device.

One drawback to this board in particular is its amount of pins. Our project likely won't need the 83 pins that the MSP board provides, but this Arduino only contains 14 digital I/O pins. This information will have to be considered when finalizing our microcontroller. Like the MSP, this microcontroller uses a crystal oscillator, albeit a 16 MHz one, while the MSP uses a 32kHz. Its voltage range is a little higher as well, ranging from 7V - 12V. Both boards contain a reset button, but this one lacks the two buttons MSP has. Both boards can use UART, SPI, and I2C, so there's no problem there. However, although both boards can use USB connection to connect to another device, only the Arduino Uno can be connected to *with* a USB. The team does not expect to use this feature, but it does seem extremely useful. Last but not least, the Arduino Uno offers six analog I/O pins that each have a ten bit resolution. It isn't 16-bit, but the team believes that the difference isn't heart breaking.

At $22, the Arduino Uno R3 is slightly more expensive than an MSP430FR6989, but its differences and options make it a board that must be considered.

	MSP430FR6989	*Arduino Uno R3*
Price	$20	$22
Pins	83	14
Operating Voltage	1.8V – 3.6V	7V – 12V
Crystal Oscillator	32kHz	16MHz
Low Power Usage	Yes, with several modes	Yes
USB Connection	Yes, connects to other devices	Yes, it can connect to other devices and can be connected to with USB-B

Table 3.8.2: Microcontroller Comparison

Ultimately, upon comparing the two, the features of the Arduino Uno do not interest the team enough to choose it over what is already familiar and available to us. Therefore, between these devices, the microcontroller that will be utilized is the MSP430FR6989.

3.8.3 MSP430F6779

Another Texas Instruments controller the team stumbled upon after researching, this microcontroller has a variety of useful features, same as the others. However, the first thing worth mentioning is its fantastic level of accuracy, with it being 0.1% or higher. Its measurements across the board are highly accurate, even when it comes to phase angle measurements. The board also has temperature compensation for its real-time clock and energy measurements. It also features a 32-bit multiplier, and this family of microcontrollers all have 512KB of flash, 32KB of RAM, and LCD displays that have a large number of 320 segments to display various statistics.

Like the MSP430FR6989, this micro controller has an ultra-low power mode, reducing energy usage and overall costs. Not only does it have an ultra-low power mode, but it also has multiple low paper modes like the other MSP mentioned above. This controller also has wide support for multiple sensors, which the team especially needs for this project. It supports shunts, current transformers, and others.

The MSP430F6779's user-friendly features are no joke, with it containing security modules within the controller that help with encryption and fight attempts to tamper with the device. If the project were to be produced on a larger scale, this would be invaluable for keeping the system safe from shady activity. Not only that, but the controller also has password protection for its real-time clock. Besides the security measures, the controller also has multiple communication interfaces, which allow for several Smart Meters to be connected, adding more utility and monitoring for the device.

The main utility for this board is centered around monitoring energy and working with smart meters, but it can do just about everything the MSP430FR6989 can, since it also has UART, SPI, and I2C capabilities. Its Input supply voltage range is the same as the FR6989, and there are two variants of this model where one has 128 pins and 90 Input/Output pins, while the other has 100 pins and 62 I/O pins, with the 90 I/O variant beating the FR6989's amount by seven pins.

Honestly, if it weren't for the fact that the team already owns multiple MSP430FR6989's, this microcontroller would've been picked due to the added usefulness of energy measurements. However, although it's the better device of the two Texas Instruments microcontrollers, it's not something that the project desperately needs, nor is it important enough to justify buying another microcontroller, so only if anything were to happen to the controllers we already own, then this one would likely be the replacement. Besides the energy measurements and accurate readings, the selected controller already serves the same uses.

3.8.4 Implemented Design

We ended up using the Arduino Uno R3 in our final design. Controlling the sensors from the arduino proved more effective than using the MSP430FR6989.

3.9 Lighting

In addition to our charging system, we also aim to include headlights and tail lights for our users that can be powered the same way as the phone charger. Also included in this section is the on/off LED that will be used to show when the system is on and charging. Obviously, it is quite important for anyone who is riding a bicycle at dusk or night time to be visible to other cars and pedestrians around them, and remembering to recharge a bicycle light could be inconvenient for anyone who bikes frequently. When choosing a suitable LED, it is important to abide by the laws surrounding bicycle lights in one's jurisdiction; in our case, that would be Florida. For a more in depth discussion, see the section under standards covering the LEDs (4.2.3). However, for this section, the main thing to keep in mind is that it is required by law to have a white light affixed to the front of your bicycle that is visible from 500 feet away, and a red light on the back of the bicycle that can be seen from 600 feet away. The two options being considered are a standard LED, and a commercial bicycle light.

3.9.1 Standard LED/Lighting

One of our options is to purchase two LEDs, white and red, to attach to the front and back of the bicycle. When looking at bare LEDs that would typically be used for an electronics project, none would be large enough to project enough light unless large amounts of them were grouped together. This is, however, the perfect option for the on/off LED. A normal bulb could theoretically be used as well, but an adapter that would allow the bulb to be plugged into the power bank would have to be purchased. We would also have to worry about the cord being long enough to extend to the front and back of the bicycle without getting tangled up in the wheels or the rest of the bicycle. A pro would be that it is easy to search for bulbs of a specific power output and amount of lumens.

3.9.2 Commercial Bicycle Lights

A second option for us would be using lights that are commercially available and sold specifically for the application of being a bicycle light. This would provide a significant advantage in that everything would come assembled, and the lights would be properly housed so there would be no safety implications there. All that we would have to worry about would be connecting the battery on these lights to our battery pack. A few of these options are explored below.

3.9.2.1 Ascher USB Rechargeable Bike Light Set

The summary of features provided by this bicycle light set is provided below:

Price	$15.99
Battery	650 mAh lithium
IP Rating	IPX4
Additional Features	Options for brightness and flash

Table 3.9.2.1 Ascher bike light features

This light set is one of the basic options that is currently listed on Amazon for $15.99. It consists of two circular LED lamps, one white and one red, for each end of the bicycle. There are four light modes included, two with varying brightness levels and options to make the lights flash. Each light comes with a 650 mAh lithium battery, and each light plugs into a charger separately. One concern with this option is that it is rated IPX4. This meets our standards for water resistance; however, it has no rating for protection against solid objects, meaning that we would likely have to modify and test it for this ourselves. There is also no information provided regarding the brightness, in lumens, of the lights, so we would also have to manually test out the visibility of the lights.

3.9.2.2 BurningSun Bike Light Set

The summary of features provided by this bicycle light set is provided below:

Price	$31.99
Battery	4400 mAh battery
IP Rating	IP65
Brightness	1000 lumens
Additional Features	Varied light modes, rotatable

Table 3.9.2.2 BurningSun bike light features

The BurningSun bike light set is a bit of a pricier option, coming in at $31.99 on Amazon. However, there are quite a few features to justify the price. It consists of two circular lights in the front with a red bar shaped light for the back of the bicycle. It has a 4400 mAh battery, more output than any other option. Its IP rating is IP65, which exceeds our goal of an IP34 rating overall. In addition, it is one of the few options that is rated in the solid object protection category, which would make our team's lives easier when it comes to testing. It has a brightness of 1000 lumens, which is very bright. The product page also claims that the lights are visible at a distance of 600 feet, and with the aforementioned brightness, that is most likely true. For the convenience of the user, the lights also come with five different modes, including three brightness settings, strobe lighting, and SOS mode. The mount that the light is housed in is also able to be rotated in any direction.

3.9.2.3 Cuvccn Bike Lights Set

The summary of features provided by this bicycle light set is provided below:

Price	$22.99
Battery	1100 mAh/330 mAh

IP Rating	IP65
Brightness	500 lumens
Additional Features	Light modes

Table 3.9.2.3 Cuvccn bike light features

Finally, we have the Cuvccn bike lights set, currently listed at $22.99 on Amazon. It contains two rectangular white and red lights for the bicycle that are rechargeable with the use of a USB-C cable. The battery life varies in both lights: the front light has an 1100 mAh battery, and the rear light has only a 330 mAh battery. Of course, since the lights will be able to be plugged into our charger, this is not that much of an issue. Like the BurningSun lights, these are also rated IP65. Again, this is more than enough to achieve our system wide rating of IP34, and takes away the issue of testing this component for ingress protection like we would have to do with the others that are not rated in the first category. The lights have a brightness of 500 lumens, which is an average amount in terms of bicycle lights. This is sufficient for city biking and commuting, but might be a little dark in completely unlit areas if you are biking fast. Additionally, there are some extra light modes included: four different modes for the front lights and six different modes for the tail lights.

3.9.3 Lighting Summary

In this section, two different methods of lighting to be used in our bicycle system were explored. The first type, regular, smaller LED lights and bulbs that you would find in electronics projects, were selected to be used for the on/off LED indicator for our system. For this, we will just order a green LED online if we don't already have one from our junior design kits.

The second method explored in this section were the USB rechargeable commercial bicycle lights. These proved to be a convenient option for us to use for our headlights and tail lights. All we will have to do is ensure that the lights' cables can be plugged into our battery pack to charge constantly or when needed. We found three very good options online, and ultimately we will be choosing the Cuvccn bike light set. While it is the cheapest option we looked at, the Ascher light set had no IP rating in the first category, with an overall rating of IPX4. This would create more work for us as we aim for an IP34 rating on our system. It also has no exact brightness specified, so that would be another thing we would have to test for. The BurningSun light set packs a punch with a brightness of 1000 lumens and a 4400 mAh battery, but the price is a little bit too high for us on our limited budget. The Cuvccn is a great all around set with the same rating (IP65) as the BurningSun for a lower price. The brightness is sacrificed, with the Cuvccn having only 500 lumens, but it should still be sufficient for our applications. It also has the more reasonable price point of $22.99, making it perfect for our team.

3.9.4 Implemented Design

We considered using ALAMSCN MAX7219 8x8 LED display Dot Matrix Modules as our lights but these would have been difficult to work with. With more time we could have ordered lights that would have either been one of the loads of the power system or receive power from the arduino. Also with more time we could have implemented either a button for the user to control the lights or a photoresistor to automatically sense when the light outside is dimming and turn the lights on.

3.10 Sensors

In order to be able to show the user various data about the system and the bicycle, we will need to use a variety of sensors interfacing with the microcontroller. Our main goals at the moment are to be able to show the bicycle's speed, the ambient temperature, the current time, the charge of the battery, and the voltage generated by the system.

3.10.1 Speed Sensor

After some research into the best way to relay speed data, we decided that it would be cost prohibitive to purchase an actual velocity/air flow sensor. The lowest priced one we were able to find was $59.95. Many of the other options were priced in the hundreds of dollars range, making them completely out of reach for us and our self funded project. Another thing that we considered was that all of these sensors were for measuring air velocity specifically, making us unsure if that would give us an accurate sense of speed. It would also be complicated to take inputs from an accelerometer and try to convert them into usable numbers for speed.

After taking all of this into account, we decided to just look for a GPS module that can display speed. In order to display the speed, we will use a GPS module, specifically the NEO-6M. It is currently $10.50 on ElectroDragon, uses SPI to communicate, and operates at 5V drawing around 35mA of current. This module is set to 1Hz frequency by default, meaning its data gets updated once every second, but it can be changed to go up to 5Hz. For our application of using this sensor on a bike, getting updates every second is more than enough, so we will stick with the 1Hz default. With this module, we will be able to show speed data to the user, and, if time permits later on, show GPS location data as well.

3.10.2 Time

To display the time, we will use a real time clock chip. The Adafruit PCF8523 Real Time Clock Breakout Board is $4.95 on Adafruit's website, uses I2C communication, and can operate on both 3.3V and 5V logic. There are versions available that are around $20 that are more precise and will lose or gain as much time, but we wanted to keep costs for this portion of our parts low and went with the cheaper, slightly less precise option.

3.10.3 Temperature

In order to sense the ambient temperature, we will be using the Adafruit Sensirion SHT40. It is $5.95 on Adafruit's website, operates from 3.3V to 5V, and uses I2C to communicate. In addition, it doubles as a humidity sensor, providing an easy additional feature for us to add if we decide to in the future when executing the project. Its accuracy is ±.2 degrees Celsius for temperature and ±1.8% humidity, which is acceptable for our project as exact accuracy is not a priority.

3.10.4 Battery and Voltage

Finally, for the battery charge and voltage generated, we will use the Adafruit INA260. It is $9.95 on Adafruit's website, uses between 2.7V to 5.5V, and, like the majority of our other sensors, uses I2C communication. It can relay information about voltage, current, and power up to 36V.

3.10.5 Sensors Summary

All of the sensors besides the GPS module are from Adafruit and use I2C communication. We decided to choose modules from the same manufacturer so that the actual integration process will hopefully be easier. They all communicate in the same way, are similar physically, and have descriptive datasheets with pictures, code libraries, and code examples. They are also all in stock and easily attainable.

3.10.6 Implemented design

In order to properly display temperature, speed, charge on the device, and voltage generated on the LCD, the system utilized three different sensors discussed below.

NEO-6M is a GPS chip that isn't as accurate as some other modules are when calculating speed, since it approximates speed based on where you are and how much movement there is, but its easily implemented components make it a suitable fit for the bike.

The Sensirion has the capability to show both temperature and humidity, and along with the INA219 and NEO-6M allows the rider to see a variety of useful features all while knowing how much charge they just gave their devices from a short and simple bike ride.

Shown here is a look at the most involved of the sensors: the voltage and current sensor. This sensor needed to be connected to the microcontroller, the LCD, and a load to measure current, voltage, and power information.

Our plans for this sensor changed dramatically after we finished our Senior Design 1 documentation, which can be seen in how different this original schematic is from our final design. The chip shown in this schematic is the Adafruit INA260, which ended up going out of stock before it could be ordered. As an alternative, we used the Adafruit INA219, with the only difference between the two being that the INA219 could only measure high side DC current.

Our initial design also included a battery to store power coming in from the generator and solar panel, which can be seen in the schematic above. However, this design was reconsidered after our testing phase, and the battery as a middleman was cut out. As a result, our INA219 sensor now measures the voltage and power generated by the solar panel.

3.11 Display

One of the goals of the project is to have a display that can show the rider of the bicycle the voltage generated, bicycle velocity, temperature, time, and battery charge. In order to do this, an LCD will be integrated into the system using a microcontroller to get the readings. To provide the best user experience, the display should be easily readable and simple to navigate. Some other things to be considered are the display size, the lighting, and how much power the LCD draws. Three possibilities for the display used are discussed below. Pictures are included to get a sense of how they will look to the user of the bicycle.

3.11.1 SunFounder LCD1602

The first option is a SunFounder LCD1602 module with I2C communication. It is listed at $9.99 on Amazon; however, our group already has one from junior design. It has a blue backlight, so it will be easy to see throughout the day. It uses 5V of power, and the screen measures 64.5 by 16 mm.

Figure 3.11.1SunFounder LCD1602

3.11.2 AMC2004HR-B-W6WFDW

A second option is the AMC2004HR-B-W6WFDW from Orient Electronics. It is one of the cheapest 20 by 4 modules listed on DigiKey, at $11.18. It also draws 5V of power, with the screen measuring in at 46 by 18.4 mm. It has a green screen with black text, which might be more difficult to read than the blue screen with white text. It also has a smaller overall display area than the LCD1602.

Figure 3.11.2 AMC2004HR-B-W6WFDW

3.11.3 HiLetgo ILI9341

Finally, there is the HiLetgo ILI9341 touchscreen LCD module. It is $16.99 on Amazon, uses 5V, and has a screen size of 36.7 by 48.9. It utilizes SPI communication. It has a white backlight, which, combined with the touch capabilities, would likely make for the most user friendly experience.


Figure 3.11.3 HiLetgo ILI9341

3.11.4 LCD Summary

A table summarizing the features of each display is below:

LCD1602	**AMC2004HR-B-W6WFDW**	**ILI9341**
$9.99 (already owned)	$11.18	$16.99
5V	5V	5V
64.5 by 16 mm	46 by 18.4 mm	36.7 by 48.9 mm
I2C	Parallel	SPI

Table 3.11.4 LCD features summary

For the final choice, we will be going with the LCD1602. We already own it, so it will not add to the project cost. The members of our group also already have experience using it, so we won't have to relearn anything in order to program it. We know it will work with the microcontroller we are using, whereas the others might not. The ILI9341 has a bigger screen with touch; however, the display on the LCD1602 is still easy to see and will be able to interface with buttons on the microcontroller in order to change between the different statistics that can be shown.

3.11.5 Implemented Design

In order to relay our sensor data back to the user, we chose to use an LCD attached to the bike. Originally, we opted to use the Sunfounder LCD 1602 that was included in the junior design kit as we knew how to use it and it was readily available. However, the row and column amounts proved to be somewhat restrictive, so an upgrade was made to the Sunfounder 2004 LCD, with double the rows and four additional characters in each. With this, the screen comfortably displays temperature, humidity, speed, voltage, power, and altitude.

3.12 Diodes

A diode is a semiconductor device that allows current to flow in one direction but stops current from flowing back in the opposite direction. They also act as rectifiers, and since the power produced from our source will need to be converted from AC to DC, this will help in that process. When a diode is in the stage that allows current to flow through it, it is called forward biased. When the diode restricts the flow of current, it is in reverse biased and acts like an insulator. A diode is a general term, and there are many different types of diodes with different applications and functions. For the purpose of this project, we will look further into Zener diodes and light emitting diodes.

3.12.1 Zener diode

We know that a diode in reverse biased will restrict the flow current back in the opposite direction. The problem that can be encountered is the damage done to the component and possibly surrounding components if reverse voltage becomes too high. The Zener diode has an avalanche breakdown process that occurs when the reverse voltage applied exceeds the rated voltage, and gets a current to flow through the diode to limit the voltage.

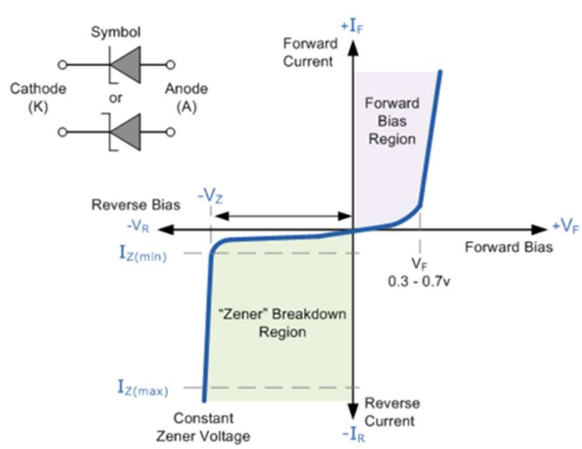


Figure 3.12.1 Zener diode characteristics. Permission pending. Reprinted from https://www.electronics-tutorials.ws/diode/diode_7.html

Voltage in a Zener diode remains almost constant regardless of how much the current changes within the breakdown current and the max current rating. This ability of Zener diodes to control itself helps in stabilizing a power source against loads. This makes a suitable voltage reference and one to rely on.

3.12.2 Light emitting diode (LED)

Light emitting diodes (LEDs) are considered in this project for the possibility of needing light around the different components attached to the bicycle such as the sidewall generator or the solar panel. They are a simple component, similar to the standard light bulb. Since LEDs do not have filament that burns out, they last as long as a standard transistor. Although they are an added expense, being able to have efficient long-lasting lighting adds to the project dynamic of being as efficient as possible with energy.

3.13 USB

A universal serial bus (USB) is used for attaching peripheral devices, like keyboards, flash drives, and external storages to a computer. Another function of USBs are for powering and charging devices like a cell phone. A usb type A head has four pins, 2 for power and 2 for data differential signals. In the table below we can see each pin's function.

Pin	Name	Cable color	Description
1	VCC	Red	+5 VDC
2	D-	White	Data -
3	D+	Green	Data +
4	GND	Black	Ground

Figure 3.13 Pins of USB type A. Permission pending. Reprinted from https://www.hobbytronics.co.uk/usb-connector-pinout#:~:text=USB%20is%20a%20serial%20bus,pair%20with%20no%20termination%20needed

In the case of using the USB for charging or for power, we will only focus on pin 1 and pin 4. We have the input source connected to pin 1 and pin 4 as ground. This type of USB is only used for power, but there are functions for data transfer only and the hybrid of both that can transfer data and charge a device which is known as “charge and sync”.

3.14 Voltage divider

A voltage divider consists of having an input voltage source, Vin, feed into a given set of resistors. The output voltage, Vout, is obtained by taking the voltage between the two resistors as the reference voltage to ground. From this, we can say that resistor R2 is dividing the input voltage Vin into two different voltages: one across R1 and one across R2. The equation for find Vout, or the voltage drop across R2 is given by:

$$Vout = Vin\ R2/(R2 + R1)$$

The sum of voltage drops across both resistors is equal to Vin. The advantage of using a current divider is how simple it is to build and implement. Given that there is an input voltage source, we can test different voltage drops across resistors in series to choose a desired voltage, depending on the value of resistors used. It should be important to keep in mind that resistors have load resistance and tolerance. It is also dependent on the input source Vin. This is where this can be a disadvantage. If the input voltage source will not be a constant value, then the output voltage will also change proportionally. Having such an unstable system can lead to not meeting output voltage requirements for load specifications.

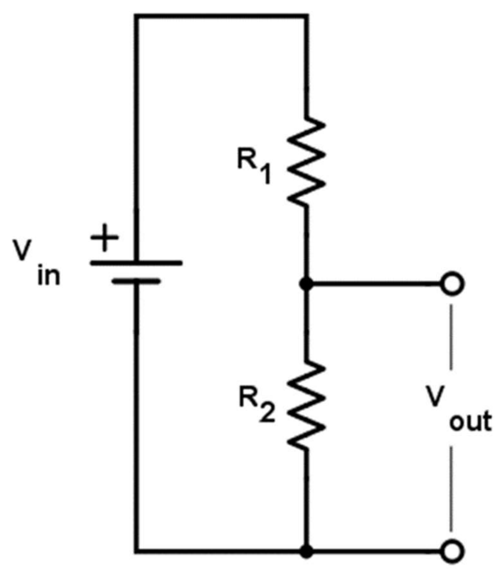


Figure 3.14 Voltage divider. Permission pending. Reprinted from https://www.allaboutcircuits.com/tools/voltage-divider-calculator/

3.15 Software Selection

While it is not necessarily a part in the traditional sense, software is an incredibly important part of almost any modern engineering project. In our project, software will be used to facilitate communication between the microcontroller, sensors, and LCD so that the time, temperature, voltage, and battery charge so that the user can see them as they are riding the bike. In order to do this, we must pick a language that we already know or can be easily picked up, and that is good for hardware applications like this one. In addition, the selection of a language depends heavily upon which type of microcontroller is selected for the project. For example, any Texas Instruments microcontroller will have to be coded using C or C++, whereas an Arduino uses exclusively C++.

3.15.1 C++ vs C

C and C++ are very similar languages with only a few key differences. C++ was developed after C, so it has somewhat expanded grammar when compared to C. Syntax in the two languages are basically identical, especially when used in embedded systems applications. The biggest difference between the two is that C++ was developed to be an object oriented programming language. Like the name implies, object oriented programming languages are structured around defining objects, whereas a normal language like C is structured around functions. This makes the two languages very different structurally in their approach to problems. However, even though this is a feature of C++, it is still able to support procedural programming structures.

Our group is made up of three electrical engineering majors and one computer engineering major. As is expected, all of us are familiar with C due to its use in the curriculum here at UCF. While none of us have significant experience with C++, we think that if it was seen in an embedded systems project, it would look so similar to C that any of us would be able to understand it. Based on these facts about C and C++, C would be the preferred language for our group just because we know everyone is familiar with it; however, we would be fine with using C++ as well if we had to.

3.16 Printed circuit boards

Printed circuit boards are used in many different ways and in very diverse applications, so it only makes sense that there are so many types that are available to choose from. There are eight PCB types, with them consisting of single sided (or layered), double sided, multi-layer, rigid, flexible, rigid-flex, high-frequency, and aluminum backed PCBs.

3.16.1 Single sided

Single sided PCBs are expectedly the most basic type of circuit boards, as they only have one layer of base material to work with. This layer is a thin layer of metal like copper that will conduct electricity most effectively. The benefit of these simple printed circuit boards is that they are also coincidentally simple to manufacture, repair, and design. This makes these kinds of PCBs the most cost effective and best to use in high volumes. They’re commonly applied in simple devices like LED boards, calculators, FM radios, and in our case, sensors.

3.16.2 Double sided

Of course, a step above the single sided PCB is a double sided one. This kind of PCB is said to be the most popular, and for good reason. These boards have both sides use a conductive layer, and so they're able to connect the circuits on either side with surface mount technology or hole technology. What appeals to the team in this case is the surface mounting but having both options is definitely appreciated. The surface mounting allows more circuits to be attached to the board and allows for both the top and bottom layers to interact with each other, making this double sided PCB quite the upgrade when compared to a single layered one. The added complexity to these boards allows for more diverse usage, leading to use of these components in various devices like amplifiers, power monitoring systems, and even mobile phone systems.

3.16.3 Multi sided / Multi-layer

Multi-layer PCBs are a dramatic change from the single and double sided variants. They offer an incredible number of layers, jumping from 1 and 2 layers to 4, 6, and even 8 layers. These layers are divided and separated by insulating materials, but overall, the board maintains a low weight and a good amount of workspace while actually being quite durable due to the process used to make such a board. Due to their large amount of layers and therefore perks, these boards are especially useful for design flexibility. When it comes to circuits that require speed, these PCBs can uphold those requirements for high speed circuits. Due to their versatility, their applications can range from fiber optics, to space equipment, and to GPS systems.

3.16.4 Other PCB Types

Rigid PCBs are quite firm, as the name implies, and they cannot be bent due to their stronger, solid base material. Their compact designs allow for complex circuits to have plenty of space to work with, not to mention that these boards are also easily maintained since components are organized and numbered.

Flexible PCBs are diverse in that they come in single sided, double sided, and multilayer formats. Their main focus is the flexibility that allows for bending and resistance to vibrations and other movement, while also maintaining a small design that allows for less overall weight.

A combination of the previous two exists in the form of Rigid-Flex PCBs that are used in many medical and military applications due to their low weight, low space, and carefully built boards with high precision.

High-frequency boards have a diverse frequency range of 500MHz - 2GHz and are essential in applications that need to deal with frequency, such as microstrip PCBs, microwave PCBs, and other communication devices.

Aluminum backed PCBs are usually reserved for high power applications, thanks to their aluminum base that allows for easier dissipation of heat. They are often used in LEDs and power supplies, and come in models that can provide durability and fight thermal expansion, thus making them ideal for situations with extreme temperatures.

3.16.5 Chosen Board Type

When considering all of the options, which there are a lot of, it would seem that double-sided PCB boards have single-sided ones beat in many ways. If the team were to use many PCBs, then single-sided would be considered more, but their low cost may not be the best option here when the double sided adds more possibilities.

Increasing layers will mean more expenses, so when comparing the double sided and multilayer PCB, this constraint is something to be considered. The team doesn't necessarily need a multilayer PCB either, even if it's the better one of the two. Opting for a double sided may make designing easier as well, thanks to their popularity. The multilayer may allow for more flexible designs, but an easy to implement design is a key desire for the team.

It's worth mentioning that a high-frequency board, while useful, doesn't seem like it will be that useful in this project's design. This makes it the last choice on the list.

If possible and not too expensive, a flexible PCB in a double or multilayer format is the best possible option. The aluminum backed PCBs are fantastic for heat, which is important, but the flexible PCB can withstand movement and other disturbances easily, which is clearly important on a bicycle, making it the ideal board the team can choose.

3.17 Part Selection Summary

In this section we list the parts we chose for our original design, their function within the project, where they can be purchased, and their prices.

Function	Part	Vendor	Price
Solar Panel	Newpowa Monocrystalline Solar Panel	Amazon	$25.49
Mechanical Generator	Wai Danie Bicycle Dynamo	eBay	$8.99 + $8.80 shipping+tax = $17.79
Charger	BQ24074GTR	Mouser	$3.65 + $7.99 shipping = $11.64
Battery	1528-1835-ND	Digi-Key Electronics	$33.08 + $6.99 shipping = $40.07
Microcontroller	MSP430FR6989	Texas Instruments	$20 + $14 shipping = $34, but the

			board is already owned
Bike Lights	Cuvccn Bike Lights set	Amazon	$22.99
Display	SunFounder LCD1602	Amazon	$9.99
Bike			Already owned

Table 3.17A: Parts selected for initial design

A table summarizing just the sensor part selection can be found below:

NEO-6M	GPS/Speed	$10.50
PCF8523	Date/Time	$4.95
Sensirion SHT40	Temperature/Humidity	$5.95
INA260	Voltage/Current/Power	$9.95

Table 3.17B Sensor selection

In total, the cost for all our sensors will be $31.35.

4. Design Constraints and Standards

4.1 Constraints

Constraints is a general term for anything that limits our project and design in some way, be it engineering related or something more general. Identifying constraints is a key component of the engineering design process, as we discussed in class. This goes hand in hand with identifying criteria of the project, which we have already done in the section above. Keeping constraints and criteria aligned and in mind helps to define a clear direction for a project. In the sections below, we will discuss specifically economic, time, manufacturing, safety, experience, resource, environmental, social, ethical, and sustainability constraints.

4.1.1 Economic Constraints

In a big bustling city, this project could prove to be quite useful due to the widespread use of bicycles and walking in place of driving to different locations. However, location is ultimately a factor that could be detrimental or very helpful. It's hard to imagine the bicycle doing as well in a rural town when compared to an urban city, but the goal of the project can still be fulfilled. The eco-friendly phone charger will still work as an alternative to a portable charger no matter the location.

With the total cost of production for the bicycle being over $100, the cost seems more worth the money in an urban area or when the portable charger is used an extensive amount. It's worth mentioning that replacing individual parts won't be too expensive, and it's about $20 depending on the component. It's also worth mentioning that this is the price with college level quality, and that could very likely change if the bicycle were to be made on a more massive scale and with government / city level quality. Since the project is self-funded, the team is going for quality at a decent cost, but with the proper funding, several features and implementations could be added no problem, thus changing the cost. The environment could affect the cost as well, since a more rain prone city would likely prefer better wheels, brakes, and other bicycle parts.

With that being said, the project itself is relatively inexpensive considering the goal it aims to accomplish and the current economy for parts. Some components are harder to find than others, driving up the prices, but even then, the production cost is decent for a charger that works with both mechanical and solar power.

4.1.2 Time Constraints

Time is one of the biggest factors and most important considerations for our project, just like any other engineering project. If this were a product we were bringing to market, we would likely spend years doing research and design. However, in senior design, we have a mere two semesters in order to research and subsequently produce a working prototype. Because of this, we do have to manage our time carefully.

The first semester is dedicated to research and technological investigation, and culminates in a draft of this very paper. It would be advantageous to be able to start testing our components and project this semester; however, writing the paper has taken up a majority of our efforts, and we do expect it to take the full 14 weeks. Most of our time will have been spent on researching and finding parts to use, as well as planning out the design of our system and creating schematics with all our components.

In the second semester, we will have to assemble all of our components into a working prototype. With only 14 weeks to do this, again, we will be on a tight timeline in order to finish in time. Our main goals are things that will absolutely be a part of our working prototype. These include having a working charging system that draws power from both a solar panel and a mechanical generator, working headlights and tail lights, as well as an LCD that displays speed, voltage generated, temperature, time, and the battery charge. In addition to these, we have also included stretch goals that we can add if we have time for them. These currently include displaying the humidity, as well as implementing a GPS system. If programming the microcontroller goes smoothly, we can expect to add these easily with little time impact. If these are successfully added within time constraints, we can consider additional stretch goals as well.

4.1.3 Manufacturing Constraints

When it came to researching parts, the team came across an incredible charger for the batteries, the BQ25672. It was multi-cell, had essentially the same features as the other chargers researched, had several more useful features for our project, like a part that could connect to photovoltaic panels, and even had the same price as the other devices. The one downside was that it was sold out, which is incredibly unfortunate for a part that seemed so perfectly fitted for this project. As a result, the team had to either wait for more to be manufactured or move on to another part. Either way, the lack of availability gave us a manufacturing constraint in the end, and the team ended up selecting another charger. The charger that was picked was still excellent, but the other component could have allowed for so much more.

4.1.4 Safety Constraints

In the event of components failing, the team must be prepared for the consequences that can occur. For example, a battery shorting or staying in the sun for too long and overheating could lead to a need for a replacement and, in a worst-case scenario, melting or damage to other components. A simple battery replacement wouldn't be dangerous, but if LEDs were to go awry during a ride in the rain, the team would partly be responsible for the dangers the rider faces.

The team expects the bicycle to be used in various weather conditions, such as rain and snow, so to prepare for situations like this, the team can implement some cosmetics to protect components, like adding protective layers or placing most of the components in a protective basket. The team will also take measures to ensure that no wiring and electrical connections are neglected, while also making sure that soldering and grounding are done properly.

As far as the bicycle itself goes, the team isn't responsible for any malfunctions that can occur with brakes, steering, etc. since the focus is the charging system. The bicycle model is a separate entity entirely, and the project will be created so that it won't interfere with any functions of a normal bicycle.

4.1.5 Experience Constraints

One of the constraints that must be considered as we embark on creating this project is that of the group's experience. The entire project experience is a new one for most or all of us. Only one of our members, Melvin, has had an internship and any potential experience with an actual workplace environment, which is of course what this entire project experience is meant to simulate. Because of this, what we will be able to do with this project is going to be limited compared to what a team of seasoned engineers would be able to do.

This set of constraints ties in very closely with the time constraints also. With our limited experience, we have and will continue to spend a lot of time researching or figuring out how to do things related to our project. This will cut into the time we have allocated to actually complete the prototype, meaning that as usual time management will be essential.

We are also a little bit less knowledgeable because of some classes taken during COVID. For example, we did not get the complete junior design experience because there were supply chain issues with the electrical part production. We learned how to use EAGLE, but we didn't really get an opportunity to use the PCB we had made, so that is going to be yet another thing we will learn while doing the project and not before. There will undoubtedly be a lot of trial and error cutting into our time as we start to assemble our final prototype.

4.1.6 Resource constraints

The limited resources available to the team imposed constraints on the project and what could be included in it and how it will be produced.

One resource that is quite limited is funds. Our project is not being sponsored and we are paying for it out of pocket. As students we do not have much disposable income, so it is in our best interest to keep costs down for this project. As a result we cannot afford the best, newest, and most efficient generators or batteries for example, or the highest quality silicone most efficient solar panels. We also have to be more selective as a result, we cannot afford to buy a component that will not work for our project. Before ordering our PCB for example, we need to make sure it works because we cannot afford to buy several iterations of PCBs only to find out that they do not work for our project after we have paid for them. This presents a trade off of compounding constraints, because while we cannot buy our way through trials and errors, meticulousness takes time, which is also a limiting factor as explored in section 4.1.2.

Another resource that the team has limited access to is tools and machinery that would help with product development. This issue is related to the limited funding constraint. If our project was being developed commercially, a company could invest into tools and experts to develop the product, effectively bypassing experience constraints through investment.

Limited availability of components is another resource constraint. Parts being out of stock or having long shipping times prevented us from selecting parts that may have been better for our project. And may yet prevent us from receiving our parts in a timely manner. This is also impacted by the time constraint because without a time constraint long shipping times would not be an issue, as we could just wait for all the parts to arrive and then perform testing on all parts at the same time.

4.1.7 Environmental Constraints

One of the team's main priorities is to be able to use this multi-source powered bike absolutely anywhere, but of course there are some challenges that come with that desire. The weather is unpredictable, and although the team is building the bike to be able to handle rain and other kinds of weather, it is a constraint, nonetheless. The team has to ensure that the components are well protected from water and rain, as even one rainy day can mess up quite a bit of the project. Due to this, the team has to add a compartment or a section on the bike where the components can be placed if it does not already have one. This may in turn add some clunkiness to the bike and may even make the project a little sloppier looking, but that has yet to be encountered.

Harsh weather once again impedes the team's flexibility since components susceptible to heat will no doubt be in peril after a hot summer day on a bicycle. Once again, the team has to ensure that the parts are in a cool, shaded compartment or there is a risk of harming the project. Charging on top of the hot sun may prove to be fatal for the project if not handled carefully. Luckily, when selecting components, they've all been stated to be able to handle high heat, but the constraint is still there. Moving forward, the team will have to take care that additional parts can handle intense temperatures.

The project will be using several very small parts in order to make the bicycle ride as smoothly as possible, which all can be very fragile and easy to break. With windy weather, deposits of sand and other grains or rocks can wear away or impact the parts if not taken care of properly, once again adding another limit to where parts can be on the bicycle. Parts on the lower end of the bicycle may not have as much longevity as others due to that fact as well.

Location is another environmental factor that has to be mentioned, since the area in which the team lives in allows for very lenient bicycle riding. However, areas with difficult terrain or many hills may impede charging capabilities, due to the inability to ride the bike smoothly. Because of this, fast and efficient chargers are especially important in the case that charging cannot occur. The team already emphasizes the importance of a good charger for this project, but for the bike to be truly versatile, it would be wise to keep in mind the scenario where mechanical energy cannot be generated as much.

Along with slowing down charging, hilly areas can also greatly assist the generation of mechanical energy when riding down said hill. Because of this fact, mechanical energy generation will no doubt be affected, and if there were to be too fast of a charge, it could negatively impact the batteries. This is why it's important to have components with overcharging monitors in place, since not all battery chargers the team has researched contain that element. Not only is it essential for every day normal use of the bicycle, but in the event that energy is generated faster than usual, it will no doubt be critical to the batteries' life span.

4.1.8 Social Constraints

Unfortunately, just like when people wear helmets to protect themselves from injury, people may have a tendency to think this project is “uncool”. Children especially might think this, since their bicycle won’t be sporting hot rod flames or a design they like, but instead some wires and nerdy looking components. Then in a commercial setting, parents will have to buy their children another bicycle if they decide this one looks unappealing at the store.

Due to this fact, people may be less inclined to use the PEDAL Bike, thus adding a social constraint the team would have to consider. It's easy to envision a child showing a new friend a bike like this for the first time and their initial reaction being, “what is that?” Thus, perhaps the team can add some decorations or other designs to make the bike more appealing. The team should also ensure that no components look sloppy, because showing a potential customer a disastrous design or unorganized mess may make them think twice about owning or even riding a bike like this.

4.1.9 Ethical Constraints

For anyone making a product that will compete against another, or for the people trying to make a similar product to another, in a way, it’s unethical to use up these resources to make something that technically already exists. In our case, the PedalCell is an existing product that is professionally made, and will no doubt trump our project in comparison. Not only that, but it’s a small component that uses up very little resources besides supercapacitors. It’s because of that that the team has another reason to want to use as little components as possible. The less resources used, the more green the team will be, so there will also be more pressure on messing up our components. The more errors and damage to a part, the more harm that is done to the environment, thus adding ethical constraints.

4.1.10 Sustainability Constraints

While the team created this project in the first place for sustainability and environmental purposes, it’s also important to the team to keep up that ideology when it comes to our selected parts and when considering the consequences of using one part over the other. Due to the nature of the project, sustainability is far more of a personal constraint than the others. It’s not essential, but ideally, the project will be long lasting and make a positive impact on the carbon footprints of many people for years to come, and that can be accomplished better by choosing a lithium ion battery rather than a lead ion battery, to name one example. The team will take care to select parts that can be long lasting, as that will further advance the goal of the project. When it comes to batteries, lead ion takes far less time to run out of life when compared to a lithium ion battery, as it only lasts 3 to

5 years or 1000 charging cycles, while lithium ion has a lifetime of triple that amount, clocking in at 3000 charging cycles and 9 to 12 years due to that fact.

The average solar panel has a longevity of 25 years, but with proper care and maintenance, experts say it can last 40-50 years. Many solar panels made in the 1980s still work at their expected capacity, and the team would like the selected solar panel to be no different. Although it doesn't make much of a difference which solar panel is chosen, how we treat the solar panel does indeed matter. Due to this, the team is a little more limited and will try to use the solar panel as effectively as possible to ensure that its longevity is at its best.

Unfortunately, the generator the team has selected may have a chance to wear down the bike's tires faster than some others that were researched. Its use of the metal roller when compared to a generator with a rubber roller will no doubt be more damaging in the long run. Ultimately though, the generator's specifications and uses are more important than whether or not it would affect the tires, especially since tires can be and are widely recycled. However, it is still noted that over time, the generator selected will go through and use up more tires than its rubber roller counterparts, thus limiting the team's sustainability slightly.

4.2 Standards

Standards are put in place to ensure that products are safe to use, meet specifications, and for greater compatibility between products. These standards are written by different organizations that certify electrical and electronic products including: The International Electrotechnical Commission (IEC), the USB-IF, the Institute of Electrical and Electronics Engineers Standards Association (IEEE SA), the International Standards Organization (ISO), and UL Solutions.

The IEC is a not-for-profit membership organization that develops globally recognized standards and certificates for electrical, electronic and related technologies, with more than 10,000 standards effective in 173 countries.

Similarly the IEEE SA has created over 2,100 standards in 175 countries dealing with the functionality, capabilities and interoperability of technologies involving Artificial Intelligence Systems, Connectivity and Telecommunications, Energy, Foundational Technologies, Healthcare and Life Sciences, and Mobility. IEEE SA also works to enact technology standards in policy making by collaborating with lawmakers.

The ISO is an independent, non-governmental international organization with members in 167 countries that has written over 24,500 standards for many technical sectors including: Information technology, graphics and photography; Transport; Health, medicine and laboratory equipment; Mechanical engineering; and Non-metallic materials.

UL Solutions is a private company that specializes in testing, inspection and certification services for the industries of Sustainability, Electrical and Electronic Products, Life Safety, Building Products, Industrial Control Equipment, Plastic Materials, Wire and Cable.

USB-IF, or the USB Implementers Forum, is a non-profit corporation comprised of and founded by the group of companies that developed the Universal Serial Bus specification. It's a support forum that aims to advance USB technology. It undersees USB Compliance workshops, development and testing, the usb.org website, USB marketing, and so much more. The USB-IF, inc. Board of Directors is made up of representatives from companies like Apple, HP, Microsoft, Texas Instruments, and the Intel Corporation, making the USB-IF a very respectable company with very respectable standards.

4.2.1 Solar System Standards

Listed in this section are several standard codes that apply to solar systems from the various organizations mentioned.

Standard	Description
IEEE 1526 - 2020	IEEE Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems Provides test methods and procedures, both in lab and field settings, for assessing the design and performance claims of off grid PV systems that include PV modules, charge controllers, batteries, and loads.
IEEE 1562 - 2021	IEEE Recommended Practice for Sizing Stand-Alone Photovoltaic (PV) Systems Provides a procedure to size off grid PV systems in which PV is the only power source and a battery is used for energy storage. These systems also commonly use controls to protect the battery from over or under charging and a power conversion subsystem (inverter or converter). Array utilization, battery-charge efficiency, and system losses are also considered in terms of their effect on system sizing. Only lead - acid batteries are considered. Does not include PV hybrid2 systems or grid-connected systems.
IEC 60904 : 2022 All parts	IEC 60904-1 : 2020 Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics IEC 60904-1-1 : 2017 Photovoltaic devices - Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices IEC TS 60904-1-2 : 2019

	Photovoltaic devices - Part 1-2: Measurement of current-voltage characteristics of bifacial photovoltaic (PV) devices IEC 60904-2 : 2015 Photovoltaic devices - Part 2: Requirements for photovoltaic reference devices IEC 60904-3 : 2019 Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data IEC 60904-4 : 2019 Photovoltaic devices - Part 4: Photovoltaic reference devices - Procedures for establishing calibration traceability IEC 60904-5 : 2011 Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method IEC 60904-7 : 2019 Photovoltaic devices - Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices IEC 60904-8 : 2014 Photovoltaic devices - Part 8: Measurement of spectral responsivity of a photovoltaic (PV) device IEC 60904-8-1 : 2017 Photovoltaic devices - Part 8-1: Measurement of spectral responsivity of multi-junction photovoltaic (PV) devices IEC 60904-9 : 2020 Photovoltaic devices - Part 9: Classification of solar simulator characteristics IEC 60904-10 : 2020 Photovoltaic devices - Part 10: Methods of linear dependence and linearity measurements IEC TS 60904-13 : 2018 Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules IEC TR 60904-14 : 2020 Photovoltaic devices - Part 14: Guidelines for production line measurements of single-junction PV module maximum power output and reporting at standard test conditions
IEC 61215 : 2021 All parts	IEC 61215-1 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Test requirements IEC 61215-1-1 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules

	IEC 61215-1-2 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules IEC 61215-1-3 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules IEC 61215-1-4 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se)2 based photovoltaic (PV) modules IEC 61215-2 : 2021 Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures
IEC 61701 : 2020	Photovoltaic (PV) modules - Salt mist corrosion testing Provides test sequences used to determine the resistance of different PV modules to corrosion from salt mist containing Cl (NaCl, MgCl2, etc.).
IEC 61724-1 : 2021 IEC TS 61724-2 : 2016 IEC TS 61724-3 : 2016	Photovoltaic system performance - Part 1: Monitoring Provides terminology, equipment, and methods for performance monitoring of PV systems. Part 2: Capacity evaluation method Provides a procedure for measuring power production of a specific PV system with the goal of evaluating the quality of the system performance. Part 3: Energy evaluation method Provides a procedure for measuring energy production of a specific PV system relative to expected electrical energy production for the same system from actual weather conditions.
IEC 61730-1 : 2016 IEC 61730-2 : 2016	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction Provides construction requirements for PV modules to provide safe electrical and mechanical operation, emphasizing the prevention of electrical shock, fire hazards, and personal injury from mechanical and environmental stresses. Part 2: Requirements for testing Provides the testing intended to verify the safety of the construction of PV modules.
IEC 61836 : 2016	Solar photovoltaic energy systems - Terms, definitions and

	symbols
IEC 61853 All parts	IEC 61853-1 : 2011 Photovoltaic (PV) module performance testing and energy rating - Part 1: Irradiance and temperature performance measurements and power rating IEC 61853-2 : 2016 Photovoltaic (PV) module performance testing and energy rating - Part 2: Spectral responsivity, incidence angle and module operating temperature measurements IEC 61853-3 : 2018 Photovoltaic (PV) module performance testing and energy rating - Part 3: Energy rating of PV modules IEC 61853-4 : 2018 Photovoltaic (PV) module performance testing and energy rating - Part 4: Standard reference climatic profiles
IEC 62109-1 : 2010 IEC 62109-2 : 2011 IEC 62109-3 : 2020	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements Provides the minimum requirements of safety for power conversion equipment. Part 2: Particular requirements for inverters Provides safety requirements for d.c. to a.c. inverter products. Part 3: Particular requirements for electronic devices in combination with photovoltaic elements Provides safety requirements for electronic elements that are mechanically and/or electrically incorporated with PV modules or systems where the combination of electronic devices with the PV is sold as one product.
IEC TS 62257-100 : 2022 IEC TS 62257-7-4 : 2019	IEC TS 62257-100 : 2022 Renewable energy off-grid systems - Part 100: Overview of the IEC 62257 series Provides an introduction to the IEC TS 62257 series of standards (over 20 parts in the series) regarding off-grid renewable energy and hybrid products and systems. The IEC TS 62257 series of standards covers all aspects of creating an off-grid hybrid power source system, including system selection and design, project management, safety and functional requirements for different components and the systema as a whole, testing methods, and system installation. Perhaps especially useful for us isIEC TS 62257-7-4. IEC TS 62257-7-4 : 2019 Recommendations for renewable energy and hybrid systems for rural electrification - Part 7-4: Generators - Integration of solar

	with other forms of power generation within hybrid power systems Provides specifications for the design and implementation of hybrid off-grid solar systems, where solar energy and other sources provide energy to a load in conjunction with each other, with or without energy storage. This could be especially useful to us as we plan on integrating two power sources to charge one battery.
IEC 62716 : 2013	Photovoltaic (PV) modules - Ammonia corrosion testing Provides test sequences used to determine the resistance of PV modules to ammonia (NH3) and to evaluate faults caused in PV modules when operating in wet atmospheres with high concentrations of dissolved ammonia.
ISO 9060 : 2018	Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation Provides classification of instruments that measure hemispherical and direct solar radiation based on results from indoor or outdoor performance tests.
ISO 9488 : 2022	Solar energy — Vocabulary Provides definitions relating to measurement of solar radiation and utilization technologies of solar power.
UL 1741, Edition 3	Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources Provides requirements for inverters, converters, charge controllers, interconnection system equipment, AC modules combining PV modules and inverters to provide AC output.
UL 3741, Edition 1	Provides a method of evaluating PV Hazard Control components, equipment, and systems that lower the level of shock hazard from energized PV system equipment and circuits located within the PV array. This is specifically with consideration for firefighters who may be exposed to electrical hazards from damaged PV equipment with live currents.
UL 62093, Edition 1	Balance-of-System Components for Photovoltaic Systems - Design Qualification Natural Environments Provides requirements for dedicated solar components like batteries, inverters, charge controllers, system diode packages, heat sinks, surge protectors, system junction boxes, maximum power point tracking devices and switchgear.

Table 4.2.1: Solar system standards

4.2.2 Battery Storage Standards

4.2.3 LED/Lighting Standards

One of the main goals in our project is to add to the bicycle a headlight and a tail light that will also be powered by our solar and mechanical powered battery. In order to do this, we must take into consideration the standards and laws surrounding bicycle lights.

Unlike in countries such as the UK, the US does not require bicycle lights to adhere to a specific standard. The main law regarding riding your bicycle after dark requires that you have a front light that is white and visible from 500 feet away, and a rear light or reflector that is red. Florida law specifically requires a light in the front, and a reflector AND light on the back.[4] A regular bicycle will come with reflectors on it already, so that part of the law will be satisfied upon purchase.

The only requirement left to make sure is satisfied is the 500 foot visibility for the front light and 600 foot visibility for the back light. When we get to the testing stage, we will test for this specifically to make sure the lights meet the standard. LEDs that are around 500 lumens would likely be able to satisfy the requirement. For riding around a city, this would be more than enough. However, just in case users decide to ride off the beaten path, we want to make sure the lights are bright enough to have them covered. Failing to have proper bicycle lights could result in being issued a ticket and/or fines, which would be very bad for the consumer as well as us as the product developers.

4.2.4 Communication Standards

In our project, we have several peripheral devices that must communicate with and through the microcontroller to be able to display environmental factors and bicycle statistics to the user. The MSP430FR6989 is able to communicate through SPI, UART, and I2C. In order to do this, these devices will communicate using two different types of communication protocols: I2C and SPI. Each communication protocol has its own standards defined in the following sections. For each communication protocol, there are not exactly strict standards defined by the ISO, so the standards we follow will be more of best practices to use when working with the protocol.

4.2.4.1 I2C Standards

I2C stands for inter integrated circuit, and it allows for multiple or one controlling device(s) (masters) connected to multiple or one following device(s) (slaves). It is a synchronous communication protocol, which means that the data sent is synchronized to the clock signal. It is also a half duplex transmission mode. The basic I2C setup is shown below.

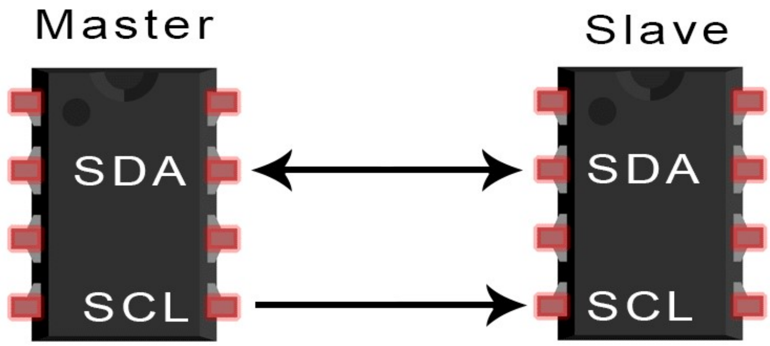


Figure 4.2.4.1 I2C communication overview. Permission pending. Reprinted from https://www.circuitbasics.com/basics-of-the-i2c-communication-protocol/.

There are two wires used to transmit I2C data: Serial data (SDA) and serial clock (SCL). As the names suggest, I2C uses a serial method of communication, which means that data is transferred over only one wire, the SDA wire. The SCL wire is used for the clock signal. Messages are carried in bits over the wire, along with a read/write bit and an ACK/NACK bit to confirm that the messages are received. When a message starts to be transmitted, the voltage on the SDA line will switch from high to low before the voltage on the SCL line switches from high to low. When the message stops being transmitted, the voltage on the SCL line switches first.

Because multiple slave devices can be connected to a single microcontroller, this protocol will work very well for our project. This also means that the microcontroller needs to be able to differentiate between each device it is communicating with. To address this issue, I2C uses a method called addressing. Each slave device has its own address, usually seven bits, that identifies it. Every message sent contains an address in order to be able to tell which device is sending or being sent data.

For our project, we will be connecting four different devices using I2C: the LCD, the real time clock, the temperature sensor, and the voltage sensor. C code following the standards of the language will be used in conjunction with the microcontroller and sensors in order to use the I2C communication protocol properly.

4.2.4.2 SPI Standards

The second protocol we will be utilizing in our project is known as Serial Peripheral Interface, or SPI. SPI is synchronous, just like I2C, and full duplex. The setup for devices communicating through SPI is shown below.

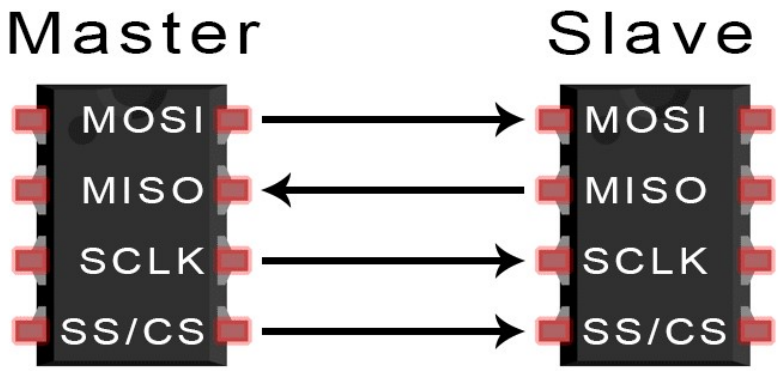


Figure 4.2.4.2 SPI communication overview. Permission pending. Reprinted from https://www.circuitbasics.com/basics-of-the-spi-communication-protocol

As can be seen in the diagram, SPI has four wires connecting the devices. They are:

- MOSI - Master Out Slave In, used to send data from master to slave
- MISO - Master In Slave Out, used to send data from slave to master
- SCLK - clock signal line
- SS/CS - Slave Select/Chip Select, used to pick which slave to receive data

In I2C, there were conditions for the start and stop of data transmission. In SPI, transmission is constant, so there is no need to stop and start. Transmission is simple, with the master device will start outputting the clock signal, and then it will choose which slave device to activate and turn the SS/CS wire to low voltage. The master then begins transmitting data. Because there is a MOSI and MISO line, the master can send data back at the same time using full duplex communication. Using the SS/CS line, multiple slaves can connect to one master, although multiple masters cannot be connected.

For our project, only one component, the GPS module, will be using SPI communication. Because of this, we won’t have to worry about daisy chaining or any hardware constrictions with SPI and multiple slave devices. We will be using C once again to facilitate communications with the GPS module and microcontroller and interpret the data received.

4.2.5 Software Standards

Software standards are defined by standards organizations in order to be used mainly in business or any other group of people working on a code base together. These standards are important because they define a common ground for working code so that anyone who maintains or adds to it later is not confused by what is already written.

Figure 4.2.5 ISO software standards

The chart above is an overview of the necessary qualities defined by the International Organization for Standardization for a good software product. Each of these qualities is expanded upon in relation to our own project in the subsequent sections.

4.2.5.1 ISO/IEC 5055 Standards

The International Organization for Standardization and the International Electrotechnical Commission have jointly defined standards relating to the development and testing of software. The first of these standards is ISO/IEC 5055.[2] This puts forth four characteristics that a program should have at any business, but can apply to our project as well. They are: security, reliability, performance efficiency, and maintainability.

For our project, we are essentially creating a working prototype and we are not bringing anything to market, so security will not be as big of a concern for us. If we were, then we would have to make sure that our software systems are not penetrable. Reliability is quite important for this project, as at the end of next semester our features need to work. This can be achieved by regular testing. Every time code is added, it needs to be tested to ensure that it actually works and that we are not just writing code that will have bugs and not run later. Performance efficiency is fairly important for the charging system. We do not want getting information from the sensors and relaying it to the screen to use too many resources that could be used to charge the phone battery. As this is a group project and several members of the team will be working on the code at different times, maintainability is of the utmost importance. Any team member that decides to work on the code at any given time needs to be able to read and understand the code. To achieve this, everyone must write code efficiently as possible with proper syntax and indentation/spacing.

4.2.5.2 ISO/IEC 25000 Standards

The ISO 5055 standards mainly refer to key qualities that should be present in the source code for a system. However, for the overall product, the ISO/IEC 25000 standards define an additional four characteristics to measure the quality of the software. The remaining characteristics are: functional suitability, compatibility, usability, and portability.[3] Our code does need to achieve functional suitability, which means that it must meet all the needs of the user. The code must be complete, correct, and appropriate and perform all of the goals we have set to do. Overall compatibility will be important, not for our system with other products but for the components within our system. We will be joining many parts together not just physically, but with code as well, and it must work for all of them. For us, the usability of the system will be similar to functional suitability. The two goals of our software are to display statistics to the LCD and to turn an LED on and off. When these two goals are achieved, our code will be usable and suitable. Finally, portability does not apply to our project because we are developing code for a very specific environment and it will not need to be updated or installed at all.

4.2.5.3 C Language Standards

In order to program the TI MSP microcontroller, we will be using the C language. The C language has its own standards defined by the ISO; the most recent version of these standards is the ISO/IEC 9899:2018, released in 2018. These standards are intended to define a common form for the C language and to promote characteristics defined in ISO 5055 and ISO 25000: portability, maintainability, and reliability. In addition, they contribute to the efficient execution of programs written in C. For the most part, the C standard defines syntax used in C and how the constructs of the language should be used. Because of this, we will not necessarily have to take specific actions in order to conform to these standards. As long as we use the proper syntax and our code is concise and efficient, we will be following the C standard.

4.2.6 Water Resistance Standards

One of the features we identified that we thought would be important to our users was some degree of waterproofing. Since our system is designed to be used in conjunction with a bicycle to harness both mechanical and solar energy, it is expected that it might be exposed to various different types of weather, including the rain. However, it is actually quite difficult to make something truly waterproof according to standards, so we have settled on water resistance.

Ingress Protection, more commonly known as IP, are a set of ratings standards developed by the International Electrotechnical Commission in order to grade how much a device is protected against both liquids and dust.[1] The rating consists of two numbers: the first number indicates how much protection the device has against solid objects, and the second number indicates how much protection the device has against the intrusion of liquids. The numbers on the scale for solid object protection range from 0 to 6, with 0 being no protection and 6 being “dust-tight.” The in between numbers are defined by how big a foreign object can enter, defined in millimeters. The numbers on the scale for water protection range from 0 to 9, with 0 being no protection and 9 being protection against both high pressure blasts of water and high temperature jets of water.

For our project, the initial goal is to make our charging system conform to an IP 34 rating. The 3 indicates that no foreign object greater than or equal to 2.5 millimeters should be able to damage the system. The 4 indicates that splashing water in any direction should not do damage to the system. Obviously, for a system like ours with a lot of electrical components, any amount of water could be severely damaging. This could make it difficult to actually test our project against the standards, as we could inadvertently harm the system. Right now, we are envisioning some kind of enclosure that could be both water tight and allow for someone to open and close it. If the IP 34 rating turns out to be too difficult to achieve due to time constraints, we can drop it down to a lower rating that may be easier to implement.

4.2.7 USB Standards

Since USBs are used in a colossal amount of household appliances and devices, it has certain requirements placed in order to properly serve its purpose. Due to the fact that there are several USB cables still in use today, it should be noted that not all cables have the same capabilities. USB 2.0 and USB Type-C are among the most popular, and so their requirements are the most important.

All USB cables are labeled with the ability to handle either 60W or 240W in order to pass the USB-IF's Compliance Program. When it comes to USB 2.0, or High-Speed USB, since they're a bit older than the more modern USB-C cable, they're not required to be marked with what kind of date rate they support. On the other hand, USB-C has to include this specification, and to use an example, a USB 20Gbps USB-C cable with 20V and 3A support must then be marked with the USB-IF's Combined Performance and Power logo of 20Gbps/60W.

A cable that fails to meet USB-IF requirements will not be allowed to be sold in the marketplace nor have the USB-IF logos, meaning that the non-profit corporation takes extensive care when putting out USB cables for sale.

Note that these standards are in place for cables with the USB connector on both ends. When it comes to captive cables, they are not USB-IF certified, due to captive cables being those that are permanently attached or have a non-USB connector.

4.2.8 PCB Standards

The printed circuit board, or PCB, is an incredibly important requirement for our senior design project. As with many other aspects of the project, PCBs also have standards. The PCB standards were developed by the Institute of Printed Circuits, also known as the IPC. The IPC is known for developing and publishing standards pertaining to each phase of the electronic product development cycle. The main standard that deals with PCBs is known as the IPC-2221.

IPC-2221 defines standards for the generic development of PCBs. This section will discuss some of the main standards. The first is clearance, which the IPC allows to different extents depending on which components are being put together. They also provide a specific equation to determine how thick a trace should be for the amount of current it will be carrying. The standards also suggest testing the insulation on your PCB.

Like any other standards, the goal of these IPC PCB standards is to improve reputation, improve the quality of the product, improve reliability, and lower costs by adhering to the standards. For our project specifically, we think that the use of EAGLE will help us to adhere to standards by being told what is okay and not okay in the program. Other, more complex elements of the standards will likely be followed by the manufacturer when we order our PCB.

4.2.9 Charger Standards

It's important to create and uphold certain requirements when creating a component as meaningful as a battery charger, something that will be used by many and for a very long time, so the charger the team selected will no doubt maintain these requirements. Although the charger selected isn't just a lithium ion battery charger, it should have been created to protect these kinds of batteries due to their volatility. Lithium ion batteries are known to be dangerous at extreme temperatures, so in order to avoid any unforeseen accidents, safely charging this kind of battery is a critical design specification to have.

Japan has established industry standards that are referred to as the Japan Electronics and Information Technology Industries Association (JEITA) guidelines that some models of chargers are explicitly stated to be compatible with, but not all variants comply with these safety requirements. Regardless, the ones that aren't compatible are incredibly safe and are extensively tested in order to prevent explosions and other incidents seen on global news and battery recalls. Although the models of the charger selected don't meet JEITA standards, their similarly constructed brethren do. This means that the charger we have is only slightly different and should nearly meet the same safety guidelines.

Accidents with batteries can be caused by either impurities seen in battery casings or electrodes, since these impurities are usually metal shards that can puncture the battery's separator, or thermal runaway, an act of producing high heat during charging due to a battery entering an irreversible exothermic reaction. These situations are said to be caused by high charge voltages and high cell temperatures, along with high charge voltage at low and high ranges of temperature.

Like it was mentioned before, some other issues presented when using lithium ion batteries are extreme temperatures and charging at these low and high temperatures. When at low temperatures, charge current and charge voltage are reduced, and if the temperature gets low enough, the system will stop charging entirely. Not to mention that the battery will be degraded when charging at this level due to permanent loss of lithium ions. For high temperatures, on the other hand, thermal runaway can happen due to the overly active cathode material within the battery, which will lead to a chemical reaction and a possible explosion in the process.

In order to fight these issues at hand, multi-cell battery chargers are equipped with components to optimize system performance, like with their fuel gauges. The models of JEITA certified chargers found during our research can use fuel gauge components developed by Texas Instruments that can easily configure battery charge current and charge voltage so that they adhere to JEITA guidelines. At the very least though, essentially every model of battery charger researched by the team has some kind of overvoltage protection or NTC thermistor, allowing the battery to fight temperature issues much easier than without those components. Single-cell chargers reduce the charge current or charge voltage when the temperature is too high, all thanks to thermistors that monitor temperature. Therefore, chargers with TS thermistor pins are invaluable to the project not only for their convenience, but also for what they contribute to safety standards.

5. Hardware and Software Design

In this section we will discuss the hardware and software design of our project. For the hardware there are two major subsystems, the power distribution subsystem, which will make up our PCB, and the sensor connections to the microcontroller. The software will control the display, reading data from all of our sensors.

5.1 Power Generation and Distribution

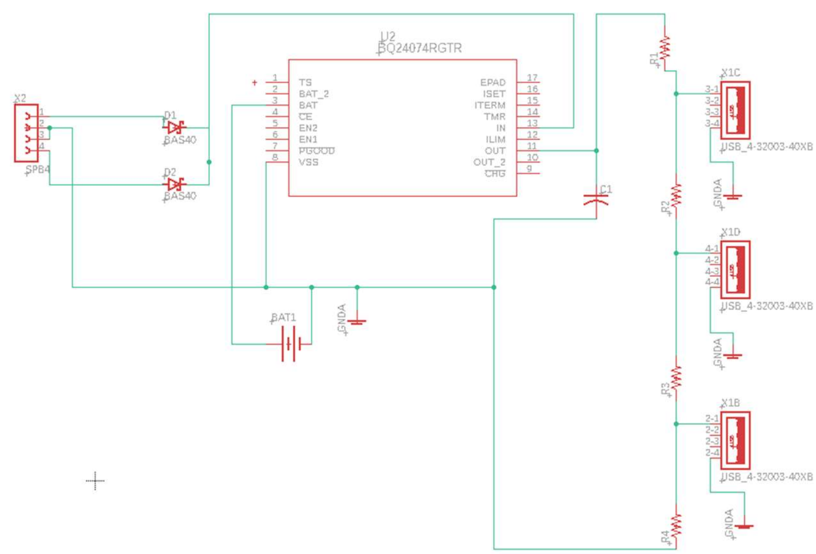


Figure 5.1 Charger, input power generation, and output

From figure 5.1, pin header X2 has 4 pins that will be where the generating power sources will connect into. In this case, Pin 1 and Pin 2 are the solar generation and generator input. Pin 2 and pin3 are grounded as no other components were connected in this case. Between the power generation sources and the receiving input of the charger (pin 13), there are two diodes, D1 and D2. The idea here is to have current flow in one direction, towards the charger. Having the diodes be forward-biased will allow this action to occur, and be in reverse biased to stop current from flowing back towards the power generation sources. After the diodes, the generated energy will be input into the charger at pin 13.

Pin 11 is the output pin and will deliver the needed energy to the receiving units, or loads. We can see that the outputs will be female USB type A ports. Energy will be delivered to each one through the construction of a voltage divider. The voltage drops will get lower from USB port X1C, to X1D, and finally to X1B. This means that the loads that will require the highest voltage will connect to X1C and the one that receives the lowest voltage without hindering the performance will be in X1B.

5.1.1 Generation

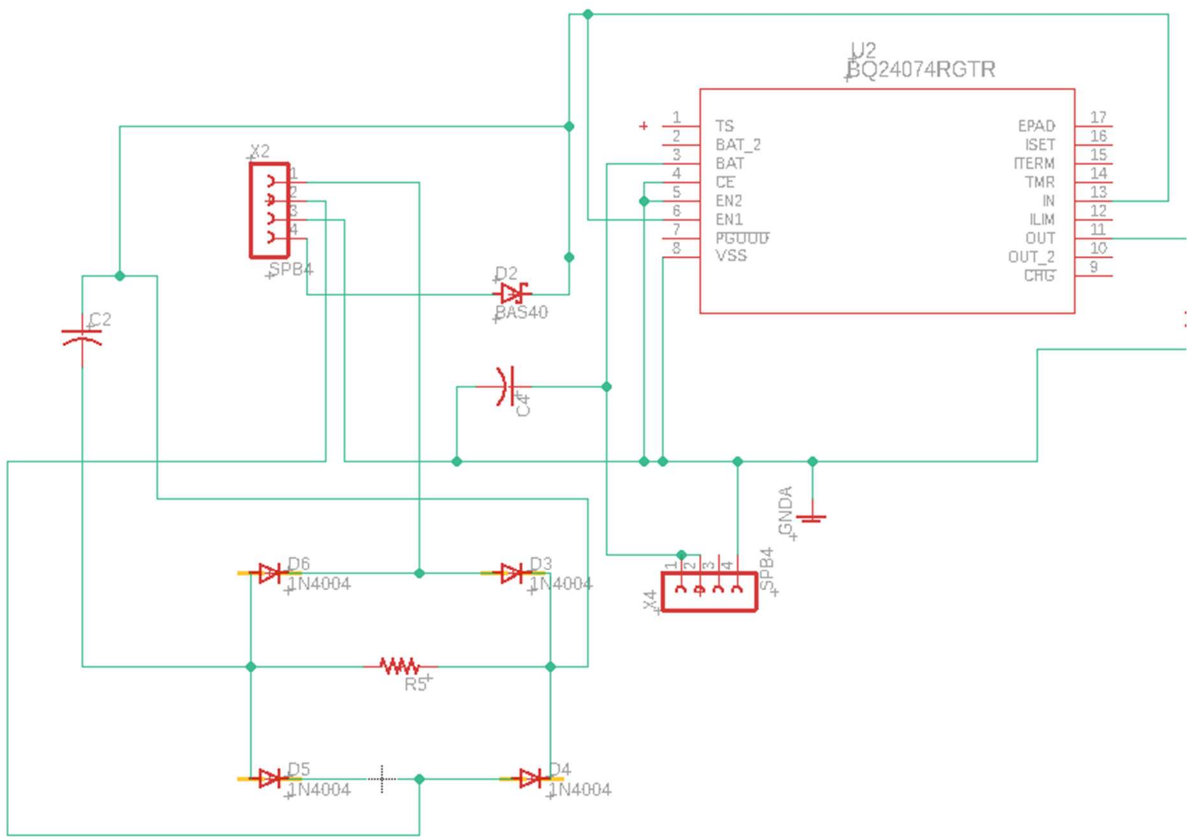


Figure 5.1.1: Power sources with rectifier.

Figure 5.1.1 shows the inclusion of a bridge rectifier. A rectifier was added to convert the incoming AC energy produced by the generator into DC energy. Pin 1 is now connected between diode D6 and diode D3. Pin 2 is now connected between diode D5 and diode D4. This is because pin 1 is coming from the positive terminal of the generator and pin 2 from the negative. Pulsating DC voltage is produced as the output of the rectifier and needs to be "smoothed" to better utilize the energy and not get too big of peaks and dips in the voltage going into the charger. To help with this, a capacitor was added in parallel to the load resistor of the rectifier, acting as a filter.

The battery included in figure 5.2.A was removed since the footprint would be too big to make sense on the PCB. instead, a 4 pin header was used to replace the battery battery too big to connect to board, decided to not attach to PCB board and instead have pin 1 and pin 2 connect to the battery. This will allow the PCB to have much less bulk, and the battery can be attached elsewhere. The output of the rectifier would then continue to the same input on the battery charger of pin 13. The connection from pin 4 on the generation pin header X2 will still have a diode to limit the current to flow in the direction of the charger only.

5.1.2 voltage sensor

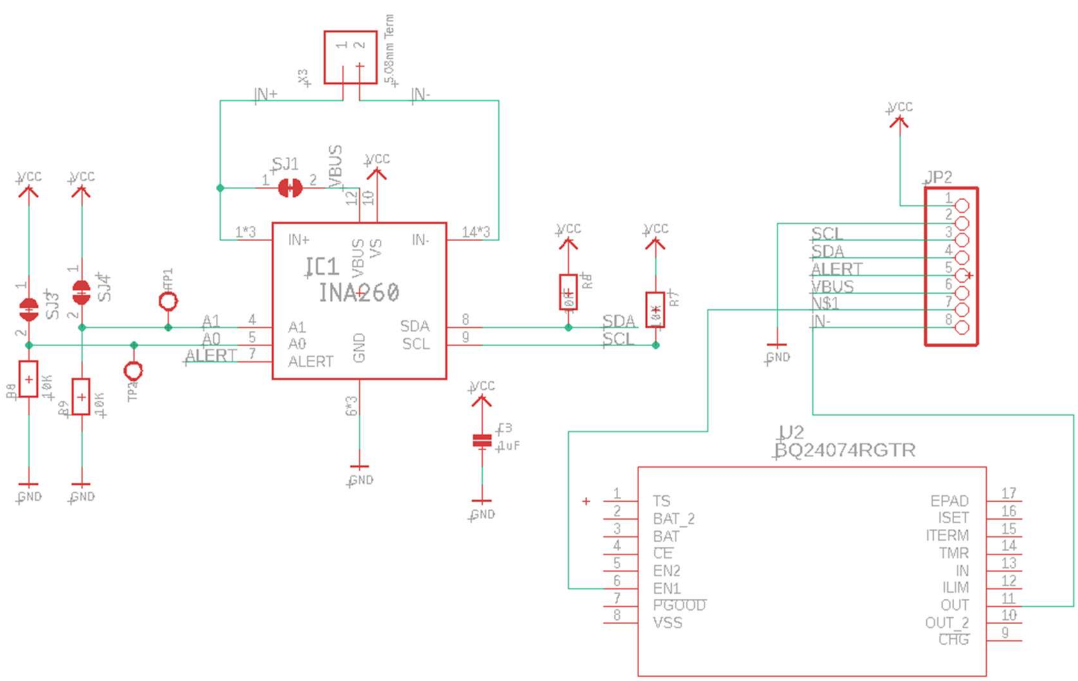


Figure 5.1.2 Charger and voltage sensor.

In this schematic, we can see the connections made between the INA260 voltage sensor and the battery we are using. In order to actually measure the voltage and current, the Vin+ and Vin- pins on the sensor must be connected to the supply and the load of the battery, respectively. This allows the sensor to calculate the difference in the voltage and current that is coming in and going out from the battery. Using the other pins that are unused in this schematic, the sensor will connect to the microcontroller and send these readings back. Those connections are discussed later on in the paper in section 5.4.4.

5.1.3 Datasheet requirements

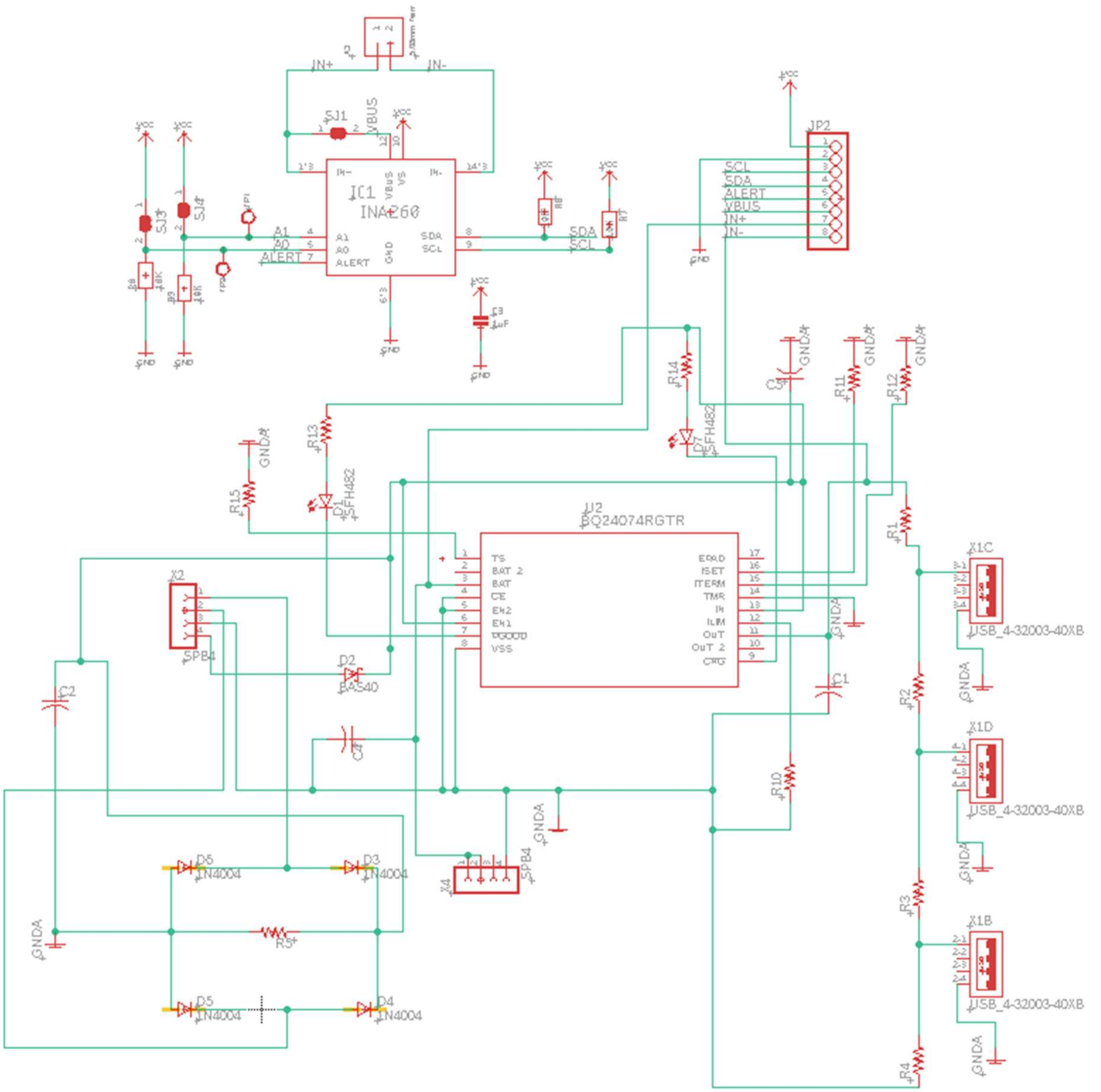


Figure 5.1.3: Power generation and distribution circuit.

Figure 5.1.3 shows the completed power generation and distribution circuit with the sources, including the rectifier, connected to the charger; the charger connected to the battery connection pins and the three usb outputs; the voltage sensor connected to the battery to measure battery performance; the battery has been replaced with a and finally all of the additional connections and capacitors recommended by the charger's datasheet for use as a standalone charger. Figure 3.6.6.3 shows the connections required to use the BQ24074 charger in a Standalone Charger Application as laid out by the charger's datasheet. We used this application setup for our circuit because at least for now we do not have a host to use the host controlled application.

5.1.4 PCB

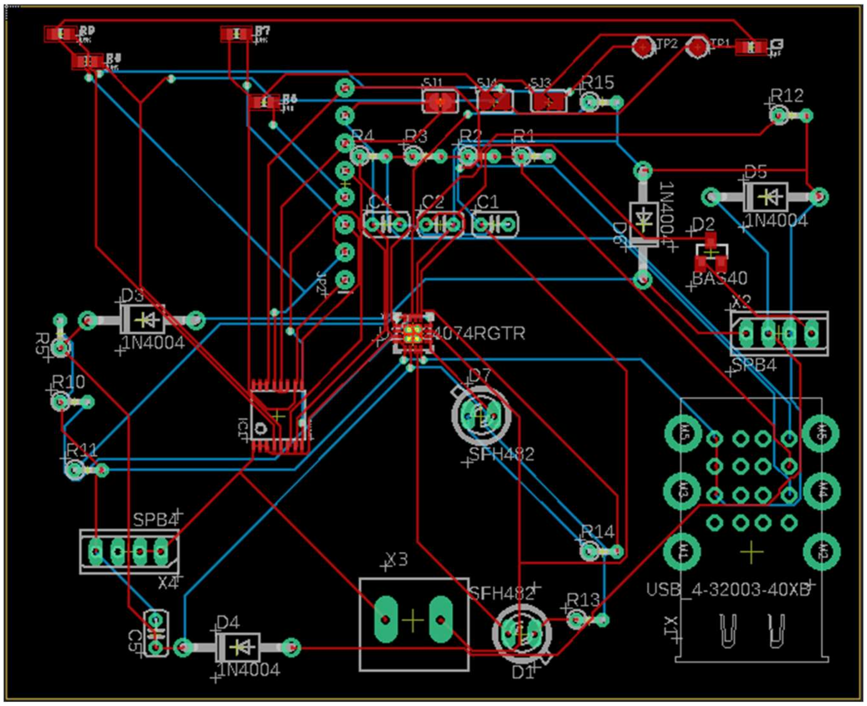


Figure 5.1.4 PCB Footprint.

Figure 5.1.4 shows the PCB footprint that was generated on Autodesk Eagle from the schematic shown in figure 5.1.3. This PCB board is 64.44mm by 80mm, equivalent to 2.53in by 3.14in. 17 vias were used to make the design operational.

5.1.5 Update

After being rectified into DC voltage the power from the generator goes through voltage regulation. The voltage regulator circuit that we utilized for the sidewall generator uses the 7805t part. This is a 5 volt regulator. The design also includes a 0.33uF capacitor and a 0.1uF capacitor. In our design we used three 0.1uF capacitors in parallel to combine up the 0.33uF capacitor needed. In the original design, a surface mount rectifier was chosen. Since that option was no longer viable, a bridge rectifier was created using four 1N4006 diodes.

The voltage regulator circuit that we designed for the solar panel uses the 7812T part. This is a 12 volt regulator. Much like the voltage regulator for the generator, the voltage regulator circuit for the solar panel includes a 0.33uF capacitor and a 0.1uF capacitor, and we used 0.1uF capacitors in parallel to make the 0.33uF capacitor. The 12 voltage regulator allows us to take advantage of the solar panel's higher voltage rating of 17V when compared to the generator's 12V. Because the solar panel outputs DC voltage, there was no need to build a bridge rectifier for this part of the system.

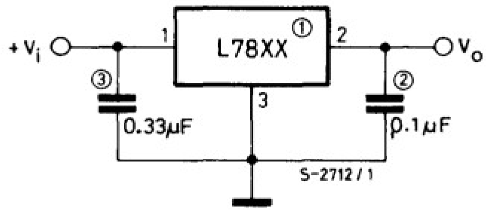


Figure 5.1.5 Schematic for the 12V solar voltage regulator

The outputs of the voltage regulation circuits of both sources are combined onto two nodes in parallel, one node for the voltage lines and one for the ground lines. The two USB loads are then also connected to the same nodes effectively connecting the two sources and the two loads in parallel. Just before the nodes and after the voltage regulation each source line has a diode to make sure that they are only supplying power and not taking it from the loads. This is especially important for the solar panel as solar panels can take power from their loads at night or during other times of low light, when the solar panels are not producing any electricity.

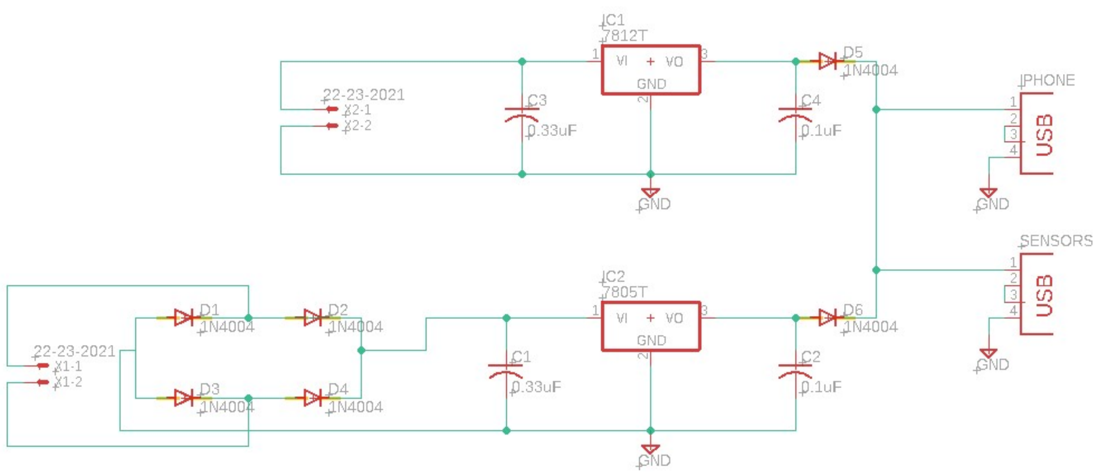


Figure 5.1.5a Eagle schematic for new power subsystem board design

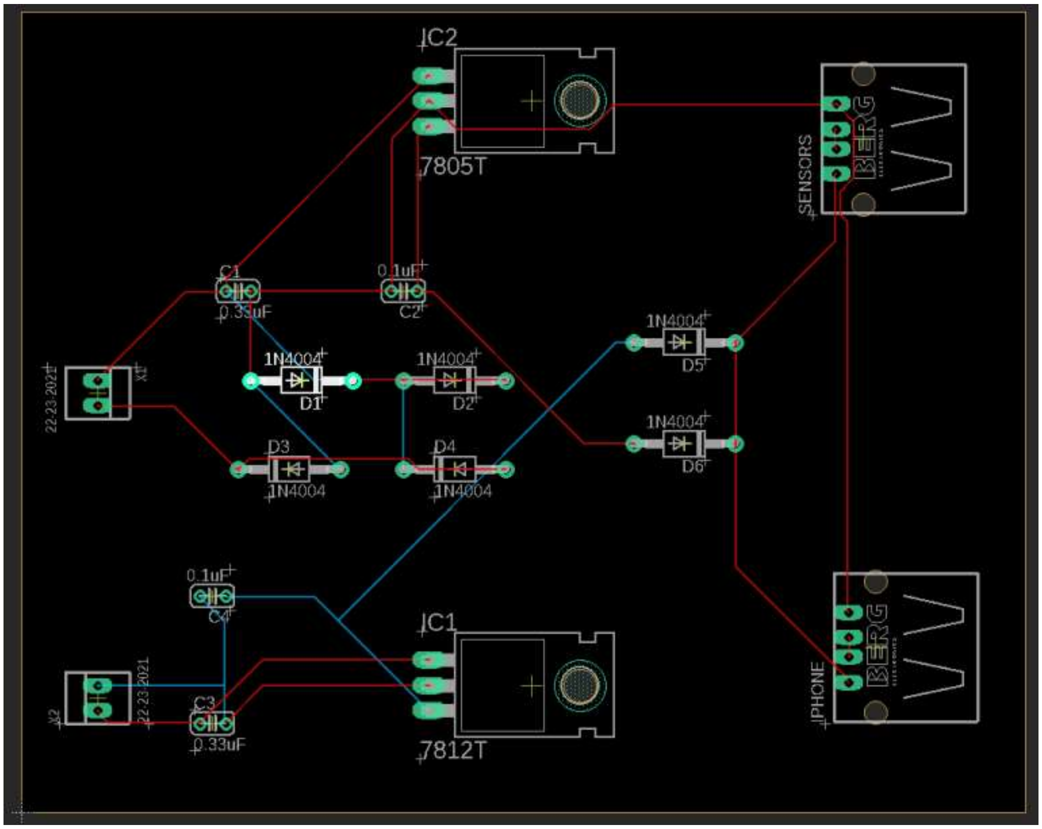


Figure 5.1.5b Broad layout for new design

Figures 5.1.5a and 5.1.5b show the new design implemented as a printed circuit board (PCB). Due to time constraints we were not able to assemble the PCBs but we built out the same design on a perf board and were able to get it working effectively. Figure 5.1.5c shows the manually soldered perf board with the functioning design.

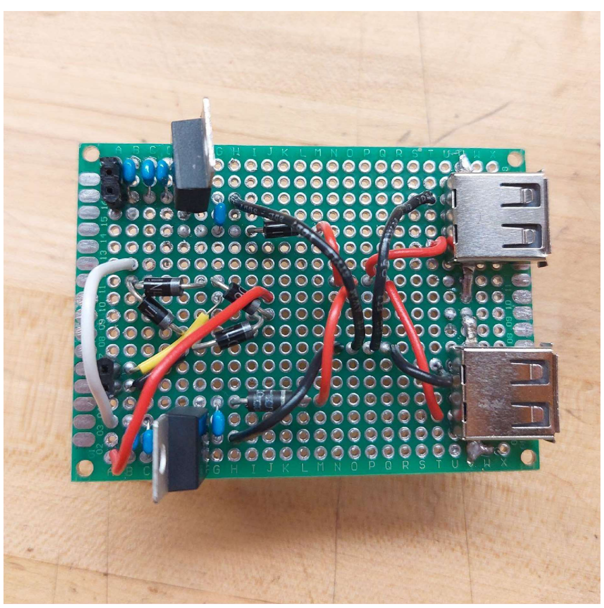


Figure 5.1.5c Manually soldered power subsystem design

5.2 Microcontroller Design

The microcontroller picked for the project will connect to the outside of the PCB through a USB connection rather than being integrated within the PCB. Because of this, the only thing that really has to be done with it is establishing a connection with the several sensors and the LCD display through the P4.0 – P4.3 pins. The microcontroller serves as a kind of medium for the components not going on the PCB, as seen below in the footprint's great amount of pins and schematic of the inputs and output of the MSP.

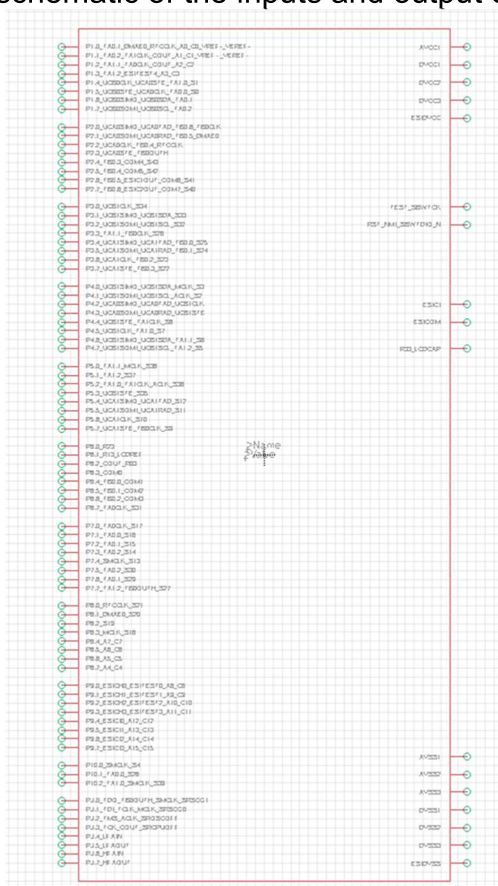


Figure 5.2.a: MSP430FR6989 Symbol for connections

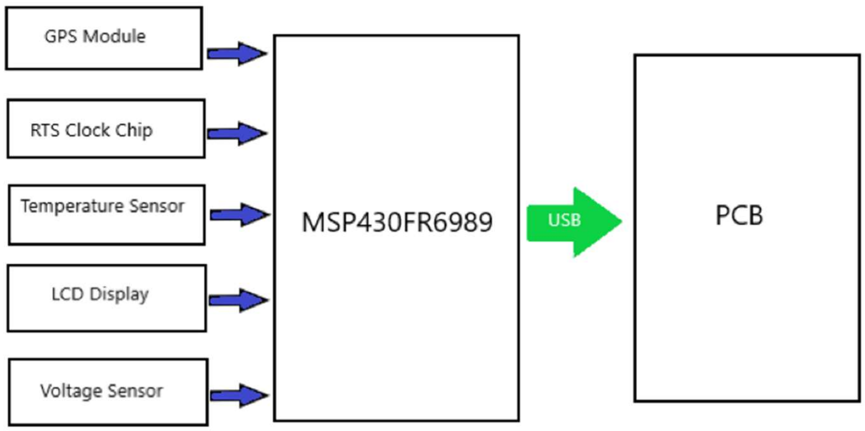


Figure 5.2b: MSP430's inputs and outputs

5.2.1 Implemented Microcontroller Design

Without any configurations, the Arduino Uno R3 offers a lot of perks due to its abundance and ability to use open source material. Although one drawback is the lack of pins available for use, many pins aren't necessary for its intended use. The microcontroller is at least quite fast, however, and it has a convenient USB plug-in that works both ways, since the microcontroller can connect to devices and can be connected to via USB-B. These attributes allow it to function properly as a critical piece of the bike's intended ease of use. Most importantly, the microcontroller is compact and powerful while also maintaining low power usage at all times, making it an important yet conservative segment of the current design.

At first, the original design used an MSP4330FR6989, but it was replaced due to it not functioning properly with the current design. The new microcontroller had a much higher voltage requirement that we could not supply with the power system, and the arduino did not work well with the variable output of our renewable sources. If we had been able to implement a battery charging circuit and battery that would have allowed us to power the sensor system directly through the battery, but we would have needed to use a higher voltage battery too.

5.3 Sensor Design

This section will discuss the design portion of the project centered around the sensors. These include the NEO-6M GPS, which uses SPI communication, and the real time clock, voltage sensor, and temperature sensor, which all use I2C communication along with the LCD, which is discussed further in section 5.5.

5.3.1 GPS Module Design

Pictured below is a rough schematic of what the GPS module looked like in our initial design when connected to the microcontroller:

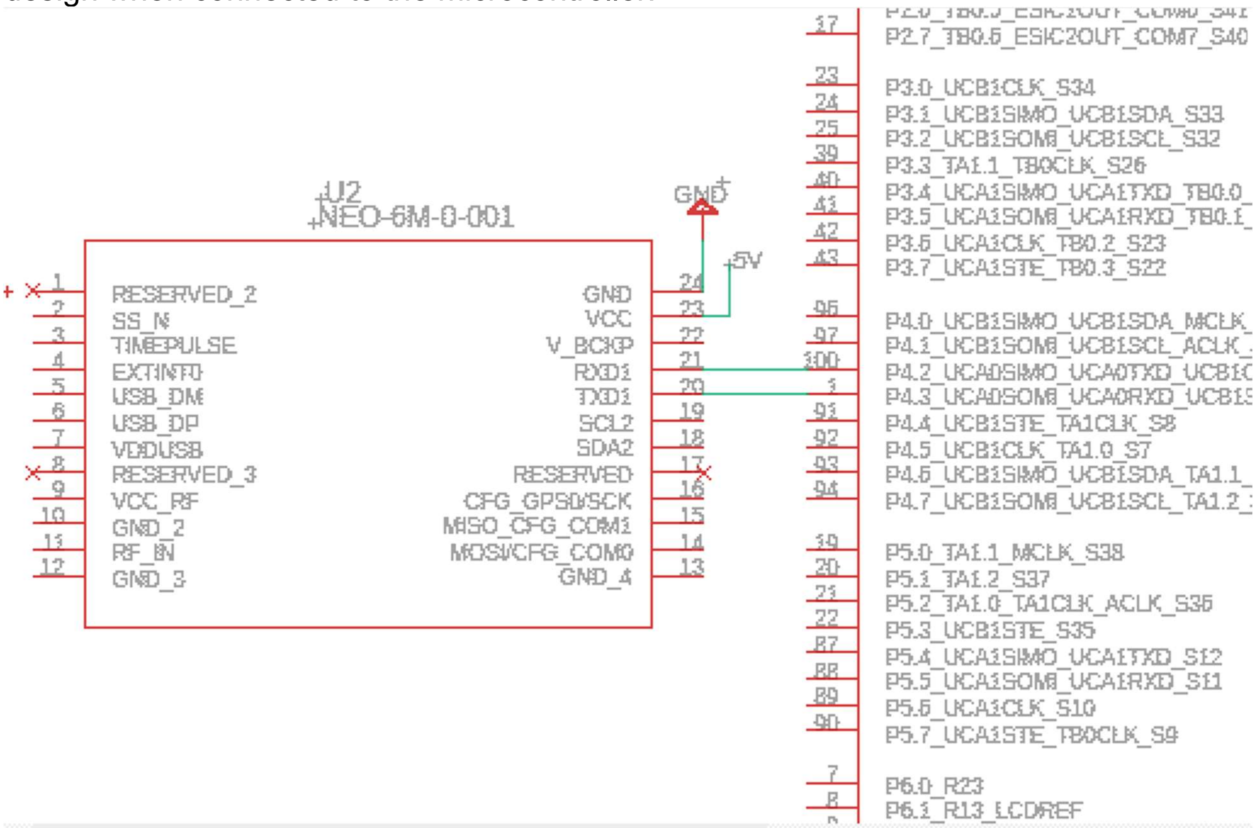


Figure 5.3.1 GPS module connections

The picture is zoomed in because the microcontroller's footprint is so large that none of the pins would be able to be seen if it were not. Only the pins connected to the microcontroller are shown; in this case, TXD1 is connected to P4.3, and RXD1 is connected to P4.2.

When searching for a schematic of the NEO-6M, we found only one. When it was added to the schematic alongside the microcontroller, it had a lot more pins on it than the one we intend to purchase for our project. Since this was the only usable footprint, we just put this one in our schematic and ignored all of the excess pins. As is mentioned in the previous paragraph, TXD and RXD on the GPS module connect to the corresponding RXD and TXD pins on the MSP430FR6989. These are the pins used for transmitting and receiving data through serial communication.

The only other two pins that our model of the NEO-6M comes with are ground and VCC. The ground pin is, of course, connected to ground. The VCC pin is connected to the 5V pin on the microcontroller, represented in this schematic by the 5V label.

5.3.2 Real Time Clock Chip Design

Pictured below is a schematic representation of how the real time clock chip was connected our initial design to the MSP430FR6989:

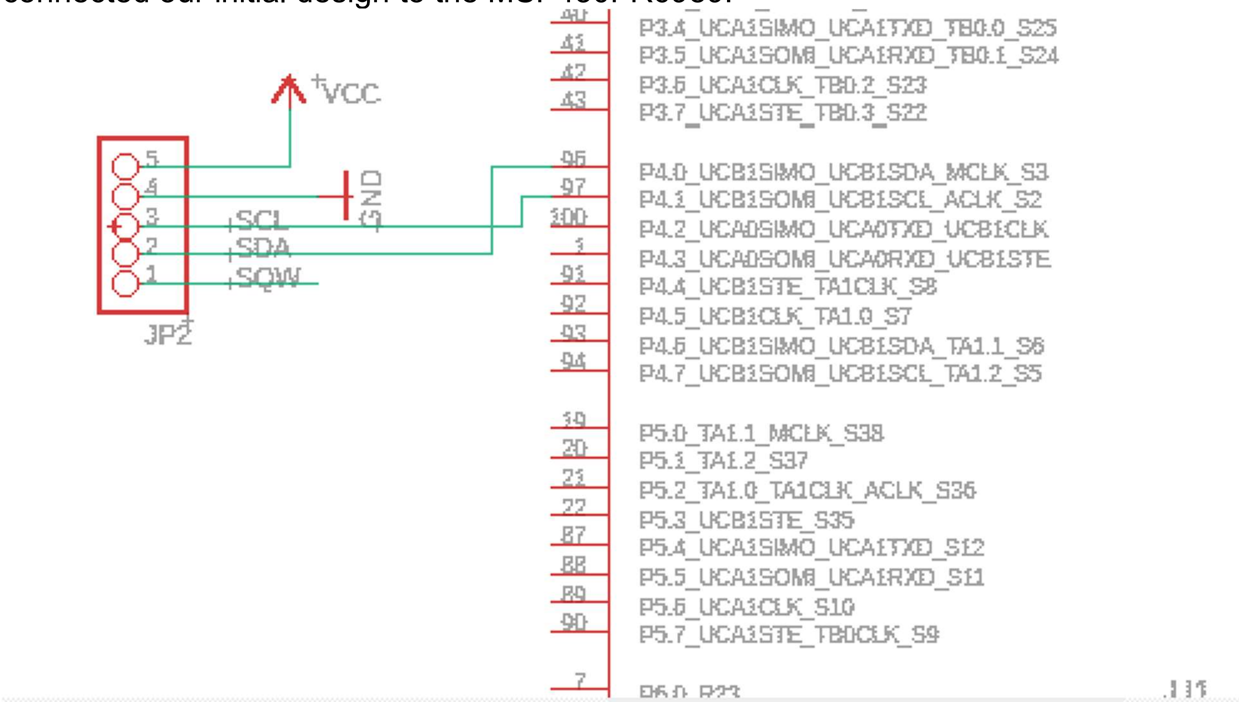


Figure 5.3.2 RTC connections

Once again, we had trouble finding a footprint for this part. The website Adafruit only maintains a database of board and schematic files for their parts, so we had to work with what was given in the schematic. Shown in this diagram is the header and pins of the real time clock chip. There are five pins, two of which connect to the MSP430FR6989: SDA and SCL. These connect to P4.0 and P4.1, respectively. These are, of course, the communication lines used for I2C communication. The SQW pin is an additional clock line that we do not need for this project.

Pin number 4 on the header is the ground pin and is connected to ground. Pin number 5 is the voltage pin and will be connected to the 5V pin on the microcontroller, but is shown in the schematic as a connection to VCC.

5.3.3 Temperature Sensor Design

Pictured below is a schematic representation of how the temperature sensor was connected to the MSP430FR6989 in our initial design:

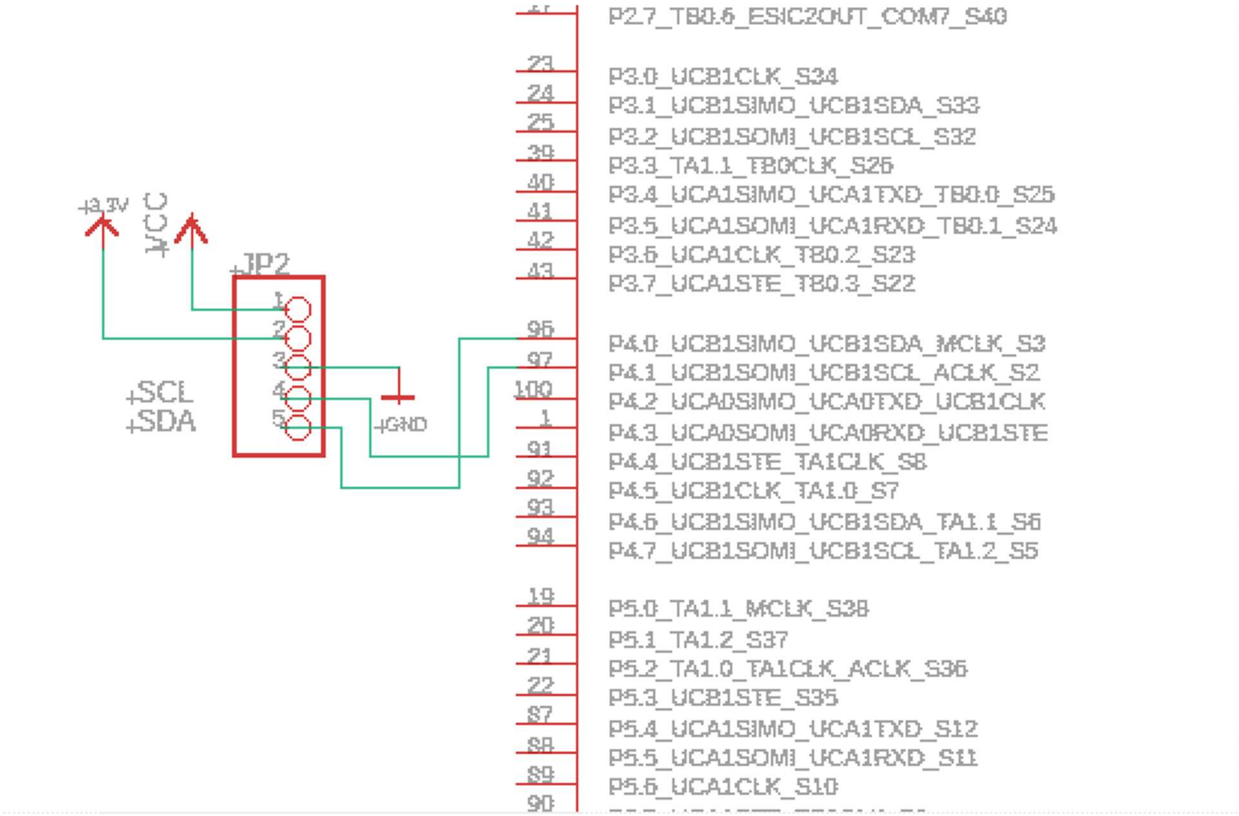


Figure 5.3.3 Temperature sensor connections

Just like the previous Adafruit sensor, we are using the 5 pin header on this sensor to show the connections to the microcontroller. As usual, the SCL and SDA pins connect to P4.1 and P4.0. These are the I2C communication lines. Pin 3 on the sensor is ground and connects to ground, and pin 1 will connect to the 5V pin of the microcontroller and is indicated by VCC in the schematic. Pin 2 is a 3.3V power output that is optional, so we will not be using it in this project.

5.3.4 Voltage Sensor Design

Pictured below is a schematic representation of how the voltage sensor was connected to the MSP430FR6989 in our initial design:

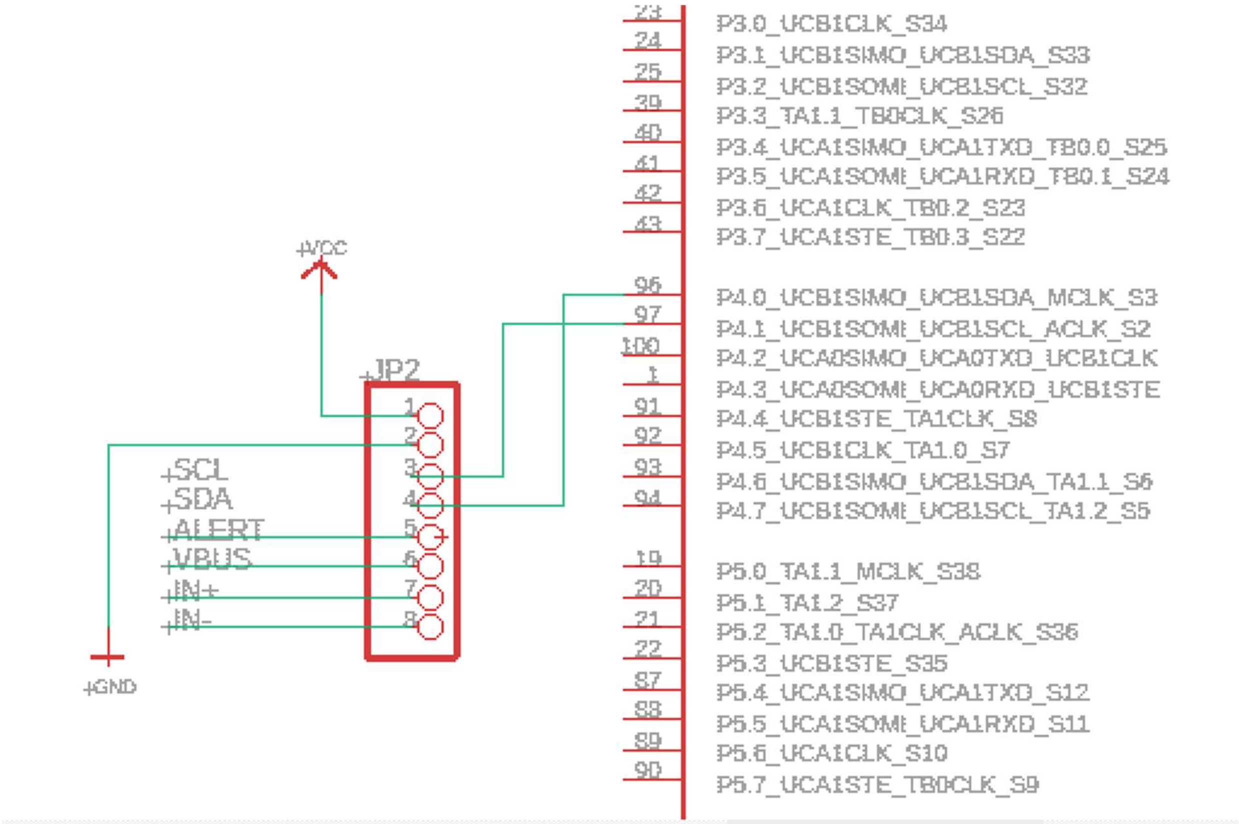


Figure 5.3.4 voltage sensor connections

Here, once again, we are using a pin header, in this case an 8 pin header, to represent the voltage sensor. Pins 3 and 4 are SCL and SDA, which connect to P4.1 and P4.0 on the microcontroller. Pin 1 is VCC and will connect to the 5V pin on the microcontroller. Pin 2 is the ground pin. Pins 5 and 6 are not needed to be used for this project.

Pins 7 and 8 are Vin+ and Vin-, respectively. In order to actually measure the voltage, Vin+ needs to be connected to the battery supply, and Vin- needs to be connected to the load. Because of this, this particular sensor will need to be incorporated into the PCB design.

5.3.5 LCD Display Design

Pictured below is a rough schematic of what the LCD looked like when connected to the microcontroller from our initial design:

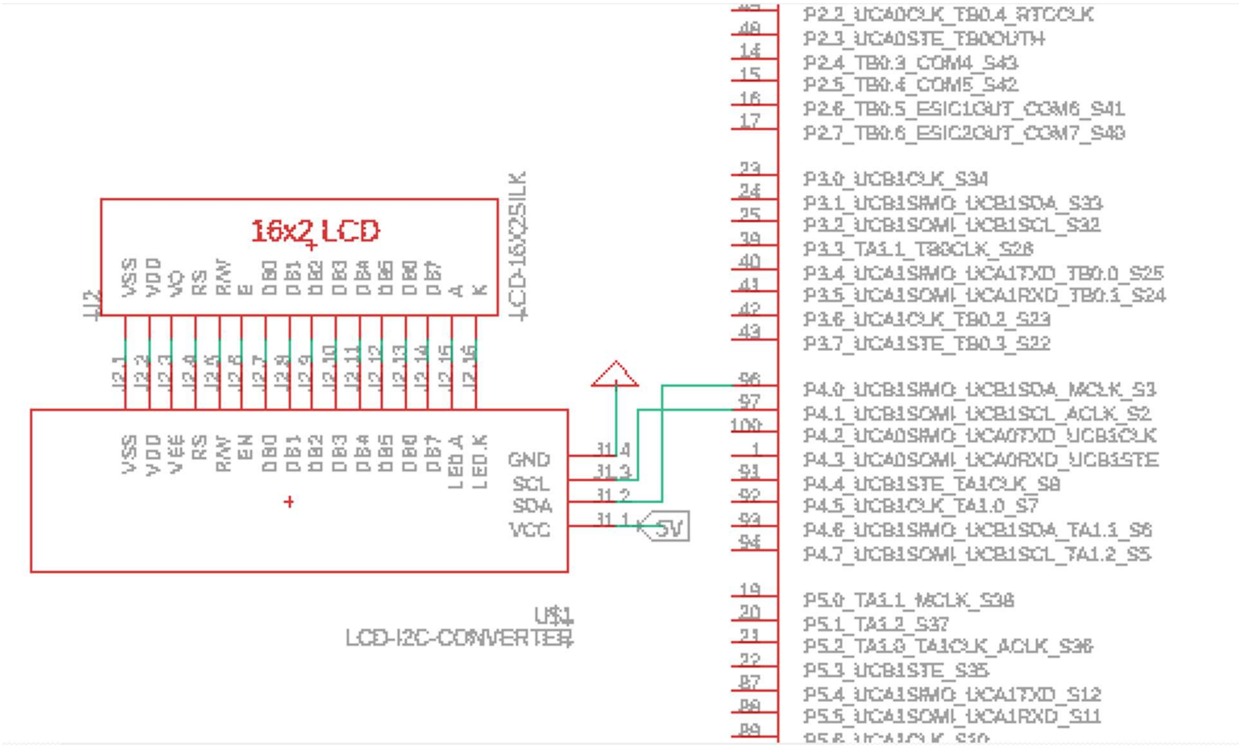


Figure 5.3.5 LCD connection

The schematic did have to be zoomed in, as the footprint for the MSP430FR6989 is so large that the LCD part wouldn't really be visible. Due to this, only the pins that are connected to the LCD are shown. These are P4.0 and P4.1, for the SDA and the SCL, respectively.

It was actually very difficult trying to find Eagle footprints for any type of I2C LCD, let alone the specific model we chose for our project. After spending quite a while scouring the Internet for this part or a similar part, we decided it would be more constructive to just use a generic 16x2 LCD footprint connected to an LCD to I2C converter. As can be seen in the schematic, using the I2C version greatly simplifies things and reduces the amount of connections we will have to make. The main I2C connections are the SCL and SDA, which connect to the microcontroller pins. Then there is GND, which obviously connects to ground. VCC is connected to the voltage source, which in this image is shown as 5V, but will be finalized during testing.

There are a few things to note, the first of which being that there is no potentiometer connected anywhere because there is a built-in potentiometer for adjusting contrast on the SunFounder LCD1602. In addition, because we are using several components with I2C communication, those components will be added on to these connections in their schematics, because they need to connect to the SDA and SCL lines as well. This will require us to use pull up resistors, but that will be further discussed in the Sensor Design section.

5.3.6 I2C Sensors Design Summary

All of the sensors described above except for the GPS module communicate through I2C. The LCD discussed in the section above does as well. All of these sensors must be able to connect to the SDA and SCL pins on the microcontroller in order to be able to send and receive data. In order to do this, the sensors and LCD will have to be wired together with resistors, looking something like this:

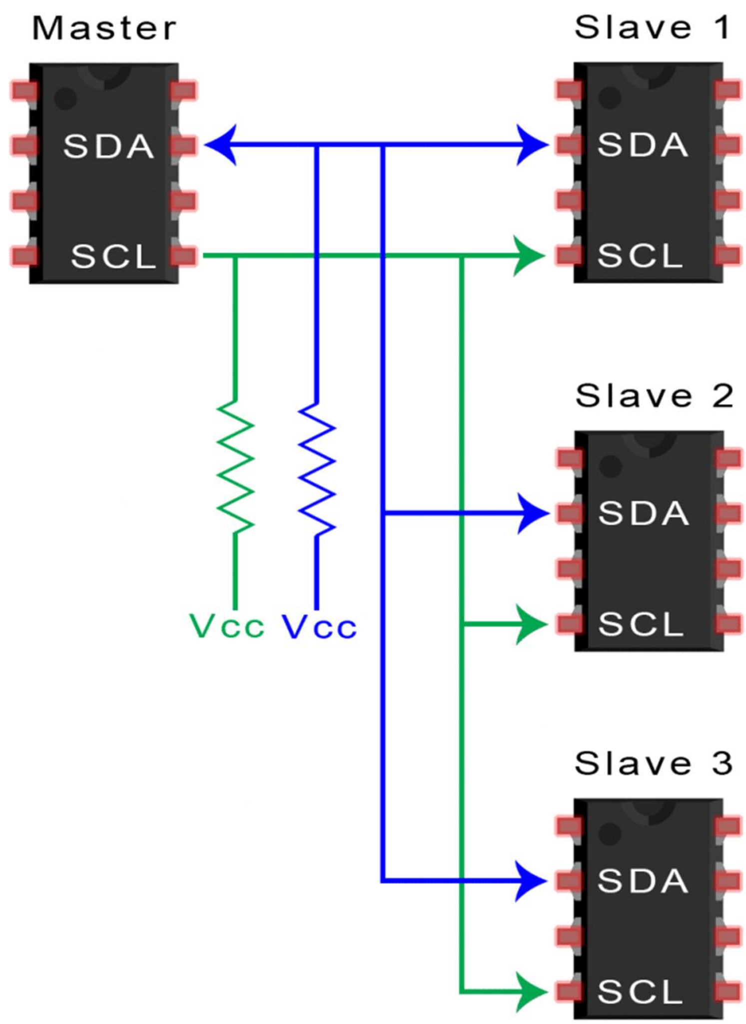


Figure 5.3.6 Multiple I2C devices. Permission pending. Reprinted from https://www.circuitbasics.com/basics-of-the-i2c-communication-protocol/

Both the SDA and SCL lines need to have a pull up resistor connecting them to the VCC line in order for all the devices to work properly. To communicate with each one, the microcontroller will address the devices using their specific device address, and each message sent by a device will have its address included in the message in order to differentiate between devices.

5.4 Software Design

This section of the paper will discuss the software design for the code that will run on the microcontroller and provide information that has been collected from the sensors onto the LCD screen.

5.4.1 Software Flowchart/Block Diagram

A common tool used by software developers is using a program to map out a flowchart of how a project's code is going to work together before starting to actually write the code. This provides a high level overview of the program you are going to write, and it can be referred to while working in order to see what steps the program should be taking next and in what order they should be.

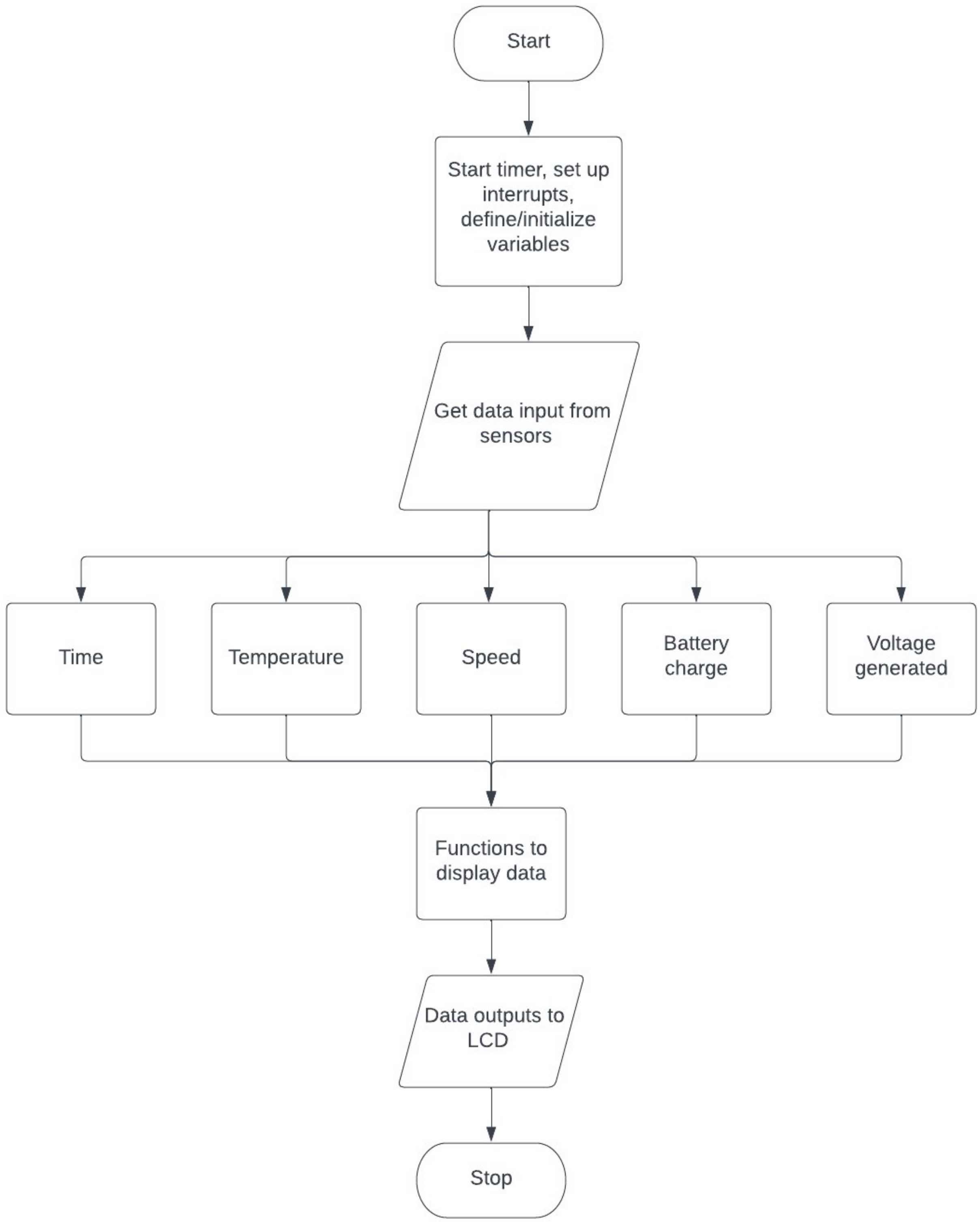


Figure 5.4.1 Software Block Diagram

As can be seen in the diagram, our program will first begin with defining and initializing variables and setting up interrupts, which will be used to control how the buttons are used to change the screen on the display. Then, data will be gathered from the sensors and sent through the microcontroller. These data include speed, battery charge, voltage generated, temperature, and time. They will all be passed to functions written to display each different type of data. Finally, the functions will display the information to the LCD, and the program will stop.

5.4.2 UML Use Case Diagram

Unified Modeling Language, also known as UML, is a modeling language that has been standardized for use in the software engineering field in order to visualize various aspects of a computer program. One of these diagram standards is something known as a use case diagram, which shows how the end user is expected to interact with a computer program. In our case, this diagram will show how the bicycle rider will interact with the microcontroller and view their statistics.

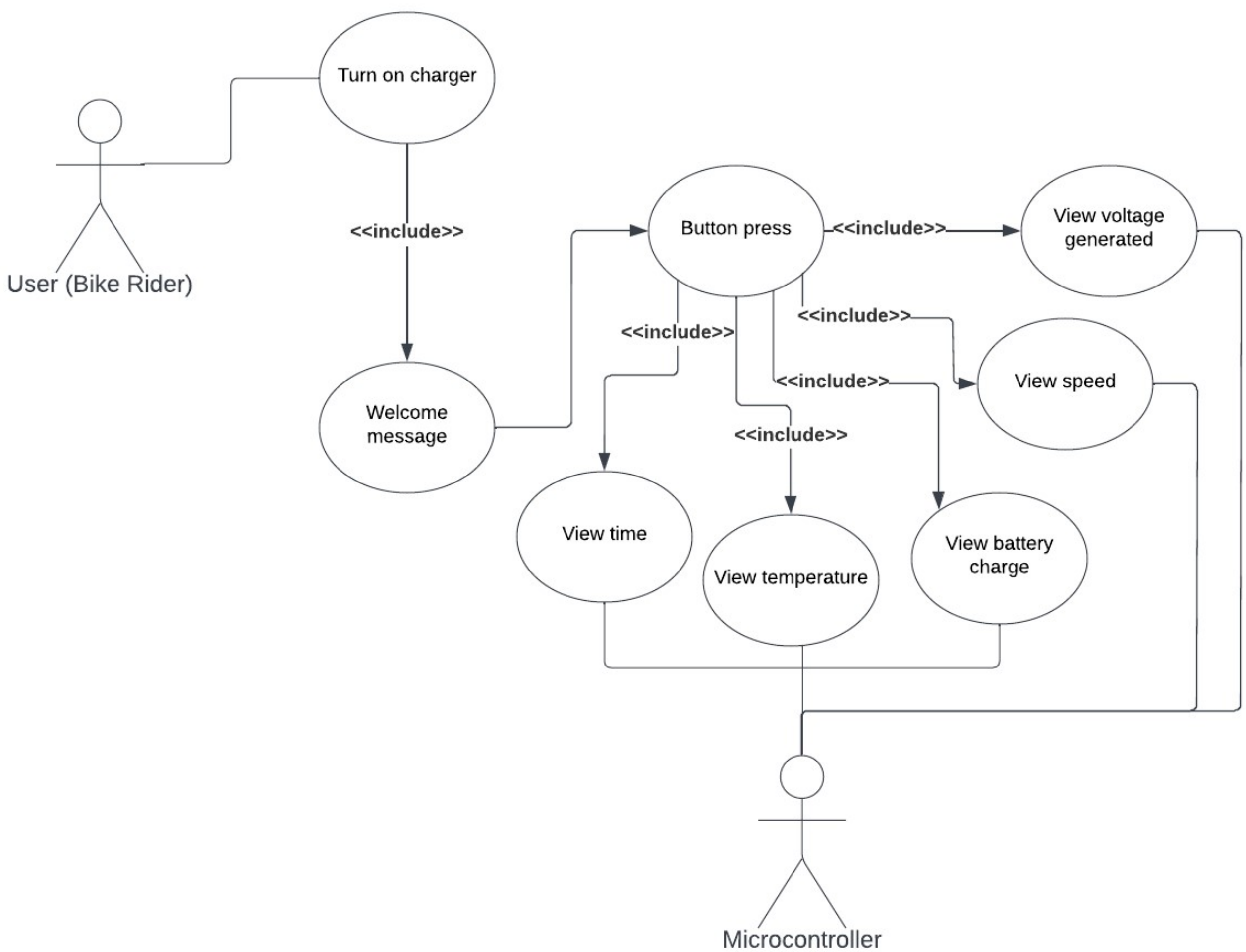


Figure 5.4.2: UML Use case Diagram

In the diagram above, both the bicycle rider and the microcontroller are represented as actors (the stick figures). They are both outside sources that interact with the program. The bicycle rider is the user, whereas the microcontroller is feeding in data from the sensors to the program. When the user turns the charging system on, they will see a welcome screen. They can then push the button on the microcontroller to display the time and temperature. When the button is pushed again, the screen will display the speed, battery charge, and voltage generated. If the button is pushed yet again, it will loop back to the beginning and show the time and temperature.

5.4.3 Function Descriptions

In this section, we will list each function to be used in our project's program and detail the steps to be taken for each function. The functions do one of two things: either display information to the screen, or fetch data from the sensors and calculate and/or make the data readable.

5.4.3.1 Display Welcome Message Function

This function is extremely simple, as all it does is print to the screen.

- Start
- Print welcome message
- Stop

5.4.3.2 Display Time and Temperature Function

This is the first of two data display functions. They have been split into parts because the screen can only hold so much information at a time, so the user will have to press a button to switch between information.

- Start
- Display time
- Display temperature
- Stop

5.4.3.3 Display Speed, Charge, and Voltage Function

This is the second of the display functions, which shows the rest of the information to the user.

- Start
- Display speed
- Display battery charge
- Display voltage generated
- Stop

5.4.3.4 Calculate Temperature Function

We recognize that our users might be from somewhere else where Celsius is the preferred system for reading temperatures, so we will display the temperature in both Celsius and Fahrenheit.

- Start
- Read temperature from sensor
- Convert temperature to Fahrenheit
- Store Celsius and Fahrenheit in two different variables and send to display function
- Stop

5.4.3.5 Calculate Time Function

This function is also very straightforward, as there is not necessarily any calculation involved.

- Start
- Read time from real time clock
- Store in variable and send to display
- Stop

5.4.3.6 Calculate Speed Function

Like with the temperature function, we will display the speed in both miles and kilometers per hour for the user's preference.

- Start
- Read speed data (in knots) from sensor
- Convert speed to kilometers per hour
- Convert speed to miles per hour
- Store miles per hour and kilometers per hour in two different variables and send to display
- Stop

5.4.3.7 Calculate Voltage Generated Function

This function is another simple one because again, no calculations are really needed here.

- Start
- Voltage data read from sensor
- Voltage stored in variable and sent to display
- Stop

5.4.3.8 Calculate Battery Charge Function

This function is going to be a little bit more involved than the others because the battery charge level needs to be estimated based on the voltage readings we are getting from the sensor.

- Start
- Voltage read from sensor
- Voltage level compared against maximum battery capacity
- Approximate percentage stored in variable and sent back to display
- Stop

6. Project Prototype Construction / Testing

6.1 Testing Plan

This section will describe the testing plan for our project. We will outline the testing of both hardware and software components. Testing along the way is important to ensure that our milestones are met on time.

As all of the components are chosen, ordered, and delivered, it is important to verify that they work as expected. Testing should be done as soon as possible after components are acquired, that way there is time to find a new part and have it delivered. Testing will be used to verify that a component meets the specifications that they are supposed to as laid out in datasheets and to verify that they will be suitable for our project.

If all of the individual components are functioning then the next step would be to test subsystems. We will do this by progressively adding components and testing along the way. For example if the solar panel, rectifier, and sidewall generator are all verified to be working, then they will be connected and the output of that system will be tested to ensure that the output is what we expect. From there we need to test to see that the charger outputs what is expected before connecting the battery and the lighting microcontroller, and load to the circuit. This way it is less likely that parts of the system will be damaged by an unexpected output. And if a problem arises we have a better idea of where to look for the issue, for example if the individual components all work as expected any issue is likely the result of how the components are connected.

Likewise software testing along the way is important because a problem can compound the further one gets into the program. It is much easier to fix a problem if it only affects a smaller part of the project.

Finally when the entire prototype is assembled some final testing will occur to ensure that all components have been integrated together properly, and to find where any improvements can be made.

6.1.1 Tools used for testing

Testing small systems and individual components can be done through software or physically. Some of the software tools that can be used are multisim, available on the computers on campus at the engineering buildings, and LTspice and multisim live online which are free software accessible from the web. These will be used to simulate circuits and get an idea of ideal values without having to build them on a breadboard. Other tools include voltage meter, oscilloscope, DC power supply, multimeter, and many more useful tools that will be found in the senior design testing lab. For the construction and assembly of parts onto the bike, a mechanics tool set will be needed. This includes wrenches, screwdrivers, sockets, and ratchets. For time saving, the use of power tools, like impact and drill sets can be used to make assembly easier. It is not a requirement, but will be a useful tool if available at a cheaper cost.

6.1.2 Solar panels

We plan to use a voltmeter to evaluate the voltage output of the solar panels. We will use the voltmeter probes to connect to the wire coming out of the panel and measure the voltage output created by exposing it to sunlight. The voltage reading should reflect voltage production in real time, so if we cover the solar panel the reading should be zero volts and if we expose the panel to full light the voltage reading should be the maximum voltage rating of the panel. Both open circuit voltage and short circuit current should be measured as part of the testing before the solar panel is connected to other components.

The solar panel can also be tested in different conditions that would reflect conditions under which someone may be riding their bicycle, so we know what kinds of output to expect. For example we could test the output on a sunny day versus on a cloudy day, and we could test at different times of day when the sun would be hitting the panel at different angles.

Another way this could be tested would be by connecting it to our voltage sensor and to the microcontroller and display. This method would only work if the sensor, microcontroller and display were already tested and their function confirmed. It may be the case that these will be tested first, it just depends on the order in which we receive the components. Otherwise this would be a method of testing the sensor once the solar panel function is confirmed.

6.1.3 Mechanical Generator

After the sidewall generator is installed onto the bicycle the positive and negative leads will be connected to a multimeter. Then while it is hooked up we will simulate pedaling manually with the wheel off of the ground. Manually pedaling the bicycle while it is not in contact with the floor is not a true representation of pedaling the bicycle on the ground with one’s legs, but it will enable us to use the multimeter while stationary. At a decent speed we expect the generator to output 12 Volt / 6 Watt / 0.5 Amps as described. Pedaling as fast as possible while the tire is off the ground will likely result in a much higher voltage that would not be typically attainable under normal circumstances when there is additional resistance from the ground.

We could also try to test for slippage or just performance loss by getting the tires wet and pedaling, simulating bicycle riding in the rain while connected to the multimeter and the output should experience interruption. Likewise we could test output at different speeds to see how performance varies. We will need to approximate a measure of speed or rotations/minute to be able to compare the different trials.

Another factor we could test for is wear on the tire or roller. Wear should not happen immediately, so if some wear is noticeable right away it likely means that something is defective.

Alternatively we can use something else that spins and hold the sidewall generator against that, so that we would have more physical control of the generator and use of the multimeter, but that would require finding the speed of the spinning surface. And the spinning surface would be even further from mimicking the actual conditions of riding a bicycle.

6.1.4 Rectifier

Testing a rectifier should be done prior to integrating into the whole system. This can be done by building a bridge rectifier on a breadboard and connecting a signal generator to the input. The oscilloscope can then be connected to both the input and across the load resistor on the bridge rectifier. The output should display the positive and negative half cycles. It is important to note that diodes can consume some energy so the output may not match exactly, but should be really close.

6.1.5 Battery

6.1.5.1 Lead acid

The purpose of the following is to provide a photovoltaic hybrid power system battery test procedure to assist in evaluating battery capacity, and appropriate photovoltaic battery charging requirements. The most important aspect of testing the battery is to make sure the personnel are protected and safe. This means using the following, but not limited to, goggles for eye protection, acid-resistant gloves, and protective clothing. The test results will provide information about the battery's performance by comparing the manufacturer's rated capacity with the measured capacity. If the user will have multiple cells of batteries strung together, this test will also help to measure individual cell performance to help identify defective or low-capacity cells. Not identifying low performance can lead to battery bank degradation. Undercharging or end of life conditions can be results of low capacity.

The test procedure uses the taper charge implemented in the system charge control. Hybrid power systems use the dispatchable power source for taper charging at regular intervals. To determine the end voltage of the battery, the capacity of the battery discharge ampere- hour is used. Parameters should be set for hybrid power systems with the battery in mind. This is because a small modification to the system can have a huge impact on the performance of the battery. More specifically, charging requirements of the battery should be clearly defined with proper controls to keep battery health at a high level. Hybrid power system parameters should be chosen while also keeping in mind the system-load profile, weather conditions, and hardware. If high costs are brought upon because of the battery, then the charging and discharging requirements should be set before designing the hybrid system. Equipment needed to perform a battery test would be a generator and a constant-current or constant-power load that can discharge at a required rate. The discharge rate should be comparable to the discharge rate the battery will undergo under normal operating conditions.

Being that a lead-acid battery may still be an option for the project, it is recommended to have a testing procedure in the case it is finalized to be chosen as the battery for the project. As it has been stated before, lead-acid batteries can supply a high voltage and are readily available making it easy to choose at a moment's notice.

6.1.5.2 Lithium-ion

The testing for a rechargeable lithium-ion battery will be to measure the ability to charge up to its max capacity and then discharge to a load that accepts a given current and voltage. Things that can be measured are the amount of time to reach a full charge and to discharge, as well as making sure the battery is providing the voltage rating as stated on the respective datasheet. This is important since designing can sometimes be around battery specifications. Lithium-ion batteries contain flammable chemicals, therefore testing should always be done where proper fire extinguishers are readily available.

6.1.6 Microcontroller

Since the microcontroller won’t be used for much else besides the pins and connections to the PCB through its USB, just a simple program is required to make sure everything works properly. If necessary, the board allows for use of a temperature measurement feature and an LCD display in the case that the other components selected aren’t enough for the project, serving as a sort of backup. With that in mind, it could be useful to display the battery’s temperature during testing. Either way, it’s essential that its low power modes work properly, so that’s another aspect that will be tested during the building of the project. Therefore, the program made during testing will perform the following:

- Ensure LCD display functions properly
- Enable temperature monitoring
- Run through all low power modes and check which one best suits the situation

6.1.7 Lighting

Once the lights are obtained, they will be tested first by plugging in the USBs and making sure that they are able to properly supply power to the lights. After this is confirmed and the lights are able to charge, the lights can be mounted onto the bike fairly easily using clips that come with the lights. The light USB chargers can then plug into the USB phone charger that is a part of the bike charging system. The lights don't require a lot of testing because they are coming pre assembled as a product purchased off of Amazon.

6.1.8 Sensors

The sensors, once obtained, can all be tested individually. For each sensor, they can first be individually connected to the microcontroller using a breadboard. The microcontroller can then run some small sample code to test each function for the sensors. Once this is all confirmed to work, all the sensors can be connected to the microcontroller simultaneously, and the code can be run yet again to ensure that it still works. The voltage sensor in particular will also need to be tested with the battery and the charger, so the testing for those will need to be completed first before the sensors can be tested.

6.1.9 Display

When the LCD arrives, it can also be tested on the breadboard connected to the microcontroller. Test code can be run to ensure that everything is working and that we can fit everything on the screen that we want to. At this stage, we can also adjust the potentiometer to get to a comfortable brightness level for our viewers. Because the LCD is technically a part of the I2C sensors, those will have to be tested together at the same time as the LCD to make sure the microcontroller is able to communicate with all the I2C peripherals simultaneously.

6.1.10 Charger

In order to make sure the battery does its job in every situation the team can think of, the battery should undergo extensive testing. The team wants to make sure it can work at both ends of the temperature spectrum, so it's in the team's best interest to charge a battery both at room temperature and outside in the sun. While doing this, the battery's temperature should absolutely be monitored at all times for safety measures. It would be useful to make sure the pre-charge and fast-charge timers are working properly as well, since those could be very beneficial features. As a result, the team will investigate and program these timers during testing.

6.1.11 Testing and prototyping

We first tested the power sources individually to ensure that they were working as expected. Then after soldering the PCBs we tested those, but due to the small parts, we were not able to get accurate readings from the PCBs. There also were likely shorts and soldering errors with the small contacts of the surface mount parts. When we moved to the final design we made sure to do breadboard testing before soldering the parts onto the perfboards. We tested the circuits first with the function generator and DC output equipment, and then with our energy sources. We tried several iterations of designs similar to this: we tried different values of voltage regulator parts, different capacitor values, tried implementing the circuit with and without a battery, with and without a load, with and without two loads, with the power sources together and independently from each other. After each step of soldering we tested the circuit again using voltmeters to make sure it was working properly. At one point we discovered that the soldered usb ports were not outputting properly and we found that we needed to resolder the USB ports, because we had used the wrong contacts. Eventually, after many trials, we landed on the design that we implemented.

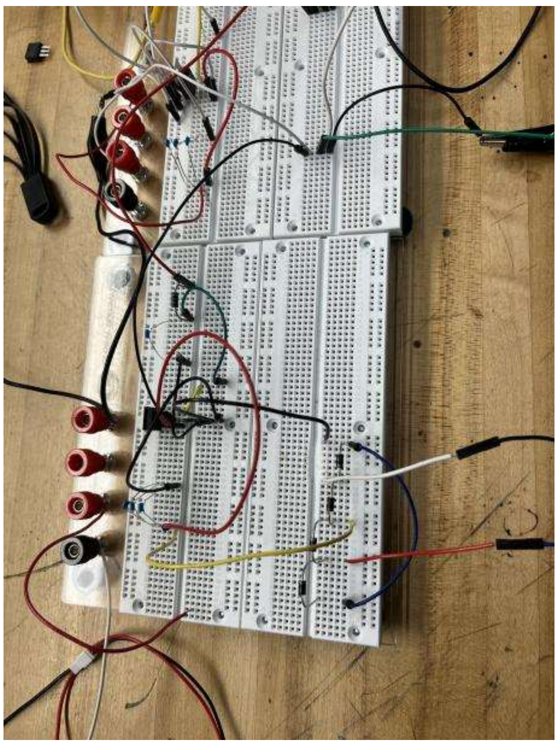


Figure 6.1.11 Breadboard for testing new design

6.2 Construction Plan

The aim of this section is to describe how the entire project will be put together. We will discuss how the different components will be attached to each other and how they will attach physically to the bicycle.

The construction of this project relies on the ability to connect the sidewall generator to the wheel and the solar panel to an appropriate location on the bike where it will be less likely to be covered by the person riding. Many sidewall generators come with a preinstalled ring loop attachment that makes it a simple installation. When this is not the case, buying extra material will be necessary to attach to the sidewall generator. The same idea will apply to the solar panel. The rest of the construction, like wiring, and mounting of all other components will be looked at further.

Before any electrical components are connected to each other they will be simulated in MultiSim or a similar software to ensure that our circuits will work as desired. Then components will be tested as described in section 6.1.

Once testing is over the Power Generation and Distribution subsystem will be constructed with the specific connections detailed in section 5.2, and simultaneously the microcontroller, sensors, and display will be connected as described in sections 5.3-5.5. Then after the two subsystems are tested separately, they will be connected to each other.

The major components need to be physically attached to the bicycle. The solar panel and the generator need to be attached to the exterior of the bicycle to function. The electronics will need to be sheltered somehow from the elements. The display should be visible to the bicycle rider as they travel so they can see the information being displayed. And likewise there should be a phone mount on the handlebars of the bike so that the rider can use a map service while their phone charges.

6.2.1 Facilities and Equipment

The construction of the bike itself will take place at a team members residence and in the senior design lab in the Engineering 1 building on UCF campus. Due to the size of the project itself, any work that can be done at the residence of a team member will be preferred due to the limited space in the senior design lab. Working on campus in the engineering atrium may also be an option, but have to weigh against the number of students that are in there at any given time. The safety of others and the team members always come first. This is why working off campus at the residence of a team member will make more sense since the possibility of any accidents occurring to bystanders will be almost zero. The senior design lab will be a key facility for testing components and assembling smaller components together. Any equipment in the senior design lab like oscilloscope, DC power supply, computer, multimeter, and even small components will be used to validate specifications and run through test cases. In terms of the assembly of the bike, the tools that will be used will be a mechanics tool set. This involves wrenches, screwdrivers, pliers, ratchet and sockets. All equipment and facilities that are planned to be used are not limited to what is stated here as there may be better suited tools that are discovered during the process of assembly and may use a different facility whenever needed.

6.2.2 Installation of solar panel onto bicycle

The solar panel needs to be exposed to sunlight to function, and to do that we will need to mount it somewhere on the exterior of the bicycle facing upwards. There are two main options for attaching the solar panel to the bicycle. The first option is to clamp or strap the solar panel to a bicycle carrier rack. The second option would be to attach the solar panel to the lid of a bicycle basket, in which the electronics could be housed. Determining factors will be the size of the solar panel and if the bike that we will use has a preexisting basket or carrier rack. If either are already present on the bicycle we will likely choose that method of attaching the solar panel to the bicycle. If neither is already present we will have to consider again the size of the solar panel and likely the cost of purchasing either a carrier rack or a basket.

The bicycle we chose had a wide basket that the solar panel fit comfortably on. The circuitry was housed in a plastic box underneath the solar panel, rather than under the basket's lid, because the basket did not have a lid and because the basket was metal wire so there was a risk of shorting.

6.2.3 Installation of sidewall generator

Installation of the generator onto the bicycle is fairly simple with the bracket that comes with the purchase of the generator that we chose. The secondary choice options do not come with brackets but do have ring loops so we would just be required to buy a bracket to attach these. Brackets themselves are rather inexpensive, so this would not be a problem. A diagram of the sidewall generator that we chose is shown in figure 6.2.3A below. In the diagram the included bracket is visible. This is a front wheel bracket, it is made up of three bolts and two pieces of metal. From figure 6.2.3A, the rightmost bolt M8 is threaded through the ring loop on the body of the generator. The two M8 bolts on the left are used to enclose the bicycle fork within the M6 gap. Figure 6.2.3B provides a clearer view of how the bracket attaches to a bicycle and sidewall generator, this is not the generator that we chose, but the bracket works in the same way.

Beyond the bracket the only thing to keep in mind when installing the sidewall generator is that the generator must be installed at an angle such that a straight line could be drawn through the center of the generator to the axis of the wheel, aligning the generator with the wheel's dropout.

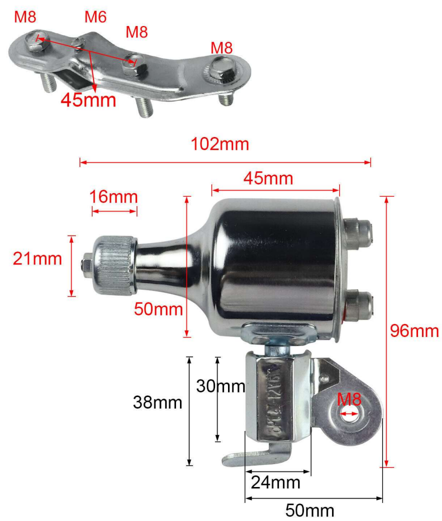


Figure 6.2.3A: Diagram of chosen Sidewall generator. Permission pending. Reprinted from https://www.ebay.com/itm/262688555528?chn=ps&mkevt=1&mkcid=28&srsltid=AYJSbAd0RuXzRSm6MwGTnRjikUuIP9WTRz6CMWtF09g49GCAqvBy-FmFNt8

Figure 6.2.3B: Clearer picture of an installed sidewall generator. Permission pending. Reprinted from https://fiveeight0sixsix.wordpress.com/2014/11/08/cheap-dynamo-bike-lights-from-ebay-what-are-they-like/

The bracket alone did not end up being enough to attach the generator to the bike in the correct position. The generator was put on the back wheel with the bracket after several attempts of placing it on the front and back wheels in different positions. We ended up using several zip ties to adjust the generator into the exact right position where it would consistently and reliably roll against the wheel to produce energy.

6.2.4 Wiring from power generation to PCB

The wiring from the generator and solar panel to PCB will be done in stages. The first stage will be a non permanent connection. This is to give the team members the ability to run through different tests on the generator and how well the placement of the PCB will be. The first, second, third, etc, placement of the PCB on the bike may not be the best solution, so having a non permanent connection will allow wires to be changed shorter or longer, depending on if the PCB gets placed closer or further away from the power generation sources.

For the last stage, the connection would be a permanent one. This could include soldering the wires to both the power generation sources and the PCB. This can be done once enough tests have been done validating the placement of the sources and the PCB are in the best suited locations.

In either case, the wiring needs to be held against the frame of the bike for the safety of the rider and for the protection of the entire power system. Leaving wires hanging loose can be hazardous to the rider. It could be possible for the wire to hang too close to the person peddling the bike, wrap around the leg and cause accidents. Riders in metropolitan areas ride side by side to cars. Tripping over a loose wire can be fatal in these situations. Loose wires can get caught against objects, like bushes, while riding and pull out the PCB, and/or the devices that are charging. Considering the time constraints to order a new PCB board and produce a project by the end of Senior design 2, breaking parts that are not accessible at the local stores is not ideal.

Wires can be held up against the frame of the bike with either velcro straps or Rubber Cushioned Insulated Clamps. The velcro straps are versatile and cost effective. The insulated clamps are more expensive but will be a stronger hold. For the clamps, one size bigger than the size of the bike frame should be used to not damage the wiring.

Figure 6.2.4.A
Rubber cushioned clamp

Figure 6.2.4.B
velcro ties

As discussed the wires were not fixed to the bike until after testing in the lab was done. Once that was done the wires were wound around closely to the frame of the bicycle from the generator to the basket of the bicycle and fixed to the frame using zip ties. We gave the wires a bit of slack around the handlebars to allow for turning while riding the bike. The wires were not soldered onto our board, instead the board had female pin headers that the wires connected to.

6.2.5 PCB placement

The placement of the PCB on the bike will be one the biggest challenges during the construction phase of the project. Being that we go to school and live in Florida, weather conditions can change from bright and sunny to midday showers in less than half an hour. This is why the PCB will most likely be placed inside of a basket with a lid or similar kind of containment that will protect it from the elements. This basket holding the PCB will be placed in the front of the bike or behind the seat of the bike. Baskets of all different sizes are available, and many are manufactured specifically to attach to bikes, so this option gives a lot of flexibility. Another option would be a product like, or similar to, the Rhinowalk Bike Bag. This bag also comes in different shapes, sizes, different material, and even waterproof options. In terms of looks, the Rhinowalk Bike Bag is sleeker and comes in neutral colors.

Wiring to the PCB inside of the basket, Rhinowalk bike bag, or a similar holding containment will be a bit difficult. Some baskets, like weaved ones, will allow for the wire to simply be passed through any opening and still be protected from the elements by the basket lid. In the Rhinowalk bike bag, the wire will be passed through the opening, but the bike bag zipper will not be closed completely because of the wire. Testing will have to be done with the bag if decided to be purchased to ensure the waterproofing will still be in effect.

Figure 6.2.5 Rhino Bike Bag placement options

Our final board and all the other circuitry was housed in a plastic box underneath the solar panel, within the basket of the bike, rather than under the basket's lid, because the basket did not have a lid and because the basket was metal wire so there was a risk of shorting.

6.2.6 Display attachment

The screen that will display different characteristics, like battery charge, will have to be placed inside of a protective container just like the PCB to protect it from extreme heat, rain, or even strong winds. If a big enough basket or container is bought for the PCB, it is possible for the display screen to go into the same basket if space permits. If not, then it would more than likely require its own containment, but located towards the front of the bike. Placing it in the back of the bike would make it inconvenient for the rider to see details like the time and battery charging details. The rider would be required to stop riding to view details if placed towards the back and make it a safety concern if the rider looks back while still in motion. Placing the display towards the front gives the rider the advantage of being able to look at the display in the basket with ease while still keeping attention on the road in front of them.

The display in our final design was attached to the base of the handlebars using velcro. Wires from the display to the rest of the sensor subsystem routed easily from that position to the microcontroller in the basket in front of it.

6.3 Issues Found During Testing

Upon starting testing, the team noticed and came across several issues varying from minor to full on time consuming. One major issue came from shipping time, as the time spent waiting on parts could have been used valuably, but instead the team was forced to be patient and wait. These shipping times intervened with acquiring parts, of course, but they also got in the way of obtaining the PCB and the PCB's assembly.

If it weren't for long wait times, fast charging may have been implemented, which was yet another issue that was discovered. Although not a major issue, fast charging was found to be too demanding, and it required more power generation, which led to it being scrapped in the final design.

When it came time to order the parts for the PCBs, another issue was unknowingly waiting for us. The parts were ordered to be extremely small, and the problem came when they were received and soldering was involved, as it was quite easy to make mistakes with parts of that size. For reference, the largest component was the battery charger with a footprint of 4mm x 4mm, which was largely overestimated in regards to its size.

Finally, an inconvenient issue came in the form of the bottleneck generator's placement. It comes with the ability to lock into place, however when used, the generator would be inconsistent and hard to get spinning correctly. After troubleshooting and using zip ties and even shoelaces to tie the generator into a suitable place, it was able to be used reliably and effectively. It wasn't a major issue in the end, but it was still one that was unexpected and problematic.

6.3.1 Removed Lighting During Testing

One of the features of the PEDAL Bike was attempted to be implemented, but unfortunately it caused too much trouble in the end and had to be thrown away in favor of other features. The lighting system was found to be too time consuming during testing, as there were several issues with the LEDs acquired and shipping times wouldn't allow the team to get more of them and have work done all before deadlines. The LEDs required different voltages to turn on and handled different amounts of voltage, which then meant that the team needed more regulators and parts that weren't on hand to connect the LEDs properly. Due to this, the team decided to focus on the rest of the project and attempt again if given the time. Although the lighting system wasn't implemented in the end, the bike still contains reflective lights on the frame and wheels that at least make the rider noticeable at night time.

7. Administration

The following section will focus on the administration of finances for the project. Being financially aware of every group member's level of ability to contribute, and the anticipated cost of the project will make sure no one in the group feels excluded or pointed out. Changes are bound to occur throughout the process of completing the project. This may include the need to purchase more parts due to damaged components during testing, or better suited parts are found that increase the functionality of the project. In any case, administrating is key to keep every step of the way in line and on time to meet completion deadlines.

7.1 Budget and Financing

Like many projects within larger companies, financial limitations play a big part, if not the biggest, in the project production. Senior Design 1 taught about how companies invest millions of dollars on the research of a new product or to make an existing product better over a certain amount of time before they expect returns on their investment. Although our project is nowhere near that magnitude, we will still be investing money to come out with a successful project. Budgeting for the project will set limitations to not spend more than each member can evenly contribute and making sure that the finances are available when needed. The next two subsections will explain the budget and finances for this project, and break down the expenses down to each individual part.

7.1.1 Budget

During team meetings, it was expressed that there would be an associated cost with senior design 1. Keeping the cost as low as possible is the main goal, but its heavily dependent on the different components and tools that are essential for the completion of a successful project. Every group member agreed that the total cost of the project would be divided evenly between all 4 members, regardless of what part of the project each member worked on. Everyone agreed that they were comfortable contributing $100.00 each, making the total budget $400.00. If the project ends up having a total cost less than the budget, everything will still be divided evenly between the four team members. There is a possibility of going over budget, depending on the development of the project as well as any unforeseen costs. This is known by everyone in the group and in the case that the cost becomes more than the budget, everyone has agreed to increase the budget and split the extra cost between all four team members.

7.1.2 Expected Expenses

The following expenses are all important for the completion of a successful project. Most parts and components will be ordered on a need basis. This is why most parts ordered will be of one quantity. The expenses list is an ongoing list that will add new expenses whenever needed. The grand total will be absolute once the project has been deemed complete.

Component	Price	Quantity	Cost
Bicycle	-	1	- Already owned
Rubber Cushioned Insulated Clamp	6.75	1	6.75
Reusable Fastening Cable Straps	11.89	1	11.89
Solar Panel	$25.49	1	$25.49
Bicycle generator	$15.70	1	$15.70
Charger	$11.64	1	$11.64
Battery	$40.07	1	$40.07
Microcontroller	-	1	- Already owned
Bike Lights	$22.99	1	$22.99
Display	$9.99	1	$9.99
PCB components & printing	$15-$60	- Estimated cost - 2 boards	$30-$120
Total	-	-	**$175.15 - $ 265.15**

Table 7.1.2: List of Expected Expenses

7.1.3 Money spent

Item	Quantity	Cost/item	Shipping + tax	total
bikes	1	$25.00	$0.00	$25.00
generator	1	$8.99	$8.80	$17.79
sensors (clock, temperature, voltage)	1	$30.00	0	$30.00
GPS module	1	$10.50	$11.00	$21.50

solar panel	1	26.5	0	$26.50
TI parts (BQ25672RQMR x2 + TPS63024YFFR x2 + TPS40345DRCR x5)	1	18	13.17	$31.17
lithium-ion battery	1	24.5	8.58	$33.08
pcbs	1	23.9	49.84	$73.74
containers for circuits, velcro, zip ties	1	19.61	1.27	$20.88
pcb parts	1	24.08	9.28	$33.36
arduino	1	27.1	0	$27.10
lcd 2004	1	10.99	0	$10.99
9v battery	1	15.99	0.98	$16.97
INA219	1	9.95	6.67	$16.62
Surface mount parts	1	-	-	$37.68
Total				**$384.70**

Table 7.1.3: List of Expenses

We spent more than anticipated due to having to order different parts for different iterations of our design. Even so, when you consider just the parts that were used in the final design, we met our low cost goal of < $250, so much less than similar products on the market.

7.2 Project Milestones

This section outlines the milestones, deadlines (self imposed or otherwise), interruption, and holidays that we have gone through in Senior Design 1 and will go through in Senior Design 2. Spreading out the workload will ensure that our project is completed on time and our goal is met.

7.2.1 Senior Design 1

For Senior Design 1, the milestone dates were set in accordance with the due dates of the documentation within the course. These milestones also revolved around the schedules of team members and various semester interruptions including hurricanes and holiday breaks.

Senior Design 1		
Milestone	**Description**	**Date**
Formation of groups	- Formation of groups for people that did not already have a group - Establish communication	8/25/2022
Senior design bootcamp		8/31/2022
Group meeting	Discussion of group values and project ideas	9/3/2022
Deadline: Boot camp assignment		9/9/2022
Deadline: Divide and Conquer Part 1	- First Draft - 10 pages max - Initial idea description and motivation - Research on similar projects - Initial Specifications	9/16/2022
Document review meeting with Dr.Richie	- Receive feedback on initial document - based on feedback select one of two potential projects - assign roles after meeting	9/20/2022
Hurricane Ian	- Classes canceled for preparation and sheltering from storm - Several members lost power and internet access	9/28/2022-10/3/2022
Deadline: Divide and Conquer Part 2	- Discuss project specifications - Discuss further design specifications - Set up a draft list of materials and their costs	10/7/2022
Document review meeting	- Receive feedback about	10/24/2022

with Dr.Richie	D&C2	
Deadline: Senior design quizzes A-G	- Submit all quizzes and get at least an 80-90% depending on the quiz	10/28/2022
Deadline: 60 page Draft Documentation	- Technology investigation - Standards - Documentation and design	11/4/2022
Document review meeting with Dr.Richie	- Receive feedback on 60 page submission	11/7/2022
Hurricane Nicole	- Classes canceled for preparation and sheltering from storm	11/9/2022-11/11/2022
Deadline: 100 page report	- Design and sketch - Create schematic diagrams - Further technology investigation	11/18/2022
Thanksgiving break		11/23/2022-11/27/2022
Deadline: Final Document	- finalize investigation and design materials - review and formatting	12/6/2022
Order Parts		Through winter break

Table 7.2.1: Senior Design 1 Milestones

7.2.2 Senior Design 2

For Senior Design 2, the milestone dates were set by trying to divide the semester such that we should have enough time to complete the tasks we are expecting to do, while avoiding holidays. The actual deadlines for deliverables are not known yet, so our self imposed deadlines are subject to change.

Senior Design 2	
Milestone	**Date**
Test Parts	1/20/2023

Test subsystems	1/27/2023
Construct prototype	2/8/2023
Test prototype	2/17/2023
Redesign if necessary	3/3/2023
Spring break	3/11/2023-3/19/2023
Test new prototype	3/22/2023
Finalize prototype	3/31/2023
Finalize documentation	4/14/2023
Deadline: Peer Review	4/25/2023
Deadline: Final Documentation	4/25/2023
Deadline: Final Presentation	4/18/2023
Classes end	4/24/2022
Final exam period	4/26/2022-5/2/2022

Table 7.2.2: Senior Design 2 Milestones

7.3 Team Member Roles

We will all make contributions in each aspect of investigation, design, testing and integration each with a focus on a specific field. We will operate with respect for each other, working as a team when things need to get done. We each have our own assigned tasks but we will help each other on those tasks when needed, striving for a collaborative environment. Our group was formed in class during the first week of the semester, we ended up together because we all expressed an interest in renewable energy sources.

Our team consists of three electrical engineers on the power track and one computer engineer. Most of the circuit board connections and power generation and distribution circuitry was investigated by the electrical engineers while the computer engineer focused on software design and designing the sensor connections to the microcontroller board. The tasks that each team member completed are listed in the figure below.

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Figure 7.3: Assigned roles

To keep track of what needed to be done and who was completing each task, we used the method pictured in figure 7.3. We made an outline of the project in the form of a preliminary table of contents and highlighted each task with our respective colors as they were completed or assigned. As the project progressed we added or changed the outline as was necessary to cover all of the topics that needed to be discussed. The highlighted colors correspond to team members as follows: Orange - Roxanna, Green - Elizabeth, Purple - Dexter, Teal - Melvin.

For Senior Design 2 the work distribution is represented by table 7.3 below.

	Research	**Software design**	**Power generation**	**Power storage**	**Sensor Design**	**Testing**	**Video Editing**	**Documentation**	**Eagle modeling**	**Soldering**	**Website creation**
Roxanna	✓		☑			✓		✓	✓	☑	☑
Elizabeth	✓	☑			☑	✓	✓	✓			
Dexter	✓					✓	☑	✓			✓
Melvin	✓			☑	✓	✓		✓	☑	✓	

Table 7.3: Senior Design 2 Work distribution

7.3.1 Roxanna

Roxanna will focus primarily on the power generation portion of this project. For both the solar panel and the bicycle generator she investigates the different types, their function, and their potential positives and negatives within the context of our project when compared to each other. Looking into several different manufacturers, options were compared and selected based on which ones would be the best for our purposes. Roxanna also managed the project organization and document formatting, making sure everyone was on the same page about what needed to be completed. Beyond the power generation focus, Roxanna will strive to support other members of the team when they need assistance in any other portions of the project.

7.3.2 Elizabeth

As the sole computer engineering major of the group, Elizabeth will be taking on primary responsibility for the software portions of the project, namely writing code for the MSP430FR6989 that shows the time, temperature, speed, voltage, and battery charge of the system. She will also ensure that all peripherals that need to communicate with the microcontroller are connected and work properly in order to send and receive data, including all sensors, LCD, and on/off LED. Additionally, she will work to support the other members of the team in any capacity that they need.

7.3.3 Dexter

Dexter will conduct extensive research on what microcontrollers and types of battery chargers that are the best for the team, and will pick several options that can provide the tools necessary to complete the project. He will also be providing said microcontroller for the team. Additionally, when it comes to his researched standards, he will make it a priority to make sure those needs are met. Dexter will also document what constraints the team has and try to come up with ways to work around them if possible. Above all else, he will try to assist his teammates to the best of his abilities.

7.3.4 Melvin

Melvin will take on the responsibility of learning and researching battery options that will be the most suitable for the project specifications. Battery characteristics, like voltage rating and footprint, will be compared between different batteries to come up with the most practical one. He will also look into different circuits and components, such as rectifiers, and how they can be integrated into the system to better achieve the goals of this project. Although the focus of Melvin is more about battery functionality, he will always offer help to all team members wherever he can be the most effective.

7.4 Team Communication

Communication is extremely important in any project, and this one is certainly no exception. In order to stay on track, the whole team needed to communicate with each other several times a week, and with the professor occasionally. The programs Discord, Zoom, and Google Docs were invaluable to us as we embarked upon the journey of writing this paper and all that entailed.

7.4.1 Discord

Like any other college engineering project, Discord was the backbone of our group's communication. It is very easy to use and offers built in voice chat so that group members can talk to each other at any time. Because one of our team members, Melvin, did not even live in the area this semester due to his internship, all of our meetings were held in our Discord. The option to share your screen in a call is another great feature that helped us immensely while we were designing our PCB and allowed us to have more of a collaborative element in our meetings. Finally, you can send any type of file you want in the chat to instantly distribute it to all team members and make sure everyone sees important things.

7.4.2 Zoom

Another piece of software that we didn't use quite as much but still proved to be important was Zoom. For many of the senior design class meetings themselves, we attended through Zoom. However, its main use for our group was to have meetings with Professor Richie and discuss our progress. In this post-COVID era, Zoom is more relevant than ever being used in place of several in-person meetings. Again, this was especially convenient for our group due to Melvin not living in Orlando. These online meetings definitely helped our group save a lot of time.

7.4.3 Google Docs

Google Docs was our preferred tool used to actually write our paper in. Everyone can access the document and write in it at the same time, and the text updates in real time as everyone edits it. Microsoft Word has a OneDrive editing tool similar to Google Docs, but the team preferred the interface and ease of access on Google Docs better. The only drawback to Google Docs so far has been the difficulty with numbering pages. Because the Table of Contents and Appendix need to be separated from the total page count, these sections had to be explicitly assigned in Google Docs and receive their own page numbers. However, there is inexplicably no option for Roman numerals in Google Docs, so to get the proper numbering for our Table of Contents, we will probably have to copy our paper over and edit the page numbers. Aside from this, Google Docs has been extremely convenient for us and has fit our work style very well.

7.4.4 Google Drive / Microsoft One Drive

Google Drive and Microsoft Onedrive were crucial in having shared files among the team and allowing all of us to work on documentation simultaneously. These also allowed us to easily share video files and pictures of testing results among ourselves.

7.5 Additional Software

While the last section discussed tools used mainly for communication purposes, this section is focused on the software the group used to help our design process. These include EAGLE for schematics and PCB design, Code Composer Studio for programming our microcontroller, and Lucidchart for making all the flowcharts and block diagrams.

7.5.1 Code Composer Studio

Code Composer Studio, also known as CCS, is a tool created by Texas Instruments to help code their microcontrollers. Since we picked the MSP430FR6989, which is a microcontroller created by Texas Instruments, we will be using CCS for our project. All of the team members have had prior experience with the software from classes like Embedded Systems, so this is a good choice due to everyone's familiarity. Also, if we do run into any problems while coding, there are many well documented places to find help online. We can even refer back to old lab manuals if we need to.

7.5.2 EAGLE

PCB design is one of, if not the most, important required components of the senior design project, and EAGLE is the computer aided design program of choice for our team when it comes to making schematics and crafting our PCB. EAGLE is available for free to all of us through the school, making it a convenient option. Also, we all had to learn how to use EAGLE for these very applications back in junior design. We already know the basics of how to make schematics and PCBs in EAGLE. If we run into any trouble, we can check the old lab instructions or just search online, as EAGLE is a very popular piece of software with lots of resources out there for it.

7.5.3 Lucidchart

The final piece of additional software that we used frequently throughout writing this paper is Lucidchart. Lucidchart is an online program that can be used to create your own flowcharts and block diagrams, and it is very popular in the software engineering world. You can sign up for a free account and make diagrams pretty quickly with their built-in library. Any software related diagrams and block diagrams in this paper were created this way. The only disadvantage to Lucidchart is that with a free account, you can only edit three documents at once. Any older documents you have will change to read only and cannot be edited again. Therefore, if you are making charts on one person's account only, you have to make sure they're perfect before you start any new ones.

8. Project Operation

In this section, we will discuss the correct operation for our charging system alongside the bike. Although the system might seem simple from the outside, even the most straightforward products come with a user's manual

First, the team would like to remind all users that before they start riding the bike, they should always wear a helmet. Failure to do so may result in legal consequences based on their jurisdiction. The system does not turn on or off. In order to start generating power, the user can take their bike outside to trigger the solar panel and/or start pedaling the bicycle. This will start charging the battery. The user must plug their phone in using a USB cable to start charging their phone. If the user is riding the bicycle at night time, they must ensure that the front and rear bike lights are turned on by pressing the on buttons on both. If they are not, the user will be unsafe in addition to likely breaking the law. If these lights are not charged, they can be plugged into the charging system alongside the phone using the USB cables that came with the lights.

The charging system will come with an LCD attached that allows the user to view certain information including the time, temperature, voltage, battery charge, and speed. When a device is detected after being plugged in with a USB cable, the LCD will flash a welcome message. This will go away after a few seconds and be replaced with the time and temperature. To switch to the next screen and view voltage, charge, and speed, the user can simply press the button on the microcontroller. To switch the screen back, the button can be pressed yet again.

Operation of the final system is much simpler, the sensors display automatically once the sensors have a reading, and to charge a load one just needs to connect a USB to the power circuit.

9. Summary / Conclusion

Upon finalizing all of our research, it's clear to the team that this PEDAL Bike is a project that is well worth the time spent on it. There are many different components involved in creating the bike system, so it was complex, and we had many issues along the way to finding a final functioning design. Through this process we all learned a lot about making PCBs specifically, soldering, website building, power systems, sensors, teamwork, and about managing work through long term deadlines.

10.Appendix

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