THE PARASOLAR EXPERIENCE

Department of Electrical Engineering and Computer Science
University of Central Florida
Dr. Lei Wei
Dr. Richie

Group 11

Jesus Pulido Garcia	Computer Engineering
Casey Mann	Electrical Engineering
Meghan Perry	Electrical Engineering
Dylan Petrae	Computer Engineering

CONTENTS

1.0 EXECUTIVE SUMMARY

Technology is undoubtedly becoming an indispensable component to most humans' lives. As time progresses, an immediate observation can be made; adults and children are spending more time on their phones or tablets, and less time outdoors in natural environments. This observation initially seems like it should have little to no effect on the well-being of the person. Staying indoors means one would be less susceptible to contracting viruses or being endangered by the element, right? While this logic appears to be soundproof, there are actually many reasons as to why these assumptions are false.

Studies have shown that lower levels of sunlight exposure can cause lower "levels of certain mood-regulating brain chemicals. [Declines of which can] trigger a form of clinical depression." [1] A similar report relating to this issue spoke about the negative health effects due to indoor air humidity and quality, such as sensory irritation in eyes and upper airways, and a noticeable decrease in work performance, sleep quality, virus survival, and voice disruption. [2] Now more than ever before, children are missing the experience of being outdoors, and are instead remaining indoors glued to whatever piece of technology they happen to be enraptured with presently. In summation, a quote taken from a study by Wells and Evans, "Time spent in contact with the natural environment has been associated with better psychological well-being, superior cognitive functioning, fewer physical ailments, and speedier recovery from illness." [3]

Now the question is, upon being equipped with the knowledge of the plethora of negative impacts staying indoors has on the body and mind, why are people remaining inside? What is the cost of moving to the outdoors amongst the shining light of the sun and the cool gentle breeze of a non-air-conditioned open space? The answer to this question is convenience; convenience is the cost. People do not want to leave the convenience of having a comfortable and secure place in which they can listen to their music, charge their smartphones, and stay connected with friends and loved ones through their various social media apps. Here is where the issue lies, and this is where our project is going to make its impact. Our product is going to deliver the ease and comfort of staying inside to the outside world. By bringing the indoor conveniences to the outdoors, people will have no excuse to, nor will they want to stay cooped up within walls. We plan on achieving this task by equipping what would be a common beach umbrella with all the necessary tools to achieve maximum convenience. Those being a charging station for the user's devices, a cooler to store cold beverages and snacks, a Bluetooth speaker for listening to their music, consistent updates on pertinent weather information, and a security system to keep everything protected while the user relaxes.

While there are products similar to that of this project's focus this product is an original concept and will therefore require the builders to conduct a substantial amount of research in order to maximize the effectiveness of the product i.e. have the largest amount of convenience achievable. This research includes, but is not limited to, establishing designs that maximize efficiency, finding parts that maintain a certain dimensional ratio that keeps the product lightweight and portable, and gather materials that ensure a high level of durability. This product will be in use in an outdoor environment therefore requiring the parts and materials to be weather and heat resistant. The product will abide by the ABET standards and constraints as well as any other relevant environmental, health and safety, or ethical standards and constraints. The resulting product should be cost efficient and reliable in order to maximize the main goal of the project. Which is bringing a level of convenience that has previously only ever been experienced indoors.

This report will document the design process that occurred in order to create the Parasolar Experience. It will first go into an explanation of the project's goals and objectives that the builders wish to meet with their end product. The report will than go into a detailed description of the project's specifications and requirements first for the end product and then broken down into the specifications of each part that will make up the final product. The research section of this report will give an overview of the products and types available of each part and then state which product or type that will be used for this application and a detailed explanation on why that specific type of product was chosen based on the requirements and specifications previously stated. Next, the report will introduce the various standards and constraints that are associated with this product and discuss the effect each will have on the project's design. The report will then dive into an extensive synopsis of the hardware and software design of the system. This will include various electrical schematic diagrams, flowcharts, class diagrams, data structures, and a comprehensive list of parts used in the build of the product. The hardware design section will also include the power management process and the PCB design. Whereas, the software design section will explain the code logic and the Bluetooth functioning. Moving forward, the report will define the methods used to test each component of the products overall design and include a single page of all the breadboard testing that occurred during the design process. As a final point there will be an Administrative section that shows the breakdown of the product's overall budget and a rundown of the project's milestones.

2.0 PROJECT DESCRIPTION

This section outlines the application of the project by defining the requirements and giving a general concept for the design team that satisfies the purpose. The section contains the motivation and influences of the product, goals and objectives that the builders aim to achieve upon completion, and a detailed list and explanation of the requirements and specifications of the parts and materials of which the product will be built.

2.1 Goals

The goal of this project is to make it as easy as possible to move outdoors while still maintaining the ease of being indoors. To make the project as easy as possible to utilize, it must be self-sustaining, provide wireless communications containing helpful information about the environment and updates about the device itself. The product must also ensure a secure environment for the devices while the user enjoys the outdoors, as well as provide entertainment and ultimate connectivity with the users handheld devices on multiple platforms. The resulting product of this project should be low-cost compared to other similar products and it should be lightweight and portable. While there have been products similar to this project, there has never been one done in quite the same way. However, this is by no means an impossible task, there is a large pool of products to use as a resource and guide in the assembly of this project. For example, the Bluetooth Cooler and Sound System by Sharper Image incorporates a few of the features that are going to be integrated into this design. The most influencing of which being the bluetooth speaker that is able to withstand harsh environmental conditions, such as sand and water. Additionally, the Solarella by Rostislav Rusinov and Pavel Nenkov applies a similar design, sans an assortment of key features utilized in this projects composition. The simplicity of this design can provide helpful information on maintaining a sleek and portable product. Lastly, the SunDen Smart Rig and Cooler applies a complex design with many extravagant features, including a built-in ice cream maker. However, this design does not incorporate the solar energy applications that appear in this project.

Figure 2.1.1 Solarella by Rostislav Rusinov and Pavel Nenkov

2.2 Objectives

The bulleted list below outlines project objectives.

- The system shall receive user input via Bluetooth
- The system shall utilize a microcontroller to interface between components
- The system shall be resistant to water.
- The system shall have the ability to play user audio input via high quality speakers
- The system shall have a display with temperature, battery life, and other relevant data
- Simple, customizable user interface
- Easy and quick two way Communication with MCU
- The system shall be resistant to small particles (Sand or Dirt)
- The system shall operate in a reduced power mode after a standby time

2.3 Specifications and Requirements

The table below (Table 2.3.1) outlines measurable and verifiable requirements and specifications for the project.

Table 2.3.1. Specification and Requirements for the ParaSolar Experience Product

1.0	This system shall cost less than or the same as similar products, the prices of which range between \$130 and \$500, (ours will be less than \$200)
1.1	This system shall weigh the same as similar products (between 10 lbs and 18 lbs). Ours will be less than 12 lbs in order to maintain maximum portability.
1.2	Response time between software and hardware for security system shall be less than 5 seconds.
1.3	Dimensions of cooler will not exceed: 1.2ft in height, 1.5ft in width, and 1.5ft in depth to maintain maximum portability.
1.4	Dimensions when closed will not exceed: 8ft in length and 1-foot in diameter to maintain maximum portability.
1.5	Dimensions when open will not exceed: 8ft in length and 8 feet in diameter to maintain maximum portability.
1.6	Voltage and Current output of USB ports (2) will be at least be 5V and 1.6A
1.7	Measures external environmental no greater error than ±2˚ temperature and ±5% humidity readings

2.3.1 Solar Cell Specifications

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the photovoltaic source used in this application. Listed below are the desired specifications for the solar panels that will be used in this product.

- Must be lightweight to maintain portability. Since the weight of the solar panels will be incorporated into the total product's weight, they will have to weigh less than a total of 1 pound.
- Must be cost efficient to guarantee an accessible and useful product. The solar panels will need to have a total cost of less than $75.
- Must be small scale to maintain portability. In order to satisfy the aforementioned dimension specifications the solar panels will need to be small enough to easily collapse into the umbrella's frame.
- Must be able to supply at least 16 Watts of power in order to sustain a sufficient charge on the energy storage device to maintain a certain level of convenience.
- Must be able to perform efficiently when subjected to high temperatures, reaching up to 60°C. This product will be used in direct sunlight for a extended period of time and the panels must maintain a certain level of durability.
- Must be able to retain a high efficiency rate when subjected to low light conditions. This will be helpful in situations of cloudy weather or crowded environments.

2.3.2 Charge Controller Specifications

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the charge controllers used in this application. Listed below are the desired specifications for the charge controllers that will be used in this product.

- Must be compatible with the rechargeable energy storage device and with the solar panels used in this application.
- Must be designed to maximize power output. This will be useful in reducing the cost of the overall project by reducing the amount of solar panels needed.
- Must be able to reduce the possibility of the battery being drained out through the solar panels. This will provide a higher charging performance overall.

2.3.3 Battery Specifications

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the rechargeable energy storage device used in this application. Listed below are the desired specifications for the battery that will be used in this product.

- Must have a high gravimetric energy density to maintain portability. Since the battery weight will be taken into account to the product's total weight the battery will have to weigh less than 170 grams.
- Must have a relatively fast charge time to maintain a certain level of convenience. The battery must be able to charge fast enough to keep up with the consumer's use of the product's main functionalities.
- Must be able to hold a charge without experiencing any substantial amount of self-discharge. Product may be kept in storage for long stretches of time, and in order to maintain a certain level of convenience the product should retain its charge for long durations.
- Must be able to maintain a high level of performance when subjected to high temperatures reaching up to 60°C. This product will be used in direct sunlight in an outdoor environment for extended periods of time and the energy storage device must be able to maintain a certain level of durability.

2.3.4 Printed Circuit Board Specifications

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to any printed circuit board (PCB) used in this application. Listed below are the desired specifications for the PCB that will be implemented in this product.

- Must satisfy appropriate flame retardant and glass transition state: FR4 and TG364. The PCB will be subjected to higher temperatures so these materials must be rated to temperatures up to 60°C to ensure environment temperature does not hinder its basic function.
- Must satisfy standard: UL94V-0, in addition to the material temperature ratings to ensure PCB functions won't cause the board and it's components to overheat.
- Must be lightweight and compact by using the common 0.8mm thick board with 2 layers (double sided). The PCB must comfortably fit inside its housing, as not to risk breaking any leads or layers. A break in the leads or layers could cause a short circuit, and reducing weight of the PCB will ensure higher portability for the user.
- PCB Design software must be capable of the complete hardware schematic to ensure ease of accessibility and troubleshooting when ordering the PCB. This will make design easier to keep track of for the design team, instead of having to open multiple files to observe/design/edit the PCB schematic.
- PCB Design Software must be able to run on: Microsoft ® Windows ® 7 or newer, 64-bit operating system; a minimum of 3GB RAM; and a maximum of 800MB of hard disk storage
- PCB Design software must be compatible with PCB Manufacturer or their "file reader" software so that the PCB can be ordered and constructed to design requirements.
- PCB Manufacturers must be able to create the PCB up to measured/anticipated designs and requirements stated above. The

manufacturer should have some form of software or internet compiler to accept and read the PCB software file containing the team's PCB design.

2.3.5 Voltage Regulation Specifications

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to any voltage regulation modules used in this application. Listed below are the desired specifications for the voltage regulators that will be implemented in this product.

- Must be low-powered, with low waste heat to prevent overheating any other electrical components. The voltage regulator must consume no more than 95µA of current when in operation or 500mW of power.
- Commercial voltage regulators must meet standard UL 60950-1 to ensure safe operation and handling.
- Any material within the voltage regulator must comply with RoHs environmental and handling standards, as the component can be subject to high temperatures for an extended period of time.
- Must have high efficiencies of at least 80% when at 100% load, and highest operating currents. This will guarantee that all features can be functional at one time, depending on user usage.
- Voltage Regulators must be able to handle any variation in input voltage to ensure the components following are not over-loaded, which could consequentially "fry" the circuitry. This can be controlled by ensure high factor of safety when evaluating different products.
- Must be able to regulate the voltage coming from the battery and supply 12V DC to the charging ports and speakers.
- Must be able to regulate the voltage from the 12V DC voltage regulator and supply 5V DC to the Display and Bluetooth module.
- Must be able to regulate the voltage from the 5V DC voltage regulator and supply 3.3V DC for the Microcontroller and remaining sensors.
- Must be able to regulate voltage with low electro-magnetic interference to ensure other electrical components work as calculated.
- Must handle potentially lower power source from battery if solar panels don't experience the most ideal sunlight.
- Must be able to operate at high temperatures for extensive amounts of time, due to high environment temperature, at minimum 30°C and preferably up to 80°C. It must operate a minimum of 3 hours, preferably 5 hours.

2.3.6 Security System Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the system's proximity security protocol used in this application. Listed below are the desired specifications for the security system that will be implemented in this product.

- Must be able to respond to someone approaching the umbrella in under five (5) seconds when activated.

- Must be able to provide a security zone around the circumference of the product.
- Must be able produce warning alarms in case unwanted people are approaching.
- Must be able to set off loud alarms once someone comes within a certain distance of the umbrella.
- Must be able to buzz different frequency tones, depending on how far the object is away from the system.
- Must be possible for the security feature to be enabled and disabled by the user in under 5 seconds.

2.3.7 Temperature and Humidity Sensor Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the quality of sensors for temperature and humidity used in this application. Listed below are the desired specifications for the temperature and humidity sensors that will be implemented in this product.

- Must be able to measure external environment temperatures with no greater error of ±2˚.
- Must be able to measure the humidity of the external environment with no greater error of ±5%.
- Must be able to produce analog signals that can be interpreted and analyzed by the microcontroller.
- Must be able to tolerate voltages in the typical range of 3V to 5V DC.

2.3.8 Microcontroller Unit Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the type of Microcontroller Unit used in this application. Listed below are the desired specifications for the microcontroller that will be implemented in this product.

- Must be able to handle inputs from various analog sensors and devices. To ensure compatibility with other components of the product.
- Must be able to communicate data to a display that will present invaluable information to the user.
- Must be able to send and receive data to and from a Bluetooth module.
- Must be able to tolerate voltages on the typical range of 3.3 V to 5 V depending on the microcontroller.
- Must have moderate to high accurate analog to digital converter in the typical range of 10-bit to 16-bit. This is required to obtain the most accurate reading possible from a sensor that outputs analog signals that the microcontroller must analyze.

2.3.9 Wireless Communication Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the wireless communications used in this application. Listed below are the desired specifications for the wireless communication that will be used in this product.

- The system must utilize a Bluetooth module to communicate wirelessly with an Android mobile device.
- Pairing the Bluetooth module to the Android mobile device must be simple for the user and not require any extensive steps that would otherwise only be known to a developer.
- The Bluetooth module must be able to receive commands from the Android mobile device, specifying whether to enable or disable the security feature of the system.
- The Bluetooth module must support AT commands, so that the programmer can potentially alter the baud rate, change how the name of the module appears on the list of discoverable devices to other devices, or change the password required to pair with the module.
- The Bluetooth module must be capable of operating at 9600 baud rate.
- The Bluetooth module must accept a 5^V supply voltage.
- The Bluetooth module must have a voltage divider between the TX pin of the microcontroller and the RX pin of the module, so that the voltage can drop from the 5^V microcontroller to a safe 3.3^V that the Bluetooth module can tolerate.

2.3.10 Display Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the housing used for this application. Listed below are the desired specifications for the display that will be implemented in this product.

- Must be large enough to display the following required information: Time and Date, Temperature, Humidity, and Battery Life.
- Must be visible in a bright environment. This is a requirement because the system is going to be used outdoors where the background light is going to be very bright and there must be sufficient contrast of the screen.
- Information displayed must be readable to the user.

2.3.11 System Housing Requirements

To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the housing used for this application. Listed below are the desired specifications for the system housing that will be implemented in this product.

- Must house all necessary electronics that don't need to be situated outside (i.e. sensors, display, solar panels, etc.) completely.
- Must protect respective electronics from the environment, such as direct sunlight, debris or particulate matter (particles larger than 10µm).
- Must be easily accessible to design team and for demonstration, taking no more than 60 seconds to clearly demonstrate to any user.
- Must not inhibit the electronic circuitry to the solar panel power source. This will ensure the cords/wire transferring power do not wear down and become exposed to open air (which could cause a short circuit, a live wire, or low efficiency when supplying power)
- Must have relative stability in sand or soft dirt, this will ensure the solar panels receive a constant and even reception of sunlight. This will also ensure the electronic components are not jostled around, as to not break or damage any modules or systems.

2.3.12 USB Charging Ports

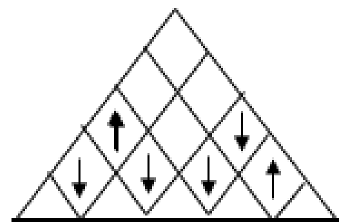
To meet the project specifications listed in the beginning of this section there are specifications that need to be met pertaining to the design of the charging ports used for this application. Listed below are the desired specifications for the power charging ports that will be implemented in this product.

- Must be able to charge any hand-held device to 5V and 1.7A. Since one of the goals of the application is to charge a user's device, it must successfully and noticeable charge a user's hand-held device.
- Must be compatible with USB Type A ports. The most popular and almost universal type of USB Type for handheld devices is Type A, which must be implemented to ensure most users can benefit from this product.
- Must be able to operate at 85˚C temperature for extended periods of time. This product will be in a high temperature environment up to 60˚C and must operate for the user through the duration of the event.

2.4 House of Quality

To help develop the project concept, tradeoffs and marketing requirements must be considered. Understanding these two developmental properties help identify what can and will be accomplished in making the concept a reality. Below these properties are classified and compared in the matrix:

House of Quality Legend:
↓ = Negative Correlation
↑ = Positive Correlation
↓↓ = Strong Negative Correlation
↑↑ = Strong Positive Correlation
+ = Positive Polarity
- = Negative Polarity



Marketing Requirements \ Engineering Requirements	Importance (1-5)	Dimensions	USB Power Output	Low power consumption	Sensor Accuracy	Security Response Time
Direction of Improvement		4	5	2	3	1
		-	+	-	+	-
Sound Quality	+	↓		↓		
Portability	+	↑			↓	
Cost	-	↓	↓↓	↑↑	↓	↓
Entertainment value	+	↑	↑	↓		
Security	+	↓		↓	↑↑	↑↑
User Interface	+	↑		↓	↑	
Targets for Engineering Requirements		<12lbs; CL:8ft/1ft; OP: 8ft/8ft	>5v and >.7A	<20Wh	<5% hum. & ±2°F	<5 seconds

Figure 2.2. House of Quality comparing Engineering and Marketing

2.5 Block Diagrams

A general outline of the hardware and software systems will help guide research and design teams to determine the flow of the design. By using block diagrams, a hierarchy of processes can be effectively demonstrated and validated as the product is developed.

2.5.1 Hardware Block Diagram

Using image and shape processors, a flowchart block diagram represents the application's hardware system and sub-systems. This image is shown below.

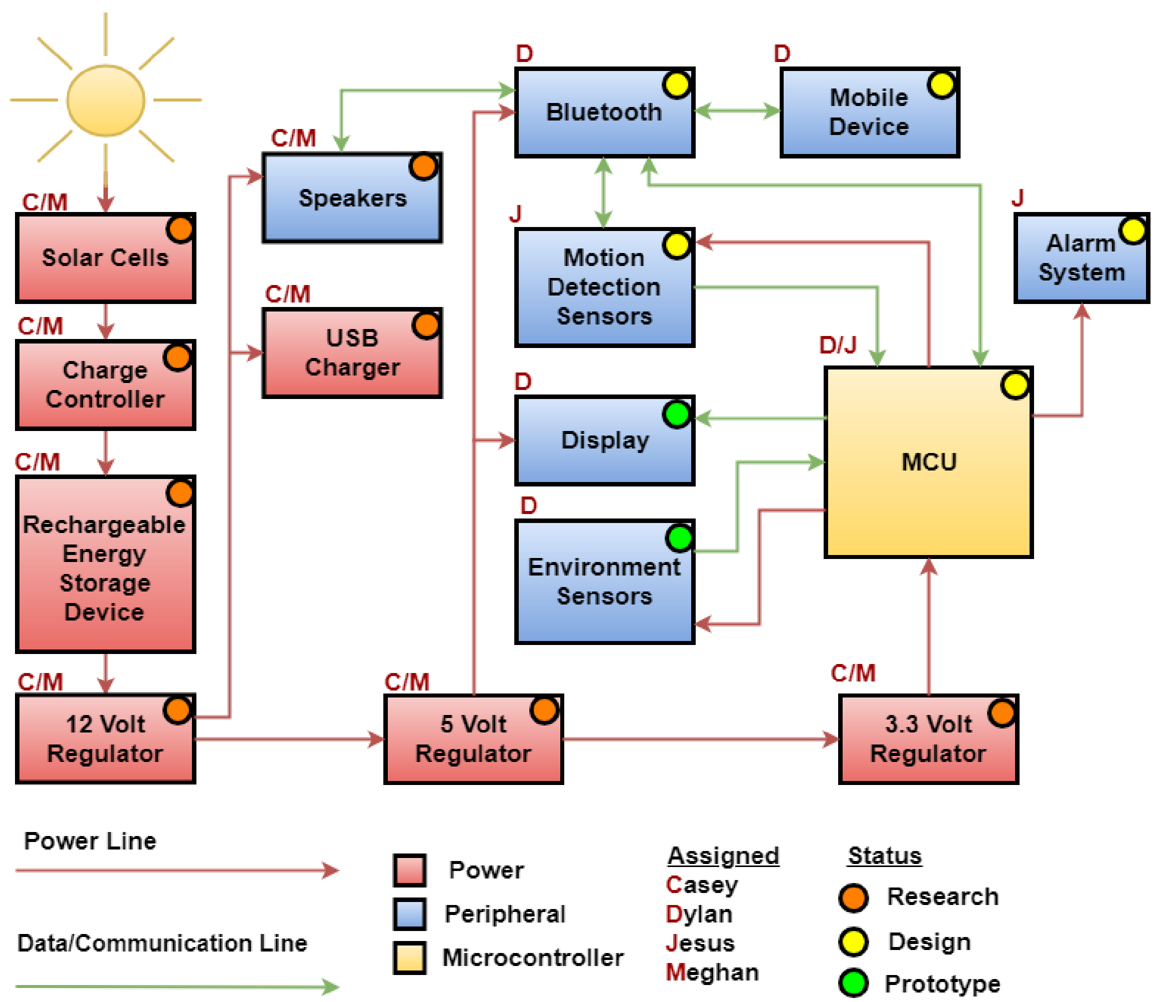


Figure 1.3. Hardware Composition and Structure

2.5.2 Software Block Diagram

Using image and shape processors, a flowchart block diagram represents the application's software system and sub-systems. This image is shown below.

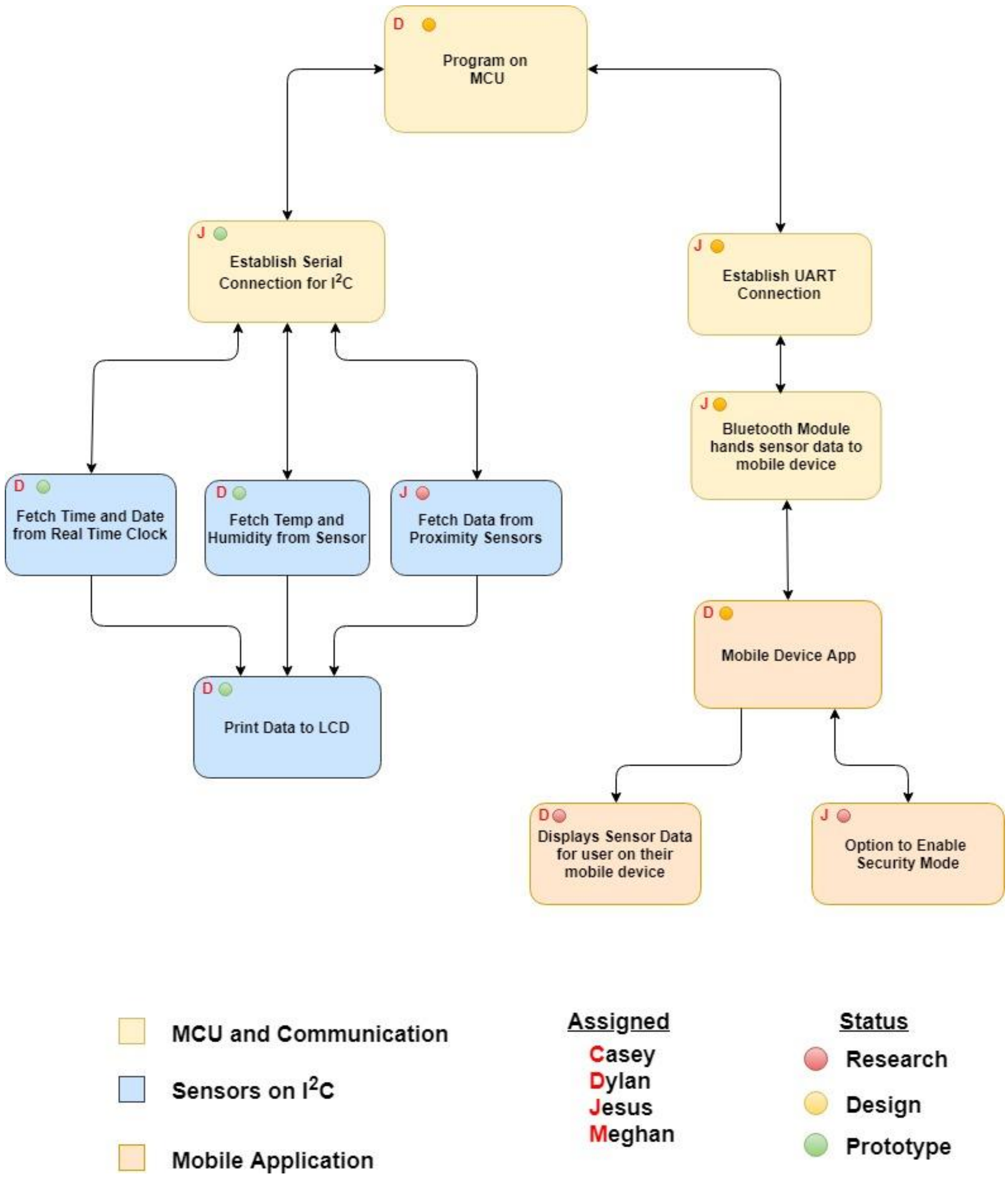


Figure 2.4. Firmware Composition and Structure

3.0 PROJECT RESEARCH

Given the requirement specification of the project, research to discover and identify the technology that will most effectively satisfy the requirements designated. Each major aspect of the design will be researched, and detailed research must be conducted to determine the appropriate products for each system.

3.1 Photovoltaic Solar Cell Types

Given that sunlight reacts and can be utilized differently depending on whether it is in space or on Earth indicates that location, in and of itself, can play a pertinent role in the process of selecting what type of solar panels to use over another. Choosing between the many types of solar cells often means distinguishing between single-junction and multi-junction panels and classifying them as first, second, or third generation. The distinction between single-junction and multi-junction panels is in the number of layers on the panel that observes the sunlight. The classification by generation of the solar cells concentrates on the materials used and the efficiency of the different types.

3.1.1 First Generation Solar Panels

First Generation Solar Panels are the most traditional of the solar panel types and are easily the most commonly used in “conventional surroundings,” making up more than 80% of the market. These types of solar cells are made from silicon; however, silicon is able to take on many different forms. The classification of these cells is based on the purity level of the silicon used to construct them. Purity being the way in which the silicon modules are aligned. The greater the purity level of the silicon molecules, the more efficient the solar cell is at converting sunlight into electricity.

Monocrystalline solar cells, also called "single crystalline" cells are the purest of the silicon based solar cells and are therefore the most efficient. Efficiencies for this particular cell have been documented at upwards of 20%. This solar panel is easily recognizable by its dark look and rounded edges. Monocrystalline solar cells consist of a n-type semiconductor (emitter) layer and p-type semiconductor (base) layer, and the surface is coated with an anti-reflection coating to avoid the loss of incident light energy due to reflection (as shown in the diagram of the monocrystalline cell construction below). These solar cells are made out of a cylindrical shaped silicon designs called “silicon ingots,” that help optimize performance. This technique is what gives the cells their signature rounded edges. Due to this process, these panels have an increased power output compared to other types of solar panels. As a result, these cells are the most space-efficient; which is logical because it would take fewer cells to produce the same amount of power. In summation, Monocrystalline panels have a high-power output, are space-efficient, have the longest lifespan (having lifespan of up to 25 years), and tend to be slightly less affected by high temperatures compared to polycrystalline panels. These benefits of course come with a hefty price tag, and this combined with the excess silicon waste in the manufacturing process makes them the most expensive solar cell type.

Polycrystalline solar cells, also known as polysilicon and multisilicon cells, were the first solar cells brought into the industry, in 1981. These panels are known for their blue, speckled look and square edge formation. This cell type does not go through the same cutting process used for the aforementioned monocrystalline cells. Instead, they are formed by melting the silicon and pouring it into a squared mold, hence the square edges. Polycrystalline solar cells tend to be much more affordable, due to the fact that hardly any silicon is wasted in the manufacturing process. However, this consequently means that the purity level of the silicon is reduced and therefore the efficiency is reduced proportionally (typically between 13-16%). Due to this reality, polycrystalline also has a lower space efficiency. Polycrystalline panels tend to have a higher temperature coefficient than panels made of mono cells and therefore a shorter lifespan since they are affected by hot temperatures to a greater degree. However, in practice these differences are minor. This cell type was once thought to be inferior to its Monocrystalline cousin due to its slightly less efficiency. However, because the production method that the cell undergoes is significantly cheaper this solar panel type has become one of the most dominant technologies on the market.

3.1.2 Second Generation Solar Panels

Second Generation Solar Panels are a totally different technology to Mono and Polycrystalline panels. This classification is made up of various types of thin-film solar cells. They are a relatively new technology compared to First Generation Solar cells and are far from being considered mature as there are extensive improvements expected to be made in the coming decade. Thin-film panels are manufactured by depositing one or more films of photovoltaic material (such as silicon, cadmium, or copper) onto a substrate (such as metal, glass, or even plastic). The photovoltaic substance that is used often varies and multiple combinations of substances have been used successfully. These will be more thoroughly discussed later in this section. The major draw of thin-film technology is its cost; mass production for this type of solar cell is much easier than crystalline-based modules – due to less materials being needed for production – making it comparatively cheaper. Thin film solar panels have solar cells that are made of layers about 350 times smaller than that of a standard silicon panel. Because of their narrow build these cell types are the lightest PV cells on the market while still maintaining strong durability. This class of solar panels also are beneficially less susceptible to losing their efficiency in high temperature situations and low light conditions. The largest disadvantage of thin-film solar panels is that in most applications they require a lot of surface area in order to produce the same amount of power as First Generation solar panels, due to the fact that in general they operate at efficiency rates between 7-16%. Additionally, they have shorter lifespans than that of First Generation solar cells. This tends to make them unsuitable for residential installations. As a result, thin-film panels are taking off more in the commercial market. As mentioned previously, Thin-film cell types vary based on the type of photovoltaic material used in its production.

Cadmium Telluride (CdTe) solar cells are the most widely used of the thin film solar cell technologies, holding roughly fifty percent of the market share for thin film solar panels. This cell type is the only of the thin-film materials that reaches cost-efficiency levels that can compete with the crystalline silicon models. Reaching efficiency levels between 9 to 11% (inclusive) and having such a low-cost production makes this cell type extremely cost-effective. Of all the solar cell technologies, this one requires the least amount of water consumption for production, making it water-efficient as well. The only major disadvantage of this solar cell type is its characteristic of being toxic if ingested or inhaled. CdTe contains significant amounts of Cadmium, which is a naturally occurring toxic heavy metal. Due to its low permissible exposure to humans, overexposure may occur even in situations where only trace amounts of Cadmium are found.

Amorphous-Silicon solar cells (a-Si) are made from the non-crystalline form of silicon (amorphous silicon). This cell type is traditionally used in pocket calculators and other smaller-scale low power applications. It is the most well developed of the thin-film solar cell technologies having been on the market for over 15 years. United Solar Systems Corp. (UniSolar) pioneered the development of amorphous-silicon solar cells and remains a major producer today. In its most basic form, this cell structure is comprised of a single sequence of p-i-n layers. However, this form of a-Si solar cell suffers from significant degradation in their power output when exposed to the sun. This is called the Staebler-Wronski Effect, and it is not ideal. This led the industry to develop more optimized forms of a-Si manufacturing involving a new process called “stacking”, in which they stack p-i-n cells of slightly different doping on top of one another. UniSolar uses a triple layer system (see illustration below) that is optimized to capture light from the full solar spectrum, however, this complex process tends to make this cell type fairly expensive.

An advantage of this type of solar cell is that it can be made to be flexible, allowing

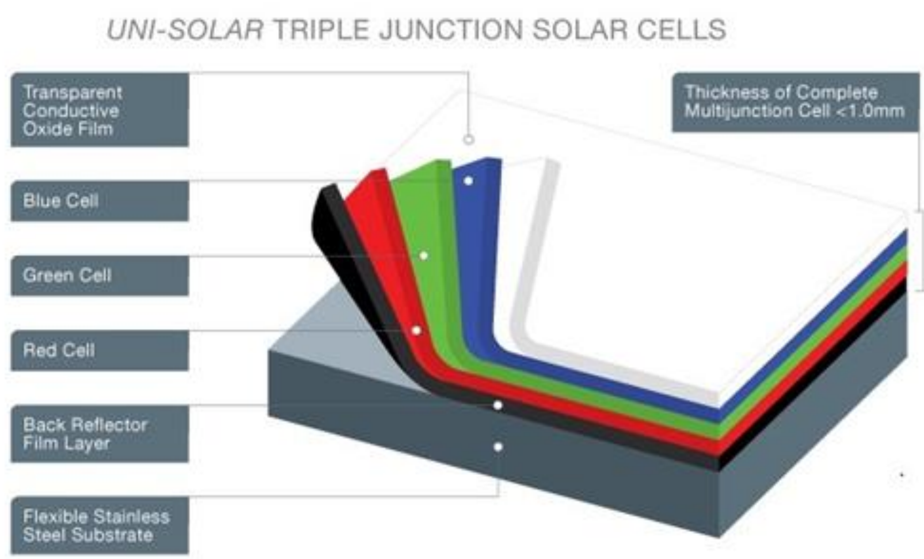


Figure 3.1.1. UniSolar Triple Junction Solar Cell Cross-Section

for opportunities for alternative applications. Amorphous silicon can be deposited at very low temperatures – as low as 75 degrees Celsius. This means it can be attached to a flexible backing sheet (such as plastic) that can be rolled up and easily transportable. Unlike crystalline solar cells in which cells are cut apart and recombined, amorphous silicon cells can be connected in series during the manufacturing process, making it easier to build panels that produce a variety of voltages. The principle draw of this cell type is that it is cost effective and can be produced in a variety of shapes and sizes. However, this is only true in purchasing by relatively large volumes.

Copper Indium Gallium Selenide (CIGS) solar cells have demonstrated efficiency levels of up to 20% in lab conditions. Unfortunately, it has turned out to be rather difficult to produce CIGS solar cells in mass quantities at competitive prices with anywhere near to that efficiency level. Average efficiency levels of this type for mass production range between 10% to 12%, which is still somewhat comparable to crystalline technologies. However, the cost of fabricating this product makes it difficult to be competitive with other solar cell types. Ninety-nine percent of the light shining on a CIGS solar cell will be absorbed in the first micrometer of material. This cell type utilizes a heterojunction structure, which is a structure that forms junctions between semiconductors that have different bandgaps. This technology is most used in larger or commercial applications.

Gallium Arsenide (GaAs) solar cells are a rather expensive technology. GaAs solar cells hold a world record 28.8% efficiency for all single-junction cell types. This solar cell type is primarily used on spacecrafts and is meant for versatile installments of Photovoltaic energy in unusual environments in massive quantities.

3.1.3 Third Generation Solar Panels

Third generation solar panels include all of the solar technology that is currently in its research and development phase. There is an exorbitant amount of research going on in this particular field. In fact, according to a number of patents filed in recent years – solar research has ranked second only to research in the area of fuel cells. This new generation of solar cells are comprised of cells made of a variety of materials besides silicon, including nanotubes, silicon wires, solar inks using conventional printing press technologies, organic dyes/materials, and conductive plastics. The goal is obvious, to improve on the solar cells already commercially available by making solar energy more efficient, less expensive, and to develop more and different uses of the technology.

The Biohybrid Solar Cell is one of the types of solar panels that is still in its research phase. It was discovered by an expert team at Vanderbilt University. The idea behind the technology is to take inspiration from nature and thus emulate the natural process of photosynthesis. Many of the materials used in this application are similar to the traditional method, but by only combining the multiple layers of photosystem one, the conversion from chemical to electrical energy becomes up to a thousand times more efficient than that of the first generation types of solar panels.

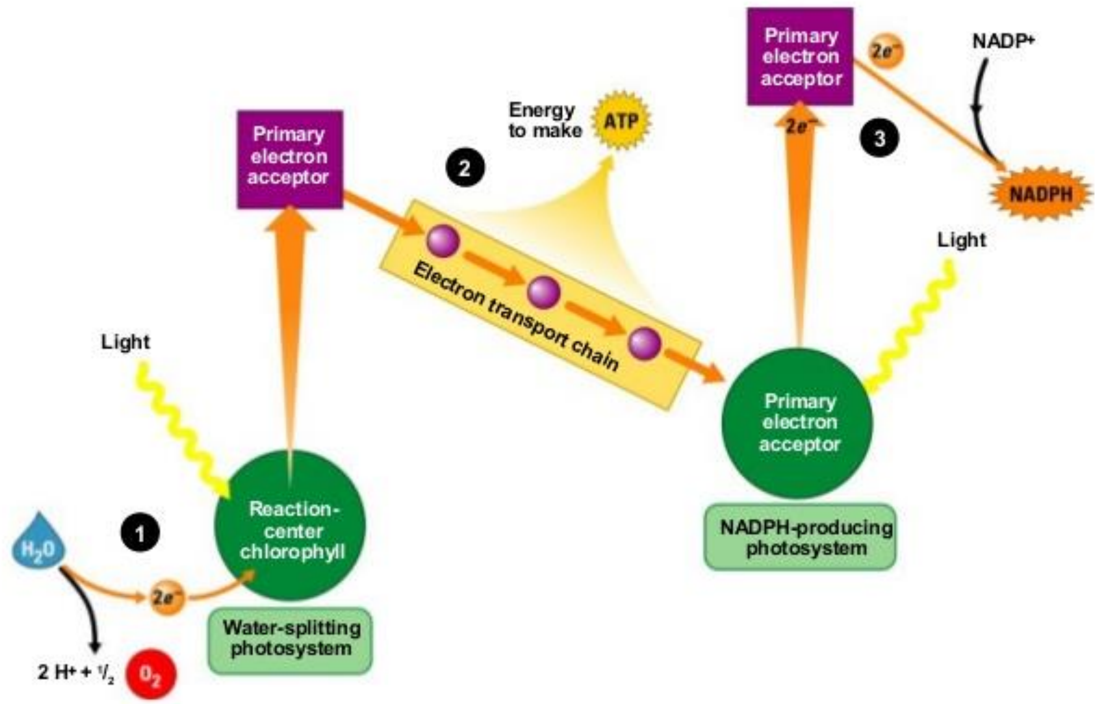


Figure 3.1.2 Illustration of Photosynthesis

Concentrated PV Cells (CVP HCVP) generate electrical energy just as conventional photovoltaic systems do, but with an efficiency rate of up to 41%. The name of CVP is related to what makes it so much more efficient compared to other solar panel types. The use of curved mirror surfaces, lenses, and sometimes even cooling systems are used to bundle the sunrays and thus increase the efficiency of the solar panel. By utilizing these methods CVP cells have become one of the most efficient types of solar cells. However, in order to reach such high efficiency rates, a solar tracker must be incorporated to the solar panel construction in order to maintain the perfect angle from the sun.

3.1.4 Product Comparison

Initial research indicated that the amorphous-silicon solar panels would be the best fit for this product's application. This cell type would be lightweight and portable, able to withstand high temperatures, unaffected by low light situations, and most importantly it was thought to be inexpensive. However, after extensive product comparison the desired features seemed to be unnecessary and surprisingly enough, costly. This cell type was just not able to produce the amount of power needed for this application without negating its cost efficiency entirely. While the features looked promising the cost goes up significantly when purchasing for applications that need higher than a few watts of power in a limited amount of space. For example, the Jiang a-Si flexible solar cell provides 1W of power and costs $12.76 for each unit. This resulting in a bill of over $200 when applied to this products usage. The realistic product comparisons shown in the table below (table

3.1.4). Take note of the indication of whether the cell is uncoated in the cost column, this means that the cells are uncoated and would need an external casing in order to ensure weather resistivity. This would require extra purchases, resulting in a much higher cost. In the end, the product that will be used for this application is a purchase of 20 of the small-scale 1W polycrystalline solar panels bought from Ali-express of the brand BCMaster. These panels ended up being relatively inexpensive, because the builders will not need to buy a large amount of the panels in order to achieve the desired wattage. They will be heat resilient, and due to their small scale and the necessity of fewer panels this purchase results in a more lightweight and portable product.

Table 3.1.2 Product Comparison for Solar Cell Types.

	Cost per Cell (Dollars)	Wattage (W)	Size (mm)	Weight (g)	Heat Resistivity (°C)	Low Light Performance
Jiang A-Si Flexible Solar Cell	19.99	1	196 X 87 X 0.1	27	0~70	Yes
BCMaster Polysilicon Solar Cell	1.12	1	110 X 60 X 2.5	13.6	-20~85	Yes
Solopower Lightweight Thin Flexible CIGS Solar Cell	7.99 uncoated	1.5	368 X 40 X 0.3	9.07	unknown	Yes
Viko Cell Mono Series Monocrystalline Solar Cell	1.55 uncoated	2.7	125 X 125 X 0.5	unknown	unknown	Yes

3.2 Solar Charge Converter

A solar charge controller is utilized in virtually every power system that utilizes a battery. The task of this solar charge controller is to regulate the power going from the solar panels to the battery. Overcharging the battery can lead to severe deterioration of the battery's performance, or even significantly reduce the life of the battery and may cause batteries to explode causing harm to consumers or damage to the product. This topic is discussed further in the following section, in which the battery is chosen for this application. The most basic design of charge controllers simply monitors the battery voltage and opens the circuit to stop the charge, when the battery voltage rises to a certain level. Older charge controllers used a mechanical relay to open or close the circuit. This form of technology is obviously a bit outdated. Modern controllers use one of two types of charge controlling. Those being Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT).

3.2.1 Pulse Width Modulation (PWM)

This technology is the older of the two technologies. It utilizes DC to DC converters and a voltage sensor to limit the voltage from the solar panel to a safe charging voltage for the battery. Pulse Width Modulators do this by applying short bursts of relatively high voltages instead of a constant charge voltage to slowly charge the battery. When the battery is fully discharged the PWM will apply pulses at a near continuous rate, however as the battery becomes more fully charged the pulses begin to be more and more tapered off and have longer intermissions between each pulse. This type of charge controller design tends to be rather inefficient unfortunately. Power is wasted as the battery is being charged and this waste only gets worse as the battery becomes more fully charged.

3.2.2 Maximum Power Point Tracking (MPPT)

The Maximum Power Point Tracking (MPPT) charge controller solves this issue. MPPT converters use a microcontroller to track the maximum power output from the solar panels before it reaches the batteries. It then regulates this voltage for a safe charging level to apply to the batteries. Instead of wasting the extraneous voltage, the MPPT will actually convert this voltage into excess current, maintaining the maximum power output of the solar cells at all times. This also allows for the time required for a full charge to decrease significantly. By continuously maximizing the power output from the solar panels the MPPT charge controller will add approximately 10 to 30 percent more efficiency to the system than a PWM charge controller, and it will maintain a constant charging voltage. The final function of a solar charge controller is preventing reverse current flow. When the solar panels are not generating any electricity, electricity can actually flow backwards from the batteries to the solar panels, therefore draining the batteries. The charge controller can detect when there is no energy coming from the solar panels and open the circuit, disconnecting the solar panels from the batteries and stopping reverse current flow. For this project a MPPT solar charge converter will be designed and built to increase power output while decreasing the number of solar cells needed. Further details of this charge controller will be discussed in the design portion of this document.

3.3 Batteries

There is a wide variety of battery types on the market today. This pool consists of two classifications, primary batteries and secondary batteries. Primary batteries, once fully discharged, can be discarded (recycled), and replaced. Secondary batteries are rechargeable and can be charged to get multiple uses before the battery needs to be replaced.

3.3.1 Primary Batteries

This category of batteries includes batteries that are familiar to users, because they need to be replaced often. Included in primary batteries are Alkaline and Carbon Zinc and Lithium which are used commonly in cameras, toys, watches, and handheld electronics. Lithium batteries can also be used in high-temperature applications. Other batteries under this classification include Mercury, Silicon Oxide, and Zinc Air. However, these types of batteries cannot be recharged and are therefore not useful towards this application.

3.3.2 Secondary Batteries

Secondary batteries are rechargeable and can therefore be charged using a solar powered source, making this category of batteries applicable towards our product. Looking at the advantages and limitations of commercial batteries, a plethora of characteristics must be considered. This includes energy density (the amount of energy stored in a system per unit volume), longevity, weight, charging requirements, maintenance requirements, self-discharge (a phenomenon in batteries in which internal chemical reactions reduce the stored charge without having a connection between electrodes), and operational costs.

Nickel Cadmium (NiCd) is a classic battery type that is well understood in this field of research. It remains a standard against which other chemistries are compared. This battery type is used when life longevity, high discharge rate and price are the most important factors at play. The NiCd battery prefers a fast charge rather than a slow one and a pulse charge rather than a DC charge. Due to their low internal resistance and excellent current conducting properties, NiCd batteries can supply extremely high currents and can be charge rapidly. Unfortunately, this also leads NiCd batteries to have a relatively high self-discharge, making it so the battery needs recharging after storage. NiCd is the only battery type that performs well under rigorous working conditions, however, a periodic full discharge is necessary for this battery, as, if not done, large crystals will form on the cell plates and it will gradually lose its performance. The main applications for this battery are two-way radios, biomedical equipment, professional video cameras, and power tools. The NiCd is the lowest cost battery in terms of cost per charge cycle, with the ability to have about 1500 charge cycles (being that it receives regular maintenance and periodic full discharges). However, NiCd contains toxic metals and is environmentally unfriendly. There are quite a few reasons why NiCd batteries will not work for this application, the biggest of which is that it has memory effects that require it to have periodic full discharges. This product requires that the battery retain a charge for indefinite, but lengthy, periods of time.

The Nickel-Metal Hydride (NiMH) battery is less prone to memory effects than the NiCd and is mainly used for satellite applications. Research for this battery type started in the 1970s, however in its early days the metal hydride alloys were unstable in the cell environment and the desired performance goals could not be met. New, hydride alloys were developed in the 1980s that were then stable enough to be used in a cell. Since then the NiMH battery has steadily improved. Research for this battery has been driven by it having a rather high energy density and its makeup of environmentally friendly materials. The NiMH battery tends to be less durable than the NiCd battery, cycling under a heavy load or staring in high temperatures can reduce its lifetime. NiMH batteries also suffer from high self-discharge, are bulky, contain high-pressure steel canisters, and cost thousands of dollars per cell. This battery requires a more complex charge algorithm because it generates more heat when being charged. A trickle charge is required and must be controlled carefully. While the NiMH battery is less prone to memory effects it still requires periodic full discharges to prevent crystalline formations.

The Lead Acid battery was invented by a French physician named Gaston Planté in 1859 and was the first rechargeable battery for commercial use. The Lead Acid battery consists of positive and negative lead and lead diode substances surrounded by an electrolyte connected in series with others identical structures. (as shown in figure 3.3.1 below) Today it is used in automobiles, forklifts, and large uninterruptible power supply (UPS) systems. These batteries come in two major types. Starting batteries that deliver short bursts of a large amount of power, and deep cycle lead acid batteries that deliver a low steady state of power for long period of time.

For this application only the second of the two is going to be considered. These batteries are designed with a low over-voltage potential to prohibit the battery from reaching its gas-generating potential during charging. Excess charge would result in gassing and water depletion, making it so that these batteries can never be charged to their full potential. The lead acid battery is not subject to memory effects and leaving the battery on float charge for a long period of time does not cause damage to its performance. This battery's charge retention is the best among rechargeable batteries, losing the same amount of charge in a year as a NiCd battery would lose in 3 months. Charging this battery can take from anywhere between 8 to 16 hours and must always be stored in a charged state. Leaving the battery in a completely discharged state for extended periods of time can make it difficult, if not impossible, to recharge. The Lead Acid battery has one of the lowest energy densities of all the modern rechargeable batteries. This makes it unsuitable

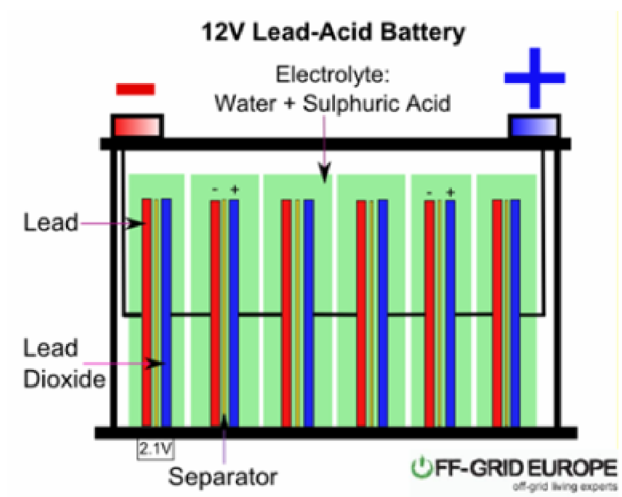


Figure 3.3.1. 12V Lead Acid Battery Construction diagram by Maxpower Technologies

for handheld devices that require compact sizes with high power usage. Another disadvantage of this battery is that requirement that it not be flipped upside-down. Due to this product's need to be transportable this is not a suitable battery for this application.

The Lithium Ion (Li-ion) Battery has been in its research and development stages since 1912 under G.N. Lewis. The first non-rechargeable Lithium battery became commercially available in the 1970s. Lithium is the lightest of all metals and has the greatest electrochemical potential the provides the largest energy density per weight. Attempts to develop a rechargeable lithium battery in failed in the 1980s due to safety problems. Due to lithium metal's inherent instability research shifted to a non-metallic lithium battery using lithium ions. While the lithium ion has a slightly lower energy density compared to lithium metal, the lithium ion is much safer provided certain precautions are taken when charging and discharging. Today, the Li-ion is the fastest growing and most promising battery chemistry. This type of battery is lightweight and does not have memory effects that require a full discharge before recharging. Its flat discharge curve offers effective utilization of the stored power in a desirable voltage spectrum. The high cell voltage allows battery packs with only one cell, which greatly simplifies battery design. To maintain the same power, higher currents are drawn, making it imperative that there is a low cell resistance. The self-discharge of the Li-ion battery is less than half that of the NiCd battery. Despite these many advantages the Li-ion battery has some drawbacks. It is fragile and requires a protection circuit to maintain safe operation. This protection circuit limits the peak voltage of each cell during charge and stops the voltage from dropping too low on discharge.

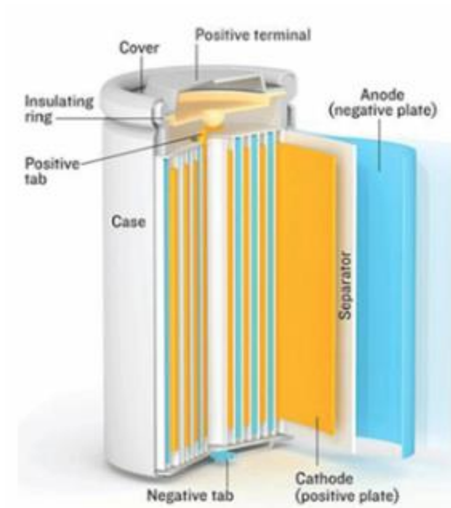


Figure 3.3.2. Lithium Ion Battery Construction Diagram by David L. Anderson

Lithium polymer (LiPo) Batteries differentiates itself from all other battery technologies in that it uses a different type of electrolyte, the solid polymer electrolyte. This electrolyte is similar to a plastic film that does not in and of itself conduct electricity but allows an exchange of ions. This replaces the traditional separator, that is soaked in electrolyte. This new dry polymer design offers many simplifications to the fabrication methods. There is no longer a risk of flammability, because there is no gelled or liquid electrolyte used. Unfortunately, this Lithium Polymer suffers from a fairly poor conductivity. The internal resistance of the design is too high and can no longer deliver the current bursts needed for modern communication devices. By heating the battery cell to 140°F the conductivity increases, however this requirement is unsuitable for portable applications. Due to this being an issue, most commercial Li-polymer batteries used for mobile phones are a hybrid and contain gelled electrolyte. These hybrids are called Lithium Ion Polymer batteries. Technical difficulties arise in the manufacturing of these types of batteries and result in no cost advantage for this technology and no improvements to capacity, if not slightly less than that of the Lithium Ion battery. The main reason to switch to this design is that it allows wafer-thin geometries, a style that is demanded by the highly competitive mobile phone industry.

3.3.3 Product Comparison

First, it is important to choose a battery type based off of the previously stated characteristics. Those being energy density (the amount of energy stored in a system per unit volume), longevity, weight, charging requirements, maintenance requirements, self-discharge (a phenomenon in batteries in which internal chemical reactions reduce the stored charge without having a connection between electrodes), and overcharge tolerance. Table 3.3.1 compares the battery types and helped establish which was the perfect type for this application.

Table 3.3.1. Comparison of Battery types by Battery University Group

	NiCd	NiMH	Lead Acid	Li-ion	LiPo
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130
Cycle Life	1500[2]	300 -500[2.3]	200 - 300[2]	500 - 1000[3]	300 – 500
Charge Time (hours)	1	2-4	8-16	2-4	2-4
Overcharge Tolerance	moderate	low	high	Very low	Low
Self Discharge (per month)	20%[4]	30%[4]	5%	10%[5]	~10%[5]
Operating Temperature (°C)	-40 - 60	-20 - 60	-20- 60	-20- 60	0- 60

After comparing the choices in table 3.3.1, the clear choice to meet the specifications described in previous sections is the lithium-ion battery type. The pack that the builders will be purchasing is a 12V DC Li-ion battery pack for a total cost of $29.45. This pack is durable and lightweight. It comes with a built in PCB that protects the battery pack from overcharge and undercharge. This will be necessary for this application in ensuring that the battery will not lose any of its performance level. This battery pack will still need a charging circuit to charge the lithium ion batteries. Lithium ion batteries require a specific constant current and constant voltage charging cycle. The charger will need to have a temperature sensor to shut down the charging process if the battery pack becomes too hot during the charging cycle. A specific cycle time shutoff is also strongly recommended. Another issue in choosing this battery pack is that it will not fit into the 1.25-inch diameter umbrella pole. Special consideration for the location will need to be considered. This will be discussed further in the design portion of this report.

3.4 Printed Circuit Board Design

At the start of most of the project design, is the Printed Circuit Board (PCB), on to which will connect all of the technologies stated above. The printed circuit board will provide environmental and marketing constraints that will define what technologies will be connected. To begin, an understanding of the structure and components of the board will help the team develop a design. Next, a PCB Design software, to create the design, must be selected after satisfying all functional requirements. Finally, the schematics to be implemented will be displayed and explained.

3.4.1 PCB Composition

At the center of any PCB is the substrate, or FR4, normally fiberglass to maintain rigidness onto which the circuits can be printed. But there are also few flexible options (for example, high-temperature plastic Kapton). FR stands for fire retardant, where the number that follows refers to a grade of the material, complying with the UL94V-0 standard (TGXXX refers to transition glass temperature, in which the material will deform). FR4 is the grade for the epoxy fiberglass that is standard for most rigid PCBs. FR2 and G10 are the next most common grades, G10 not being flame retardant at all. Depending on the supplier, typical thickness ranges from 0.8 mm to 1.6 mm with a proportional substrate layers 4 to 8.

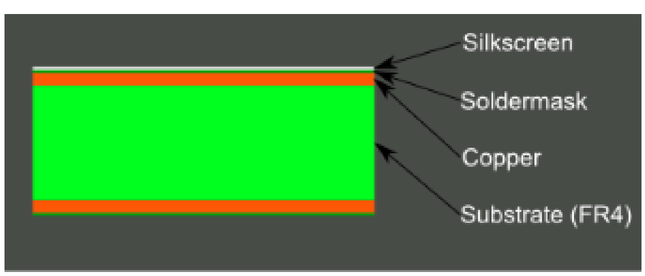


Figure 3.4.1. Cross-section of a Printed Circuit Board

The next layer is copper, and can be double sided (on either side of the base substrate), a PCB that is referred to as a double sided or 2-layer board has two sides or layers of copper. These layers are measured in ounces per square foot, which translates to 35 micrometers (making it easier to present it as oz/sq). We can expect the PCBs for our use to have about 1 oz of copper per square foot (anything more is used for high performance computation, which is not necessary for the project definition). This copper layer provides the connection, or traces, that the signals will run through to each component.

Soldermask is the layer on top of the copper, and gives the PCB it's "color", Texas Instruments boards are red, and Arduino boards are blue. The soldermask also insulates copper traces from short circuiting and guides solder points. Silkscreen is the top layer that applies letters, symbols, and numbers for ease of use.

3.4.2 PCB Design Software

Regardless of the design, there are five key parameters when determining which of the hundreds of PCB Design software to use. Troubleshooting support, Ease-of-use, Features, Compatibility, and Price. Troubleshooting support can come from either the software developers own webpage, in the form of FAQs, Tutorials, or forum. Support can also be found in online community sources unassociated with the particular software developer (i.e. stack overflow, Tech Design Forums, etc.). The more troubleshooting and technical support a software has, the most useful it will be in case of unexpected design errors via the software UI. Ease-of-use will come to prove its importance as the design becomes more complex, and reading a simple UI navigation overlay will help overcome any design issues. The Features that a PCB design software has will help ensure that the team is only using the proper amount of design tools, to either aid in a unique design or prevent confusion with higher UI complexity. Finding a perfect balance of features, that create a flawless design but not too many features that would be more useful for

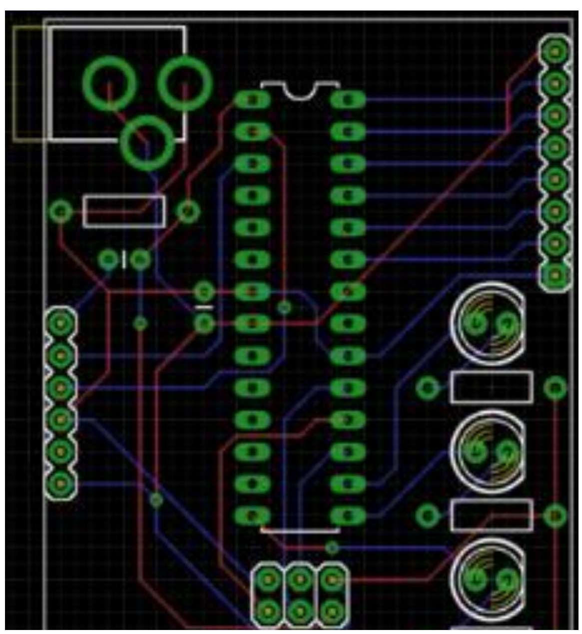


Figure 3.4.2. Example PCB design with Autodesk Eagle- PCB design software

commercial use, than prototype design. The software must also be Compatible with schematic designs from online databases, for integrating after-market technology, such as sensors or MCUs. It must also be accepted by the PCB manufacturer chosen. The last factor to consider is price, despite the importance of this project, it would seem unreasonable (in an academic environment that supports open-source technology) to use software that requires a $700 subscription. Five popular PCB design software were compared, and Autodesk's Eagle was deemed most suitable for the project.

From the results of the comparison, Autodesk Eagle is the PCB design software that will be used. The team has familiarity with the product, and with the software company, and is free for students. The software has been used previously in other projects and was deemed more than enough for the schematic work to be completed. Eagle is also a standard for most PCB manufacturers and has a wide backing of troubleshooting support via Autodesk resources on their website, and community forums. Eagle features a SPICE simulator, modular design blocks, electronic rule checking, and real-time design synchronization. It's PCB editor allows "push and shove routing", alignment tools, obstacle avoidance routing, and design rule checking to make the layout clean cut.

Table 3.4.1. PCB design software comparison

	CircuitMaker	Autodesk Eagle	Protel Altium	OrCAD	Allegro
Troubleshooting Support	X	X	X		X
Ease-of-Use	X	X	X	X	
Features		X	X	X	X
Compatibility	X	X			
Price	X	X			

3.4.3 PCB Manufacturer

The last aspect of PCB design and creation to consider, is the manufacturing of the PCB. Finding the best quality manufacturer for the best price is a challenge, but by comparing the top PCB manufacturers against each other, a decision can be made. A few of the manufacturers that will be compared are: 4pcb.com, jlcpcb.com, pcbway.com, and rushpcb.com. The criteria that will help determine the best PCB manufacturer, will be cost per inch of board, shipping price, shipping time, and quality of board. All the criteria except quality, will change depending on the actual PCB design, and who has the best quotes. Once developing the final PCB layout and submitting it to each website, will determine which PCB manufacturer is the most desirable for this project.

3.5 Voltage Regulator

One of the most critical components to include in our PCB design is a voltage regulator. Every electronic components included in our design functions at some optimal voltage level. To ensure no extreme voltage variations between components, which could leave some components completely fried, a voltage regulator is used to keep a constant magnitude regardless of current pull or input voltage. A voltage regulator can either operate linearly or switching, but the most basic voltage regulator will use a reference voltage to amplify the ratio of the feedback and gain. Any voltage regulator has three main components: a current amplifier, a reference voltage, and an error amplifier.

The reference voltage is the voltage sought to output, part of it is sent through a negative feedback to the error amplifier which helps maintain the sought output voltage; the current amplifier is used to obtain the desired load current.

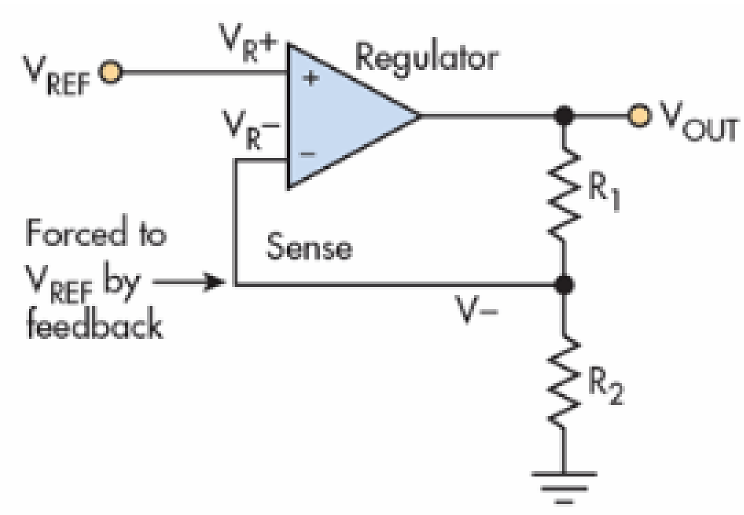
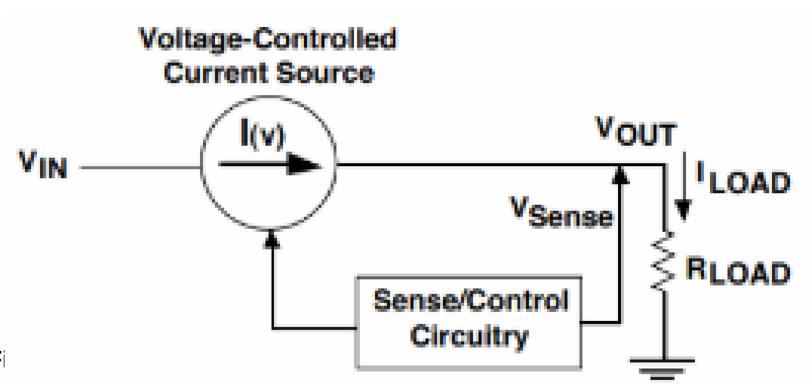


Figure 3.5.1. Standard Voltage Regulator circuit

Our design is going to utilize three voltage regulators, which depend on line regulation and load regulation. Line regulation is critical as our input voltage can vary if solar cell efficiency decreases due to cloudy conditions. Load regulation calculations will help maintain a steady output voltage as the output current changes, when some features are turned on or off within the umbrella.

3.5.1 Linear Voltage Regulator

Linear Regulators main distinction from Switching regulators is that they work via “buck” operation. This means the output voltage can only be less than the input voltage. Linear Regulators don’t have the same efficiency or duration as Switching Regulators, but as the difference between input and output voltage becomes



Fi s)

larger, Linear Regulators work best. Other factors when deciding if Linear regulators are to be used, is that there is a very high amount of heat lost (proportional to the ratio of output voltage to input voltage), but the circuit itself is not as complex, small physically, and provides a low ripple and electromagnetic interference. There are two types of linear voltage regulators: Shunt and Series.

3.5.1.1 Shunt and Series Linear Voltage Regulators

Shunt Voltage Regulators are less efficient than series regulators, because the current flows through to the ground, wasting most of the current. Shunt regulators will absorb current, but series regulators will not draw full current regardless of load.

Series Voltage Regulators uses an element in series to adjust the output voltage, since any elements in parallel have the same voltage, using an element in series will aid in adjusting voltage drop from the input to the output voltage.

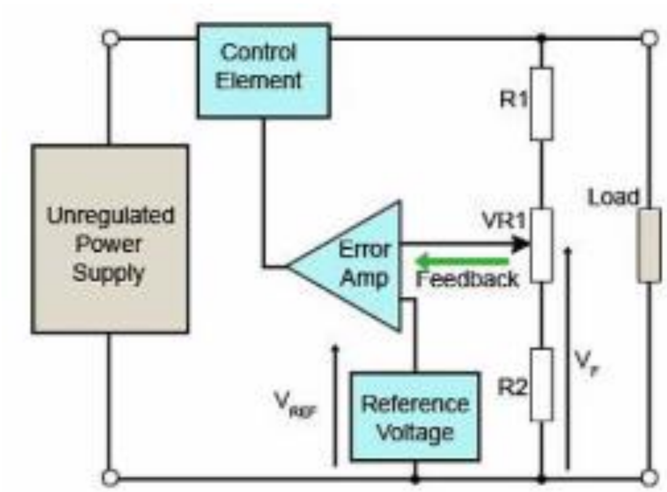


Figure 3.5.3. Shunt Voltage Regulator circuitShunt Voltage Regulator circuit from Learnabout-Electronics

For this project, which could be subject to direct sunlight for prolonged amounts of time, a linear regulator could prove to make the immediate environment around the circuitry inoperable. The system will also be driving loads over 200mA for certain components, making a linear regulator highly efficient and impractical.

3.5.2 Switching Voltage Regulator

The most notable feature of a Switching Voltage Regulator is that it can output a voltage higher than the input, as well as output a voltage less than the input voltage. This is because instead of continuously “adjusting” the input voltage, it “adjusts” the output voltage little by little. Due to the small changes in voltage, there is very little heat lost, and higher efficiency than a linear regulator. Despite the advantages, switching voltage regulators have a high ripple voltage and more complex circuits. There are three different types of switching regulators: Pulse Width/Frequency Modulation, Hysteresis, and Buck/Boost Converting.

3.5.2.1 Using Pulse Width Modulation for Voltage Regulation

Pulse Width Modulation is a type of digital signal control for analog circuits, typically used for motor control. As the name implies, it pulses the regulated voltage at certain intervals, or duty cycle. Depending on the output voltage, that

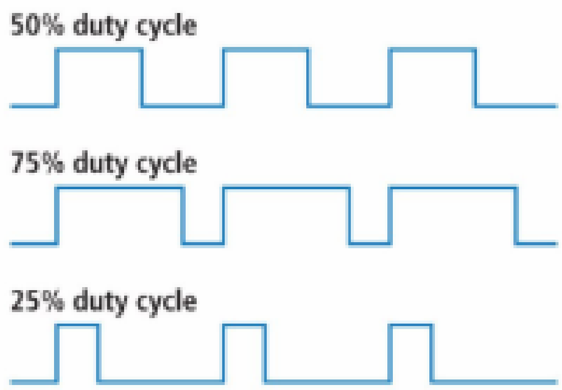


Figure 3.5.4. Pulse Width Modulation varying duty cycles

duty cycle changes faster or slower. The advantages of using PWM is that there is low noise interference due to the systems constant frequency; interference can be predicted. Regardless of the current pull, the number of switching operations doesn't change. Making light current pulls result in higher number of operation loss, and lower efficiency.

3.5.2.2 Pulse Frequency Modulation

Pulse Frequency Modulation is similar, in that it uses a variable (instead of fixed) duty cycle, to turn the voltage on and off. Depending on the load, the next time the voltage turns on varies, for example, if the load decreases, the frequency of the duty cycle increases. This increases efficiency regardless of the load, however,

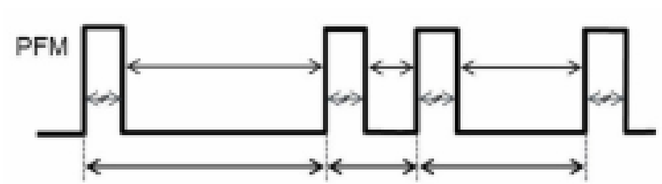


Figure 3.5.5. Variable off-time; fluctuating duty cycleVariable off-time; fluctuating duty cycle(Texas Instruments)

PFM circuits are more susceptible to noise, making the filter process difficult to manage. Due to the possible nature of other sensors, PWM may be the better modulation circuit for our project.

3.5.2.3 Hysteresis and Hysteresis-based Voltage Regulation

Hysteresis and hysteresis-based control come to be the simplest signal control (making it naturally more stable), most cost-effective, and fastest. Using only a

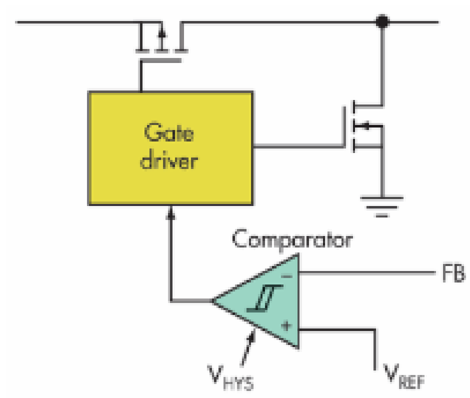


Figure 3.5.6. Hysteresis Voltage Regulator circuit

comparator and a reference voltage, this control type has direct control of the output voltage. The latency delay is affected by the gate driver and comparator and there is no bandwidth error amplifier that the "difference" error must pass through. It seems the only disadvantage is that there is no clock, or duty cycle, only the components on hysteresis amount; making it potentially inaccurate.

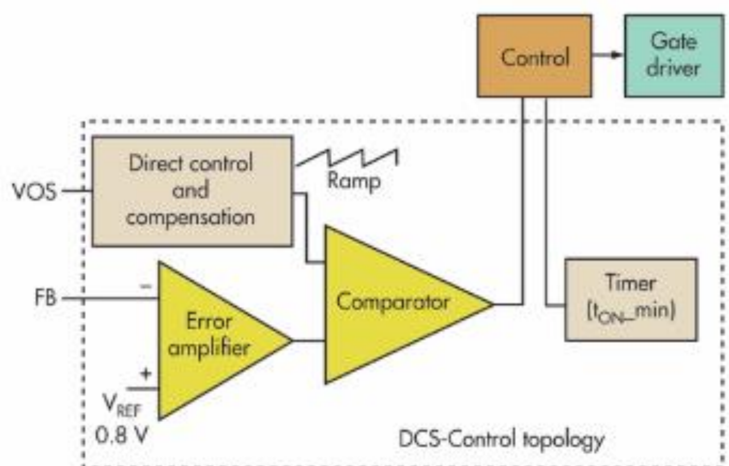


Figure 3.5.7. Hysteresis-based Voltage regulator circuit

Hysteresis-based control takes features from previous voltage regulation methods and the hysteresis method. It uses comparators, an error amplifier, a feedback loop (for stability), and a pace not set by a clock. The rate of the hysteresis-based control is created using a special system connected with the output and input voltage. The most notable disadvantage would be that it cannot be synchronized with a clock. For this application, despite featuring low power alternatives, accuracy and synchronization is still critical, and hysteresis and hysteresis-based control circuit may not satisfy the requirements for the task.

3.5.2.4 Buck-Boost Converting Voltage Regulation

The last method, buck-boost converter, takes the two separate methods buck (step-down) and boost (step up), and combines them into one circuit. Using the advantages of both methods becomes particularly useful when incorporating a DC battery. As a DC battery charges, using a buck regulator may be more useful. But if the DC battery charge is lower than the necessary regulated output voltage, boost regulation becomes more helpful. Having one circuit that switches between the two, using Pulse Width/Frequency Modulation as a control unit, makes this method most useful for a battery/solar-powered application. Texas Instruments makes custom Buck-boost inverting voltage regulators that will depend solely on our PCB design.

The switches in Figure 3.5.7 can either be Bipolar Junction Transistors (BJTs) or Metal Oxide Semiconductor Field Effect Transistor (MOSFET). For this application, and for efficiency, MOSFETs are most the best decision.

3.5.3 Technology and Product Comparison

Using the research above, the three voltage regulators can be selected and ordered to match requirement specifications. Given the pros and cons, a few types of Voltage regulators will be selected.

Table 3.5.1. Voltage Regulator Technology Comparison

Voltage Regulator	Type	Pros	Cons
Shunt	Linear	Simple circuit, Low ripple/emf interference	Draw current to ground; can only buck
Series	Linear	Won’t pull full current regardless of load	Can only buck
PWM	**Switching**	**Highest efficiency**	**More complex circuit**
PFM	Switching	High efficiency regardless of load	May cause heavy interference with other electronics
Hysteresis	Switching	Simple and stable circuit	Not synchronized
Hysteresis-based	Switching	Low power and stable	Not synchronized
Buck-Boost	**Switching**	**Wide application**	**More complex circuit**

3.5.3.1 Battery Source to 12V Regulation

The 12V DC Li-ion battery outputs 12V, for the first voltage regulation, it may need to boost up to 12V if the battery depletes its charge too much. However, if it goes even 1% over 12V it could mess up the system. The first regulator maintains this voltage regardless of battery level. Since we can guarantee that the maximum output is no more than 12V choosing a product with a max input voltage of 12.5V will provide an agreeable factor of safety for the input voltage. A short summary of products compared is presented in Table 3.5.2, and detailed examination in the sections to follow.

Table 3.5.2. Source to 12V Voltage Regulator Product Comparison

Manufacturer-Model	V(in) V	V(out) V	I(out) A	Features
TI-TL494	7.0-40.0	<40.0	200m	Incredible versatility, simplicity
Microchip-LM2576	4.0-40.0	3.3/5.0/12	3A	High-function, High output current and efficiency

3.5.3.1.1 Texas Instruments TL494 PWM Regulator

Texas Instruments leads the integrated chip industry, delivering high-quality, customizable/adjustable, and low-cost modules to suit any project from hobby-ist to industrial applications. The TL494 is a Pulse Width Modulation Controller specifically design for power-supply control, with uncommitted outputs for 200mA source current. It has a recommended operating temperature capped at 85°C. The most notable feature, according to it's website on Texas Instruments is its incredible simplicity. It utilizes only two error amplifiers, an adjustable oscillator, a DTC comparator, a pulse-steering control flip-flop, a 5V-5% regulator and an output-control circuit.

Texas Instruments has this product for $0.70, with shipping between 2-3 business days and minimum order quantity of one. Digi-key sells this product for $0.74, shipped immediately, and minimum order quantity of one. Mouser electronics has a factor lead time of 28 weeks when the product is not in stock. At the time of this report, the product is in stock with a minimum order quantity of one for $0.61 each.

Table 3.5.3. Texas Instruments TL494 Supplier Comparison

Product Supplier	Min. Quantity	Shipping time	Price per 1 unit
Texas Instruments	1	2-3 days	$0.70
Digi-key	1	Immediately	$0.74
Mouser Electronics	**1**	**28w lead (imm.)**	**$0.61**

3.5.3.1.2 Analog Devices LT8708 80V Buck-Boost Controller

Since its inception in 1965, Analog Devices has been providing innovation teams in automotive, industrial, and communication with unique and custom solutions. Analog Devices provide a wide variety of high-performance integrated circuits, ranging from analog to digital signal processing. The LT8708 is supplied by a wide input voltage range of 2.8V to 80V to regulate an output voltage range from 1.3V to 80V. The included synchronous rectification provides up to 99% efficiency and allows for bidirectional charging. This product is brand new to Analog Devices and will need to be ordered ahead of time. The current manufacturer lead time is unknown, making the product undesirable until further notice.

3.5.3.1.3 Texas Instrument's LM25118 Buck-Boost Controller

Similar to the TL494 and also designed by Texas Instruments, the LM25118 Wide Voltage Range Buck-Boost Controller works a little differently from the regulator. It will work whether the input voltage is below or above the output voltage, switching to buck if the input is above 12V, and boost if the input is below 12V. The accepted input voltage ranges from 3V to 42V, completely encompassing any possible battery DC supply. The buck-boost controls the output to always be 12V, featuring smooth transitions between the two modes, programmable soft-start time, ultra-low shutdown current, and thermal shutdown. Because of Texas Instruments Sample program, the design team will be able to secure free samples for testing, and have no need to compare possible suppliers.

3.5.3.2 12V Regulation to 5V Regulation Product Comparison

To power the Bluetooth module and Display, a 5V regulator must be integrated. A short summary of products compared is presented in Table 3.5.2, and detailed examination in the sections to follow.

Table 3.5.4. 12V to 5V Voltage Regulation Product Comparison

Manufacturer-Model	V(in) V	V(out) V	I(out) A	Features
muRataPS-NCS12S1205C	12.0	5.0	2.4	84-88% efficiency, UVLO, thermal shutdown
TI-PTH08080WAH	4.5-18.0	0.9-5.5	N/A	93% efficiency, over-current/thermal protection
Adafruit-MPS2307	4.75-23.0	0.925-20.0	3.0	80-93% efficiency, high thermal protection, simple

3.5.3.2.1 MuRata Power Solutions NCS12S1205C

MuRata Power Solutions meets the demands for advanced design, reliable standard products that lead the market in efficient power and high-density technology. MuRata PS's isolated NCS12 series satisfy the UL 60950 standard and UL 94v-0 materials, with a wide range of input voltage (to potentially be reused for lower voltage regulation). The series also features thermal shutdown, no electrolytic capacitors, Under Voltage Lock Out, and current fold back. The specific part being considered has a high efficiency, between 62-88% for load ranging from 10-100%, displayed in Figure 3.5.8. The NCS12S1205C also features a high temperature operation, which will be beneficial for the high temperature environment that the system will be suspected to. This feature is displayed in Figure 3.5.9.

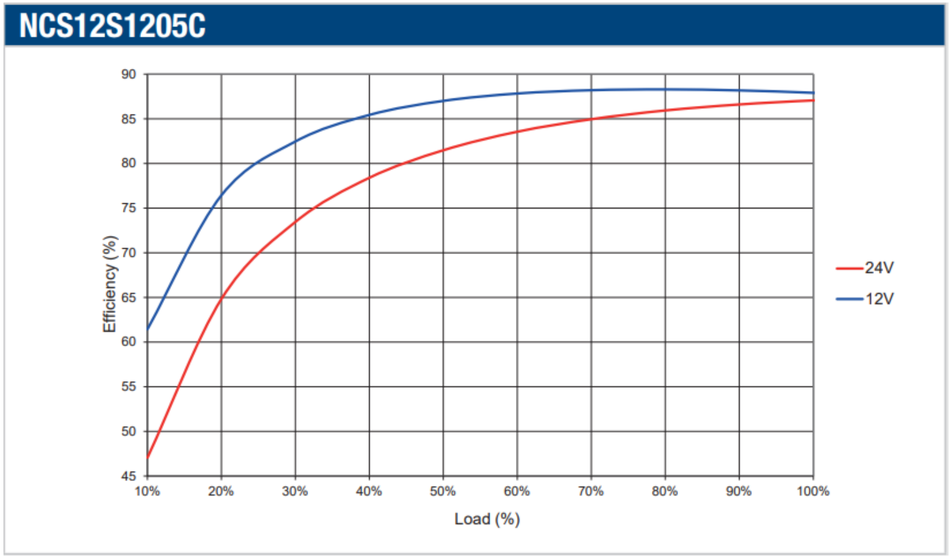


Figure 3.5.8. MuRata PS NCS12S1205C efficiency to load (%)

The final consideration is the price and shipping time, at approximately $22.00 from Future Electronics is the least expensive option, with a minimum order quantity of 15, shipped immediately. Newark ships 2-3 business days, with a minimum order quantity of 1, priced at $30.46 each. TTI prices this product at $28.35, with a minimum order quantity at 1, with a 13 week manufacturer lead time.

Table 3.5.5. NCS12S1205C Supplier Comparison

Product Supplier	Min. Quantity	Shipping time	Price per 1 unit
Future Electronic	15	n/a (immediately)	$22.00
Newark	1	2-3 days	$30.46
TTI	1	13weeks	$28.35

3.5.3.2.2 Texas Instruments PTH08080WAH

Texas Instruments leads the integrated chip industry, delivering high-quality, customizable/adjustable, and low-cost modules to suit any project from hobby-ist to industrial applications. The PTH08080W features a 4.5-18V input voltage range with a 0.9-5.5V adjustable output voltage, up to 93% efficiency, on/off inhibit, UVLO, Overcurrent and Over-temperature protection, and standard approvals UL/CUL 60950, and EN60950. This product provides a very high efficiency regardless of working current, approximately 85% and higher for currents above 0.4A. One of the features to consider against the product, is that it's operating temperature caps at 85°F, which may not function well enough for the high temperature application (further testing will determine actual system environment). Pricing for the PTH08080WAH is a lot cheaper than muRata's option, with TI's store offering $9.53 per unit, shipped within 2-3 business days, with a minimum

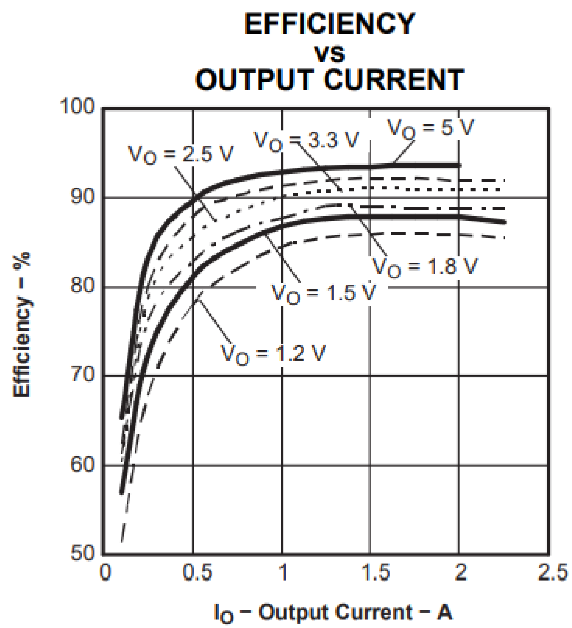


Figure 3.5.10. Texas Instruments PTH08080W Efficiency vs Output current for 12V input

order quantity of one. Digi-Key offers $7.92 per unit, shipped immediately, with a minimum order of one. Newark also has a minimum order of 1, $7.62 per unit, and delivered in 5-7 days. The most notable consideration for this product, is the option

to receive a free sample through Texas Instruments Sample Program.

Table3.5.6. PTH08080WAH Supplier Comparison

Product Supplier	Min. Quantity	Shipping time	Price per 1 unit
Texas Instruments	1	2-3 bus. days	$9.53
Newark	1	immediately	$7.92
Digi-key	1	Immediately	$7.62

3.5.3.2.3 Adafruit UBEC DC/DC Step-Down Converter (1385)

Adafruit is well known in the electronic community for providing reliable solutions to hobby-ists world-wide. Providing low-cost, simple products with all the community and technical support needed for first-timers or experienced-users. This product uses a MP2307 synchronous rectified step-down converter, with a input voltage range from 4.75V to 23V and outputting an adjustable voltage from 0.925V to 20V. The MP2307 has a 95% efficiency, over current protection, and IVLO, rather than UVLO. The MP2307 has a thermal shutdown at 160°C, which is enough factor of safety for this product’s purpose.

Due to MPS's collaboration with Adafruit, the datasheet comes with a PCB guide. Adafruit offers this product for $9.95, shipped immediately, whereas Monolithic Power System requests quotes to provide instant prices (possibly for buck purchase).

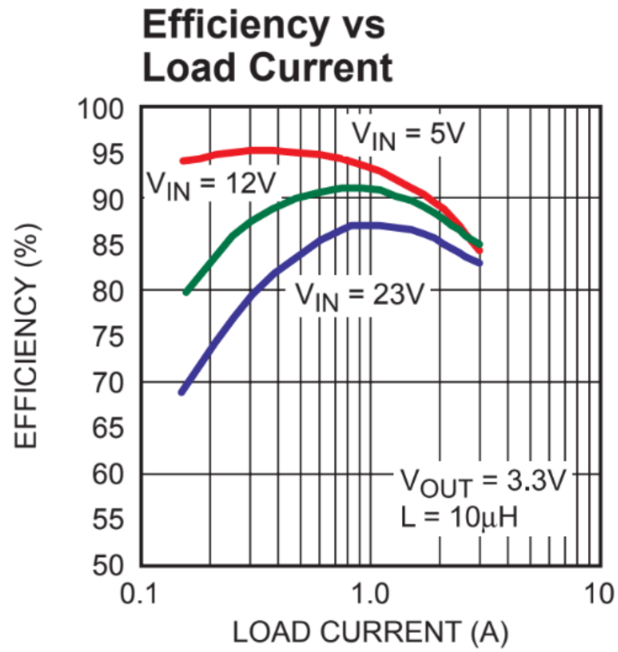


Figure 3.5.11. Adafruit – MP2307 Efficiency vs Load Current

3.5.3.2.4 Texas Instruments LM2576

Another Texas Instruments regulator, but this is an adjustable buck regulator. The LM2576 takes a 12V voltage input and outputs 5V. Because of the previous lab work and Texas Instruments no charge Sample program, this is the most obvious choice for our design.

3.5.3.3 5V Regulation to 3.3V Regulation

Finally, to power the Microcontroller Unit and all remaining sensors, a 3.3V regulator must be incorporated. A short summary of products compared is presented in Table 3.5.5, and detailed examination in the sections to follow.

Table 2.5.7. Product Comparison of 5V to 3.3V Voltage Regulators

Manufacturer-Model	V(in) V	V(out) V	I(out) A	Features
TI-PTH08000W	4.5-14.0	0.9-5.5	<=2.25	85% efficiency, UVLO, over-current/thermal protection
MicroChip MIC4720	2.7-5.5	>1.0	<2.0	94% efficiency, over-thermal/current
Adafruit TSR12433	4.75-32.0	3.3	<1A	91% efficiency, low standby current

3.5.3.3.1 Texas Instruments PTH08000W

Texas Instruments leads the integrated chip industry, delivering high-quality, customizable/adjustable, and low-cost modules to suit any project from hobby-ist to industrial applications. The PTH08000W features an input voltage range of 4.5V to 14V, with a wide output voltage range of 0.9V to 5.5V, with efficiencies up to 94%. This product also features UVLO, and over-current/temperature protection, with the ambient temperature range capping at 85°C. If the product is run at least

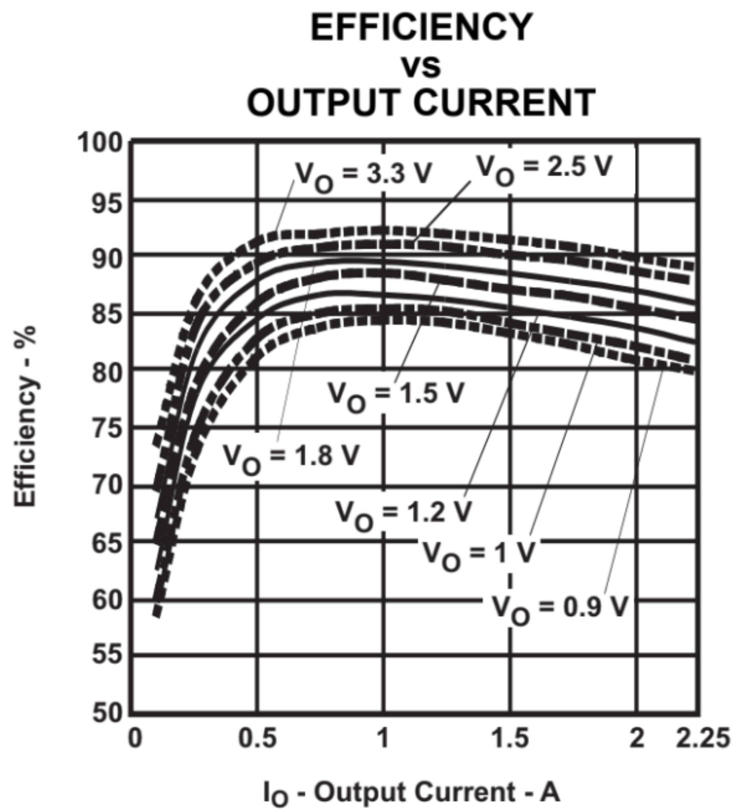


Figure 3.5.12. TI PTH08000W Efficiency vs Current with 3.3V out

at 0.3A, the product can expect to operate with 85% or higher efficiencies.

Texas Instruments offers a sample program, however, if a sample cannot be secured, they sell each unit at $9.32, with a minimum of one order quantity, shipped immediately. Digi-key sells each unit at $8.31, with a minimum order of one, in-stock, and shipped immediately. Mouser Electronics has a 20week factory lead-time, but when the piece is in stock, ships immediately at $8.32 with a minimum of one order quantity.

Table 3.5.8. TI PTH08000W Supplier Comparison

Product Supplier	Min. Quantity	Shipping time	Price per 1 unit
Texas Instruments	1	2-3 bus. days	$9.32
Digi-key	1	immediately	$8.31
Mouser Electronics	1	Immediately(20 week lead time)	$8.32

3.5.3.3.2 Microchip MIC4720 Buck Regulator

Microchip Technology Inc. is an embedded control solutions company, a competitive provider for IC solutions, providing lower cost and a faster market to customers worldwide. The MIC4720 has a supply voltage range of 2.7V to 5.5V,

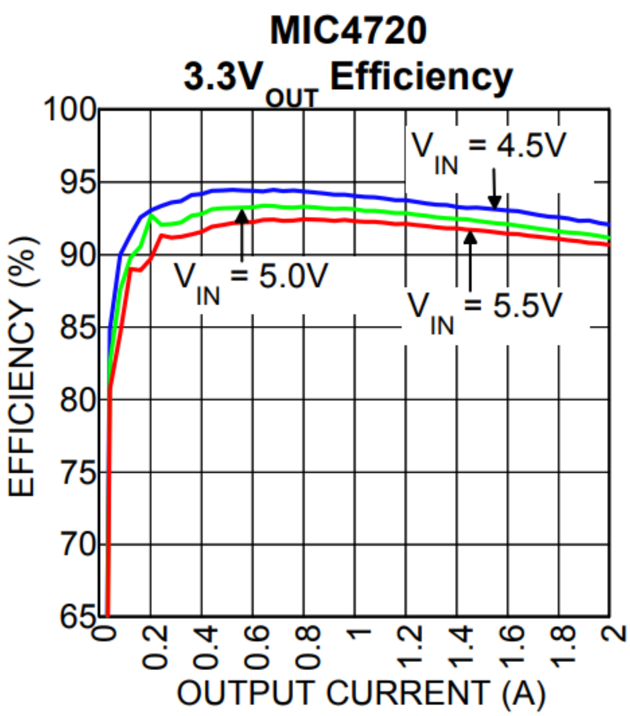


Figure 3.5.13. Microchip MIC4720 Efficiency vs Current at 3.3V out

with an adjustable output voltage down to 1.0V and output current up to 2A. It features up to 94% efficiency, and thermal shutdown and current limit protection and operating temperature up to 125°C.

Purchasing this product from Microchip may be impossible, as purchasing options are in multiples of 100, 2500 and 5000. This is way more than needed for this application, so other options must be considered. The other option offered is through Digi-key, priced at $0.90 per unit, with a minimum quantity option of one, shipped immediately.

3.5.3.3.3 Adafruit TSR12433 - Mini DC/DC Buck Converter

Adafruit is well known in the electronic community for providing reliable solutions to hobby-ists world-wide. Providing low-cost, simple products with all the community and technical support needed for first-timers or experienced-users. The TSR12433 has a fixed 3.3V regulated output with a supply voltage range of 4.75V

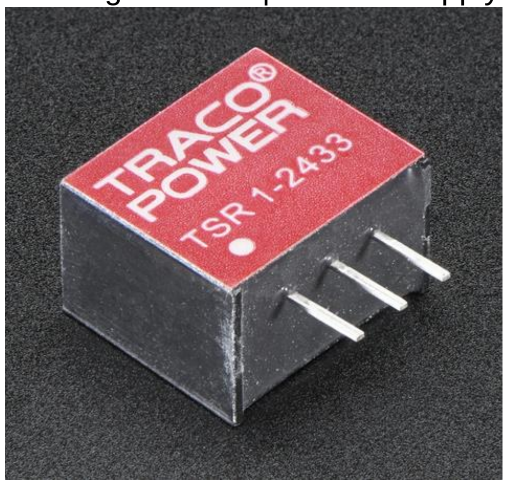


Figure 3.5.14. Adafruit TSR12433 Mini DC/DC Buck Converter

to 32V up to 1A output current, with up to 91% efficiency (non-variable). The product operating temperature caps at 85°C with excellent line/load regulation and low standby current, but no over-current/temperature protection.

Adafruit offers this product for $14.95 shipping immediately, with a minimum order quantity of one. Newark ships this product immediately with a minimum order quantity of one as well, but offers the product for $6.12. Mouser Electronics can ship this piece immediately when in stock, with a factory lead time when not in stock, at $6.07 per unit, minimum order of one.

Table 3.5.9. Adafruit TSR12433 Supplier Comparison

Product Supplier	Min. Quantity	Shipping time	Price per 1 unit
Adafruit	1	2-3 bus. days	$14.95
Newark	1	immediately	$6.12
Mouser Electronics	1	Immediately (8w lead)	$6.07

3.5.3.3.4 Original work (LM2576 lab work)

Another Texas Instruments regulator, but this is an adjustable buck regulator. The LM2576 takes a 5V voltage input and outputs 3.3V. Because of the previous lab work and Texas Instruments no charge Sample program, this is the most obvious choice for our design

3.6 MOSFETs

The MOSFET (or Metal Oxide Semiconductor Field Effect Transistor) is a type of transistor (a semiconductor device with three connections, capable of amplification or rectification) that utilizes an insulated "Gate" and a thin layer of silicon dioxide n- or p-channel Source and Drain. The Metal gate behaves like a large capacitor, with the resistance across the insulator reaching Mega-ohms. Because of this high resistance, there is absolutely no current flow into the gate. When a positive charge is placed across the gate for a NMOS (n-type), it attracts electrons, creating a n-type channel across the top of the substrate, closest to the insulator, allowing electrons to flow from source to drain. This low resistivity to being “ON” and high resistivity to being “OFF” makes MOSFETs extremely effective at switching. An electric field is generated through the channel, which brings handling to attention, as the MOSFET can easily be damaged if precautious are not taken. There are two types of MOSFETs: Depletion and Enhancement, depending on the design criteria. Enhancement mode pertains to a MOSFET who is “OFF” until turned “ON”. Whereas a MOSFET in Depletion mode, is always “ON” until a channel is made, in which it turns “OFF”. Typically, NMOS transistors are used in enhancement mode, and PMOS transistors are used in depletion mode. But most technology utilizes a combination of them, or CMOS, Complementary MOS. If we utilize buck-boost converter switching voltage regulator, using a NMOS transistor only will be more than necessary.

3.7 Security Mode Using Proximity Sensors

As demonstrated in the hardware block diagram, the product will feature different sensors, such as motion detection sensors and environment sensors. The motion detection sensors will be used to enable the product to go into security mode where the user will have the option to activate this feature through a mobile device and can leave his or her belongings while knowing the items will be safe. In security mode, the motion security sensors will be activated. If someone gets too close to the umbrella in an attempt to steal the user's belongings, the motion detecting sensors will trigger the alarm system components in order to dissuade theft. The other sensor that will be on the product is a humidity and temperature sensor that will be displayed to inform the user.

In other to activate the alarm system, a motion detection sensor will be used and here different types of sensors will be explored. Types of motion sensors include: passive infrared, reflective infrared, microwave, ultrasonic, and a combination. The goal of the sensors used by the product is to be efficient while maintaining a low cost and a high ease of use.

3.7.1 Passive Infrared Sensor

The most common method of detecting motion, a passive infrared sensor is a pyroelectric sensor "that generates a surface electric charge when exposed to heat in the form of infrared radiation." [1] Changes within the charges and detected heat can be measured and analyzed to obtain results. Passive infrared sensors have limited range if used on its own; however, this range can be enhanced by using a focusing device in front of the pyroelectric sensor. Several focusing devices include: infrared window, pinhole lens, shadow lens, and Fresnel lens. [2] The most common focusing device is a Fresnel lens. The purpose of this lens is to focus infrared radiation from a long distance into the sensor for it to be read. A passive infrared motion sensor module [3] can be added to the umbrella and be used to set off the alarm system if someone gets too close. However, for a passive infrared sensor to work best, an object has to pass across the sensors instead of approaching it so that the changes in infrared detection can be accurately measured. Due to this fact, this type of sensor might not be the best suited for our purpose. Figure 3.7.1 illustrates what a typical passive infrared sensor and Fresnel lens looks like.

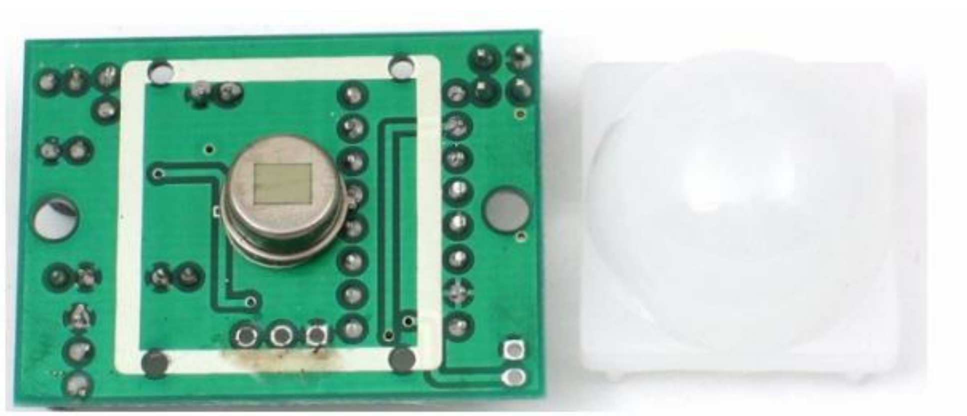


Figure 3.7.1. Left: PIR Sensor module. Right: Fresnel Lens by adafruit.com [3]

3.7.2 Reflective Infrared Sensor

This type of sensor also works with infrared radiation, but no longer requires the object approaching it to be emitting infrared radiation to work properly. This type of sensor produces its own infrared signal with an emitter that is sent out, for a very limited range, until it reaches an object and that object reflects the signal back to the sensor where an infrared receiver takes the signal back. This type of sensor excels at detecting a stationary object within the sensors field of view or an object that is approaching the sensor unlike the passive infrared sensor where an object has to pass through the sensor's field of view. The downside of using this type of sensor is that it has a limited range compared to the passive infrared

Figure 3.7.2. IR LED Emitter and Receiver Pair

sensor. Below as shown in table 3.7.1, is a very informative table depicting the main differences between passive and reflective. The reflective infrared sensor can be created using infrared LED emitters and an infrared LED receiver [5], depicted in figure 3.7.2. These components are inexpensive and would drive the cost of our product down. This type of sensor also is easy for a user to enable and

Table 3.7.1. PIR vs RIR

Characteristics	**Pyroelectric Infrared Sensor (PIR)**	**Reflective Infrared Sensor (RIR)**
Sensor Type	Passive	Active
Infrared Wavelength	5 to 15 micrometers	940 nanometers
Detects IR from body	Yes – Detects IR emission	No – needs LED IR source
Detects Metal Objects	No	Yes
Detection Range	More than 100 feet	Up to 20 feet
Detects movement from side to side	Yes	Yes
Detects movement towards and away the device	No	Yes
Field of View	Wide with Fresnel Lens	Only narrow
False positive due to rain or snow	No	Yes
Power Consumption	About 50 microamps	About 200 miliamps

focuses more on what the security mode needs to do; detect someone approaching the product and the user's belongings.

3.7.3 Microwave Sensor

Similar to the reflective infrared sensor, this type of sensor produces electromagnetic waves [6] that are reflected back by an object to the sensor and picked up by the sensor to be analyzed in order to detect motion. Microwave sensors are typically used in areas where the temperature is very low and infrared radiation might not be able to be obtained from someone, or an environment that has high ambient temperature [7] where differences in infrared radiation might be difficult to discern. These types of sensors tend to be slightly more costly and while it might be a good choice due to the high heat of the environment of where the product will be placed, the cost of the sensor will drive the cost of the product higher. Also, the fact that it produces an electromagnetic field will produce unnecessary design constraints for the product. A typical microwave sensor is shown below in figure 3.7.3.

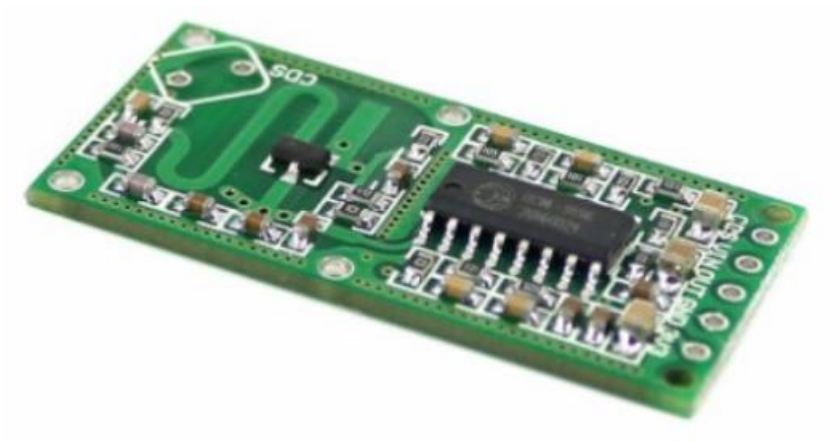


Figure 3.7.3. Microwave Radar Module

3.7.4 Ultrasonic Sensor

Much like the reflective infrared sensor and the microwave sensor, the ultrasonic sensor also falls under the active sensor category where it works by emitting a burst of a signal that travels to an object and the signal returns to the receiver part of the sensor. The ultrasonic sensor emits high frequency acoustic waves that are inaudible to human ears. The typical range for the sensor is 2 centimeters to 4 meters [8]. The device depends on the sound to travel to the object and return to the sensor; therefore, the sensor is limited to the speed of sound for operation. The speed of sound through a gas has to consider the humidity and temperature of the gas. The humidity of the gas has a very small effect on the total speed of sound; this effect can be ignored. The temperature has a bigger effect on the total speed of sound and to produce accurate results, the temperature should be considered when using the speed of sound to determine how far an object is [9]. The cost of a ultrasonic sensor is somewhat similar to that of a microwave sensor. While temperature can affect the accuracy of the ultrasonic sensor, these changes can be adjusted by tailoring the speed of sound equation to consider temperature, thus improving the accuracy. The ultrasonic sensor module in figure 3.7.4 is a common module used for ultrasonic motion detection, but it has a low measuring angle [8] that can be resolved by adding more modules. Lastly, the ultrasonic sensor does not produce unwanted design restrictions via the creation of electronic magnetic fields and due to this, an ultrasonic sensor will easier to incorporate into the product design.

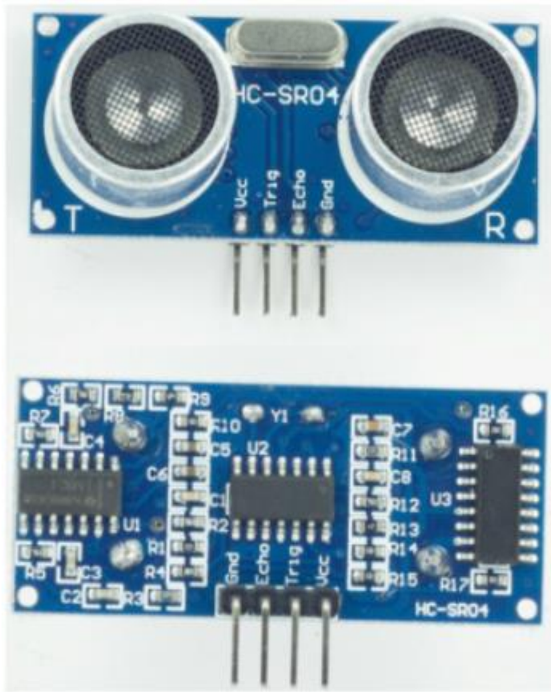


Figure 3.7.2. Ultrasonic Sensor Module

Table 3.7.2 below compares the characteristics of the microwave sensor and the ultrasonic sensor.

Table 3.7.2 Microwave vs Ultrasonic

Characteristics	Microwave Sensor	Ultrasonic Sensor
Sensor Type	Active	Active
Working Voltage (V DC)	4 ~ 28	5
Working Current (mA)	3	15
Working Frequency	3.1 GHz	40 KHz
Max Range	7 m	4 m
Min Range	Not specified	2 cm
Detects movement from side to side	Yes	Yes
Detects movement towards and away device	Yes	Yes
Measuring Angle	360 °	15 °
Affected by environment temperature	No – Doppler Radar	Yes – Depends on the Speed of Sound

Despite the Microwave sensor having better characteristics compared to the Ultrasonic sensor, the product does not require high accuracy in determining what object is approaching the umbrella. The Ultrasonic sensor fits the product in the sense that it accomplishes what the simple security function is supposed to do; to have a method of detecting motion as someone who is wanted approaches the umbrella.

3.7.5 Combination of Sensors

To maximize the security mode feature of the umbrella, a combination of sensors will be considered. Based on the above discussion and research, the combination of reflective infrared sensors with ultrasonic sensors is a strong candidate where the ultrasonic module will focus on looking for objects that approach the umbrella and the reflective infrared will cover the area that the ultrasonic sensor cannot detect.

3.8 Temperature and Humidity Sensors

To accommodate the user with as much convenience and information as possible, a sensor that can determine the ambient temperature and humidity will prove to be beneficial for the product. The measured temperature and humidity can be displayed for the user and the user can now make an informed decision on whether to stay at their location or go somewhere else depending on preference. Moreover, having the ability to measure temperature and humidity will be used to improve the accuracy calculations for the speed of sound as mentioned above should the ultrasonic sensor be used. DHT11 and DHT22 are very common temperature and humidity sensors that are inexpensive and will serve the purpose of obtaining desired ambient temperature and humidity. DHT11 and DHT22 both operate at the same voltage; however, DHT11 is slightly cheaper and has a lower operating range from 0°C to 50 °C where DHT22 has a slightly higher price and a higher operating range from -40 °C to 80 °C [10] [11].

One more sensor to consider is the HTU2XY(F) Sensor. This sensor also senses and measures both humidity and temperature and is capable of providing signals that are useable by a microcontroller in I^2C format. The sensor is optimally calibrated to record and generate calibrated signals that provide readings of very high accuracy. Moreover, this sensor requires very low power to operate and due to its small size, it fits perfectly for projects that have a high constraint in cost and space. Table 3.8.1 provides more information regarding the parameters and compares all of the sensors while figure 3.8.1 shows what the DHT11 and DHT22 components look like.

Table 3.8.1. Specifications for DHT11 and DHT22

Parameters	DHT11	DHT22
Working Voltage (V DC)	3 ~ 5.5	3.3 ~ 5.5
Temperature Operating Range (°C)	0 ~ 50	-40 ~ 80
Temperature Accuracy (°C)	± 1 ~ 2	± 0.5
Humidity Operating Range (%RH)	20 ~ 80	0 ~ 100
Humidity Accuracy (%RH)	5	2 ~ 5

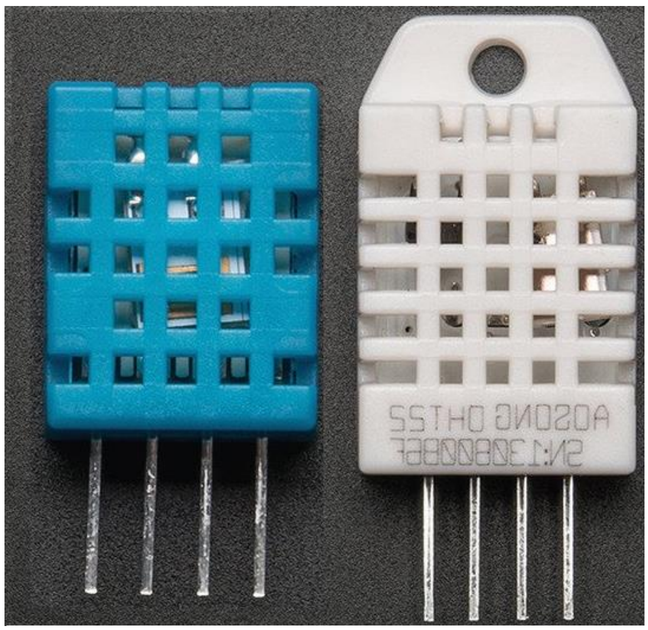


Figure 3.8.1. Left: DHT11 Right: DHT22

Due to the nature of the location of where the product will be, the typical temperature range of the environment will be 3 ~ 38 °C. Furthermore, based on the specifications and requirements, the product must be able to measure external environmental temperature with no greater error than ± 2. Also, it must be capable of measuring humidity with no greater error than ± 5%. Based on this analysis, the temperature and humidity component that best suits the product's needs is DHT11 as extremely accurate readings are not required by the product nor is a wide range of readings a critical part of the design.

3.9 Microcontroller Architectures

With the increasing number of components and features that the product will offer, a microcontroller has to be considered and implemented into the design. Three different computer architectures for different microcontrollers are explored and their advantages and disadvantages are discussed.

3.9.1 Modified Harvard Architecture

The Modified Harvard Architecture is a computer architecture that, as its name implies, is modified version of the Harvard Architecture in where it enables a higher performance for data and instruction access [17]. The Harvard Architecture works by separating data and code from each other where each can be accessed concurrently allowing parallelism depicted in figure 3.9.1. A common family of microcontrollers that use the modified Harvard Architecture are the Atmel AVR®; more specifically, ATmega328/P which uses a 8 Bit RISC architecture.

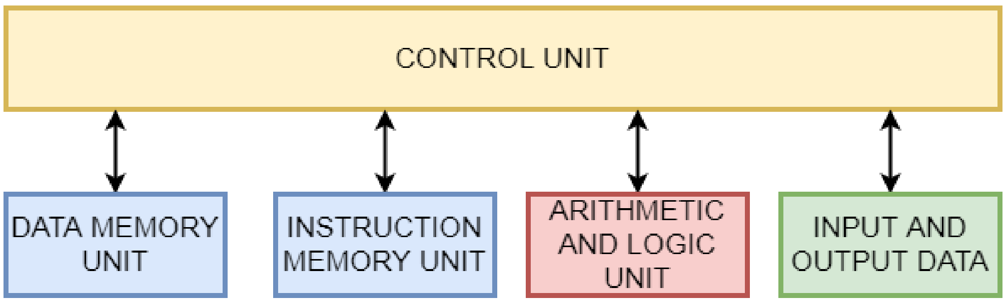


Figure 3.9.1. Harvard Computer Architecture

The ATmega328/P, produced by Atmel also known as Microchip Technology Inc., is the microcontroller found in the Arduino UNO development board shown in figure 3.9.2. Since the foundation for the architecture of this microcontroller is based on the Modified Harvard architecture, the ATmega328/P allows for parallel programming. The ATmega328/P requires an operating voltage from 1.8 V to 5.5 V. The current drawn when the microcontroller is on active mode at 1.8 V is 0.2 mA and 0.75 µA on idle and offers 32 pins for input, output, and communication; moreover, a 10 bit analog to digital converters are offered by the microcontroller for reading analog data. [18]

Figure 3.9.2. ATmega328/P in Arduino UNO development board [19]

3.9.2 Von Neumann Architecture

A very popular architecture that is still used today in modern computers. Revolves around the concept of storing instruction and program data together in the same memory [12]. The architecture is composed of four major components: control unit, arithmetic and logic unit, memory unit, and registers. These components together can also take in input data from another device and produce output data to another device. Due to having both instruction and program data be stored together in the same memory, the Von Neumann architecture is incapable of handling parallelism where more than one set of instructions can operate concurrently; also, program data and stored data cannot be used at the same time.

As mentioned above, the Von Neumann Architecture is susceptible to harsh slowdowns where the total throughput of a computer using this architecture is hampered. This issue is referred to as the Von Neumann Bottleneck. This architecture only has one bus that it can use to move data from a memory unity to the central processing unit. Fortunately, there are ways to improve the throughput of a machine using the Von Neumann Architecture. Adding several levels of cache for data to be stored within the central processing unit will considerably improve the throughput by not requiring the use of the single bus to the memory unit[13]. A simplified diagram of the architecture is demonstrated on figure 3.9.3.

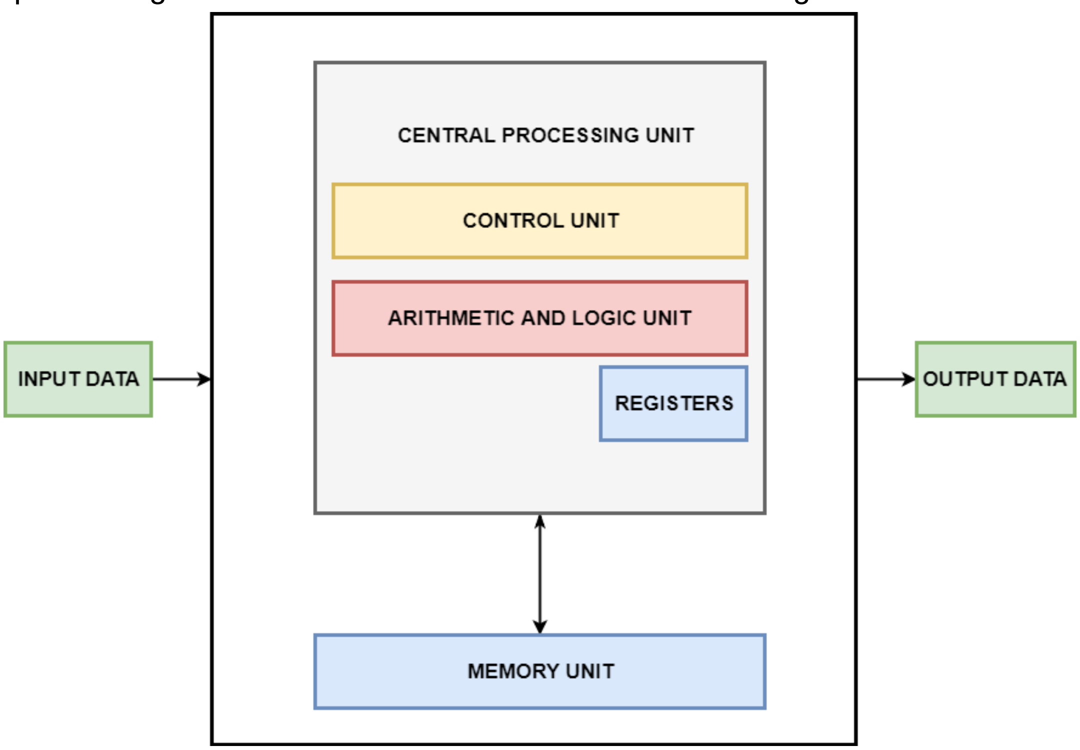


Figure 3.9.3. Von Neumann Architecture

A very common microcontroller that also has a wide range of support articles is the TI MSP430G2 line of microcontrollers from Texas Instruments shown in figure 3.9.4 inside Texas Instruments' LaunchPad development board. These microcontrollers operate at low supply voltages between 1.8 V to 3.6 V and draw very little current at 0.5 µA when standby and 230 µA on active mode to consume very low power. The microcontroller also allows for UART, SPI, and I2C communications and offers 10 bit Analog to Digital converter for moderate accuracy when receiving analog inputs. Another line of microcontrollers, the MSP430FR59 line which operates at a low supply voltage from 2 V to 3.6 V and draws a low amount of current 100 µA/MHz for the active mode and 0.4 µA for the standby mode. Both the MSP430G2 and MSP430FR59 lines use a 16 Bit RISC architecture and are considered to be ultra-low power microcontrollers. One notable advantage for the MSP430FR59 line is that it offers a 12 bit Analog to Digital converter which offers a higher accuracy when reading analog inputs and has a higher pin count for more inputs or outputs allowing the controller to communicate with more devices.[14] [15]

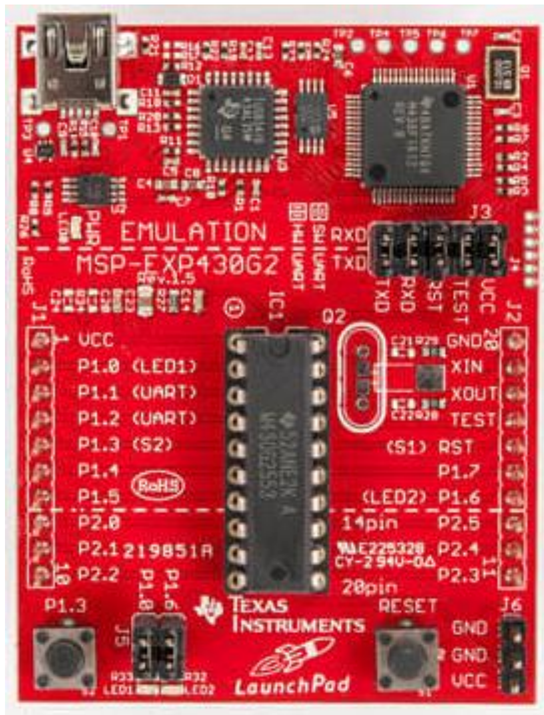


Figure 3.9.4. MSP430G2 in development board. [16]

3.9.3 ARM Architecture

ARM Architecture is the most popular architecture found in embedded systems; found in many smartphones and tablets. The architecture focuses on RISC based machines and improves upon them. The ARM Architecture splits into three categories, the Cortex-MX series, the Cortex-RX series, and Cortex-AX. Cortex-AX series focuses on applications for large systems that require a lot of memory management; in other words, it is made to handle operating systems like Linux. The Cortex-MX and Cortex-RX are intended for embedded devices where Cortex-MX are found in microcontrollers and the Cortex-RX focuses on high performance and throughput where correct timing of interrupts and functions is a critical necessity for real-time and safety-critical systems. For the purposes of this product, Cortex-MX series will the architecture of interest. In summary, ARM

Architectures are based on system on chip where a processing core, clock and reset controller, interrupt controller, peripherals, and memory are all required to be on the same chip and their configuration allows for parallel programming. [20]

As mentioned earlier, the Cortex-MX series ARM Architectures is used for microcontrollers where low voltage supply voltage and low power consumption is desired. Atmel's SAM3X/A series is built on the 32 Bit Cortex-M3 architecture. This microcontroller operates with a voltage supply from 1.62 V to 3.6 V. The microcontroller has a maximum operation speed of 64 MHz. The power consumption while active varies around 1.74 mA to 57.66 mA depending on the core clock while idle power consumption is 2.5µA. Moreover, this microcontroller offers a 12 bit analog to digital converter to offer high accuracy for reading analog signals and a 12 bit digital to analog converting useful for producing accurate analog signals with a digital signal source. [21] SAM3X/A can be found in the Arduino Due development board as seen in figure 3.9.5.

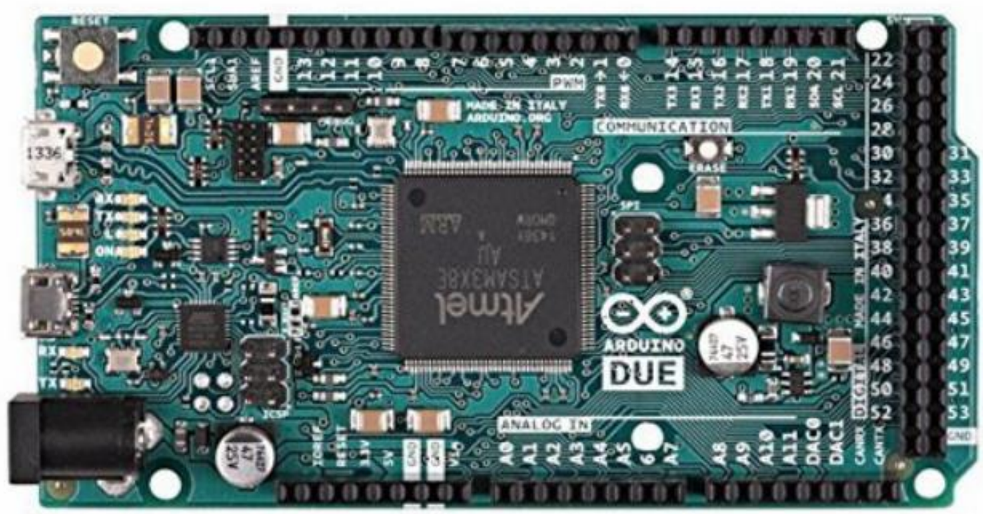


Figure 3.9.5. Arduino Due [24]

Another ARM architecture to consider is the 32 Bit Cortex-M4 found in TI's MSP432 line of microcontrollers and the Atmel's SAM4S line of microcontrollers. The Cortex-M4 focuses on digital signal processing with high performance and high accuracy targeted for power management [22]. The MSP432 line of microcontrollers, found in TI's MSP-EXP432P401R LaunchPad™ Development Kit, operates on a frequency up to 48 MHz and a voltage supply range from 1.62 V to 3.7 V. It is also considered an ultra-low power microcontroller where it only draws 80 µA/MHz when active and as low as 25 nA on low power idle mode. Furthermore, the MSP432 is capable of storing up to 256KB of flash memory and offers a 16 Bit Analog-To Digital converter [23]. Atmel's SAM4S microcontroller operates at a maximum frequency of 120 MHz and a voltage supply of 1.62 V to 3.6 V. SAM4S power consumption depends on its core clock frequency ranging from 0.2 mA to 21.2 mA. While on low power idle, the current consumption is 32 µA. Lastly, similar to SAM3X/A, SAM4S offers a 12 bit digital to analog converter pin.

Table 3.9.1 Microcontroller Comparisons

Microcontroller	ATmega328/P	MSP430G2	MSP430FR59	SAM3X/A	MSP432	SAM4S
Operating Voltage (V)	1.8 ~ 5.5	1.8 ~ 3.6	2 ~ 3.6	1.62 ~ 3.6	1.62 ~ 3.7	1.62 ~ 3.6
Power Consumption	Low	Ultra-Low	Ultra-Low	Low	Ultra-Low	Ultra-Low
Operating Speed (MHz)	20	16	24	84	48	120
Flash Memory (KB)	32	2 ~ 16	4 ~ 16	256 ~ 512	128 ~ 256	128 ~ 2048
On Chip Analog-To-Digital Converter	10 Bit	10 Bit	10 Bit	12 Bit	16 Bit	12 Bit
On Chip Digital-to-Analog Converter	None	None	None	12 Bit	None	12 Bit
Architecture	Modified Harvard	Von Neumann	Von Neumann	ARM Cortex-M3	ARM Cortex-M4	ARM Cortex-M4
Manufacturer	Atmel/ Microchip (Atmel)	Texas Instruments (TI)	TI	Atmel	TI	Atmel

Whichever microcontroller architecture is chosen for the tasks the product must accomplish has to be able to interface Bluetooth communication between components, has to handle analog and digital inputs from the sensors, has to be able to produce analog output through supplementary components to drive speakers, and be able to drive a display screen that will show the user desired and valuable information. Table 3 above can aid in finding the correct microcontroller for the product. Based on all of these demands, a microcontroller that utilizes the ARM architecture is the most probable architecture to be used for the product because of its low power consumption along with its capabilities of handling multiple tasks simultaneously and wide offered support due to its rise in popularity.

3.10 Wireless Communication

The ParaSolar Experience must utilize a method of communication from the umbrella to a mobile device. This communication is used to send data bi-directionally. The microcontroller onboard the umbrella will gather data from its sensors and then relay the obtained data to be displayed on the mobile device for the user to see. Similarly, the mobile device will receive input from the user, mostly in the form of key presses that will need to be sent to the microcontroller with the purpose of prompting a responsive function that the microcontroller can handle.

3.10.1 Communication Types

Many forms of communication between devices exist, including wired and wireless methods. For the purposes of convenience to the user and practicality of the technology, the Parasolar Experience will utilize wireless technology.

There are a few reasons that immediately dissuade the use of a wired technology. The only viable and cheap wired technology to transmit data from the microcontroller to a mobile device would be a serial communication from the microcontroller to the mobile device's USB/Thunderbolt port. Since one of the key features of the ParaSolar Experience is to be able to charge the user's mobile devices, that port will already be in use with a cable supplying power, ruling USB out. Also, it is desired that the user has the capability to communicate with the microcontroller, even while they are away from the umbrella, so that they can still receive updated data from the sensors and activate and control the system's security mode.

After narrowing the decision down to wireless technology, different methods of wireless communication are investigated. These include using Bluetooth modules, Global System for Mobile Communication (GSM) modules, Wi-Fi modules, Zigbee, or radio frequency technology. All of these means of communication need to be explored to find which best suits the application for the ParaSolar Experience. The technology needs to have a sufficient range, use minimal power, be cost-efficient, and not require a myriad of additional hardware that will complicate the system.

3.10.1.1 Bluetooth

The first method of wireless communication that will be explored is Bluetooth. It's primarily used for sending data as packets within a short range. It accomplishes this with Ultra High Frequency (UHF) radio frequency, using the ISM band of 2.4Ghz. Bluetooth is currently handled by the Bluetooth Special Interest Group (SIG). Originally, Bluetooth was standardized by the IEEE as IEEE 802.15.1, until SIG took over management of the specifications of the technology [32].

The frequency range that Bluetooth operates in is 2402-2480 MHz and this is in the aforementioned 2.4GHz radio frequency (RF) band. It uses a method called Frequency-Hopping Spread Spectrum (FHSS) for the radio communication. Spread spectrum provides three improvements, compared to transfer of data on a fixed frequency. It opposes narrowband interference well, intercepting the data signals are also challenging, and lastly bandwidth can be more cleanly used, since it can share the bands of frequency with other devices sending data, meaning less noise [33]. A subset of FHSS that Bluetooth uses is called Adaptive Frequency-hopping Spread Spectrum (AFH). It increases the likelihood of a quality transmission with less interference because it can evade frequencies that are overly populated by skipping them in the process of jumping between frequencies.

Bluetooth has 79 channels assigned to it and each of these channels have a width of 1 MHz [34].

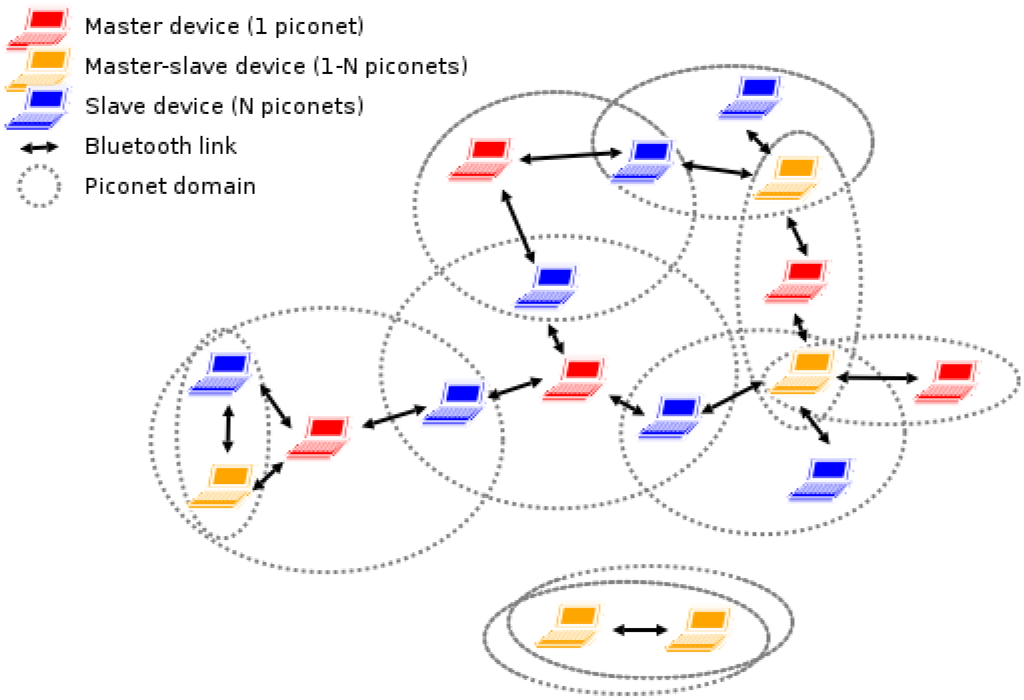


Figure 3.10.1. Bluetooth topology

Bluetooth creates a personal area network (PAN) that uses a master/slave architecture. A single master can connect and communicate with seven slaves simultaneously on a piconet, which is an ad hoc network that does not depend on a preceding infrastructure. All slave devices will inherit the master's clock. The master device will transmit within all even slots, while the odd slots will be when it receives the data. The opposite situation is true for the slave devices. They will transmit within the odd slots and receive in the even ones. Bluetooth uses a packet-based protocol and these packets can be 1, 3, or even 5 time slots in length [35].

The above figure is the topology of the Bluetooth technology. From left to right, it demonstrates a single slave piconet, a multi-slave piconet, and a scatternet, which is made up of more than one piconet, where a device can behave as a slave within one of the piconets, while behaving as a master within a different piconet. The master devices have the ability to form a connection and talk with up to seven slave devices within a piconet. These devices can also reverse their schemes, such that a master can become a slave and vice-versa. A simple example of this is when you are syncing your phone to an automobile's media player with Bluetooth, the media player might begin as the master, since it must initialize the connection, but afterwards it behaves as the slave device, simply receiving the media data that the phone is sending to it. The master device of the piconet may only transmit to a single device at one time. It makes this decision, using round-robin technique, and changes quickly between all the respective slave devices [36].

There are a few different classes that Bluetooth devices are categorized. Bluetooth was created with using low power in a short range application. Since it uses RF, the devices do not need to be optically in view of one another. Its range differs between the classes that the technology is categorized into. The range of Class 3 radios are typically 1 meter. The most prevalent category for portable applications and typically present in phones is Class 2, which has a range of 10 meters. Lastly, Class 1, mainly used in industrial applications has a range of 100 meters. Effective range is diminished by a variety of circumstances, including the quality of both the master and slave device, and also the environmental conditions that enclose the area of operation. Typically, the effective range of the connection is set by the lower classed device. The specifications set forth by Bluetooth require a minimum range of 10 meters, however, no maximum range requirement is set [33].

Table 3.10.1. Bluetooth Class Categorizations and Typical Ranges

Class	Max Permitted Power (mW)	Typical Range (m)
1	100	100
2	2.5	10
3	1	1

3.10.1.1.1 Bluetooth Low Energy (BLE)

There is a newer version of Bluetooth that fits the bill for even lower power use cases. It is a subset of Bluetooth 4.0 and known as Bluetooth Low Energy (BLE). It was developed with a brand-new protocol stack and designed to be powered from a coin cell battery. The ranges of these BLE devices remain very similar to the Bluetooth Classic implementations. Bluetooth Low Energy devices are equipped with an impressive low power idle, or “sleep”, mode. While Bluetooth requires a continuous broadband connection for applications such as streaming audio and video, Bluetooth Low Energy does not require that continuous connection and only comes online when it needs to send a short burst of packeted data at infrequent variables, therefore using much less power and could be a much better choice for our use case. It also has better encryptions for security precautions and the reliability of the connection between nodes in the network are improved [37].

3.10.1.1.2 Bluetooth High Speed

There is also a third type of Bluetooth called “Bluetooth High Speed,” which utilizes a chip that contains Bluetooth and Wi-Fi, making this solution quite expensive. Since incredibly fast transfer rate is not necessarily a requirement, the Bluetooth High Speed option was immediately dismissed [38].

3.10.1.1.3 Adaptive Frequency Hopping

Since Bluetooth and wireless LAN both exist in the 2.4GHz band, there is a chance that collisions occur and will introduce interference, which in turn translates to poor quality of data transfer on that specific frequency. This drop in quality is more evident in real-time transfer of data, like voice communication, as opposed to strictly data transfers. Bluetooth Special Interest Group (SIG) addresses this problem with a solution known as Adaptive Frequency Hopping (AFH) [39].

Before AFH was utilized, Bluetooth simply hopped between frequencies randomly within its 79 channels, in order to avoid the collisions. It did this around 1600 times every second, however, with each additional device added to the surrounding system, the probability of collisions increases. Using this primitive random frequency hopping, provides no avoidance for these collisions [40].

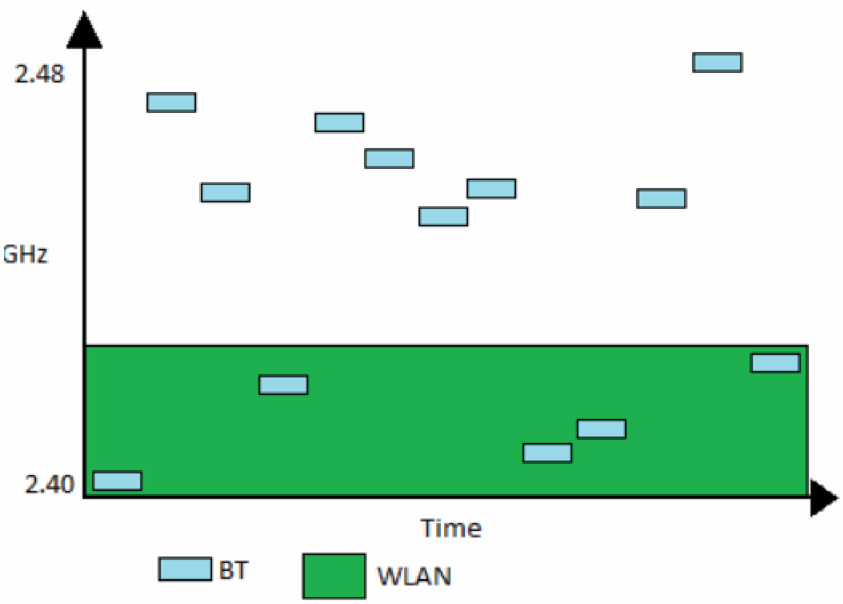


Figure 3.10.2. Random Frequency Hopping and Collisions

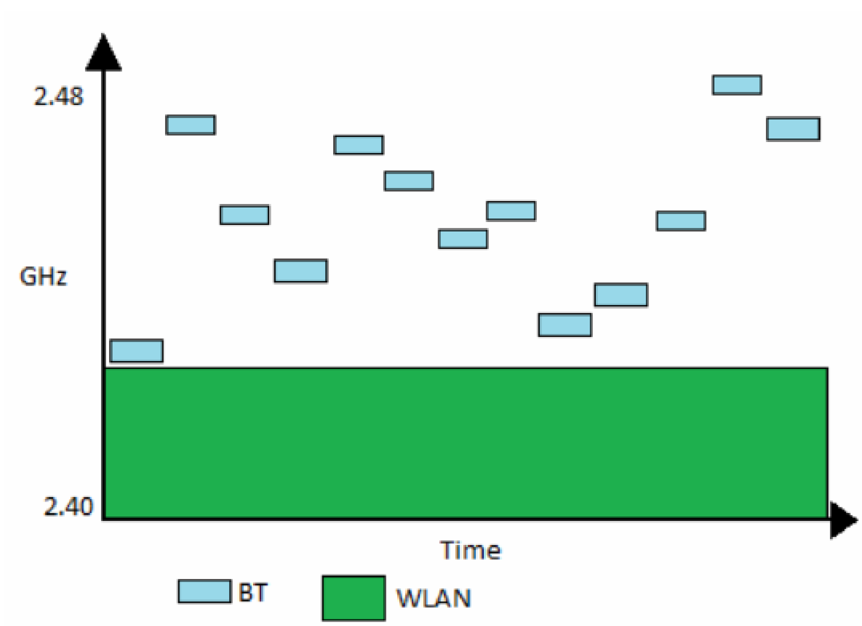


Figure 3.10.3. Adaptive Frequency Hopping Eliminating Collisions

Adaptive Frequency Hopping permits the Bluetooth technology the ability to classify a channel as a fixed origin of interference. Once a channel is labeled as such, it will no longer hop to this channel, during its frequency hopping process. Originally there are 79 available channels for the Bluetooth device to hop between, but since AFH remaps and begins an exclusion list of channels, it trims down the amount of available channels. A requirement is set by Bluetooth that there must be 20 or more channels available to a device [40].

There are two common methods implemented by Bluetooth to assess the available channels and identify those that are poor quality and need to be excluded from the frequencies to hop to. The first is Received Signal Strength Indication (RSSI). The threshold strength value varies between manufacturer, but, essentially, only the channels that meet or exceed the signal strength threshold make it onto the list of available channels that Bluetooth will visit [41]. The second methodology is Packet Error Rate (PER). Given that N is the number of bits in a data packet, packet error rate is obtained using the formula 1-(0.999 N). This method is less accurate than RSSI, however, it uses less power and can potentially consume more bandwidth [42].

Another solution that Bluetooth uses to combat contention on frequency bands is to require master and slave devices to utilize the same channel when transmitting using AFH. This method is advantageous because it removes the occurrence of one of the devices communicating on a good quality channel, whilst the other is using a poor quality channel. This leads to Bluetooth only needing to hop 800 times per second, opposed to the original 1600 times per second. It also means that slave devices do not have to waste bandwidth on assessing channels for quality, as the master device handles it and they just inherit the channel that the master device uses.

3.10.1.4 Similarities and Differences between Bluetooth and Wi-Fi

Some similarities and differences exist between Bluetooth and Wi-Fi technology. They both set up a network and both transfer data over that network, however Bluetooth was designed for use in conjunction with portable devices, using a wireless personal area network (WPAN). In contrast, Wi-Fi was designed to be a stand-in for high-speed local area network (LAN). Wi-Fi is able to use the high speeds because the topology involves configuration from the user and all the traffic on the network is typically routed through an access point. On the other hand, Bluetooth is much better suited for simpler use cases where the user needs minimal preliminary configuration in order to connect the devices and uses a symmetrical connection between the master and slave devices.

3.10.1.5 Considerations for Bluetooth Modules

There are many popular wireless bluetooth modules that the system can integrate, in order to obtain a means of wireless communication between the system and mobile device. The selection process to make the ultimate decision of which module to choose is based upon a few factors. These factors include the range between the system and the mobile device, the power requirements, and which communication interface protocol the module will be connected to on the microcontroller.

3.10.1.5.1 HC-05 Bluetooth Module (FINAL CHOICE)

The first Bluetooth module that will be investigated is the HC-05. It is affordable at a low cost of a couple dollars online on sites, such as eBay or Digikey. The HC-05 is a Bluetooth Serial Port Protocol (SPP) wireless module that can be utilized as a master or slave device. The configuration can be selected via AT commands. Slave devices cannot be the device to initiate a Bluetooth connection, however, the ParaSolar Experience System does not require the module to be a master device, since the mobile device will be the one initiating the Bluetooth pairing and not the microcontroller. The default baud rate, while in slave configuration, is 9600. There are 8 data bits, 1 stop bit, and no parity.

The HC-05 employs an integrated antenna, which saves time and money in the developing phase, since an external antenna translates into purchasing additional hardware and writing more software, in order to successfully implement a communication tether.

Table 3. Table 3.10.2. Specification for HC-05 Module

Specification	Value
Class	2
Version	2.0 + EDR
Frequency	2.4 GHz
Data Rate	3 Mbps
Power	4 dBm
Supported Interface	I2C, UART, USB
Modulation Type	AFH
Sensitivity	-80 dBm
Voltage Supply	5 V

Unfortunately, this module still utilizes version 2.0 of Bluetooth, which does not employ Simple Pairing Protocol (SPP). Simple Pairing Protocol is a feature that was released in version 2.1 and makes pairing easier and more secure than before. Prior to SPP, pairing was based only on a PIN-code where there was essentially no security against malicious users from sniffing the code. This new method of pairing uses elliptic curve cryptography, which eliminates using a PIN as an element of calculating the Link Key that was traditionally used. Instead, very large random numbers are used to compute the Link Key. A shared secret, named the Diffie-Hellman Key, is established between the two devices involved with the Bluetooth connection. This key is a 192-bit random number, which is a number that is far too large for any fathomable attacker to possess the ability to crack. Both Bluetooth devices have a public and private key where the public key is available and known to anyone, while private keys are not shared. The nature of the protocol is that the private key is nearly impossible to calculate, utilizing the public key, while the public key is extremely simple to calculate, utilizing the private key. This permits the two devices to pair with each other without sending sensitive data into the air. Another disadvantage of using the HC-05 module is that the available documentation is limited, which makes it more difficult to configure and debug any potential issues [68].

3.10.1.5.2 HM-10 Bluetooth Module

The second Bluetooth module that will be investigated is the HM-10. It utilizes Bluetooth version 4.0 and a sub classification called Bluetooth Low Energy (BLE). Most Bluetooth Low Energy modules employ a Texas Instrument CC2541 or CC2540 chip. The firmware and board for the module is developed by a Chinese manufacturer, Jinan Huamao Technology, however, developers should be wary of a multitude of clones out in the market. These clones behave similarly as the original module, but may have differing power uses, AT commands, and data rates, making troubleshooting your module and finding accurate documentation difficult.

Table 3.10.3. Specification for HC-10 Module

Specification	Value
Class	2
Version	4.0 BLE
Frequency	2.4 GHz
Data Rate	2 Mbps
Power	Sleep Mode: 400µA~1.5mA Active Mode: 8.5mA
Supported Interface	I2C, UART, USB
Modulation Type	GFSK
Sensitivity	-84 dBm
Voltage Supply	5 V

Similar to the HC-05, the HM-10 requires a connection to 3.3 volts. The breakout board versions have an integrated DC to DC logic level converter and six male pins already soldered.

The standard work mode of the module is that of emulating a serial connection. It supports bidirectional communication between the HM-10 module and another Bluetooth supported device. The connection service defines one characteristic, or packet, that has a storage of 20 bytes of data that is unformatted. When the other device would like to transmit data to the module, it writes a characteristic with the data of choosing. On the other hand, when the module is the one that wants to transmit data, it will transmit a notification to the other device. This module behaves as a serial connection with microcontrollers. Its pin 1 (TXD) and pin 2 (RXD) is logically linked to the aforementioned Bluetooth Low Energy service. When it receives data in the RXD pin, that data is passed through notifications and sent to the other Bluetooth enabled device. Data that is transmitted and sent as a write from the other Bluetooth enabled device is output through the TXD pin on the module.

3.10.1.2 Wi-Fi

Wi-Fi is a wireless communication technology that is utilized for Wireless Local Area Networks (WLAN), using radio under the Wi-Fi Alliance and IEEE 802.11 standards. Devices that use Wi-Fi can access the internet with a wireless local area network and an access point. Its range, using a single access point, could be the size of one room or about 20m. This range can be extended to much further, on the order of square kilometers, utilizing many access points that overlap. Typically Wi-Fi applications will use two popular ISM radio bands. These are the 2.4 GHz Ultra High Frequency (UHF) and the 5.0 GHz Super High Frequency (SHF). The two bands are divided, forming many channels that the Wi-Fi technology can share between networks. The wavelengths that these applications operate in are easily hindered by structures, lowering their effective range, so they work best when they are in sight. As a benefit, this sensitivity to surrounding materials can actually aid the system in avoiding interference from outside networks [74].

The communication protocol for Wi-Fi is rather unique. It uses the 802.11 standard from IEEE and is a combination of physical layer specs and Media Access Control (MAC). The initial version distributed in 1997 and has been updated periodically ever since. The updates typically will develop into their own standards, since the industry will commonly advertise the added features of their product brought with the new updated standard.

3.10.1.2.1 Wi-Fi Speed and Range

The range of Wi-Fi can vary quite a bit based on a multitude of factors. These include, the output strength of the radio, the frequency that the network is utilizing, the quality of the antenna, the type of modulation being used, surrounding materials interfering with the signal, and the quality of the receiver.

Transmitters for Wi-Fi use a low amount of power and are limited in their power that they can send by a maximum threshold that is usually set by regulations in one's local area. The amount of power consumed for WiFi is typically higher than that of technologies that utilize Personal Area Networks, such as Bluetooth and Zigbee. This lends to be problematic for systems that require a low power consumption mode of communication, which is the criteria for the ParaSolar Experience, since its power source are the onboard batteries that are charged by the solar panels.

There are a few options when it comes to antennas for a Wi-Fi transmitter. One of the simplest and most common solutions is an omnidirectional antenna. These have a range of about 100 meters. You can also vary the shape of the antenna. Using a semi-parabolic antenna, the same receiver could increase its range to almost 100-fold. The later IEEE standards even support multiple antennas, which permit the transmitter to hone in on the receiver. This allows for a stronger signal and less interference between the transmitter and receiver.

While the standard of 802.11 updated to allow greater throughput and speed, it also required a larger bandwidth. For example, the 802.11n standard uses a 40 MHz bandwidth, while the earlier 802.11g and 802.11a standards utilize a 20 MHz bandwidth. The newest standard, 802.11ac, solely utilizes the 5.0 GHz frequency band and can accomplish speeds of more than 1 Gbps when using multiple WLAN stations and more than 500 Mbps when using one station [73].

3.10.1.2.2 Wi-Fi Security on the Network

Security is a major issue when it comes to Wi-Fi's wireless network. Out-of-the-box, an individual is only required to be within range of the network, in order to view it and potentially connect. This introduces a lot of problems where sensitive data can be intercepted by a user that it was not intended for when little to no precautions are taken to encrypt the network.

There are many approaches to securing a network. One of the most common methods is to simply disable the function of broadcasting the service set identifier (SSID), which hides the name of the access point from the list of available networks. This, however, is not that effective because a user can just query the SSID and obtain it. A slightly more advanced method is to limit network access to machines with a familiar media access control (MAC) address. This also has a vulnerability, though, where a user can spoof their MAC address to mimic that of a verified user on the network. The first encryption algorithm used with Wi-Fi was the Wired Equivalent Privacy (WEP) method, however, software specifically created to snoop networks could easily retrieve the key to unlock the network quickly. Afterwards, IEEE and the Wi-Fi Alliance jointly released Wi-Fi Protected Access (WPA), using Temporal Key Integrity Protocol (TKIP), which proved to be a replacement to WEP that would not need legacy hardware to be updated. Later, WPA2 was released with a few improvements over WPA. It introduces Counter Cipher Mode with Block Chaining Message Authentication Code Protocol (CCMP), which replaces TKIP. For backwards compatibility, WPA2 will still utilize TKIP as a fallback measure, if CCMP fails or is not supported. One of the only vulnerabilities for WPA2 requires a malicious user to already have acquired access to the network and only then can they obtain the required keys to further their attack on susceptible devices on the network.

3.10.1.3 Global System for Mobile Communications (GSM)

The GSM standard was created by European Telecommunications Standard Institute in 1991. It is used as the protocol for mobile cellular networks and has more than 90% of the market share for mobile device communications world-wide. It works by digitizing and compressing data. Afterwards, it transmits the data on a channel alongside two streams of user data, each having their respective time slots. It conducts its work on a 900 MHz or 1800 MHz frequency band, except where these frequencies were already in use, like the United States, where it was issued the 850 MHz and 1900 MHz bands alternatively.

Integrating a GSM module with the microcontroller, there are a few features that the system could utilize. The system would be able to send and receive SMS messages, GPRS data (such as HTTP and TCP/IP), and would have the ability to acquire GPS data. Using the ability to send and receive SMS messages could act as the exchange of data and commands between the microcontroller and the user's mobile device. The user could text the microcontroller, in order to activate the system's security procedure, and the system could text back, if there are any breaches in security. There are also a multitude of use cases where the system could take advantage of the GPS data obtained through the module. For example, if the system were to get stolen, the user could track the thief and retrieve the system. The GPS has sixteen acquisition channels and the amount of time required to obtain a fix on the position from a cold start is 100 seconds on average, while the time required from a hot start is 1 second. The accuracy of the GPS is approximately 2.5m, which is sufficient for any application that ParaSolar would require.

There are some disadvantages to using a GSM/GPS module in the system, though. Primarily, the cost and convenience. The price of these modules are not cheap, coming in at around $20-30 for the module alone. Also, the module would benefit from an external antenna for better GPS positioning and a faster lock. This is excluding the SIM card that the user would have to buy, additionally paying for a cellular plan for the SIM card to be activated and working. All of these things add up to a lot of responsibility being placed on the user and diminishes the purpose of the system, which is to be convenient.

3.10.1.4 Zigbee

Zigbee is a specification that is established with the IEEE 802.15.4 standard. Its purpose is to create a Personal Area Network (PAN). It specializes in low power and low bandwidth-consuming wireless communications. One of the unique features of Zigbee is that it allows you to control Zigbee supported devices with other Zigbee devices, even if they are not from the same manufacturer. This differentiates it from point-to-point technologies, like Bluetooth.

3.10.1.4.1 Mesh Networking

It operates in what is likened to a mesh network, where data can hop from multiple Zigbee devices along its path to the destination, in order to make a further traversal and extend its range. This is an ideal scenario, if the devices along the way are low-power devices as well. It also provides a bit of a fail-safe, if you one node is trying to communicate with another node on the network, but one of the intermediate nodes fails. It will simply use a different node to hop from, instead. Within the network, there are three classifications of Zigbee nodes, including coordinators, end devices, and routers. The role of the coordinator is to build the network and hold onto crucial data, such as keys. Routers are the intermediate nodes that pass along data that is hopped to them. Lastly, end devices are able to broadcast to routers and coordinates, but not other end devices. The upper limit of nodes on a Zigbee network is 65,000.

3.10.1.4.2 Security of Zigbee

The basic security figure relies on keys. These keys cannot pass between a channel that is deemed insecure, except for when a new device is being added to the network. Zigbee utilizes a 128-bit key for its security keys. These keys can correlate to the network or to a link among devices on a network, also known as a link key. The creation of these link keys are rooted in a master key. The primarily created master key has the security of the entire system depending on it, so it is required to be transmitted initially through safe means.

3.10.1.5 Radio

Radio Frequency modules are an option for a system, if Bluetooth or Zigbee's networking topologies are not required, or if GSM proves to be unnecessary. Most modules will utilize an antenna and crystal matching circuit, making it easier on development. It also consumes very little power. Two popular frequencies for these RF modules are 433 MHz and 2.4 GHz. They support low data rates, around 250kbps, while offering a respectable range of about 250 meters when in sightline [76].

3.10.1.6 Comparing the Wireless Communication Technologies

Wireless Communication	Bluetooth	Wi-Fi	GSM	Zigbee	Radio
Operating Voltage (V)	3.3 ~ 5.0	3.3	3.4 ~ 5.0	3.3	3 ~ 12
Power Consumption	Ultra-low or Low	Medium	Low	Ultra-low	Medium
Operating Frequency	2.4GHz	2.4GHz / 5GHz	850MHz / 1900MHz	2.4GHz	433.92MHz/ 915MHz
Max Transfer Speeds	3Mbps / 24Mbps	~7000 Mbps	12-50Mbps	250Kbps	2Kbps

3.11 Software Tools

A handful of software tools were used to ensure reliable communication between design team members, allowing the team to exchange ideas, files, source code, and meeting times. There are also tools used to aid the development process of writing code, collaborating on code, and designing a PCB for the final product of the system.

3.11.1 Development

It can sometimes be difficult to develop software that successfully behaves with the hardware the way you want it to. This process is made much easier with the correct tools. A development environment with utilities that are specific to the task at hand can make all the difference when balancing efficiency and effectiveness. There also needs to be a medium of sharing software progress between group members that aids in building up the existing project with proper documentation and task delegation, instead of stepping on the toes of others.

3.11.1.1 Energia

Since the ParaSolar Experience system uses a Texas Instrument (TI) microcontroller, the open-source integrated development environment (IDE), Energia, was used. It utilizes the open-source Wiring framework that is designed for microcontrollers. It's extremely intuitive and makes it simple to incorporate libraries and APIs for programming the microcontroller to use the sensors that will be integrated and communicating with the mobile device serially. It has a built-in serial monitor, which will make debugging the UART communication simple.

Another benefit of the code environment being open-source is that it makes it much easier to seek out advice and help, along with existing tutorials and documentation for features that the design team is seeking to implement.

3.11.1.2 Android Studio

It is a pretty easy decision to use Android Studio as the integrated development environment (IDE) for development on the Android platform. It is the official environment from Google for creating applications for Android and it is established, using JetBrains' IntelliJ IDEA software as a base. It features gradle build support, android refactoring hints and tips that are specialized for Android applications, templates for common user interface components, and support for device emulation, allowing the developer to quickly debug and view UI elements without installing the application on a physical device.

3.11.1.3 Git

An important part of working with software is documentation and version control. Git is a distributed system that aids with version control where you can maintain more than one repository. This makes it easier for teams to collaborate on a code base where they can tweak and work on pieces of the program independent of one another. Then, when an individual is finished working and debugging their share of the work, they can push their changes to the repository. Another benefit of Git is that you can add documentation and notes whenever you push a change to a branch, allowing others and yourself to recall what the purpose of the push was and make it simpler to rewind to a specific point in a branch, if something were to break.

3.12 Possible Amendments

In order to accommodate the user of the umbrella as much as possible, a mechanism to cool the drink of the user has been considered. This will be done with the combination of a drink holder, a Peltier element (shown in figure 3.12.1), a heatsink, and a DC fan. The premise of this combination of devices stems from utilizing thermoelectric cooling to bring or hold the temperature of the user's beverage to a range from 2 °C to 5 °C (35.6 °F to 41 °F). The dimensions of Peltier elements vary from 15 mm x 15 mm to 40 mm x 40 mm. The measured diameter

Figure 3.12.1 Peltier Module for Cooling

of a soda can is 66 mm; therefore, it will be best to use the large, 40 mm x 40 mm, Peltier module to cool the can as quickly as possible. The input voltage for the Peltier module depends on its model number ranging from 15.4 V to 24.1 V and both of these Peltier modules require an input current of 8.5 A [25]. Already from viewing the voltage and current requirements, it is obvious that to cool the user's drink will require a lot of power which will drain the umbrella's battery rather quickly. This doesn't consider the power consumed by the fan; which requires 12 V input and 0.16 A. While the idea of providing the user a method to cool a beverage will certainly accommodate the user's needs, the cooling system is very likely to consume a lot of power harshly decreasing the battery life. Instead of allowing the cooling system to be a core element to the umbrella, it will be considered as a possible attachment for the umbrella that the user can connect and use at any time.

Another amendment to the system would be to implement a switch which could draw power directly from the solar cells during high-sunlight periods, but as sunlight decreases and voltage to the system decreases, the system would draw power from the battery instead.

3.13 Display

To accommodate the user's needs, a way of inform the user of important information such as: time, temperature, humidity, and battery life has to be incorporated. This information can be presented to the user through some form of display. Different display are considered for this project, those being character Liquid Crystal Display, Organic Light Emitting Diode display, Thin Film Transistor Liquid Crystal Display, and Thin Film Transistor Liquid Crystal Display touchscreen.

3.13.1 Character Liquid Crystal Display (Character LCD)

Perhaps the most common LCD for many projects. This type of LCD shows information by having the background be one color and the characters be another and neither can change color. There do exist some RGB LCDs that allow for changing the color of the characters to a desired color and even the background color, but there usually won't be more than two colors at a time on the display. This is the most basic method to display information to a user aside from LED matrices which require a higher power consumption than LCDs. A problem for LCDs is that it requires backlighting as it is difficult to see the characters in moderately to highly lit rooms. Since backlighting is required, a character LCD will require a higher power consumption. Character LCDs are typically inexpensive and display information accurately and understandably.

3.13.2 Organic Light Emitting Diode Display (OLED Display)

These displays are much newer than character LCDs and are still in research and development to drive the cost and price for consumers down. OLED gets the name from the material it is manufactured from which is an organic electroluminescent flexible sheet. Each pixel for a OLED is one LED that produces its own light, what this means is that the OLED does not require backlighting. Since each pixel of the OLED is an LED, each pixel can be turned off completely to produce a darker black to add a higher contrast for images.

3.13.3 Thin Film Transistor Liquid Crystal Display (TFT LCD)

Another solution for adding a display screen for a project that can be used to give a user useful information would be the use of a Thin Film Transistor Liquid Crystal Display. This type of display offers images of very high quality and are typically in the resolution range of 320 by 240 pixels and 480 by 320 pixels. This type of display is very powerful and is capable of displaying both characters and images in any combination of colors and is even has the potential of showing video. The cost of these displays is slightly higher than that of character LCDs as it would be expected considering how powerful and how many features the display can offer. The speed of the refresh rate of the images in the display is limited to the operating speed of microcontroller unit driving it. Therefore, this display requires a high speed microcontroller for the most optimal display and refresh of characters or images shown. Finally, the thin film transistor LCD requires a lot of general purpose input and output pins from the microcontroller thus limiting even further the options for compatible microcontrollers.

Table 3.13.1. Comparing Different Displays

Characteristics	Character LCD	OLED Display	TFT LCD	TFT LCD Touchscreen
Working Voltage (V DC)	5	5	Depends on Size 5 ~ 13.2	Depends on Size 5 ~ 13.2
Number of General Purpose Input and Output Pins Required	Two with I^2C Backpack 14 ~ 18 without.	Four with I^2C 14 ~16 without.	Varies Greatly Depending on Color Complexity 10 ~ 40	Varies Greatly Depending on Color Complexity 10 ~ 40+
Limited by MCU Operating Speed	No	No	Yes	Yes
Backlight Required For Viewing In Bright Environments	Yes	No	Yes	Yes
Text Limit	Varies Greatly	Varies Greatly	Varies Greatly	Varies Greatly
Can Display Images	ASCII Based	Yes	Yes	Yes

3.13.4 TFT LCD Touchscreen

An advanced solution for offering a display option to a user. This type of display has the same technology as the Thin Film Transistor; in fact, most thin film transistor have the option to enable touchscreen features for the device. This of course requires even more general purpose input and output pins from the microcontroller. Also, the refresh speed and data to be displayed is limited by the operating speed of the microcontroller. In conclusion, in order to have the thin film transistor liquid crystal display touchscreen operate at peak performance, a high number of general purpose input and output pins from a microcontroller are required and that microcontroller must have a high operating speed so that images do not appear to exhibit a strobing effect.

Based on the above research and table 3.13.1, it is apparent that either a character LCD or an OLED Display is the best candidate for this product. Both the character LCD and OLED Display require a minimal amount of general purpose of input and output pins when supported by I^2C communication protocol. Neither of the two displays is limited by the performance of the microcontroller unit, thus allowing a large range of microcontrollers to be used for the product. Where these two displays differ is that the character LCD would require backlighting to enable the characters to be read in bright environment while the OLED display provides its own backlighting by each pixel. Finally, the OLED display offers the ability to display images if an image is deemed suitable for conveying information to the user.

3.14 System Housing

The most visually noticeable part of the project is the systems housing, which will house the solar panels on the outside, the security system, and the contain electronics in its entirety.

3.14.1 Beach Umbrella

There are a few types of beach umbrellas to consider, anchored, screw-base, or inserting pole. Because of our application, having a standard pole, with no features to ensure a sturdy base, the standard pole option can be immediately eliminated. The two other options, a screw-base or anchoring the beach umbrella will be considered.

Due to the amount of equipment that may be housed on the umbrella, using a base with a weighted anchor will not only be lighter while not in use but also works as a contingency plan if the original hole widens from use. A weighted anchor that uses either sand or water may be an even better alternative. The sand anchors can either be directly surrounding the umbrella, or, attached to a rope external to the umbrella. By convenience only, a sand anchor at the base will provided that the rope does not break or fray over time and compensate for any extreme changes in wind. BeachBUB is a complete beach umbrella, beach umbrella base, and anchor system, utilizing sand to keep the umbrella from moving in windy environments. The whole system can be found at $139 on Walmart’s online store or $434.60 on the BeachBUB website. This system seems to surpass the previous complete budget estimated and will likely not be incorporated into our design. ABC

Canopy makes industrial grade weight bags for canopies that could be repurposed for our umbrella. A pack of 4 can be bought on Amazon for $19.95 that holds 20-25 pounds of sand or dirt. The last option would be to pile sand up against the base, similar to the BeachBUB but only costing the user calories.

3.15 Charging Station

As previously stated in the executive summary of the report, there will be a portion of this product that has the ability to charge the user's various devices. This charging functionality will require a Universal Serial Bus (USB) charging port.

3.15.1 USB Ports

Ubiquitous in modern society, USB technology can be found in at least one or more devices a person uses on a daily basis. It has become widely popular due to its compatibility with various platforms and operating systems, its low cost of implementation, and its ease of use. USB ports are commonly used to charge devices and/or interact with a host device by making data transferable between the two. USB cables come in a variety of connections, most of which, however, are incompatible with one another. For this reason, USB port selection for a novice can be a troublesome task, especially when the differences between each may seem trivial.

The USB was developed to improve and simplify the interface between the user's personal computer and their peripheral devices. This is perfect for this product, seeing as how the designer's main goal is simplicity and convenience for the user. These simplifications and improvements presented themselves in a variety of ways from the user's perspective. The USB interface is self-configuring, meaning the user does not have to adjust any settings on the device, direct access memory channels, or anything else of the like. USB connectors are standardized at the host so any device can connect to any host. The USB interface is generalized with no signal lines dedicated to only one function of one device.

As stated previously, there are many different types of USB ports, those including but not limited to A-Type USB, B-Type USB, C-Type USB, various Micro-USB types, USB mini-b (4 pin or 5pin), and USB 3.0 versions. Seeing as how there are such a large variety of USB ports the designers decided to stick with the most popular USB ports used for an application like the one desired for this product's charging function, those being 2.0 A-Type and 3.0 A-Type (as shown in Figure

3.15.1). These will be the ports considered due to simplicity and also compatibility with numerous devices.

USB Ports can be classified as either male or female. For this application, the designers will be needing female USB port. This is because the user will most likely already have a charger that they wish to plug into the USB port charging station.

Figure 3.15.1 Two USB 3.0 Standard-A receptacles (left) and two USB 2.0 Standard-A receptacles (right) on a computer's front pane

Type A 2.0 USB ports are found mostly on host controllers in computers and hubs, the A-style connector is a flat, rectangular interface. This interface holds the connection in place by use of friction which makes it very easy for users to connect and disconnect their devices. Additionally, instead of round pins, this connector uses flat contacts which can withstand continuous attachment and removal.

USB 3.0 A-Type ports are also known as 'SuperSpeed' ports and were released in November of 2008. This connector is similar in size and shape to the 2.0 Type-A connector. However, these connectors are often blue in color to help identify them from previous versions. The USB 3.0 conforms to the latest set of USB standards and offers faster transfer rates. Additionally, the connector is backwards-compatible, meaning it can be used with devices that were originally designed to be compatible with USB 2.0 ports. Although, the increased speeds are only available when all components and USB 3.0 compatible.

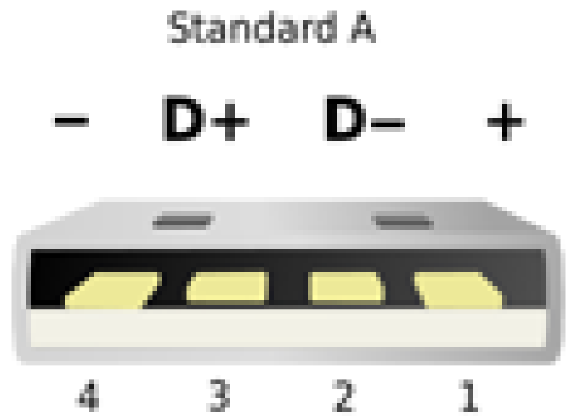


Figure 3.15.2 Typical USB Type-A Connector

In addition to the two classifications, there are three different source types for these specific ports. Those being the Standard Downstream Port (SDP), the Charging Downstream Port (CDP), and the Dedicated Charging Port (DCP). Most devices are able to interpret what type of port they are connected to based on the circuit configuration of the D+ and D- pins (shown in figure 3.15.2). In this illustration Pin 1 is the Voltage Bus for +5V source, Pin 2 is the negative Data Terminal, Pin 3 is the positive Data Terminal, and Pin 4 is Ground. To make them distinguishable from one another there is specific circuitry within the two Data terminals that differs from one source type to the next.

A Standard Downstream Port (SDP) is the typical form found in desktop and laptop computers. This type of port is used in the 2.0 USB specifications and features a 15k pull down resistor on the data terminals both positive and negative. This 15k resistor tells whichever device that connects to it that this is a Serial Downstream Port. Therefore, telling the device that there is only a current of 0.5 amps available from the host to be used in charging the devices battery. The main purpose of these ports is to supply power to low powered devices like a mouse or a keyboard. In order to use this type of port for this application there would have to be enumeration between the host and the device.

In USB 2.0, it is not strictly legal to draw power without enumerating when using a Standard Downstream Port as it is a violation of the specifications of the port. Due to this requirement the builders will not be utilizing this type of port.

Because the Standard Downstream Port restricts the max current available to 0.5 Amps, another type of port will need to be considered. The requirement for this new port type is that it must allow an increase in the output and be able to supply a charge to a higher power device. This is where the *Charging Downstream Por*t or CDP comes into play. This port is used in USB 3.0 specifications and can supply up to 1.5 Amps, which can be supplied without enumeration. A device is able to recognize this type of port by the means of a hardware handshake implemented by manipulating and monitoring the data terminals. This hardware test takes place before turning the data lines over to the USB transceiver, thus allowing a CDP to be detected before enumeration.

However, this type of port also requires a USB controller IC to be connected to the data terminals in order to determine what type of device to which the port is connected. This entails a much more complicated circuit design than the USB 2.0 and therefore will not be used in this application.

The last type of port that will be discussed in this report is *the Dedicated Charging Port* (DCP). This type of port is most commonly used in wall outlets and auto adapters which usually have a connection to larger power supplies. These power supplies do not enumerate and therefore charging can occur with no digital communication at all. Making this a much more simplified circuit than that of the previous Charging Downstream Port's. A DCP is able to supply up to 1.5 Amps and are easily identified by the device by using a less than 200 Ohm resistor as a short between the positive and negative data terminals. This short allows for the creation of DCP "wall warts" that feature a USB mini or micro receptacle instead of a permanently attached sire with a barrel or a customized connector. Such adapters will allow any USB cable (with the correct plugs) to be used for charging.

Due to the simplicity of the circuit and the ability to supply a charge to a higher power device the designers have decided that this is the type of port that will be used for this application.

4.0 STANDARDS AND REALISTIC DESIGN CONSTRAINTS

During the development of requirements, it's critical to understand the unmoving standards and constrains that the design may experience. By identifying the design constraints, specification requirements and ultimately the progress of product design will improve. Standards for each different technology involved in the product will be explored and explained in detail. Constraints pertaining to the economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability impacts on the design will also be specified in the sections below

4.1 Related Standards

Creating and specifying standards for any project is crucial in developing a well-made project and displaying a team's professionalism. By understanding the economic, environmental, social, ethical, and time constraints, a better product can be developed that satisfies all the necessary specifications.

4.1.1 Requirements for Information Technology Equipment

For most of the electronic components used on this product, standard UL 60950-1 ensures safe operation of the equipment regardless of source of power. It states that all conductive material must be grounded, to prevent electric shock. It also prevents unsafe industrial design. The standard is used when testing each individual product, that look for fault conditions, foreseeable misuse, consequential faults, and environmental factors such as temperature, altitude, debris, and moisture.

Although small, some of our components may have electromagnetic interference, and this information technology equipment must comply with EN 55022/CISPR 22 EMC Standard. This standard includes the testing policy for devices with possible radio disturbance characteristics. There are two classifications of equipment, class A and class B, where certification is needed for equipment over the range 0.15MHz to 30MHz. Tables 4.1.1 and 4.1.2 give the field strength limits and radiated emissions according to CISPR 22. According to the FCC's equivalent standard, Class A devices are used for commercial, business or industrial environments. Class B devices are those marked for personal use, domestic or residential.

Table 4.1.1. CISPR Class A EMF Interference Test Values

CISPR Class A Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (DBMV)	
	Quasi-peak	Average
0.15-0.50	79	66
0.50-30.0	73	60

Table 4.1.2. CISPR Class B EMF Interference Test Values

CISPR Class B Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (DBMV)	
	Quasi-peak	Average
0.15 – 0.50	66 to 56	56 to 46
0.50 – 5.00	56	46
5.00 – 30.0	60	50

4.1.2 Flame Retardant Standards

The flame retardant standard for our PCB design is standard UL94V-0, which is given to standards that meet the following criteria, according to RTP Company: may not burn with flaming combustion for more than 10 seconds after either application of the test flame, the total flaming combustion time may not exceed 50 seconds for the 10 flame applications for each set of 5 specimens, the specimens may not burn with flaming or glowing combustion up to the holding clamp, the specimens may not drip flaming particles that ignite the dry absorbent surgical cotton located 300mm below the test specimen, and the specimens may not have glowing combustion that persists for more than 30 seconds after the second removal of the test flame.

FR4 is a flame-retardant classification, as mentioned in section 3.4. Table 4.1.1 (on the following page) includes all relevant values of the specification, which corresponds with standard UL94V-0.

Table 4.1.3. FR4 Classification Data Sheet

Test/Specification	Fr4 Laminate Typical Values
Thermal Stress, Solder bath 288 deg. C	>60
Dimensional Stability, E-2/150	<0.04% Warp/fill; <1.00% Bow/Twist
Flammability, Classification UL94	V0
Water Absorption E-1/150	0.10%
Peel Strength After Thermal Stress	11 lb./in After 10s/288 Deg. C
Flexural Strength	100,000 lbf/in(62) lengthwise; 75,000 lbf/in(^2) crosswise
Resistivity after damp heat volume	10^8 M ohms cm
Resistivity after damp Head surface	10^8 M ohms
Dielectric Breakdown. Parallel to laminate	>60KV

Dielectric Constant @ 1MHz	4.7
Dissipation Factor @ 1MHz	0.014
Q-Resonance @ 1MHz	>75
Q-Resonance @ 50MHz	>95
Arc Resistance	125s
Glass Transition Temperature	135 Deg. C
Temperature Index	130 Deg. C

4.1.3 Environmental Standards

The environmental standards that will affect the design of the electrical components is the Restrictions of Hazardous Substances (RoHS). This constraint restricts the amount of six hazardous materials found in electrical components. Listed in table 4.1.1 are the six materials and the amounts that are allowed.

Table 4.1.2 Restrictions of Hazardous Substances

Material Name	Amount allowed
Lead	Less than 1000ppm
Mercury	Less than 100ppm
Cadmium	Less than 100ppm
Hexavalent Chromium	Less than 100ppm
Polybrominated Biphenyls	Less than 1000ppm
Polybrominated Diphenyl Ethers	Less than 1000ppm

The battery pack and other electrical components purchased for this product are RoHS compliant and meet these standards. Another decision that was affected by this standard occurred when selecting the photovoltaic solar cell type. After much consideration it was concluded that this product could not utilize the Cadmium Telluride solar cell type due to the cell containing a fair amount of cadmium, which is a highly toxic substance.

An environmental consideration for some of the power management systems is Military Standard MIL-STD-810F, which, according to the Everyspec.com website, is a standard and test method “for considering the influences that environmental stresses have on material throughout all phases of its service life”. This standard can certify that the respective product or system component can withstand certain environmental stresses that they may experience.

4.1.4 Manufacturability Standards

One standard that may influence this product was found on the NSSN website document number DIN EN ISO 9223:2012. This standard was created to establish a form of classification of the corrosion of metals and alloys. This standard defines the corrosivity categories for the atmospheric environments by the first-year corrosion rate of standard specimens. This includes corrosion due to temperature humidity complex, pollution by carbon dioxide, and airborne salinity. This will obviously be a constraint for this product, because the main use for this product is to experience a new level of convenience at the beach. The beach is an environment that has high humidity levels, high temperatures, and salt mist conditions. Proper coating must be applied to all steel parts of the product when designing or altering the umbrella pole or spines in the umbrella as they may corrode over time. The umbrella purchased for this product will conform to these standards. This standard will also need to be considered on any external wiring going to the solar panels, sensors, and LEDs. Proper covering of there parts will be required to sustain the desired lifetime of the product established in section 4.2.7 Sustainability constraints.

Further consideration will also need to be addressed in safely routing any wires around any detachable parts of the product. This is in case there is any jostling or straining of the connection. Additionally there will need to be special care taken when wiring and attaching the solar panels as these sections will be folded in on themselves when storing the product. Any external wiring will need to be suitably protected and hidden from sight as much as possible. This restricts the way the umbrella can be built and potentially increase the cost of the design.

4.1.5 Bluetooth Standards (802.15.1)

There is a group of standards named 802.15, which encompasses an array of technologies that support a Wireless Personal Area Network, unlike 802.11, which is the Wi-Fi standard that supports Wireless Local Area Networks. Bluetooth falls within the 802.15 grouping of the standard and is specifically a member of the 802.15.1 standard. While Bluetooth was originally made a standard of IEEE 802.15.1 by IEEE, the Bluetooth Special Interest Group has taken over management and spec development of the technology.

Bluetooth SIG is a non-profit group of more than 30,000 companies. Their primary concern is to preserve the Bluetooth trademark and develop new specifications for the technology. One of the functions of this group is to manage a qualification process that everyone that desires to utilize the Bluetooth technology in one of their products must pass, if they intend to go to market with said product. The process ensures that these products conform to the specifications that are put forth by the Bluetooth Special Interest Group by reviewing the documentation and tests that the product creators have completed.

4.1.6 Safety Standards for Electro Static Discharge

For the voltage regulation and power management system of the application there are a couple standards that are in place to protect users from unexpected electrostatic discharge. The standards and testing procedures are as follows:

ANSI/ESDA/JEDEC JS-001: *Human Body Model Testing of Integrated Circuits*, according to the JEDEC website, is a “standard [that] establishes the procedure for testing, evaluating, and classifying components and microcircuits according to their susceptibility (sensitivity) to damage or degradation by exposure to a defined human body model (HBM) electrostatic discharge (ESD).” The human body model is the most popular model used to simulate what discharge could occur when there is physical contact between a human and an electronic device.

The test procedure involved with ANSI/ESDA/JEDEC JS-001 is JEDEC JESD22-C101F, *Field-Induced Charge-Device Model Test Method for Electrostatic Discharge Withstand Thresholds of Microelectronic Components*. According to the JEDEC website, “this new test method describes a uniform method for establishing charged-device model electrostatic discharge withstand thresholds … [The model] simulates charging/discharging events that occur in production equipment and processes”.

4.1.7 Infrared Light Emitting Diode Eye Safety Standard

In order to effectively use an active infrared sensor that can determine the proximity of an object, an Infrared Light Emitting Diode is required. As its name implies, these types of diodes produce infrared radiation that is potentially harmful for the naked eye if exposed for a certain amount of time. Two standards that are important to Infrared Light Emitting Diodes are IEC-60825 and IEC-62471 from the International Electrotechnical Commission (IEC). These standards deal with laser sources and lamp sources respectively. Proximity sensing devices, also can be referred as illumination applications, fall under the Lamp Sources standard IEC-62471. As with any type of prolonged exposure to radiation, infrared radiation coming from IR LEDs could have hazardous effects on human eyes. The term that measures this effect is known as photobiological effects. The most common biological effect caused by excessive exposure to infrared radiation is called Infrared Cataract where chronic exposure, decades of being exposed, to the infrared radiation is absorbed by the eyes, namely the iris and lens part of the eyes.

4.2 Related Constraints

Regardless of the design, the product will be inherently experience constraints that are completely out of control to the design team. These constraints include any impacts on the environment, health or safety of the user, as well as social, political, ethical, economic and manufacturing factors.

4.2.1 Health and Safety constraints

Health and safety constraints are any restrictions on a product’s design due to health and safety concerns. One of the implicit uses of the ParaSolar Experience is taking it outdoors. Users should always be wary of the current weather conditions, and their surroundings. Components should be properly insulated and grounded from all external surfaces, and isolating the circuit. The renewable energy feature will restrict the need of removing or handling the internal battery for charging. The IEC 61730 and EN 61730 standards are for Photovoltaic module safety qualifications. Since the solar cells, sensors and some other electrical components will be located close to the umbrella’s cloth top special considerations and safeguards will need to be applied in order to ensure a safe product. This entails applying an appropriate and sufficient heat disbursement to prevent overheating and fires that may cause harm to the users. All electrical components will require a minimum resistance of 1 Mohm between components and surrounding materials per IEC 61032 standards. For this application the electrical connections will be surrounded by a rubberized shrink tubing that when heated will "glue" itself to the connection thus forming a greater than 1 Mohm resistance between parts. This will create a waterproof barrier that will also protect from sand or salt mist reaching the electrical connections. All connections and components will be thermally tested to verify that they will not reach temperatures anywhere near the flashpoint of the umbrella material. This will be done using a digitized thermal meter.

An additional safety constraint that will affect this products design is the circuitry pertaining to the battery pack. The charge controller circuit must contain certain components that will ensure a safe product. For example, a thermistor will be placed in the circuit that will completely shut the charging system down in the event that the battery pack is reaching too high of a temperature during its charging cycle. Small venting in the packaging of this circuitry and battery pack will also ensure that the components are operating at a safe temperature. The lithium battery pack that was purchased also has a built in PCB to keep the battery from overcharging which may cause an explosion or harm to the user. A safe battery charging chip will also regulate the battery charging system and decrease the risk of the battery have a catastrophic failure resulting in injury to the consumer.

4.2.2 Economic and Manufacturability constraints

The design of the system is limited to components that can be made by electronics companies that must be able to withstand possible elemental exposure. The components cost must not exceed the budget designated in section 7.1. Builders will be completely financing the project with no outside financial assistance. This will limit the resources available and require the builders to look for more cost-efficient parts and materials while still maintaining a high level of efficacy. Reducing this budget will depend on the components manufactured, whereas the most technologically advanced components may not be selected due to these economic constraints.

An additional constraint that will affect the product's overall cost of the product is the shipping costs. Since the battery pack that was chosen was classified as a lithium ion type, there will have to be more restrictive forms of shipping. Lithium ion batteries have certain restrictions for transporting by plane, as they cannot be shipped by commercial airlines. These batteries must be labeled as dangerous goods and therefore meet the dangerous goods specifications established by the International Air Transport Association (IATA). Specifications for global shipping of hazardous material that were established by the International Civil Aviation Organization (ICAO) which is a United Nations regulated organization must be met. These restrictions could increase the cost of shipping for the consumer.

4.2.3 Social Constraints

Social constraints are constraints that societal views place on a product. The consumer expects the product to work in a certain way and to look a certain way. The key social constraint that this product will be subjected to is the overall aesthetic of the product. In order to achieve this constraint products were chosen strategically with the end design appearance in mind. For example, the solar panels that will be used were specifically chosen to satisfy this constraint. Instead of buying a single solar panel of the same power output that would be simply draped across the top of the umbrella or erecting obtusely from a pole at the center of the umbrella, the designers decided to attain an array of individual solar cells to create a more visually pleasing and less restrictive pattern atop the umbrella. This will also allow the umbrella to be more easily condensed and stored when not in use.

An added social constraint that is expected of this product is the factor of interoperability. This meaning that items such as the outlets and the Bluetooth modules used must be compatible with all devices that the consumer wishes to utilize.

4.2.4 Political Constraints

Political constraints are restrictions put on a product due to political concerns. This product will not in any way discriminate against any specific race or ethnicity or any other discriminatory factors pertaining to the consumer. This product will in no way be used or specifically sold to consumers that intend to do harm to either the citizens of this country or to the country itself. This product will not be sold with the intention of harming the consumer neither physically or emotionally.

4.2.5 Ethical Constraints

Ethical constraints are any type of constraint that effects the design due to ethical concerns. The only ethical constraint pertaining to this product’s design is product safety. To satisfy this constraint the builders will only be using high quality parts in the design of this product. Additionally, the builders will perform rigorous testing in a variety of conditions to ensure the durability of the product. The product will be constructed in a way that makes it easy to use as long as the consumer is utilizing the product properly and according to its intended functionality. The product will be safe and will not contain any hazardous materials that may cause harm to the consumer. Numerous safety systems will be put into place to ensure the security of the electrical components and to guarantee the safety of the user. This will increase the cost of the design but is an ethically sound decision.

4.2.6 Environmental Constraints

Environmental constraints are constraints on how the product will/ may affect the environment surrounding it. Due to this product running on a completely renewable source of energy there will be no emission or pollution concerns pertaining to the Parasolar Experience. The main environmental constraint that needs to be applied to this product has previously been discussed in the environmental standards section above pertaining to the RoHS.

4.2.7 Sustainability Constraints

Sustainability constraint are constraints that affect the operational lifetime of the product under normal operating conditions. The product will be warranted for manufacturing errors for one year. The builders have decided a goal of a five year product lifetime should be achievable. This constraint requires that all components of the build must be of a high quality to ensure a durable product. This 5 year lifetime does not include the battery pack with falls under user maintenance. Further consideration in the component packaging will have to be conducted in order to allow easy access to the battery for replacement by the user.

5.0 HARDWARE DESIGN

Once individual products are selected from individual design teams, it must be gathered into its system, based on the flowcharts outlined in the Project Description. A complete list of materials and components and images of schematics will be presented and annotated, specifying their exact implementation into the complete application.

5.1 Hardware Bill of Materials

Listed below are all the parts ordered for the application, its purpose and product information are included.

Table 5.1.1 Bill of Materials (Hardware)

Hardware Description	Product Description	Legend For 5.1.1 Image
Beach Umbrella	Johnny Bahama	A
Cooler	Coleman Cooler	B
Solar Panels	BCMaster Polysilicon Solar Cells	C
Charge Controller	Designers will build an MPPT Type Charge Controller	-
Battery	12V DC Lithium Ion Battery Pack Model Number: ZC923400	D
Voltage Regulator (Source to 12V)	Texas Instruments TL494CN	E
Charging ports		-
Speakers (Buzzer)	Piezoelectric Buzzer	F
Voltage Regulator (12V to 5V)	MicroChip LM2576 Original Circuit	E
Display	Keyestudio 20x4 I^2C LCD	G
Bluetooth module	HC-05 SerialWireless Bluetooth ProductModule	H
Voltage Regulator (5V to 3.3V)	MicroChip LM2576 Original Circuit	E
Microcontroller Unit	ATmega328/P	I
Real Time Clock Module	Holdding DS3231 I^2C Real Time Clock	J
Temperature Sensor	HiLetgo DHT11 Humidity & Temperature Sensor	K
Humidity Sensor	HiLetgo DHT11 Humidity & Temperature Sensor	K
Proximity Sensor (for security system)	Ultrasonic Ranging Module HC - SR04 Elegoo HC-SR04 Ultrasonic Sensor	L
Motion Detection Sensor	Infrared LED Emitter and Receiver	M

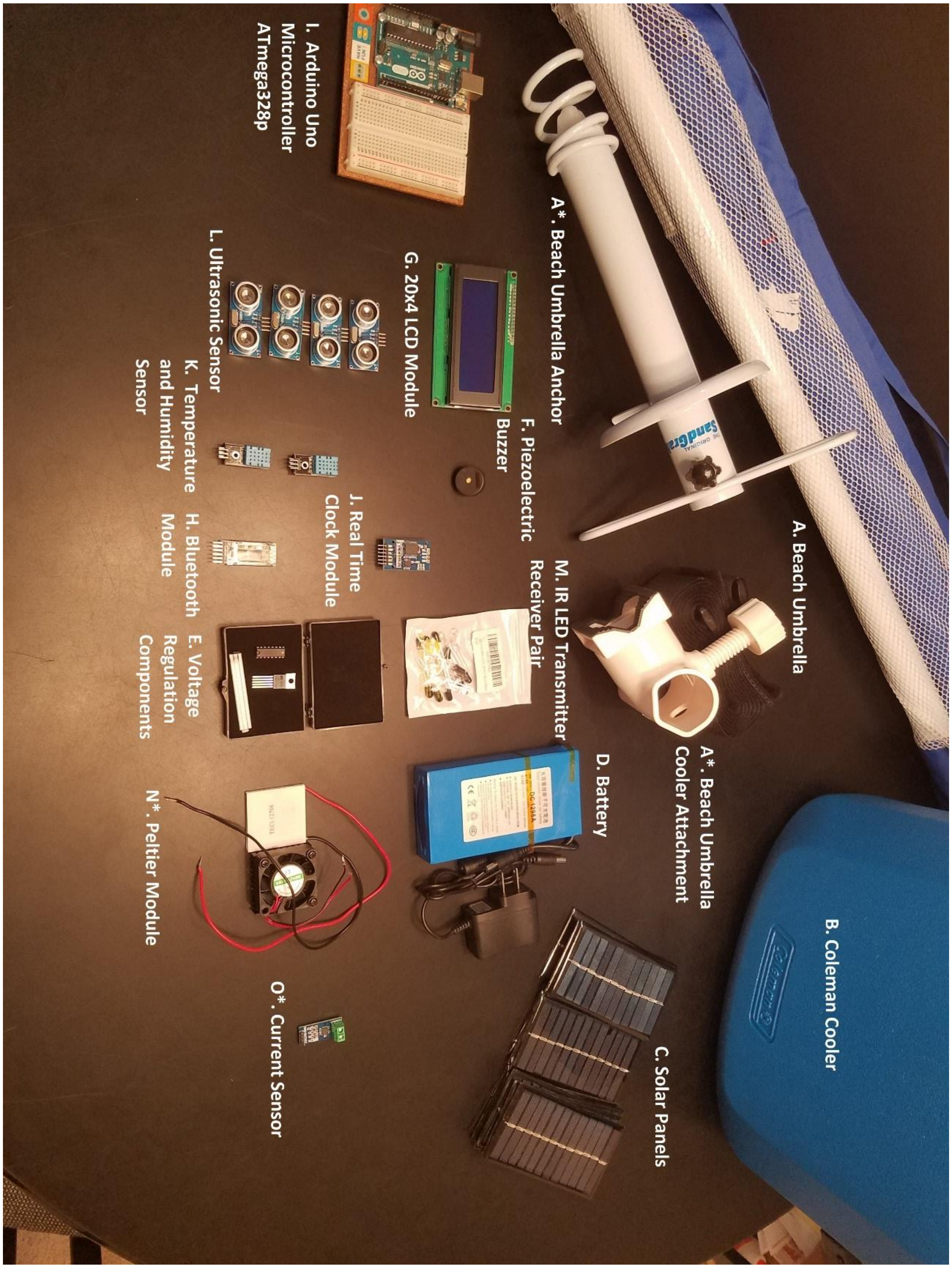


Figure 5.1.1. Labeled Components.

Components N* and O* in figure 5.1.1 are components that are part of bigger systems. N* are some of the components for a Peltier cooling system and the O* component is a current sensor part of the Maximum Power Point Tracking system.

5.2 Maximum Power Point Tracking Charge Controller

In conducting the research for the MPPT controller in previous sections designers discovered a similar MPPT solar charge controller previously designed by Debasish Dutta on his website Open Green Energy. Open Green Energy is a website designed specifically to share Debasish's projects as open-source products. The verification of this statement is established in the appendix section. The designers will build upon this design making various modifications to use for this application. A block diagram of the MPPT controller design is shown in figure 5.2.1 below.

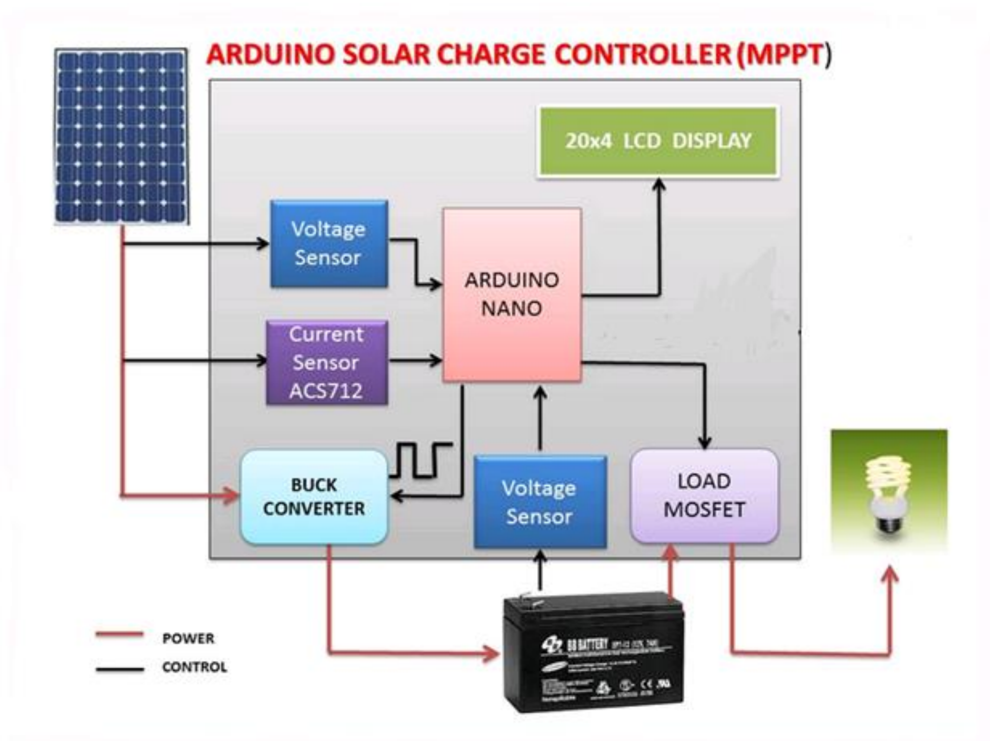


Figure 5.2.1 MPPT Solar Charge Converter Initial Block Diagram by Debasish Dutta

This design utilizes a microcontroller to detect and locate the maximum power point and control the output to the battery. It does this by tracking data received from a voltage sensor and a current sensor that is located at the solar panels and calculating the maximum power point at any given time. This is pertinent to the design of this product because as previously mentioned the power coming from the solar panels in constantly changing due to various environmental factors. These factors include, but are not limited to, cloud cover or partial shading from some other block, angular position of the sun in respect to the panel, and temperature of the solar panel's surroundings. An additional voltage sensor circuit will be placed by the battery to read data there and maintain a constant voltage. The DC to DC buck converter will be controlled by the microcontroller to regulate this constant voltage, in order to satisfy the battery's charging conditions previously stated in the research section on batteries. To provide the user with an up-to-date reading of the level of charge the battery is holding, there will be five LEDs that will show the state of the battery.

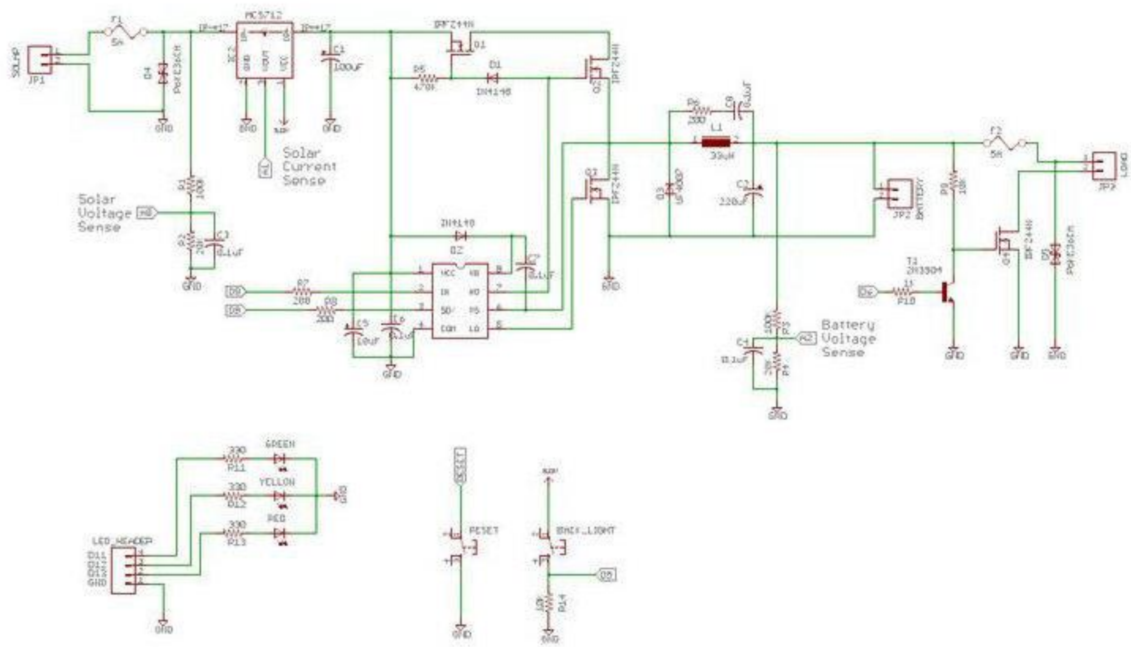


Figure 5.2.2 MPPT Solar Charge Controller Schematic

5.2.1 Charge Controller Microcontroller Design

Using the Maximum power point tracking algorithm (explained further in the software design section), the microcontroller will track the power output from the solar panel and the voltage from the battery. The microcontroller will then make adjustments based off of these readings to the MOSFET driver in the synchronous buck converter to regulate the output. Another analog sensor will be located at the load MOSFET which will collect load data. The microcontroller will then use five outputs to transfer the data to the five LEDs to light up the LEDs corresponding to the level of charge at this sensor location. The microcontroller the designers have chosen will also be able to have enough I/O pins and memory to operate the rest of the project.

5.2.2 Synchronous Buck Converter

In this design the main component that needs to be constructed is the synchronous buck converter. This is a DC to DC converter that will take the inconsistent voltage supply from the solar panels and convert the voltage to a steady stream of constant voltage that is needed to charge the battery pack. The output of the buck converter

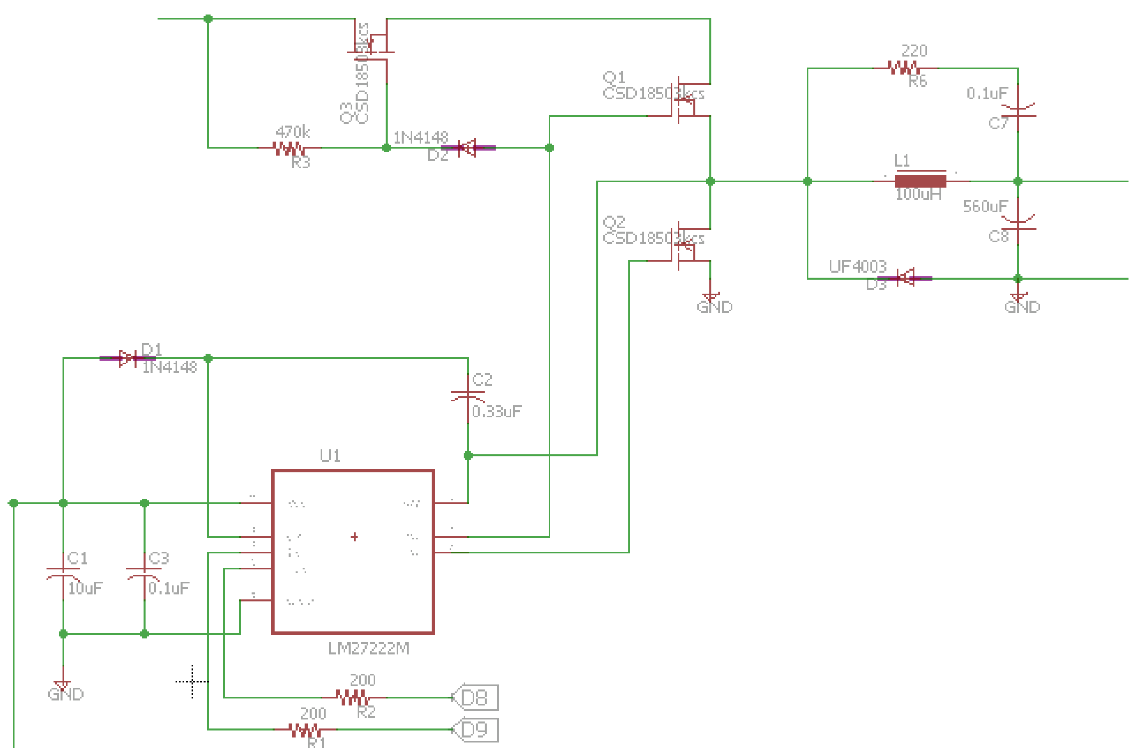


Figure 5.2.2 Synchronous Buck Converter Schematic

is always lower or the same as the input voltage. The schematic for the buck convertor is shown below.

In designing this component there are many things to consider. To start, the switching frequency is inversely proportional to the size of the inductor and capacitor and directly proportional to the switching losses in MOSFETs. This means that a higher frequency requires smaller inductors and capacitors, but higher switching losses. Therefore, there is a mutual trade-off between the cost of components and efficiency when it comes to selecting the appropriate switching frequency. Keeping this constraint in to consideration the selected frequency for this application shall be 50kHz.

Calculation of the inductor value is the most critical part in designing a buck converter. In order to calculate this value, the designers must first make an assumption that the converter is in continuous current mode (CCM). This implies that the inductor does ot fully discharge during the switch-off time of the converter. The following equations are under the assumption that the switch is ideal (0 on-resistance, infinite off-resistance, and 0 switching time) and also the diode is ideal.

<u>Assumptions</u>

This design is for a 20W solar panel array and a 12V battery.

Input Voltage (Vin) = 15V

Output Voltage (Vout) = 12V

Output Current (Iout) = 20W/12V = 1.667 = 1.7 (approx)

Switching Frequency (Fsw) = 50kHz

Duty Cycle (D) = Vout/Vin = 12V/15V = 0.8 = 80%

Calculation

L = (Vin - Vout) * D * (1 / Fsw) * (1 / dI)

Where dI is the Ripple current

For a good design a typical value of the ripple current is in between 30% to 40% of the load current.

Designers will let dI = 35% of rated current

dI = 35% of 1.7 = 0.35 * 1.7 = 0.595A

Therefore L = (15.0 - 12.0) * 0.8 * (1 / 50k) * (1 / 0.595) = 80.67uH =81uH (approx)

Inductor peak current = Iout + dI / 2 = 1.7+(0.595 / 2) = 1.9975A = 2A (approx)

From these calculations the designers deduce that the buck converter will need an inductor of 81uH and 2A.

Designers then must calculate the capacitance required to minimize the voltage overshoot and ripple present at the output of the buck converter. Large overshoots are the result of an insufficient amount of output capacitance, and large voltage ripples are the result of insufficient output capacitance as well as a high equivalent-series resistance (ESR) in the output capacitor. Therefore, to meet the ripple specification for the buck converter circuit, the designers must include and output capacitor with ample capacitance and low ESR.

Calculation

The output capacitor (Cout) = dI / (8*Fsw*dV)

Where dV is the ripple voltage

To satisfy conditions designers let the ripple voltage (dV) = 20mV

Therefore Cout = 0.595 / (8*50000*0.02) = 74.375 uF

The equations used for the above calculations for the inductor and capacitor values were take from the article LC Selection Guide for the DC-DC Synchronous Buck Converter.

Another vital component of the synchronous buck converter is the MOSFET. Choosing the right MOSFET from the variety that are available in today’s market can be quite the challenging task. Below is a list of the basic parameters the designers used for selecting the right MOSFET for this application.

1. Voltage Rating: Vds of the MOSFET should be greater than 20% of the rated voltage.

2. Current Rating: Ids of the MOSFET should be greater than 20% of the rated Current.

3. ON Resitance: Rds(on) of the MOSFET should be low almost equal to zero, to satisfy the assumptions made in the previous calculations

4. Conduction Loss: The Conduction Loss of the MOSFET should be kept to a minimum, however this value depends on the Rds(on) and the duty cycle of the MOSFET.

5. Switching Loss: Switching Loss occurs when the MOSFET is in a transition phase. This switching loss should be kept to a minimum, however, this value depends on the switching frequency, voltage, current, etc.

In this design the maximum voltage is the solar panel open circuit voltage (Voc) which is nearly 21 to 25V and the maximum load current is 2A. Therefore, the designers have chosen a IRFZ44N MOSFET. The Vds and Ids values have enough margin for this design. Additionally, this MOSFET has a low Rds(ON) value.

5.2.3 Current Sensor

The application of the current sensor in this MPPT converter is to measure the current coming from the solar panels so that the maximum power point can be determined by the microcontroller. Figure 5.2.2 shows the current sensor circuit. For this application the designers chose to use a Hall Effect current sensor ACS712 (5A) (as shown in figure 5.2.3-1). This sensor will read the current coming from the solar panel array and convert it to a relevant voltage value. The value that links these two measurements is sensitivity. As told by the ACS712 (5A) model's datasheet the sensitivity of this sensor is 185mV/A, this sensor can measure both positive and negative currents (-5A to 5A), the needed power supply is 5V, and the middle sensing current is 2.5V when there is no current through the sensor.

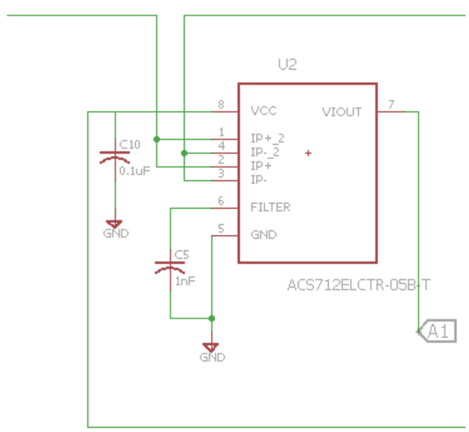


Figure 5.2.3 Current Sensor Circuit

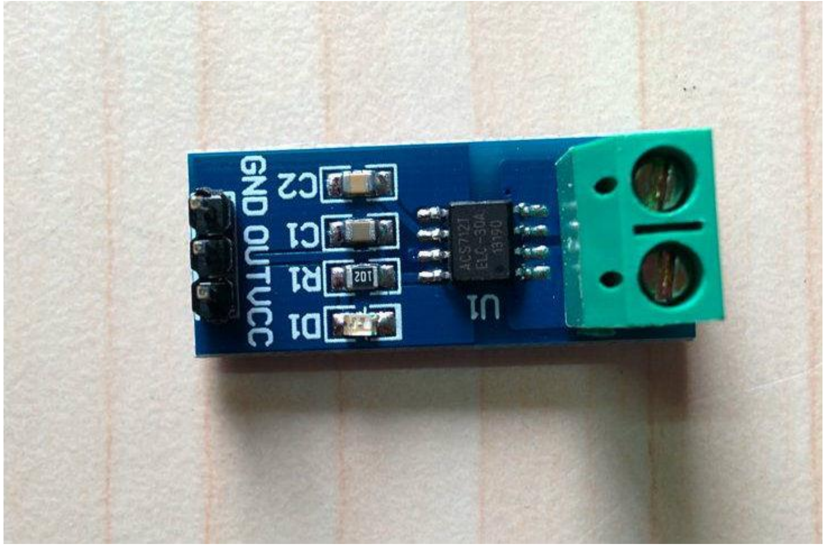


Figure 7.3.3 Hall Effect Current Sensor ACS712 (5A)

5.2.4 Voltage sensor

Two voltage sensors will be used in this application, the first will be located along with the current sensor by the solar panels to supply the microcontroller with the information it needs to calculate the maximum power point. The second sensor will be located by the battery load MOSFET to read the data and transfer it to the microcontroller to calculate the charge of the battery. Below in figure 5.2.3 and 5.2.4 are the schematics of the voltage sensors that will be used.

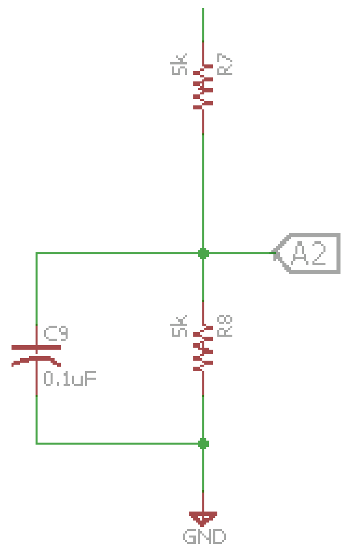


Figure 5.2.4 Voltage Sensor for Reading Battery Voltage Schematic

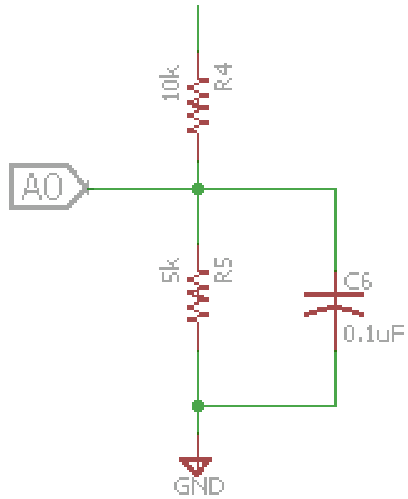


Figure 5.2.5 Voltage Sensor for Reading Solar Voltage Schematic

These circuits will produce a continuous signal to the analog input of the microcontroller, and this will allow the microcontroller to continuously and accurately determine the maximum power point coming from the solar panels. This will provide the microcontroller with the information it needs to maintain a constant voltage flowing to the battery. The capacitors, C6 and C9 in the schematics above are to help stabilize the voltage signal going to the microcontroller.

5.2.5 Load MOSFET

This portion of the circuit is connected to the buck converter in the previous section. Below (in figure 5.2.5) is a schematic of the load MOSFET that will be utilized in this application. The transistor shown in this schematic as T1 can be regulated by the microcontroller to turn on when sufficient power to the load is supplied.

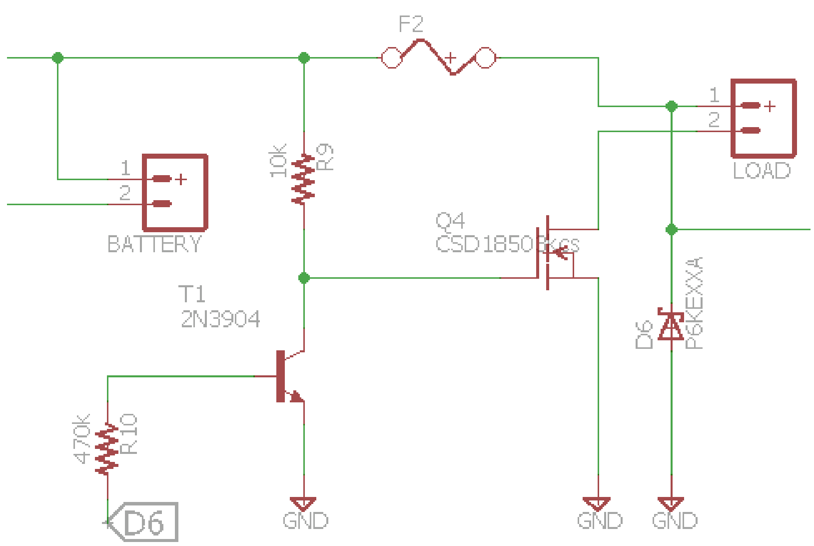


Figure 5.2.6 Schematic of Load MOSFET

This Load MOSFET design consists of a 5A fuse makes sure that the current going to the load is not too large. Without this fuse the large current may cause damage to the components of the circuit. Another safety precaution incorporated into this design is the TVS diode, this diode is placed in the circuit to remove any transient voltage spikes from the load.

5.3 Power Distribution

The design for power distribution for the project is implemented by a system of three voltage regulators, The first voltage regulator will take power from the DC Battery, and ensures the remainder of the system is supplied with 12V DC. The 12V DC will send power to the Speaker system, USB Charging ports and onward to the second voltage regulation system. The second voltage regulation system will be supplied by the first voltage regulator and provide power to the Display and Bluetooth module. The last voltage regulation system is supplied by the second voltage regulator and provides power to the Microcontroller Unit and remaining sensors. The following sections describe each system in detail.

5.3.1 Source to 12V Voltage Regulation

The battery source provides 12V DC, capping the 12V voltage regulator input at 12V, however as the battery drains the input voltage will eventually drop to 0V. The system should work as long as possible for user convenience, shutting down at around 5.5V. Because the input voltage ranges from 5.5V to 12V, and the output is a fixed voltage of 12V, the voltage regulator should be a boost-buck switching

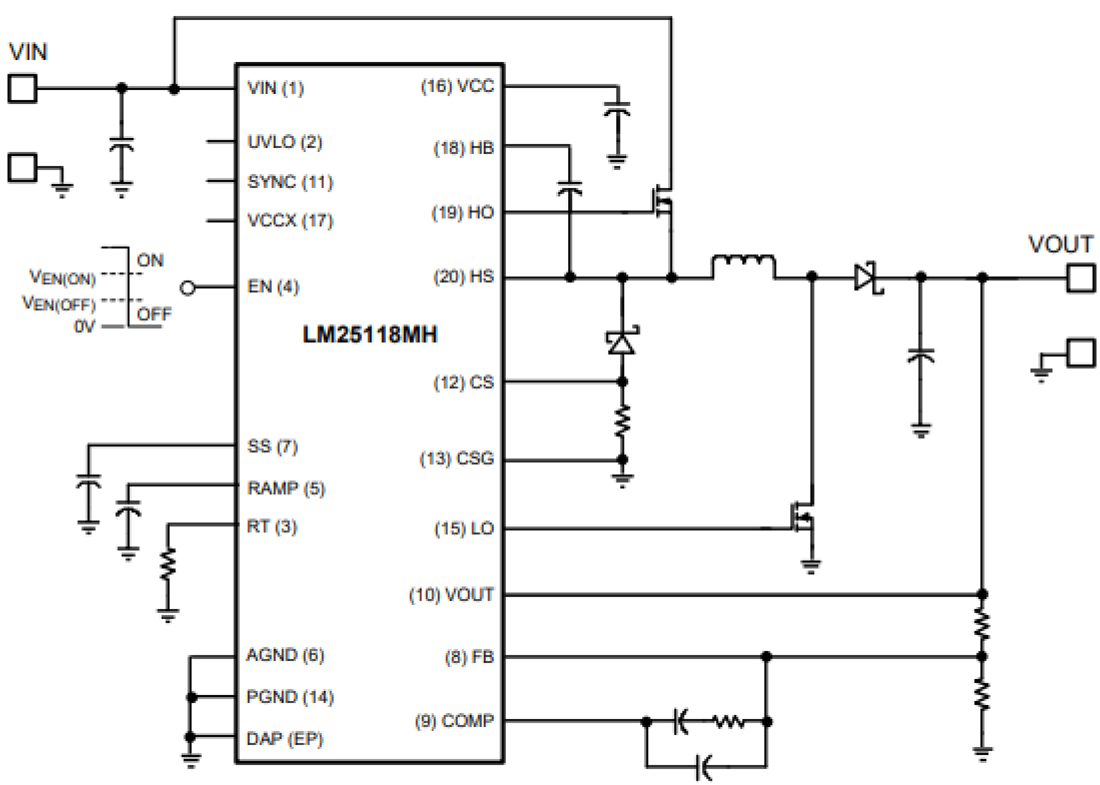


Figure 5.3.1. Source to 12V circuit design diagram

regulator, to either boost up or step-down voltage (if the battery supplies 12.01V at any point). Texas Instrument's LM25118 Wide Voltage Range Buck-Boost Controller will provide the appropriate power designated for these requirements. Given the LM25118's datasheet, a system can be designed after calculating the appropriate resistive, inductive, and capacitive values.

5.3.1.1 Design Requirements and Calculations

The design requirements for the battery source to 12V voltage controller are as follows:

- V_O = 12V
- V_I = 5V to 15V
- f = 300kHz
- Minimum load current (CCM operation) = 600 mA
- Maximum load current = 3A

The oscillation switching frequency is set by R_T which is calculated with the desired frequency, 300kHz was selected for its efficiency for the size of the component.

$$R_T = \frac{6.4 \, x \, 10^9}{f} - 3.02 \, x \, 10^3$$

Inductors are selected based upon input and output voltage, load current, ripple current, and operating frequency, to keep the circuit in continuous conduction mode (CMM), the desired maximum I_{RIPPLE} should be less than twice the minimum load current. If minimum load current specified is 0.6A, the maximum ripple is 1.2A. The inductor value must be calculated for both buck and buck-boost modes, and will be a value in-between the two calculated values. The formula for the inductor values are similar:

$$L1 = \frac{V_{OUT}(V_{IN(MAX)} - V_{OUT})}{V_{IN(MAX)} \, x \, f \, x \, I_{RIPPLE}} \text{ for buck mode and}$$

$$L1 = \frac{V_{IN(MAX)} \, x \, V_{OUT}}{(V_{OUT} + V_{IN(MIN)}) x \, f \, x \, I_{RIPPLE}} \text{ for buck-boost mode}$$

The inductor value chosen between the two resulting calculations should still favor the buck-boost mode, and once chosen, $I_{RIPPLE(BUCK\text{-}BOOST)}$ should be recalculated with the desired inductor value. Calculating the peak current is critical for determining the current limit threshold. This is important to recognize as the LM25118 double the current limit threshold in buck-boost mode. The following peak current formula will help determine the current limit:

$$I_{PEAK} = \frac{I_{OUT}(V_{OUT} + V_{IN(MIN)})}{\eta \, x \, V_{IN(MIN)}} + \frac{I_{RIPPLE(BUCK-BOOST)}}{2(1 - L_{TOL})}$$

where η is efficiency and L_{TOL} is inductor tolerance, typically inductor value tolerance is 20% and typical efficiency is 80% for the converter. For all remaining resister and capacitor formulas, please see Datasheet LM25118 in appendix B.

Calculations must also be made for the current sense resistor, R_{SENSE}, which will ultimately reduce the risk of short circuiting the system and protecting the components within. C_{RAMP} calculations are based on the inductor value selected above, and is crucial for the emulation ramp circuit, which can create a smooth output and high resolution. Reducing reverse recovery current will ensure performance and efficiency increase, so a Schottky diode will be used for the LM 25118 application. Using a Schottky diode will be vital for how long the current surge lasts and minimizing the peak instantaneous power when buck mode is activated. The reverse breakdown rating of the diode should include some safety margin for maximum input voltage. There is a capacitor between the HB and HS pins, as well as at the VCC pin that supplies the current to charge the buck switch gate during turn-on and provide noise filtering and stability at the VCC regulator, respectively. Both capacitors should be good-quality, low-ESR, ceramic capacitors. There is also a capacitor at the SS pin, which provides a soft start for the system. Soft start is the slow turn on of the power supply to avoid overloading the components by the spontaneous surge associated with charging the capacitors in the system. The LM25118 also features a snubber network, that can reduce ringing and spikes at the switching node, which can cause unexpected operation and increase noise at the output. Once all of these factors are considered, a flawless source to 12V controller can be created.

5.3.2 12V to 5V Voltage Regulation

The second voltage regulator, 5V voltage regulator will receive 12V of power from the 12V voltage regulator, capping the input voltage at 12V. Depending on the current draw to the speakers and USB ports, it could be less, but no less than 5V. The input voltage is between 5V and 12V, outputting 5V of power. Microchip Technology's LM2576 simple switcher buck voltage regulator will ensure these requirements are met. Given the LM2576 datasheet, a system can be designed after calculating the appropriate resistive, inductive, and capacitive values. This new 5V source will be used to power components such as the Ultrasonic sensor and the LCD. See section 5.3.3 for formulas and general schematic for Texas Instruments LM2576 buck voltage regulator.

5.3.3 5V to 3.3V Voltage Regulation

This third and last stage to the voltage regulation will take an input voltage of 5 from the 12V to 5V voltage regulation stage and provide a 3.3V output. This new output will be used to power components like the microcontroller, Bluetooth module, and the environmental sensors. The design for the 5V to 3.3V Voltage Regulator will follow the design of the 12V to 5V Voltage Regulator very closely, where the design will also use the LM2576 component and calculations will be completed based on the circuit design formulas found in the LM2576 datasheet. Given a voltage input of 5V, a desired output voltage of 3.3V, and using the Reference Voltage value given by the datasheet, 1.23V. The following equation can be used to determine resistor values.

$$R_2 = R_1(\frac{V_{OUTPUT}}{V_{REF}} - 1)$$

To maximize simplicity, the value of the R_1 resistor will be 1 kΩ; therefore, R_2 resistor value will be 1.69 kΩ. Figure 5.3.2 from Texas Instruments illustrates the schematic for the circuit to be built to have a desired output voltage with resistor values that were obtained through the above equation.

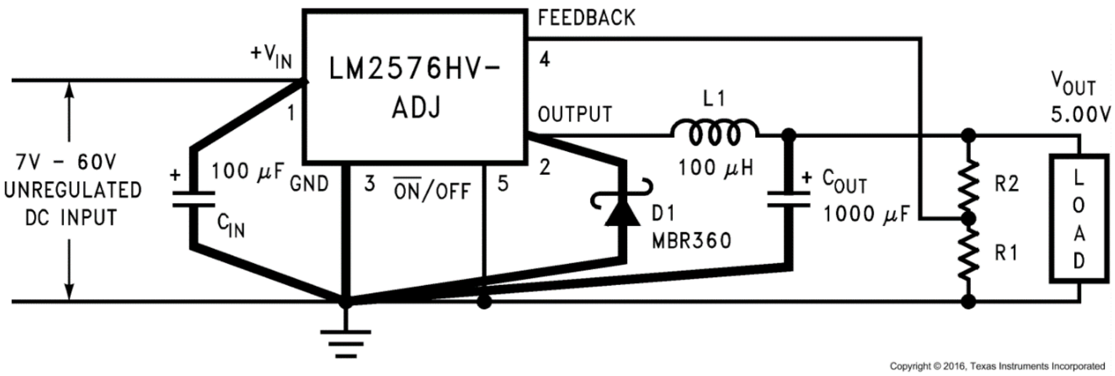


Figure 5.3.2. Texas Instruments LM2576 schematic for Adjustable Voltage Output

5.4 PCB Schematic

The PCB Schematic for the Solar MPPT Battery Charger, Voltage Controller, and Voltage Regulators are split up for ease of sight below. The schematic was made in Autodesk Eagle and are in its earliest stages of development. Further testing and design must be completed before ordering the board. The images were darkened and sharpens for clarity.

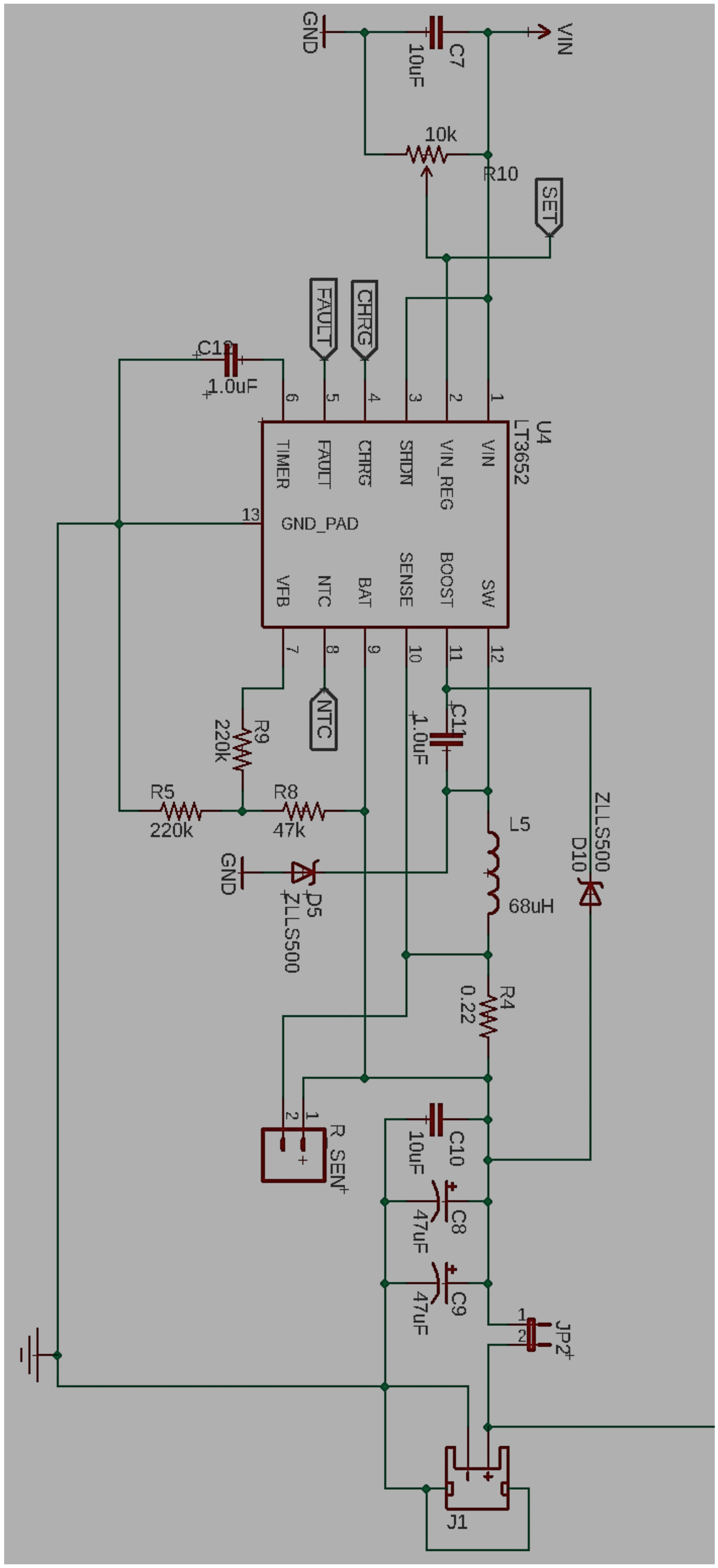


Figure 5.3.3. PCB schematic of Solar Battery Charger utilizing Maximum Power Point Tracking (MPPT)

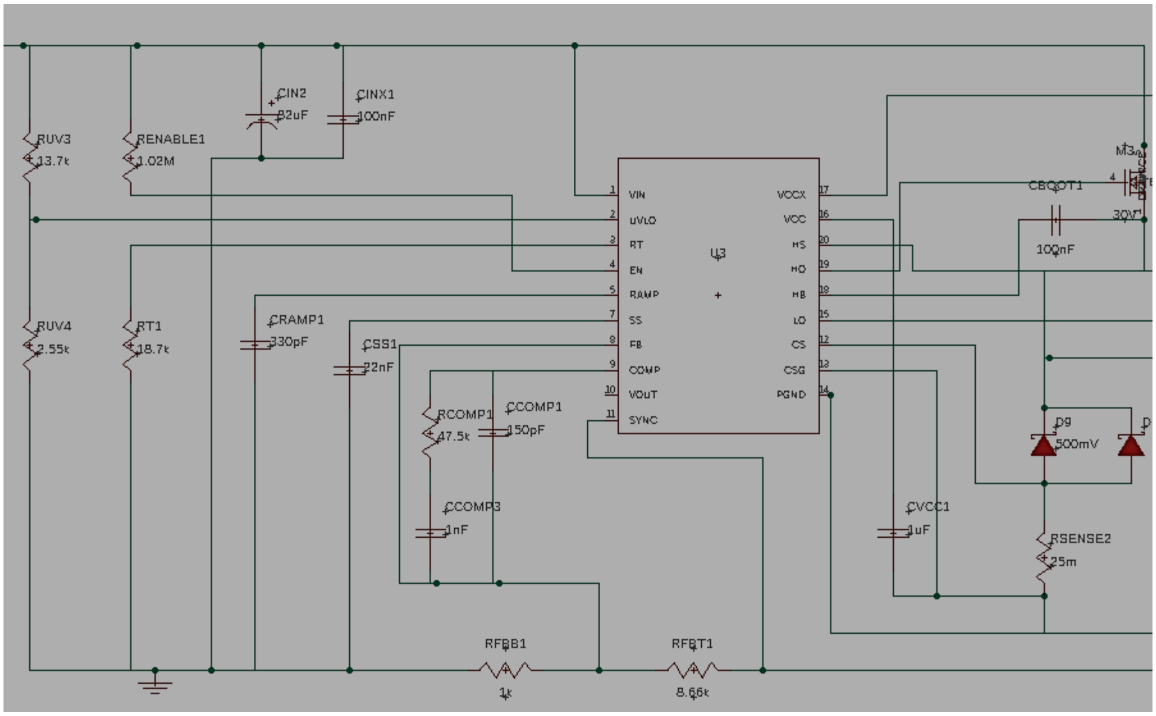


Figure 5.3.4. PCB Schematic of left-half of LM25118 12V voltage controller design

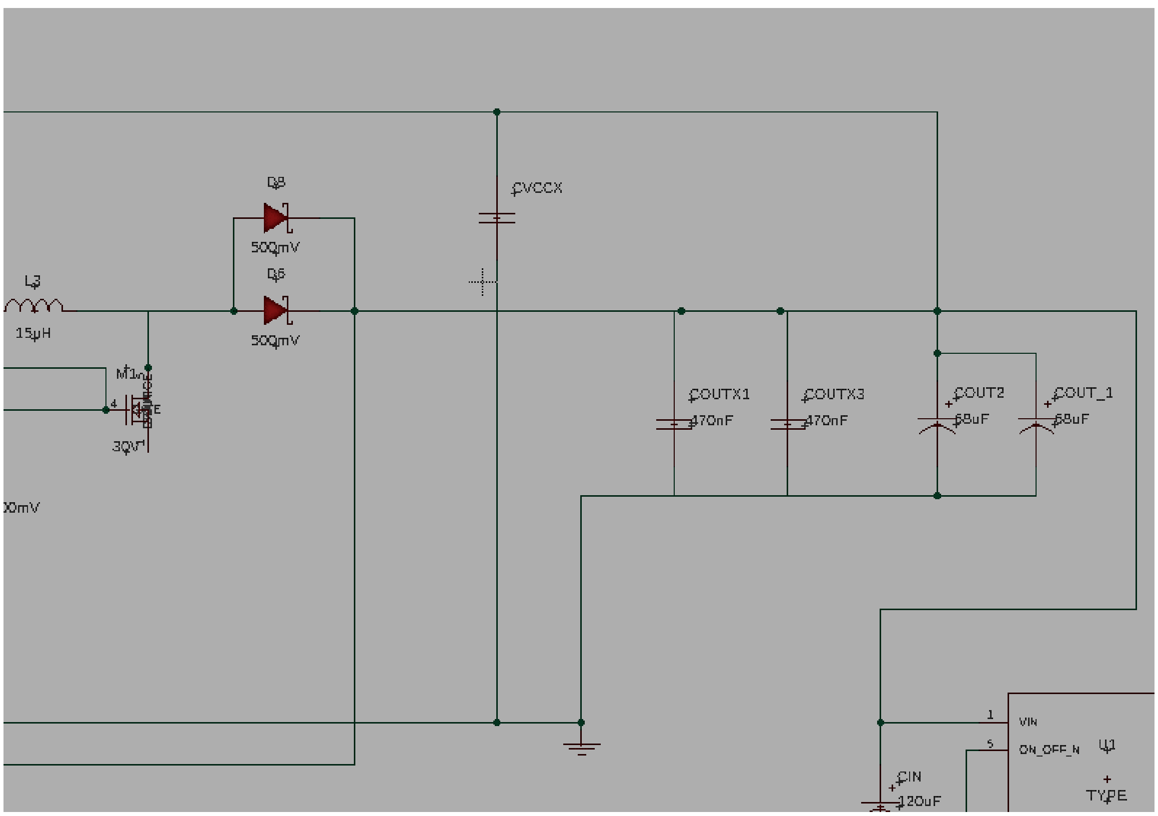


Figure 5.3.5. PCB Schematic of right half of LM25118 12V voltage controller design

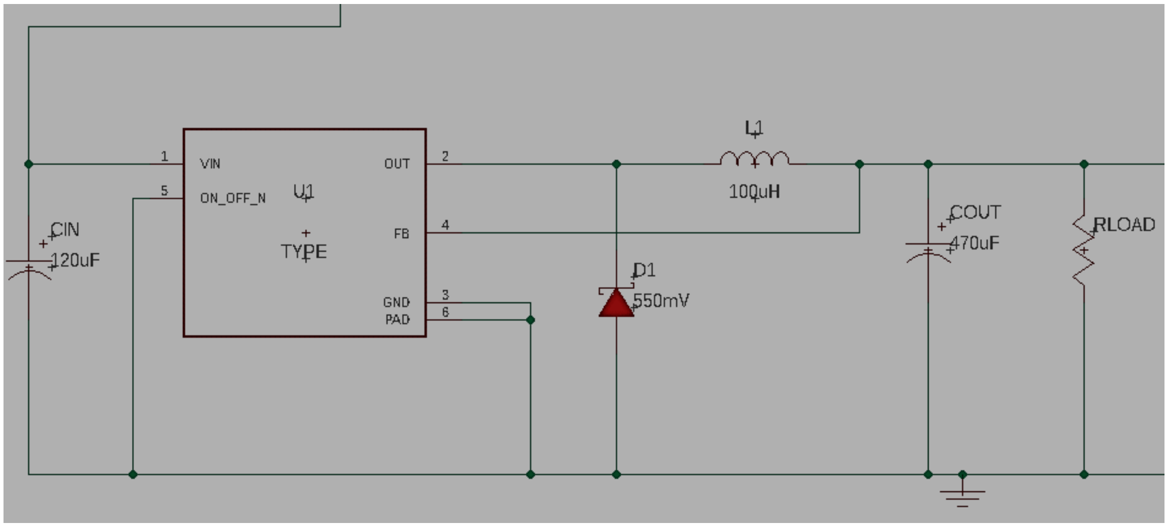


Figure 5.3.6. PCB Schematic of 12V to 5V LM2576 voltage regulator with replacement load

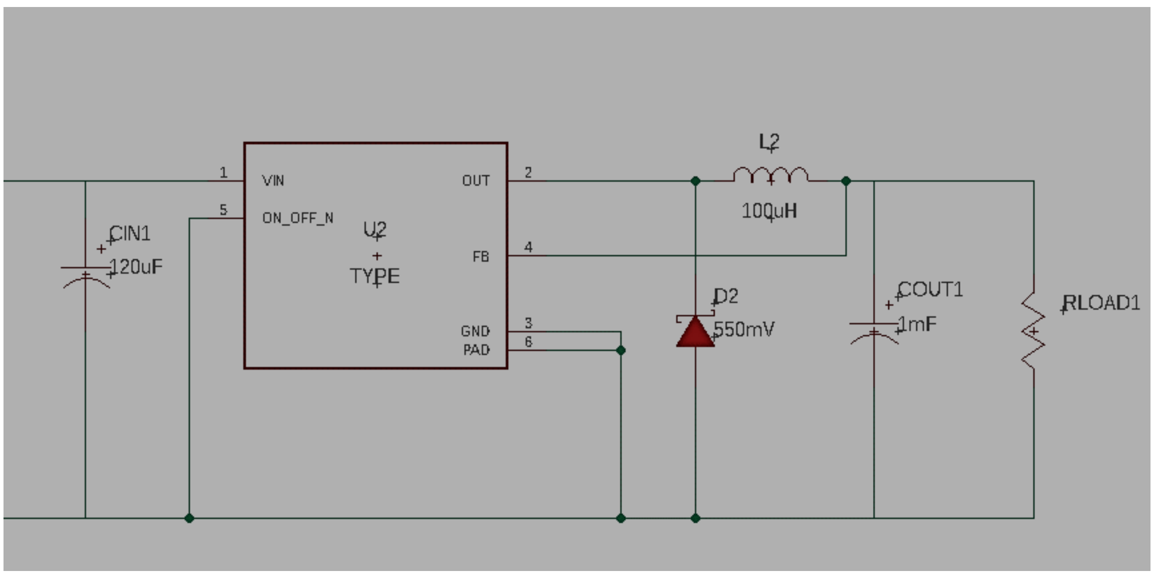


Figure 5.3.7. PCB Schematic of 5V to 3.3V LM2576 voltage regulator with replacement load

5.5 Breadboard testing

The following page consists of all breadboard testing that was conducted during the design process for this project. These tests were performed to ensure functionality and efficiency of all components of the product preceding the actual build. All of this testing was done on breadboards to reduce error and cost. This discussion will be elaborated on in the System and Component Testing section of this report. Below is the picture of the breadboard followed by a caption of what prototype is being built in the picture.

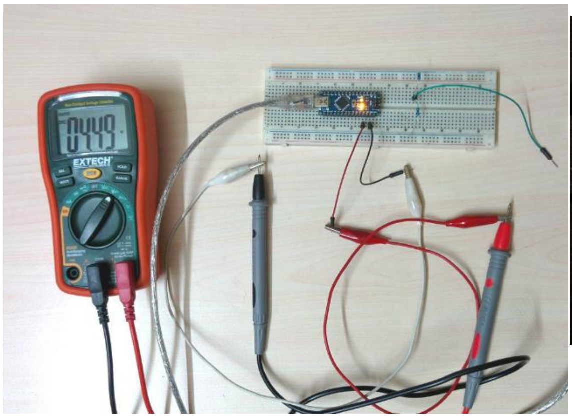


Figure 5.5.1 Voltage Sensor Testing

Figure 5.5.2 Solar Cell Testing

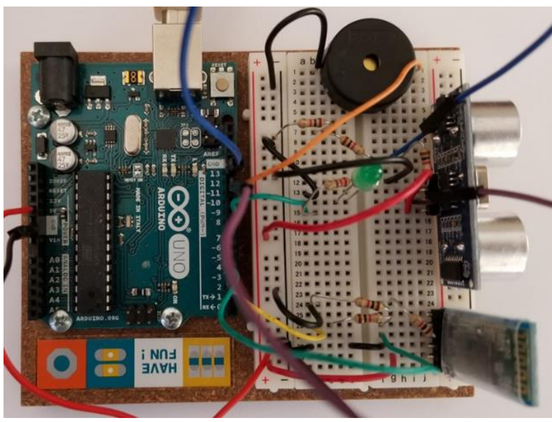


Figure 5.5.3 Security Mode Circuit Built on Physical Breadboard

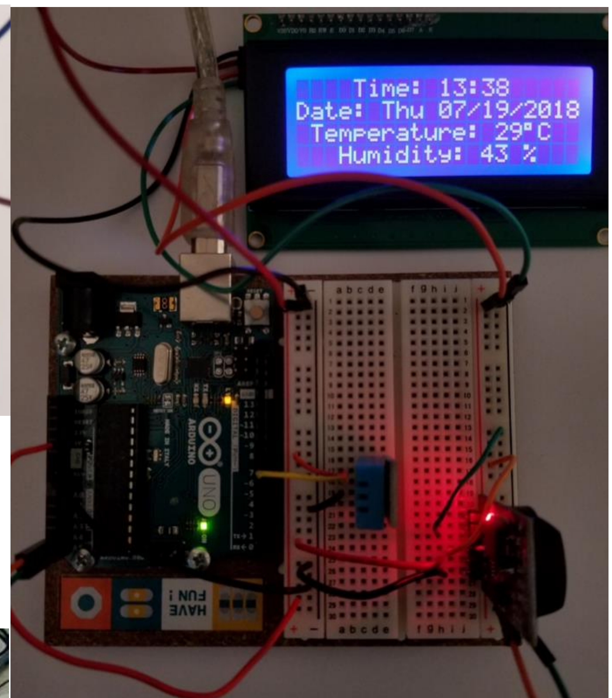


Figure 5.5.4 Temperature/Humidity Sensor, Real Time Clock, and LCD on physical breadboard

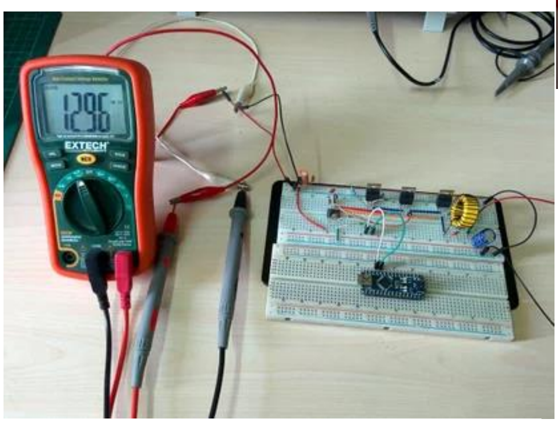


Figure 5.5.5 Synchronous Buck Converter Testing

6.0 SOFTWARE DESIGN

This section discusses how the software for the system is designed to incorporate operability of all the physical components. The software is used to make decisions for the system and provide functionality that the user wants.

6.1 Security Mode Design

The security mode for the system will involve two major devices and some accompanying components, namely sensors and modules. The two devices are the microcontroller and the Android mobile device. These two devices will exchange data using the Bluetooth technology. Essentially the mobile device needs to transfer a signal to the microcontroller that the microcontroller can interpret as either a command to initialize or exit security mode. The security mode involves using ultrasonic sensors to determine the proximity distance of an object from the system and toning a piezo buzzer, if the object becomes too close.

This Bluetooth wireless communication is accomplished by the HC-05 wireless Bluetooth module. The HC-05 is connected to the microcontroller like any other UART serial connection device would be. As far as the microcontroller is concerned, it is simply communicating with the Bluetooth module, and it does not even know the mobile device even exists. It behaves as if it is just carrying out standard serial communication with the module. The Bluetooth module, however, is the one that must accept and establish a wireless pair with the mobile device. It then exchanges data from the mobile device. This can be accomplished by using a software serial library and creating an instance of the software serial class, using the defined RX and TX pins of the microcontroller as parameters, and then beginning a serial connection at 9600 baud rate, which is the typical baud rate of these modules.

These software serial pins are defined as the RX Pin on pin 4 and the TX Pin on pin 2. The ultrasonic sensor pins are defined as the Trigger Pin being on pin 12 and the Echo Pin being on pin 13. The Piezo Buzzer Pin is defined as being on pin 11.

Next, the pins and variables must be initialized. The two pins on the ultrasonic sensor, trigger pin and echo pin, are defined as output and input, respectively. The Piezo Buzzer pin is defined as output. A variable that holds the current security state is declared and initialized as 0, or “false”.

After the setup is complete, the program will begin its loop. It begins by the Bluetooth module viewing the serial line and seeing if there is any command from the mobile device. If there is not, it keeps waiting for one. If there is a command, it reads in the command and stores it in a character variable. The microcontroller then views the saved character and determines whether the input was to enable the security mode (1) or disable the security mode (0). If the command was to disable the security mode, the security state variable is reset to 0 and the Bluetooth module continues to wait for a command. If the command was to enable the the security mode, the security state variable is set to ON (1) and the module once again checks if there is a command on the line. If yes, it will read the command

and interpret the state again and make the same decision process as before. If not, the microcontroller will begin the process of getting a reading from the ultrasonic sensor. The program must first clear the trigger pin, to make sure there is no interference from a previously set high pin by setting the trigger pin LOW and then waiting a couple microseconds. Then the program digitally writes HIGH to the trigger pin for 10 microseconds. This tells the ultrasonic sensor to send out an 8 cycle sonic burst which will be received by the echo pin. The trigger pin is then reset to LOW. The pulseIn function is then called on the echo pin to return the duration of time it took for the sound burst to hit the object and return to the sensor. Using this duration value, the microcontroller can solve for the distance. It divides the duration in half, since the system is only interested in the sound travel from the sensor to the object, and not the duration of the round trip. That value is then divided by the pace of sound, 29.1µs/cm, giving the value of distance between the sensor and object.

Finally, using the distance value, the microcontroller can compare it to some defined distance thresholds. If it falls within some distance range, it can force the piezo buzzer to tone at a specific frequency. If it falls within a farther distance range, it will tone at another frequency. Then, if the object is outside a specific “safe” range, the program will halt the toning of the buzzer and return to looking on the serial line for a command from the phone. If there is not one, the ultrasonic sensor will continue making distance readings and repeating the process, until a command comes on the serial line, ordering it to disable security mode.

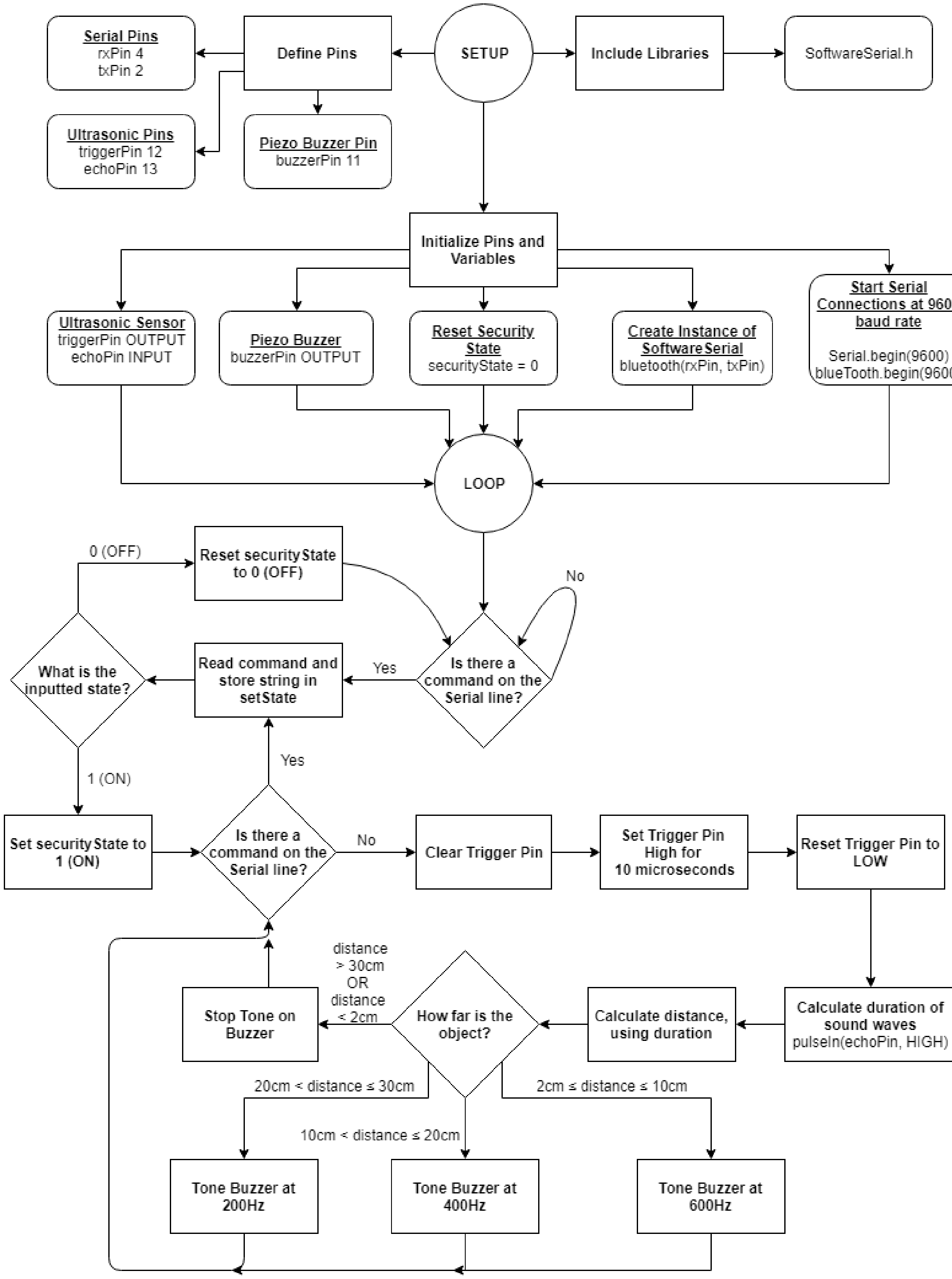


Figure 6.2.1. Flowchart for Security Mode Design

6.2 Displaying Date, Time, and Weather Design

One of the functions of the system will be to keep time and record temperature and humidity of the surrounding environment accurately and then display this information to the user on an LCD. Three major components are involved with this task, aside from the microcontroller. These are the temperature/humidity sensor (DHT11), the real time clock module (DS3231), and the 20x4 character LED module with an I^2C backpack.

First the program must include the necessary libraries. The first is Wire, which allows I^2C communication. The next is the DHT library, which is designed to pull weather information from the temperature/humidity sensor. Then, the LiquidCrystal_I2C library is included, which is specifically for writing characters to the LCD screen. The last library is the RTClib, which helps with pulling the current date and time from the real time clock module.

After the libraries are included, the control pin for the temperature/humidity sensor is defined to be on pin 7 of the microcontroller. An instance of the real time clock and temperature/humidity sensor is then initialized. Next, the program defines the LCD pins to interact with the I^2C serial bus. Also, a 2D array of characters is initialized to represent the days of the week to make accessing them faster and easier.

When the declarations and initializations are complete, setup can begin. Serial communication is initialized at a 9600 baud rate, which is a typical rate. The program then checks to see if the real time clock is available or if it has lost power. If it has, it allows the user to input the correct time. If there are no troubles with the real time clock, the program continues to initialize the LCD display and declare it as a type of 4 rows of 20 characters and printing the welcome message on the display. The welcome display stays on the screen for 3 seconds and then the display is cleared, providing a smooth transition.

Following the setup, the loop of the program begins. The DHT object reads in and stores the temperature and humidity values from the control line of the temperature/humidity sensor. The current time and date is also read in from the real time clock module. The first line of the LCD will print out the current time, the second line will print out the date, the third line will contain the temperature, and the fourth line will show the humidity. These readings will occur every 5 seconds and update the LCD screen.

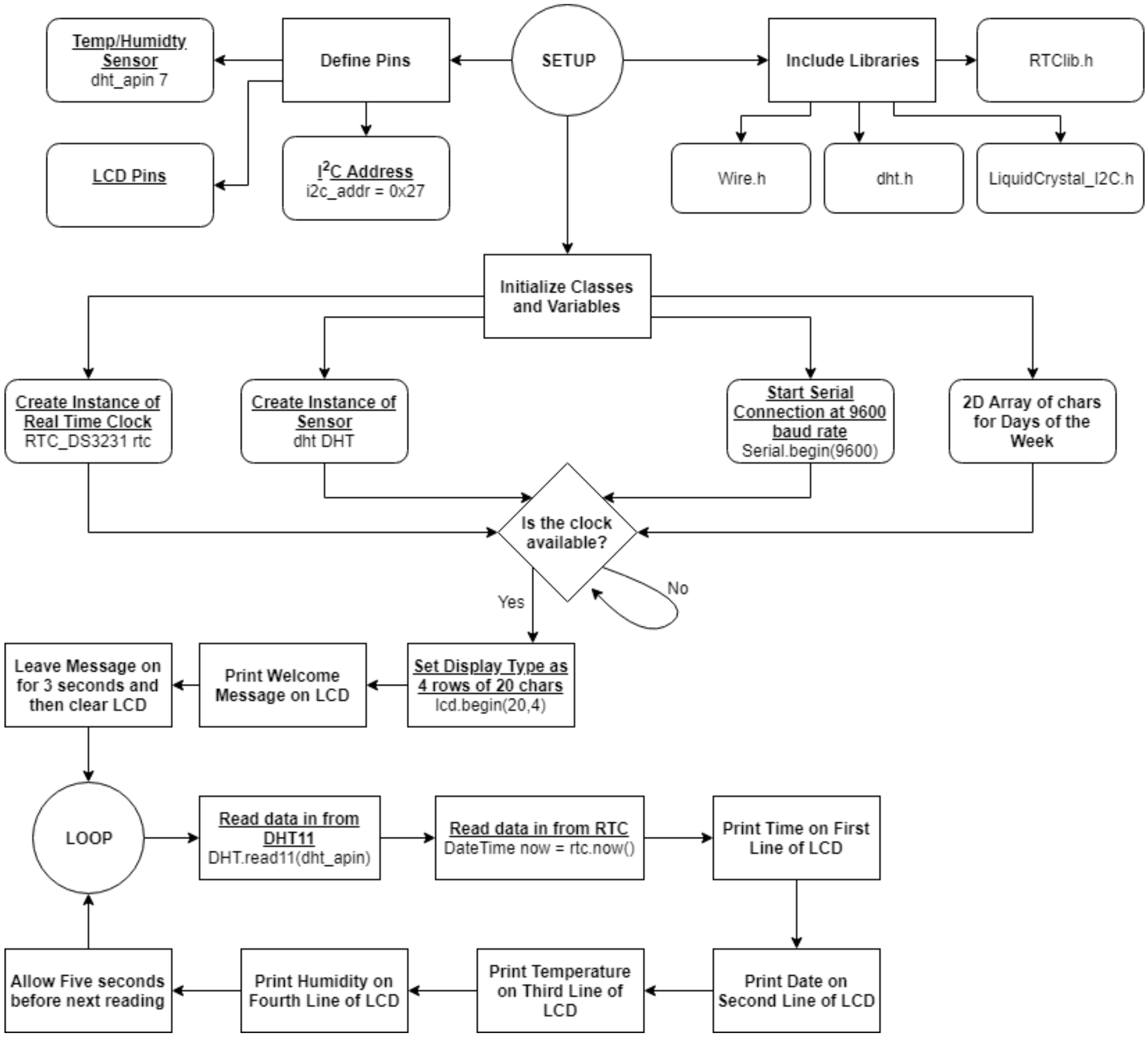


Figure 6.2.2 Flowchart for Displaying Date, Time, and Weather

6.3 Programming Language Implementation

This chapter will discuss the various programming languages used, while developing the system. The software comes down to two major parts of the system. The first part being the microcontroller that will be using the C programming language to interpret sensor data, output data to a display, and perform serial communication with the Bluetooth module. The second part of the system will utilize the Java programming language and XML.

6.3.1 C Language

The programming language of choice for the microcontroller programming is C. C programming language has been standardized by the American National Standards Institute 1989. C falls under the category of being an imperative procedural language where it can change a program’s state many times while following an orderly structure. The main reason C is chosen as the programing language to code the programs in this product is because of the nature of what the code is working on, that is, a microcontroller. Microcontrollers are limited to what programming language are compatible with it; this is due to a typical low number of registers within the microcontroller used for program flow, and very high level languages like Java, C#, or Python are not recommended for programming microcontrollers. Ergo, due to their simplicity, microcontrollers prefer high level languages on the lower end such as C and sometimes C++ or even low level languages like Assembly. The difference between C and C++ is minimal where either one could be chosen to write the code necessary to implement the product's requirements.

All of the components have pre-built libraries that are utilized in conjunction of using the C programming language to making them operate and produce the desired results. The libraries themselves are written in C, thus writing the product's code in C as well will prevent anyone from reading the code to be confused as to what language is being used. Since most of the code utilizes pre-built libraries, it will be observed that most of the actual code for the product consists of calling functions that are pre-defined within their respective libraries. These functions are available once the libraries are defined for the product's code to use. Beyond using the pre-defined functions from the libraries that each individual component has, Display, Bluetooth module, Proximity Sensor, Temperature and Humidity Sensor the other code observed will be for variable management, simple calculations, and structure program flow with decision making.

6.3.2 Java Language

For the mobile device application, the primary language used is Java. This is an object and class-based programming language. One of the great benefits of an object-oriented language is that the design process more closely resembles how humans think in their day-to-day life, as the implementation of code is at a higher level of abstraction. One of the processes of design that make development much easier to manage is the modularity of the code with functions. This allows for the developer to reuse code and recycle it, avoiding the use of repetitive lines of code that can harm the readability of the code.

Java was first released to the public by Sun Microsystems in 1996. The appeal was that the code did not need to be compiled on the machine that ran the program and that the machine running the code only needed to support Java, allowing the language to be cross-platform. They called it "Write Once, Run Anywhere" [66]. Java has become the official development language for the Android mobile environment.

6.3.3 XML

In addition to Java, another programming language for the mobile application is XML. It stands for Extensible Markup Language. The purple of the language is to establish guidelines for document encoding that is readable by human and machine. Android Studio application development uses XML to create a structure for the user interface (UI) of the application. It has potential for a modular design, allowing the development of activities within the app separately.

7.0 SYSTEM AND COMPONENT TESTING

After all the products for the system have been selected and ordered, its critical to ensure they produce expected results. By testing each system individually, functionality can be ensured between these systems. This section will look over the testing of both the hardware components and the software components. After specifying the components in the system to be tested, a test will be designed and concluded on whether or not the testing was successful.

7.1 Testing Environment

Testing of the any hardware or circuitry systems will be first simulated using Multisim™ Simulation Software. This will show any unexpected errors made in the design stage and allow for correction before any physical testing on the hardware is conducted. This will protect the components from any unnecessary damage.

Most testing will be done in an electronics lab or an otherwise indoor air-conditioned environment using any necessary tools or equipment. However, testing that includes the Solar panels and solar array must be conducted outdoors and will be repeated on a number of days with varying levels of cloud coverage and shadow casting. The results of these tests will be recorded and simulated for any indoor testing done on other components pertaining to solar charge conversion.

7.1.1 Testing Equipment

Below is a list of all the equipment used by the builders when performing these initial testing procedures.

- Tektronix DMM 4060 6.5 Digit Precision Multimeter
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator 25 MHz
- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Agilent E3630A Triple Output DC Power Supply
- Eteckcity MSR-500 UT33D Digital Multimeter
- Arduino IDE

7.2 Voltage Regulation System

To ensure the Voltage Regulators properly regulate to anticipated values, they must be tested one at a time, and measured at each input and output for voltage levels. All voltage regulation testing procedures will be similar, with only variations in measured output between each individual regulator. The testing procedure for the voltage regulators is as follows:

Objective: By testing different aspects of the voltage regulation hardware, there is assurance that the electronics are working properly and are safe to use. This test requires the voltage regulator circuit set up according to its data sheet, and desired values.

Setup: Due to its heavy circuitry requirement, testing must be completed in an electronics lab with full signal processing and circuit analysis equipment. The University of Central Florida's Senior Design Laboratory (in Engineering 1 Room 456) has all the necessary testing equipment:

- Tektronix DMM 4060 6.5 Digit Precision Multimeter
- Tektronix AFG 3022 Dual Channel Arbitrary Function Generator 25 MHz
- Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel
- Agilent E3630A Triple Output DC Power Supply
- Texas Instruments LM25118 (source to 12V) regulation system design
- Texas Instruments LM2576 (12V to 5V) regulation system design
- Texas Instruments LM2576 (5V to 3.3V) regulation system design

Procedure: The testing process will be as followed:

1. Build the voltage regulator design and make sure to correctly wire the voltage regulator's polarity, minding all design constraints from the datasheet, triple check the wiring before applying any power.

2.1. Hook up the Agilent E3630A Triple Output DC Power supply to the input of the voltage regulator.

2.2. Vary the input voltage V_{in} ±10V around the desired output, measuring V_{out}, I_{out}, and I_{in} with the Tektronix DMM 6.5 Digit Precision Multimeter. Plot the output current and input current as a function of input voltage.

2.3. Plot as P_{out}/P_{in} as a function of V_{in} from step 2.

2.4. Compare the I_{out} vs V_{in} and P_{out}/P_{in} to its respective datasheet and note variations larger than 5%.

3. Hook up channels of the Tektronix MSO 4034B Digital Mixed Signal Oscilloscope, 350 MHz, 4 Channel, to the voltage output.

3.1. Set V_{IN} to anticipated input voltage, measure output pin voltage on one channel, output pin current on one channel, inductor current on one channel and output ripple voltage AC coupled on another channel. Record these waveforms.

4. Compare recorded data to datasheet data

Setup: For temperature testing, its necessary to expose the regulation system to extreme temperatures. The easiest way to complete this is by setting the system in it's anticipated environment, the beach or a park. The test team must take the voltage regulators for testing to these environments along with some testing equipment:

- Eteckcity MSR-500 UT33D Digital Multimeter
- Battery
- Texas Instruments LM25118 (source to 12V) regulation system design
- Texas Instruments LM2576 (12V to 5V) regulation system design
- Texas Instruments LM 2576 (5V to 3.3V) regulation system design

Procedure: The testing process for temperature testing will be as followed:

1. Build the voltage regulator design and make sure to correctly wire the voltage regulators polarity, minding all design constraints from the datasheet, triple check the wiring before applying any power.
2. Use replacement resistor loads for the peripherals and connect the three regulation systems together.
3. Apply battery power to the source to 12V regulation system, record output voltage value.
4. Record input and output voltage for the 12V to 5V regulation system.
5. Record input and output voltage for the 5V to 3.3V regulation system.
6. Repeat every 30 minutes.
7. Plot voltage versus time, and observe any notable events.
8. Compare recorded plots to datasheet plots

Conclusion: If the differences between testing and datasheet values are minimal and all requirements are satisfied then the voltage regulator can be expected to work as intended. Otherwise, re-evaluation of design is necessary.

7.2.1 Battery to 12V Results

<work in progress>

7.2.2 12V to 5V Results

<work in progress>

7.2.3 5V to 3.3V Results

<work in progress>

7.3 Software Design and Sensor/Module Testing

The following sections discuss how the sensors and modules that are attached to the microcontroller were tested. The components were tested to see if they were in working condition and provided accurate and expected results.

7.3.1 Security Mode

This section discusses how the security mode feature is tested for the system. The ultrasonic sensors, which determine proximity of an object, and the Bluetooth module, which provides communication between the mobile device and the microcontroller, are tested for functionality, accuracy, and reliability.

7.3.1.1 Ultrasonic Sensor (HC-SR04)

An ultrasonic sensor (HC-SR04) is used for the implementation of the security mode in the system. In order to verify that the sensors worked correctly and accurately, they were prototyped with an Arduino UNO. The sensor works by sending out an ultrasonic sound wave from its trigger pin and measuring the duration of time that it takes for the sound wave to return to its echo pin after bouncing off an object, followed by deriving the distance the object is from the sensor. It accomplishes this by first setting the trigger to high for 10 microseconds.

This tells the sensor to send out its 8 cycle ultrasonic 40kHz pulses outwards. The echo pin will receive the ultrasonic wave, provided it bounces off an object and returns. The echo pin can then output the number of microseconds that it took for the sound waves to make the journey. This is a simple calculation, since the speed of sound is known at 343.5 meters per second or 0.03435 centimeters per microsecond. The reciprocal of this is 29.1. The time it takes for the echo to return is stored in a variable named “duration.” The distance is calculated using the formula:

$$distance = \frac{\left(\frac{duration}{2}\right)}{29.1}$$

The duration is halved because the amount of time that the sound wave travels is including the flight time towards the object and the return journey from the object, so the duration of the one-way trip is half that. Then, that value is divided by the pace of sound, 29.1μs/cm, which is the reciprocal of the speed of sound. This resultant value is the distance from the sensor to the object and is what is printed to the serial monitor and the data that will be compared to the set threshold values for the alarm.

A sketch was written, using the Arduino IDE, that performs the above operations and prints each distance reading into the serial monitor for the programmer to confirm proper operation. A meter stick was then placed in front of the ultrasonic sensor and an object was moved to a specific distance away from the ultrasonic sensor on the meter stick. This distance of the object on the meter stick was compared to the distance that was being printed out by the ultrasonic sensor on the serial monitor to verify accurate readings from the sensor.

Another function that was tested for the ultrasonic sensor was connecting a piezo buzzer to the microcontroller and varying the frequency of the buzzer’s tone, depending on the distance of an object from the ultrasonic sensor. For the testing distances, a distance between 2cm and 10cm would tone a 600Hz buzz, a distance between 10cm and 20cm would tone a 400Hz buzz, a distance between 20cm and 30cm would tone a 200Hz buzz, and any object that was more than 30cm away or less than 2cm (the minimum read distance for the sensor) would halt the buzzer’s tone.

7.3.1.2 Bluetooth Module (HC-05)

It was decided to test the Bluetooth Module (HC-05) concurrently with the ultrasonic sensor (HC-SR04). A Bluetooth terminal application was used on an Android device for the test to monitor communication between the mobile device and the microcontroller. All of the connections on the breadboard (Figure 5.5.3) were made.

Both the echo pins of the ultrasonic sensor and the data line between the RX pin of the Bluetooth module and the TX pin of the microcontroller contain a voltage divider. A 2kΩ resistor is placed between the echo pin and ground. A 1kΩ resistor is placed between the echo pin and Pin 13 on the microcontroller. Similarly, there is a 2kΩ resistor between the RX pin of the Bluetooth module and ground, while there is a 1kΩ resistor between the RX pin of the Bluetooth module and Pin 2 (TX pin) of the microcontroller. This is because both the HC-SR04 and the HC-05 logic levels are 0V for LOW and 3.3V for a digital HIGH, while the microcontroller that is being used for the testing has logic levels of 0V for LOW and 5V for a digital HIGH. The Tx line from the microcontroller needs to have the voltage divider to drop the voltage down to a safe 3.3V for the module, so it does not get damaged. Some devices are 5V tolerant, but it is much safer and does not require any expensive additional parts to implement the voltage divider.

Since the Bluetooth module does not need to run in master mode, as the mobile device will be initiating the pairing, and the default is slave mode for the module, it is not necessary to use AT commands to switch operating modes. The written program below (Figure 7.3.1.1) was flashed to the microcontroller chip. Like most 2.0V+ Bluetooth devices, one simply goes into the Bluetooth settings on their mobile devices and initiates the discovery process. While the HC-05 has power and is not yet paired, the red LED should be blinking rapidly on the module. On the mobile device, the Bluetooth module will show up as HC-05 and can be clicked to initiate the pairing. When asked for a password to pair, the default “1234” is inputted. The red LED then began blinking much more slowly at a rate of about one blink every two seconds, indicating a successful pairing. In order to test that the Bluetooth communication is working between the module and the mobile device, a Bluetooth terminal application is opened on the mobile device. The character “1” is sent from the mobile device on the terminal to the Bluetooth module. This indicates to the microcontroller to turn on the security mode. For testing purposes, this entails turning on the green LED on the breadboard and initiates distance measuring from the HC-SR04 ultrasonic sensors. The piezo buzzer will also tone according to the object’s distance from the sensor, as explained above. Finally, to turn off the security mode for the system, the character “0” is sent from the mobile device on the terminal. The green LED is then turned off. To ensure that the security system was disabled, an object was placed at a distance that would ordinarily initiate a tone from the buzzer, if it was on, but no tone was sounded. Also, the distance measurements in the software’s serial monitor halted, indicating the test worked.

7.3.1.3 Breadboard for Software Design

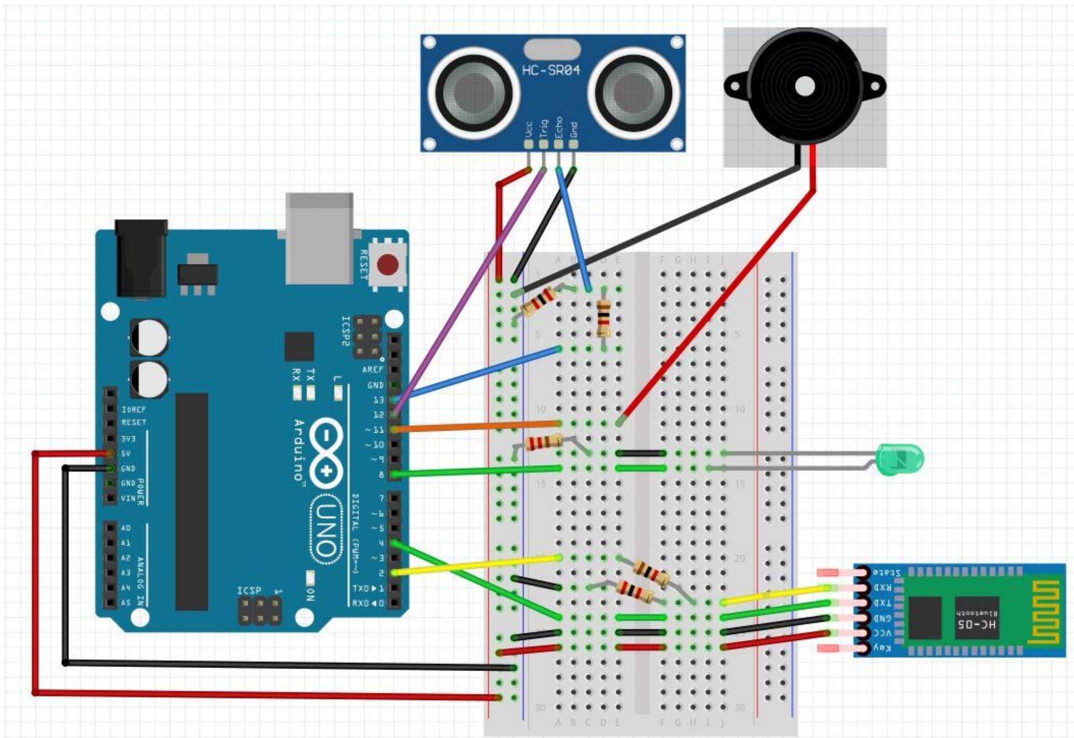


Figure 7.3.1.1 Security Mode Breadboard built in Fritzing software

7.3.2 Displaying Date, Time, and Weather

One of the features that the system has is the ability to measure the temperature and humidity of the surrounding environment. Another is to keep the time and date, using a real time clock module with an oscillating crystal, accompanied by a battery for it to maintain time even when power is lost. Lastly, the system has a liquid crystal display to present the user with these pieces of data.

7.3.2.1 Temperature / Humidity Sensor (DHT-11)

A DHT-11 temperature and humidity sensor is implemented in the system to provide the user with information about the weather conditions of their proximity. It reads temperatures between 0 and 50°C with a ±2°C accuracy. It also reads humidity between 20 and 80% with a 5% accuracy. The testing environment and the climate of the future use environment fall within these ranges. The module testing will simply verify that the device works and provides an accurate reading. The device operates with an input voltage of 3-5V and cannot sample more than one time per second. The Vcc pin is connected to the 5V rail on the breadboard, the ground is connected to the ground rail, and the control pin is connected to pin 7 on the microcontroller. A program was written that reads in the temperature and humidity values from the sensor and prints them to the serial monitor for the programmer to observe. There were two methods of verification to confirm these values as accurate and consistent. The first being that the outputted value onto the serial monitor was compared to the value that was obtained by pointing an infrared thermometer at the sensor. If this value was within the ±2°C accuracy, it was considered an accurate result. The second method was simply testing multiple sensor modules and noting if they were all in agreement with their readings.

7.3.2.2 Real Time Clock Module (DS3231)

A DS3231 real time clock module is implemented in the system to provide the user with the current time and date on the display. The Vcc pin is connected to the 5V rail, the ground is connected to the ground rail, the SDA pin is connected to the SDA rail that is connected to pin A4 on the microcontroller, and the SCL pin is connected to the SCL rail that is connected to pin A5 on the microcontroller. A program was written that initializes the clock and date to the current date and time of the computer at the time of compiling the code. From there, the oscillating crystal onboard the module keeps time and will update the variable in the program every 5 seconds and printing the result to the serial monitor for the programmer to observe. This updating value on the serial monitor is compared to the clock on the desktop computer, verifying the module is keeping time accurately.

7.3.2.3 LCD Screen (20x4)

An LCD screen with 4 rows of 20 characters is implemented in the system to display the data from the two previous modules to the user. It utilizes an I^2C backpack that has been soldered to the back of the display, meaning that the display only needs four wires to connect, instead of the usual 16, freeing up many pins on the microcontroller. It only requires power (V_{CC}), ground, clock, and data. The V_{CC} pin is connected to the 5V rail, ground is connected to the ground rail, data (SDA) is connected to the SDA rail that the real time clock is also on, and the clock (SCL) is connected to the SCL rail that the real time clock is also on. Since two devices are being used on I^2C, it must be confirmed that the LCD is the only device on the bus with an address of 0x27. The test for the LCD is comprised of testing it with the real time clock module and the temperature/humidity sensor. Along with printing the data from the other two modules to the serial monitor, the program will also print it to the LCD screen. The data in these two locations are compared and verified that they agree. This also confirms that both the LCD and real time clock are communicating on the I^2C bus without interfering each other.

7.3.2.4 Breadboard for Software Design

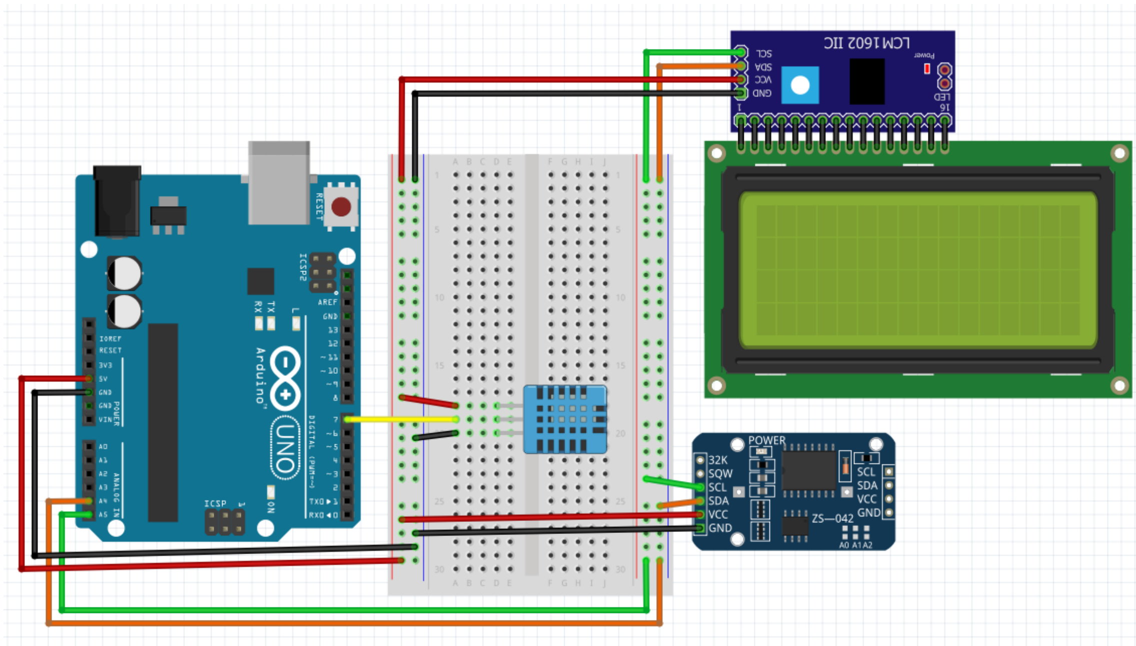


Figure 7.3.2.1 Temperature/Humidity Sensor, Real Time Clock, and LCD on Fritzing Software breadboard

7.4 Maximum Power Point Tracking Charge Controller Testing

The MPPT consists of a plethora of parts that need to be individually tested for functionality and efficiency. To reduce error and cost all testing will be done on breadboards as shown in the design section of this report.

7.4.1 Synchronous Buck Converter Testing

The working principle of a Synchronous Buck Converter can be described as the following. When the MOSET is On, current will flow through the inductor, load, and the output capacitor (as shown in figure 7.4.1). In this condition the diode is reversed biased. Making it so that there is no current flowing through the diode. During this On state magnetic energy is stored in the circuit's inductor and electrical energy is stored in the output capacitor.

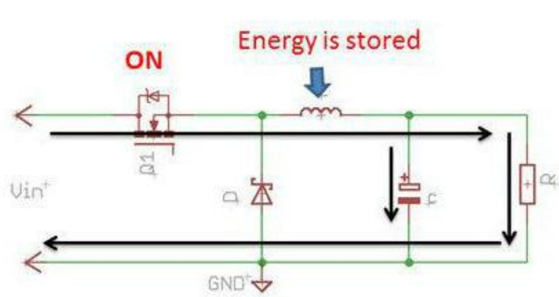


Figure 7.4.1 Buck Converter Current Flow when MOSFET is On.

When the MOSFET is off the stored energy in the inductor is collapsed and the current is able to complete its path through the diode, meaning the diode is in forward bias (as shown in figure 7.4.2). When this stored energy in the inductor vanishes the stored energy in the capacitor is supplied to the load to maintain the desired current.

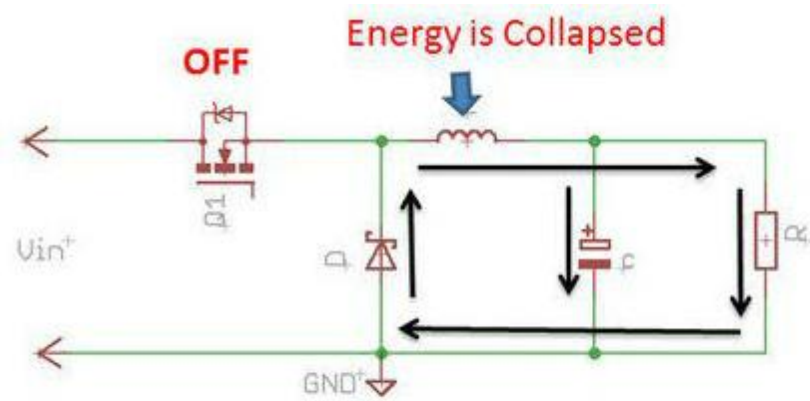


Figure 7.4.2 Current Flow in the Buck Converter Circuit when MOSFET is off.

For this application builders are using a synchronous buck converter. The only difference between the two is that the synchronous buck converter incorporates a power electronics switch to improve the efficiency of the previous design. This is the circuit that the builders ran their tests on via a breadboard.

In the previous sections the builders calculated the inductor and capacitor values necessary to complete the circuit.

Procedure: The testing process will be as followed:

1. To start testing the builders constructed the circuit on a breadboard as shown in figure 5.4.5 with the addition of 0.1uF capacitors placed in parallel with the input and output capacitors. This is to give a more clear result.
2. Then the designers test the resistance between the input rail and the circuit. The value should be a resistance in the thousands, if the resistance is too low the builders must recheck the circuit for errors.
3. Once the desired value is seen the builders can then give power to the input rail.
4. Now the builders can connect the probe of their oscilloscope in between the output capacitor and ground. The output should be a steady 12 V DC voltage.
5. Adjusting the duty cycle to 50% should result in a 6V DC output.
6. Upon concluding that all components are working the builders can now attach the third MOSFET, the 470k resistance, and the diode IN4148. The output should remain the same.

7. Lastly, the builders should check the voltage output of the circuit by placing the probe between the gate of the Q1 MOSFET as per the schematic and ground.

Conclusion: If the builders obtain the desired results from the oscilloscope readings then the buck converter is functioning properly. If any readings are undesired then adjustments must be made to the design and further testing is required.

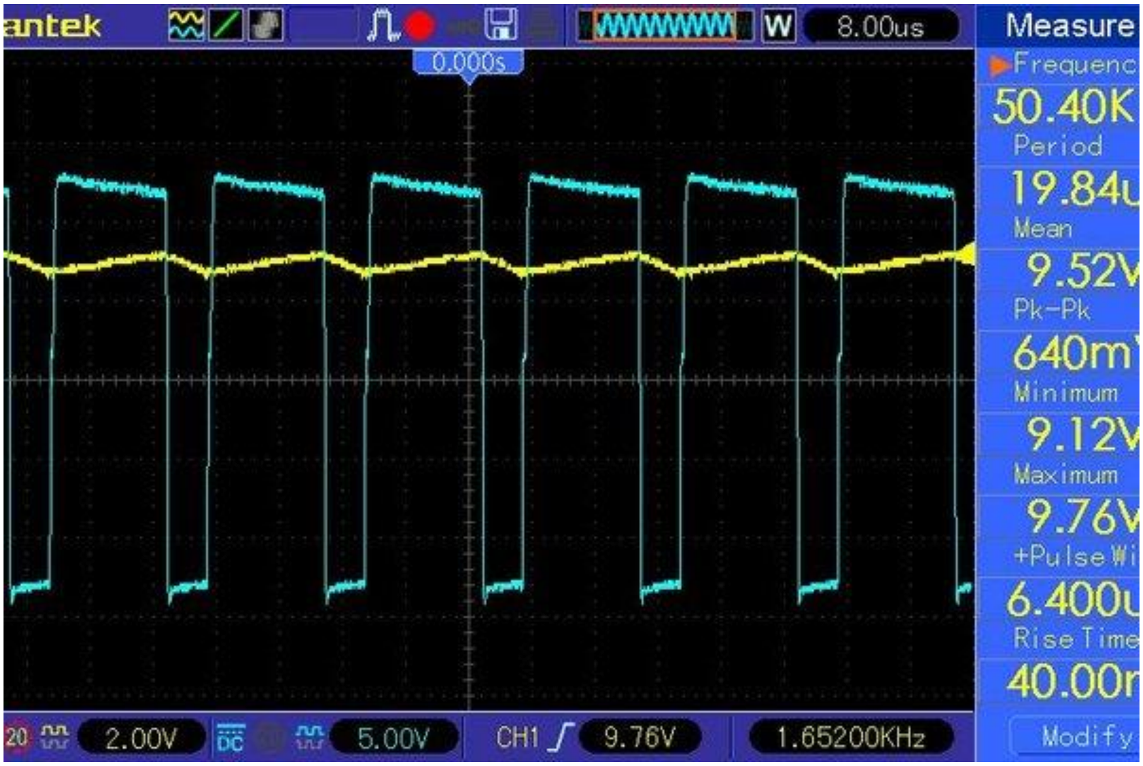


Figure 7.3.3 Oscilloscope results of step 7 showing Vout.

7.4.2 Voltage Sensor Testing

To test the Voltage sensors the builders constructed the circuit from section 5.2.4 on a breadboard. Builders then calibrated the sensor with the microcontroller using the designed code and they used a digital multimeter to record the results.

7.4.3 Current Sensor Testing

To test the current sensor the builders constructed the circuit from section 5.2.3 on a breadboard. Builders then calibrated the sensor with the microcontroller using the designed code and they used a digital multimeter to record the results.

7.4.4 LED Testing

To test the LEDs the builders constructed a simple breadboard circuit as shown in figure 5.4.2 and connected it to the microcontroller and the battery. Builders then calibrated the sensor with the microcontroller using the designed code and used the chart in figure 7.3.4 to determine the LEDs accuracy.

State of Charge	12 Volt battery	Volts per Cell
100%	12.7	2.12
90%	12.5	2.08
80%	12.42	2.07
70%	12.32	2.05
60%	12.2	2.03
50%	12.06	2.01
40%	11.9	1.98
30%	11.75	1.96
20%	11.58	1.93
10%	11.31	1.89
0	10.5	1.75

data from **http://www.windsun.com**

Figure 7.4.4 Chart to determine LED testing

7.5 Solar Cell Testing

To test the solar panels the builders simply soldered wires to the positive and negative terminals of the panels. Then using a DMM the builders were able to measure the desired power output from the panels in direct sunlight. This testing had to take place outdoors with access to direct sunlight.

7.6 Battery Temperature Testing

Due to the nature of the environment and the system's design, the battery will be in constant use, either being charged or drained, or both at any given time. Because of this possible condition, there could be a situation where energy is lost as heat. The testing procedure for the battery temperature is as follows.

Objective: To observe any energy lost as heat in extreme environments and analyze the design to minimize this loss. This will ensure high performance of the most critical source of power storage for the system.

Setup: For temperature testing, its necessary to expose the battery system to extreme temperatures. The easiest way to complete this is by setting the system in it's anticipated environment, a beach or a park. The test team must take the battery for testing to these environments along with some testing equipment and replacement loads:

- Eteckcity MSR-500 UT33D Digital Multimeter
- Battery
- Solar Cells
- Charge controller system
- USB Charger

- Hand-held device to be charged

Procedure: The testing process for temperature testing will be as followed:

1.Build the battery charging system and make sure to correctly wire the solar cells/ MPPT system and USB charging system, minding all design constraints from the datasheet, triple check the wiring before beginning recording.

2. Record battery level charge and power output.
3. Repeat every 30 minutes for 5 hours.
4. Plot power and battery charge versus time, and observe any notable events

Conclusion: Compare to the datasheet and control (in a room-temperature environment) and if differences are within 10%, it can be stated that the design works effectively enough for this application.

8.0 ADMINISTRATIVE WORK

At the base of the project, is the timeline and financing. A general estimation of the expenditures and milestone events throughout the duration of the project are outlined below. Further administrative decisions and conclusions are also detailed in this section.

8.1 Project Budget

The project budget for the design is outlined below in Table 8.

Table 8. Project Budget for Senior Design

Item	Quantity	Price Estimate (total)
Beach Umbrella	1	$20
Battery	1	$30
MCU	1	$5
Solar Panel	20	$16
LCD Display	1	$12
Speakers	3-4	$25
LEDs	10	<$5
Temperature and Humidity Sensor	5	$8.99
Proximity Sensor	5	$9.50
Bluetooth module	1	$5.65
Custom PCB	?	$12
Energy Storage Device	1	$45
Waterproof/Particle materials for encasement	N/A	Free
USB Type A Female Ports	2	$3
Resistors, Capacitors, and ICs	N/A	<$4
Trips to the beach?	Many	As much as it takes

Total: $198.15 - $230.15

8.2 Project Timeline

The milestones and respective deadlines are outlined below.

Deadline	Milestone
6/8/2018	Divide and Conquer Report
6/13/2018	Half hour meeting with Dr. Wei
6/15/2018	Update Divide and Conquer
6/22/2018	Research and document detailed design and parts
6/23/2018	Build user interface for display
7/2/2018	Finalize fist design and parts
7/6/2018	60 pg draft
7/8/2018	Interface sensors with MCU
7/9/2018	2nd Half hour meeting with dr. Wei
7/10/2018	Interface screen and display sensor data
7/10/2018	Design housing for mcu and sensors
7/11/2018	Integrate system with wireless communication to mobile device
7/12/2018	Update 60 pg draft
7/20/2018	Build android application
7/20/2018	100 pg submission
7/30/2018	Final Report Submission
8/3/2018	Design PCB and Order Parts deadline
8/31/2018	Build project on designed initial PCB (start 17 august)
9/19/2018	Integrate components and housing
10/26/2018	Final testing and revisions

8.3 Division of Project Responsibilities

The workload pertaining to this project was divided evenly amongst the members of the group. Each component of the project was assigned a primary and secondary group member. The primary member does most of the designing and testing of the component and the secondary member provides assistance where needed and verification when necessary. Clearly defining roles among group members is essential, however this can be a challenging task with so few members as each member will most likely take on many different roles depending on their skillset.

Table 8.3 Division of Project Responsibilities

Component	Primary	Secondary
Solar Panel Configuration	Meghan	Casey
MPPT Charge Controller	Meghan	Casey
Power Distribution	Casey	Meghan
Bluetooth Modules	Dylan	Jesus
LCD Display	Dylan	Jesus
Sensor Configuration	Jesus	Dylan
LED Configuration	Jesus	Dylan
PCB Design	Casey	Jesus
Energy Storage Device	Meghan	Casey
Proximity Sensor Code	Dylan	Jesus
Microcontroller Programming	Dylan	Jesus
Synchronous Buck Converter	Meghan	Casey
Housing System Design	Casey	Meghan
USB Configuration	Jesus	Meghan
App Configuration	Dylan	Jesus

8.4 Suppliers

Selecting a supplier is an important task for any purchase. One must consider a handful of attributes when buying an item, including the quality of the item, its price, credibility of the vendor, and the amount of time the item is going to take to arrive after shipping.

A balance is required between how much something costs and how reliably it performs. It does not bode well for a project when the designers sacrifice properly performing components for a cheaper price tag, yet the parts cannot be so expensive that the design becomes unfeasible. Credible vendors are also important. The reputation of the company that the items are being purchased from plays a big role in the process. Companies that are well established, stock items that are well-reviewed, and are capable of shipping items rapidly are desired. It is too excessive of a risk to select a supplier that has poorly reviewed items, simply because they are cheap or offer quick shipping.

Since many of the components that were selected for the design are open-source hardware, there is an abundance of options available for online vendors. A benefit of purchasing open-source hardware is that many different manufacturers will sell parts that are identical, driving the price further down. Also, the design files, source code, and schematics tend to be readily available for view to anyone. The transparency of this hardware design lends to a surrounding community that contains a myriad of tutorials, documentation, and individuals willing to assist in troubleshooting, if a component does not work properly.

8.4.1 Amazon

The first internet retailer selected was Amazon. While Amazon is an extremely prominent public company with a hand in many things, it tends to be most known for its e-commerce. Searching for content is intuitive, they pride themselves on credible reviews, and they support 3rd part vendors. There is also a subscription available for an annual fee that allows its users an exclusive discount on an array of items, accompanied with 2-day shipping time. The accelerated arrival of components is a perk for the prototyping phase when a team must quickly refine the component list to only the best working parts.

8.4.1.1 Elegoo

One of the 3rd party vendors that does business on Amazon is Elegoo. This is the company that supplied the ultrasonic proximity sensors for the system's security system. They are an open-source hardware company that participates in research and production. They operate in China and can provide less expensive versions of other pricier open-source models from a different manufacturer, yet are capable of completing the same task. They provide documentation on their website, as well, allowing the designers to understand the specs.

8.4.1.2 HiLetgo

Another 3rd party vendor of Amazon is HiLetgo. This is a different open-source manufacturer of sensors and robotic parts located in China. They create development boards and sensor modules that are cheap and drive competition to make better and cheaper parts.

8.4.1.3 KeyeStudio

Keyestudio is also a vendor on Amazon that is considered a specialist in developing cheap and quality open-source boards, modules, and sensors. This is where the system obtained its 20x4 character LCD unit.

8.4.2 eBay

The second choice for an internet retailer was eBay, which is another e-commerce company that specializes in business-to-consumer and consumer-to-consumer transactions. The site is formatted with auction style listings, as well as items that can be purchased immediately. Purchases from eBay tend to be less expensive than Amazon, however, they take longer to arrive after shipping. This is a trade-off, but the decision was made to purchase some parts from eBay, if they were not needed immediately, were too expensive from another vendor, or were simply not available on Amazon.

8.4.2.1 LeaningTech

This vendor on eBay is an online wholesaler that carries a wide gambit of products, but has a supply of consumer electronics. Their prices are low because of the volume that they produce and efforts put forth improving efficiency of their products. LeaningTech provided the Bluetooth module for wireless communication ability between a mobile device and the system.

8.4.3 Texas Instruments

For most individual electronic components, such as the voltage regulators, voltage controllers, and PCB design work, Texas Instruments is the best provider. Not only do they provide thorough datasheets for their components, but have a Sample Program that allows students and other designers to order a limited amount of parts free of charge. Texas Instruments encourages innovation through use of their parts and designs, especially for a young team of engineers. Purchases from Texas Instruments greatly benefit the design team, and the logistics team, giving the rights to use designs for no charge to the project.

8.5 Communication

Communication is a key component to working on an engineering project. This is to ensure that each member is able to voice their opinions and concerns throughout the process of construction of the product. This is also the only way each member is able to obtain any assistance needed by other team members. Communication also ensures that each team member has a complete understanding of the end goal of the project.

8.5.1 Slack

The application and web application “Slack” is a cloud-based software that Stewart Butterfield created in 2013. It allowed people to collaborate on projects more easily. It is simple to form a group and send out invites via URL. Groups are broken into channels to keep chat logs clean and relevant to specific topics. This prevents congestion and chaos in other channels, optimizing workflow, so that the design team can have a painless development process of ideas. Slack also has a feature to share files between members of the group. There are many file types supported, but one highlight of this feature is the ability to send pictures. This allows for quick troubleshooting between design members when the situation is difficult to describe through words and an image would prove much more useful. Another beneficial feature of Slack is support for code-snippets. It’s an incredibly straightforward method of simply pasting in code from an IDE and Slack giving it syntax highlighting, depending on the language. This makes it much better for the team than reading code snippets in plain-text and greatly increases the readability.

8.5.2 In-person Meetings

In addition to Slack, members also made the commitment to meet every Friday at 10:00am and also before any important deadlines, meetings lasted anywhere between two and five hours.

8.6 Information Sharing

To further the communication between group members, the team needed a way to share information quickly and effectively. So the group utilized the Google Drive application to share any large files with one another. Initially the group utilized Google Docs to provide live edits of the project report, however after extensive formatting issues and many late nights repairing the document the group decided to abandon this platform. The team then switched to Word Online, a document sharing website run by word, that provides a platform to perform live edits on a document, so that the members could see any adjusting another member does to a document in real time. This provided the team with an easy way of maintaining a well formatted report during the design process of this project.

9.0 OPERATIONS MANUAL

This operations manual contains all essential information to ensure the consumer utilizes the product in its most optimal conditions while also maintaining the user's safety. This manual includes a description of the system's functions and capabilities, contingencies, alternate modes of operation, and step-by-step procedures of assembly and use.

9.1 How to Use Mobile Application

One of the features of the Parasolar Experience is its Security Mode, which uses proximity detection, to deter thieves and notify the user, if someone is too close to the system. This security mode is controlled from the mobile application. The mobile application is designed for Android devices and can be found on the Google Play Store.

9.1.1 Installation

First, the user must download and install the mobile application from the Google Play Store. Ensure the mobile device has an internet data connection and once the Play Store is opened, type "Parasolar Experience" into the search field at the top of the screen and then press enter. Select the top result from the search and press the green "INSTALL" button when redirected to the app page. The mobile device will briefly download the application from the Play Store and then continue installing the application onto the phone. Once the installation is complete, the user can either press the "OPEN" button on the app's Play Store page to launch the app or launch it from the application bin on the user's phone by clicking on the Parasolar Experience icon that now appears on the mobile device.

9.1.2 Connecting to Bluetooth

The primary use of the mobile application is to allow the user to enable and disable the security feature of the system. The mobile device performs the communication with the system via Bluetooth, so the next step, after installing the application, is to ensure a proper Bluetooth pairing is made between the mobile device and the wireless Bluetooth module on the microcontroller. This step can be achieved by two different methodologies. One technique is to go into the mobile device's settings and navigate to the "Connections" tab. Then press the "Bluetooth" option and the mobile device will display all the Bluetooth settings, including an option to turn on and off Bluetooth, toggle discoverability for the mobile device (allowing other Bluetooth-enabled devices to see this mobile device), and also scan for other visible devices that are eligible for pairing. The Parasolar unit is always in a discoverable state by default, while it is not paired to any mobile device, so all that must be done is press the "SCAN" button on the mobile device. The Parasolar unit's Bluetooth device will appear as "Parasolar." Click the device to initiate the pairing process. In order to finish the pairing, one must insert the device passcode, which is by default "1234." The device will display no errors and a "Connected" label will appear next to the device, if the pairing was a success. The alternative method to pairing with Bluetooth, if the user cannot locate the Bluetooth options in the mobile device's native setting menus, is to utilize the Parasolar Experience's in-app Bluetooth scanner. Navigate to your applications on your phone and launch the "Parsolar Experience" application. If the mobile device does not detect a Bluetooth connection made currently with the mobile device, it will direct the user to a view in the application where several Bluetooth options will be available. The first option will be to toggle Bluetooth on the mobile device. If Bluetooth was off on the device and the button is pressed, Bluetooth will be enabled, and vice versa. When the other option, "DISCOVER", is pressed, a list of nearby Bluetooth devices will show in the list below. Select the device that is named "Parasolar." The user will then enter the passcode to finish the pairing process, which the default value is "1234."

9.1.2 Enabling/Disabling Security Mode

Once the mobile device recognizes that it is connected to the Parasolar Experience system by Bluetooth, it will direct you to a view in the application where the user will be able to press a button to turn the security mode feature on and off. In the middle of the view, there will a button labeled "SECURITY MODE". Depress the button and it will turn RED when the security mode is OFF and GREEN when the security mode is ON. The Parasolar Experience system remembers the state of security, even if the user loses Bluetooth connectivity. This way, if the user wants to take a stroll down the beach, out of Bluetooth range, the mobile device can simply be repaired when the user returns to in-range.

While in Security Mode, the Parasolar Experience will attempt to dissuade any theft attempts from any person that approaches the umbrella by playing loud beeps in hopes to draw attention to the umbrella thus scaring the would be thieve away and let the user know that there is someone that is too close to the Parasolar Experience should the user be within range of hearing the beeps.

9.2 How to assemble the Parasolar Experience

This section will supply the user with a step-by-step procedure of assembly for the Parasolar Experience.

1. Loosen screw on Umbrella Anchor to allow room for umbrella pole.
2. Screw anchor into dirt or sand in a clockwise motion. Continue turning in this manor until sand is collected in the tray at the top of the Umbrella Anchor. It's recommended to angle the anchor towards the sun, but also note the direction of the wind to prevent any premature departure of your ParaSolar Experience.
3. Remove knob from the center of the Umbrella StrapShade holder and insert it clockwise into the threaded hole.
4. Insert tapered end of the Velcro strap into the StrapShade slots, make sure the felt side of the Velcro is facing the StrapShade Cylinder
5. Insert strap through buckle and tighten around the cooler.

6. Place cooler next to the Umbrella Anchor aligning the holes of the Anchor and the StrapShade.
7. Insert Umbrella through the aligned holes and tighten the screws on both the StrapShade and the Umbrella Anchor.
8. Connect the solar power wire from the Umbrella to the receiving wire of coming from the cooler. The Screen should power on soon after.
9. Relax and enjoy the convenience of being indoors in an outdoor environment.

10.0 CONCLUSION

There were many challenges and obstacles specifically pertaining to engineering that the group members had to overcome in the research and development stages of this project. This included testing failures and the resulting redesigns of prototypes, learning curves when members were introduced to new components and new software, and the extensive research necessary for each component of the project.

As with most engineering projects the members had to establish a process of completing tasks and then maintain this process to ensure optimal working conditions. The group members of this project were able to work together with very little to no conflict. Organization and communication is key in to maintain this level of teamwork and cooperation.

The specifications and requirements outlined in the beginning of the report were constantly taken into account for each and every component that went into this product. These specifications and requirements were satisfied along with the constraints detailed near the middle of the report. These were considered for many reasons, including but not limited to, the efficiency of the product, the usability of the product by the consumer, the safety of the consumer, and so on…

Moving forward the team hopes to build a product that has a sustainable high efficiency and satisfies their initial desire to create a product that can bring the convenience of being indoors to an outdoors environment.

APPENDICES

Appendix A - Copyright Permissions

This section will provide proof that the team obtained the necessary permissions in order to utilize images that were not originally created by themselves.

Permission for Figure 3.1.1

This image was taken from a website called Appropedia which is a website similar to Wikipedia but for appropriate technology. Here is a screenshot of their privacy policy explicitly stating that anything posted to this website is then under public domain and can be used by anyone.

Appropedia:Privacy policy

This policy is based on the WikiMedia Foundation privacy policy.

Summary

If you only read the Appropedia project websites, no more information is collected than is typically collected in server logs by web sites in general.

If you contribute to the Appropedia projects, you are **publishing** every word you post publicly. If you write something, assume that it will be retained forever. This includes articles, user pages and talk pages. Some limited exceptions are described below.

Permission for Figure 3.1.2

This image was part of a PowerPoint that was uploaded to a website called SlideShare and was posted as a public resource. There was an attempt to contact the author to receive permission, but there was no response. Below is a screenshot stating that authors have the ability to post either privately or publicly and the author chose to post this image publicly.

SlideShare

From Wikipedia, the free encyclopedia

LinkedIn SlideShare is a hosting service for professional content including presentations, infographics, documents, and videos. Users can upload files privately or publicly in PowerPoint, Word, PDF, or OpenDocument format[2]. Content can then be viewed on the site itself, on hand held devices or embedded on other sites.[3] Launched on October 4, 2006, the website is considered to be similar to YouTube, but for slideshows. It was acquired by LinkedIn in 2012.[4] The website was originally meant to be used for businesses to share slides among employees more easily, but it also has expanded to become a host of a large number of slides that are uploaded merely to entertain.[5] Although the website is primarily a slide hosting service, it also supports documents, PDFs, videos and webinars.[6] SlideShare also provides users the ability to rate, comment on, and share the uploaded content.

Permission for Figure 3.2.1

This image was taken from a website called Off-Grid Europe. Below is the attempt that was made to contact the owners of the image to request permission to use the image. The team is awaiting a response.

Meghan Perry <meghan.perry17@gmail.com> 4:21 PM (0 minutes ago)
to info

Hello,
I am an Engineering student at the University of Central Florida. I am currently writing a report for my Senior Design project and I would like to use an image you created as an illustration in my report. This will be for purely educational purposes and the proper accreditation will be given. Below is the link to the article that has the image I would like to use. It is the first image on the page. Thank you for your time.

https://www.off-grid-europe.com/info/lead-acid-battery/

Thank you,
Meghan Perry

Permission for Figure 3.2.2

Lithium Ion Battery Construction Diagram by David L. Anderson is licensed under a Creative Commons Attribution 3.0 United States License. You are free to:

Share — copy and redistribute the material in any medium or format

Adapt — remix, transform, and build upon the material for any purpose, even commercially.

Permission for Figure 3.4.1, 3.4.2 and 3.5.4

This image was taken from a website called Sparkfun. Below is the attempt that was made to contact the owners of the image to request permission to use the image. The team is awaiting a response

Image Copyright Permission

Casey Mann 4:24 AM (0 minutes ago)
to customerservice, bcc: contact, bcc: legal

Hello,

I am an Engineering student at the University of Central Florida. I am currently writing a report for my Senior Design project and would like to use an image found on your website for non-commercial, educational purposes, that will be disclosed only to my adviser and his team. I do not intend to pose as your organization and will give proper accreditation in the report.

Thank you,

Casey Mann

Permission for Figure 3.5.1, 3.5.6, and 3.5.7

This image was taken from a website called Informa. Below is the attempt that was made to contact the owners of the image to request permission to use the image. The team is awaiting a response

Image Copyright Permission

Casey Mann 4:24 AM (0 minutes ago)

to customerservice, bcc: contact, bcc: legal

Hello,

I am an Engineering student at the University of Central Florida. I am currently writing a report for my Senior Design project and would like to use an image found on your website for non-commercial, educational purposes, that will be disclosed only to my adviser and his team. I do not intend to pose as your organization and will give proper accreditation in the report.

Thank you,

Casey Mann

Permission for Figure 3.5.3

Copyright Notice

This website and its content is copyright of "learnabout-electronics.org"

© "learnabout-electronics.org" 2005. All rights reserved.

Any redistribution or reproduction of part or all of the contents in any form is prohibited other than the following:

You may print or download to a local hard disk, those complete files designated as "Downloads" from this website, or extracts from information on this website, in either case such downloads or copying must be for your personal and non-commercial use only.

You may copy the content to individual third parties for their personal use, but only if you acknowledge the website as the source of the material.

You may not, except with our express written permission, distribute or commercially exploit the content. Nor may you transmit it or store it in any other website or other form of electronic retrieval system.

Permission for Figure 3.7.1

The image depicted in figure 3.7.1 was taken from a website named adafruit. This website offers many components for do it yourself projects and offers a lot of coding tutorials dealing with microcontroller use, especially the Arduino Uno. This site operates under Open Source Hardware where anyone is allowed to use content, including images, of the hardware that is posted on this site for studying, modifying, distributing purposes and more. Below is an exert from the website's FAQ section.

I see the words 'Open Source Hardware' everywhere on your site. What the heck are you talking about?

Open source hardware is hardware whose design is made publicly available so that anyone can study, modify, distribute, make and sell the design or hardware based on that design. The hardware's source, the design from which it is made, is available in the preferred format for making modifications to it. Ideally, open source hardware uses readily available components and materials, standard processes, open infrastructure, unrestricted content, and open-source design tools to maximize the ability of individuals to make and use hardware. Open source hardware gives people the freedom to control their technology while sharing knowledge and encouraging commerce through the open exchange of designs. If any of our products include software or firmware to operate, we also provide all of the source code for your hacking pleasure.

Permission for Figure 3.5.8

Intellectual Property Rights

The Website and its entire contents, features, and functionality (including but not limited to all information, software, text, displays, images, video and audio, and the design, selection, and arrangement thereof), are owned by the Company, its licensors or other providers of such material and are protected by United States and international copyright, trademark, patent, trade secret, and other intellectual property or proprietary rights laws.

These Terms of Use permit you to use the Website for your personal, noncommercial use only. You must not reproduce, distribute, modify, create derivative works of, publicly display, publicly perform, republish, download, store, or transmit any of the material on our Website, except as follows:

Your computer may temporarily store copies of such materials in RAM incidental to your accessing and viewing those materials.
You may store files that are automatically cached by your Web browser for display enhancement purposes.
You may print or download one copy of a reasonable number of pages of the Website for your own personal, noncommercial use and not for further reproduction, publication, or distribution.
If we provide desktop, mobile, or other applications for download, you may download a single copy to your computer or mobile device solely for your own personal, noncommercial use, provided you agree to be bound by our end user license agreement for such applications.
You must not:

Modify copies of any materials from this site.
Use any illustrations, photographs, video, or audio sequences or any graphics separately from the accompanying text.
Delete or alter any copyright, trademark, or other proprietary rights notices from copies of materials from this site.
You must not access or use for any commercial purposes any part of the Website or any services or materials available through the Website.

Permission for Figure 3.5.11

This image was taken from a website called Monolithic Power Supplies. Below is the attempt that was made to contact the owners of the image to request permission to use the image. The team is awaiting a response

Image Copyright Permission

Casey Mann 4:24 AM (0 minutes ago)
to customerservice, bcc: contact, bcc: legal

Hello,

I am an Engineering student at the University of Central Florida. I am currently writing a report for my Senior Design project and would like to use an image found on your website for non-commercial, educational purposes, that will be disclosed only to my adviser and his team. I do not intend to pose as your organization and will give proper accreditation in the report.

Thank you,

Casey Mann

Permission for Figure 3.5.13

If you would like to reproduce, translate, and/or reprint Microchip copyrighted material for commercial purposes you must request Microchip's written permission by following the 3-step process described below. Microchip's written permission is not required for personal use or educational (non-profit) use of copyrighted material.

Personal Use of Copyrighted Material: If you use Microchip copyrighted material solely for your personal use you do not need Microchip's written permission to use such material. However, distribution or reproduction of such materials and images to others (including posting on a website) does require Microchip's written permission.

Educational and Non-Profit Use of Copyrighted Material: If you use Microchip copyrighted material solely for educational (non-profit) purposes falling under the "fair use" exception of the U.S. Copyright Act of 1976 then you do not need Microchip's written permission. For example, Microchip's permission is not required when using copyrighted material in: (1) an academic report, thesis, or dissertation; (2) classroom handouts or textbook; or (3) a presentation or article that is solely educational in nature (e.g., technical article published in a magazine). Please note that offering Microchip copyrighted material at a trade show or industry conference for the purpose of promoting product sales does require Microchip's permission.

Permission for Figure 3.10.1

The figure of the Bluetooth topology is licensed under Creative Commons Attribution-Share Alike 2.5 Spain license. This license specifies that, as long as one gives credit, provides a link to the license, and indicates whether changes were made, that it is free to use. The creator of the image is Rob Blanco and the following is a link to the license:

https://creativecommons.org/licenses/by-sa/2.5/es/deed.en

Changes were not made to the figure.

Permission for Figures 3.15.1-2

Important note: The Wikimedia Foundation does not own copyright on Wikipedia article texts and illustrations. **It is therefore pointless to email our contact addresses asking for permission to reproduce articles or images**, even if rules at your company or school or organization mandate that you ask web site operators before copying their content.

The only Wikipedia content you should contact the Wikimedia Foundation about is the trademarked Wikipedia/Wikimedia logos, which are not freely usable without permission.

Permission to reproduce and modify text on Wikipedia has already been granted to anyone anywhere by the authors of individual articles as long as such reproduction and modification complies with licensing terms (see below and Wikipedia:Mirrors and forks for specific terms). Images may or may not permit reuse and modification; the conditions for reproduction of each image should be individually checked. The only exceptions are those cases in which editors have violated Wikipedia policy by uploading copyrighted material without authorization, or with copyright licensing terms which are incompatible with those Wikipedia authors have applied to the rest of Wikipedia content. While such material is present on Wikipedia (before it is detected and removed), it will be a copyright violation to copy it. For permission to use it, one must contact the owner of the copyright of the text or illustration in question; often, but not always, this will be the original author.

If you wish to reuse content from Wikipedia, first read the Reusers' rights and obligations section. You should then read the Creative Commons Attribution-ShareAlike 3.0 Unported License and the GNU Free Documentation License.

Permission for Figures 5.2.1-6 and Various Testing Images/Tables for MPPT

These images were taken from a website called Open Green Energy. This website was created by Debasish Dutta as a place for him to share his DIY projects for anyone interested in green energy. Below is a screenshot of the about section of this website explicitly stating that all projects on the website are open source DIY projects.

HELLO - MY NAME IS DEBASISH DUTTA

I am a DIY hobbyist by passion and a power Engineer by profession. Most of my works are related to Solar Energy and Arduino. My main goal is to provide basic need of electricity and improve the socio-economic positions of rural people. So I work hard to make open source product to generate, harvest and store clean energy.

Apart from Electronics I love 3D printing, Woodworking and to make crafts from used household stuff.

Permission for Texas Instruments design schematics and graphs/images

Notice from datasheets of each specific part, LM25118, LM2576, voltage controllers and regulator or any captions specifying Texas Instrument related work.

Appendix B – Bibliography

[1] SPECIAL REPORT. WARDING OFF THE HIBERNATION EFFECT: How to stay healthy, happy and active until the robins return., Consumer Reports on Healthy, Pg. 8 (November 2007)

[2] Wolkoff, Peder. "Indoor Air Humidity, Air Quality, and Health - An Overview." International Journal of Hygiene and Environmental Health, vol. 221, 2018, pp. 376–390.

[3] Wells, Nancy M, and Gary W Evans. "NEARBY NATURE: A Buffer of Life Stress Among Rural Children." Environment and Behavior, vol. 35, no. 3, May 2003, pp. 311–330

[4] Nenkov, Pavel. "Solarella: The Solar Umbrella." Indiegogo, 1 Dec. 2014, www.indiegogo.com/projects/solarella-the-solar-umbrella#/.

[5] "Bluetooth Cooler and Sound System." The Sharper Image, The Sharper Image.

[6] ntro and fig 1 source: https://learn.sparkfun.com/tutorials/pcb-basics

[7] CCL Classification Standard: https://www.pcbcart.com/pcb-capability/pcb-materials.html

3.4 and 3.5 Sources

[8] "FR-4 PCB Material." *Seeedstudio*, 25 Mar. 2018, www.seeedstudio.com/blog/2017/09/20/fr4-pcb-material/.

[9] "PCB Basics for Electronics Beginners | EAGLE | Blog." *Autodesk 2D and 3D Design and Engineering Software*, Redshift EN, 30 Apr. 2018, www.autodesk.com/products/eagle/blog/printed-circuit-boards-10000-feet-introduction-electronics-beginners/.

[10] Swartz, Robert. "Extend Low-Voltage Digipot Resolution to Control an Adjustable Regulator." *Electronic Design*, 21 Jan. 2016, www.electronicdesign.com/analog/extend-low-voltage-digipot-resolution-control-adjustable-regulator.

[11] Infineon Technologies AG. "Voltage Regulator PCB Layout." *Infineon Technologies*, www.infineon.com/cms/en/product/promopages/aim-mc/Selecting-a-linear-voltage-regulator/Voltage-Regulator-PCB-Layout.html.

[12] "Understanding the Advantages and Disadvantages of Linear Regulators." *Improving the Efficiency of LED Light Emission | DigiKey*, www.digikey.com/en/articles/techzone/2017/sep/understanding-the-advantages-and-disadvantages-of-linear-regulators.

[13] "Learnabout Electronics." *Temperature Effects on Resistance*, www.learnabout-electronics.org/PSU/psu22.php.

[14] "A Beginner's Guide to Switching Regulators." *Dimension Engineering*, www.dimensionengineering.com/info/switching-regulators.

[15] Glaser, Chris. "Voltage-Mode, Hysteretic, Or Hysteretic-Based: Which To Choose?" *Electronic Design*, 7 Jan. 2014, www.electronicdesign.com/power/voltage-mode-hysteretic-or-hysteretic-based-which-choose.

[19] "Using EAGLE: Board Layout." *Alternating Current (AC) vs. Direct Current (DC)*, learn.sparkfun.com/tutorials/using-eagle-board-layout.

[20] Company, RTP. "UL94 V-0, V-1, V-2 Flammability Standard." *RTP 4920-1620 UV-ASTM Thermoplastic Polyolefin (TPO) Product Data Sheet - RTP Company*, web.rtpcompany.com/info/ul/ul94v012.htm.

3.7 to 3.9 sources

[22] How Infrared Motion Detector Components Work, www.glolab.com/pirparts/infrared.html.

[23] Lens and Focusing Devices for Pyroelectric Infrared Sensors, http://www.glolab.com/focusdevices/focus.html

[24] Overview | PIR Motion Sensor | Adafruit Learning System, https://learn.adafruit.com/pir-passive-infrared-proximity-motion-sensor?view=all

[25] Reflective Infrared Sensor (RIR), http://www.glolab.com/RIR/RIR.html

[26] Simple IR Proximity Sensor With Arduino, http://www.instructables.com/id/Simple-IR-proximity-sensor-with-Arduino/

[27] SIRIUS Technology - ecosirius.com, http://www.ecosirius.com/technology.html

[28] Microwave Sensors | Southwest Microwave, http://www.southwestmicrowave.com/products/microwave-sensors/

[29] Ultrasonic Sensor SRF-04 - ePro Labs WiKi, https://wiki.eprolabs.com/index.php?title=Ultrasonic_Sensor_SRF-04

[30] Speed of sound in air temperature barometric pressure calculator without no table air density of air formula temperature calculation mach 1 acoustic impedance room temperature propagation air density sea level velocity ideal gas 20 degrees or 21 degrees Celsius C cold warm - sengpielaudio Sengpiel Berlin, http://www.sengpielaudio.com/calculator-speedsound.htm

[31] Mouser Electronics

3.10 - 3.11 Sources

[32] Bluetooth History

“Our History | Bluetooth Technology Website.” Bluetooth, www.bluetooth.com/about-us/our-history.

[33] Bluetooth Frequency Range and Modulation Techniques

Poole, Ian. “Bluetooth Radio Interface, Modulation, &Amp Channels.” *Radio Electronics*, www.radio-electronics.com/info/wireless/bluetooth/radio-interface-modulation.php.

[34] Frequency Hopping in Bluetooth

Jaap C. Haartsen and Stefan Zurbes; Frequency Hop Selection in the Bluetooth Radio System, Spread Spectrum Techniques and Applications, 2002 IEEE Seventh International Symposium on, Czech Rep. 2002.

[35] Wireless Personal Area Networks in Bluetooth

Garg, Vijay K. “Wireless Personal Area Network — Bluetooth.” *Wireless Communications & Networking*, 2007, pp. 653–674., doi:10.1016/b978-012373580-5/50053-3.

[36] Bluetooth Topologies

“Topology Options | Bluetooth Technology Website.” *Bluetooth*, www.bluetooth.com/bluetooth-technology/topology-options.

[37] Bluetooth Low Energy

Naik, Akhilesh G., et al. “Energy and Current Consumption Analysis for Classic Bluetooth and Bluetooth Low Energy (BLE).” *Emerging Research in Computing, Information, Communication and Applications*, 2015, pp. 87–95., doi:10.1007/978-81-322-2550-8_9.

[38] Bluetooth High Speed

Gratton, Dean Anthony. “Bluetooth Classic and High Speed.” *The Handbook of Personal Area Networking Technologies and Protocols*, Aug. 2013, pp. 279–321., doi:10.1017/cbo9780511979132.021.

[39] Bluetooth Adaptive Frequency Hopping

Golmie, N., et al. “Bluetooth Adaptive Frequency Hopping and Scheduling.” *IEEE Military Communications Conference, 2003. MILCOM 2003.*, 2003, doi:10.1109/milcom.2003.1290352.

[40] Random Frequency Hopping

Morrow, Robert. *Bluetooth Operation and Use*. MacGraw-Hill, 2002.

[41] Received Signal Strength Indication (RSSI) for Bluetooth.

“Proximity And RSSI.” *Bluetooth Technology Website*, Bluetooth Special Interest Group, blog.bluetooth.com/proximity-and-rssi.

[42] Packet Error Rate for Bluetooth

Khalili, R., and K. Salamatian. “A New Analytic Approach to Evaluation of Packet Error Rate in Wireless Networks.” *3rd Annual Communication Networks and Services Research Conference (CNSR'05)*, 2005, doi:10.1109/cnsr.2005.14.

Sources for section 3.1-3.3

[43] “3 Generations of Solar Cells: Solar Facts and Advice.” *Amorphous Silicon Solar Cells: Solar Facts and Advice*, www.solar-facts-and-advice.com/solar-cells.html.

[44] Bagher, Askari Mohammad. “Types of Solar Cells and Application.” *Sciencepublishinggroup*.

[45] “Blog.” *Solar Reviews*, Solar Reviews, www.solarreviews.com/blog/pros-and-cons-of-monocrystalline-vs-polycrystalline-solar-panels.

[46] "CIGS Solar Cell Technologies: Advanatages & Disadvantages." *Amorphous Silicon Solar Cells: Solar Facts and Advice*, www.solar-facts-and-advice.com/CIGS-solar-cell.html.

[47] Davison, Alan. "Common Types of Solar Cells." *Solar Energy as Renewable and Alternative Energy, Solar Technology & Energy Information*, 2017, www.altenergy.org/renewables/solar/common-types-of-solar-cells.html.

[48] "Home." *Solar Reviews*, Solar Reviews, www.solarreviews.com/solar-panel-reviews.

[49] match, green. "7 Different Types of Solar Panels Explained." *United Kingdom*, 2018, www.greenmatch.co.uk/blog/2015/09/types-of-solar-panels.

[50] Osborne, Mark. "Trina Solar Sets 21.25% Multicrystalline Cell Efficiency Record." *PV Tech*, PV-Tech, 9 Nov. 2015, www.pv-tech.org/news/trina-solar-sets-new-21.25-multicrystalline-cell-efficiency-record.

[51] Richardson, Luke. "Thin Film Solar Panels: Do They Make Sense? | EnergySage." *Solar News*, EnergySage, 21 Mar. 2018, news.energysage.com/thin-film-solar-panels-make-sense/.

[52] sdc07cfsu Follow. "Photosynthesis." *LinkedIn SlideShare*, 20 Apr. 2014, www.slideshare.net/sdc07cfsu/photosynthesis-33744613.

[53] "Semiconductor Recycling Plant Case Study of a-Si:H Photovoltaic Manufacturing." *Conventional Farming - Appropedia: The Sustainability Wiki*, www.appropedia.org/Semiconductor_recycling_plant_case_study_of_a-Si:H_photovoltaic_manufacturing.

[54] Thituveedi, Vasista. "Solar Cell." *LinkedIn SlideShare*, 27 Apr. 2015, www.slideshare.net/vasistatiruveedi/solar-cell-47447105.

[55] UCF Senior Design Group 9. "Main | Smart Umbrella." *Major Programming Paradigms*, www.eecs.ucf.edu/seniordesign/su2015fa2015/g09/.

[56] "What Is Amorphous Silicon? Why Is It so Interesting Now?" *Amorphous Silicon Solar Cells: Solar Facts and Advice*, 2013, www.solar-facts-and-advice.com/amorphous-silicon.html.

[57] "Battery Types." Battery Solutions, www.batterysolutions.com/recycling-information/battery-types/.

[58] Curitiba, Pintura De Casa Em. "Lowering Costs of Lithium-Ion Batteries for EV Power Trains." Fabricators & Manufacturers Association Intl. (FMA), 1

Oct. 2010, www.fmanet.org/blog/2010/10/01/lowering-costs-lithium-ion-batteries-ev-power-trains.

[59] "Lead–Acid Battery Construction." Maxpower, 8 May 2017, www.maxpowerbatt.com/lead-acid-battery-construction/.

[60] "Types of Batteries." PRBA Types of Batteries Comments, www.prba.org/battery-safety-market-info/types-of-batteries/.

[61] "Battery Types." *Battery Solutions*, www.batterysolutions.com/recycling information/battery-types/.

[62] beach base type: screw: https://www.everywherechair.com/beach-umbrella-sand-anchor?gclid=CjwKCAjwp7baBRBIEiwAPtjwxHhloZ0y9i3aXrp9nO0Oy92tG5eHxUiH1qJQ4PFad5K2prqXs3u3dRoCaTsQAvD_BwE

https://www.trendhunter.com/trends/umbrella-base

[63] safety standard electrostatic discharge: https://www.jedec.org/document_search?search_api_views_fulltext=js-001-2017

[64] test for electrostatic discharge: https://www.jedec.org/document_search?search_api_views_fulltext=JESD22-C101

[65] military environment standard: http://everyspec.com/MIL-STD/MIL-STD-0800-0899/MIL_STD_810F_949/

[66] Java History

Binstock, Andrew. "Java's 20 Years Of Innovation." *Forbes*, Forbes Magazine, 20 May 2015, www.forbes.com/sites/oracle/2015/05/20/javas-20-years-of-innovation/.

[67] Ismail, Mohamed. "Overview of USB Battery Charging Revision 1.2 and the Important Role of Adapter Emulators." The Fundamentals of an ECDSA Authentication System - Tutorial - Maxim, www.maximintegrated.com/en/app-notes/index.mvp/id/5801.

[68] Sherman, Len. "The Basics of USB Battery Charging: A Survival Guide." The Fundamentals of an ECDSA Authentication System - Tutorial - Maxim, www.maximintegrated.com/en/app-notes/index.mvp/id/4803.

[69] "USB." *Wikipedia*, Wikimedia Foundation, 30AD, en.wikipedia.org/wiki/USB.

[70] "USB and USB Micro/Mini Cable Connector Guide." *C2G*, www.cablestogo.com/learning/connector-guides/usb.

[71] Bluetooth Module HC-05 Datasheet

Co., Ltd, Guangzhou HC Information Technology. “HC Serial Bluetooth Products User Instructional Manual.” *Makezine*, 2014, cdn.makezine.com/uploads/2014/03/hc_hc-05-user-instructions-bluetooth.pdf.

[72] Bluetooth Module HM-10 Datasheet

Company, JNHuaMao Technology. “HM-10 Datasheet.” *Microduino*, 2013, wiki.microduinoinc.com/images/f/fc/Bluetooth40_en.pdf.

[73] Wi-Fi Speeds

Mitchell, Bradley. “What Is the Speed of a Wi-Fi Network?” *Lifewire*, Lifewire, 2018, www.lifewire.com/how-fast-is-a-wifi-network-816543.

[74] History of Wi-Fi

Alliance, Wi-Fi. “History of Wi-Fi.” *Wi-Fi Alliance*, 2014, www.wi-fi.org/who-we-are/history.

[75] GSM

Sauter, Martin. “Global System for Mobile Communications (GSM).” *From GSM to LTE*, 2011, pp. 1–61., doi:10.1002/9780470978238.ch1.

[76] Radio

Yang, Guohua, et al. “Finding Optimum Settings for a 433MHz Radio for Long Range Communication.” *2015 2nd International Conference on Information Science and Control Engineering*, 2015, doi:10.1109/icisce.2015.60.