The ParaSolar Experience

Experience indoor convenience outdoors

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Abstract – The goal of this project is to eliminate technological ties to indoor locations, while at the same time make it more convenient to be outdoors. The ParaSolar Experience uses an array of sensors and other electronic devices that allows the user to entertain themselves, securely leave the product and belongings unattended, learn about their environment; for hours at a time. These features include a radio-frequency sensor, Bluetooth and Liquid Crystal Display (LCD) display communication, solar-charged battery, temperature-humidity sensors, auxiliary input stereo speakers, and USB charging ports. By compiling these features in a modified cooler and sun umbrella, The ParaSolar Experience is the ultimate outdoor experience for people of all ages.

Index Terms – Maximum Power Point Tracking, Pulse Width Modulation, duty cycle, Bluetooth, Liquid Crystal Display, MOSFET, Gravimetric Energy Density, Cycle Life, Charge Time, Overcharge tolerance, Microcontroller (MCU), Printed Circuit Board (PCB), UART, Radio Frequency (RF), Class-B output stage, Piezoelectric buzzer, through-hole, surface mounted,

I. INTRODUCTION

Technology is a common and useful tool to our everyday lives. As it develops, one immediate observation can be made; adults and children are spending more time on their phones, desktops, and tablets, and less time outdoors in natural environments. Despite technology's usefulness, there is an effect on the well-being of the person by staying indoors for extended periods of time.

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 spoke about the negative health effects caused by indoor air humidity and quality, such as sensory irritation in eyes and upper airways, a noticeable decrease in work performance, sleep quality, and an increase in 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 their technology. Lastly, a study by Wells and Evans reports, "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]

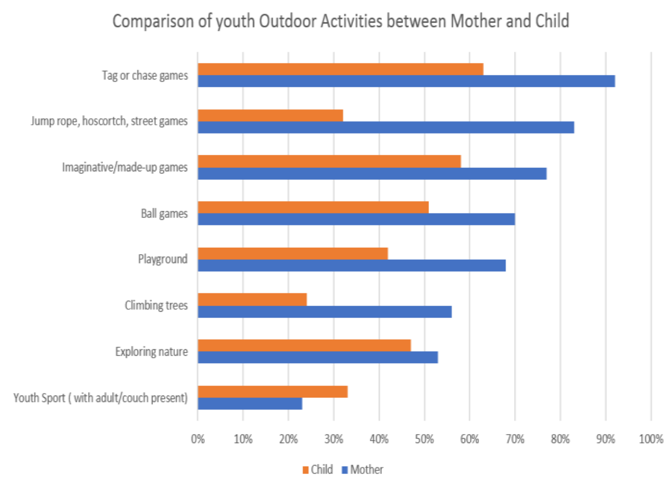

Figure 1. Comparison of Youth Outdoor Activities between Mother and Child

Despite knowing the negative effects of remaining indoors for extended periods of time, people continue to stay indoors. The "penalty" of moving outdoors is convenience. 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 various social media apps.

Having identified these factors, technical specifications can be made for a physical product. This product will deliver the ease and comfort of staying inside to the outside world. This product will achieve this task by modifying a common beach umbrella with all the necessary tools to achieve indoor convenience. This product includes a USB charging station for the user's devices, a cooler to store cold beverages and snacks, a speaker for listening to music, consistent updates on pertinent weather information, and a security system to keep everything protected while the user relaxes.

II. SOLAR POWER CELLS

Third generation solar panels include all the solar technology that is currently in its research and development phase. There is an exorbitant amount of research going on in this field. In fact, according to several 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.

Table 1. Solar Cell Product Comparison Table
**uncoated*

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

A few things were considered when choosing solar panels for this design. Including: Cost, Wattage, size, weight, heat resistivity, and performance under low light.

The solar cells used for this product are the BCMaster Polysilicon Solar cell. 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.

III. BATTERY CHARGER (SOLAR)

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).

A MPPT charge controller uses 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 convert this voltage into excess current, maintaining the maximum power output of the solar cells always. 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 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

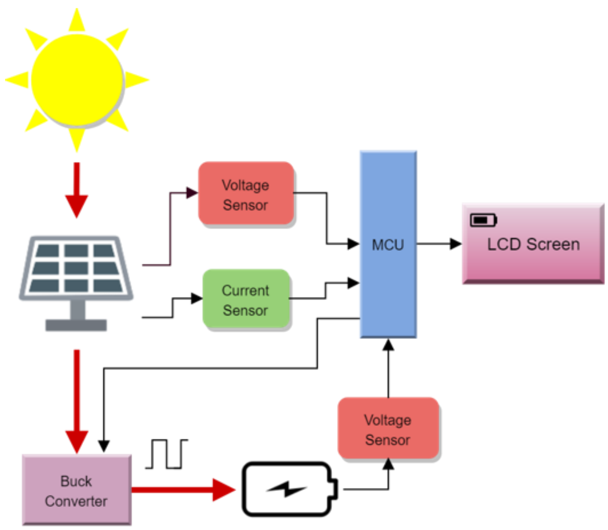

Figure 2. MPPT Signal/Power Design Block Diagram

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.

A. Design Considerations

Similar MPPT solar charge controller previously designed by Debasish Dutta on his website Open Green Energy was modified for this product. Open Green Energy is a website designed specifically to share Debasish's projects as open-source products. A block diagram of the MPPT controller design is shown in Figure 2.

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 adjust the duty cycle based off 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.

IV. BATTERY

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.

For this application, secondary batteries will be used. 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.

A few things were considered when choosing a battery for this design. Including: Gravimetric Energy Density, Cycle Life, Charge Time, Overcharge tolerance, Self-Discharge, and operating temperature.

The battery used for this application is the lithium-ion battery. 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.

Table 2. Secondary Battery Product Comparison Table

	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

V. ENVIRONMENTAL 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.

Table 3. Temperature/Humidity Sensor Comparison Table

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

When deciding between the temperature and humidity sensors, the following factors were considered: operating voltage, operating temperature range, temperature accuracy, operating humidity range, and humidity accuracy.

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.

VI. 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.

Table 4. HC-05 Bluetooth Module Specification Table

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

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. 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.

A few factors were considered for selecting wireless communication technologies. Including: Operating Voltage, Power Consumption, Operating Frequency, Cost and Max Transfer Speeds.

Bluetooth technology was selected for wireless communications and 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.

VII. SECURITY

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. But to detect the object, a sensor must be selected.

In order to utilize the alarm system, different types of motion detection sensors will be explored. Types of motion sensors include: passive infrared, reflective infrared, microwave, ultrasonic, and radio frequency.

When selecting sensors, the following factors must be considered: accuracy, detection range, field of view, low power efficiency, low cost, and ease of use.

Radio frequency (RF) detection was selected due to its efficiency to detect humans. The user's belongings will only be affected by other human, Radio frequency also has a wide operating input for motion detection, almost 360 degrees, and will be critical in the product's security feature.

VIII. USER INTERACTIONS

There are multiple ways that the user can interact with this product. The product provides environmental (temperature/humidity) information, battery life of the system, and security mode status, as well as current time and date via LCD screen. The product also allows users to play music through an auxiliary cord and provides to USB Type-A ports for charging hand-held devices. The following sections detail the selection process and specification of product chosen for implementation.

A. LCD

To satisfy informing the user of important information such as: time, temperature, humidity, and battery life, a screen must be utilized. Different display is 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.

Factors considered for the design include: operating voltage(a), number of general-purpose input and output pins(b), operating speed limited by MCU(c), additional backlight required for viewing in bright environments(d), text limit€, and ability to displace images(f).

Table 5. Liquid Crystal Display Product Comparison Table

Factor	Character LCD	OLED Display	TFT LCD	TFT LCD Touchscreen
a (V DC)	5	5	5 ~ 13.2	5 ~ 13.2
b	Two with I^2C Backpack	Four with I^2C	Varies	Varies
c	No	No	Yes	Yes
d	Yes	No	Yes	Yes
e	Varies	Varies	Varies	Varies
f	ASCII	Yes	Yes	Yes

Character Liquid Crystal Display (LCD) was selected for implementation. The Character LCD shows information by having the background be one color and the characters be another and neither can change color. This is the most basic method to display information to a user aside from LED matrices which require a higher power consumption than LCDs. Character LCDs are typically inexpensive and display information accurately and understandably.

Additionally, this allows the design to include custom symbols, specifically to display battery life, through using *createChar* . To determine the battery life, a percent ratio of current voltage to max voltage. This is done by measuring the voltage at the voltage sensor (implemented from the MPPT) and finding the difference to the lowest voltage possibly outputted by the battery (11.3V) and divided by the maximum battery voltage minus the minimum battery voltage.

B. ENTERTAINMENT SYSTEM

For additional convenience, a speaker system is implemented. Two 25-W speakers output sound using 4 power amplifiers in a B-class output stage setup for analog auxiliary input from a user's handheld device headphone jack. Other audio systems were considered, including: using Bluetooth communication to transmit digital signals (and let an IC convert digital to analog), a USB Type-A digital to analog conversion, and straight analog auxiliary port. Factors to consider for the input data systems include: cost, ease of use (user and design), communication distance, electronic complexity, data transfer rate (wireless).

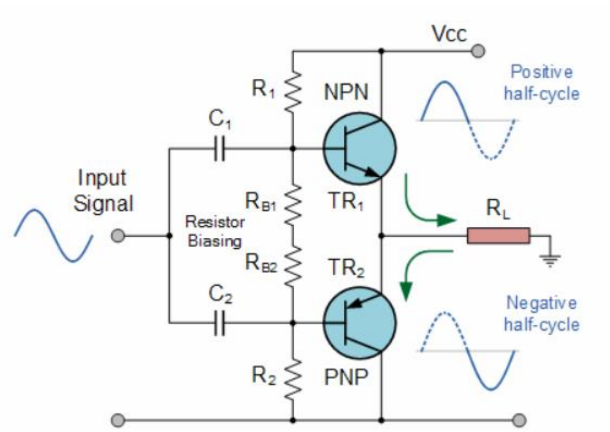

Figure 3. Class B Amplifier Output Stage Diagram

For this application, Auxiliary input was implemented due to the ease of use, cost, and minimal complexity. No digital to analog conversion is needed for Auxiliary input, and only amplification is needed. The amplification device used was the LM 358 power amplifier, with a Class-B output stage. Class B Amplifier uses two transistors such that each transistor transmits during one half cycle of the input. Class B output reduces power wasted as heat and utilizes both NPN and PNP high current transistors.

C. CHARGING FEATURE

Since this product revolves around the user being able to use their device, implementing a USB charging Type-A port is critical. Type-A was chosen due to its extreme popularity in most handheld devices. 5V is applied to pin 1, grounding pin 4, and creating a voltage divider on both D+ and D- (pins 2 and 3) to provide 2.62V across the data lines for "fast charging" capabilities. This data voltage value was discovered by reverse engineering an AC-USB adapter, and measuring the output voltage lines to the data lines.

IX. PCB DESIGN

The printed circuit board for this project will house all electronic components mentioned in previous sections, excluding peripherals for user interaction. Two ATmega328 microcontrollers will complete the

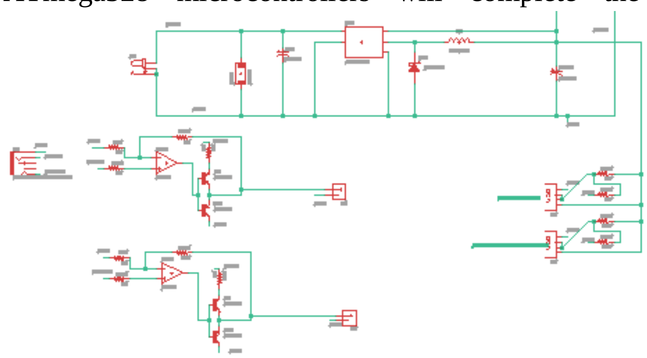

Figure 5. Voltage Regulator, USB charging ports and Audio Amplification/Output stages

calculations needed for the MPPT, LCD, sensor data, and Bluetooth communications. Other ICs are surface mounted, one LM2576 5V Voltage regulator, three IRFZ44N n-channel MOSFETs, one IR2104 MOSFET driver, and a through hole LM358 power amplifier. To complete the B-output stage of the amplifier, two TIP122 NPN transistors and two TIP127 PNP transistor. Jumper pins are used to connect the LCD screen, Real-Time Clock (RTC), Bluetooth module, DHT11 sensor, RF sensor, Current sensor, Battery charger, solar MPPT input, piezoelectric buzzer, and speakers to the electronics on the board.

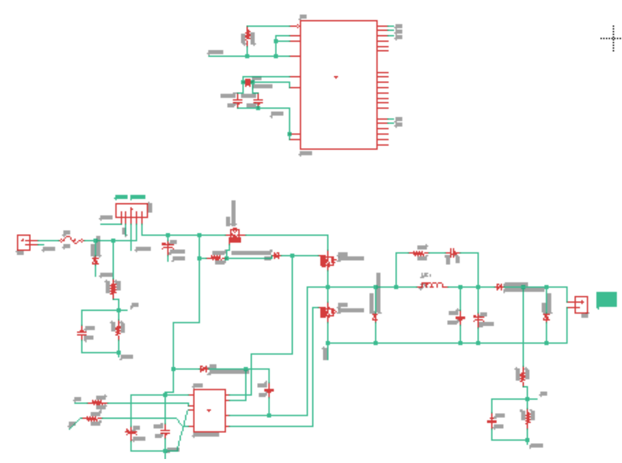

Figure 4. MCU for MPPT, MPPT design

A. Board Layout

Most components are surface mounted, while some through-hole components such as diodes and capacitors were selected as such due to voltage rating and relationship to price. The trend is the higher the voltage ratings for larger capacitors the higher the cost for a surface mounted capacitors and diodes.

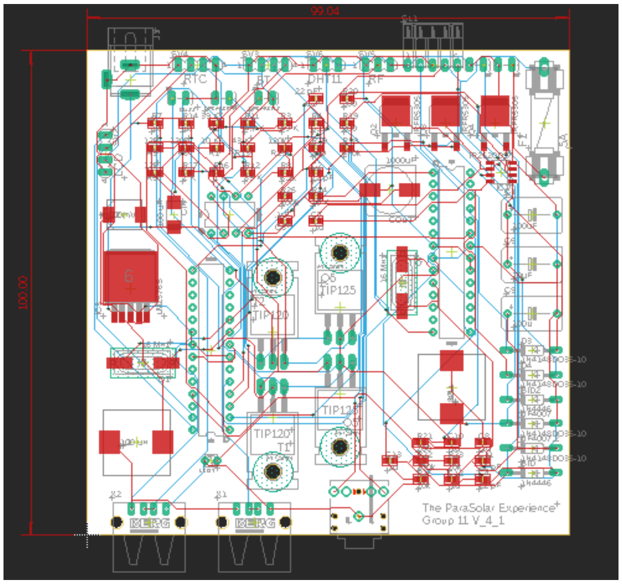

Figure 6. PCB footprint for The ParaSolar Experience

X. SOFTWARE FLOW

The software flow for the ParaSolar Experience can be broken down between the two microcontrollers. The first microcontroller (MCU1) that oversees data to and from the LCD screen, the RTC, Bluetooth, DHT11, piezoelectric buzzer, and RF sensor. The second microcontroller (MCU2) oversees the MPPT processes for solar power charge controlling.

After power on, MCU1 initializes the LCD screen, and moves into two major states. While security mode is inactive, time and date are updating every 30 seconds, temperature and humidity updates every 5 seconds, and the battery level is checked and displayed every 10 seconds. MCU1 is also actively checking for a signal from the phone to move into the next state, security mode activated. When security mode is active, it constantly checks for the disable security signal from the phone. Once activated, MCU1 gives the user 10 seconds to step away from the ParaSolar Experience, then actively checks for the RF signal to return “high”. If the RF sensor reads “high”, and alarm hasn’t tripped recently (10 seconds), and the initial activation has expired, the security alarm will trip and inform the phone that motion has been detected. Battery life is updated from the analog pin from the voltage sensor (see LCD).

After power on for MCU2, it begins to adjust the PWM for battery charging. First, it reads the voltage and current from the solar panels and calculates the average power of 50 microseconds. Using this value, the duty cycle is linearly set between the minimum and maximum power output (24W). The minimum is 60% of 24W, and the duty cycle is set to 60%, where the maximum is 100% of 24W with duty cycle of 100%.

XI. CONCLUSIONS

The ParaSolar Experience created satisfied all of the initial specifications. Upon further development of this prototype, test studies can provide data for an analytical report of feature usage. This report can provide a basis for new upgrades from the old goals and objectives for this prototype.

This senior design project has been an excellent learning experience for all team members of the group. From extensive technical documentation, analog/digital design, software/application, teamwork, and communication are just a few of the skills we strengthened through completion of the course.

XII. REFERENCES

Images:

Figure 3: Class B Amplifier - Class-B Transistor Amplifier Tutorial. (2018, June 15). Retrieved from https://www.electronics-tutorials.ws/amplifier/amp_6.html

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XIII. BIOGRAPHY

Jesus Pulido is a senior at University of Central Florida and will be graduating with a Bachelor of Science in Computer Engineering in December of 2018. He oversaw the schematic part selection with PCB layout along with the phone charger portion and part of the security feature. He is pursuing a career that will allow him to merge knowledge of electronics and software with a system in the medical field.

Casey Mann is a senior at the University of Central Florida and will be graduating with a Bachelor of Science in Electrical Engineering in December 2018. She oversaw power regulation design and selection, PCB design, physical component housing, and general analog device implementation within the design. With a heavy background in analog/digital design, robotics and space vehicles, she is pursing an entry-level position that will give her a unique perspective into a career in space exploration.

Dylan Petrae is a senior at the University of Central Florida and will be graduating with a Bachelor of Science in Computer Engineering. He oversaw the software for the microcontroller that controlled the peripherals, the application for the Android device, and the wireless communication between them. He is pursuing a career in software development, specifically web development. His interest in computers began when he built his first desktop computer in middle school.

Meghan Perry is a senior at University of Central Florida and will be graduating with a Bachelor of Science in Electrical Engineering in December of 2018. She oversaw the selection and wiring of the solar panels and battery and designing and implementing the MPPT charge controller. She will begin working at SubGrid Solutions LLC as a Protection and Controls engineer in the beginning of January 2019.