

EE 492: Wireless Recharging System

Client: National Carwash Solutions

Final Project Report

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Definitions

H-Bridge : Multi transistor circuit that can transform a DC signal into an AC signal

NCS : National Carwash Solutions (this is our client)

FET : Field effect transistor

BJT : Bipolar junction transistor

VR (Voltage Regulator): Device that regulates voltage to a particular level

AC : Alternating current

DC : Direct current

NEC : National Electrical Code

ISU : Iowa State University

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1.Introduction

1.1 Acknowledgement

We would like to thank Jose Avendano and Ivan Chan for their continued support and funding of our project for their company, National Carwash Solutions (NCS). Additionally, we would also like to thank Würth Elektronik for their assistance in making our first prototype possible. Lastly we would like to thank Infineon Technologies and others for their very helpful customer support and advice in implementing certain integrated circuits.

1.2 Problem Statement

The problems we faced are quite simple to explain but difficult to remedy. Our client has a sensor on one of their car washers that runs off of a battery. This battery however is not rechargeable, and must be replaced repeatedly every couple of months. The sensor's location prevents it from being directly powered, so the previous battery set up has been used to remedy this issue. If power could be sent more constantly to the sensors location, a rechargeable battery could be used, and additional power could allow for more sensors and features.

1.3 Solution

Our goal is to create a system that can transmit power wirelessly from the wired portion of the machine into its moving washing arm. Once power is transmitted, received and transformed into an acceptable form, we will charge batteries that can power both the sensors, newer sensors, LEDS / LED strips, and other controlling circuits. The controlling circuits will consist of microcontroller(s) that we can use to monitor and manage power flow through our receiver system. We can also using the microcontrollers to give feedback to the operators and indicate the state of the system.

1.4 Operating Environment

The expected environment for the wireless charger will be in the car wash unit itself. The transmitter portion of the charger will be placed on the stationary part of the car wash. The receiver will be attached to the car wash arm, which rotates around a car completely and eventually comes back to a stationary charging base. The car wash unit would most likely be placed in an indoor environment, when bought by a customer. We expect the charging system to be exposed to ambient temperatures and partially to cleaning liquid residue.

1.5 Intended Users and Intended Uses

The end user of project's product(s) will be the average person who wants to wash their car. Although they may not see a majority of our work (the power systems, control, and battery storage), they will see LEDs powered by our creation. Not only will the average car wash user have new refreshing experience, but the operators of the machine itself will see an improvement in operations as well.

Since we are designing a wireless recharging system, the sensor(s) that previously powered by a non-rechargeable battery will no longer need frequent replacement. Furthermore, adding LEDs and programming capabilities to the system can allow for further customization based on the owner's needs. Things such as themed light shows or additional attachments to the arm or within reach while still maintaining a high level of reliability and safety.

1.6 Similar Products

One of the relevant systems that we considered as a benchmark for our wireless charging solution was the wireless charging units in cars. Although these systems deliver power at lower rates, they follow the Qi standard. We also used resonant inductive coupling in our wireless charging solution. However, one of the biggest disadvantages that we had differently compared to the wireless charging system in the cars was the inconsistency of the range between the coils due to the position of the arm. In the cars, the charging unit has a cover where the phone is put directly on top that ensures the distance between coils, whereas the area that we need to locate our system is prone to be shaken, twisted and turned due to the rotation of the arm.

1.7 Assumptions and Limitations

Assumptions:

- The max load that we will see at a given point is 12-24W.
- Max efficiency of wireless power transfer is 60%
- Our system will align accurately during charging phase

Limitations:

- 3V/12V @ 0.1/1A (respectively) specifications for load values
- Distance between transmitter coil and receiving coil should be between 0.1 and 1.5cm
- Space for our components is less than
- Tuning our coils to resonate to maximize efficiency

1.8 Deliverables

Wireless Power Transfer

Our circuits allow us to transform a DC signal into an AC signal with a variable frequency. By changing this frequency we can achieve higher efficiencies when transferring power. Since no wired connection can be made between the sensor and the current power supply, a wireless method of power transfer was developed.

Battery charging / management

To allow for power source to be sporadic and not constant, new charging circuit was designed and used in conjunction with rechargeable batteries to not only operate the components desired by NCS, but also the subsystems of the circuits themselves (charge controlling, system monitoring, microcontrollers, ect.)

Additional Features and Expansion Options

By using multiple charging circuit setups, we left room for possible expansion for adding more loads to the batteries, and including those added loads in new code that could be easily uploaded to the onboard microcontroller. Further refinement of our design would also open up more powering options as increasing efficiency would leave more power to be used on the receiving end.

2. Requirements specification

2.1 Functional requirements

- Transmit power wirelessly through the air
- Provide a stable 3v/100mA supply for sensor load
- Provide a stable 12v/1A supply for an LED strip
- Separate Battery Charging systems for both LED and sensor loads
- Monitor the system(s) with an onboard microcontroller

2.2 Non-functional requirements

- Environmentally protecting device(s) against water and heat
- Alerting the user in case of critical battery or system state
- Having a long battery back lifespan
- Allowing options in the future for expansion and development

3. System Design & Development

3.1 Design Planning

In order to meet and complete the requirements and tasks we were met with, we had to start from the basics of the project and work our way up. After doing some looking around on the internet, we found very little, to no reference for projects that used a similar power level when transferring power. Because of this, we dedicated a larger portion of our Project time to figuring out and refining the power transferring aspect of our project. From there, we decided that following other schematics for charging and operating a battery powered system would be more straightforward. The results were very satisfying, and after completing our first transferring prototype, we felt comfortable executing the next portion of our planned design.

3.2 Design Objectives

Although our objectives (functional and nonfunctional) were simple in material, but were sometimes much more difficult to achieve than they appeared. Our goals that we needed to accomplish were transmitting power wirelessly and using that power to run components on the receiving end of the transmitted power. By doing this, we could power sensors, LEDs, controllers, and anything else our client would want. By following the plan we had laid out in the beginning, we were able to focus our efforts on researching and designing the transmitter, complete its prototype, and then go on to design and complete our receiving circuit.

3.3 Constraints Considerations

Due to the nature of our project, the space we worked in is not only relatively small and limited, it was also set in a rough environment. For these reasons, the system needed to be protected with a cover or a other protective covering(s). Our final product had to be stable over long working hours and last longer than what is currently used in NCS systems, although the priority was to prove feasibility and show that with a working prototype. Another goal of ours was to follow the guidelines set by standards such as the OSHA standard and the NEC standard. In addition, we used RoHS compliant parts for our circuits. Considering the power levels we worked with and designed for, safety was a top priority. More specifically, we designed as many safety features as possible into our project to prevent such catastrophes as fire or circuit shorting and destruction. Another constraint was the compounds of the washing liquid, which involved sodium hydroxide, hydrochloric acid, amines, and butyl cello solve. Since we used PLA as the filament for the boxes, the durability of the boxes over longer periods was in question. As a result, an epoxy coating is used to increase the durability of the surfaces. Although the cost was not directly a concern, keeping costs low forced us to optimize designs and helped to provide a feasible solution to our client.

3.4 Trade-offs

Power and efficiency :

When designing our prototypes, we took an approach that had as few spaces for errors as possible. To achieve this, we opted for simple voltage regulation as well as optimizing efficiency over power, since high power meant more waste heat of the voltage regulators. Future expansion on this project could solve these problems by using more efficient components so higher power levels would not be an issue.

Containment :

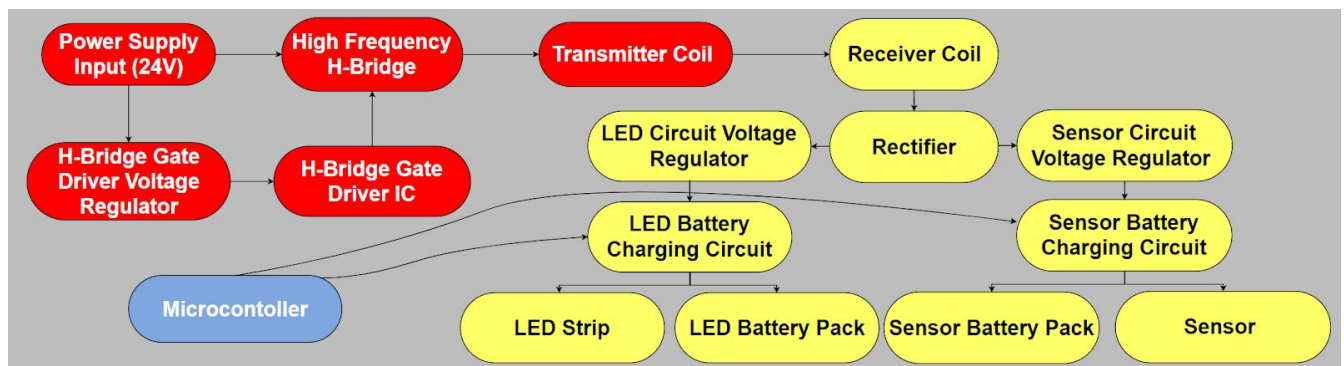
For both of the receiver and transmitter boxes, we wanted to keep the boxes as lightweight as possible due their delicate mounting points and angles. The concern for the lightness limited the material choice for the designing process. While trying to keep the costs feasible, we decided to use 3D printing with PLA as the filament. As the receiver box was at a more compromised position to the cleaning liquid of the car wash, we used an inclined lid to direct the splashing liquid away from the openings of the box as well as an epoxy layer to increase the water resistance of the box. For the transmitter box, the only additional safety measurement was the

epoxy layer as this box was not as prone to splashes as the receiver box. However, due to the more restricted area for mounting this box, the lid needed to be placed on the side of the box instead of the top like the receiver box. This increased the concerns for the splash proofness of the box.

3.5 Architectural Diagram

Shown below in figure one is an overview of how our system works and consists of the main components of the project. It displays how power is taken in, converted, transmitted, received, and then distributed.

Design Block Diagram : Figure 1



When interfacing with our device, one can simply upload new code to achieve new functions or observe the outputs from the controller to be up to date with how the system is operating.

3.6 Description of Modules With Their Constraints

Power Supply : This is a 24V DC source that our transmitter will use to create an acceptable signal for power transfer

- Constraint(s) : There will be no direct control of this power source, so using safety features like fuses will be necessary.

Gate Driver Regulator : This is a voltage regulator used to step down the voltage from the power supply into something that is suitable for the gate driving IC.

- Constraint(s) : The linear regulator we used was not efficient but got the job done and helped us validated viability.

H-bridge Gate Driver IC : The gate driving IC is used to turn of and on pairs of transistors of an H-bridge to create an AC signal and tune the frequency of that signal to any desired frequency within its operating range.

- Constraint(s) : This IC is very sensitive and expensive, so lots of care and time was giving to it. This time could have been used for additional features, but getting the transmitting to work was a priority.

H-bridge : An array of four transistors that fluctuates the direction of current through the transmitting coil. The transistors are controlled by the aforementioned gate drive IC.

- Constraint(s) : At times, some power can be dissipated across the resistors and lost as waste heat, reducing efficiency.

Transmitting Coil : A copper coil with a magnetically insulating backplate (for increased magnetic field projection) is used to create an oscillating magnetic field.

- Constraint(s) : The optimal resonating frequency of the coils is slightly different

Receiver Coil : Another copper coil with additional turns for increased voltage. This coil resonates magnetically with the other coil, and generates an equal and opposing magnetic field which then induces a current and voltage that we can use to power the receiver. (The magnetic field is generated through induction)

- Constraint(s) : The optimal resonating frequency of the coils is slightly different

Rectifier : Simple circuit used to turn the AC input from the receiver coil, into a DC signal the charging systems could use.

- Constraint(s) : Very large and bulky. Took up loads of space one our final prototype.

Receiver Voltage Regulators : Stepped down the voltage from the rectifier to the desired levels for their respective components.

- Constraint(s) : These regulators were inefficient, but similar to the regulator the the gate driver, they were chosen to be used as more of a proof of viability.

LED & sensor Battery chargers : These components charged and controlled the battery packs used to power their respective system.

- Constraint(s) : The ICs were very complex and tooks lots of design planning time and assembling time.

Battery packs : simple battery pack setups used to store power when the transmitter was not active.

- Constraint(s) : The physical location limited us to use large batteries. As the packs needed to be seperate, we needed to choose batteries that can fit in the allowed space while providing the necessary capacity.

Sensor & LED strip : With batteries attached and charged, these components can be powered and operated. The sensor detects unwanted motion and the LED strip acts as a form of Entertainment for the user.

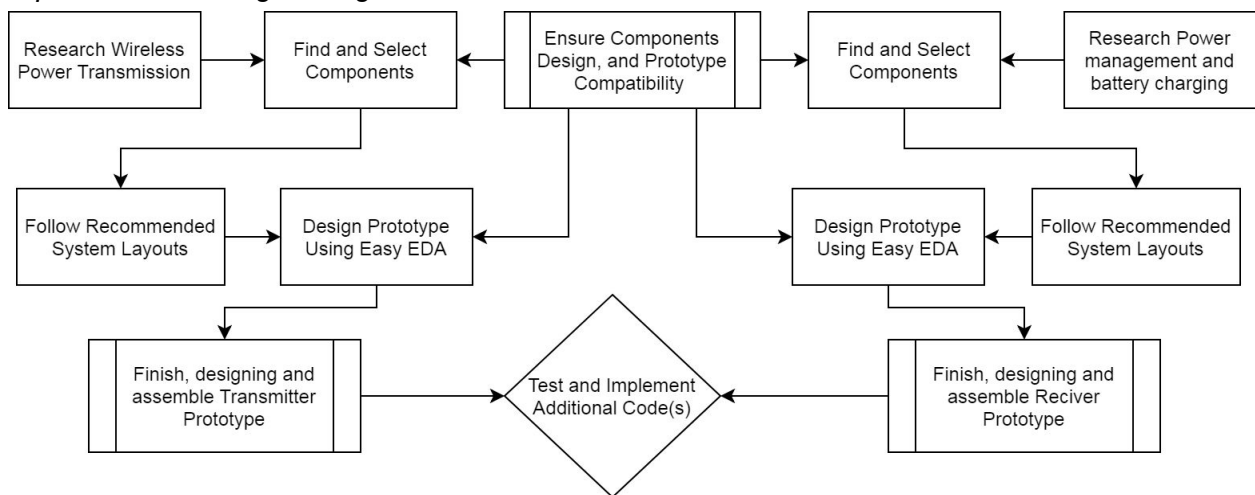
- Constraint(s) : The LED strip is very power hungry and the different voltage levels of the LED strip and the sensor mean a more complicated system is needed.

Microcontroller : When interfacing with our device, one can simply upload new code to achieve new functions or observe the outputs from the controller to be up to date with how the system is operating

- Constraint(s) : Although the controller has a lot of input from the system and can understand what is happening, it is limited in its ability to interact with the system and must rely on notifying an operator to come and inspect it.

4. Implementation

Implementation Diagram Figure 2



4.1 Technologies and Software Used

Assorted Electrical Equipment: We used Multimeters, Oscilloscopes, and power supplies when testing our circuits and prototypes. The equipment let us observe how our components were operating and helped us debug issues while constructing and testing earlier builds,

- Rationale : By using these resources provided by ISU, we would not need to purchase our own and incur any extra financial cost.

Easy EDA: This software was used to digitally design a schematic and layout for both our transmitter and receiver prototypes. This software also allowed us to directly purchase printed circuit boards from the company, JLC PCB.

- Rationale : Was free and easy to use, and used cloud storage that allowed us to access and edit our design from any computer anywhere.

Arduino Programming: By using the arduino IDE, we were able to create code and program an on board microcontroller that could monitor the receiver's systems and provide feedback to an operator. This controller would also leave room for additional coding or expansion options.

- Rationale : Trying to attach an arduino to the receiver would be a long and costly process, so by just using an arduino to program another smaller controller, we could have the best of both worlds. A small controller that took up little space on the receiver, and a user friendly programming software provided by the arduino creators.

Solid Works: This software was used to digitally design the boxes and their lids for both the receiver and the transmitter prototypes.

- Rationale : Solidworks was chosen for this design process due to its ability to save files in .STL format and due to our limited knowledge of the non-electrical CAD tools.

LulzBot Taz Pro: The Solidworks schematics were used for 3D printing of the boxes and their lids by the LulzBot Taz Pro with PLA filament.

- Rationale: This 3D printer offered relatively cheaper and faster production compared to the other available printers.

The Internet: Used when researching relevant projects to help us advance our understanding of the fundamentals of our project.

4.2 Applicable Standards and Best Practices

Throughout the project, we followed the IEEE code of ethics while making it a priority to ensure OSHA and NEC standards over the soldering processes of the circuits, sanding and curing of the containment pieces, and throughout the power transmission tests and measurements. In addition, we picked components that are RoHS compliant whenever it was applicable. For the batteries, we followed the safety report that Samsung provided as our guideline for preventing accidents and malfunctions.

5. Testing, Validation, and Evaluation

Power Generation and Transmission Test:

5.1.1 Transmitter Test Plan Overview

In this section, we will describe a list of necessary test steps to ensure the functionality of our transmitter board. The transmitter board is used to convert a DC signal to a high frequency AC signal, which is then transmitted via a coil. There are few ways to do this conversion. One way is to use an H-Bridge, which can work very well at high frequencies and at high power rates. We will need to test the H-Bridge and the circuit's ability to wireless transfer this power via the transmitter coil.

5.1.2 High Frequency H-Bridge Operation

Our H-Bridge has the following sub-components:

1. -High Frequency Power MOSFETs(H-Bridge)
2. -IR2086s(Oscillator/Gate Driver)
3. -Passive components : schottky diodes, Ceramic capacitors, Resistors / Pot.s

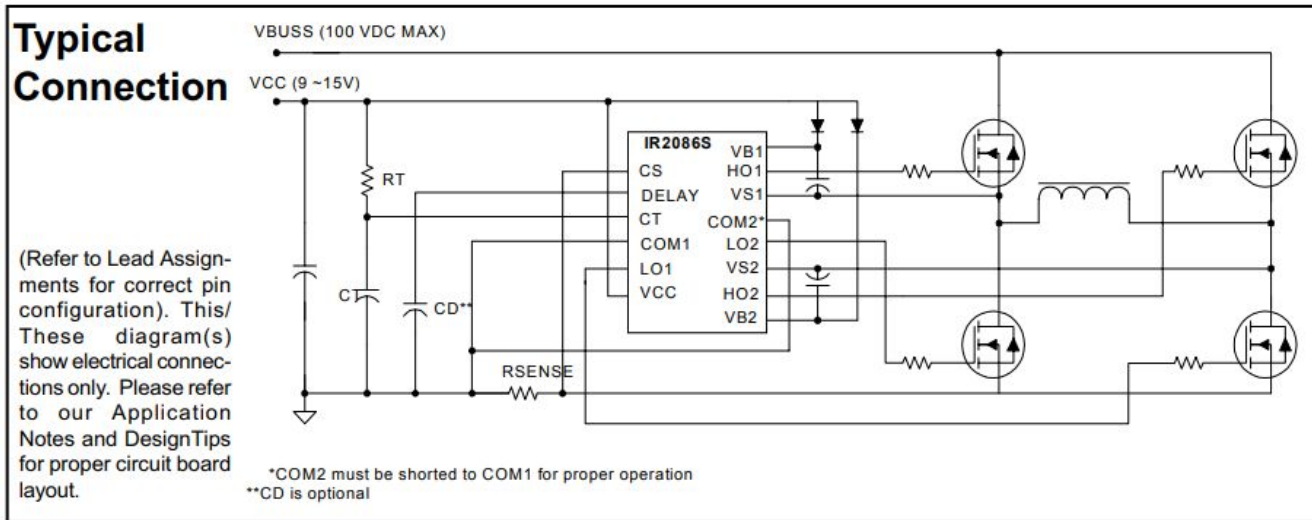
The IR2086s is a self oscillating IC that takes in a 9-15V source, which is used to drive the H-bridge MOSFETs. This has a number of pins and which are used for a variety of I/O options. The main pins are 15, 12, 10 and 6, which are the output that drive the gates to the FETs. The steps to test this IC are as follows:

1. Design the IR2086s IC circuit as shown in the recommended connection schematic. Include capacitor and resistor values based on parameter requirements.
2. Test pins 15,12,10 and 6 to determine the output voltage to the gates of the FETs.

The high frequency power MOSFETs are the framework of the H-bridge design. The design allows for current to flow in two different directions in reference to our output. This allows for a high frequency square wave to be generated, if the gates could switch on/off fast enough. The steps to test the H-Bridge are as follows:

1. Test each MOSFET to verify their condition/operation.
2. Test our H-Bridge design manually by switching pin combination to be on and off for the first-fourth and second-third transistor groups.
3. Connect H-Bridge circuit to IR2086s IC circuit.
4. Measure voltage waveform of the output for the fully connected circuit.

Figure 3



5.1.3 Coil Power Transfer Test:

We have two coils that either transmit or receive power wirelessly. The steps to test the coils are as follows:

1. Use function generator to generate various voltage peak-peak waves at different frequencies
2. Use function generator as input to transmitter
3. Test power transfer at different separation distances, voltages and frequencies using oscilloscope
4. Verify that we can test 24W power transfer using function generator/power supply

5.1.4 Transmitter Validation and Evaluation

The final test for our prototype ensures that the power we generate from the H-bridge circuit can be used to power the transmitter coil to create sufficient magnetic field levels for power transfer. Trying to transfer power as efficiently as possible is ideal. In a perfect setting and environment the power waveform generated from the H-bridge should be nearly the same as the output from the receiver coil. The steps to test the prototype are as follows:

1. Follow the schematic shown in figure 3
2. Connect the output of the H-Bridge to the transmitter coil
3. Place the receiver coil at different separation distances to test various output waveforms on oscilloscope

Figure 4

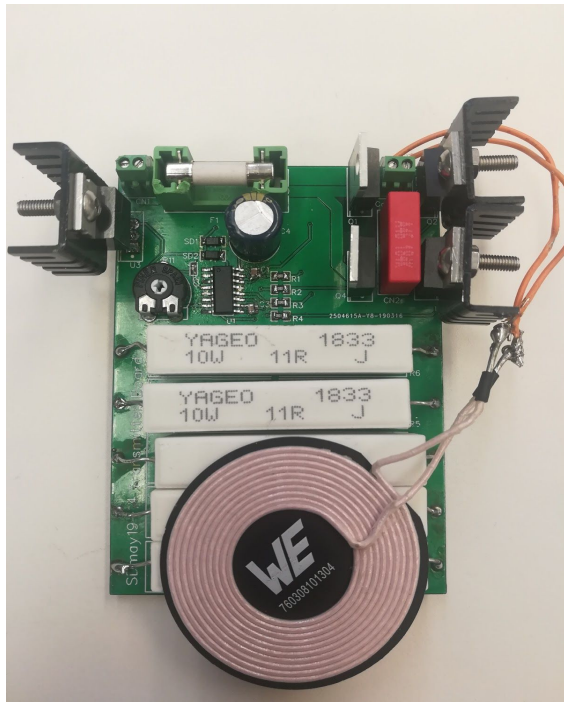


Figure 5



Figures 4 and 5 show the completed transmitter PCB prototype and its power transmission values respectively

Power Receiver and Battery Charger

5.2.1 Receiver Test Plan Goals

In this section, we will describe a list of goals, tests, and milestones that we will work on in order to confirm the functionality of our power receiver component for our project. While following this plan we also aim to document our results and make changes to our component(s) and this document if we run into issues. This document will also layout some possible scenarios for test that we may or may not end up having to do in the event of an issue. We intend to follow this document as closely as possible to ensure everything operates correctly. We also desire this test plan to be easily followable if another person or persons decides to try and replicate or reverse engineer our work. Continue reading for introductory information on what the power receiver and battery charger are in more detail.

5.2.2 Desired Functions/Deliverables

The entire purpose of our project is to be able to power a sensor constantly without having it wired up directly to a power source. Normally a non-rechargeable battery would be used for this, but in our case, we want to have the battery be charged so human intervention for sensor operation is minimized. In doing this, we also intend to make the system flexible enough to handle other charging loads. More specifically, we are going to power and charge two separate battery packs that will power a sensor and an LED strip. Below is a list of deliverables that we aim to achieve ordered from highest priority to lowest:

- Battery charging
- LED and sensor battery(ies) charging
- Monitored power usage
- LED control
- System status indication

5.2.3 Receiver and Charger Design Overview

When designing, we tried to leave options for not only adding additional features, but also making it compatible with a variety of applications. This device is intended to be used with an AC power transmitter, but can also be directly powered with an AC source. Within the board itself we added a number of integrated circuits to handle charging, monitoring, and controlling the batteries and their power. We have used 2 IC (integrated circuits) to control charging the batteries, one IC for balancing the LED battery pack, and one micro controller IC for monitoring, controlling, and outputting the system status. Many more passive components such as inductors, resistors, and capacitors, as well as other activer components like Mosfets we also used alongside the main ICs on the board. The first figure on the next page shows a schematic overview of the receiver and charging board, followed by a second figure that shows the completed printed circuit board design in digital form. To make our design more flexible, we also used a few variable resistors in case adjustments to charging needed to be made when testing.

5.2.4 Parts List

This section will outline the majority of the parts we used by giving their ID and purpose. Since most of our components are passive, we will simply label their technical specification and type.

Manufacturer part No.	Description
ATTINY84A-SSFR	Microcontroller used to monitor system : ATN
BQ77915PWR	Battery balancer IC (used for multi-cell LED battery pack) : U1
BQ24610RGER	Battery charging IC used to charge LED battery pack : U3
BQ24133RGYR	Battery charging IC used to charge sensor battery : U5
L78M05ABDT-TR	5 volt linear voltage regulator (used to power microcontroller) : U4
SI7617DN-T1-GE3	MOSFETs used to control power input to LED battery / system : Q6-7
SI7617DN-T1-GE3	MOSFETs used to control power from and to battery : Q8
N6-L50T0C-103	Potentiometers used to change charging IC voltages : S-ISET,S-ACSET, L-ISET1, L-ISET2, L-ACSET
PT10LV10-103A202-PM	Potentiometers used to change voltage regulator output : RLED, RSEN
FQD10N20CTM	MOSFETs used for charging and discharging control on balancer IC : Q1-2
SIS412DN-T1-GE3	MOSFETs used for synchronous switching charging
CSD25310Q2	MOSFET used to control power coming from batteries
CSD17313Q2T	MOSFETs used to control power coming from adapter to sensor
LM338T	Linear voltage regulator used to regulate voltage for LED and sensor sub-systems

L78M05ABDT-TR	Linear voltage regulator used to regulate voltage to microcontroller
MUR410G	Rectifying Diodes D1-4
890283422005CS 15uF	Capacitor for receiver coil : C58
ECA2AM101 100uF	Filter capacitor for rectifier : C2
CC0805ZKY5V9BB105 1uF	Filter capacitor for ICs :
CC0603ZRY5V9BB104 .1uF	Filter capacitor for ICs :
CRG1206F33R 33 Ohm	Resistors for individual battery cells in LED battery pack
CR1206-FX-1000ELF 100 ohm	Resistors for current sense filtering on balancing IC
CR1206-FX-10R0ELF 10 ohm	Gate resistors for charge and discharge MOSFETs on balancing IC : R15-16
RC0603FR-07100KL 100k ohm	Resistor for MOSFET controlling LED battery pack power
CR0603-FX-4021ELF 4.02k ohm	Resistor used in voltage divider for temperature sensing
RC0603JR-0747KL 47k ohm	Resistor used for voltage dividers going to current control pins on charging ICs
CR0603-FX-5231ELF 5.23k ohm	Resistor used in voltage divider for temperature sensing
CR0603-FX-3012ELF 30.1k ohm	Resistor used in voltage divider for temperature sensing
AC0603FR-07430KL 430k ohm	Resistor used in voltage divider for temperature sensing
RC0603FR-079K31L 9.31k ohm	Resistor used in voltage divider for temperature sensing
RC0603FR-071KL 1k ohm	Resistor used in LED battery charge controller adapter power control
CR1206-FX-1001ELF 1k ohm	Resistor used to limit current flow to power balancer IC power
CR0603-FX-4993ELF 499k ohm	Resistor used to sense voltage in LED battery pack for charging IC

CR1206-FX-15R0ELF 15 ohm	Current sense resistor for balancing IC : R11
CR1206-FX-1002ELF 10k ohm	Pull down resistor used for balancing IC : R10, R20
RL2010FK-070R01L 10 mohm	Current sense resistors used in both charge controlling ICs
UMK107BJ105MA-T 1uF	Filter capacitor :
ZLLS350TA	Diode used for LED battery pack charge controlling IC pin
UMK316B7225KLHT 2.2uF	Input filter capacitor : C15
885012206112 4700pF	Filter capacitor : C33
885012206118 .047uF	Filter capacitor : C35
PE2010FKE070R02L 20 mohm	Current sense resistor for sensor charging IC : R27
282834-2	2 pin header connectors used for sensor, battery and temperature sensor connections
282834-4	4 pin header connector for LED battery pack

5.2.5 Overview of Manual Testing

Our design is a combination of multiple different sub-systems working together to complete both individual and collective goals.

The 5 subsystems we will be breaking this design into are as follows:

1. Power Input
2. Sensor Battery Pack Charging
3. LED Battery Pack Charging
4. LED Battery Pack Balancing
5. Microcontroller Sensing

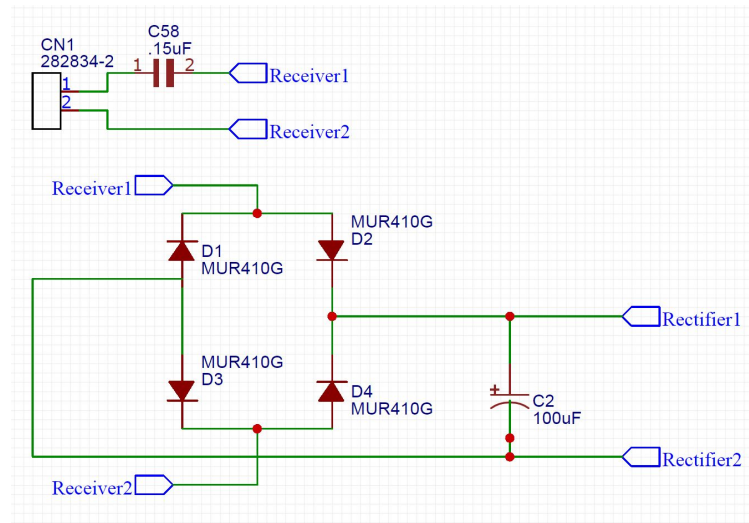
Each subsystem will be installed in this order and tested directly after, before moving on to the next.

5.2.6. Power Input

The first step to ensuring this board works is verifying that there is enough power to supply all of our downstream components. We will begin by soldering on all of the components associated with receiving and rectifying the AC input power to DC. We will then place the transmitter coil parallel to the receiver coil so power can be transferred. The final step is to test the output voltage across the rectified input and output. This will be a no-load test, so our voltage should

be very high, but it will verify if the input circuitry works at all. We will continue to measure this output voltage as we continue to add more loads, to ensure the input circuitry could supply enough current, while maintaining the voltage.

Figure 6

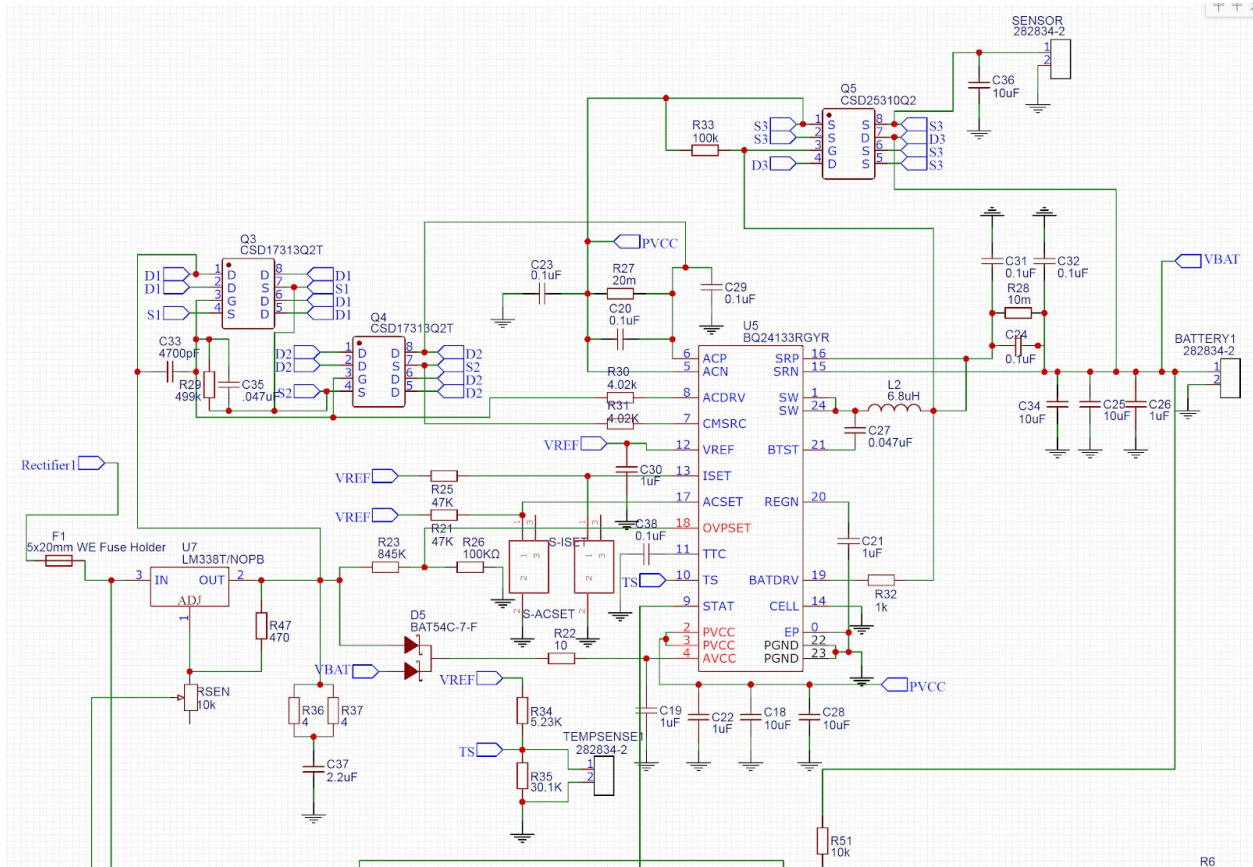


Here is the schematic (figure 6) for power input to the receiver. The receiver 1 and 2 pins are connected to the receiver coil and the rectifier 1 and 2 pins are connected to a filter capacitor

5.2.7. Sensor Battery Pack Charging

The main load of this project is the sensor and its battery pack. We will begin by first soldering on the linear regulator responsible for powering the charge controller IC. The linear regulator will be tuned to 8V and it will be measured to ensure 8V is being outputted. The IC and its respective components will be soldered on next. Before the IC gets power, we will tune the variable resistors for V-ISET and V-ACSET. The lower these values are, the less voltage will be at these pins. This will cause input and charge currents for the system to decrease. These variable resistors will then be increased until the desired input and charge currents are acquired. Since we are using voltage dividers the following equation will be used for obtaining the voltage at these 2 pins: $V = 3.3\left(\frac{X}{X + 47k}\right)$. The following equations are used to find the charge current and total input current respectively: $I = \frac{V_{ISET}}{20(10m)}$, $I = \frac{V_{ACSET}}{20(20m)}$. If our total input current is 300mA, then 200mA will be used as the charge current, since the sensor requires 100mA to be powered. The IC will first be tested without the battery pack. Input power should be able to supply the load in the absence of the battery pack. Once this is ensured we, will then insert the battery into the circuit. We will then test if the battery is being has been charged. This will be done by first measuring the voltage of the battery before inserting it into the circuit. Then after some time being placed into the circuit, we will test the voltage once again to determine if it has been increased. If the voltage has increased, we can confirm that charging on this IC works as intended.

Figure 7



The previous figure 7 displays the sensor charging circuit and gives each parts value (same parts from earlier list)

5.2.8. LED Battery Pack Charging

The second load of this project is the LEDs and its battery pack. Like the sensor sub-system, we will begin by soldering on the linear regulator responsible for powering this charge controller IC. This linear regulator will be tuned between 13.5V and 15V. The input voltage just needs to be higher than the highest possible voltage of the battery pack, which would be 12.6V. The minimum operating voltage between 13.5V and 15V that leads to the IC being completely functional will be selected. We will measure the voltage at the output of the linear regulator to ensure that we are obtaining a voltage between 13.5V and 15V. This IC also has pins that can be tuned, so that the precharge current, charge current and total input current can be controlled. Voltage dividers according to the following equation will be used for obtaining the voltage at the 3 pins: $V = 3.3\left(\frac{X}{X+47k}\right)$. Potentiometers will be used to set this voltage for additional flexibility. The following equations are used to find the precharge current, charge current and total input current respectively: $I = \frac{V_{ISET2}}{100(10m)}$, $I = \frac{V_{ISET1}}{20(10m)}$, $I = \frac{V_{ACSET}}{20(10m)}$. The LEDs will be connected first to the IC, in the absence of the battery pack to ensure power is being delivered to the load.

After verification of the LEDs being powered, we will then insert the battery pack into the system. This battery pack will incorporate 3 lithium ion batteries in series. Before the battery pack is inserted into the system, the voltage will be measured. Once time has passed after being inserted into the system, the voltage will be measured again. If the voltage has increased, we can confirm that charging on this IC works as intended.

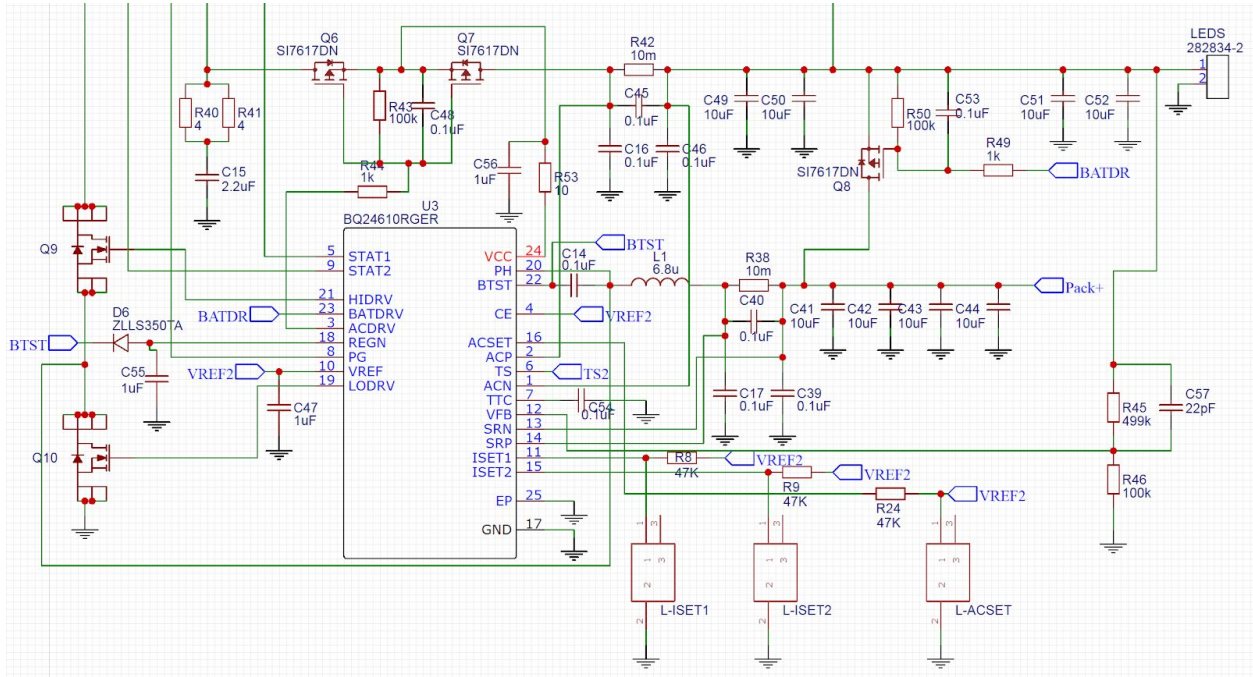
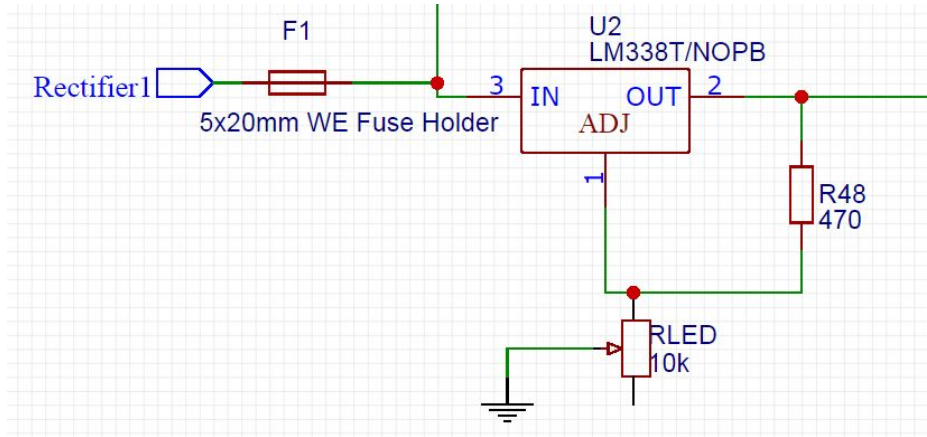


Figure 8

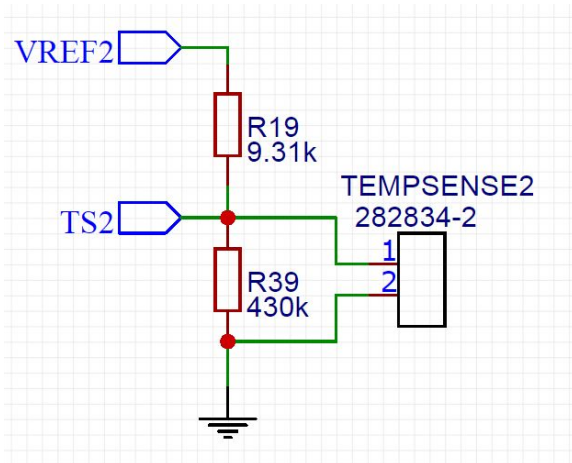
The wire connected to Q6 and R40 comes from a voltage regulator in figure 8
 The other wires that head upward to nothing seen on figure 5 are connected to the microcontroller.

Figure 9



In figure 9, we can see the regulator set up for the LED charging circuit. The wire mentioned earlier that powers this IC is seen exiting figure 6 on its upper right side, connected to R48 and OUT 2

Figure 10 In this figure 10, we see the temp sensor set up for the LED battery pack



5.2.9. LED Battery Pack Balancing

After we verify that the LED battery pack charging IC works, we will then move onto verifying the functionality of the balancer IC. The balancer IC is used to ensure that each battery in the battery pack is charged at the same rate. We would begin by soldering on the balancer IC, as well as its components. Each individual battery cell's voltage would be measured before turning the system on. Once the system is on, the batteries will then be charged. After some time, we will then measure the voltage of each battery cell and ensure that they are relatively the same value. If this holds valid, then we can confirm the balancer IC works as intended. In figure 11 we see the balancer schematic. Wires coming from CN2 pin 1 goes off the left side to power the microcontroller as well as act as a sensing voltage for the controller to monitor the voltage levels of the battery pack

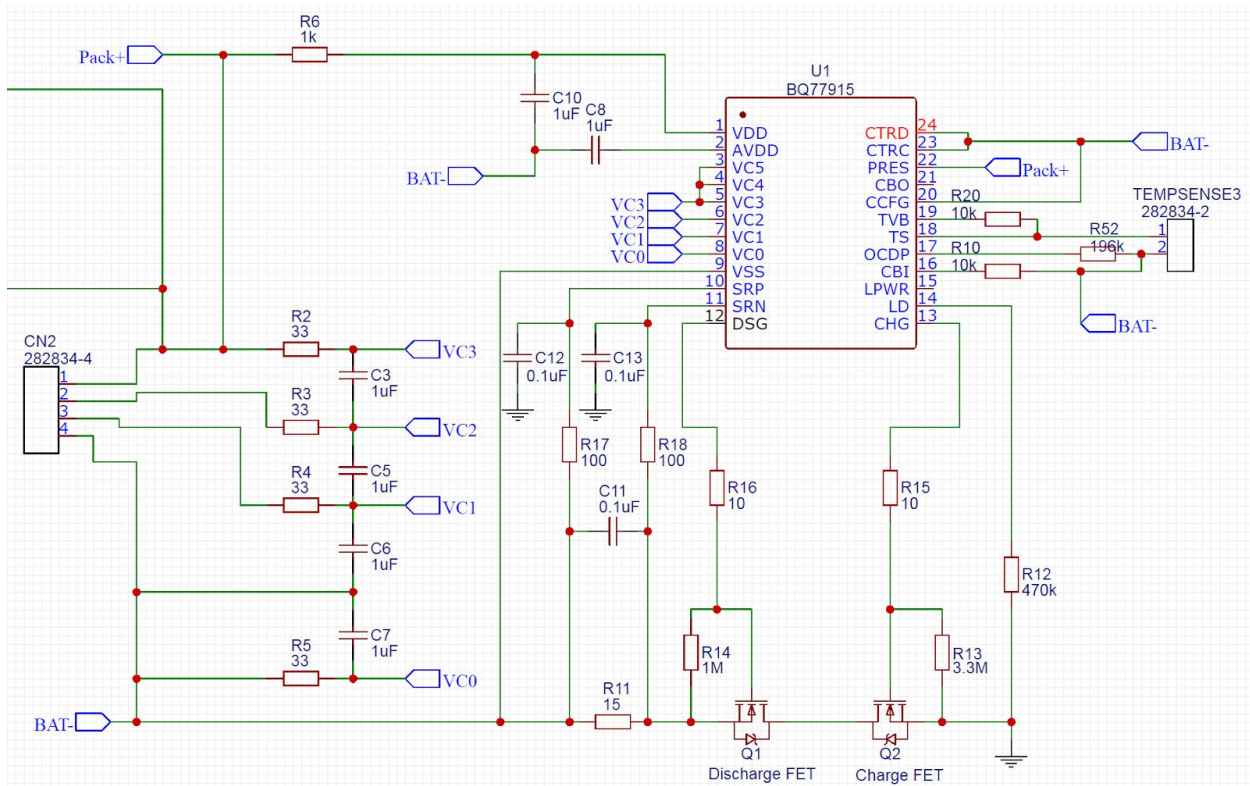


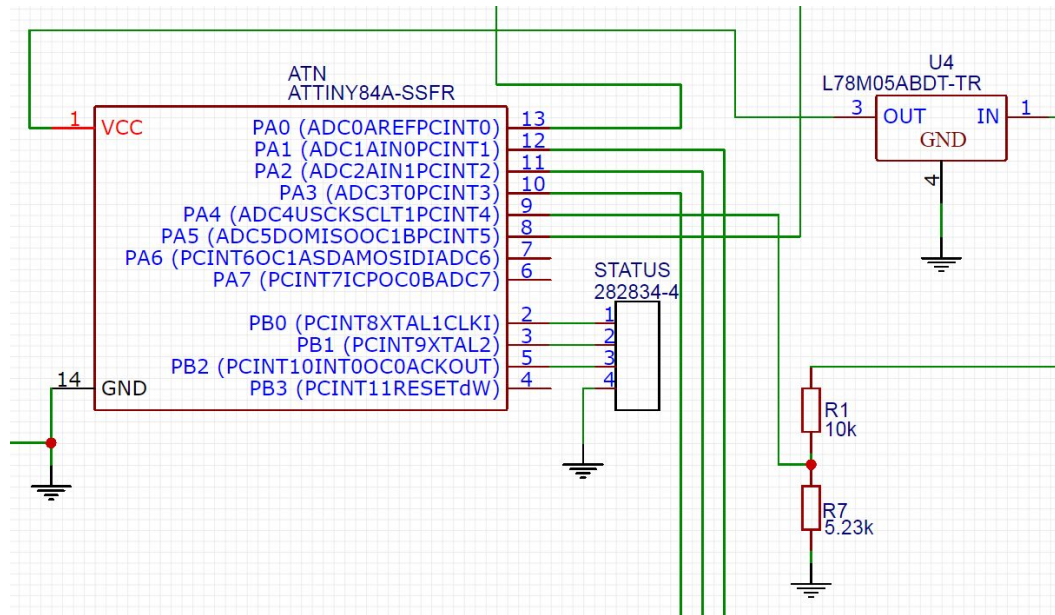
Figure 11

5.2.10. Microcontroller Sensing

The microcontroller will be the final component to install and test. It will be used to measure both battery pack's voltages and also give LED indications based on the status of the 2 charge

controller ICs. We will first start by soldering this IC and the various components that support it onto the board. The microcontroller will have been pre-programmed for inputs, outputs and calculations, before being placed on the board. In the event a program doesn't work properly or needs updating, we left pinouts to connect our programmer to.

Figure 12



In figure 12, the schematic shows how to wire up the microcontroller as well as the where the wires from the previous figures 6, 7, and 11 come from.

Programming:

To program, we will be using the arduino software to create and compile code for the controller. In order to upload code, we will be using an Arduino Uno as a programmer and use code and libraries provided by the arduino software and created from authors and available as open source code. Since programming specifically is not what is being tested, the method to program will be left out. If you wish to know more about this topic, check out tutorials on using Arduino Uno's as ISP programmers for ATTINYs or continue reading on and observe our microcontroller test plan.

Receiver Validation and Evaluation

5.2.11. Testing Receiver

In figure 19, The electrical characteristics of the sensor battery charger can be seen. From top to bottom, the battery voltage, the charging current, and the supply voltage and current (this supply then runs through a regulator). In figure 20 you can see the receiver PCB prototype with a linear regulator attached as well as the recifying components and sensor charging components.



Figure 19

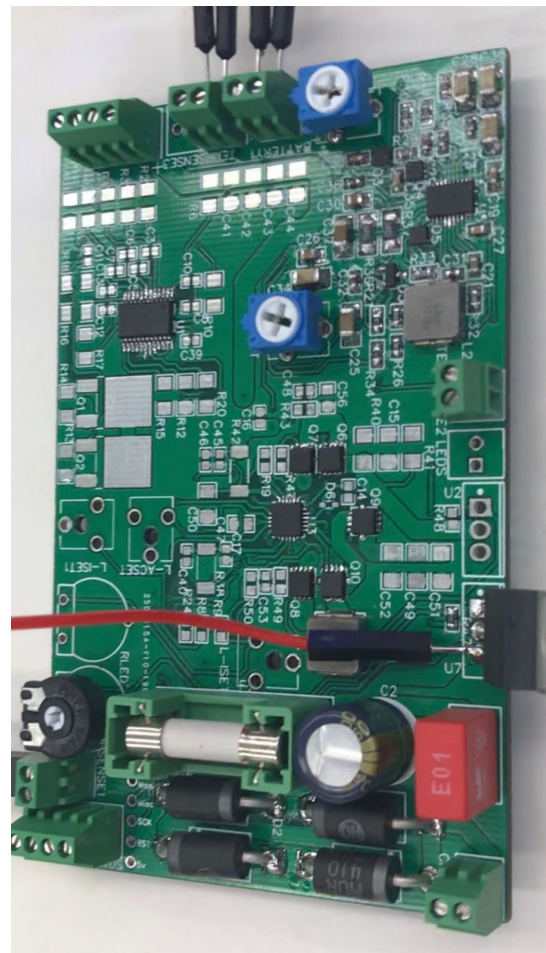
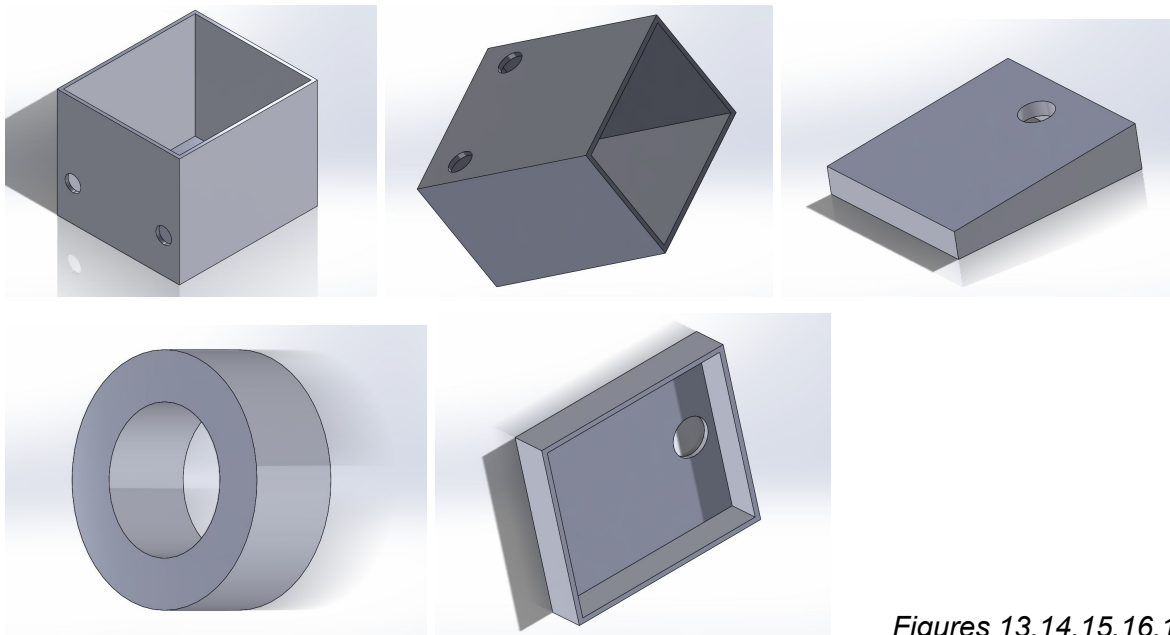


Figure 20

3D Printing

5.3 Circuit Enclosure Design

In figures 13 to 17, the main schematics of the boxes and the lids are shown. The ring is used for directing the liquid away from the main entry point of the receiving coil due to its splash prone position on the arm. In figure 18, the unsatisfactory printing attempts are depicted. The faults in these components were originated from calibration and precision issues of the LulzBot Taz Pro in the output center, where we didn't have a chance to intercept with the process.



Figures 13,14,15,16,17

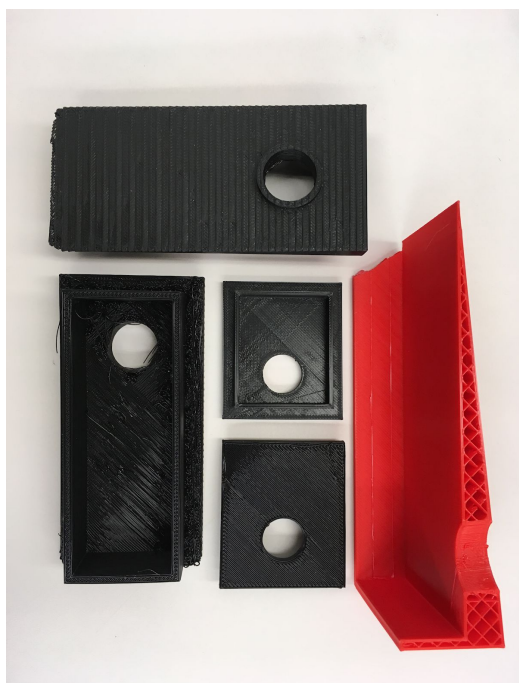


Figure 18

Microcontroller

5.4.1. Test Plan Goals

The goal of this test plan is to both show how we used the microcontroller and to make our actions repeatable by following this document. We intend to show how we set up our controller, test its functionality, and implement it into our system. For our project, we chose to use an ATTINY44 microcontroller, but the same procedures we will carry out with this controller should also work with other Microchip Technology products like the ATTINY85/45/44 ect. Additional tutorials exist online for other products if what is being tested does not appear to be able to follow along with the procedures.

5.4.2 Desired Functions / Deliverables

Our controller has a near limitless amount of programming options, making future updates or upgrades as simple as making new code for it. Although there are numerous features we would like to add, we are focusing on just a few.

- Measuring battery voltage while circuit is charging, Idle, and running
- Monitor IC operation and alert operators if needed
- Controlling LEDs to conserve power
- Flexibility to change (leave space for additional features)

These functions may not be tested in order, but they are all set to be done and working for when integration between the controller, and the receiver board is complete. The next section will include helpful design material that will include diagrams useful for the programming procedure.

5.4.3. Microcontroller Design Overview

The below figure 1 shows How one can connect an Attiny44 to an arduino for programming. This layout / design is what we will be using when making changes to code.

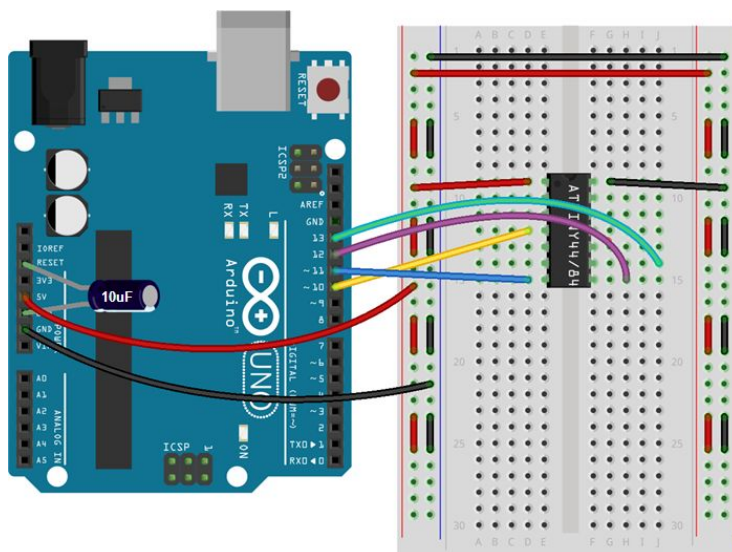


Figure 21

Microcontroller Programming

5.4.4. Programming Procedure:

To program, we will be using the arduino software to create and compile code for the controller. In order to upload code, we will be using an Arduino Uno as a programmer and use code and libraries provided by the arduino software and created from authors and available as open source code. By following online schematics, we will simply upload a programming code to the arduino, and then hook up the arduino to the tiny and upload new code to the tiny. The process for doing this is done as follows:

1. Open Arduino programming software
2. Click : File -> examples -> Arduino ISP -> Arduino ISP
3. Upload the code that appears to the Arduino
4. Click : File -> Preferences -> then add links into “Additional Boards Manager URLs”
specifically :
https://raw.githubusercontent.com/damellis/attiny/ide-1.6.x-boards-manager/package_damellis_attiny_index.json
The board manager was created by David A. Mellis and is available on github if needed. It is downloadable via the Arduino programming software's boards manager feature.
5. Once this is copied, click OK
6. Click : Tools -> Board(s) -> Board Manager and search, “attiny”
7. Select the first option, attiny by David A. Mellis , and install
8. Now to upload code, we simply follow the diagram in Figure 1
9. Click : Tools -> board -> Attiny24/44/84
10. Click : Tools -> Processor -> Attiny44
11. Click : Tools -> Clock -> Internal 1Mhz
12. Click : Tools -> Programmer -> Arduino as ISP

At this point, the Arduino programming software is ready to upload code to the attiny, so to test all steps have worked, we will add an LED to the arduino to ensure its program (from step 2) has uploaded correctly. This is done by observing the previously mentioned LED pulse when connected to pin 9 and ground on the Arduino.

Next, we can hook up an LED to a pin of the ATTINY and see if an uploaded blink code is running. Once confirmation has been made that the program has been uploaded, we can safely proceed to add more complex code either on the fly, or from previous tests.

Program Description:

The Program itself takes two analogue inputs upwards of 5V, which the microcontroller reads as anywhere between 0 and 1072. It converts these values to 0 to 5 by multiplying the input value by 5/1072. It samples 10 inputs and averages these inputs to get the value of the voltage coming in. Then using this current Voltage we divide it by the maximum expected voltage that can be output by the battery system to get the percentage of power left in the battery system. This varies between the Sensor and the LED strips, the Sensor being a maximum expected of 4.2V and the LED strips being 4.3V, the LEDs also require the code to compensate for the voltage divider. The system is set up so that there is a set of possible states that are conveyed by the LEDs attached to the microcontroller. $\geq 80\%$ to $< 95\%$ is green which means optimal operation, $< 80\%$ and $\geq 79\%$ is flashing Yellow, and is considered a warning stage that something may be amiss with the battery, $> 79\%$ is yellow and red flashing and is suboptimal and likely there is a problem with the battery or that it is not getting charged properly. At $> 95\%$ we are flashing red only which means there's an overcharge going on. This is all modified depending on the charge controllers Status, if its charging there's a greater tolerance for the values as the voltage will be nominally higher.

The program will also read information from the charge controller which has two Status bits that will be read into the Arduino. It will take those bits and check for a charge being sent to it. STAT1 and STAT2 will be checked for currently 2.5Vs, and if they have that or more then it will be read as 1. If the two read 10 then it's fully charged, if it reads 01 then its charging, if it reads 00 there's a fault. In case of 10, We default to the stated values above, in the case of 01 we increase the values tolerance for the voltage percentage, in the case of 00 we flash all the lights.

Parts List

Item	Description
Microchip Technology ATTINY44	Microcontroller used for control / monitoring
Arduino Uno	Used as a programming for ATTINY44
LEDS	Indicated arduino and ATTINY functionality
Breadboard	Used to create test bench for ATTINY44
Wires / connections	Interconnected components when breadboard was insufficient

Additional Notes

If you would like to inquire more information about this project, please visit our website linked in the title of this document. Other additional information, like ATTINY and Arduino datasheets will be linked in the description.

Microcontroller Validation and Evaluation

5.4.5. Testing Microcontroller

By following the steps above, we made and uploaded code to our microcontroller and tested it to ensure it could operate the way we wanted it to. Figure 22 shows the uploading circuit as well as the code in action. The green light indicates that the battery voltage level is at acceptable value. If this changes, the controller will go from green to flashing yellow, to flashing yellow and red. A steady red flash indicates an overvoltage. This of course can easily be changed in the code to make a sound with a speaker or set off other lights/alerts, but for the purpose of this project, we decided to stick with these interfacing / notification methods.

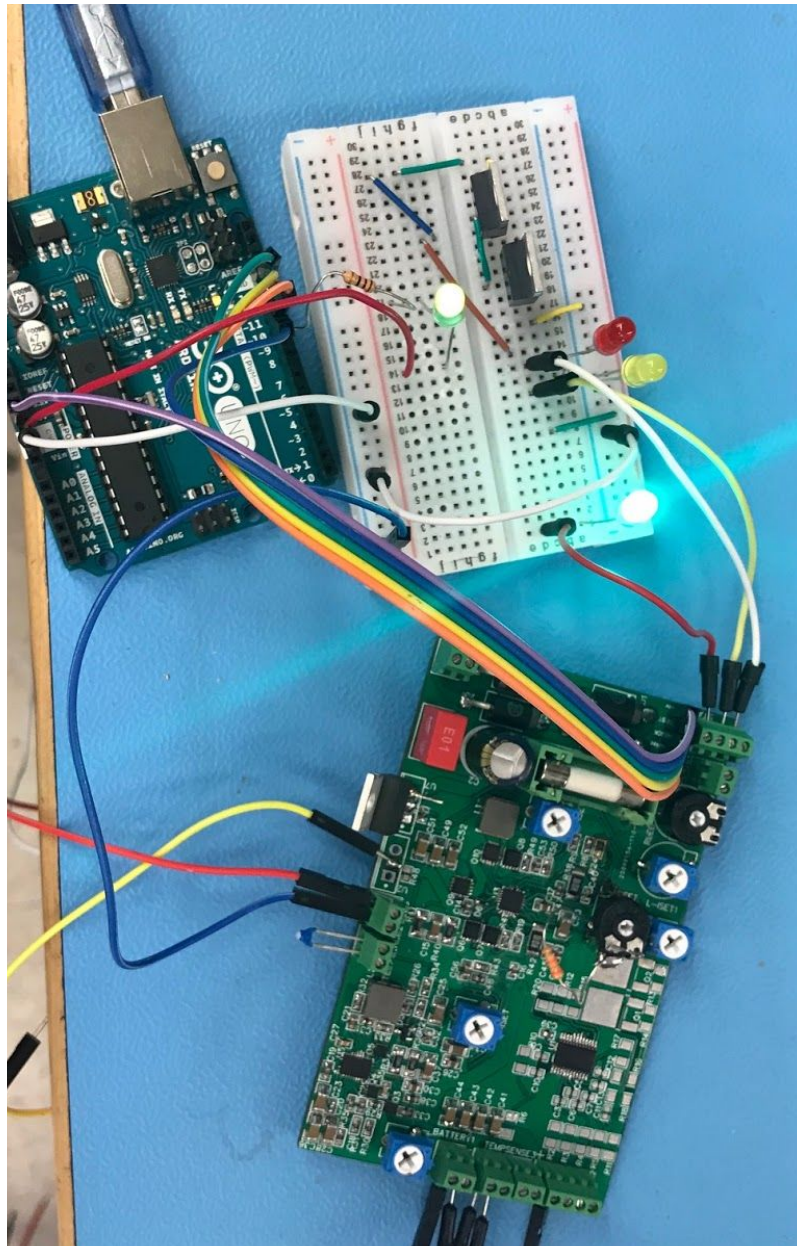


Figure 22

CODE NEXT

```
double maxVoltageSensor=4.2;
double currentVoltage=0;
void setup() {
  pinMode(10,OUTPUT);
  pinMode(9,OUTPUT);
  pinMode(5,INPUT);
  pinMode(8,OUTPUT);
}
// the loop routine runs over and over again forever:
void loop() {
  //10 is red 9 is yellow 8 is green
  if(currentVoltage/maxVoltageSensor<0.79){
    //flash five times before proceeding
    digitalWrite(8,LOW);
    for(int i=0;i<5;i++){
      digitalWrite(10,HIGH);
      digitalWrite(9,LOW);
      delay(500);
      digitalWrite(10,LOW);
      digitalWrite(9,HIGH);
      delay(500);
    }
  }else if(currentVoltage/maxVoltageSensor<0.8 && currentVoltage/maxVoltageSensor>=0.79){
    digitalWrite(8,LOW);
    for(int i=0;i<5;i++){
      digitalWrite(9,HIGH);
      delay(1000);
      digitalWrite(9,LOW);
      delay(1000);
    }
  }else if(currentVoltage/maxVoltageSensor>=0.8 && currentVoltage/maxVoltageSensor<0.95){
    digitalWrite(10,LOW);
    digitalWrite(9,LOW);
    digitalWrite(8,HIGH);
  }else if(currentVoltage/maxVoltageSensor>=0.95){
    digitalWrite(8,LOW);
    digitalWrite(9,LOW);
    //flash 10 times before proceeding
    for(int i=0;i<10;i++){
      digitalWrite(10,HIGH);
      delay(250);
      digitalWrite(10,LOW);
      delay(250);
    }
  }
}
```

```

// read the input on analog pin 5:
//commented out variables are currently not in use, but will be when testing the LED strips power management
//double sensorValues1;
double sensorValues2;
// double sensorValue;
double sensorValue2;
for(int i=0;i<10;i++){
//double tempsensorValue = analogRead(A5);
//sensorValues1+=tempsensorValue;
double tempsensorValue2 = analogRead(5);
sensorValues2+=tempsensorValue2;
}
sensorValue2=sensorValues2/10.0f;
currentVoltage=sensorValue2*(5.0f/1072.0f);
double batteryCharge=currentVoltage/maxVoltageSensor*100;
}

```

```

File Edit Sketch Tools Help
PowManSysV0_1a $

|
boolean flip=false;
double maxCapacity=.550*3600;
double currentCapacity=maxCapacity;
double maxVoltageSensor=4.2;
double currentVoltage=0;
void setup() {
  // initialize serial communication at 9600 bits per second:
  // Serial.begin(9600);
  pinMode(10,OUTPUT);
  pinMode(9,OUTPUT);
  pinMode(5,INPUT);
  pinMode(8,OUTPUT);
}

// the loop routine runs over and over again forever:
void loop() {
  //10 is red 9 is blue
  if(currentVoltage/maxVoltageSensor<0.79){
    digitalWrite(8,LOW);
    for(int i=0;i<5;i++){
      digitalWrite(10,HIGH);
      digitalWrite(9,LOW);
      delay(500);
      digitalWrite(10,LOW);
    }
  }
}

```

13 ATtiny24/44/84, ATtiny44, Internal 1 MHz on COM3

Figure 23

6 Project and Risk Management

6.1 Task Decomposition, Roles, and Responsibilities

Task list:

1. Client communication and discussion
2. Design conceptualizing and analyzing
3. Creating schematics based on Designs
4. Documentation of work and tests done (pictures and values)
5. Keeping the group on task and on track
6. Assembling prototypes based off of schematics / PCB layouts
7. Running tests on prototypes and making changes when & where needed
8. Research on topics of wireless charging and related fields
9. Tracking system overview and development progress
10. Deciding components to be used (based on design)
11. Purchasing components or other resources for project
12. Developing code and researching upload methods
13. Testing and debugging code
14. Designing containment device for components based on planned environment
15. Battery optimization and ideal type research
16. Poster design, and creation
17. Team website uploading and maintenance

Team member	Role	Responsibilities	Tasks (numbers)
Benjamin Gisler	Project Manager	-Make sure group and project are on track - Review other members' work	3, 6, 4, 10, 11,17
Miguel Hennemann	Team Leader/Client Liason	- Communicate with client - Keep group connected - Review all group work and progress	1, 3, 6, 8, 10, 11, 13, 16
Kyle Henricksen	Design Engineer	-Design overall layout of project -Consult group members on design decisions and coding questions	2, 7, 4, 12, 13, 16 17
Doruk Er	Systems Engineer	- Ensuring system integration - System containment - Research	8, 9, 11, 14, 15

6.2 Project Schedule

Proposed :

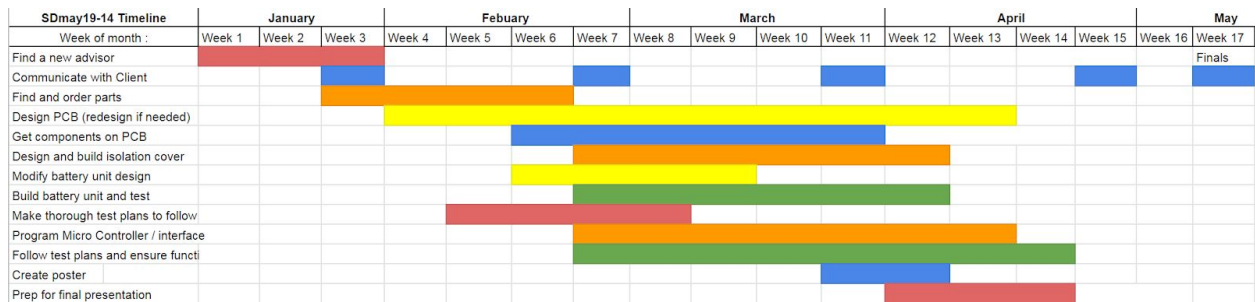


Fig 24

Actual :

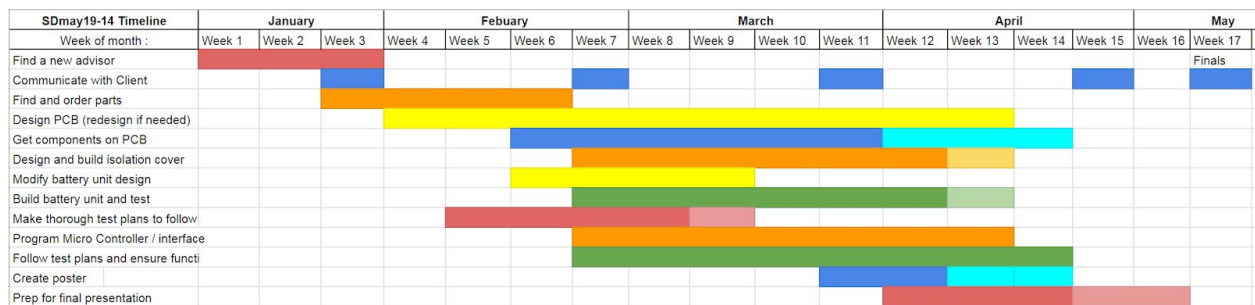


Fig 25

6.3 Risks and Mitigation:

Potential Problems

When developing our systems, we decided to keep them as simple as possible, and test them in a very step by step manner. By doing this, we hoped to avoid technical surprises and find smaller kinks and flaws in our design that could be remedied. We were able to cut down on pcb space used by using Linear voltage regulators instead of more complex buck/boost converters.

As for problems with reaching our goals, we had a few that concerned us:

1. Not being able to transfer enough power
2. Not being able to transfer power over long enough distance
3. Getting complex battery charging circuits to function as intended
4. Failing to transfer any power at all
5. Receiving liquid or vapor at a higher rate than expected into the boxes

Although these events came close to occurring, we were able to avoid most of these issue with little compromise

Actual Problems

Despite our efforts to make thing simpler, we still had strange things happen in the testing phase of our final prototypes. Here is a list of things that went wrong and how they were solved, or understood for future development:

1. Incorrect component placement on LED charger. A voltage divider was not correct.
- This issue, when fixed, should allow for correct charging to the led battery pack. We recommend redesigning PCB to incorporate a fix along with the following issue fixes
2. Linear regulators wasting heat and possible not functioning properly. - To remedy this, using more efficient buck converter should not only reduce power loss, but also create a more steady voltage output for the components.
3. A charging IC appeared to not function. The sensor battery charger seemed not to work, even after careful planning, building, and designing. -After going through IC checklist, we found that the IC would not work without a temp sensor installed. Thankfully, all we had to do was add the sensor and the IC worked like a dream
4. Precision errors over the 3D printing processes despite the added safety margins for the dimensions.

Lessons learned

We found that we had the best results of our work when we spent time not only reviewing and carefully constructing, but when we planned things out and followed through with them. We also now realise the value of going through each system on their own to make sure it works, and that more time dedication also gave us better results when solving unexpected implementation errors.

7 Conclusions

7.1 Closing Remarks

When obtaining this project, we were very excited to work on such an interesting task and to solve a very challenging problem. When we began to do research on wireless power transfer, we noticed that there were practically no references to the application we were attempting to create a design for. Although, there were numerous references for very low voltage applications, such as cell phone and tablet chargers. and also references pertaining to high voltage applications such as electrical car chargers, there were no references pertaining to medium voltage applications. For quite some time our project was in limbo between being a design or being a research project. Months later from the initiation of our project, we now have a near completed product. A product that can effectively transfer power wirelessly, within a distance requested by our client. A product that can also monitor the battery levels of 2 independent battery packs and regulate the power going to them appropriately. While our product accomplishes many of the requirements our client desired, there were still some undesirable challenges that arose that inhibited it from being completely functional.

7.2 Future Works

Due to the transmitter board being essentially a power supply, some components get extremely hot. This board can take an input of 48W and perform our well needed task of wirelessly transferring power. Specifically, the MOSFETs used for the H-Bridge and the 12V regulator used for the gate driver IC generate a ton of heat. We have placed heat sinks on these components, but bigger heat sinks may be necessary. Bigger heat sinks will increase the surface area to allow the heat to dissipate more. A cooling fan may also be used to cool these components down. A buck-boost converter may also be best to use instead of the 12V regulator used for the gate driver IC. In addition, adding an additional isolating layer for the cables that goes into the boxes at the entry points may be useful in increasing water resistance of the system.

8 List of References

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<https://easyeda.com/>

9 Team Information

Miguel Hennemann - Team Leader/Client Liason

I was born and raised on the beautiful island of St. Croix, U.S. Virgin Islands, where the sun is always warm and the water is crystal clear. I enjoy solving problems and I operate at my best when collaboratively working with others to do so. I value hard work and having a head strong moral compass.

Benjamin Gisler - Project Manager

Born in California, but raised in Iowa, I have had the honor and privilege to study at ISU for the past five years. I enjoy tinkering with electronics and computers in my spare time, and dabble in digital logic / ALU design. My position in the group ensures that the tasks we set out to do are completed and done so on time.

Kyle Henricksen - Design Engineer

Born in Iowa City, Iowa. Raised in Camanche, Iowa going to its elementary, middle and high schools. I am currently a 5th year senior of the Iowa State University Software Engineering program. I enjoy messing with various video game files in my free time as well as designing software systems.

Doruk Er - Systems Engineer

I am from Turkey. I went to a French high school with a science specialization. It is my fifth year at ISU as an electrical engineering student. I like sailing, windsurfing and snowboarding. Motorsports, philosophy, art and music are some of the things that I am passionate about.