UCF
COLLEGE OF ENGINEERING AND COMPUTER SCIENCE

Charge Spot

Revision 1

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1 Executive Summary

Today there is a great push for more electronic devices to operate using some kind of wireless technology. This can be seen from RC cars to game controllers to the daily charging of cell phones. Society is becoming less and less wired and this project aims to take that phenomenon one step further with the aid of available technology.

Charge Spot is intended to demonstrate the feasibility of an autonomous electric vehicle charging system for residential use. A vast majority of today's electric vehicles are being charged with a power cable connecting the car to the charging station. The goal of Charge Spot is to have very little user interaction and no physical connection between the car and the charging station.

We chose to use a highly resonant frequency charging system as our main means of transmitting power wirelessly to the vehicle. Resonant power transfer works by making a coil ring with an oscillating current; this generates an oscillating magnetic field. Because the coil is highly resonant any energy placed in the coil dies away relatively slowly over many cycles. If a second coil is brought reasonably near to it, that coil can pick up most of the energy before it is lost, even if it is some distance away.

This method of wireless energy transfer is better than capacitive coupling like the high electric field of the tesla coil. This method also allows for more charging current and better efficiency. For this project, the concept will be implemented using a PowerWheels electric toy car. Upon successful testing of our design, it can be successfully scaled to meet the charging requirements of a full size electric vehicle.

This project takes aim at the future where electric vehicles will be more abundant and autonomous systems will be widespread. This system even has the capability of being a smart appliance that is communicates with the smart grid and charges only when electric energy cost is at a reduced price. Also more parameters can be displayed on the panel and it may even have the capability of being monitored on your smart phone.

2 Project Definition

In the next section we will be discussing our motivation and goals for this project. We will see what objectives we will need to meet and the project's specifications and requirements. Furthermore, we want to discuss the project's functionality and practicality; how does Charge Spot work?

2.1 Project Motivation and Goals

With electric vehicles slowly becoming a more popular choice among car shoppers due to government incentives and tax breaks, a more user friendly means of charging these vehicles makes economic sense. Remembering to charge your electric vehicle every day is hard enough as it is. And if you forgot to charge it overnight there is a possibility you may not make it to work the next day. An electric vehicle cannot be charged in five minutes and if you do not have a backup means of transportation owning an electric vehicle can prove to be impractical if you continually forget or neglect to recharge it. Having a Charge Spot charging system will however give you one less thing to worry about, as the system is totally autonomous and there is no need to rely on you remembering to charge it.

Also the task of undoing cables and precisely aiming the plug connector can be a bit cumbersome at times. Charge Spot is designed to eliminate these concerns and also include added features necessary for peace of mind, such as battery temperature and the charge capacity of the battery being displayed. This is a hands-free, intelligent charging system, capable of fully charging your electric vehicle without human intervention. The user simply parks their electric vehicle as they normally would and the rest is taken care of.

Since its discovery, the interest in highly resonant wireless power transfer is growing, as this technology has a wide array of uses in many markets and application sectors. With this feature added to an electric vehicle, it thus becomes more desirable to purchasers, especially those who would rather eliminate the need for power cable connectors. Also, in this new age of smart phones and smart devices, an app can be used to view your car's battery status on-the-go, which already exist in Chevrolet's Volt and the Tesla brand car models.

We also believe that this method of charging increases the reliability factor of the vehicle, by eliminating one of the most failure prone component when it comes to electronic devices – the cords and connectors, especially those requiring multiple connecting and reconnecting. In addition, safety would also be enhanced, by eliminating the sparking hazard associated with conductive interconnections. There is no scientific evidence of resonant wireless charging, or even inductive wireless charging, causing harm to humans, animals, or the environment.

2.2 Objectives

After the group came up with this exciting project idea there are a few objectives that we would like to achieve in order to determine if the implementation is successful or not. Efficiency played a major part in us choosing to go with high resonant frequency charging and as a grouped decided on the added features that would make this an exciting project to work on. After carefully analyzing our project our main objectives include:

- Design and implement a wireless charging system using high resonance frequency charging technology.
- The charging system must be user friendly and have very little user interaction.
- Receiving coil attached to car must be lightweight and properly concealed as to not interfere with the normal safe operation of the vehicle.
- The charge ability of the system must be at significantly efficient as the charging ability of a directly connected cable to justify loss in power.
- The system should provide a reasonable charging rate, with the ability to minimize charge time by adjusting charge current based on battery level.
- Battery status and temperature displayed on panel using LED displays.
- Proximity status for alignment displayed on panel to guide user using LED displays.
- No physical cable connectivity between car and charge system.
- Proximity sensor capable of detecting car within 5 feet of panel.
- A fail safe shut down switch for added safety.
- Automatic shutdown when fully charged.
- Car should begin charging within 5 seconds of successful alignment.
- Project should be successfully completed within budget of $600.
- System should charge standard 12V battery to full capacity within 5 hours.
- The weight of the car system should not exceed 20 lbs.
- The efficiency should be at least 40 percent.

2.3 Project Specifications and Requirements

The specifications discussed below are some of the major guidelines that this project has to abide by in order to be successful. Each component in the overall design was given a great deal of thought before being selected. These specifications were arrived at by the individual group member responsible for researching that part.

LED Bar Display	• 16 LEDs at least (minimum 8 red and 8 green) • 10-20mA optimal current
LED Temperature Display	• At least 3 7-segment displays with decimal point • 10-20mA optimal current
Proximity and Motion Sensor	• Range of 5 feet minimum for proximity sensor • Range of 10 feet minimum for motion sensor
Copper Coils	• Lightweight (less than 2lbs each) • Small measured inductance (0.63H according to preliminary calculations)
AC to DC Converter	• Capable of up to 3A of current
Temperature Sensor	• Minimal pin usage for MCU • Range of 0°C to 80°C at least
Microcontroller	• Range of 3V-5V supply voltage • Enough pins for sensors and displays (20+)
Wireless Data Connectivity	• Secured syncing (only able to talk to each other) • Minimal pins usage for MCU
Fan	• Small (2 inches diameter ideal) • Able to cool surrounding temperature by at least 20°F
Battery	• UL Listed • 6V/12V, 200Ah minimum • Able to show a difference between fully charged and little/no charge in performance (for testing)
Oscillator/Resonator	• Yield upwards of 8V/14V up to 2kHz
Charge Controller	• Designed to charge 6V/12V battery within 3 hours • Capable of up to 3A of current

Table 2.3.1 – Initial Specifications and Requirements

2.4 Functionality

This charging system was designed to be purely hands free and user friendly. It charges the battery embedded within the electric vehicle to full capacity, with a few added features. It functions as an autonomous system as shown in Figure 2.4.1, where everything begins when the car begins to pull into the garage or designated parking area. A proximity sensor detects the presence of the vehicle and immediately activates Bluetooth connectivity between the car and the charge panel. While Bluetooth pairing is underway, the car is being guided into place by the proximity sensor. The driver continues to proceed forward while observing the visual aid which indicates the distance to proper alignment of both the car coil and the floor coil. The green LEDs signals the driver to keep moving forward until the red indicator LEDs comes on telling the driver it is almost time to stop, further explained in Section 4.3 MCU Display.

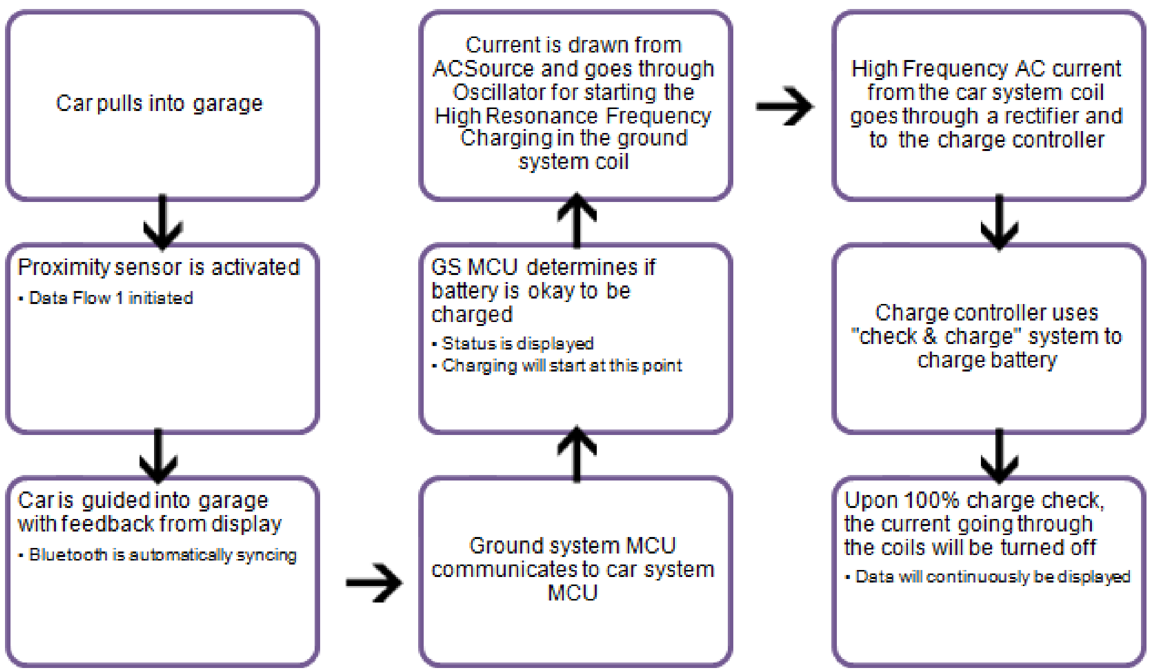

Figure 2.4.1 - Flow diagram for Charging System

3 Research

In order for us to get a broad knowledge on the project; we researched into similar wireless car charging project that has being performed or has been finished. We explored into projects that were being designed or has been developed from several engineering associations, like Society of Automotive Engineers (SAE International), companies like WiTricity, and other government projects.

3.1 SAE International

The reality of having an in-motion charging technology for motorsports like NASCAR and Formula One may be possible; even for electric vehicles. The idea of not having to stop at the pit for fuel is an ideal scenario for motorsports. Not stopping on a road trip or on your way to work could also be very beneficial to electric car users.

Inductive power transfer (IPT) was developed by a HaloIPT (U.K.–based start-up); IPT was developed purposely for electric vehicles that require wireless charging. HaloIPT was founded in 2010 by the New Zealand-based R&D commercialization company UniServces, Trans Tasman Commercialization Fund, and design consultancy Arup); the company has recently formed a planned partnership with Drayson Racing Technologies to develop an electric drive train package to replace a racecar's internal-combustion engine and also to test their IPT Technology on the race track.

The initial idea is that a transmitter will be buried underneath the surface of the road, or racetrack in the case of a racecar; the transmitter will then supply power to a receiver pad with a controller that is installed under the car. The controller converts the magnetic energy to DC power to charge the battery of the racecar. Dr. Anthony Thompson, Chief Executive at HaloIPT, explains in more detail:

> *"Power is transferred by tuning the pick-up coil to the operating frequency of the primary coil with a series of parallel capacitors. The power transfer is controllable with a switch-mode controller. In an electric vehicle, IPT wireless charging uses strongly coupled magnetic resonance to transfer power from a transmitting pad on the ground to a receiving pad on the car."*

Because installing the charge circuit beneath millions of miles of established roadways will be very costly and time consuming, the two companies decided to perform and test this technology on a short, confined surface at the racetrack. In order to maintain a continuous charge a pad will have to be placed one per linear meter with a gap of 250mm between each pad; so that there would be 100pads/100m. There can be up to 400mm gap between the vehicle and the pad; the vertical gap is also automatically adjusted by the IPT system, when adjustment is needed. According to HaloIPT, “The literal alignment between vehicle and pad can be ±250 mm (9.8 in) with minimal loss of efficiency.”

This technology follows the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines because the system emits a very low magnetic field that does not interfere with the electronics within the vehicle. Late last year there was a Citroen C1 converted by Electric Car Corporation demonstrated in London. There was also an electric Phantom launched at the Geneva Motor show in March that demonstrated a 7kW system for a larger car featured on the Rolls-Royce 102EX. There is an expectation to deploy a new 18kW product that will be suitable for electric vehicles like taxis, delivery vans, and trucks.

Thomson said “IPT is a vehicle agnostic technology and can therefore be used to power any electric vehicle regardless of size and weight. HaloIPT’s system allows cars, vans, buses, and trucks to travel along the same stretch of IPT highway, with each vehicle harvesting the appropriate amount of energy, controlled from within the vehicle.” For the past ten years in Turin and Genoa, Italy, HaloIPT system which has power levels up to 60kW, are being successfully used in about 40 buses. HaloIPT system can be compared to a plug-in system because it takes the same amount of time to recharge a battery; the bigger the battery the longer it takes for the recharging. It will take five hours for a 3kW IPT system to charge a 15kWh system.

Many co-operations and public sector bodies like Transport for London (the local government body responsible for most aspect of transport system in London), TSB CABLED (the U.K.’s largest trial of Electric Vehicle), and Oxford Brookes University have been working with HaloIPT to help create more wireless electric charge (inductive charging) vehicles to introduce into the mainstream.

There is an estimate of 70,000 units of wireless electric vehicles to be produce by 2015, because of this estimate there have been a recent agreement between a manufacture of lithium-ion battery packs for electric vehicle (Evida Power Ltd) and HaloIPT to jointly manufacture about 40,000 IPT system over a five-year period. Thomson said, “We are now working tirelessly with numerous government bodies and private companies to define infrastructure development, which represent the key next stage of development for charging network implementation. There is a need for government and private-public partnerships to deploy the infrastructure to encourage the production of electric vehicle with smaller battery packs.”

Wireless charging of electric vehicles is becoming more popular due to high demand of clean energy. Companies like HaloIPT inspire us to learn, and work with this technology. If it can be eventually placed in all roads, to charge all future electric vehicles everywhere, think what else this technology holds for the future, and we want our project to branch off, or at least be a part of its growth.

3.2 WiTricity

A little over a century ago, Nikola Tesla had an idea of transmitting power through air by using the earth's ionosphere. In terms of wireless power transfer, the frequency of some electromagnetic (EM) fields is the most used method to transmit or send the energy to where it's needed. In order for a detector to receive photons from the high frequency end of the spectrum, an optical technique is used. This technique uses laser to send power via a collimated beam of light to a remote detector where the photons are converted into electrical energy. There is a possibility of transmitting over a long range distance using this technique but there will be the need of complicated tracking and pointing devices to sustain proper alignment between a moving transmitter and receiver. Radiated electromagnetic fields from an appropriate antenna can also be used at a microwave frequency to transmit power over a long range.

There is a common set of functional blocks when it comes to application-wireless energy transfer based on HR-WPT that extend power levels of smaller watts to a level of multiple kilowatts. Figure 3.2.1 below shows a general diagram for HR-WPT system and Table 3.2.1 explains each block.

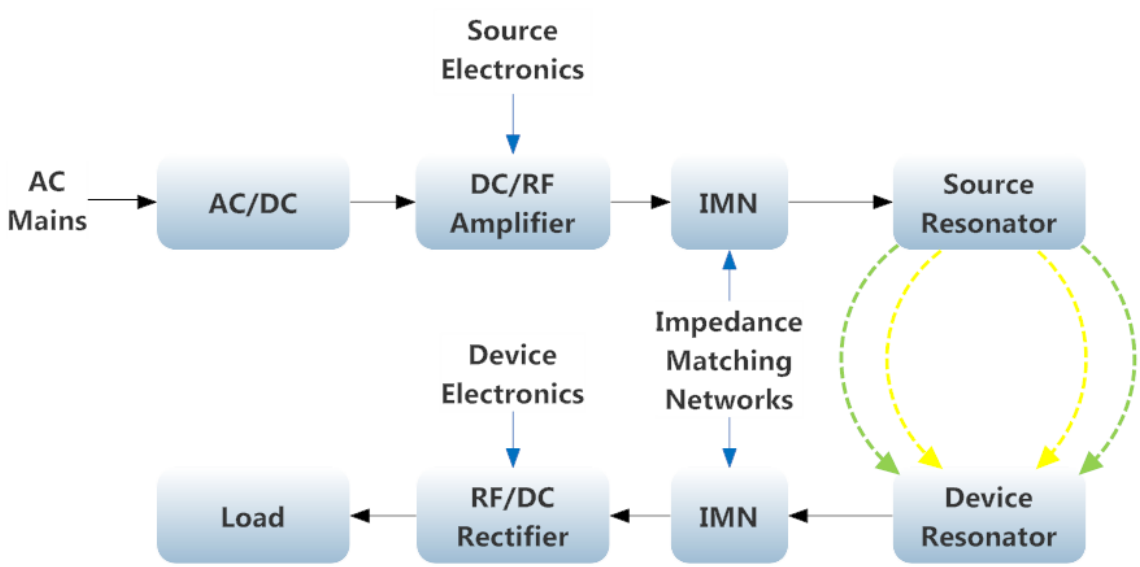

Figure 3.2.1 - Block diagram of a wireless energy transfer system

Inductive coupling into the source resonator and out of the device resonator was used in the earlier work at MIT to achieve impedance equivalence. There was an alignment between the source input coupling coil and the source resonator and also between the device output coupling coil and the device resonator to adjust or alter the input and output impedances. Optimum power efficiency was also possible to achieve by properly adjusting the coupling values.

AC Mains	This is the power that comes from the plug on the wall in the garage or house.
AC/DC	Converts the AC to DC; power factor correction may be included in this block when using a high power application.
DC/RF Amplifier	At this stage a high efficiency switching amplifier is used to convert the DC voltage into a Resonance Frequency voltage wave form, which is used to drive the source resonator.
Impedance Matching Network (IMN)	This is often used to efficiently couple the amplifier output to the source resonator while enabling efficient switching-amplifier operation. It also serves to transform the source resonator impedance, loaded by the coupling to the device resonator and output load, into such impedance for the source amplifier.
Source Resonator	Generates a magnetic field to the device resonator; that causes energy to build up in the device resonator.
Device Resonator	Transfers the buildup energy within it to a load or a charging battery.
Second IMN	Used to efficiently couple energy from the resonator to the load.
RF/DC Rectifier	Converts the AC power received back into DC for a load that requires DC voltage.
Load	This is what we're powering through wireless energy transferring; usually charging a battery.

Table 3.2.1 - Explanation of Figure 3.2.1

WiTricity is known for their wireless energy transfer products, most notably the wireless cell phone charging pad. Simple-to-use devices and products like this is what we aim for when designing and building a prototype for Charge Spot. Ideally we want an easy, convenient product for consumers that will make that daily routine easier. We are essentially making a giant cell phone charging pad, but for a heavier load, being an electric vehicle's battery. WiTricity has great insight for what we're doing, as holds the basis for our idea for construction and design.

3.3 Relevant Technologies

Wireless power transfer dates back to the days of Nicola Tesla so the idea is not entirely new. In fact the operation of a transformer can be considered a form of wireless power transfer as it functions on the principle of electromagnetic induction to transfer power from the primary coil to the secondary coil. When considering our goal of wireless charging, there are two prominent methods on the wireless transfer of energy: inductive coupling and magnetic resonance.

3.3.1 Inductive Coupling

When current passes through a current carrying conductor a magnetic field is created around this conductor and inductive coupling makes use of this effect. Turning this conductor into a coil amplifies the magnetic field. A larger coil of more turns results in a larger magnetic field. If a conducting wire or a second coil is placed in this magnetic field, a current is induced in this wire. Inductive chargers, such as those found commonly in electric toothbrushes, operate on this same principle. Figure 3.3.1 shows the inductive coupling method. The efficiency of these systems is greatly reduced if the primary coil and the secondary coil are not located in very close proximity to each other. Also, they must be carefully positioned to allow for maximum magnetic coupling between both coils else there will be substantial energy losses.

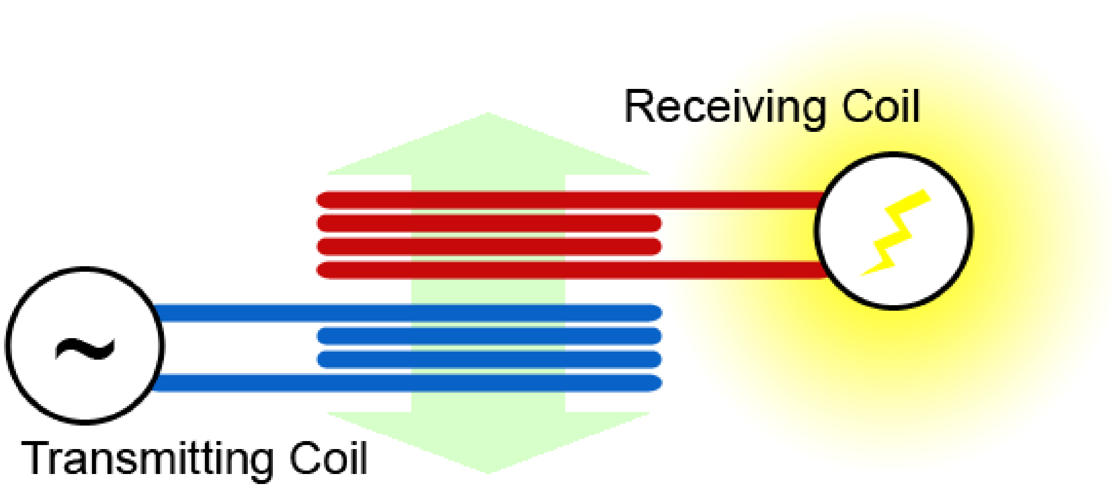

Figure 3.3.1 – Inductive coupling method

3.3.2 Magnetic Resonance

Transferring power at a greater distance using the inductive coupling method proved to be somewhat impractical as this would require a great deal of power. A larger, much stronger field from a transmitter coil could induce current into a receiver coil from farther away, but the process would be extremely inefficient. Since a magnetic field spreads in all directions, making a larger one would waste a tremendous amount of energy.

In November 2006, a few researchers at MIT discovered an efficient way to transfer power between coils separated by a few meters. The team developed a theory that extended the distance between the coils by using resonance frequency. This is a nonradiative approach, and by using resonance the efficiency of the energy transfer is greatly enhanced. It is also important to note that this method of energy transfer has the ability to maintain a high efficiency, not only over a range of distances, but also with positional and orientational offsets. Figure 3.3.2 below shows the magnetic resonance method in which energy transfer at greater distances and/or with more positional freedoms depicted.

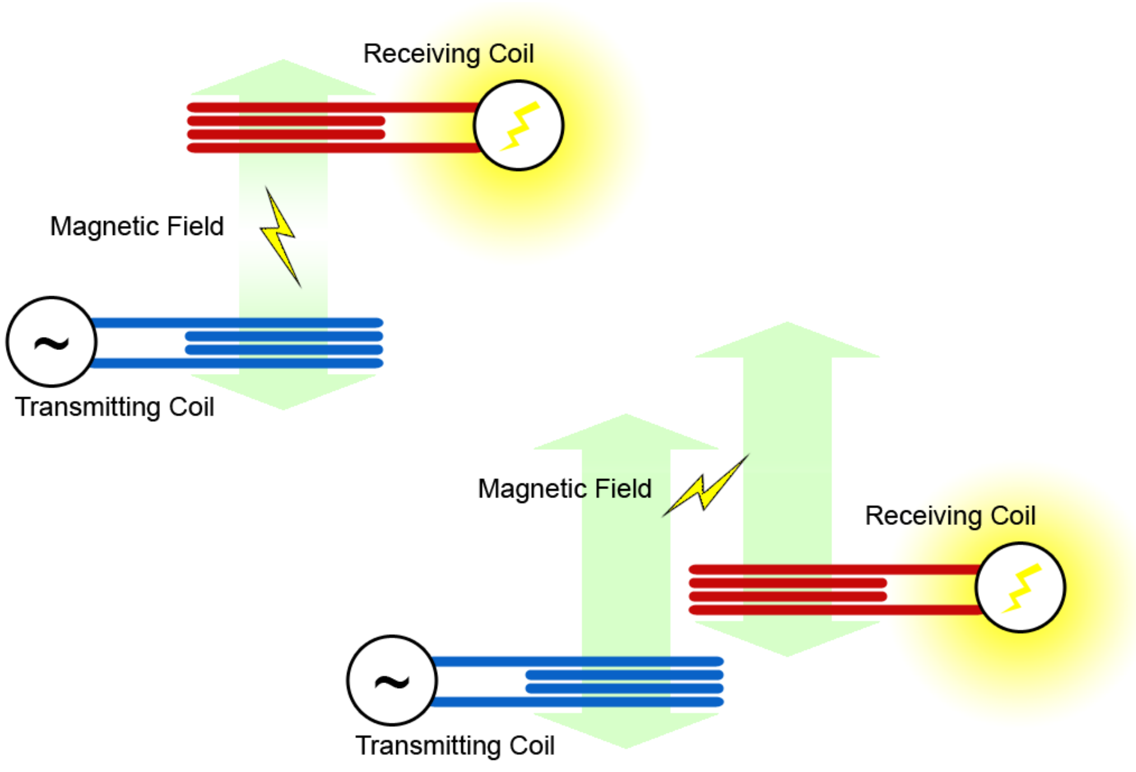

Figure 3.3.2 – Magnetic resonance method

The primary reason we chose to use the magnetic resonance method for our project was due to its high efficiency rating. Even though we will have to deal with energy losses in our charging system this method enables the project to be more practical and comparable to directly connecting the power cable of a standard charging station to the vehicle. The second reason why we chose this method is the fact that it allows for orientational and positional flexibility. Since, the car will be driven into alignment by a human; there is no certainty that the vehicle will be precisely positioned every single time. Having the flexibility to be slightly out of alignment and still capable of maximum power transfer enables this method to be best suited for our application. Thirdly, the distance feature of the resonant frequency power transfer method, gives us the benefit of mounting the receiver coil to any vehicle with little to no restrictions on the height clearance beneath it, provided that both coils are within range of each another.

3.4 Strategic Components

In order for this project to be realized we had to use our knowledge gained from relevant coursework to prescreen various components necessary to perform the functions needed. First of all we need a car that will be fitted with the car system components. For this project a PowerWheels toy car will be used for demonstration purposes. A receiving coil is mounted to the bottom of the car and its primary purpose is to capture the wireless power transmitted by the ground coil. The receiving coil sends the received power to an AC/DC converter which is basically a rectifier circuit.

The Charge controller now takes this power and optimally charges the battery. We added a temperature sensor and a voltmeter to the system to give reliable feedback of the battery capacity and temperature. As soon as the battery capacity reaches 100%, the charging system will be automatically turned off. If the battery temperature exceeds our predefined nominal value, the charging system will shut down as a safety measure.

The Bluetooth communication between the car and the control panel is handled by a Bluetooth chip mounted to our PCB which also houses the microcontroller. There is also a receiving Bluetooth chip mounted to another PCB located inside the control panel. The control panel also has a microcontroller used for system shutdown and for displaying the relevant data on the front of the panel.

We have to ensure that our control panel is of suitable size. It must be large enough to fit all the enclosed components and be able to act as the visual aid with the LEDs mounted to it. This panel will also be mounted to the wall, therefore the components inside must clear the four corners to allow for the mounting apparatus.

The correct turns ratio must be determined for the ground coil as well as the car mounted coil. In order for these coils to be securely mounted, we plan on building two molds, placing a coil in each mold and pouring fiber glass resin into the molds to cover the coils. When the resin is properly dried mounting holes will be drilled into the fiberglass.

Power for the system will be provided by a DC power supply (battery) capable of 5V for the electronics within the car system, and an AC power supply (outlet) capable of delivering 14V DC for charging purposes and 5V DC for the electronics located in the control panel; AC power supply will go through transformer and rectifier. The 14V will be connected to a high frequency oscillator that oscillates at a predefined resonant frequency, thus ringing the ground coil at the said frequency and allowing wireless power transfer to the car coil.

3.5 Parts Research

Throughout this section we will be looking at possible parts to use in the construction of our prototype. The following tables presents a general parts list for the ground system (Table 3.5.0.1), the car system (Table 3.5.0.2), and all systems (Table 3.5.0.3). We will discuss each potential part and choose one for each subsection. The final parts list (specific parts list) will be listed in Section 6.1 Parts Acquisition. These generic parts lists are the initial parts we're looking for based on previous research. We may add more and take away when we design and develop our prototype. The estimated costs are roughly our budget, but they are high estimates.

Table 3.5.0.1 - Ground System Generic Parts List

Part	***Requirements***	***Est. Cost***
Metal Box	Able to house the displays and electronics	$30
Proximity Sensor	Able to determine range within 5ft, able to work with microcontroller	$10
Motion Sensor	Must be able to have larger range than Proximity Sensor, low power	$10
LED Bar Display	Two-color (green/red), 8 bars, large enough to see	$15
LED 7-Segment Display	At least 3 displays, color preferably red/blue/green, large enough to see	$15
Kill Switch	Push button, able to be mounted to metal box	$5
Transformer	Able to supply Power Distributor with enough current	$5
Fan	12/5V, able to be mounted in metal box and cool it	$5

Table 3.5.0.2 - Car System Generic Parts List

Part	***Requirements***	***Est. Cost***
Charge Controller	Detect voltage and charge battery, able to work with microcontroller	$10
Battery	6V/12V, able to run testing vehicle (ideally come with vehicle)	$30
Test Vehicle	Smaller scale than car, battery-powered, able to drain battery	$100

Table 3.5.0.3 - All Systems Generic Parts List

Part	***Requirements***	***Est. Cost***
Temperature Sensor	Range of 0°C to 80°C at least, able to work with microcontroller	$25
Microcontroller	Enough pins and programmable memory, easily programmed	$15
Bluetooth Module	Able to work with microcontroller, quick and secure data transfer	$15
Copper Coil	Appropriate thickness for current needed, rod or coil	$60
Conduit	Able to cover coil/oscillator, able to protect wiring	$10
Plaster Setting	Coat coil without interfering with wireless charging	Provided
Frame Setting	Able to mold coil in plaster setting, removable	Provided
Assorted Parts	Miscellaneous parts for certain circuits	$15

3.5.1 Control Panel

The control panel will be a metal box mounted to the wall inside of the garage. This box will house all the major components of the ground system, including the power supply, power distribution, resonator/oscillator circuitry as well as the MCU and Bluetooth communication circuit boards. If the garage is susceptible to lots of moisture (for example a carport) then we have to consider a metal box enclosure suited for water tight conditions. However, we'll be designing our system for the average garage that is enclosed and may opt for a standard metal box.

<u>Junction Box</u>

Vendor	Graybar	Features	• Height: 13.4 in • Width:12.94 in • Depth: 6 in • Continuous hinged
Manufacturer	Hoffmann Enclosures		
Quantity	1		
Price/Unit	$all for price		
Part Number	88131257		

Table 3.5.1.1

Figure 3.5.1.1

This control panel has a robust structure, and has the dimensions capable of holding all the parts we will be using for the ground system. This enclosure is used in indoor and outdoor settings that are frequently wet or have constant exposure to water. This would definitely be our box of choice for a carport application.

Steel Junction Box

Vendor	DigiKey	Features	• Height: 10 in • Width:10 in • Depth: 4 in • Hinged door
Manufacturer	Bud Industries		
Quantity	1		
Price/Unit	$ 27.30 (+S&H)		
Part Number	377-1868-ND		

Table 3.5.1.2

Figure 3.5.1.2

Another option to consider is this steel metal box from DigiKey. Even though it is a bit smaller in terms of dimensions we can still comfortably fit all the necessary components associated with the ground system inside. Another advantage of using this enclosure is that it has knockout holes which make it easy for us to connect the conduit leading to the coils on the ground. For the purposes of this project, we will be going with this box for now, unless we can find a better-suited, cheaper one before prototype construction.

3.5.2 Proximity Sensor

In order for us to choose the right sensor for this project, there are some important factors that we had to take into consideration before choosing the appropriate one for our design. Among all the factors that are recommended for this design, the range and limitation of the sensor is the most basic of them all. If a sensor does not meet this basic requirement, then it must be immediately discarded as a choice for our design.

The price of the sensor was also one of the factor’s that was essential in determining the best sensor for our design. Because we are funding our own project we had to stay within a fixed budget in order to minimize any excess expenses. Thus, it is necessary that each sensor that is selected is not only based on optimum capabilities with our design but also within our budget range.

Sound navigation and ranging was the original acronym for sonar; it is also referred to as acoustic sensing or ultra-sonic sensing. Passive sonar and active sonar are the two main technologies that share the name sonar. Passive sonar is basically listening for sound created by vessel, and active sonar is emitting pulses of sounds and listening for echoes. The frequencies used in acoustic locations may vary from very low (infrasonic) frequency to extremely high (ultrasonic) frequency. The time lapse between when the frequency is transmitted and when it received is also very relevant to our project because we need our wireless electronic vehicle to be at certain location and range before charging. This time factor is also important because we need the sensor to be able to detect and alert the charge system about the approaching vehicle.

The minimum and maximum range the sensor can detect an object is also very crucial to our project. We don't want the vehicle to get too close to our charging spot before the sensor detects it; any sensor that does not meet at least the minimum distance of 4.5 feet is automatically discarded. The typical maximum range of a relatively economical sonar sensor is no greater than 6-25 feet. Among the sonar sensors ultra-sonic and infra-red looks like a good choice for this project. Due to our budget and cost being an important factor in deciding which sensor to use in the wireless charge spot project, our best option is to buy the least expensive sensor while still maintaining an adequate range for detecting purposes. The least expensive ultra-sonic sensing system costs between $30 and $50. Although this system option looks very economical for our project, the ranges are not nearly suitable enough to cover the expected distances in the design for our project. The range of minimum one to two inches range is the distance for an inexpensive ultrasonic sensor, meaning with this limited range we will have to consider a more expensive ultra-sonic detection for this project.

Because of the delicacy of ultra-sonic sensing, it is easier to miscalculate the distance between the object and the sensor. Unless the object being detected—in this case an automobile—is directly in front of the sensor and perfectly flat, there will be a miscalculation in the distance to the object. If the detected object is at a sharp angle there will be no guarantee that the reflected wave will reach the receiver. Reception and transmission of sound can be interchanged or alternated by a special type of sonic transducer called UEDK 20; it is normally used as an ultrasonic proximity sensor. What makes this type of sensor special is that, when the transducer emits a sound wave towards an object or target, it switches over to receiving mode in order to be able to receive the reflected sonic wave that is bouncing back from the object. The time it takes between the emitting and receiving of the reflected sonic waves is proportional to the distance of the object from the sensor.

Regardless of color or transparency of the vehicle this highly integrated ultrasonic proximity sensor will be able to detect the vehicle. This sensor will be very useful for our project because there will be no need for us to write a program or code for each color type of vehicle. That will certain reduce some of our work load. There is isolated housing for both the emitter and the receiver. When a sonic wave signal is propel from the emitter, it will keep propagating until it hit a target or an object and the reflected sonic wave is picked up by the receiver. After the reflection beam is detected the receiver then reacts to give an output. Because of its range it did not look like a possible choice for our charge spot project; it an ideal sensor for application that requires minimum distance. It is only possible to sense a target within a conic region produce from the emitter. Although it initially comes with a minimum range; the required sensing range can be adjusted with the built-in potentiometer. We can also customize our specification of this sensor if we choose it, because the operation range can be adjusted and the output function will be selected. There is a built-in LED that helps to indicate when an object is within the set area of detection by changing it state.

Among all the sensors that we had researched; infrared looked like our best logical choice for our charged spot project. It is not only compatible with Arduino-boarded microcontrollers but also other controllers such as PICAXE, PIC, and Parallax. This sensor can be used efficiently for most indoor application where no important ambient light is present. Because we want to element other factors like wind or weather change; our project is going to be design purposely for indoor charging. The IR proximity sensor uses LED’s to emit infrared light. The sensor then detects anything that reflects that light back to it. This information is then in turn used to determine proximity of the detected object to the sensor’s position. As the range of the sensor being one of the factors or characteristics that we discussed earlier; the cheapest one we found was within the price range of $5 to $10. It was a very good price because that fitted perfectly into our budget, but one of the problems with this price of sensor is its range. The highest range at that price, range no more than 25 to 35 centimeters. Although the range can be extended by increasing the amount of current into the LED; we noticed that our range will still be limited since there is a maximum current that can be generated into the IR sensor. Increasing the current in this type of sensor is going to require more power which will reduce the efficiency of our system. So we decided to increase the price for the type of sensor we are going to use in our budget.

We noticed that the infrared proximity sensor for our project should be able to detect objects from ranges between 100 to 150 centimeters. The amount of ambient light within the area where the object is to be detected can have effect on the range of an infrared proximity sensor. The more the ambient light within the vicinity of detection the less the effective the sensor becomes. This means that if we set up our Charge Spot in an open area, the IR sensor would have been a very wrong choice especially for sensing during daytime. The headlight of the car can also create significant amount of ambient light that could cause problem with the sensor. This problem can be fixed with an ambient light ignoring sensor which can work in conjunction with the proximity sensor or we can back the car into the garage. This type of proximity design uses a pair of

LEDs; one of the LEDs emits the light and the other detects the reflected light. The problem with this design is that the LED emitting light must be constantly emitting light and therefore be constantly on and active. This constant emission will reduce the battery life of the sensor and severely impede energy efficiency.

Although this is a problem we have a way to rectify this problem; we can be designed to send IR pulse from the transmitter instead of constant emission. The price of this type infrared proximity sensor is reasonably inexpensive and it fits perfectly in our budget; a typical price of a long range infrared proximity sensor ranging from $20 to $30 per sensor. The low cost is not the only advantage of using this IR proximity sensor, but a few parts are required to build this type of sensor. Although this is very beneficial to our project we noticed a few problems that we might run into. One of the problems was finding parts for the circuit.

Another variation of an infrared sensor is PIR or a passive infrared sensor. This type of infrared proximity sensor is essentially a motion detector and is the same type of technology that is used in most companies or industrial security motion detectors system, but this is ideal for our motion sensor decision in Section 3.5.3. Due to the high cost and the lack of necessity for this project, we will not be considering a laser sensor. The proximity sensor will be fixed to a position that will require the least amount of range, which would most likely be beneath or attached to the bottom of the metal box in order to be aimed at a bumper.

MB1414 USB-ProxSonar-EZ1

Vendor	MaxBotix	Features	• 6in to 120in range • Sonar Sensor • USB interfacing
Manufacturer	MaxBotix		
Quantity	1		
Price/Unit	$49.95 (+S&H)		

Table 3.5.2.1

This MaxBotix ultrasonic sensor is ideal for the consumer, since it has large enough range for a life-sized garage and a real vehicle. Range maxes out a little over 10 feet, with minimum range being 6 inches and resolution of 1 inch. It has the ability to be setup with multiple sensors in case more are needed in the final product. It uses USB interfacing and power to connect to a computer or microcontroller. However, for our prototype testing, this expensive piece isn't a good decision. We do not need so much range for our prototype, and thus don't need to spend so much on it. It's still an option if an infrared sensor doesn't work out.

IR Distance Sensor (GP2Y0A02YK)

Vendor	Adafruit Industries	Features	• 8in to 60in range • Infrared Sensor • JST interfacing
Manufacturer	Sharp		
Quantity	1		
Price/Unit	$15.95 (+S&H)		

Table 3.5.2.2

Another plug-in-play type of component from Adafruit, this infrared sensor is perfect for our prototyping purposes and supposedly easy to use. Most importantly, its range is fine for what we will be dealing with: 20cm to 150cm (about 8in to 60in). It uses a JST interface with three wires: power, ground, and analog out. The sensor itself runs on 5V and the analog out ranges from 3V to 0.4V (to the MCU). Of the two proximity sensors, the infrared one is the most bang for our buck.

3.5.3 Motion Sensor

We decided to add motion sensor to this project to reduce the prevent wasting too much power; without the motion sensor we would have to use the proximity sensor for object detection, thus it would have to keep sending signal until an object is detected. We decided to use RK115FCUL00A- ROKONET Cosmos DT 50ft Dual Technology Motion Detector for this charge spot project because it's provided to use for free. The purpose of this motion sensor is to detect an object and send a signal to turn on the proximity sensor if an object is detected. As long as an object is detected the transducer within the proximity sensor would emit a sound pulse wave to the object then switch to receiving mode.

This motions sensor is suitable for harsh residential or commercial environment that uses both infrared and microwave channel for false alarm because it has series of dual technology infrared and microwave motion detector. The following features are included in this motion sensor, and some specifications are included in Table 3.5.3.1.

- Patented True Temperature Compensation
- Microprocessor Controlled
- Microwave Range Adjusted
- Low Current Consumption
- Anti-Fluorescent Interference Signal Processing
- Ceiling and wall/ Corner Mount Swivel Bracket
- Memory and Form-C Relay Model Available

Table 3.5.3.1 – Specifications of Motion Sensor

ELECTRICAL	
Current Consumption	25 Ma at 12 VDC 45Ma at 16 VDC (MAX with all LEDs ON)
Voltage Requirements	9-16 VDC regulated
Alarm Contact	24 VDC , 50Ma
Temper Contacts	24 VDC, .1A
OPTICAL	
Filtering	White Light Protection
PHYSICAL	
Size	127.6x64.2x40.9mm (5x2.5x1.6in)
ENVIRONMENT	
Operation Temperature	0C to 55C (32F to 131F)
Storage Temperature	-20C to 60C (-4F to 140F)

3.5.4 LED Bar Displays

Due to the intricacy of the design we have in mind, and the size, we plan to custom make our LED bar displays (not the 7-segment display) using a series of green and red LEDs. We can either have a series of LEDs per color per bar, or one LED per color per bar. The most likely case is the former, so we can a big and bright display. A huge problem we will face is how to control each LED with the available pins with have. The simplest and most inefficient way is to brute force it; connect each LED to a pin. However, we don't have enough pins and possibly not enough power (to have multiple LEDs on at once).

To fix this we will be using a 4:16 decoder; we will be using a 74154N. Since it outputs inverted signals, it would have to be sent through an inverter, for which 74F04Ds can be utilized (inverters with 20mA output). In actuality, there are six gates per 74F04D chip, so we would use three chips for this display. Two 74LS377Ns, which are D latches, can be used for more control on the LEDs, with its CLK and EN_G pins. Table 3.5.4.2 shows the vendor stats for the components.

Table 3.5.4.2 - LED Bar Components List

Component	Vendor	Manufacturer	Quantity	Cost per unit
74154N	Mouser	Texas Instruments	1	$4.15 (+S&H)
74LS377N	Mouser	Texas Instruments	2	$1.55 (+S&H)
74F04D	Mouser	Texas Instruments	3	$0.63 (+S&H)
Green LED	Mouser	Lumex	8 min	$0.28 (+S&H)
Red LED	Mouser	Lumex	8 min	$0.23 (+S&H)

Since we're constructing our own displays, we'll house the 8 bars in a paper setting, molded and cut for allotted space in the metal box. We can either use a type of paper for the film to put over the bars, or a sturdier glass or plastic; preferably clouded. The housing for each bar will depend on how many LEDs we'll have in each bar. Most likely we will take advantage of a 2x2 design of alternating colors (top: red/green, bottom: green/red) and scale it to whatever size we desire. However, we are limited with how many we can have, due to power. Running a 4x8 display will take 320mA if we run at minimal brightness, and 640mA if we run at the optimal 20mA per LED, so we have to take into consideration how much current we can pull from the microcontroller and power supply.

3.5.5 LED 7-Segment Displays

The 7-segment LED displays are being used to display temperature of the battery to the user. The temperature will be displayed in °C and will require at least three separate 7-segment displays. The LED color will preferably be white or red, and the LEDs themselves should be large enough to see, as it will be mounted on the metal box. Searching for 7-segment displays we found that the larger the display the price would exponentially increase. To compromise we want to try to stay under $15 which would give us decently sized displays--enough for the small-scale testing for this project. We found simple single 7-segment displays that are cheap and small, and would require some work to have them work together, but use many pins. We also found 7-segment displays that are already multiplexed together and requiring less pin usage, but are also more expensive.

<u>WaveShare 4-Digit 8-Segment LED Display Tube Board Module</u>

Vendor	DealExtreme (dx.com)	Features	• 4 7-segment displays • Easy use/setup • Really small
Manufacturer	WaveShare		
Quantity	1		
Price/Unit	$6.80 (+S&H)		

Table 3.5.5.1

First to look at is this display module that includes all necessary 7-segment displays, and includes a decimal point. The dimensions are quite small, however, with the entire board being 4.8cm x 2.6cm x .8 cm and for that price it doesn't seem worth it. Although it does come printed on a board with easy-to-connect pins and a test program to make sure the display is working correctly, it just seems you're paying for easy setup than for what you actually want. The pros for this display are its ease of use and connectivity. It also comes with all the displays we need instead on one of each. The one con however outweighs the pros; the display being too small for what we can get with the same price. However this will stay on the backburner as a viable option for a display.

Kingbright BC56-12SRWA

Vendor	Mouser Electronics	Features	• 3 7-segment displays • 14.2mm character height • Red illumination
Manufacturer	Kingbright		
Quantity	1		
Price/Unit	$3.46 (+S&H)		

Table 3.5.5.2

Another display we found is this Kingbright display that is a combination of three 7-segment displays with decimal points. It is white/grey and illuminate red. Unlike the previous display, Mouser is kind enough to give us all the technical specs so choosing a specific part is easier, especially when there are numerous other similar products. This particular Kingbright display uses common cathode and runs on 1.85V/20mA and has appropriate operating temperatures for what we need. Dimensions are large enough, 37.6mm x 19mm x 8.1mm and the characters themselves measure 14.2mm in height. The pros here are the price and convenience of the three displays being in one. With the addition of the given data sheets from Mouser and the absence of any noticeable cons makes this display highly considered.

Adafruit 0.56" 4-Digit 7-Segment Display

Vendor	Adafruit Industries	Features	• 4 7-segment displays • 14.2mm character height • Variety of colors • Easy to use 4-pin header
Manufacturer	Adafruit Industries		
Quantity	1		
Price/Unit	$9.95 (+S&H)		

Table 3.5.5.3

A third option is this Adafruit display. Although the vendor isn't as thorough as Mouser, this display should be very identical to the Kingbright display from Mouser. This one has a white illumination, although many other colors are available, and it has the same character size (14.2mm) as the Kingbright display. The added benefit this display brings is the "easy to use" 4-pin header and the addition of another 7-segment, which isn't a big deal for us since we only require three. The pro for this display is that everything seems to be "plug and play" but the con is the relatively high price. The first option is simply too small for its price. And while the third option is tempting with its choice of color and "ease of use", the second option, the Kingbright 7-segment display is the one we'll be using, simply because of its relatively cheaper price and technical backing of Mouser.

3.5.6 Kill Switch

The kill switch offers the user a means of power control and also for system shutdown in case of an emergency. Concerns stemming from coil getting too hot or a pet stuck underneath the car can be quickly resolved by simply pushing the kill switch. This action disengages the AC mains from the power supply, thus shutting down the entire system. The switch also offers a sense of user intervention in case of a malfunction, since all aspects of the charging system are automated.

<u>DPST Push Button Switch</u>

Vendor	Amazon	Features	• Voltage: 660V AC Max • Current: 10A • Latching action • Double pole • Hole mounted
Manufacturer	Amico		
Quantity	1		
Price/Unit	$5.38 (+S&H)		

Table 3.5.6.1

3.5.7 Fan

The control panel houses a few devices that generate heat and since it will be a closed box under normal operation, provisions must be made to dissipate as much of the heat produced as possible. The box will have vent holes cut in the sides and some of the devices will be mounted to heat sinks. However, to ensure the safe operation of our charging system we are taking the cooling a step further by adding a cooling fan. The fan is mounted to one side of the box and extracts hot air by blowing it out from the box. At the same time cool air rushes in from the opposite side and passes over the circuit components keeping them cool. As soon as the charging system is activated the fan spins at a constant RPM and remains on for the duration of charging. This cheap and simple fan from NewEgg can serve our purpose.

Cooling Fan (EC8010LL05E)

Vendor	NewEgg	Features	• Voltage: 5 VDC • Current: 0.26 AMP • 80 x 80 x 10 mm • 2000 RPM • High air flow
Manufacturer	Evercool		
Quantity	1		
Price/Unit	$9.99 (+S&H)		

Table 3.5.7.1

3.5.8 Power Supply

The Power Distribution system which is located inside of the control panel comprises of a number of ICs and diodes listed in Table 3.5.8.1. The transformer is a step down type which converts the AC mains to $18V_{rms}$ which is then rectified by a bridge rectifier made up of four 1N4007 diodes. It is important to note that parts of the power distribution system will be duplicated to power the devices on the car. This includes the 5V, 3.3V and 1.8V sections only. See section 4.2 for further details on the design of the power management system.

The LM338K IC is a 12V regulator that will produce a constant 12V output and is configured to produce a high output current to power the rest of the devices in the charging system. The LM7805 is a 5V voltage regulator that takes a 12V input from the output of the 12V section. The LM3940 is a 3.3V voltage regulator that takes its input from the 5V section. Finally we have a 1.8V section that is regulated by an LN59018M voltage regulator and gets its input from the 3.3V section.

The transformer will be an integral part of the power supply circuit. We have to ensure that the output power of the transformer is sufficient to power all the devices and circuitry within the control panel and most importantly the oscillator circuitry which will be supplying the high frequency power to the ground coil. The transformer listed below in Table 3.5.8.2 is capable of producing a maximum secondary current of 5A and from a design standpoint this is sufficient power. The transformer is made with a double bobbin design therefore no electrostatic shield is required. It is also UL listed with a Hi-Pot test of 2000V RMS. The open style, channel bracket has two holes which allows for easy mounting to either the control panel or the circuit board.

Table 3.5.8.1 – Power Distributor Components List

Component	Vendor	Manufacturer	Quantity	Cost per unit
LM338K	Mouser	STMicroelectronics	1	$9.53 (+S&H)
LM7812	Mouser	Fairchild Semiconductors	1	$0.71 (+S&H)
50SQ080	Mouser	Vishay	8	$3.34 (+S&H)
LM7805	Mouser	Fairchild Semiconductors	2	$0.69 (+S&H)
LM3940	Mouser	Texas Instruments	2	$1.81 (+S&H)
LV59018M	DigiKey	ON Semiconductor	2	$0.37 (+S&H)
1N4007	Mouser	Fairchild Semiconductor	2	$0.14 (+S&H)

<u>Transformer (166P18)</u>

Vendor	Allied Electronics	Features	• AC input 115V AC • AC output 18V AC • Sec current: 5A • Class B insulation • UL Listed
Manufacturer	Hammond Manufacturing		
Quantity	1		
Price/Unit	$30.64 (+S&H)		

Table 3.5.8.2

3.5.9 Charge Controller

We will need a charge controller to help protect our battery from overcharging. The reason for the charge controller is to help our battery have better performance and also a longer lifespan by preventing overvoltage. Overvoltage causes poor performance in battery and also hurts the battery's lifespan. Preventing the battery from overcharging can also prevent safety issues; in our project we don't want our battery to fail so using a charge controller will help us eliminate that problem.

For a car charge controller for a 12V battery we found to be the simplest and a viable design for our project because it's designed mainly for car batteries and also has few components. The circuit has BTY79 which is made up of a 10A silicon-controlled rectifier with an operational temperature range from 0C to 125C. For consumers with high volume applications like light, speed control, temperature, and warning systems that have important operations, this circuit provides a function that has reverse-blocking thyristors designed for such consumers; this function is made from a 4A sensitivity gate silicon-controlled rectifier. Another charge controller we found is meant for a solar panel, and can handle upwards of 10A. This charge controller is going to serve as a medium power DC current switch between the positive terminals of the resonance charge system and the battery system. The high efficiency and reliability of this 10A charge controller makes is a unique current regulator. The best part of this circuit is its variable design for 6V, 12V, or 24V batteries. The table below outlines important components of the two designs that are up for consideration.

Table 3.5.9.1 – Charge Controller Components List

Component	Vendor	Manufacturer	Quantity	Cost per unit
Trimmer VR	eBay	ThaiShine USA	1	$0.30 (+S&H)
C106DG	Tayda	ON Semiconductor	1	$0.20 (+S&H)
S4006DRP	Mouser	Littelfuse	1	$1.00 (+S&H)
GBU6A	Mouser	Fairchild Semiconductors	1	$1.04 (+S&H)
TLC2272CP	Mouser	Texas Instruments	1	$2.09 (+S&H)
2N3906	Mouser	Central Semiconductor	1	$0.36 (+S&H)

3.5.10 Vehicle and Battery

Our goal in regards to choosing a test vehicle is to acquire a PowerWheels and its battery/charger. This is supposed to be a small-scale test, to show that the idea and logic work. Another option is a golf cart, or go-cart, but our budget right now calls for something a lot cheaper and easy to obtain, so our designs will be for a PowerWheels vehicle and battery. Looking through Fischer-Price's website, they have numerous kinds of PowerWheels ranging from baby-sized to 2-passenger toddler-sized, and rightfully priced so ($85 to $400+). Our ideal PowerWheels would be a toddler-sized one, preferably a Jeep model, so it can surely hold our car coil and have enough ground clearance, although everything can be "adjusted by force" if need be. I also found five products that are important to note in Table 3.5.10.1 from their site. As you can see they are very expensive vehicles and batteries, so buying directly from the site or store for a new PowerWheels is not a viable option.

Table 3.5.10.1 - Batteries and Chargers from Fischer-Price

Product	Type	Cost
Single Battery Toddler 6V Charger	6V Charger	$22.00 (+S&H)
12V Charger	12V Charger	$45.00 (+S&H)
Toddler 6V Rechargeable Battery	6V Battery	$45.00 (+S&H)
6V Rechargeable Battery	6V Battery	$45.00 (+S&H)
12V Rechargeable Battery	12V Battery	$70.00 (+S&H)

We have to look to other sources to find a PowerWheels we want. Good news for us because at the time of parts acquisition, it will be the holiday season, and hopefully parents will be buying new toys for their children and selling unwanted, used ones (PowerWheels included). When we decide to acquire parts, we will be looking at various internet-based vendors and classifieds. We will be looking through Craigslist, eBay, Amazon, and Reddit if need be. Our goal is to not spend more than $100 for both the vehicle and charger, and we will be deciding on our purchase together. Right now our designs rely on a 6V vehicle battery, but if we end up acquiring a 12V, we can alter the designs. If a vendor states that battery is damaged or doesn't come with it, we may also look at just purchasing an additional battery.

3.5.11 Temperature Sensor

There are mainly four types of temperature sensors used in modern technology: thermocouples, thermistors, RTDs, and infrared temperature sensors. A thermocouple can measure a huge range of temperatures, and are inexpensive and reliable. Thermistors and RTDs are identical to thermocouples, except they are used for more precise measurements. The infrared temperature sensor can have a variable range and uses the thermal energy from an object's wavelength to convert into signal for temperature; therefore it's touch-free. We would ideally want either a touching sensor, that is attached to the battery physically, or an infrared sensor, that is mounted close to the battery at the point where we want to measure its temperature. We will also be using a temperature sensor to make sure the metal box of the ground system doesn't overheat.

<u>GE Sensing ZTP-115</u>

Vendor	DigiKey	Features	• Infrared Sensor • -20C to 100C range • High Sensitivity • Very small
Manufacturer	GE Sensing		
Quantity	2		
Price/Unit	$3.82 (+S&H)		

Table 3.5.11.1

This infrared temperature sensor is packaged into a small bottle-cap shaped package with the infrared sensor at the top (diameter is 9.25mm and the height is 3.5mm, not including pin length). Four pins (two grounds) extend at the bottom for connection. This sensor is quite ideal for our setup, considering its precise range, high sensitivity, cheap cost, small size, and as an added luxury, non-touching setup. The sensor outputs voltage based on the object temperature, as shown in Figure 3.5.11.1. However, this is but one small piece in a larger circuit required to get the temperature.

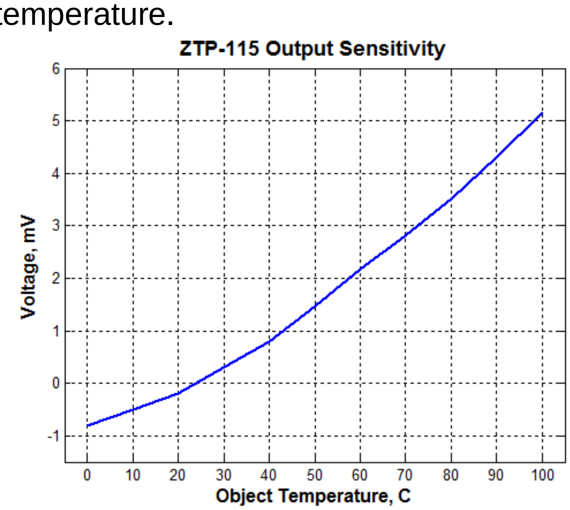

Figure 3.5.11.1 – ZTP-115 Output Sensitivity

Thermistor Sensor Surface-Mount Stick-On (SA1-TH-44000 Series)

Vendor	Omega	Features	• Touching Sensor
Manufacturer	Omega		• -80C to 120C range
Quantity	2		• Re-applicable
Price/Unit	$44.00 (+S&H)		• Long cable

Table 3.5.11.2

This is an alternative approach for temperature sensing, a touching sensor. This sensor uses a thermistor. Installation requires peeling off a strip on the thermistor and applying it to the dry solid surface you want to measure, in our case the battery. The thermistor strip itself measures 19mm by 25mm and about 1mm thick, attached to a two-pronged meter-long wire (ground and output). This setup is easy to integrate into the car system, due to the cable length, but the price is very off-putting. If we can find a similar touching sensor locally for cheaper we may use that, but as of right now an infrared temperature sensor is what we want.

GE Sensing ZTP-115M

Vendor	Mouser	Features	• Infrared Sensor
Manufacturer	GE Sensing		• -20C to 100C range
Quantity	2		• High Sensitivity
Price/Unit	$11.88 (+S&H)		• Easy setup

Table 3.5.11.3

This brings us to the ZTP-115M. Just like the other GE sensor, this is the module version of the ZTP-115, meaning that all the internal circuitry finds the corresponding temperature sensor as analog V_{out}. This part has the exact same specifications as the ZTP-115, since it uses it, so Figure 3.5.11.1 applies to this part too. The extra cost is for the ease of use and integration. It is most likely we'll be using this part, unless we decide to construct the thermo circuit ourselves. It's still much cheaper than the stick-on thermistor.

3.5.12 Microcontroller

We will need two microcontrollers--one for each main system--to drive the data through and make everything work as intended. The requirements are quite simple for both microcontrollers, so we will save time and energy and get two of the same. The car system microcontroller will only be obtaining data from its two sensors (temperature and battery charge status) and processing them into an understandable form, then finally sending it to its Bluetooth module. The Bluetooth module will then send the data to the ground system's Bluetooth module, which will send it to the ground system's microcontroller. The ground system's microcontroller will be taking this data and processing it to display the data onto the LED displays and to allow/disallow the charging unit to send current through the coil. We do not think we will need heavy processing microcontrollers.

Atmel ATMEGA32A-PU

Vendor	Mouser Electronics	Features	• 8bit, 32kB memory
Manufacturer	Atmel		• 32 pins
Quantity	1		• 2-Wire, SPI, USART
Price/Unit	$3.76 (+S&H)		• 2.7V - 5.5V supply

Table 3.5.12.1

This 8bit microcontroller seems to be the most simple and most ideal for our uses. It has 32kB of programmable memory, operates between 2.7V and 5.5V, and has appropriate operating temperatures. Having 32 programmable I/Os is ideal for the ground system microcontroller due to the possible large amount of pins required for the display. It uses USART for interfacing and is programmable through Atmel Studio 6 obtainable from Atmel's website. This part is definitely on top of our list in regards to microcontrollers because we already have one and have experience with how to use it. We have an Arduino board that comes with an ATMEGA32A that we were playing around with to get a feel for embedded programming. Since we can just pop out the microcontroller from the Arduino board, we can just buy one more to satisfy our microcontroller needs.

TI 595-MSP420F5529IPN

Vendor	Mouser Electronics	Features	• 16bit, 128kB memory • 63 pins • I2C, IrDA, SPI, UART • 1.8V - 3.5V supply
Manufacturer	Texas Instruments		
Quantity	0		
Price/Unit	$8.05 (+S&H)		

Table 3.5.12.2

This familiar Texas Instrument 16bit microcontroller is the one we used extensively in our Embedded Systems class through the MSP430 Launch board. It has 128kB of programmable memory, operates between 1.8V and 3.5V (ultra-low power), and has appropriate operating temperatures like the ATMEGA. This microcontroller has 63 programmable I/Os, which supports the phrase "It's better to have it and not need it than to need it and not have it." With this many pins we would definitely not have to worry about any amount of LED wiring problems for the displays. It uses UART for interfacing and is programmable through TI Code Composer. Just like the Atmel ATMEGA, this TI MSP430 is a very good choice. If we can find our old Launch boards, we would be able to use those microcontrollers by taking it off the Launch boards and putting it in our own printed circuit board; it means we wouldn't have to buy any! On the other hand, if we can't safely remove the chip, we'll just have to buy two (it is significantly more expensive than the ATMEGA). All of us have substantial experience with TI Code Composer and programming the MSP430 through that class and lab, so it's definitely a plus.

Atmel ATXMEGA32A4U-AU

Vendor	Mouser Electronics	Features	• 8/16bit, 32kB memory • 34 pins • I2C, SPI, UART • 1.6V - 3.5V supply
Manufacturer	Atmel		
Quantity	2		
Price/Unit	$4.13 (+S&H)		

Table 3.5.12.2

This Atmel 8bit/16bit microcontroller combines the ATMEGA and the MSP430 in certain aspects. The ATXMEGA has two different versions, an 8bit or 16bit (pricing is for 8bit), but we only really need 8bit. It has ultra-low power consumption like and uses UART just like the MSP430, although it is programmed in Atmel Studio 6. It has 32kB of programmable memory and 34 programmable I/Os. This microcontroller option is like meeting in the middle relative to the first two options. This could be viable, although we would definitely need to purchase both since we have none, unlike the first two. This is the solution to compromise, and it's great to have the best of both worlds. The ATXMEGA32A4U is our choice for microcontrollers.

3.5.13 Bluetooth

Two Bluetooth modules will be needed for the project; one will be mounted on the ground system microcontroller and the order will be mounted on the car system. The car system module will collect data from the microcontroller mounted on the car system then transfer that data to the ground system; vice versa. We researched into multiple Bluetooth modules in order to get the right module that we needed for the project.

<u>CC2540 RHAT</u>

Vendor	Mouser Electronics	Features	• 2V - 3.5V supply • 22.1mA receiving • 31.6mA transmitting • -40°C to 40°C • 2.4 GHz Frequency
Manufacturer	Texas Instrument		
Quantity	2		
Price/Unit	$6.58 (+S&H)		

Table 3.5.13.1

This 8bit, 2.4GHz, CC2450 processor Bluetooth module is a low power System-On-Chip solution for low energy Bluetooth applications. It has other powerful supporting features like 128 or 258KB flash memory combine with an excellent RF transceiver with an industry-standard enhanced 8051 MCU and an in-system programmable flash memory.

<u>RN41-XV Bluetooth Module</u>

Vendor	Karlsson Robotics	Features	• 3V - 3.5V supply • 35mA receiving • 65mA transmitting • -40°C to 85°C • 2.4 GHz Frequency
Manufacturer	Roving Networks		
Quantity	2		
Price/Unit	$29.95 (+S&H)		

Table 3.5.13.2

This RN41XV has a 79 channel at 1MHz intervals with 128 bit encryption of secure communications. This Bluetooth can also be configured through local UART and over-the- air RF. Although this RN41 module is a little above our budget range rang it looks like a good choice for our projected because of it 100 meters range, 16dBm output transmitter and the -80dBm receive sensitivity. It also has a RR transmission power of less than 4dBm and an initial carrier frequency tolerance of 75 KHz. One feature that makes this Bluetooth module unit is the reset circuit that a reset pin which has an optional power-on-reset delay that helps to protect the module is there is uncertain or unstable power up or when there is a very slow ramp in the input power supply.

BC04-B Bluetooth Module

Vendor	Alibaba	Features	• 3V - 3.5V supply • 10mA receiving • 20mA transmitting • -40°C to 75°C • 2.4 GHz Frequency
Manufacturer	LM Technologies		
Quantity	2		
Price/Unit	$14.95 (+S&H)		

Table 3.5.13.3

BCO4-B master-slave Bluetooth module is a Class 1, low cost and small size Bluetooth module that does not support only UART but also USB, PCM, SPDIF interface and SPP Bluetooth serial protocol. This feature makes it the ideal Bluetooth for our project. It has a very good short range wireless data transmission field which will be perfect for your short range data transfer between the two modules that will be mounted on the ground system microcontroller and the car system microcontroller.

ENW-89841A3KF

Vendor	Mouser	Features	• 1.7V - 4.8V supply • 1278 kbps Data rate • 10.5dBm Output Power • -40°C to 85°C • 2.4 GHz Frequency
Manufacturer	Panasonic		
Quantity	2		
Price/Unit	$13.45 (+S&H)		

Table 3.5.13.3

Although this PAN1322 is a bit pricy compare to some other module it can also so be useful to our project, because it has an inbuilt antenna to will help in data transfer between the Bluetooth modules and also and embedded microcontroller, Bluetooth 2.1+EDR stack, serial port profile (SPP), AT command set API, and ARM 7 core with a Bluetooth controller.

BL600 Series

Vendor	Mouser	Features	• 1.8V - 3.5V supply • 1Mbps Data rate • 10.5dBm Output Power • -40°C to 85°C • 2.4 GHz Frequency
Manufacturer	Laird Technologies		
Quantity	2		
Price/Unit	$13.30 (+S&H)		

Table 3.5.13.4

BL600 Series has a total of 28 lines for host interface and this line are all multifunctional; it is compatible not only with UART but also with GPIO, SPI, I2C and ADC. It has 128 bit of AES encryption with a link Budget of 95dB; among all the features on this BL600 series module, its use of *Smart*Basic is what makes it a unique Bluetooth module. *Smart*Basic is an event-driven programming language that enables standalone operation of the module while a sensor can be attached to any of interface without the need for and external processor. The unique feature can help us modify our sensor connectivity if needed without any interference.

TiWi-uB2

Vendor	Mouser	Features	• 2.2V - 4.8V supply • 4Mbps Data rate • 10dBm Output Power • -30°C to +85°C • 2.4 GHz Frequency
Manufacturer	LS Research		
Quantity	2		
Price/Unit	$8.99 (+S&H)		

Table 3.5.13.5

This Bluetooth module is the best one out of all the ones we researched; it is the least expensive and the easiest to be connected to a microcontroller. It has a SIP module that provides UART interface and audio PCM interface for Bluetooth. This Bluetooth is specifically made for smart phones and portable devices.

3.5.14 Coils

A ground coil and a car coil will be used as the energy transfer medium since there will be no physical contact between the car and charging system. These coils will be handmade into the desired form based on the turns ratio calculated. Copper will most likely be the material of choice for the coils. According to our research, we can use solid copper wire, copper tubing, Litz wire or even Aluminum to make good quality coils capable producing the needed magnetic field. We are estimating that this design will require between 9 to 18 turns of the coil material with a maximum outside diameter of one and a half feet. This brings us to a rough estimate of 50 ft. of conductor. Of course, material availability will dictate the size of the coil.

<u>10 AWG Solid Copper Conductor</u>

Vendor	eBay	Features	• Excellent conductivity
Manufacturer	n/a		• Easily terminated
Quantity	50 ft		• Easy to shape
Price/Unit	$19.95 (+S&H)		

Table 3.5.14.1

The solid copper conductor is great for making coils, in fact most coils in everyday electronics is made from it due to its excellent electrical conducting properties. We are most likely going to use solid copper.

<u>3/8 dia. Copper Tubing</u>

Vendor	eBay	Features	• Excellent conductivity
Manufacturer	n/a		• Easily terminated
Quantity	50 ft		• Easy desired shape
Price/Unit	$65.99 (+S&H)		

Table 3.5.14.2

Copper tubing is mostly used for applications such as gas piping or in the HVAC uses, however, due to the properties as mentioned before it can be an excellent candidate for making the coils needed for the design.

Litz Wire

Vendor	eBay	Features	• Excellent conductivity • Very flexible • Easy to shape
Manufacturer	n/a		
Quantity	50 ft		
Price/Unit	$38.00 (+S&H)		

Table 3.5.14.3

Litz wire is a type of cable used to carry alternating current in electronics. This wire is designed to reduce the skin effect and proximity effect losses at up to about 1MHz. This would be great for making our coils since we would like our system to be as efficient as possible. The cable consists of many thin wire strands, individually insulated and twisted or woven together in a specific pattern. It is expensive but it is our best option because it reduces losses which is ideally what we want.

Aluminium

Vendor	eBay	Features	• Excellent conductivity • Very flexible • Easy to shape
Manufacturer	n/a		
Quantity	39 ft		
Price/Unit	$9.01 (+S&H)		

Table 3.5.14.4

Aluminum being used as a coil is not uncommon in electronics. However coils wound with aluminum have similar losses and performance as copper coils. Aluminum wire requires approximately 1.6 times as much cross section as copper to carry an equivalent amount of current. Therefore Aluminum wound coils are larger than an equivalent copper coil. Applications such as our design require very tight dimensions and generally require copper coils.

3.5.15 Oscillator

The word oscillator and resonator may be used interchangeably for our purposes. In our design the oscillator is used generate the resonant frequency of the ground coil and capacitor tank circuit. The LC circuit created by the ground coil and its corresponding capacitor has one degree of freedom and therefore has one resonant frequency. The term resonator most often refers to the use of a homogenous object in which vibrations travel as waves at an approximately constant velocity, bouncing back and forth between the sides of the resonator. To understand further how resonators operate, consider the distance between the sides as being separated by a distance "d", the length of a round trip is 2d. To cause resonance, the phase of a sinusoidal wave after a round trip must be equal to the initial phase so the waves self-reinforce. These waves take a much longer time to die out and this is why this method of wireless energy transfer has a higher efficiency. See circuit in Figure 4.2.1 for the circuit diagram for the oscillator that will be used in this design.

We chose this circuit because of its simple design and its ability to produce the output signal that is needed. The main components of this oscillator circuit are listed below in Table 3.5.15.1 along with the associated costs.

Table 3.5.15.1 – Oscillator Components List

Component	Vendor	Manufacturer	Quantity	Cost per unit
1N4740A	Mouser	Fairchild Semiconductors	2	$0.23 (+S&H)
BYV26E	Mouser	Vishay Semiconductors	2	$0.66 (+S&H)
IRF2807	Mouser	International Rectifier	2	$2.81 (+S&H)
LM7812	Mouser	Fairchild Semiconductors	1	$0.71 (+S&H)

3.5.16 Conduit and Mounting Apparatus

The conduit will be used to securely channel the wire from the control panel to the ground coil. There are a number of different types of electric conduit each of which has its advantages and disadvantages. The non-metallic flexible conduit was chosen because it is one of the easiest to use. These conduits are also widely used because there is no need to use specialized tools to bend or form the conduit into the right angles for bends.

<u>Non-Metallic Conduit</u>

Vendor	Home Depot	Features	• Material: Nylon • Size: ½ inch • Liquid tight • Rugged • Color gray • UL Listed
Manufacturer	AFC Cable Systems		
Quantity	25 ft		
Price/Unit	$ 9.99		
Part Number	88131257		

Table 3.5.16.1

Figure 3.5.16.1

Figure 3.5.16.1 shows what the flexible conduit looks like. The only problem with flexible non-metallic electric conduit is that it may not be as strong as regular conduit, but for our purposes, it works well. The connector is used to connect one end of the conduit to the metal box and also to connect the other end of the cable to the double gang electrical outlet box attached to the ground coil. Figure 3.5.16.2 shows what the connectors look like. These connectors offer watertight protection which makes it difficult for moisture to enter the conduit and cause corrosion. The connector itself is made with nylon and will not rust or corrode. No disassembly is required when using these types of connectors, just simply insert the conduit and hand tighten the nut.

Halex 1/2 in. Liquid Tight Connector

Vendor	Home Depot	Features	• Material: Nylon • Size: ½ inch • Liquid tight • Rugged • Color gray • UL Listed
Manufacturer	Carlon		
Quantity	2		
Price/Unit	$ 1.42		
Part Number	76205B		

Table 3.5.16.2

Figure 3.5.16.2

The clamp is used to strap the conduit to the wall and also to the floor. The simple design makes it easy to install and it keeps the cable in place. Figure 3.5.16.3 shows what the flexible conduit looks like. Each clamp fits securely over the conduit and takes two screws.

1/2 in. PVC Conduit Clamps

Vendor	Home Depot	Features	• Material: Nylon • Size: ½ inch • Liquid tight • Rugged • Color gray • UL Listed
Manufacturer	Carlon		
Quantity	5		
Price/Unit	$ 0.68		
Part Number	E977DC-CTN		

Table 3.5.16.3

Figure 3.5.16.3

2 Gang Weatherproof Electrical Outlet Box and cover

Vendor	Home Depot	Features	• Material: Aluminum
Manufacturer	Greenfield		• Corrosion resistant
Quantity	1		• Liquid tight
Price/Unit	$ 10.54		• Rugged
Part Number - box	B232PS		• Color gray
Part Number - cover	CB2PS		• UL Listed

Table 3.5.16.4

Figure 3.5.16.4

The double gang box will be partially submerged into the fiber glass casing of the ground coil. This box also houses the capacitor for the ground coil tank circuit and the necessary connections. Figure 3.5.16.4 shows what the flexible conduit looks like. The cover provides a water tight seal to prevent moisture from getting to the connections and causing corrosion.

4 Hardware/Software Design Detail

Perhaps the most important section in this report, this section is devoted to the design of our hardware and software components for our prototype. After looking through our research and we've come up with ideas and designs for our subsystems, starting with an Initial Design for the overall system. Then we will look into each subsystem for specifics. The terms GS and CS stand for Ground System and Car System, respectively, and they will be used interchangeably in this section.

4.1 Initial Design Architecture and Related Diagrams

Charge Spot is designed to be a hands-free, charging system that is intelligent enough to detect and charge an electric vehicle to full capacity. Figure 4.1.1 shows a basic outline of the design. As depicted in the figure, a metal box housing the ground system components is mounted to the wall of the user's garage and two connections are attached to the box. One of the connections carries the AC mains into the unit's power supply while the other connection is used for connecting the ground coil to the oscillator. The control panel and the ground coil is all that the user will see as far as hardware, the rest of the system will be embedded in the car and the control panel.

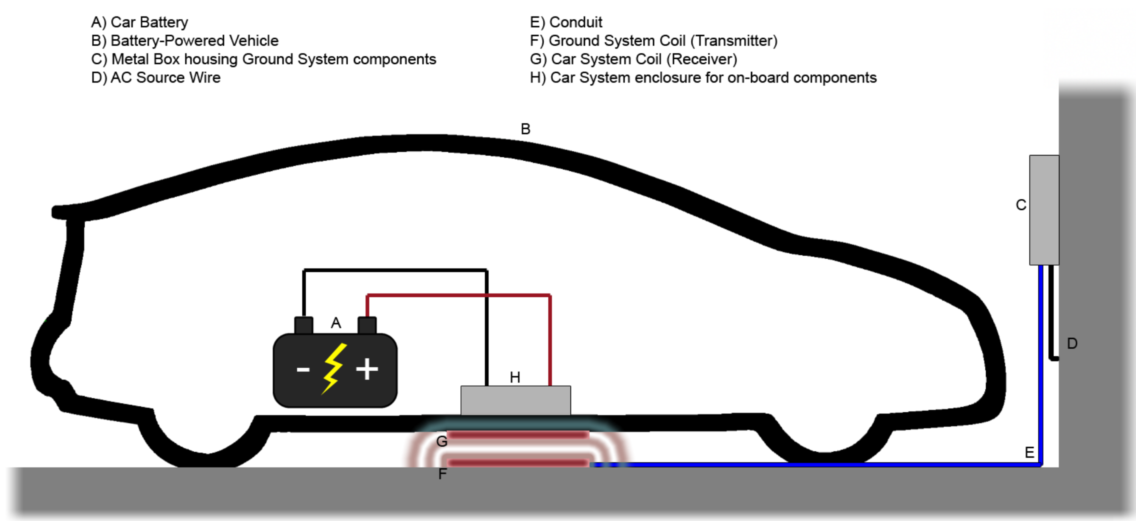

Figure 4.1.1 – Basic outline of Charging System

The cover of the control panel has led displays which indicate the battery percentage of charge as well as the temperature of the battery being charged. The LED display is also used to guide the user into position for proper alignment before charging is initiated.

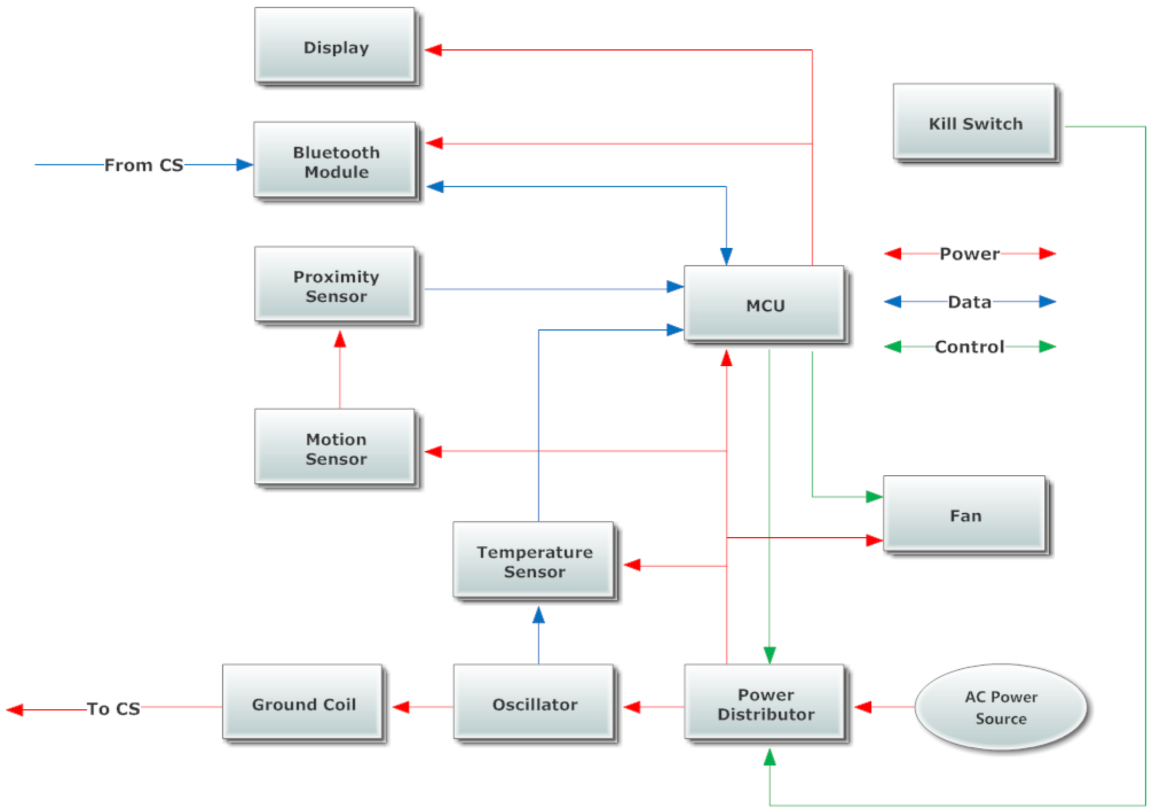

Figure 4.1.2 – Block Diagram for Ground System

Figure 4.1.2 shows the ground system's block diagram, with power, data, and control flows. From the AC power source (120V 60Hz) the power will go into the power distributor which will provide power for both the oscillator and the ground system components (5V). The motion sensor will act as a switch and sends power to the proximity sensor only if motion is detected. By implementing this configuration power is saved, since only the motion sensor will be on all the time instead of the proximity sensor. The MCU will collect data from the Bluetooth module (from the car system), proximity sensor, and temperature sensor. Certain data is displayed to the LED bar and 7-segment displays. Depending on temperature of ground system and battery (from Bluetooth), the MCU will shut down the oscillator from the power distribution side, or alternatively, directly from the oscillator. A fan will also be turned on to control temperature is conditions are too hot. Finally a kill switch, for emergencies, will be able to shut down all power from the source.

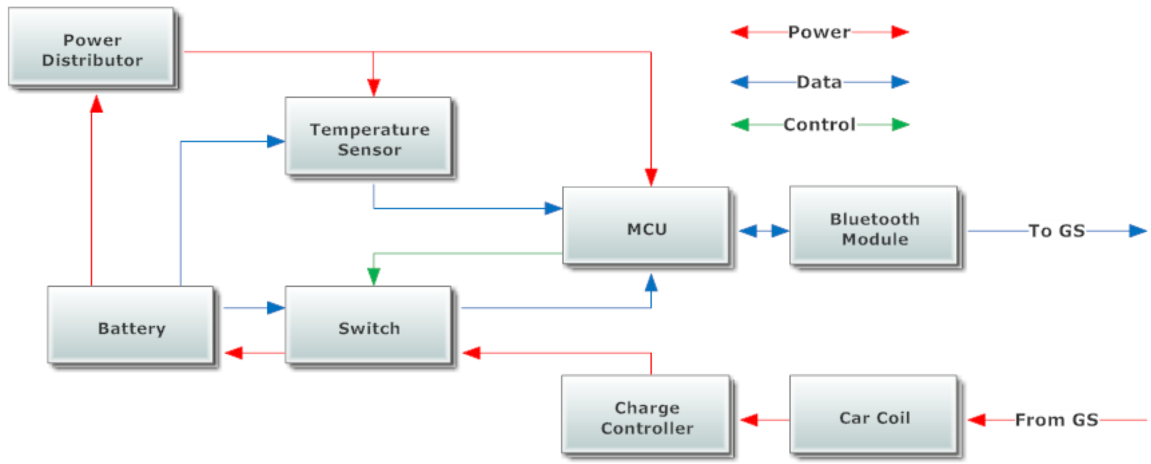

Figure 4.1.3 – Block Diagram for Car System

The car system's block diagram is shown here in Figure 4.1.3. The car system components are powered from the power distributor, which gets its power from the battery itself. To charge, power is taken wirelessly from the ground coil to the car coil and taken into the charge controller. The MCU will have to control when the battery is connected to the MCU or the charge controller via a switch (e.g. DPDT). An alternative design would include the switch with the charge controller, and the voltage of the battery can be directly accessed from the charge controller. Once the MCU gathers the voltage and temperature data, it sends it to the Bluetooth module to be sent to the ground system.

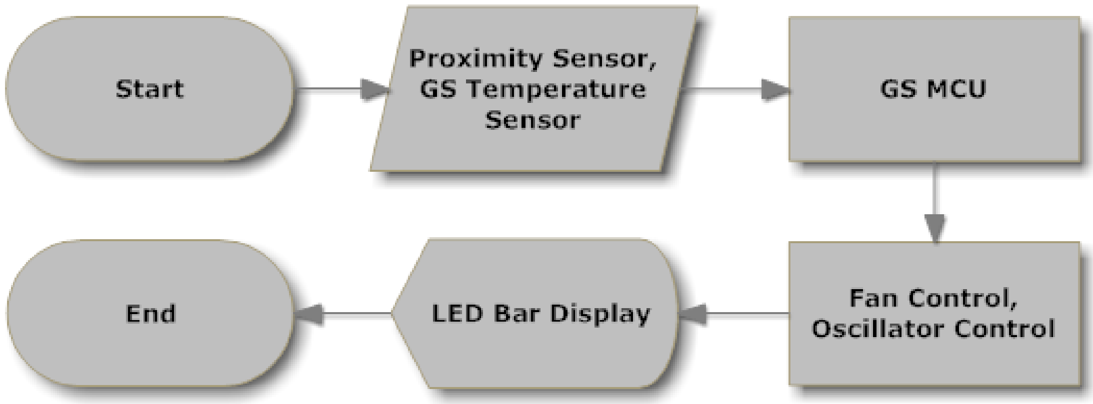

Figure 4.1.4 - GS Data flow

As a vehicle activates the proximity sensor and Bluetooth sensor, the GS MCU reads and displays the proximity to the LED bar display and at the same time monitor the metal box temperature to prevent overheating. Once certain conditions are met, the MCU will be able to turn on/off the fan and oscillator (which will start the wireless charging through the coils). This is illustrated in Figure 4.1.4 as a simple flow diagram. Upon successful Bluetooth pairing, the battery status and temperature information is sent from the car to the control panel wirelessly via Bluetooth. Figure 4.1.5 shows how this data is handled until it gets to the control panel's LED display. After preset parameters for battery temperature are met and battery status is determined to be less than 100%, the charging system is activated and the car battery will be charged with the high resonance frequency charging system. Battery status is monitored and continually displayed on the face of the control panel along with battery temperature. When fully charged the charging system is designed to shut down automatically while keeping the displays active.

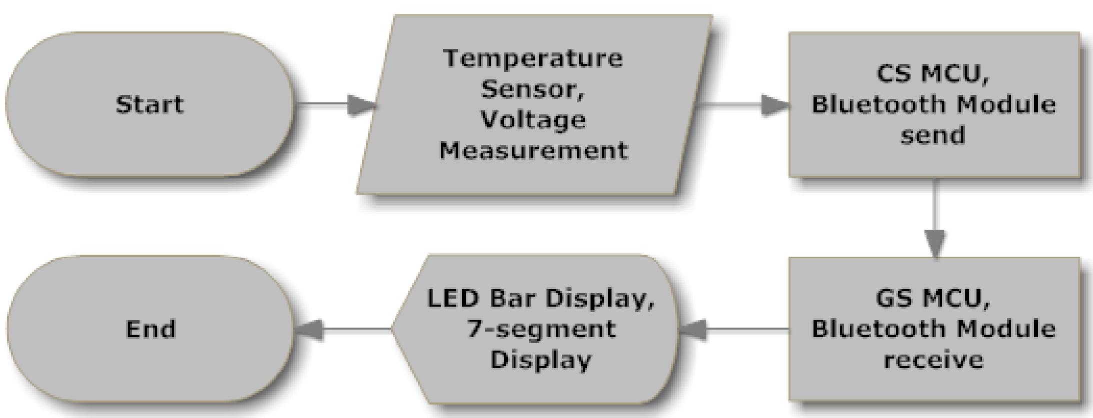

Figure 4.1.5 – CS to GS Data flow

4.2 Power Management

The power supply for the entire charging system will be located inside the control panel of the ground system. After acquiring the transformer of suitable power rating, the power distribution circuit must be designed such that the correct voltage is seen by each device requiring power. This circuit is simply a series of voltage regulator circuits beginning with a 12 V regulated output voltage. The 12V/5A output circuit is shown below in Figure 4.2.1 and is used primarily to power the oscillator circuit and the rest of the power distribution circuitry.

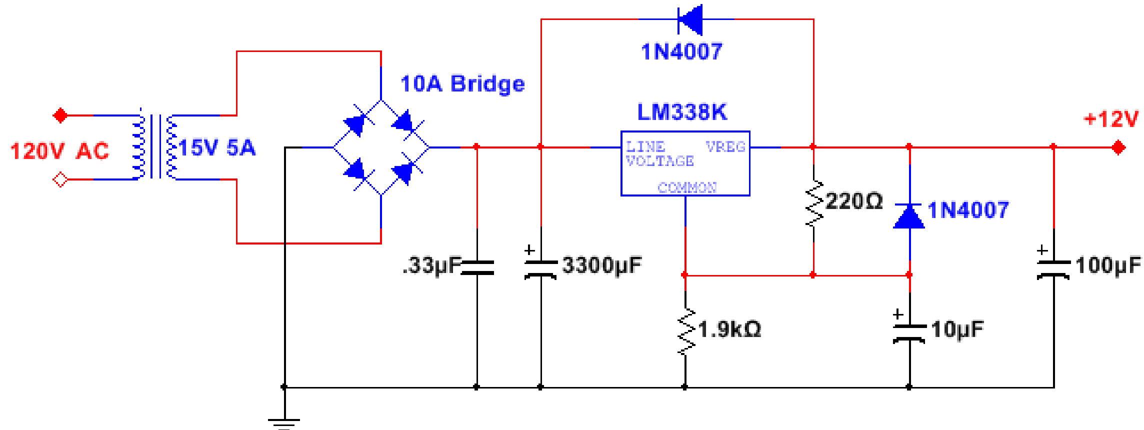

Figure 4.2.1 - 12V/5A Power Supply using LM338 IC

The transformer steps down the AC voltage to $18V_{RMS}$ and the bridge rectifier produces a DC voltage. The Capacitors are used to filter the output signal of the rectifier producing a DC level free of ripples. The 12V/ 5A power supply circuit uses an LM338 IC adjustable voltage regulator IC available with three terminals. This IC also contains many built in features like current limit constant with temperature, thermal regulation, short circuit protection etc. The output voltage of the LM338 is adjustable between 1.2 to 37 volts depending on the circuit's resistor configuration. The circuit we are using in our design is built to deliver a fixed output of 12V at 5 amperes. We are expecting the IC to become hot during the operation and will be using a suitable heat sink to help in dissipating the heat. The temperature inside the control panel will also be cooled by a fan.

For the 5V section of the power supply, it will be getting its input from the output of the 12V section. Therefore a 5V regulated power supply designed with the LM7805 IC will be used for this section. Figure 4.2.2 shows the circuit diagram with the accompanying capacitors for additional filtering of the output voltage signal. The 5V section of the power supply will be powering the sensors, various board components, and the fan.

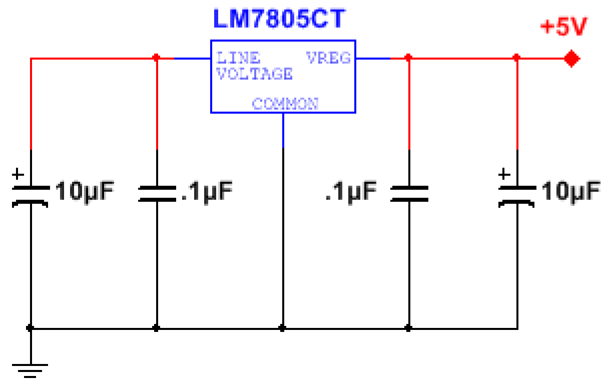

Figure 4.2.2 – 5V Power Supply using LM7805 IC
Input is on the left red line.

We also need a 3.3V output signal to power the microcontroller and Bluetooth module. This section will be getting its input from the output of the 5V section. Figure 2.2.3 shows the circuit diagram of the 3.3V section with the accompanying capacitors for additional filtering of the output voltage signal.

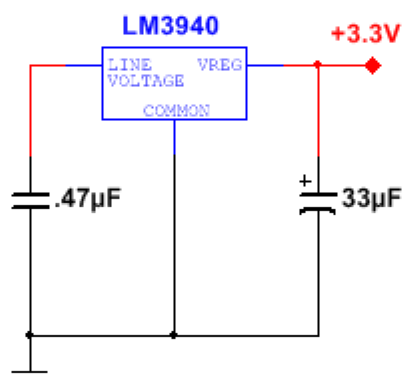

Figure 4.2.3 – 3.3V Power Supply using LM3940 IC
Input is on the left red line.

The LM3940 IC used is a 1A low dropout regulator suited for systems which contain both 5V and 3.3V logic devices. The LM3940 also has the ability to maintain a constant 3.3V output in regulation with input voltages as low as 4.5V. Additionally, in most applications the full 1A of load current can be delivered without using an additional heat sink.

The final section of the power distribution system is to deliver an output voltage of 1.8V which will be used to power the Bluetooth's I/O pins. The input for this section will come from the output of the 3.3V section. Figure 4.2.4 shows the circuit diagram with accompanying capacitors for the 1.8V section. The LV59018M offers a constant 1.8V output with additional features such as over-current protection and thermal protection.

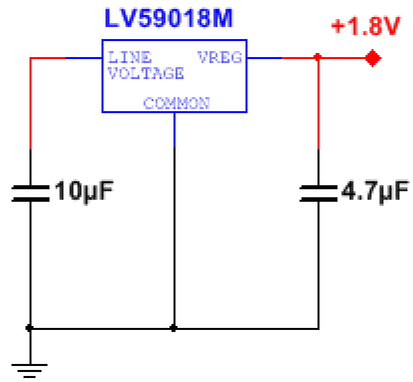

Figure 4.2.4 – 1.8V Power Supply using LV59018M IC
Input is on the left red line.

4.3 MCU Display

All accessible information will be viewable through the ground system MCU display on the metal box. The main data collected (from the car system MCU--temperature and battery charge level) will be sent to the ground system MCU via Bluetooth and processed then sent to be displayed. The display will be mounted into the metal box that will house all the electronics for the ground system. The display will consist of three 7-segment LEDs to display the temperature, eight LED bars to display the proximity status and the charging status, and finally some accessory LEDs that provide further user interfacing and informative data.

Most likely the 7-segment displays and the LED bars will not be on the same printed circuit board as the MCU. Temperature can be read from the 7-segment displays only, with total possible temperature readings ranging from 0°C to 99°C. To the average user, knowing the battery temperature means nothing, because an average user might not know what a good temperature for a battery is. According to Fischer-Price, the optimal operating temperature and charging temperature for their 6V or 12V batteries for their PowerWheels line of toys are the same, ranging between -25°C and 30°C. Since we are performing tests in Florida, we don't have to worry about any temperatures less than 0°C. This can be accommodated by having a fourth 7-segment display to display the negative sign, or even more to accommodate the Fahrenheit scale.

The LED bars can be approached by two ways. We can either obtain eight multi-colored LED bar displays or make each LED bar ourselves, putting the appropriate LED colors in each. If we go with the first option, we are restricted to size, price, and color. If we go with the second option, we are free to make them any size we want, with any range of colors, but the downside is we have to construct them ourselves. Regardless, this display will be mounted above the 7-segment displays. The data that will be fed through the display will involve two sets of information: [Mode 1] the range of the vehicle given the proximity sensor and [Mode 2] the charge level of the batter and status.

In Mode 1, which can also be considered the idle mode, the vehicle is pulling into the driveway, passively activating the Bluetooth via connection between the two systems and thus activating the proximity sensor. The proximity sensor will feed the ground system MCU data and will be processed to the LED bar display as a viewable way to ascertain your distance from the garage wall for the systems to work most efficiently. You will be able to see the LED bar displays and know when exactly you should stop; the displays will act as a distance meter using green as good/go and red as bad/stop (blinking red will indicate that you need to reverse). An example of what we're trying to create can be seen in Figure 4.3.1. The LED bar will fill with green as you approach (4.3.1a), and once you're in the correct position, the last LED bar will fill red (4.3.1b), indicating to stop. If you go over, the LED bars will all fill red and blink (4.3.1c), indicating to back up.

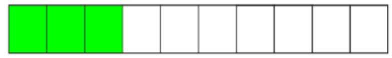

Figure 4.3.1a

Figure 4.3.1b

Figure 4.3.1c

This figure shows 10 bars, but the actual amount is 8 bars.

The modes will transition once the vehicle is in place (satisfying a proximity condition), and upon entering Mode 2, the LED bar displays will turn off. While the modes are transitioning, the car system MCU and ground system MCU are communicating vital information regarding whether or not to charge the battery. Once charging is determined, the LED bar display will light up with information relevant to both the level of charge of the battery and the charge status (charging, not charging). Similar to Figure 4.3.1a, the green will fill up to the nearest 12.5 percent of charge (12.5%, 25%, 37.5%, etc) and blink while charging. Between 87.5% and 100% charge, all bars will be filled green and will blink. Once 100% charge is achieved, all the bars will be a solid green. If the battery is not charging, due to temperature, the LED bars will fill up to the current level of charge with red and blink. For example, 37.5% charge remains on the battery but it is not charging because it is too hot. The display will show the first three bars as a blinking red. If it is fully charged at 100% but the battery is too hot, the display will show eight blinking red bars. As soon as the temperature falls to an optimal value, the display will transition to eight solid green bars. This is also useful to the consumer; since a fully charged battery isn't necessarily going to perform optimally if the temperature is not within a good range, so this setup shows that the battery is both fully charged and is at an optimal temperature. However, if the reason it's not charging isn't due to the battery being out-of-range temperature-wise, the bars will be solid red, indicating there is something wrong with the battery or the systems.

Additional LEDs will be used for further information acquisition by the user. Two LEDs (green and red) will be fixed near the temperature display. As previously stated, the average user might not know what the optimal temperature for their battery is. The two LEDs will help the consumer understand the temperature display by indicating optimal temperature (green) and out-of-range temperature (red). This can be simplified to one green or red LED if necessary, by stating that if the green is on, the temperature is optimal, or the inverse, that if the red is on, the temperature is out-of-range and the system must wait for the battery to cool down. Two more LEDs (of any color) can be used for the LED bar display to physically show what Mode the display is in; we wouldn't want misinformed consumers. An extra LED can be added to show power is being supplied correctly, but this isn't necessary.

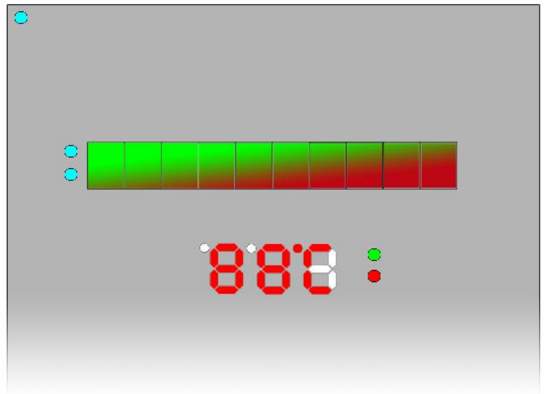

Figure 4.3.2 – Visual example of display setup.
Figure shows 10 bars, but there will actually be 8 bars.

Figure 4.3.2 is an example of what the final metal box will look like. In the top left is the optional power-on LED indicator, which tells the user if power is properly being supplied to the system. The eight LED bars display lies prominently in the middle, as that indicates both proximity and charge level/status, according to the mode it is in, which is further indicated by one of the two LEDs to the left of the bar display. The bar display will have at least two separate colors, preferably green and red. Below the bar display are the three 7-segment displays, arranged upside-down so that the decimal point can be used as a degree symbol (°). The third (farthest right) display will always be C, indicating Celsius. As said before, adding more 7-segment displays can allow us to use Fahrenheit, or even toggle between the two, but the first method is the cheapest and simplest. Finally, the two LEDs on the right of the temperature display are there to indicate optimal temperature or out-of-range temperature. Once again, only one LED indicator is really necessary, and we will most likely only use a red LED to indicate the temperature is out-of-range. All these displays and LEDs will be mounted onto the metal box and the wiring will be connected to the correct boards that will be housed inside the metal box, the core of the ground system.

We've come up with two designs for the LED bar display, both utilizing decoders that reduce pin use from 16 to 7. The first design, seen in Figure 4.3.3, has 4 pins connected to the inputs of the decoder, and 1 pin connected to the control line of the decoder, and 2 pins connected to the control line and clock of the D latches. A second design uses only 5 pins because it sacrifices more control by dismissing the D latches and going straight to the inverters. The purpose of the inverters before the LEDs is to keep only one LED on at a time, stead of all on and only one off at a time. This is because the output of the decoder is inverted, so essentially we are "un-inverting" the signal.

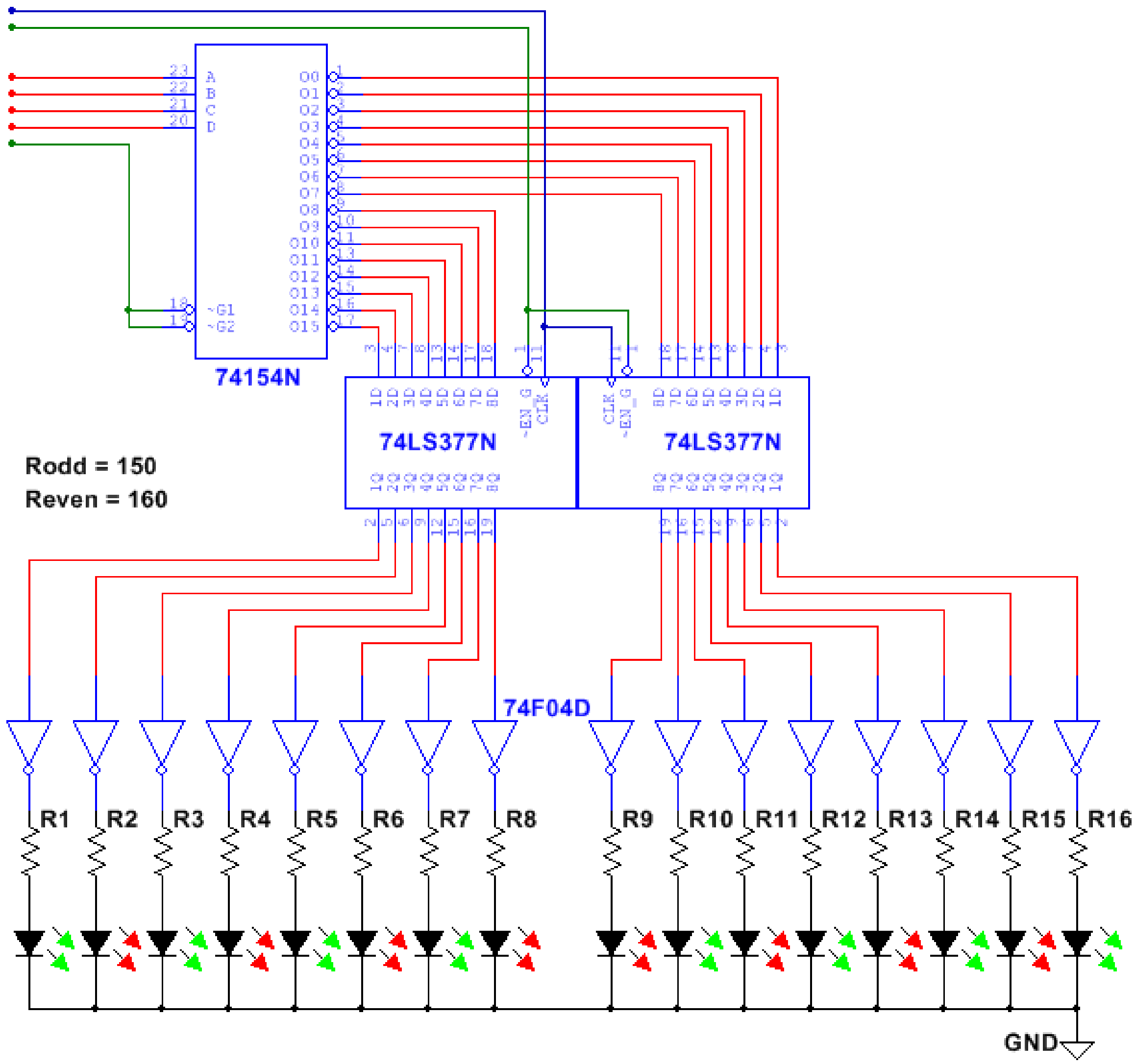

Figure 4.3.3 - LED Bar Display

Table 4.3.1 on the next page illustrates the truth table for the decoder and the corresponding LED that will be turned on. When any LED is on, all others are off; this means there can only be one LED on at any given time. Since the frequency will be too high to notice with human eyes, it will seem as if multiple LEDs are on when applicable. The two pins not listed, EN_G and CLK, only add the ability to set or hold an LED to be kept on. So in the truth table scenario, CLK is alternating at each change and EN_G is digitally grounded.

Table 4.3.1 - LED Bar Display Decoder Truth Table

Pin D	Pin C	Pin B	Pin A	Pin G	LED Status
0	0	0	0	0	LED16 On
0	0	0	1	0	LED15 On
0	0	1	0	0	LED14 On
0	0	1	1	0	LED13 On
0	1	0	0	0	LED12 On
0	1	0	1	0	LED11 On
0	1	1	0	0	LED10 On
0	1	1	1	0	LED9 On
1	0	0	0	0	LED8 On
1	0	0	1	0	LED7 On
1	0	1	0	0	LED6 On
1	0	1	1	0	LED5 On
1	1	0	0	0	LED4 On
1	1	0	1	0	LED3 On
1	1	1	0	0	LED2 On
1	1	1	1	0	LED1 On
X	X	X	X	1	All Off

Each set of LEDs (green/red) will be in each bar, so there will be 8 bars total. The numbered resistors correspond to the LED they are connected to. The odd resistors correspond to green LEDs and the even resistors correspond to the red LEDs; if necessary, they can be rewired to be efficient with the bar placement/wire outs. The resistances 160Ω and 150Ω allow for ~19.8mA of current flow to each LED for brightest and most efficient lighting (for simulated LEDs). There is some disambiguation for the LEDs though. The simulation software sets the red and green LEDs to a preset turn on voltage that can't be easily change. According to Mouser, the green LED we will be using has a turn on voltage of 2.2V and the red LED has a turn on voltage of 2.5V. To get the actual resistance values you need to apply the following equation to each LED:

$$R = \frac{V_{CC} - V_{\gamma}}{I_S}$$

Where V_{CC} is the power supply (5V), V_{γ} is the turn on voltage of the LED (2.2V or 2.5V), and I_S is the steady current for ideal lighting (25mA for these specific LEDs). So the resistance values will be 112Ω for green and 100Ω for red; or 280Ω for green and 250Ω for red if we were doing 10mA for low lighting. The same method can be similarly used for finding the resistance values (if not built-in) for the following design for the 7-segment display.

The 7-segment display has a similar problem as the LED bar display--too many pin inputs. Our chosen component has 12 input pins, detailed in Figure 4.3.3. This is an unnecessarily large amount and we can definitely reduce that. We designed a way to connect the display using only 6 pins. Figure 4.3.4 (next page) shows the design, and is similar to the design of the LED bar display, minus the D latches. The 7-segment display design uses the same 74154N 4:16 decoder, except only 3 pins will be needed, since we're only able to control 8 LEDs on each display (the 7 segments plus the decimal point). The 3 other microcontroller pins attach to the display pins that control which digit of the display is turned on. An alternative design would be to use a 2:4 decoder to use only 2 microcontroller pins instead of 3 (for a total of 5 instead of 6), but since we have the extra pins, we can go with the first design. Pin G isn't considered to be a counted pin (thus making 7) since it can be connected to the previously used Pin G on the other 74154N for the LED bar display as it is a control to essentially turn on or off the decoder, so this 7-segment display only uses 6 microcontroller pins. If you want to be able to turn off the displays separately then you would need that extra Pin G.

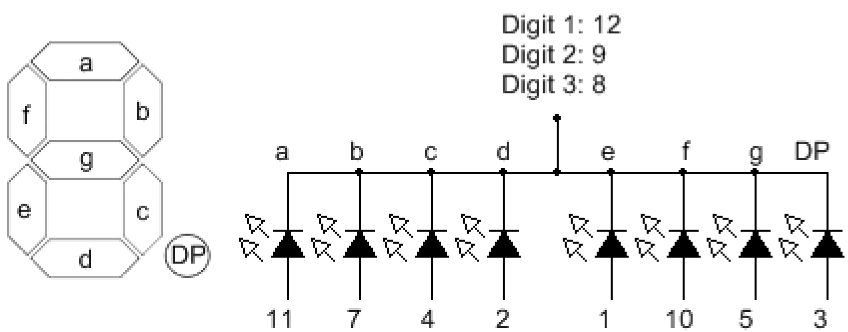

Figure 4.3.3 - Pin layout for 7-segment display. Pin 6 is ground (not shown).

Our simulation software did not have a footprint for our 7-segment display, so we combined 3 displays and made the internal circuitry so that it mimics the actual device. Pin 6, ground, is a hidden pin on the displays. Also, each 74F04D chip contains 6 gates, so we'll need at least 2 chips. However, from the LED bar display, 2 gates are unused on its third chip, so we can have an even 4 chips with all 24 gates being used (16 for LED bar and 8 for 7-segment). Also, in regards to the 7-segment in Figure 4.3.3, they will be upside-down (turned 180 degrees), so that must be taken into consideration when coding the displays.

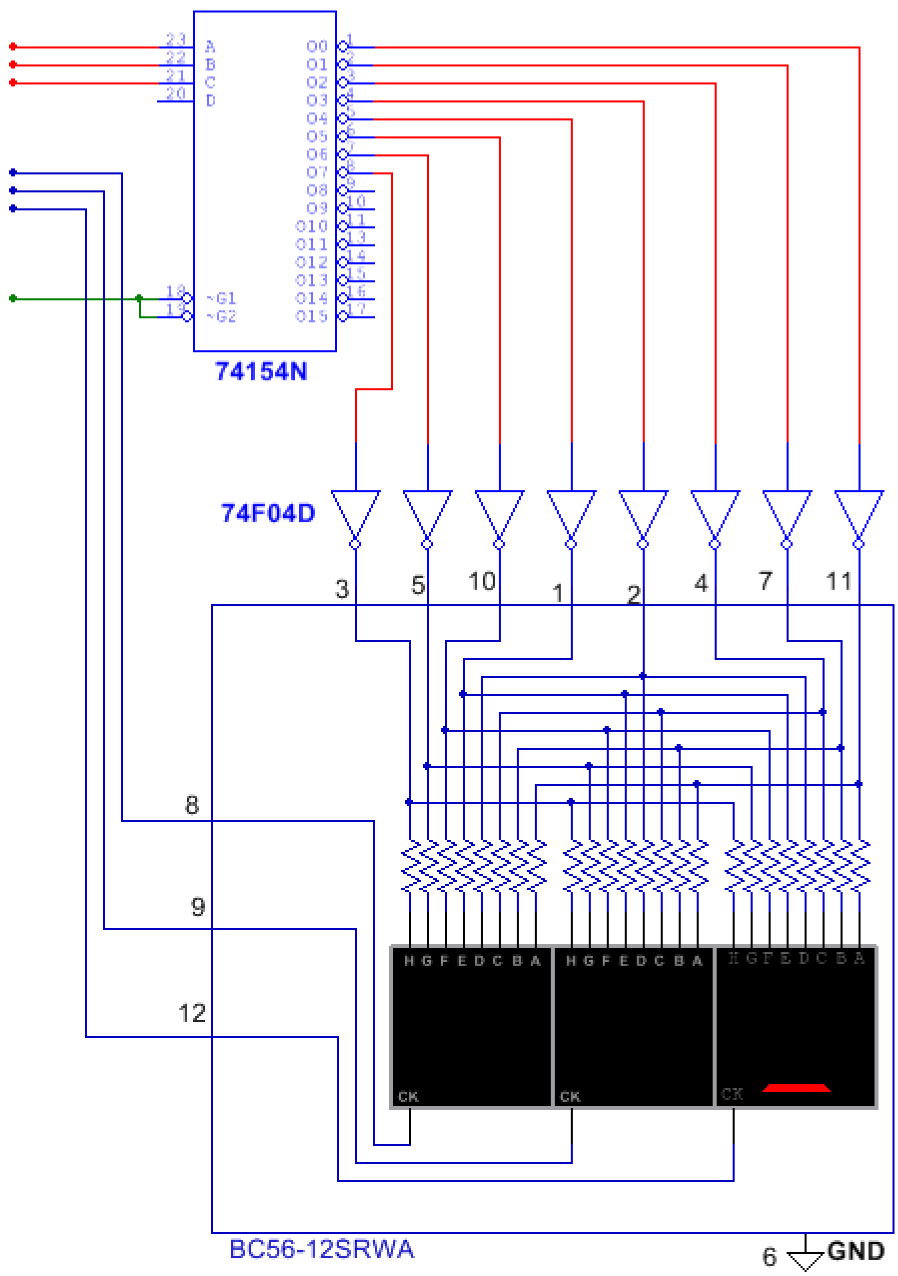

Figure 4.3.4 - 7-segment Display

On the next page, Figure 4.3.5 shows how both displays will be put together in regards to pin connections to the microcontroller. As you can see, for the LED bar display it is using our second design, the one without the D latches. It also shows the accessory LEDs (AccLED1, AccLED2, and PWRLED) that can be used to show what mode it's in and if the temperature is out-of-range. They can also be any color, but may be red/green to save on ordering. A total of 13 digital microcontroller pins will be used; they are shown on the top of the diagram (Figure is flipped counterclockwise to fit).

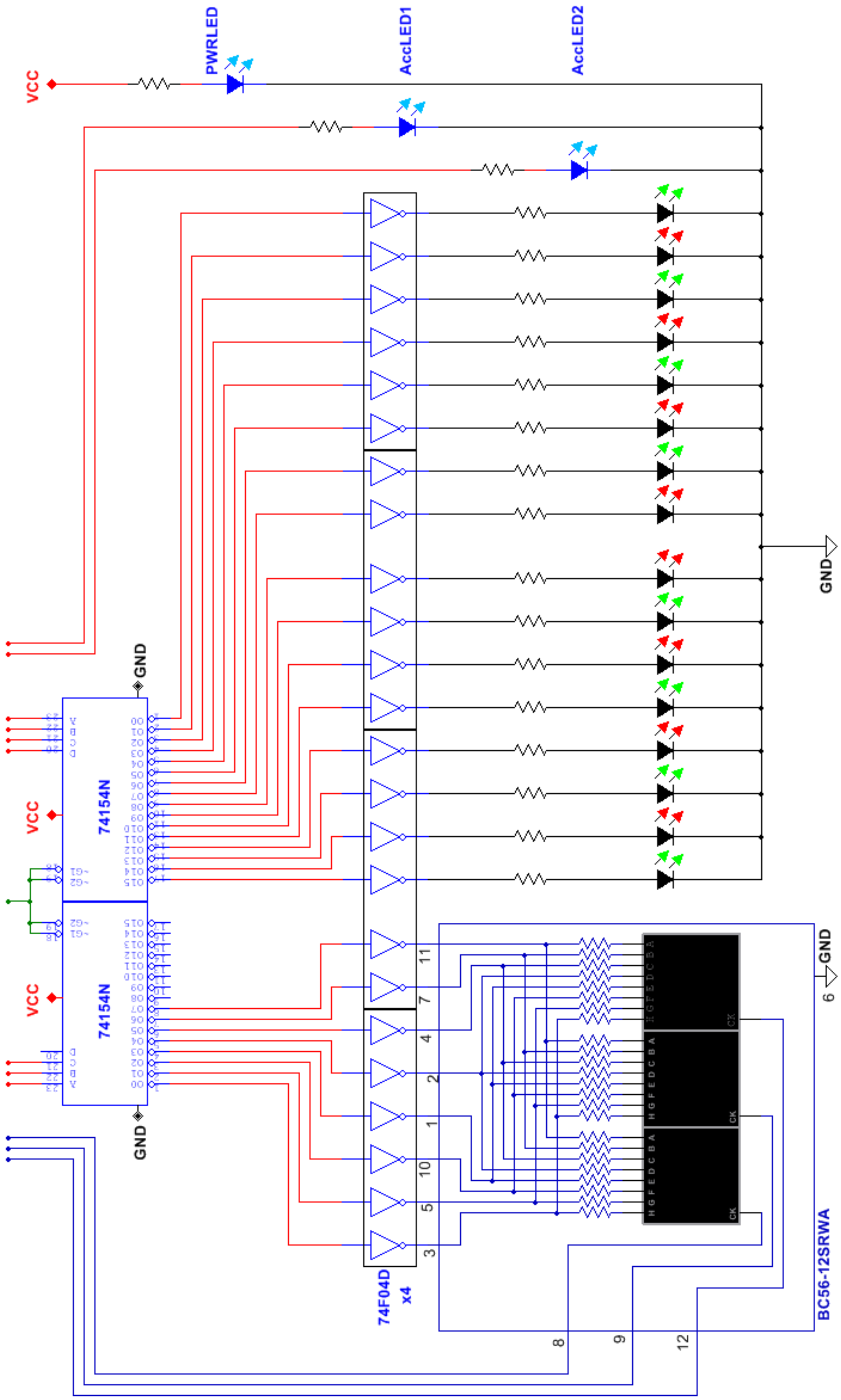

Figure 4.3.5 - Ground system LED setup

4.4 Proximity and Motion Sensor

The design for the proximity and motion sensors is really simple. We use a motion sensor to activate the proximity sensor, as a power-saving benefit as well as to make up for possible shortcomings of the range of the proximity sensor. The motion sensor (RK115FCUL00A) takes in a 12V supply. If motion is sensed through its passive infrared detection, the switch connecting the In and Out pins on the sensor closes, allowing the 5V input to enter the proximity sensor (GP2Y0A02YK) and power it. The Vout pin on the proximity sensor connects to an analog pin on the microccontroller.

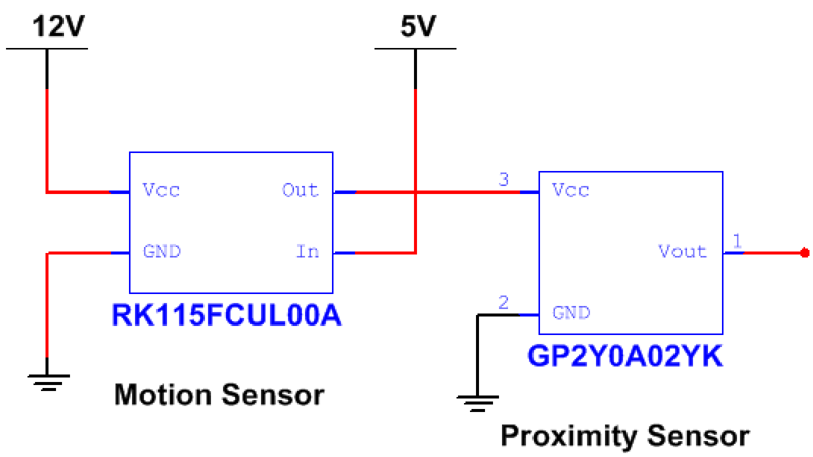

Figure 4.4.1 – Proximity and Motion Sensors

4.5 Ground System - Device Enclosure

As shown before in Figure 4.3.2, most of the ground system will be enclosed or mounted in a metal box. The only subsystem that won't be placed in or around the metal box will be the ground system coil. Figure 4.5.1 shows exactly what's inside the metal box and the input and output wires (looking through the metal faceplate of the box). The red wire, representing AC input, goes straight to the Power Distributor--the blue wire, representing DC output, goes straight to the ground system coil. The displays will be taking up the larger half of the top of the metal box. The proximity and motion sensors are placed at the bottom of the metal box because they need to be as close as possible to the car or car bumper for accurate proximity results. The fan will be placed close to the oscillator because that is the component we anticipate will need cooling (the temperature sensor will be focused on the oscillator). For detailed connections within the subsystems, see Section 4.1 for block diagrams or Section 5.1 for full schematics.

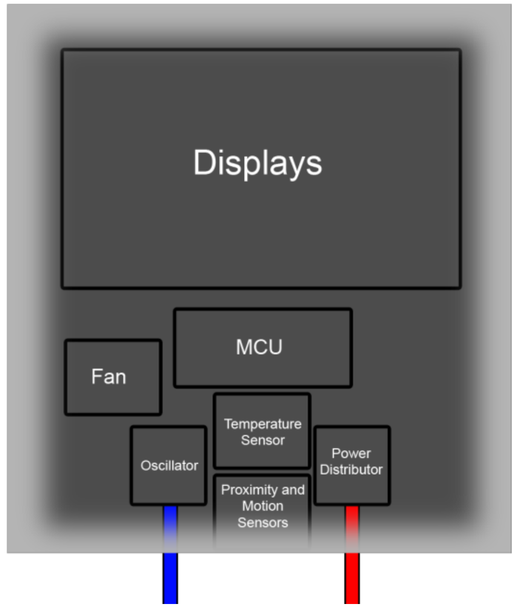

Figure 4.5.1 - Ground System Components

Physically, you can imagine a first aid box, perhaps larger, and a solid generic color, ideally unpainted, mounted onto the back of a garage wall. Something that you may already have installed could be a key box, or a thin mailbox, or even a circuit breaker panel that's extruded from the wall a bit. For this project and testing purposes, the metal box will be like that key box, and if put into production, could be installed into the wall like a circuit breaker panel and everything would look seamless and integrated. Our testing version will have two wires going in and out of the box. The input wire being power from the AC home outlet; usually a few are in the garage. The output will be powering the coil. In the consumer world, the metal box will be getting power straight from the house's grid, instead of from an outlet, so this rids of the input wire. The output wire can either come out of the metal box to the coil or be integrated into the wall and/or garage floor. The ground system coil itself will be housed in an encasing of plaster, using a wooden frame to mold it-think pouring cement to make a sidewalk. This plaster will not interfere with the wireless energy transfer and will also make it safer from accidental touching and damage. In the consumer world it can be integrated into the garage floor. This is explained more in Section 4.10 Coil Enclosures.

4.6 Charge Controllers

From our research, the charge controller in Figure 4.6.1 was the first one we picked for our project, because it was designed purposely to produce or provide the exact voltage or current for an automobile with 12V batteries only. It is easy for a car battery to overcharge when in use while charging because the battery has a design that produces a few amperes when it is continuously charging while in use. This overcharging can be prevented by this charge controller; it provides a retroactive control circuit that monitors the charging conditions of the battery. The retroactive circuit as an LED that indicates when charging is full and deactivates the charge circuit. One thing we noticed about this circuit was that there can be voltage drop when the current is flowing through the cable connected to the transformer because of the heat the current produces. This voltage drop can be decreased by increasing the cross-sectional area of the cable being used.

After the circuit has been designed we can adjust the elements (shown in Table 4.6.1) to make sure we are getting the right current or voltage going through the circuit to the battery. We can set TR1 to null so we can check the LEDs and make sure they're on before connecting the battery. After connecting the battery, this circuit will allow us to send between 2A to 4A of current through while we make sure that LED2 is turned off. We can use the hydrometer technique to adjust TR1 very carefully by 100mA until LED2 is turn on; by carefully adjusting TR1, LED2 will start flicking which indicates that the battery is charging. Q1 can be biased by R3-R4 and LED2 in each half circle to act like a rectifier that charges the battery. C1, TR1, R2, and D2 can combine together to activate Q2 when the voltage of the battery goes beyond the predetermined value. After Q2 has been activated, Q1 gets deactivated by the current supply cut off as the battery terminal voltage is increased. This increased terminal voltage is fixed by TR1 to stay above the lowest voltage of the battery; after this happens Q2 shifts the control of Q1 gate.

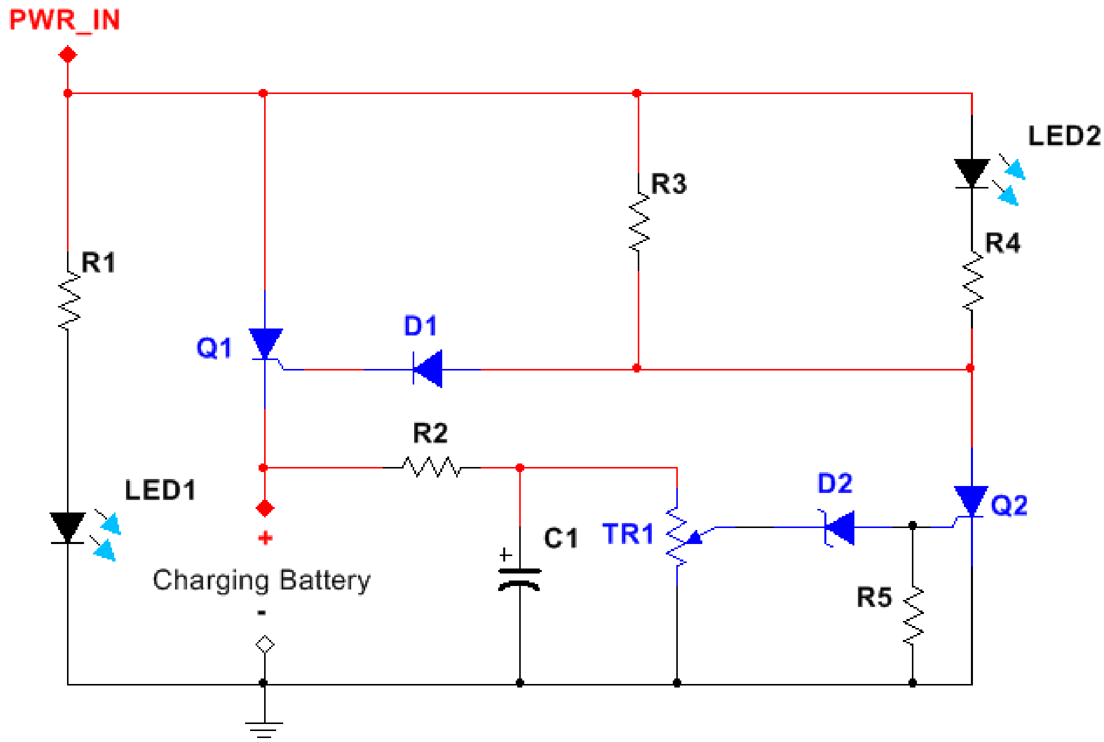

Figure 4.6.1 – Design 1 for Car Batteries

Table 4.6.1 – Design 1 Parts Reference

COMPONENT	SPEC	COMPONENT	SPEC
R1	1K Ω	R2	1.5 K Ω
R3,R4	470 Ω	R5	10 K Ω
D1	1N4001	D2	6.8V .5W Zener
TR1	4.7K Ω trimmer	Q1	BTY79 / 6A SCR
Q2	C106D SCR	C1	10µF
LED1	Green LED	LED2	Red LED

The charge controller in Figure 4.6.2 would make a great choice for this project because its features are easy to setup with one potentiometer for adjusting the float voltage. The most important fact about this design is that it has been designed purposely to make a charge controller with analog simplicity, high efficiency, and reliability. We will be using this charge controller as a medium for power between the terminals of our receiving coil and a 12V battery. Table 4.6.2 gives the references to the parts used in this design.

The reverse current flow from the battery to our resonance terminal will be prevented by D1. Q2 turns on the power for the rest of the circuit when there is power input. The reference voltage for the comparator IC1a is provided by IC2; this same IC2 provides a 5V regulated voltage to power up the comparator circuit. Q1 and Q3 activated and turned on by the comparator IC1a when the battery voltage is below the desired full voltage and charging is required. Because Q3 is a P-channel MOSFET we will be able to allow the circuit to be wired with a common ground. IC1a functions as a biased Schmidt trigger oscillator to switch the charging current off and on when the battery reaches its set charge current or voltage point. This switching causes the battery voltage to oscillate a few millivolts above and below the desired voltage set point. In order to get a better operation will be using a rail-to-rail op-amp. Between the output of IC1a and IC1b there will be a red/green LED; the signal from IC1b will be an inverted version of the IC1a. Since we don't want another reference divider circuit, pin 5 of IC1b which needs only an approximate center point to work as an on-off comparator, will be connected to the varying IC1a pin 2. The comparison between the battery voltage and the reference voltage coming from IC2/R8/R9 is done by a resistive bridge circuit formed from the resistors and thermistor on the input side of IC1a. The voltage point at which the circuit will oscillate on full load is adjusted by the potentiometer. The maximum frequency for oscillation is set by C6 and the positive feedback is added by R7 to the IC1a for Schmidt trigger characteristics.

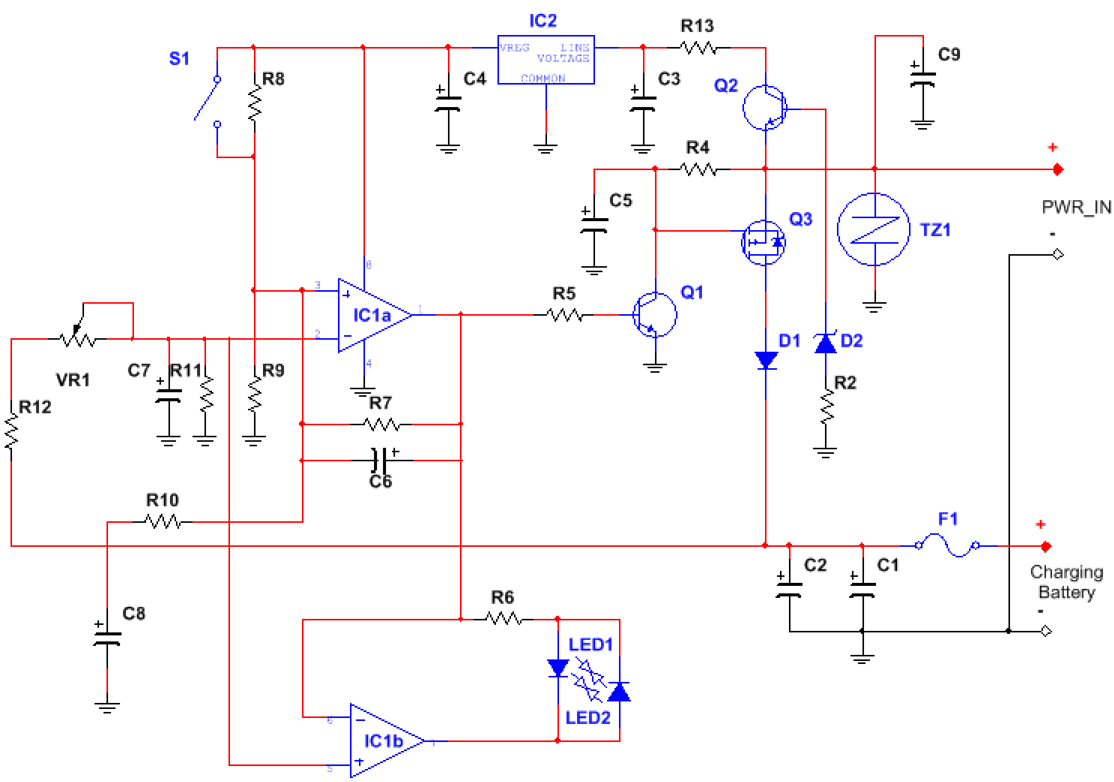

Figure 4.6.2 – Design 2 for 6V/12V/24V Batteries

Table 4.6.2 – Design 2 Parts Reference

COMPONENT	SPEC	COMPONENT	SPEC
IC2	TLC2272CP	IC2	78L05
D1(6V,12V)	19TQ015	D1(24V)	18TQ045
D2(6V)	1N5231 zener	D2(12V)	1N5242 zener
D2(24V)	1N5252 zener	Q1	2N3904
Q2	2N3906	Q3	IRF9Z34N
LED1,LED2	Red/Green LED	C1	47µF
C2-C4,C7-C9	0.1µF	C5,C6	0.001µF
TZ1(6V,12V)	27V Transzorb	TZ1(24V)	47V Transzorb
TM1(12 V)	2.2K Ω@25C Therm	TM1(12V)	3.3K Ω@25C Therm
TM1(24V)	4.3K Ω@25C Therm	R1	~
R2(6V)	1K Ω	R2(12V)	2.2K Ω
R2(24V)	3.9K Ω	R4	10K Ω
R3	~	R5,R8	100K Ω
R6	750 Ω	R11	75K Ω
R10	180K Ω	R9	200K Ω
R12(6V)	100K Ω	R12(12V)	300K Ω
R12(24V)	470K Ω	R7	100 Ω
VR1(6V,12V)	100K Ω	VR1(24V)	500 Ω
F1	10Amp Fuse	S1	2 position DIP switch

4.7 MCU Sensors

In order to have some control over the charging of the battery, and not having it continuously charge, thus possibly destroying your battery, vehicle, and home, we must add sensors to the battery. These sensors will provide data about the status of the battery, whether it's at a safe temperature to charge, and whether it needs to be charged so as to not overcharge. For this to be possible we need two sensors: a temperature sensor and a charge sensor.

The simpler temperature sensor is needed to make sure the battery is within a safe temperature to charge. If the battery is too hot, charging it will not only be very inefficient, but it can also cause a battery fire. If the battery is too cold, charging will also not be very efficient. The sensor will physically be attached to the battery, specifically a place where the enclosure of the battery is the thinnest, but not near the cathode or anode. Safe temperatures for charging are determined by the battery and its manufacturer.

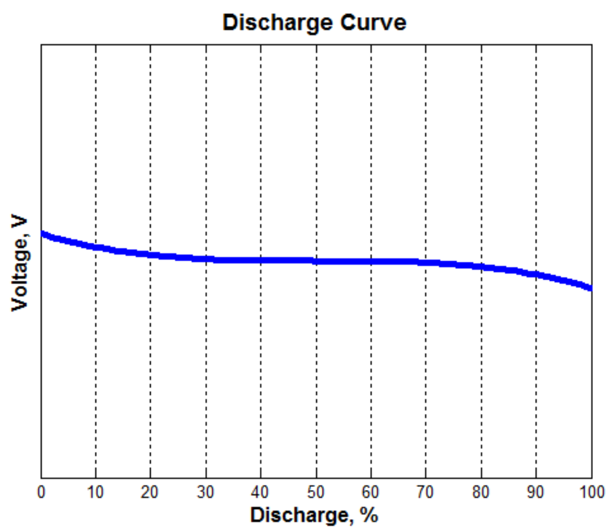

Figure 4.7.1 - Example of Discharge Curve

The charge sensor is needed to make sure the battery is not overcharged by measuring its state of charge (SOC). There are different ways to approach this problem. The easiest way is to measure the voltage of the battery terminals compare it to its discharge curve (see Figure 4.7.1), which is usually supplied by manufacturer, but can be created by us if needed. This gives us a very rough idea of the battery's SOC. For greater accuracy, we can find the current proportional to the voltage at each stage and use that (Current versus State of Charge) in conjunction with the discharge curve.

As far as the importance of sensors goes within the MCU, the temperature sensor takes priority, with the battery having to "pass" the temperature test in order to be charged. Upon passing the temperature test, the battery will be tested again in regards to voltage (and possibly current) through its terminals, and its SOC will be assessed. If its current values will allow it, the charge controller will charge the battery. The temperature sensor is pretty straightforward--read analog values and send to MCU for data processing. However, the charge sensor will require a little more finesse. Once the MCU determines that the data allows for charging, the MCU must disconnect before connecting the charge controller. If the MCU remains connected to the battery's terminals while the charge controller attempts to charge the battery, the values the charge sensor will read would be corrupted—it is no long reading the values of the battery, but rather of the charge controller itself. So the system we need to put in place can be followed in the series of events illustrated in Figure 4.7.2.

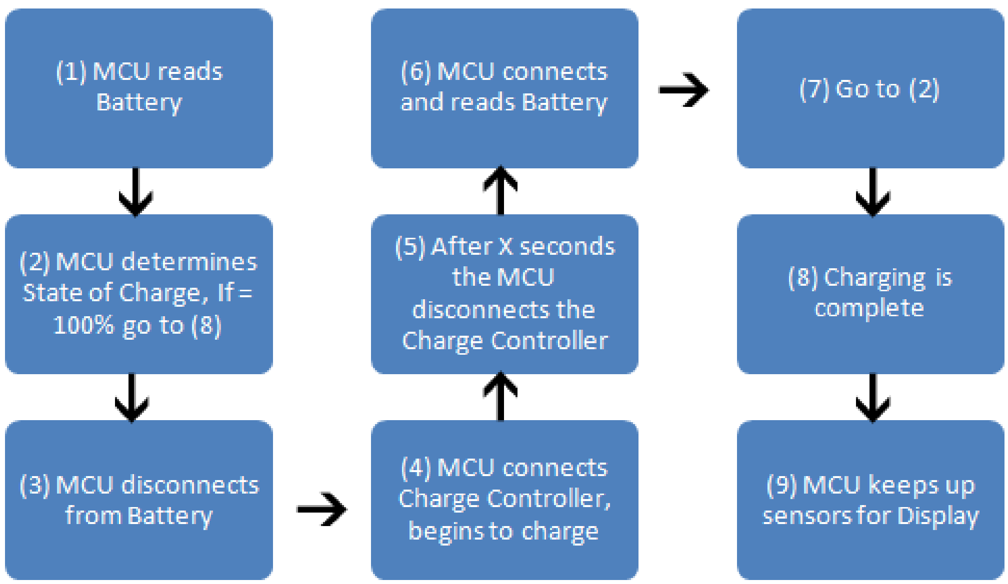

Figure 4.7.2 – Sequence of Events for "Check and Charge"

This is where the switches from Section 3.5.x come in. Their connection to the battery will be as follows in Figure 4.7.3. The battery terminals connect to a DPDT (dual pole dual throw) switch and to the power supply. The power supply will be able to power the car system devices without damage from charging. The DPDT switch is controlled via the green line from the microcontroller. Let's assume when the control line is 1 that the charge controller is connected (node 1) and when it's 0 the microcontroller is connected (node 2). While the battery is being checked for its charge status, the control line is 0, so that the microcontroller can read the battery's terminals and determine SOC. If charging is required, the control line will be set to 1, disconnecting the microcontroller from the terminals and connecting the charge controller to charge. After a set amount of time, the microcontroller will set the control line to 0 again to determine SOC. This process repeats as explained in Figure 4.7.2.

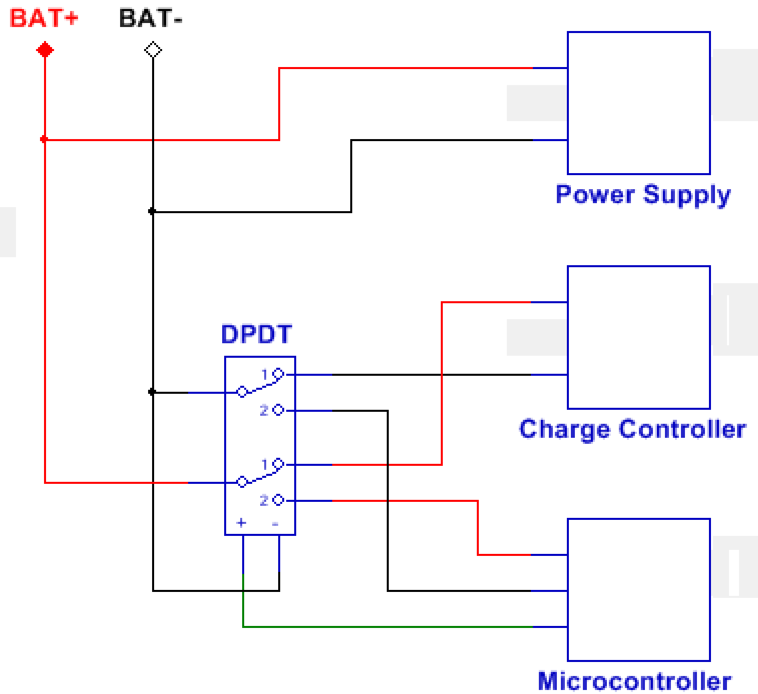

Figure 4.7.3 - Car system setup to battery.
Other components (R, C) not shown.

The temperature sensor we chose (ZTP-115M) has three pins, labeled in Figure 4.7.4. One pin for power, one pin for ground, and one pin for analog V_{out} which goes to the microcontroller--easy setup.

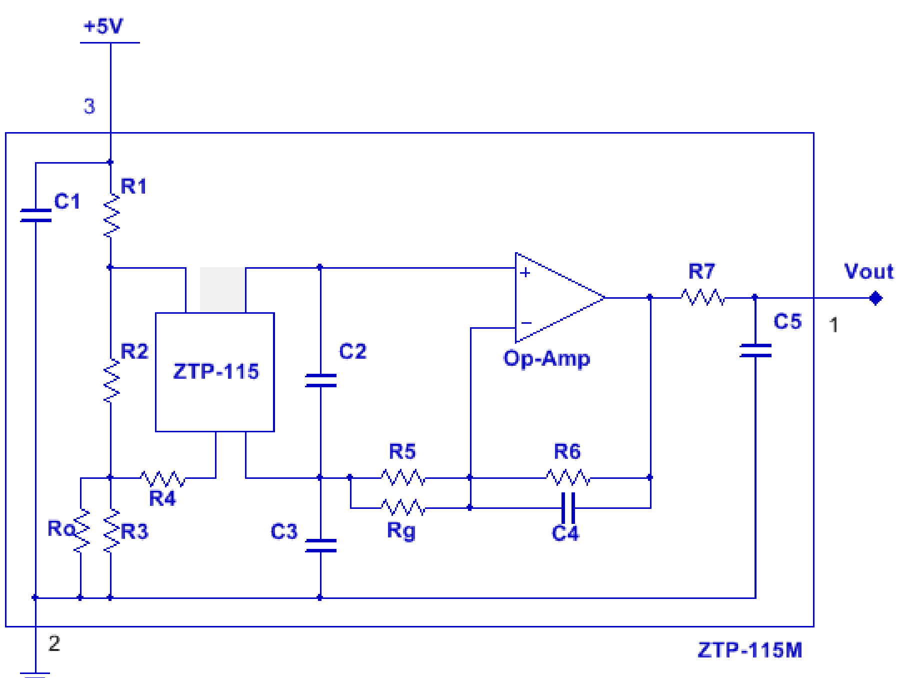

Figure 4.7.4 - ZTP-115M details

4.8 Car System - Device Enclosure

Similar to the ground system device enclosure, the car system version is almost the same except instead of a metal box the subsystems will be mounted near the battery, ideally hidden from everyday view and viewable when accessing the battery. Preferably the sensors that are attached to the battery won't be on the same printed circuit board as the car system MCU, to avoid heat interference. Figure 4.8.1 imagines a yellow PowerWheels, and you're looking through the hood at the car system's components. The battery will take up most of the space, and the subsystems will be placed near the battery. The coil, shown through the floor of the "engine compartment", will be fixed under the vehicle. Power is transferred from the coil through the charge controller, which includes an AC/DC converter (rectifier). The charge controller is either directly or indirectly connected to the battery, depending if it has an internal switch for the purpose of the MCU connection. The battery gives power to the power distributor for the car system. The temperature sensor sends data to the MCU concerning the battery, and the MCU is either connected through the switch to the battery, or through the charge controller to measure the battery's terminals. Section 4.1 explains in further detail through block diagrams and Section 5.1 has more detailed schematics.

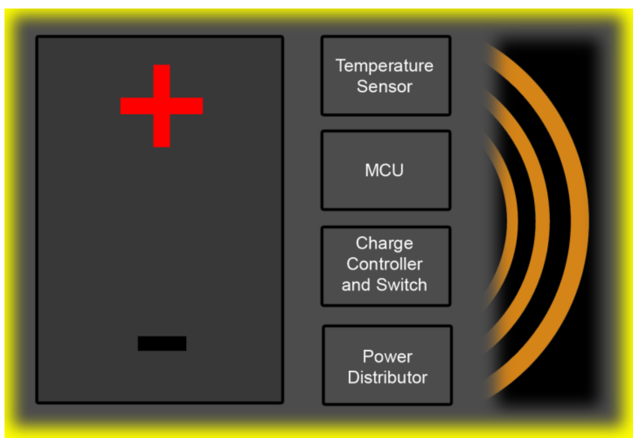

Figure 4.8.1 - Car System Components

The car system coil will be very similar to the ground system coil. Both will be encased in a plaster, as explained in Section 4.10, via a wooden frame around the coil. However, the difference will be where it's mounted. The car system coil and its encasing will be mounted directly under the car. Due to the fact we're using a PowerWheels the coil might outweigh the vehicle itself, so we're going to have to securely mount the coil onto the bottom of the PowerWheels.

4.9 Transmitting and Receiving Coils

The two main coils that will be used for this design will both be air core inductors. We chose this type of inductor because we do not want to depend upon a ferromagnetic material to obtain a specific inductance. Also, air core coils are relatively free of iron losses which pose a problem for coils with ferromagnetic cores. Other advantages of air core coils include the fact that its inductance is unaffected by the current it carries and this helps a great deal in our application since charging current can vary depending on battery charging needs. In addition, since we have to maintain magnetic resonance in both coils, fluctuations in inductance due to current capacity would greatly affect the efficiency of our system. The production of harmonics can also affect the sensitive electronics in our design and cause unwanted behavior. Using an air core coil prevents the production of harmonics and you also obtain a better Q-factor, greater efficiency, greater power handling, and less distortion. These coils can be designed to perform at frequencies as high as 1GHz, although most ferromagnetic cores typically tend to be rather lossy above 100MHz.

There are definitely some disadvantages in using the air core coil, however, they are overshadowed by the benefits and most of them can be tolerated without greatly affecting performance. Without a high permeability core, more turns and/or a larger coil is needed to achieve a given inductance value. In designing our coils we have to be mindful of the fact that more turns means larger coils, lower self-resonance due to higher inter-winding capacitance and higher copper loss. Since in our application we'll be using a high frequency voltage signal which generally doesn't need high inductance, this would not be a problem.

The air core coil also provides the benefit of providing an external radiated field at our resonance frequency which we want to be strong enough to be picked up by the receiver coil. Figure 4.9.1 shows a cross section of what the coils will typically look like once wound. We plan on using around 9 turns per coil which we believe will provide a strong enough magnetic field for testing purposes. These coils will be carefully hand-wound to our precise specifications.

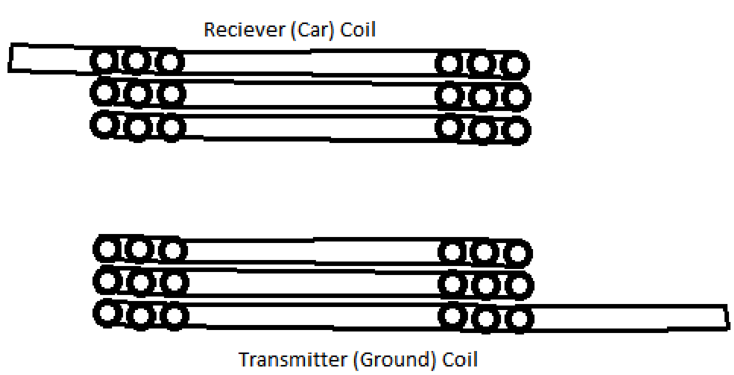

Figure 4.9.1 – Cross section of transmitter and receiver coils

Another design that is being considered poses the coils to be flat as shown in Figure 4.9.2. This is a space saving design and works out well if the car does not have much ground clearance. For this design, the receiver coil can be made smaller than the transmitter coil to compensate for misalignment.

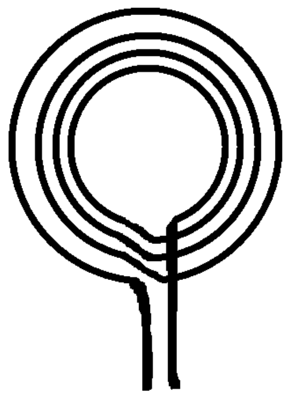

Figure 4.9.2 – Basic formation of transmitter coil (receiver coil is identical)

The condition of resonance is experienced in a tank circuit design when the capacitive reactance is equal to the inductive reactance. Because the reactance of an inductor increases with frequency and the reactance of a capacitor decreases with increasing frequency, when placed in parallel, there will be only one frequency where these two reactances are equal. This frequency is the resonant frequency of the tank circuit. We cannot obtain the resonant frequency of our circuit until the coil is wound. After the coil is wound and the inductance is determined using a method described in Section 7.2. The capacitance value will be chosen based on the output frequency of the oscillator circuit. The relationship is given by the formula:

$$f_{resonant} = \frac{1}{2\pi\sqrt{LC}}$$

We may not be able to acquire the exact value of the capacitance needed for the resonant condition. In this case we will have to tweak our oscillator frequency or adjust the number of turns of the coil. The same condition for resonance must be adhered to in the tank circuit on the receiver side. The coil inductance and capacitor values must be such that it matches the resonant frequency of the transmitter coil.

4.10 Coil Enclosures

Upon successful testing of the final coil designs, they will have to be permanently mounted. One will be mounted to the car and the other fixed to the ground. We cannot simply place a few screws through the coils and mount them as that would be impractical. The idea for our design is to encase each coil in fiberglass resin and then drill mounting holes into the hardened fiberglass. This offers the rigidity that we need for secure mounting of the coils, in addition to protection from the elements. It is also very light weight.

Since the coils will be one of the main elements of our design that will be seen, we want to ensure that it looks good in terms of aesthetics. The idea is to build two square wooden frames and set the coils inside as seen in Figure 4.10.1. After ensuring that the coil is correctly positioned, fiberglass resin will be poured into the enclosure until it just covers the coil. This is then left to dry overnight before removing the wood and revealing the finished product.

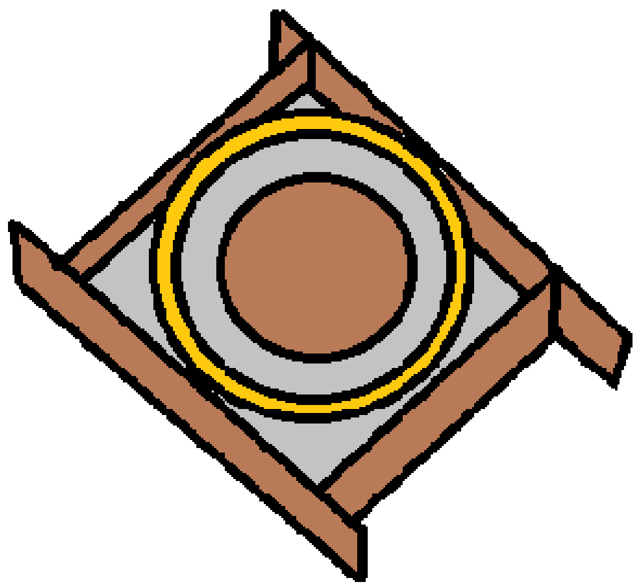

Figure 4.10.1 – Coil inside wooden enclosure frame

Provisions will also be made to accommodate mounting conduit couplings to the finished coil enclosure. The conduit will be used to secure the wire connecting the coil to the control panel. After inspecting the chassis of the vehicle, mounting holes for the car coil will be drilled accordingly to ensure secure mounting.

4.11 Microcontroller and Bluetooth

Amongst our researched parts for microcontrollers and Bluetooth modules, we finalized our decision; ATXMEGAG32A4U microcontroller and TiWi-uB2 module are the best–in terms of cost, availability, programming, and reliability–components for our project. The details of why we choose these components for our project are further explained in Section 3.5.12 and 3.5.13. Both components will be mounted on the same PCB with other miscellaneous components if necessary. The following are footprints of both components and the function of their pins we would need in our project.

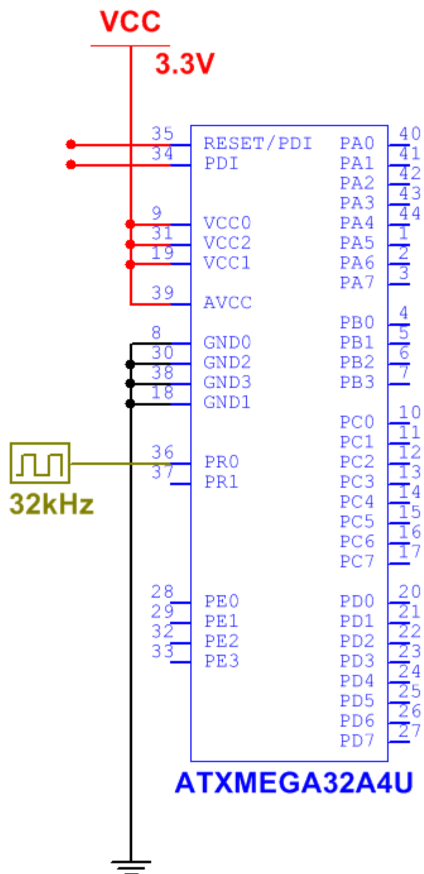

Figure 4.11.1 – ATXMEGA32A4U Microcontroller

Figure 4.11.1 shows the microcontroller's footprint, created in NI Multisim. Starting at the top left, pins 34 and 35 are used for programming and debugging, and will be utilized when we want to program out microcontroller. Pins 9, 31, 19, and 39 are V_{CC} pins, and are powered by a 3.3V source. The analog V_{CC} pin (39) can be powered by the same source as the other pins. This microcontroller can take in a clock, max of 32MHz, on pin 36, 37, 32, or 33; we chose pin 36. All the pins on the right that are named PAX or PBX are analog I/O pins, and those named PCX and PDX are digital I/O pins. The pins named PEX can also be used as digital I/O, and PRX pins are meant for clock or general I/O.

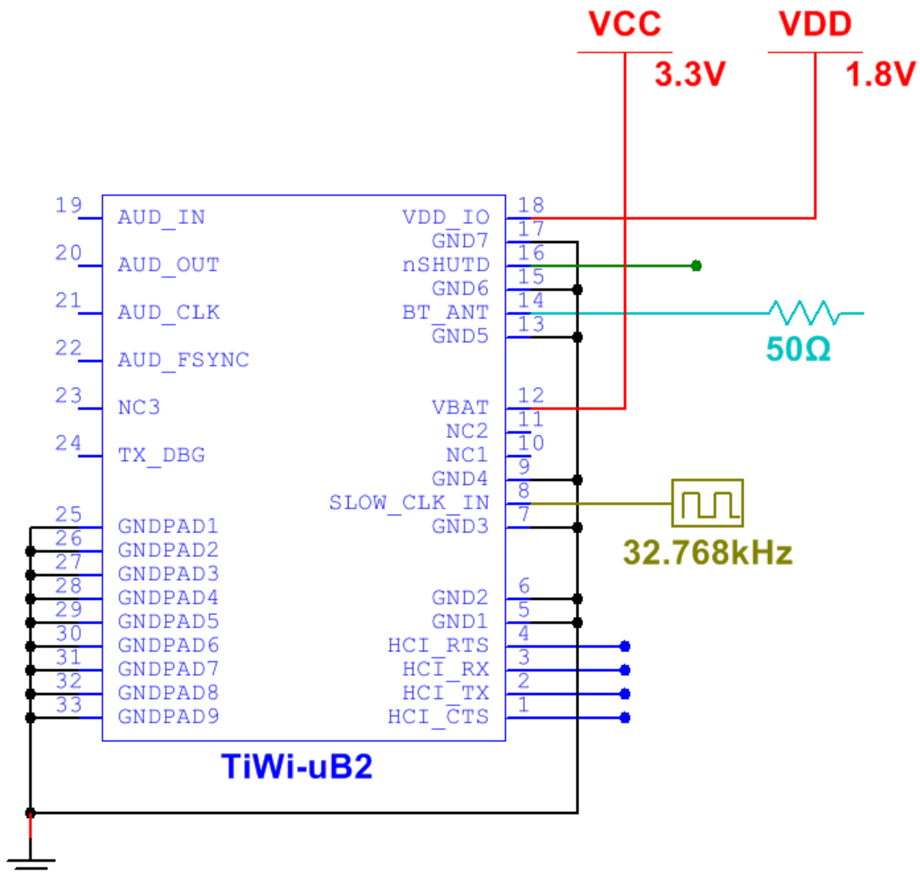

Figure 4.11.2 – TiWi-uB2 Bluetooth Module

The next component is the Bluetooth module, shown in Figure 4.11.2. Starting from the top left, the audio/PCM pins (19-22) are not going to be used, so they must be left unconnected. All the NCX pins (23, 10, and 11) must also remain unconnected. Pin 24 is a debugging pin for logging. This module takes in two power supplies: pin 18 takes in 1.8V to power the I/O pins and pin 12 takes in 3.3V to power the device. Pin 16, named nSHUTD, is a control pin that connects to the microcontroller. Pin 14 is used for a 50OHM antenna. Pin 8 connects a clock that must be 32.768 kHz for operation. Finally, pins 1-4 are the data pins connected to the microcontroller that allow for data to be sent and retrieved wirelessly.

4.12 Oscillator

The oscillator generates the resonant frequency required to oscillate the ground coil. Oscillations are limited when resistance is taken into consideration, either from a resistor component or resistance due to the inductor windings. We have quite a few designs to choose from for this section; however, we limited our selection to three. The first one shown in Figure 4.2.1 is a circuit taken from a wireless power transfer demonstration video on YouTube. This circuit features a wireless power transmitter, oscillating at 63 KHz, that is capable of powering a 12V load from a distance of 10cm which is generally the ground clearance of a PowerWheels electric car. It is important to have the receiver correctly aligned with the transmitter in order to obtain maximum performance.

R1 = R2 = 460Ω, R3 = R4 = 10KΩ
L1 = 1000µH, C1 = 0.47µF
The transmitter coil is center tapped and consists of 9+9 turns

The circuit also has two IRF2807 power MOSFETS to handle the power drawn by the transmitting coil. These will have to be mounted to a heat sink to effectively dissipate the heat generated in their operation. The zener diodes (1N4740A) are used to maintain constant amplitude in the oscillations and the two ultra-fast avalanche sinterglass diodes (BYV26E) are capable of handling the reasonably high operating current and fast switching of the circuit. The receiver section of this configuration consists of a coil made up of 18 turns in parallel with a capacitor that matches the resonant frequency of the transmitter coil as close as possible. In this example a 0.44µF capacitor was used, our design may require a different value depending on the inductance of the inductor.

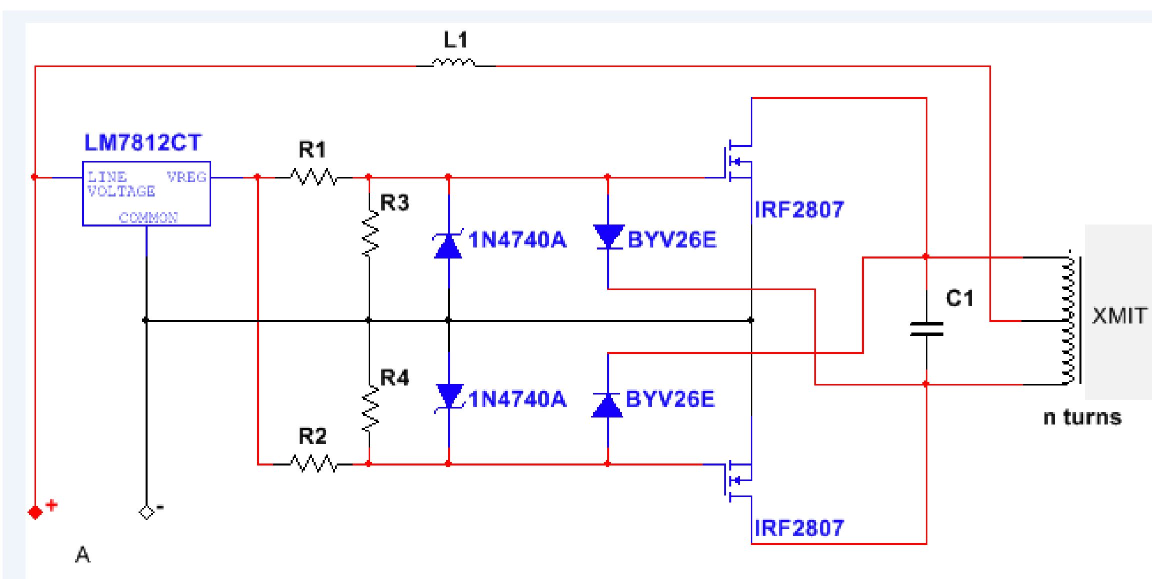

Figure 4.12.1 – Wireless Power transfer oscillator circuit diagram

Another oscillator design that will be considered is the Colpitts Oscillator shown in Figure 4.2.2. The circuit consists of a single stage inverting amplifier and an LC phase shift network. The two series capacitors C1 and C2 form the potential divider used for providing the feedback voltage – the voltage developed across capacitor C2 provides the regenerative feedback required for sustained oscillations. Parallel combination of Re and Ce along with resistors R1 and R2 provides the stabilized self-bias. The collector supply voltage V_{CC} is applied to the collector through a radio-frequency choke (RFC) which permits an easy flow of direct current but at the same time it offers very high impedance to the high frequency currents. The presence of coupling capacitor Cc in the output circuit does not permit the dc currents to go to the tank circuit. The flow of DC current in a tank circuit reduces its Q-factor and for our circuit a high Q-factor is desired. The radio-frequency energy developed across RFC is capacitively coupled to the tank circuit through the capacitor Cc.

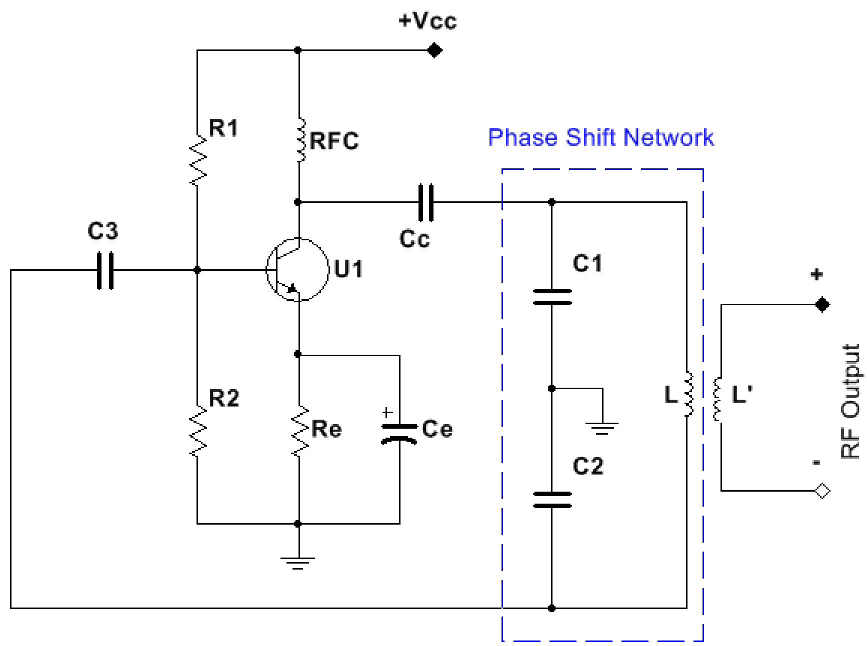

Figure 4.2.2 – Basic Circuit for Colpitts Oscillator

The output of the LC phase shift network is coupled from the junction of L and C2 to the amplifier input at base through coupling capacitor CC, which blocks dc but provides path to AC. The transistor itself produces a phase shift of 180° and another phase shift of 180″ is provided by the capacitive feedback. Thus a total phase shift of 360° is obtained which is an essential condition for developing oscillations. The output voltage is derived from a secondary winding L' coupled to the inductance L. The frequency is determined by the tank circuit and is varied by gang-tuning the two capacitors C1 and C2. It is to be noted that capacitors C1 and C2 are ganged. As the tuning is varied, values of both capacitors vary simultaneously, the ratio of the two capacitances remaining the same. The frequency of oscillations is determined by:

$$f = \frac{1}{2\pi\sqrt{\frac{1}{LC1} + \frac{1}{LC2}}}$$

We are also looking into the Hartley oscillator as a possible candidate for our oscillator design. This oscillator is just as popular as the Colpitts oscillator and is widely used as local oscillators in radio receivers. The simplified circuit diagram is shown in Figure 4.2.3 and it can be seen that the Hartley Oscillator circuit is quite similar to the Colpitts oscillator circuit with the main difference being found in the configuration of the phase shift network. The Hartley consists of two inductors L1 and L2 and a capacitor while the Colpitts has two capacitors and one inductor.

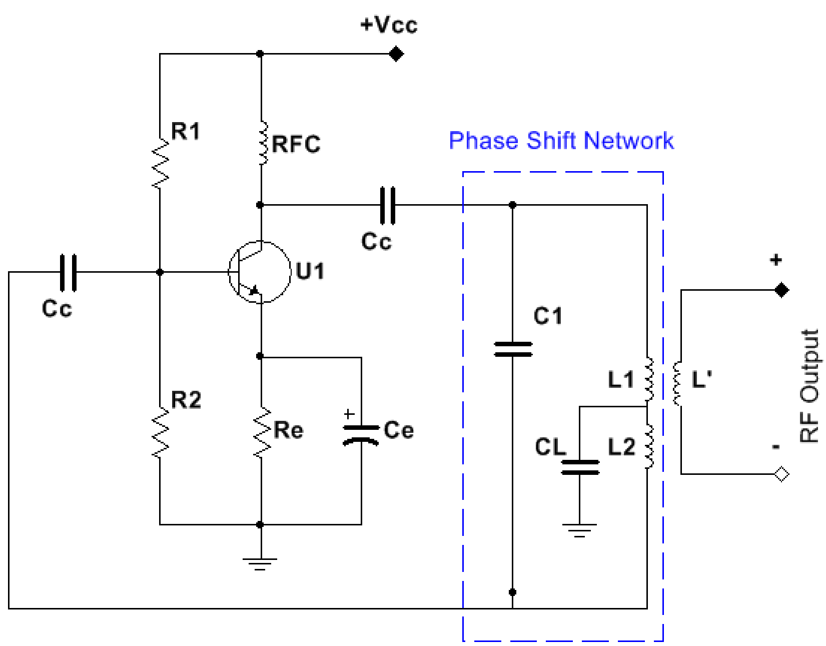

Figure 4.12.3 – Basic Circuit for Hartley Oscillator

The output of the amplifier is applied across inductor L' and the voltage across inductor L2 forms the feedback voltage. The coil L1 is inductively coupled to coil L2, the combination functions as an auto-transformer. However, because of direct connection, the junction of L1 and L2 cannot be directly grounded. Instead, another capacitor CL is used. The operation of the circuit is very similar to that of the Colpitts oscillator circuit.

Since L1 and L2 are wound on the same core, there exists mutual inductance between the coils and their net effective inductance is increased by mutual inductance *M*. Therefore, the effective inductance is given by:

$$L = L1 + L2 + 2M$$

Therefore the resonant or oscillation frequency is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The frequency of the Hartley oscillator can be easily adjusted by varying the inductances which may be achieved by making the core movable or varying the capacitance. Hartley oscillators are not suitable for low frequency work because at low frequency, the value of inductance required becomes large and for this reason it may not suit our design if we have inductor size constraints.

5 Design Summary of Hardware and Software

This section will summarize Section 4 and piece everything together in a single circuit, so as to make sure no one piece is incorrect in any way. Below will include detailed diagrams of the ground system and the car system. Also there will be detailed logic flow diagrams summarizing the coding process required for the software side. Software and coding implementation will be discussed in detail in Section 6.3 Final Coding Plan as this is just the code design.

5.1 Hardware Design

We shall start off at the AC source and follow the flow of power from the ground system to the car system, looking into each circuit along the way. Figure 5.1.1 on the next page takes a look into the ground system's power distributor. From the home outlet (120V AC source), the two AC lines enter the power distributor into a transformer that brings down the power to 18V 5A. For safety and protection there will be an installed kill switch and fuse before the transformer. A bridge allotted for 5A will be used for the high current demand of the oscillator. Before the 12V voltage regulator, a line will go to a switch, which connects to the oscillator circuit (Figure xxx) via **Osc**. A 12V line will supply power to the motion sensor (Figure xxx) via **G**. After the 5V voltage regulator, a 5V line will supply power to all those connected to **A**. A line will also supply 5V into a switch that connects to the fan (Figure xxx) via **Fan**. After the 3.3V voltage regulator, a 3.3V line will supply power to the MCU board (Figure xxx) via **B**. The last component in the power distributor is the 1.8V voltage regulator, which feeds a 1.8V line power to the MCU board via **C**. The switch that holds on/off states for an 18V line and a 5V line is controlled via **Control1** by the microcontroller. Table 5.1.1 gives a short summary of the nodes and connections that will be present through this section, since we prefer to show you the details of the circuit up close in sections rather than the entire design zoomed out and on one page.

Table 5.1.1 - Off-page Connector Nodes

Node	Type	From	To
A	5V DC power	Power Distributors	Sensors, LED Displays
B	3.3V DC power	Power Distributors	MCU Boards
C	1.8V DC power	Power Distributors	MCU Boards
D	Specific Connection	Motion Sensor	Proximity Sensor
G	12V DC power	GS Power Distributor	Motion Sensor
Osc	Specific Connection	GS Power Distributor	Oscillator
Fan	Specific Connection	GS Power Distributor	Fan
Control1	Control line	GS MCU Board	GS Power Distributor
Data1	Data line	GS MCU Board	LED Displays
T+	Battery + terminal	Battery	Car Power Distributor
T-	Battery - terminal	Battery	Car Power Distributor

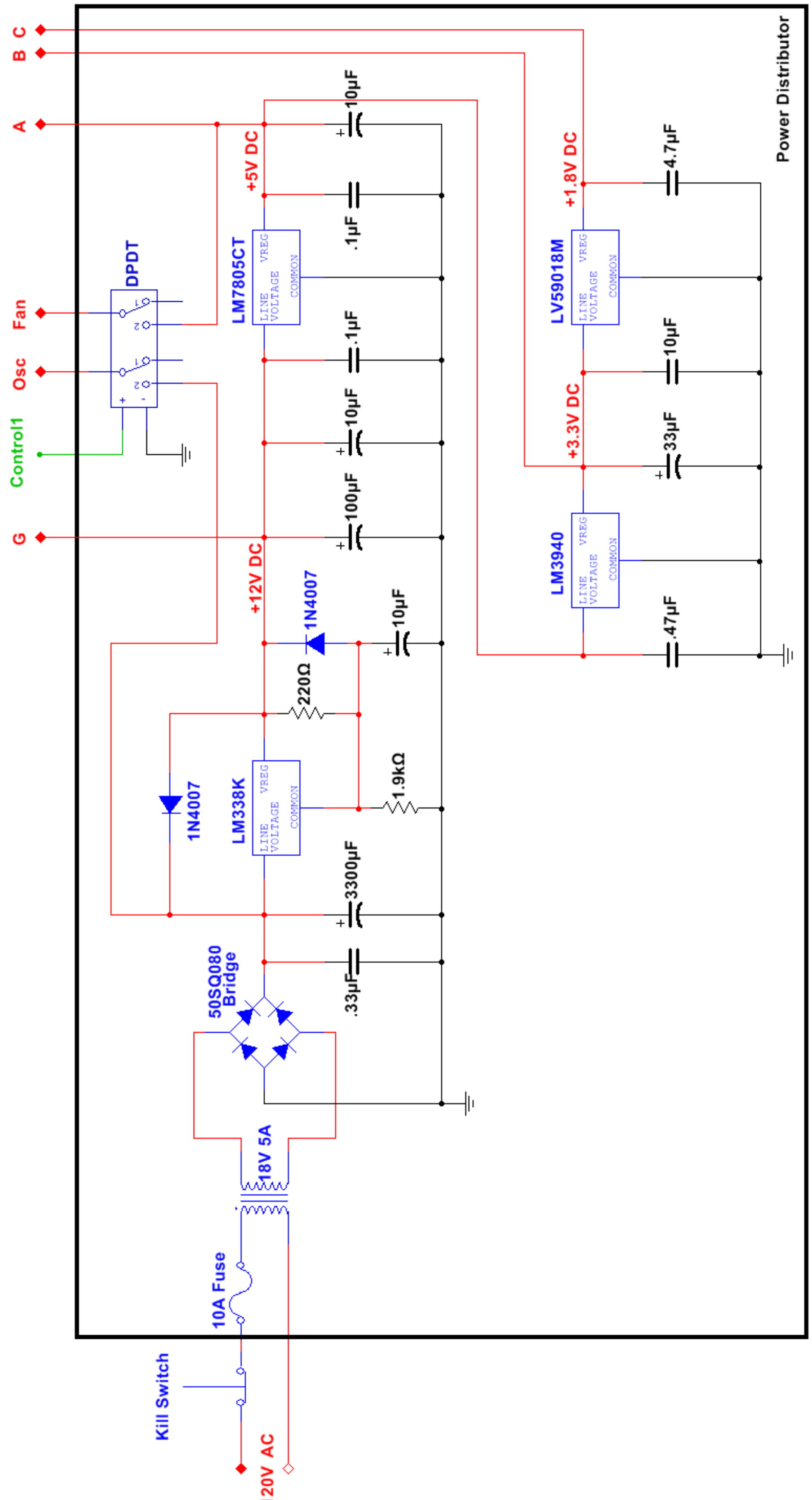

Figure 5.1.1 - Ground System Power Distributor

The next few circuits to review are the ground system's MCU board, temperature sensor, and proximity sensor, seen in detail in Figure 5.1.3 on the next page. As you can see, the nodes that send power are connected to arbitrary capacitors to prevent spikes from damaging the circuit. The two main components on the MCU board are the microcontroller and the Bluetooth module. Other components, such as the decoders and inverters from the LED displays, can be placed on this board to save on space and PCB costs. The data and controls lines that make up **Data1** go to the LED displays, consisting of 13 individual lines (4 control lines and 9 data lines). The 4 data lines in purple connect to the Bluetooth module for communication between the two devices. Another control line, **Control1**, goes to the power distributor and controls the switch for the oscillator and fan. The optional temperature sensor connects to the MCU board via a data line, as well as the proximity sensor.

Figure 5.1.2 shows the connections for the motion sensor, and how it basically controls the power supply of the proximity power. This component is powered by the 12V node **G**, and has an internal switch that, when motion is sensed, connects the 5V node **A** to the node **D**, which will power the proximity sensor. The purpose of this is to save power by having a low-power motion sensor on all the time instead of a higher-powered proximity sensor on all the time.

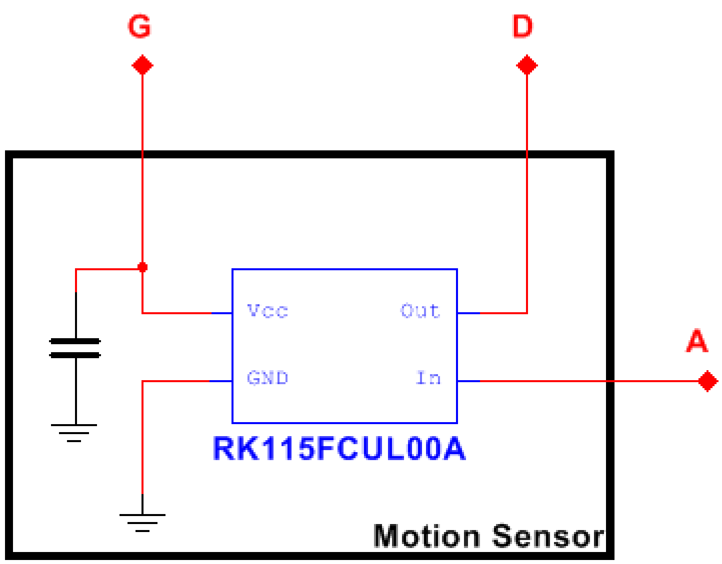

Figure 5.1.2 - Motion Sensor

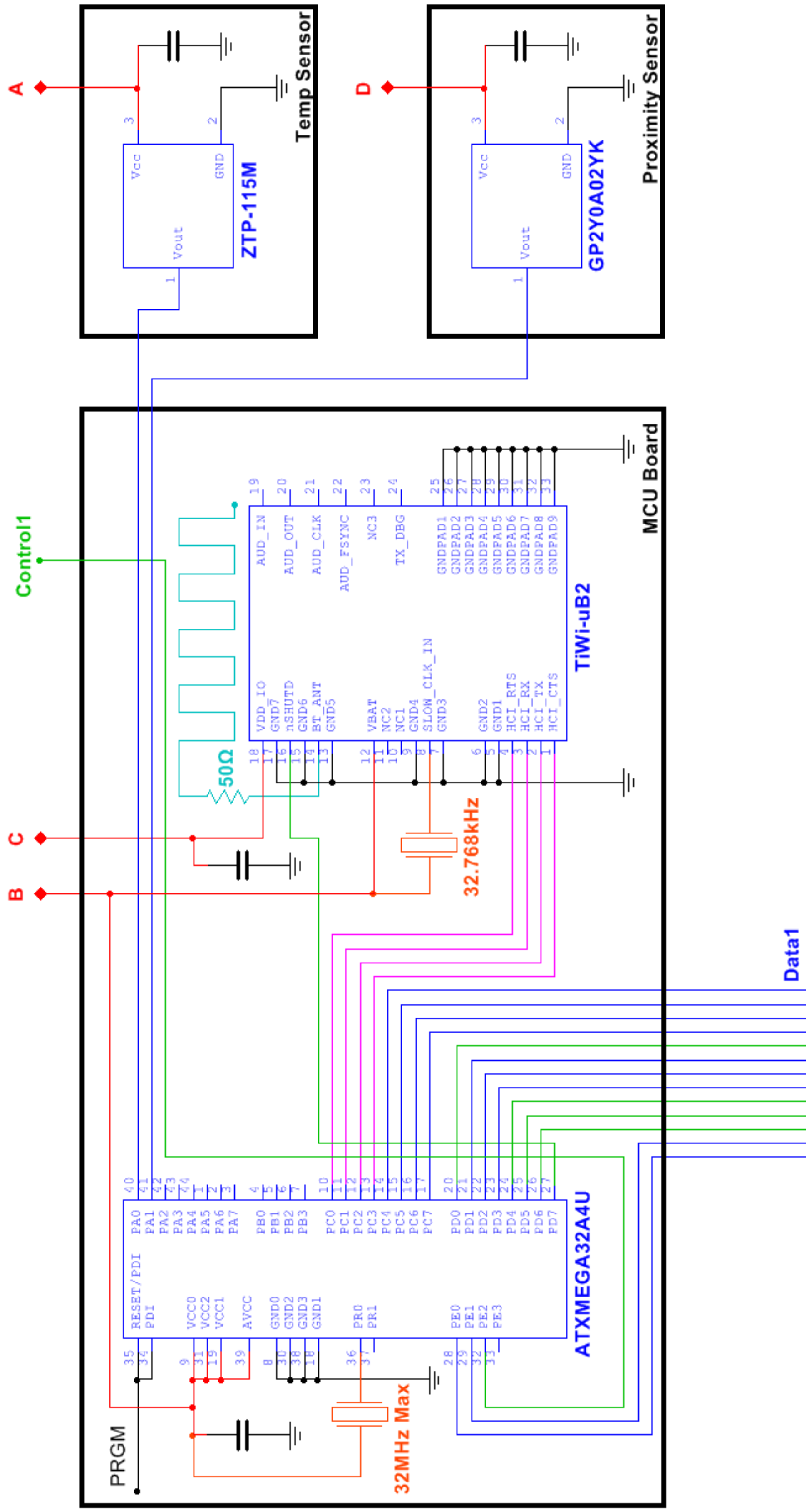

Figure 5.1.3 - Ground System MCU Board

The LED display is a combination of the LED bar display and the 7-segment display. In Figure 5.1.5, the decoders and inverters are shown in the LED display block, even though they may be on the MCU board; however it is easier to have everything organized this way for display purposes. These components are powered by the 5V node **A**, whereas the LEDs themselves are powered via the MCU's data lines, **Data1**, as logic 1 (3.3V). The only exception is the PWRLED which tells the user that power is being supplies from the power distributor.

Last and certainly not least in the ground system is the oscillator circuit, for which wireless charging would be impossible without in this project. Shown in Figure 5.1.4, the node **Osc** provides power to the circuit, which then connects to the transmitter coil via a long protected wire. The real-life distance between the oscillator and transmitter coil is not represented in this figure, as this only shows the schematics. The value Ct for the capacitor attached to the coil provides for a specific frequency, which will vary based on the values we wish to use. The fan is powered by the node **Fan**. Both these nodes can be shut down via the switch in the power distributor, which is why we felt the need to include these two otherwise unconnected blocks in the same diagram.

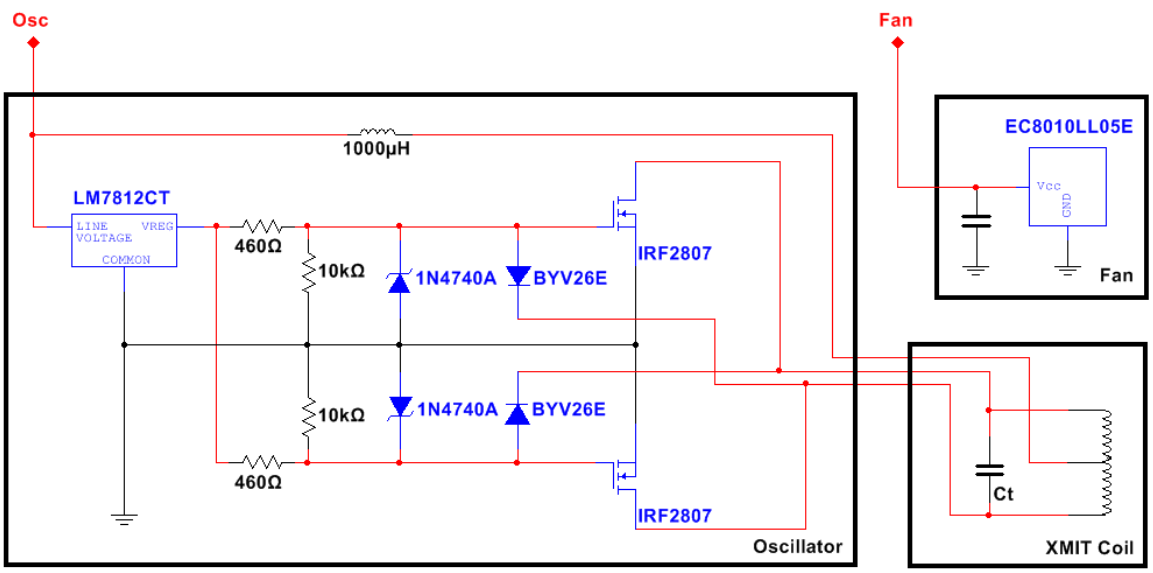

Figure 5.1.4 - Oscillator/Fan/Transmit Coil

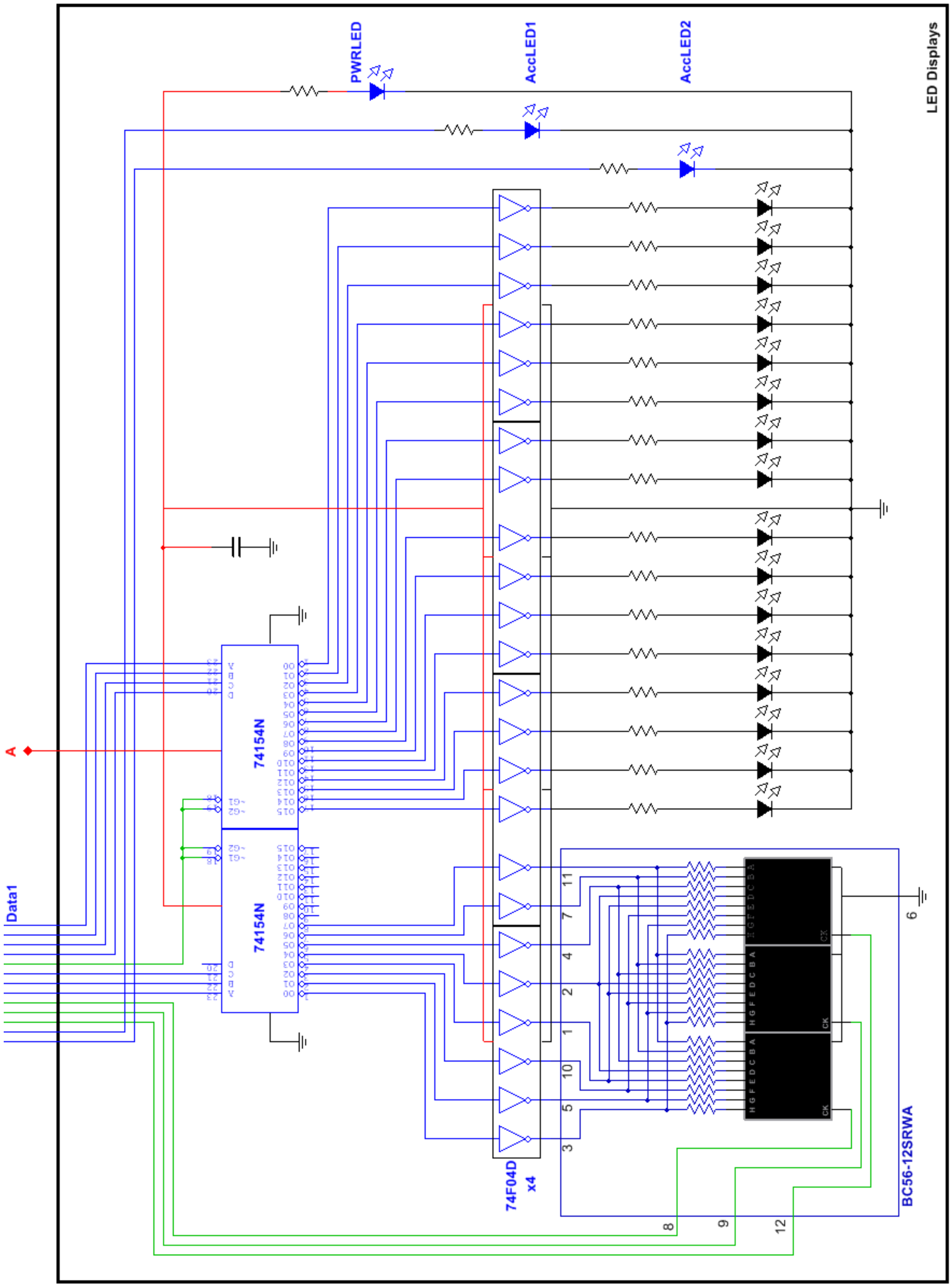

Figure 5.1.5 - LED Displays

The car system's blocks aren't as complicated as the ground system. We'll start with the car system's charge controller, MCU board, temperature sensor, and battery in Figure 5.1.7, since that's where the energy flow picks up from the transmitter coil. Just like the transmitter coil, the capacitor value Cr will depend on the inductance value from the coil and the frequency of the transmitter coil. The transferred energy goes into the charge controller. The charge controller then takes this energy and applies it to the battery to charge it. It is also connected to the MCU board so that the microcontroller can read the status of the battery to send to the other MCU for displaying. The nodes connected to the battery, **T+** and **T-**, connect to the car system power distributor, explained a little bit later. Finally, just like the ground system counterpart, the MCU board and temperature are almost exactly the same, minus the LED display data lines.

The charge controller, seen in further detail in Figure 5.1.6, is an altered version of the design seen in Section 4.6 for our own custom use for this project. It takes in the AC lines from the receiving coil (pins VIn+ and VIn-) and converts the signal to DC. The battery is connected respectively to the Term+ and Term- pins. The LEDs present are for quick access for charge status. It's red while charging and green when fully charged. From those lines when can connect to the MCU+ and MCU- pins for microcontroller connection.

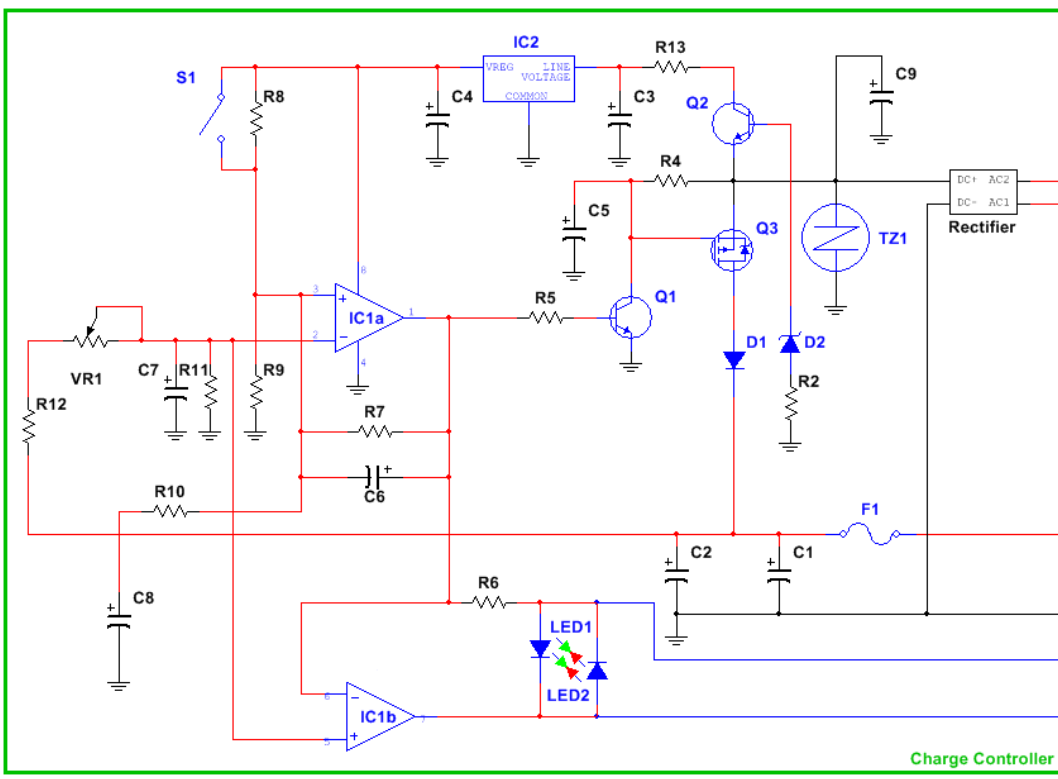

Figure 5.1.6 - Charge Controller block details

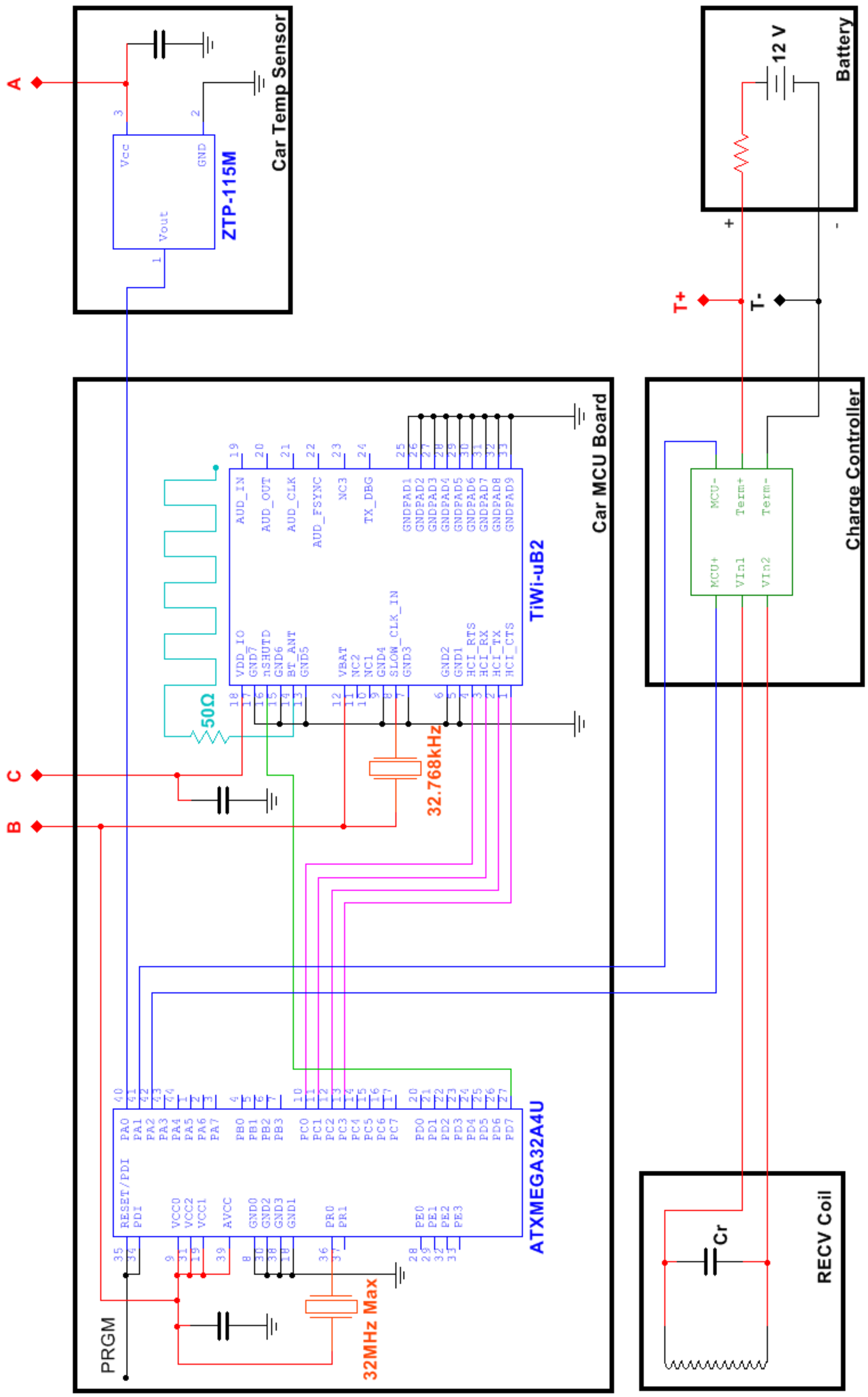

Figure 5.1.7 - Car System MCU Board/Sensor/Charge Controller

The car system's power distributor, in Figure 5.1.8, connects to the car's battery terminals respectively via **T+** and **T-**. Aside from the initial diode for backwards current protection, it is essentially the same as the ground system counterpart looking from the 12V line onwards (in the ground system's power distributor). The nodes **A**, **B**, **C**, have the same values as the ground system's, expect they power the car system's components.

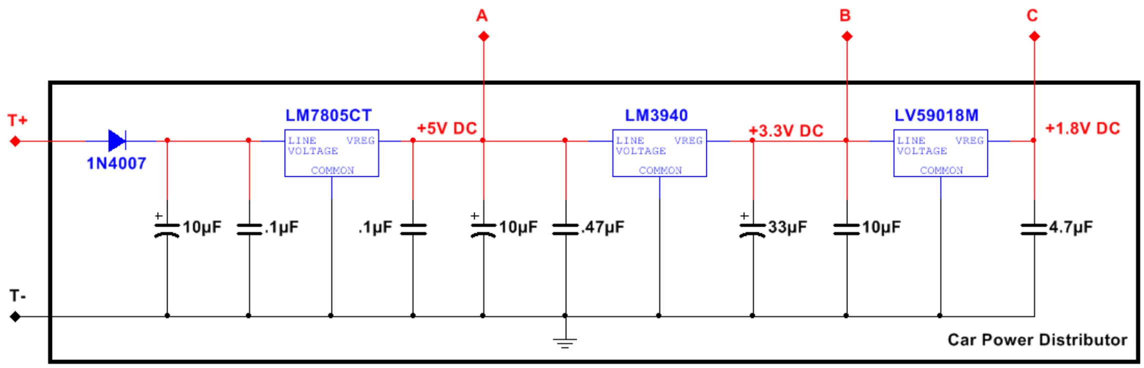

Figure 5.1.8 - Car System Power Distributor

5.2 Software Design

Concerning the software side of our project, there will be two main routines, one for each system. Starting with the ground system, its purpose is to collect data from the Bluetooth module, ground system temperature sensor, and proximity sensor, and send relevant data to the displays while using other data for control over the subsystems.

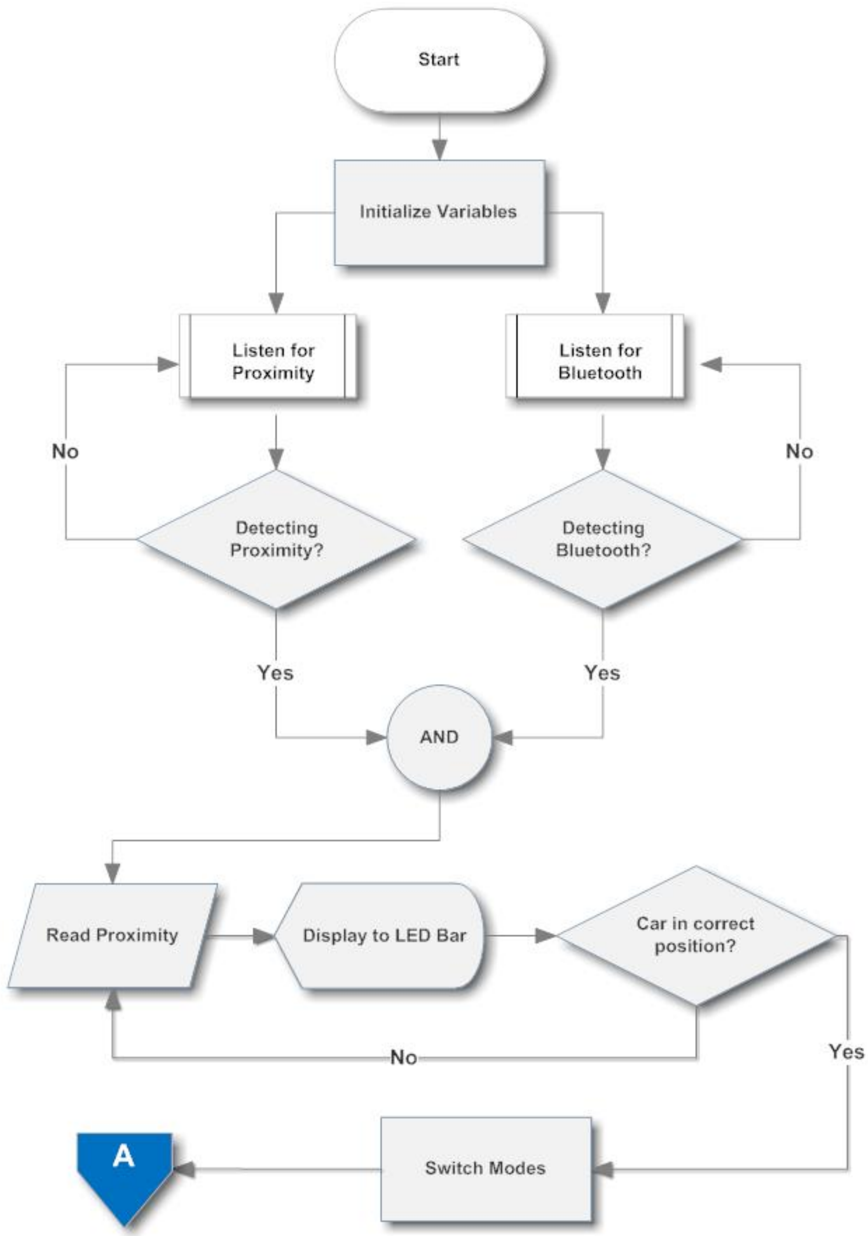

Figure 5.2.1 - Ground System Logic Flow Diagram Part A

Figure 5.2.1 shows the logic flow diagram of the ground system's microcontroller. Startup will initialize certain variables and flags that will be used throughout this flow. The microcontroller will then listen to both proximity and Bluetooth, and will only continue if both of those are being detected. The Bluetooth modules on both systems will be pre-programmed to only be able to communicate with each other. Once these conditions are met, proximity will be read and displayed to the LED bar display--it starts in mode 1. Once a pre-determined proximity reading is met, the proximity flag will be set and the microcontroller will switch modes to mode 2 and flow to marker A. The flow continues to Figure 5.2.2 on the next page.

From marker A, the Bluetooth module is now read (BT Temp and BT Voltage). These values are displayed to the 7-segment display and LED bar display, respectively. Following the entire flow, we'll assume the BT Voltage is not 100%, so then the flow asks if the BT Temp is within a pre-determined range. If not, the flow will loop until it is, and that's when the Oscillator is turned on. To prevent the Oscillator and the surrounded components from overheating, we have a ground system temperature sensor (GS Temp) and a fan aiming towards the Oscillator.

The subroutine for the Oscillator temperature control involves reading GS Temp, and if it's not in range, the fan is turned on for a preset amount of time (*X* seconds). If the GS Temp is still not in range, the Oscillator is turned off for another preset amount of time (*Y* seconds). Otherwise, once the GS Temp is within range, the flow asks if BT Voltage is 100%. If the BT Voltage at this point isn't satisfied, it loops again. If the BT Voltage reads at 100%, the Oscillator is turned off for *Y* seconds, and then loops to the top, but this time when BT Voltage is asked again, we'll be able to break off the rest of the flow. At the end of charging, the program will loop and continuously read and display the appropriate data, meaning Idle will be no. But if for some reason you want to turn it off, for power reasons, Idle can be set on, and will end the flow.

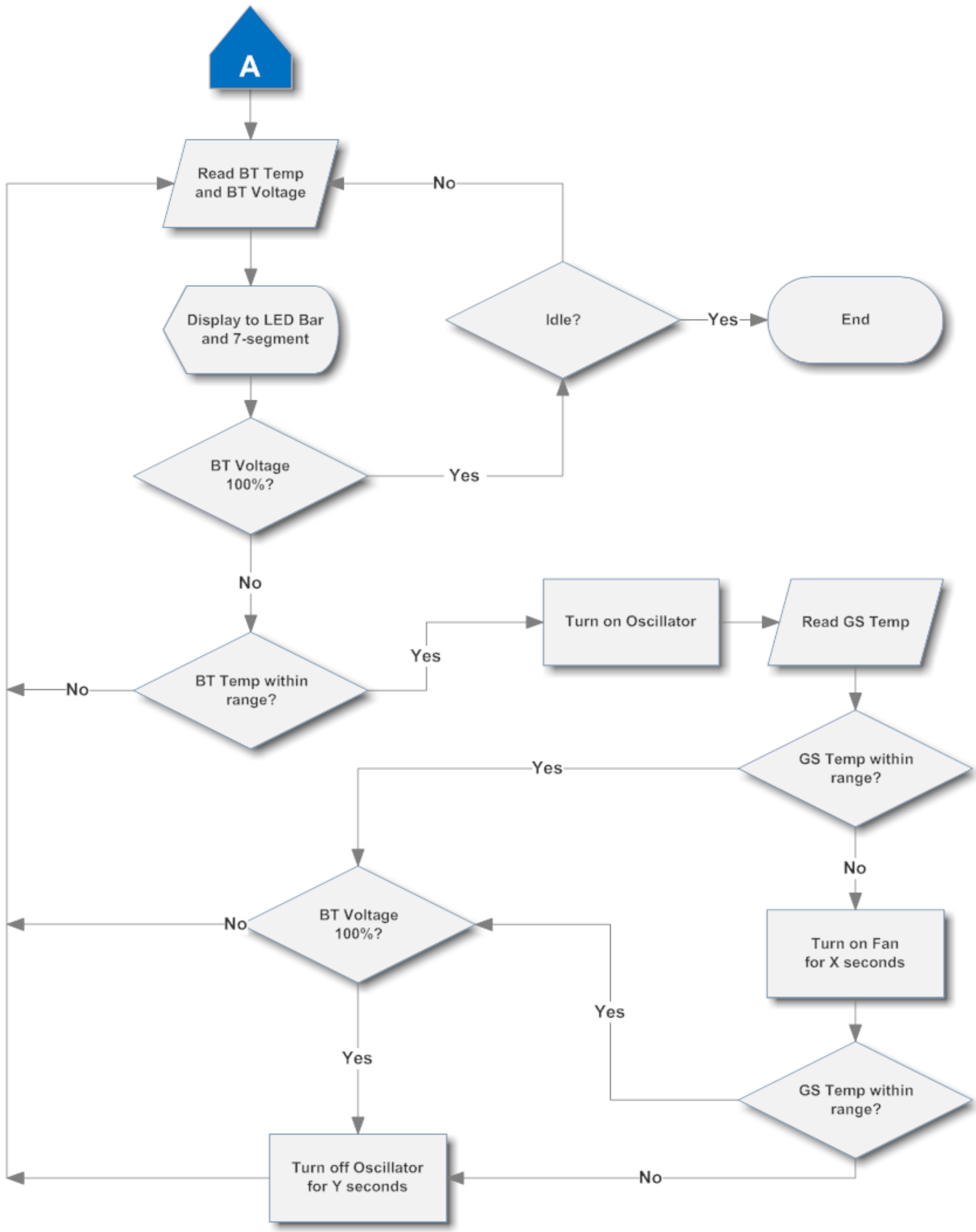

Figure 5.2.2 - Ground System Logic Flow Diagram Part B

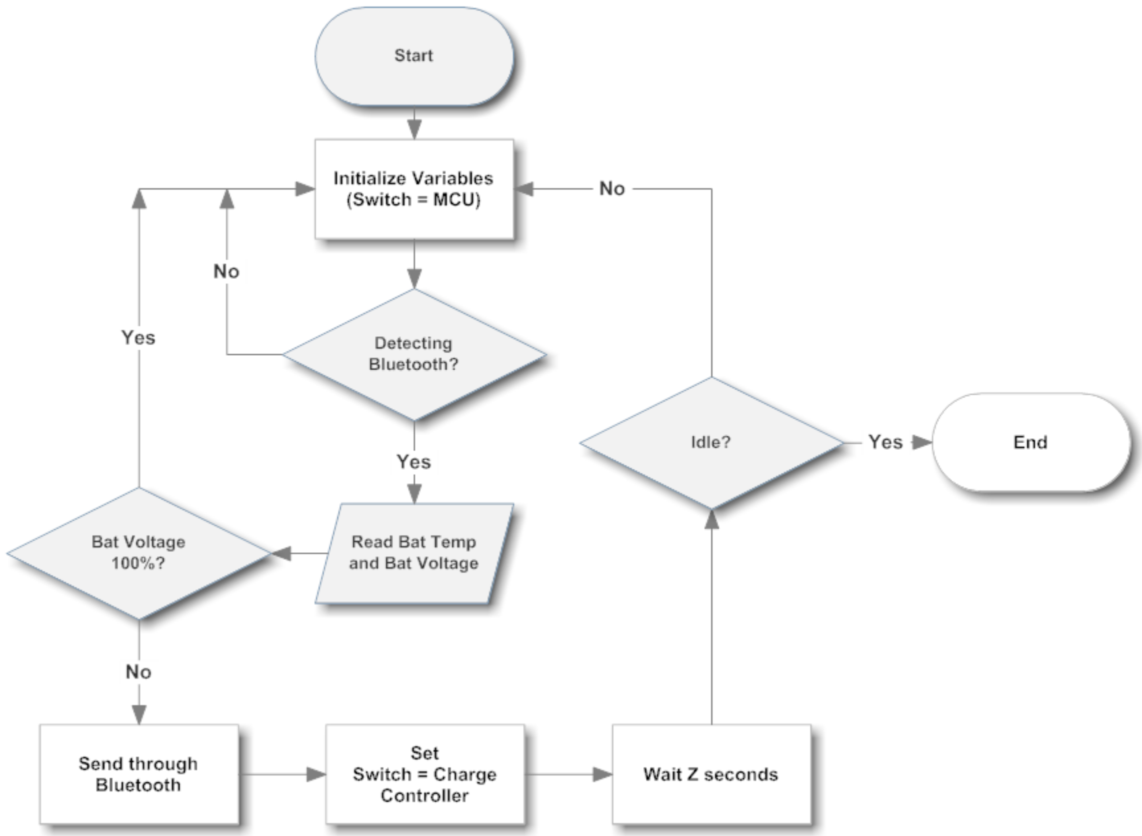

Figure 5.2.3 - Car System Logic Flow Diagram

The logic flow diagram for the car system is a lot simpler than the ground system counterpart, seen in Figure 5.2.3. Starting the flow, variable and flags are initialized (Switch is set to MCU) and the microcontroller waits until Bluetooth is detected. Once detected, the battery temperature (Bat Temp) and its voltage (Bat Voltage) are read, and if Bat Voltage is not 100%, it's sent through Bluetooth to the ground system (as BT Temp and BT Voltage, respectively). The Switch is then set to the Charge Controller and waits for *Z* seconds (while the battery is being charged). The Idle query is to end the program from looping if wanted. Once the Bat Voltage is 100%, the flow will loop. An alternative would be to send the data through the Bluetooth before the Bat Voltage = 100% query, which will allow for more updates to the ground system, rather than keeping all the updates within the car system and only sending if the Bat Voltage changes, regardless of Bat Temp changes that could be displayed.

All variable times (*X*, *Y*, *Z*) will be tested and determined while programming in the testing phase. Further details about program implementation can be found in Section 6.3 Final Coding Plan, details about testing can be found in Section 7.3 MCU Testing.

6 Prototype Construction and Coding

Now that the designing is out of the way we need to make sure we can build it. This section will outline all parts decided upon from Section 3.5 Parts Research. We will also look at PCB vendors and discuss integration and assembly of the circuit boards and parts. Finally we'll take a detailed look into the coding aspect in the software, but not so detailed that you'll just be reading code. A further look into finance can be found in Section 8.2.

6.1 Parts Acquisition

The following tables provide a specific parts list for our prototype construction. Table 6.1.1 lists the specific parts and cost for all the components covered in the parts research section. Details about each table can be found in Section 9.1 (especially regarding "assorted components") and budget details can be found in Section 8.2.

Table 6.1.1 - Specific Parts List Summary

Part	***Specific Part/s***	***Cost***
Metal Box	Steel Junction Box	$27.30
Proximity Sensor	IR Distance Sensor	$15.95
Motion Sensor	RK115FCUL00A PIR	$54.45
LED Displays	Assorted components	$21.89
Kill Switch	DPST Push Button Switch	$5.38
Fan	Evercool Cooling Fan	$9.99
Power Distributor	Assorted components	$72.91
Charge Controller	Assorted components	$4.99
Vehicle/Battery	PowerWheels 6V/12V	$100*
Temperature Sensor	ZTP-115M Temperature Sensor	$23.76
Microcontroller	Atmel ATXMEGA32A4U	$8.26
Bluetooth Module	TiWi-uB2	$17.98
Oscillator	Assorted components	$8.11
Coil, Conduit, Mounting	Assorted components	$46.72

**Estimated budget*

6.2 PCB Vendor and Assembly

Now that we have our design and part picking out of the way, we can start to assemble our circuits. It is required that we design our own circuit boards and have them crafted from a PCB vendor, instead of using a pre-made development board such as an Arduino board. However, this is only for the final product and presentation--we can use boards like Arduino for testing purposes. We're most likely going to have to create our own Gerber file, which is used to read circuit boards, and we can do this in NI Multisim/Ultiboard, CadSoft Eagle PCB Software, or perhaps AutoCAD, or even custom software that the vendor may supply us with.

To get a quote from a PCB vendor they need our Gerber file ideally, or many specifics if we don't have one. After searching through a few PCB vendors we've compiled a list in Table 6.2.1. Once we complete a satisfactory Gerber file and are ready for testing we will request quotes from the vendors, and decide which one (or multiple) we will choose. We're also taking advantage of vendors who have flat-rate deals for certain sized-boards.

Custom Circuit Boards	888-906-6331
ExpressPCB*	support@expresspcb.com
Advanced Circuits*	1-800-979-4PCB
PCB Solutions	866-956-5291
OnBoard Circuits	602-753-2113
American Circuit Technology	714-777-2480

Table 6.2.1 - List of potential PCB Vendors
*Has available software for use.

Once we obtain our circuit board, we'll need to place the parts onto the board. We can either do this ourselves, risking damaging both the board and parts but no extra cost, or we can pay for it to be done. The Amateur Radio Club at UCF can help us mount the parts onto the board, for a small donation. There are also plenty of tutorials online and on YouTube explaining how to mount using a hot plate or various other techniques.

6.3 Final Coding Plan

Our software design, as shown in Section 5.2, will be implemented and tested using Atmel Studio 6. This is a free-to-download and free-to-use application that allows customers of Atmel microcontrollers to program and debug their microcontrollers; it can also used for pre-made development boards using Atmel microcontrollers, such as Arduino. Using the programming/debugging pins on our ATXMEGA32A4U, we can program our microcontrollers for their specific purpose in each system. Test will be run to make sure our coding works and the microcontroller's pins are acting accordingly; further explained in Section 7.3.

Another piece of our MCU board that we may need to program is the Bluetooth module. However, due to its very small size (smaller than a dime) with relatively many pins (33 pins), we will need to place it in a printed circuit board first to even test it, or another developmental board which we may need to design. The programming may all be on the microcontroller side, and only utilize the four pins (Clear to send, Request to send, Data receive, Data transmit) for communication, since we won't need the Audio (PCM) pins.

7 Prototype Testing

In this section we will discuss the specifics of testing our prototype. First are the test environments for the hardware and the software. Then we'll look into our procedures for testing the coil's wireless energy transfer--the whole point of this project. Afterwards we'll look into MCU testing for both systems, and their Bluetooth connectivity between each other (making sure they can communicate). Lastly, we'll look at overall system testing once we have all the subsystems working. This will be the last phase of testing.

7.1 Hardware/Software Test Environments

Testing the hardware is crucial before integrating everything together and finding out a subsystem has failed, therefore having to disassemble everything and find out the issue. The software testing can be performed virtually anywhere. As far as the hardware testing goes, we'll break it up by car system and ground system. Once each subsystem is completed/finalized, we will test it to make sure it works with other subsystems that is connects to. For instance, the Oscillation subsystem needs to successfully connect to AC power (a given subsystem) and also successfully connect to the Power Management subsystem to power everything on the ground system side, including correct power allocation to the coil. To make things easier, we plan to test each subsystem as soon as each is finished, rather than waiting for all subsystems to be completed, then testing, then figuring out which subsystem/s is/are at fault. Once each stand-alone system and subsystem are harmoniously working with each other, we can integrate them into their final placements.

For the car system, everything will be mounted in their allocated space on the test vehicle. For the ground system, everything will be placed on a pseudo-stationary wall (meant to represent a garage wall), and possibly inside the metal box, which will house the delicate MCU and display. At this point, everything is assembled to their final placements and, in theory, works like a charm. Here is when we'll begin "consumer" testing. We will drive the test vehicle into the "garage" and see if our subsystems act accordingly. This is literally a group member pushing the test vehicle (since we're all too big to actually drive a PowerWheels) into where we set up our ground system. There are definitely bound to be issues, despite having tested each subsystem before integration, and at that point we'll need to figure out what they are. Most likely it will be human error, such as possibly disconnecting wires during assembly, or damage to the components during assembly.

For our systems to work, the most important condition that must be met (other than it actually being powered via home outlet) is that the battery is less than one hundred percent charged. If the battery is fully charged, the systems will recognize that (hopefully) and not do anything other than display it. But we want to make sure our wireless charging is working--the purpose of this senior design project. To drain the battery, we can simply connect it to the test vehicle and let it run until we know for sure it's no longer fully charged. We will also use a digital multimeter to read the battery's voltage and current at full charge and at other levels of charge.

Due to the complication of assembly, we will most likely hold these hardware tests at one of our homes/garages, which is also where we will keep the majority of our systems. Same goes with software, which can be moved between computers. Right now it's most likely that we'll be using Atmel Studio 6 for the coding of the microcontrollers. Further details about specific tests for hardware and software are explored in the next sections.

7.2 Energy Transfer Testing

The following tests will be used to validate the integrity of the wireless power transfer system that we have designed. This includes a distance checking test, alignment test, temperature test, obstruction test, coil inductance test, and efficiency test.

Distance Check Test
Purpose and Objective: The distance check is an important aspect of our design as we want to ensure that maximum charging efficiency is obtained. Since the average height of a power wheels car is approximately 10 cm our design should work flawlessly within that range. The main objective of this test is to verify the output power received by the charge controller when the height of the receiver coil is varied.

Supplies:
- Voltmeter
- Measuring tape
- Thin wooden variable platform
- Prototype charging apparatus

Procedure:
1. Disconnect rectifier circuit on car and connect the voltmeter across the rectifier output leads.
2. Place the receiver coil on the wooden variable platform then place this directly on top of the transmitter coil mounted to the ground.
3. Energize the transmitter coil.
4. Increase the height of the receiver coil one cm at a time and record the output voltage seen on the voltmeter.

This test is successful if we obtain 12 Volts or greater in the operating range which is between 6 to 12 cm above the ground. If this test fails enough power is not making it to the receiver coil and the necessary adjustment to our circuit will have to be made.

Alignment Test:

Purpose and Objective: Once we have determined the height of our vehicle's undercarriage, we would like to know implications of misalignment between transmitter and receiver coil. The main objective of this test is to verify the output power received by the charge controller when the alignment of the receiver coil is varied while the transmitter coil remains stationary.

Supplies:

- Voltmeter
- Measuring tape
- Thin wooden movable platform
- protractor
- Prototype charging apparatus

Procedure:

1. Disconnect rectifier circuit on car and connect the voltmeter across the rectifier output leads.
2. Place the receiver coil on the wooden variable above the transmitter coil at the predetermined height of the vehicle.
3. Start with the coils perfectly aligned above each other.
4. Energize the transmitter coil.
5. Move the receiver coil parallel to the ground, one inch at a time and record the output voltage seen on the voltmeter.
6. For each movement, vary the orientation of the platform ± 30 degrees in increments of 10 degrees and record the voltage seen on the voltmeter.

This test is successful if we obtain 12 Volts or greater with a misalignment of 6 inches off center. If this test fails enough power is not being radiated and the transmitter coil may have to be rewound using a different formation.

Temperature Test

Purpose and Objective: Copper losses in the coils will cause them to heat up. The coils should be able to operate for extended periods of time without overheating. The main objective of this test is to verify that the coils operate within a safe temperature range.

Supplies:

- Infrared Thermometer
- Prototype charging apparatus
- Stopwatch

Procedure:

1. Energize the transmitter coil.
2. Use the Infrared thermometer to check the coil temperature.
3. Repeat every 2 minutes for 20 minutes recording each temperature reading.

The test is successful if the coil temperature remains below 83 degrees Fahrenheit. If the test fails, the charging current may be too high and needs to be adjusted. Or, the size of the wire making the coil is too small.

Obstruction Test:

Purpose and Objective: Any obstacle placed between the ground coils and the car coil may or may not affect its ability to function as designed. The system should be robust enough to continue to operate if an obstacle is place over the ground coil whether intentionally or unintentionally. The main objective of this test is to measure the effects of different kinds of obstacles placed between the coils when it's in operation.

Supplies:

- Prototype charging apparatus
- 2X2 ft piece of wood
- 2X2 ft piece of metal
- 2X2 ft piece of plastic
- 2X2 ft piece of glass
- voltmeter

Procedure:

1. Disconnect rectifier circuit on car and connect the voltmeter across the rectifier output leads.
2. With the car in place (receiver coil correctly aligned with transmitter coil)
3. Energize the transmitter coil.
4. Measure and record the voltage across the leads of the rectifier. This is the reference voltage.
5. Place the piece of wood between both coils and record the voltage seen by the rectifier.
6. Remove the wood and repeat step 5 for the metal, plastic and glass.

The test is successful if we obtain a drop in output voltage of no more than 3% compared to the reference, when any of the obstacles are placed between the coils. If the test fails there has to be a warning label placed on the coils so that the user is aware of the loss in energy transfer if obstacles are placed between the coils.

Coil Inductance Measurement

Purpose and Objective: To obtain the inductance of the coil after it has been formed into its final shape.

Supplies:

- Inductor
- Signal Generator
- Oscilloscope
- 100 ohm resistor precise to within 1% or less

Procedure:

1. Connect the inductor coil in series with the resistor.
2. Using the function generator, connect a sine wave of 1Vp-p to the circuit
3. Monitor both the input voltage and the voltage where the indictor and resistor meet. Adjust the current until the junction voltage where the inductor and resistor meet is half the input voltage.
4. Record the frequency of the current.

The relationship between R and L is, as derived below:

$$L = \frac{R\sqrt{3}}{2\pi f}$$

Efficiency Test

Purpose and Objective: The efficiency of the wireless charging system tells us how much of the power being used to create the wireless energy transfer is actually making it to the charge controller. This also helps us in determining the feasibility of such a project.

Supplies:

- Voltmeter
- Prototype charging apparatus

Procedure:

1. Disconnect rectifier circuit on car from the charge controller and connect the voltmeter across the rectifier output leads
2. With the car in place (receiver coil correctly aligned with transmitter coil)
3. Energize the transmitter coil by turning on the oscillator
4. Use the voltmeter to measure and record the voltage at the input of the oscillator (this is Vin)
5. Use the voltmeter to measure and record the voltage across the rectifier output leads on the car (this is Vout).

The efficiency of the system is calculated by the equation:

$$Efficiency = \frac{Vout\ X\ 100\%}{Vin}\ .$$

Our goal is to achieve an efficiency of at least 40% for our prototype.

7.3 MCU Testing

There will be two MCUs within our project: one in the ground system and one in the car system. Each microcontroller will have different tasks, so they won't be clones of each other. In order for them to communicate with each other, they will utilize a Bluetooth module. This section is about MCU testing specifically, and communication between them is covered in Section 7.4 Bluetooth Testing.

Pin Usage Test

Purpose and Objective: We need to determine if every pin on the microcontroller is working correctly, just in case it may be faulty and to save us a world of trouble when debugging. This test will ensure that the pins we will be using all work, and if there are problems, that it's not the microcontroller or pins.

Supplies:

- Microcontroller
- Development Board
- Resistors and LEDs
- Breadboard (optional)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)

Procedure:

1. Once the microcontroller is securely mounted on a development board, and connected to a computer for coding, place resistors and LEDs, in series, to each I/O pin to test them. Can be tested one at a time if limited resources are available.
2. Code the microcontroller to apply output of 1 if digital, or output of 3.3V if analog, to the pin/s you are testing.
3. If the LED lights up, the pin is working correctly. Remember to choose an appropriate value for the resistor. For the ATXMEGA32A4U, 165OHM should be used for 20mA and 330OHM should be used for 10mA, depending on your preference for LEDs.
4. Disconnect the resistor/s and LED/s and redo the test for other pins you wish to test.

If all the pins are working correctly, we can move on to the next test that will cover the MCU connections to all other devices. If this test fails, then we need to get another microcontroller if the I/O pins are the actual problem.

LED Displays Testing

Purpose and Objective: The microcontroller must be able to communicate to the user, and this is done via the LED bar display and 7-segment display. This tests the communication between the microcontroller and LED displays and makes sure all is well in the kingdom.

Supplies:

- Microcontroller
- Development Board
- LED displays (set up prior)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)

Procedure:

1. The microcontroller must be setup in correspondence to the LED displays and the pins assigned to them. Since only one LED per display can be turned on (one bar and one segment in total), code will have to be written that will alternate a loop and loop it fast enough so it's unbeknownst to us.
2. Start with the LED bar display and turn on each bar and each color at a time. Then do multiple bars and colors. Finally, turn them all on.
3. Next test the 7-segment display by turning on each segment of each character at a time, then start making recognizable characters, starting from 0 through 9, then A-F, including the decimal point.
4. Finally, combine the two codes and turn on both the displays and make sure they are both working correctly in accordance with the code.

So now the microcontroller can work with the LED displays. In the final code, a self-test can be implemented that will turn on all LEDs on start up for a couple seconds. Also, all accessory LEDs should be tested and working, but that's simple since each is connected to its own pin.

Proximity Testing

Purpose and Objective: This is to test the connection between the microcontroller and proximity sensor. The data from the proximity sensor will be the analog input for the microcontroller, which will then send the corresponding data to the LED displays.

Supplies:

- Microcontroller
- Development Board
- Proximity Sensor (set up prior)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)

Procedure:

1. The proximity sensor should be constantly powered, instead of being setup through the motion sensor, as shown in our design.
2. Connect the analog input line from the proximity sensor to the appropriate microcontroller pin.
3. Code the microcontroller to read its value, and using a pre-existing table of values in correspondence with proximity (found in datasheet), create an output that can be placed into the LED bar display.
4. For added integration, you can test these values to the LED bar display.

The analog proximity values are taken into the microcontroller and digitized to 3 bits for 8 possible outcomes (for 8 LED bars). A similar test can be applied to the temperature sensor in the car (the ground system's temperature sensor may or may not be included in the final design).

Power Distributor Switch Test

Purpose and Objective: This is a very important test, for it allows the oscillator to be turned on and off, essentially allowing charging of the battery to happen or not. The microcontroller must be able to activate a switch in the power distributor once a given value is reached.

Supplies:

- Microcontroller
- Development Board
- Power Distribution circuit, with switch (set up prior)
- Resistor and LED
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)

Procedure:

1. Once everything is setup, connect a control line to the switch in the power distribution circuit to the appropriate microcontroller pin.
2. The value that will be determining the status of the controlling pin will be determined from the status of the car's battery or the ground system's temperature sensor (optional), only after meeting certain proximity and Bluetooth conditions.
3. Create a dummy variable that represent the level of charge of the battery and use that to control the switch. Fully charged means turn the switch off; under-charged means turn the switch on.
4. The resistor and LED should be connected to the output of the switch, so if activated, it will turn on.

The switching is working if the LED is turned on and off, which represents the flow of power being turned on and off to the oscillator and fan.

Battery Voltage Testing

Purpose and Objective: The car system's microcontroller needs to be able to read the voltage of the car battery to determine its state of charge. This data is relayed back to the ground system and displayed. In our design, the wires that determine the state of charge are connected inside the charge controller. This test is to make sure the voltage of the battery itself can be read via analog wires connected to the microcontroller.

Supplies:

- Microcontroller
- Development Board
- Battery with accessible terminals (set up prior)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)

Procedure:

1. Connect, from the battery terminals, two wires that will be analog input to the appropriate microcontroller pins.
2. Write code to read these two pins and determine an absolute value, and using a pre-existing table of values corresponding with state of discharge and voltage reading (found in datasheet, or can be created), create an output in terms of percentage of battery life.
3. This value will be sent through the Bluetooth and be used for display to the LED bar display and control in the ground circuit. Therefore extended tests may be performed to simulate the flow of this data.

This is a crucial test for it will determine the status of the battery for charging, thus allowing all other systems to react to it. Once everything is complete, testing this again is necessary since it will be now connected through the charge controller instead of the battery itself.

7.4 Bluetooth Testing

There will be two Bluetooth modules in this project communicating between each other. One will be housed in the ground system and the other in the car system. These tests are necessary to ensure properly functioning modules.

Security Testing

Purpose and Objective: We need to ensure that no other Bluetooth device can be connected to any of these Bluetooth modules. Any interference by another Bluetooth device whether intentionally or unintentionally may cause unwanted conditions in the charging system.

Supplies:

- Microcontroller
- Development Board
- Resistors and LEDs
- Breadboard (optional)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)
- Bluetooth Modules
- Cell phone with Bluetooth connectivity

Procedure:

1. Once the Bluetooth is securely mounted on the development board and connected to the microcontroller.
2. Program the Bluetooth i.e. set the pass code for authorized connectivity.
3. Turn on any one of the Bluetooth to start broadcasting (make visible).
4. Using the cell phone, attempt to connect to the Bluetooth chip and when prompted enter a random password.
5. Repeat for the other Bluetooth module.

If the cell phone fails to get connected, then the test is successful. If the cell phone gets connected with a generic password (0000) or connects without a password then the test has failed and a more secure Bluetooth module will be required for communication purposes.

Communication and Connectivity

Purpose and objective: We need to ensure that there is a good communication between both Bluetooth modules. Data collected from the car must always make it to the control panel's microcontroller with guaranteed integrity. In the procedure below the car's Bluetooth module will be sending data to the control pane's Bluetooth module.

Supplies:

- Microcontroller
- Development Board
- Resistors and LEDs
- Breadboard (optional)
- Power Supply
- Communication Interface for Coding (Atmel Studio 6)
- Bluetooth Modules

Procedure:

1. Ensure that both modules are connected to each other.
2. Have the Car system Bluetooth module send a Request-To-Send (RTS) data signal to the control panel's Bluetooth module. RTS must be set to logic 1 meaning data is ready to be transmitted.
3. The Clear-To-Send on the on the Control Panel's Bluetooth module must be set to logical 1 indicating that it is ready to receive data. If CTS remains logic 0 that means the data is not ready to be received.
4. HCI Data Transmit must be set to logical 1 after CTS is set to logical 1, so that the data can be transmitted.
5. HCI Data received on the receiving Bluetooth must set to 1 to indicate that data has been received.
6. Repeat steps 1 through 4, but this time with the Bluetooth modules swapping roles.

If the above does not work accordingly then communication is flawed and must undergo troubleshooting.

7.5 System Testing

This is the final stage of testing; all the systems prior to these tests are assumed to be in proper working order. System testing includes ensured battery charging and proper safe shutdown of all the systems.

Battery Charging Check

Purpose and Objective: The battery charging check simply substantiate the charging time of the battery from various discharge levels.

Supplies:

- Prototype charging apparatus
- Stopwatch timer

Procedure:

1. Start with the battery totally drained. (0 Volts).
2. Ensure that the energy transfer coils are properly aligned and kill switch is open.
3. Manually energize the charging system by closing the kill switch and start the stopwatch simultaneously.
4. Battery will commence charging momentarily. Continue to check battery charge capacity every 10 minutes.
5. Record charge time and battery capacity at each 10 minute interval until fully charged.
6. Allow batter to discharge fully by connecting a 12V bulb across the terminals.
7. Repeat steps 1 to 5 every other day ten times.

The data collected will be averaged and used to construct a charging vs time graph. The objective is to have the battery fully charged from 0 Volt within 5 Hrs.

System Shutdown Test

Purpose and Objective: This is to test the functionality of the automatic shutdown feature of the project. The charge system must shutdown when the battery is fully charged or if the temperature of the battery rises above 30ºC.

Supplies:

- Prototype charging apparatus
- Temperature sensor
- Metal can of water heated up to 25ºC
- Cigarette lighter
- Thermometer

Procedure:

1. Energize the charging system.
2. Place the thermometer onto metal can of water preheated to 25ºC and verify temperature.
3. Point the beam from the IR temperature sensor into the can of water then apply heat to slowly raise the temperature of the water.
4. Observe the temperature reading on the thermometer. Upon surpassing the 30ºC graduation the system should shut down momentarily.
5. Record the temperature at which the system shuts down.
6. Remove the IR temperature sensor from the can of hot water and allow the system to resume charging.
7. Visually inspect the control panel displaying the charge capacity as the battery is charging up to 100%.
8. System should shut down automatically on reaching 100%.

This test is successful if we observe a system shutdown upon battery capacity reaching 100% and we also observe a system shutdown between 30ºC to 35ºC. If any of these tests fail then recalibration is necessary.

8 Administrative Content

8.1 Milestones

Table 8.1.1 outlines our milestones from the beginning of our project. Sections 1, 2, and 3 represent our first semester, up until the due date of our first draft paper on December 2, 2013. Sections 4, 5, and 6 represent the second semester, the construction of our project, which will end in our presentation at the end of April.

Table 8.1.1 – Outline of our milestones

Task Name	***Duration***	***Start***	***Finish***
1) Definition	**2 weeks**	**Sept 3rd 2013**	**Sept 9th 2013**
➢ Define project	2 weeks	Sept 3rd 2013	Sept 9th 2013
2) Research	**8 weeks**	**Sept 16th 2013**	**Nov 10th 2013**
➢ Type of Vehicle	2 weeks	Sept 16th 2013	Sept 29th 2013
➢ Blue Tooth T/R	3 weeks	Sept 16th 2013	Oct 6TH 2013
➢ Temperature Sensor	3 weeks	Sept 16th 2013	Oct 6TH 2013
➢ Charge Controller	2 weeks	Oct 7th 2013	Oct 20th 2013
➢ Volt Meter	3 weeks	Oct 7th 2013	Oct 28th 2013
➢ Type of Coil	3 weeks	Oct 13th 2013	Oct 30th 2013
➢ Display	3 weeks	Oct 13th 2013	Oct 30th 2013
➢ Proximity Sensor	3 weeks	Oct 13th 2013	Oct 30th 2013
➢ MCU	3 weeks	Oct 21st 2013	Nov 10th 2013
3) Design	**6 weeks**	**Oct 6th 2013**	**Nov 30th 2013**
➢ Hardware			
• Oscillator	6 weeks	Oct 31st 2013	Nov 30th 2013
• Blue tooth	6 weeks	Oct 6th 2013	Nov 30th 2013
• Charge Controller	6 weeks	Oct 20th 2013	Nov 30th 2013
➢ Software			
• Microcontroller	6 weeks	Nov 11th 2013	Nov 30th 2013
4) Prototype	**9 weeks**	**Jan 6th 2014**	**Mar 9th 2014**
➢ Hardware			
• Oscillator	9 weeks	Jan 6th 2014	Mar 9th 2014
• Blue tooth	9 weeks	Jan 6th 2014	Mar 9th 2014
• Charge Controller	9 weeks	Jan 6th 2014	Mar 9th 2014
➢ Software			
• Microcontroller	9 weeks	Jan 6th 2014	Mar 9th 2014
5) Test	**3 weeks**	**Mar 10th 2014**	**Mar 30th 2014**
➢ Whole System	3 weeks	Mar 10th 2014	Mar 30th 2014
6) Final	**2 week**	**Mar 31st 2014**	**April 13th 2014**
➢ Documentation	2 week	Mar 31st 2014	April 13th 2014
➢ Presentation	2 week	Mar 31st 2014	April 13th 2014

8.2 Budget/Financial Discussion

Since we are paying out of pocket, we were very frugal in regards to part acquisition and considered services. Figure 8.2.1 shows our initial thoughts on our budget before any part research was done and is very general. Figure 8.2.2 shows a newer budget that is more detailed and based on our research. Figure 8.2.3 shows our [current] cost for parts and services and its relation to our new budget. For a complete list of parts and services involved see Section 6.1.

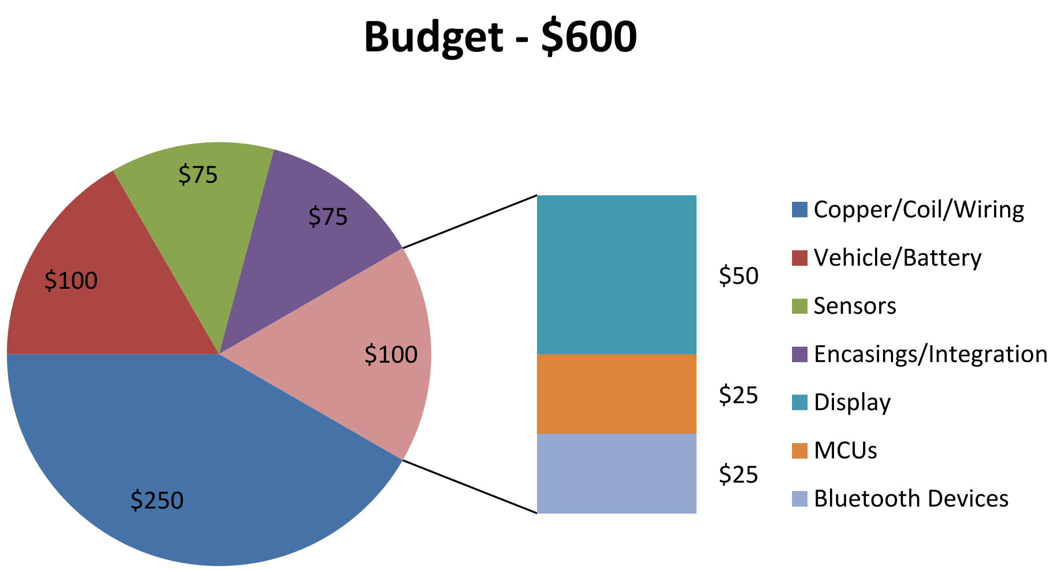

Figure 8.2.1 - Initial Budget

The generous budget to the copper coil and wiring is due to the necessity of the amount we need. The coil itself with either be molded by us or bought that way, depending on cost and availability. The wires will also be a special wire used solely by the coils; this does not include the wiring for other devices. The vehicle we will be using will be a PowerWheels with its stock battery. We will be obtaining a used, working one preferably for a sound amount of money--see recent Craigslist postings.

The sensors, display, MCUs, and Bluetooth chips are given a bloated budget, just in case they don't work and we need to acquire another or a different type. The encasings/integration involves the encasing of the two coils and the encasing of the display. This slice basically involves the cost of putting everything together, soldering and wiring cost, the cost of physical parts used for encasing (wood frame, metal box), and possibly the cost of labor required, if applicable.

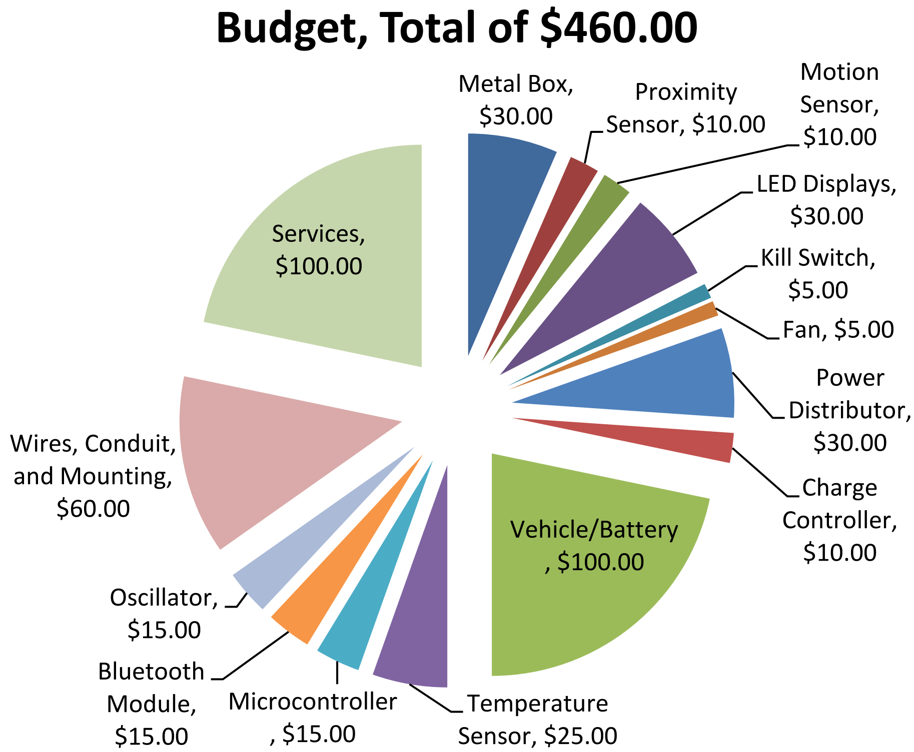

Figure 8.2.2 - Revised Budget as of December 1, 2013

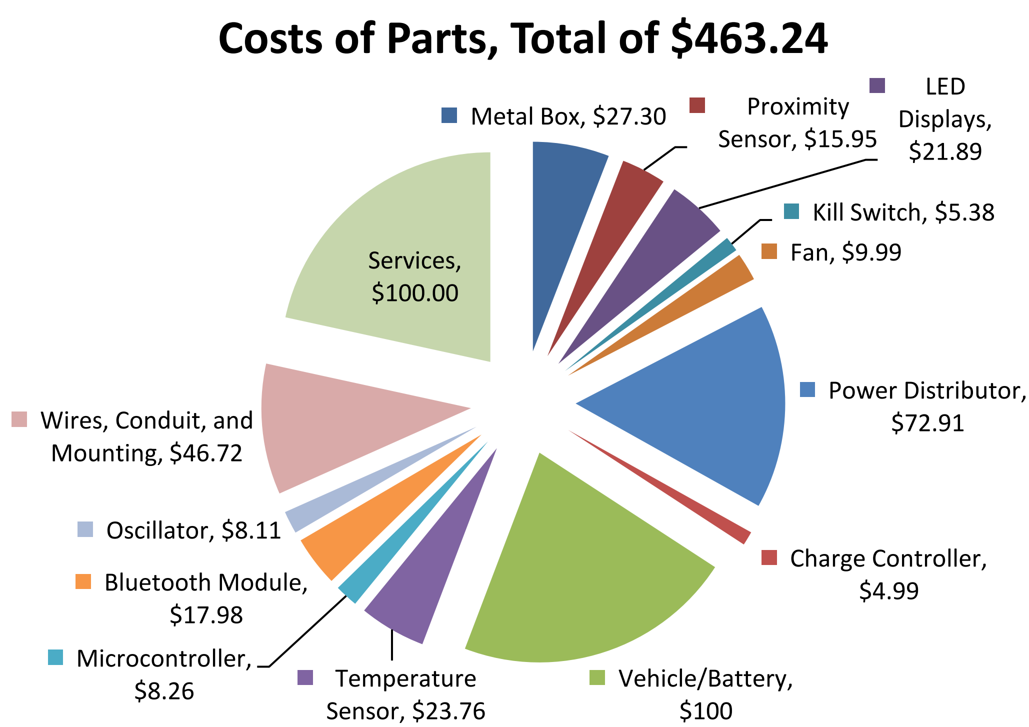

Figure 8.2.3 – Cost of Parts

9 Appendix

9.1 Table of Tables

Table 3.5.5.1	WaveShare 4-Digit 8-Segment LED Display Tube Board Module http://dx.com/p/4-digit-8-segment-led-display-tube-board-module-w-point-blue-black-176813
Table 3.5.5.2	Kingbright BA56-12SRWA http://www.mouser.com/ProductDetail/Kingbright/BA56-12SRWA/?qs=SxaZfIVsCL2GBVly1l0tvQ==
Table 3.5.5.3	Adafruit 0.56" 4-Digit 7-Segment Display http://www.adafruit.com/products/1002
Table 3.5.6.1	DPST Push Button Switch http://www.amazon.com/Amico-Mushroom-Emergency-Button-Switch/dp/B0094GM004
Table 3.5.7.1	Cooling Fan (EC8010LL05E) http://www.newegg.com/Product/Product.aspx?Item=N82E16835119129&Tpk=EC8010LL05E
Table 3.5.8.1	Power Distributor Components List LM338K http://www.mouser.com/ProductDetail/STMicroelectronics/LM338K/?qs=sGAEpiMZZMvHdo5hUx%252bJYuOUXojIh3B1 LM7812 http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/LM7812CT/?qs=sGAEpiMZZMtUqDgmOWBjgC5jv%252bsRCBsGZyYOsz27OnY%3d 50SQ080 http://www.mouser.com/ProductDetail/Vishay-Semiconductors/50SQ080GTR/?qs=sGAEpiMZZMtQ8nqTKtFS%2fJprle8Jw5aC1U64yrL8KjY%3d LM7805 http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/LM7805CT/?qs=sGAEpiMZZMtdAabcSkQOlwJydEoyhc9b LM3940 http://www.mouser.com/ProductDetail/Texas-Instruments/LM3940IS-33-NOPB/?qs=sGAEpiMZZMvu8NZDyZ4K0RCH7yDxBCEJ LV59018M http://www.mouser.com/ProductDetail/ON-Semiconductor/LV59018M-TLM-H/?qs=%2fha2pyFaduiClO%252bHpq3J2U26XJ2BtQBR%2f5K8OUb2CcI%3d 1N4007 http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/1N4007/?qs=sGAEpiMZZMuQUXCJI7Y4lvWy%252b1U8RtCq
Table 3.5.8.2	Transformer (166P18) http://www.alliedelec.com/search/productdetail.aspx?SKU=70181275#tab=similar

Table 3.5.9.1	Charge Controller Components List Trimmer VR http://www.ebay.com/itm/10-x-4-7K-OHM-Trimmer-Trim-Pot-Variable-Resistor-6mm-/220630307995 C106DG http://www.taydaelectronics.com/scrs/c106d-scr-4a-400v-200ua-to-225-3-c106dg.html S4006DRP http://www.mouser.com/ProductDetail/Littelfuse/S4006DRP/?qs=sGAEpiMZZMuAO0%252bGuNbnQp3KYSxDRymlOo4tFuUi0lE%3d GBU6A http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/GBU6A/?qs=sGAEpiMZZMuQUXCJI7Y4lu4jiJAwYUBz TLC2272CP http://www.mouser.com/ProductDetail/Texas-Instruments/TLC2272CP/?qs=sGAEpiMZZMtCHixnSjNA6NDQA1eMYwPy1dlIO6ln6a4%3d 2N3906 http://www.mouser.com/search/ProductDetail.aspx?qs=Ypxpq5eNvNU%2FcZclrdZCRg%3D%3D
Table 3.5.10.1	Batteries and Chargers from Fischer-Price http://www.fisher-price.com/fp.aspx?e=search&N=0&Ntk=Products&Ntx=mode%2Bmatchany&Nr=171&st=900000&Ntt=powerwheels
Table 3.5.11.1	GE Sensing ZTP-115 http://www.digikey.com/product-detail/en/ZTP-115/235-1346-ND/446799?WT.mc_id=PLA_446799
Table 3.5.11.2	Thermistor Sensor Surface-Mount Stick-On (SA1-TH-44000 Series) http://www.omega.com/pptst/SA1-TH-44000.html
Table 3.5.11.3	GE Sensing ZTP-115M http://www.mouser.com/ProductDetail/GE-MC-NovaSensor/ZTP-115M/?qs=sGAEpiMZZMvPLCW7ruiZXv5UBy3UHzn5srgnzKsfxUI%3D
Table 3.5.12.1	Atmel ATMEGA32A-PU http://www.mouser.com/ProductDetail/Atmel/ATMEGA32A-PU/?qs=sGAEpiMZZMvnwheKzbT%252bF%2fUkeb%2fIhzVI
Table 3.5.12.2	TI 595-MSP430F5529IPN http://www.mouser.com/ProductDetail/Texas-Instruments/MSP430F5529IPN/?qs=sGAEpiMZZMsp%252bcahb6g%252bW5GRVF96zD1p3cdRJ47A0tA%3d
Table 3.5.12.3	Atmel ATXMEGA64A4U-AU http://www.mouser.com/ProductDetail/Atmel/ATXMEGA64A4U-AU/?qs=sGAEpiMZZMsrb0xF%2fYczNw6pPTLsFZw3LtTyE5HqpqM%3d

Table 3.5.13.1	CC2540 RHAT http://www.mouser.com/ProductDetail/Texas-Instruments/CC2540F256RHAT/?qs=sGAEpiMZZMsyM1rGGtQxrPlhStm%2fMGm9
Table 3.5.13.2	RN41-XV Bluetooth Module https://www.karlssonrobotics.com/cart/RN41-XV-Bluetooth-Module-Chip-Antenna/
Table 3.5.13.3	BC04-B Bluetooth Module http://www.alibaba.com/product-gs/1341340611/BC04_B_Bluetooth_module.html
Table 3.5.13.4	ENW-89841A3KF http://www.mouser.com/ProductDetail/Panasonic/ENW-89841A3KF/?qs=sGAEpiMZZMvs8H5ZmPej46VPYd%252baqYMJ
Table 3.5.13.5	BL600 Series http://www.mouser.com/Search/Refine.aspx?Keyword=bl600&Ns=Pricing%7c0&FS=True
Table 3.5.13.6	TiWi-uB2 http://www.mouser.com/ProductDetail/LS-Research/450-0104/?qs=sGAEpiMZZMsGelYiB%252bjhZvL7JMtcPKyqecVPcbS7SYE%3d
Table 3.5.14.1	10 AWG Solid Copper Conductor http://www.ebay.com/itm/10-gauge-AWG-Green-Ground-Wire-50-ft-Solid-Copper-UL-Listed-CABLE-SATELLITE-/151083682236
Table 3.5.14.2	3/8in Copper Tubing http://www.ebay.com/itm/3-8-INCH-BY-50-FEET-ROLL-REFRIGERATION-HVAC-COPPER-TUBING-/231034134240?pt=LH_DefaultDomain_0&hash=item35cab51ee0
Table 3.5.14.3	Litz Wire http://www.ebay.com/itm/Litz-wire-660-46-for-crystal-radio-coil-Loop-anten-60-/160428065987?pt=LH_DefaultDomain_0&hash=item255a4204c3
Table 3.5.14.4	Aluminum http://www.ebay.com/itm/39-Ft-Silver-Aluminum-Craft-Wire-12-Gauge-Jewelry-Making-Beading-Wrapping-/140976317160?pt=LH_DefaultDomain_0&hash=item20d2d7e2e8

Table 3.5.15.1	Oscillator Components List 1N4740A http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/1N4740A/?qs=sGAEpiMZZMtQ8nqTKtFS%2fD313Kx94AdFYpyoBaIVrwg%3d BYV26E http://www.mouser.com/ProductDetail/Vishay-Semiconductors/BYV26E-TAP/?qs=sGAEpiMZZMtbRapU8LlZD0OYaqOCagf0iiwRcz8lGpY%3d IRF2807 http://www.mouser.com/ProductDetail/International-Rectifier/IRF2807PBF/?qs=sGAEpiMZZMshyDBzk1%2fWi5%252bqVgN3%252bWS8amFH3ptirs4%3d LM7812 http://www.mouser.com/ProductDetail/Fairchild-Semiconductor/LM7812CT/?qs=sGAEpiMZZMtUqDgmOWBjgC5jv%252bsRCBsGZyYOsz27OnY%3d
Table 3.5.16.1	Non-Metallic Conduit http://www.homedepot.com/p/AFC-Cable-Systems-1-2-in-x-25-ft-Non-Metallic-Liquidtight-Conduit-6002-22-00/202286718?N=bohlZ1z113d9#.UppdEMRwqM5
Table 3.5.16.2	Halex 1/2in Liquid Tight Connector http://www.homedepot.com/p/Halex-1-2-in-Liquid-Tight-Connector-Nylon-Multipiece-25-Pack-76205B/202241095?MERCH=REC-_-SearchPLPHorizontal1-4-_-NA-_-202241095-_-N#.UppdHcRwqM5
Table 3.5.16.3	1/2in PVC Conduit Clamps http://www.homedepot.com/p/t/100404168?langId=-1&storeId=10051&catalogId=10053&N=5yc1vZ1z117vu&R=100404168#.UppfVsRwqM5
Table 3.5.16.4	2 Gang Weatherproof Electrical Outlet Box and Cover http://www.mouser.com/ProductDetail/Panasonic/ENW-89841A3KF/?qs=sGAEpiMZZMvs8H5ZmPej46VPYd%252baqYMJ
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