Wireless Recharging System

PROJECT PLAN

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Table of Contents

List of figures/tables/symbols/definitions

H: Henry, a unit of inductance
L: Inductance, measured in Henrys
F: Farad, a unit of capacitance
C: Capacitance, measured in Farads
Ω: Ohm, a unit of resistance
R: Resistance, measured in Ohms
Hz: Hertz, a measure of oscillations per second.

H-Bridge*:* Circuit made with MOSFETs that can modulate a higher voltage source with a smaller one to a desired frequency for a load.

NCS: National Carwash Solutions (this is our client)

FET: Field effect transistor

BJT: Bipolar junction transistor

Voltage Regulator: Device that regulates voltage to a particular level

AC: Alternating current

DC: Direct current

Capacitor: An electrical component that resists DC flow and can store a charge via electron build up

Inductor: An electrical component that resists AC flow and can store a charge via magnetic field

IC: Integrated circuit

Magnetic resonance: When two objects have the same resonant frequency in an electromagnetic field. This is similar to having two bells that vibrate at the same frequency. When one vibrates, resonance induced vibration in the other. In our case, we oscillate a current, which oscillates the transmitter's electric field, which creates a varying magnetic field, which induces a similar electric field in the other coil.

1 Introductory Material

1.1 Acknowledgement

We are very grateful for our client's contributions and involvement in our project. We have been in constant contact and have received ample amounts of information that is relevant to our work. NCS has also treated us to a visit of their facility so we could figure out what our project was really for and be more in touch with their view of the project. We would also like to thank those who helped fund our project. Additionally, we would also like to thank Würth Electronik for their assistance in making our first prototype possible. Lastly we would like to thank Infineon Technologies for their very helpful customer support and advice in implementing their parts.

1.2 Problem Statement

The problems we face are quite simple to explain but difficult to remedy. NCS has a sensor on one of their machines that runs off of a battery. This battery however, is not rechargeable, and is located in a difficult to power location. The sensor basically detects whether or not the washing arm of the machine has been damaged or struck and shuts down the machine to prevent further damage to the system. NCS also wants the option of adding other sensors as well as LEDS to the washing arm for additional safety and entertainment in their car wash.

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

1.3 Operating Environment

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

1.4 Intended Users and Intended Uses

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

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

1.5 Assumptions and Limitations

Assumptions:

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

Limitations:

- 3V-24V @ 1A specifications for load values
- Distance between transmitter coil and receiving coil should be between ½'' to ¾''
- Space for our components is less than
- Tuning our coils to resonate to maximize efficiency

1.6 Expected End Product and Other Deliverables

- Prototype - December 7, 2018:
  - We expect to have a functional breadboard circuit prototype of our design by the end of the semester. This physical prototype will demonstrate that we can transmit sufficient power-with copper coils through the air. This will be done by following the design we have created in section 2.5 (page 7). Furthermore, this prototype will test the abilities of our circuit, such as maximum oscillating frequency, and max power flow.

- Final Design - May 3, 2018:
  - Once we have optimized our power transfer method, we will assemble the necessary components to utilize our power transfer as effectively as possible. With this focus, we aim to complete our project on time and include the specified desires of our client. The final version of our design will be put on a custom components on PCBs and presented to our clients along with its documentation.

  - More specifically, we plan to provide NCS with a system that can power LEDs and sensors during busy hours and charge while not operating. The system will be able to manage power in such a way that the batteries within do not drain completely, and that power is consistently provided to the sensors. It will also have the ability to toggle on the LEDs to keep power draw at a minimum when idle or, if needed, when operating.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

We aim to do this:
– Wirelessly transmit power from the a source on the machine to a washing arm
– Receive the power and rectify/regulate it
– Charge batteries to store power for when arm is in operation
– Light and LED strip to make are more entertaining
– Make the system as reliable and long lasting as possible
– Transfer as much power as efficiently as possible

2.2 Functional/Non-Functional Requirements

Functional:
The main functional requirement is to transfer power over a ½ to 1 inch gap of air to charge batteries that power sensors and LEDS. This power must at least be enough to account for losses in the receiving end as well as for the power consumed by controlling systems (such as microcontroller) and sensors that cannot be disabled. More specifically, we need to send a minimum of 2 watts to compensate for sensor power, controlling power, and losses through components. The system will also need to run over longer periods of time with minimal charging, as this would represent a busy day with lots of cars being washed leaving little resting time. To do this, we will size our batteries to handle these kinds of loads, in the range of 24 to 72 amp-hours. Those are the most essential functions desired of our project. The large gap would allow the system to be flexible to the machines various movements. The system will also need to be able to run during high demand hours and not fail or run out of power. The batteries will need to last longer than the current battery configuration does and supply significantly more power as well.

Non-Functional:
One of the main non-functional requirements we have looked at is the user interface and controlling of our system. At the moment, we plan to provide a system that is ready to plug in and go and have little to no maintenance. But if our client desires to edit code or change its functions, then making that an option for them would be ideal. Also, making the overall system efficiency is another goal that we would like to achieve, but is not necessary for it to function.

2.3 Constraints Considerations

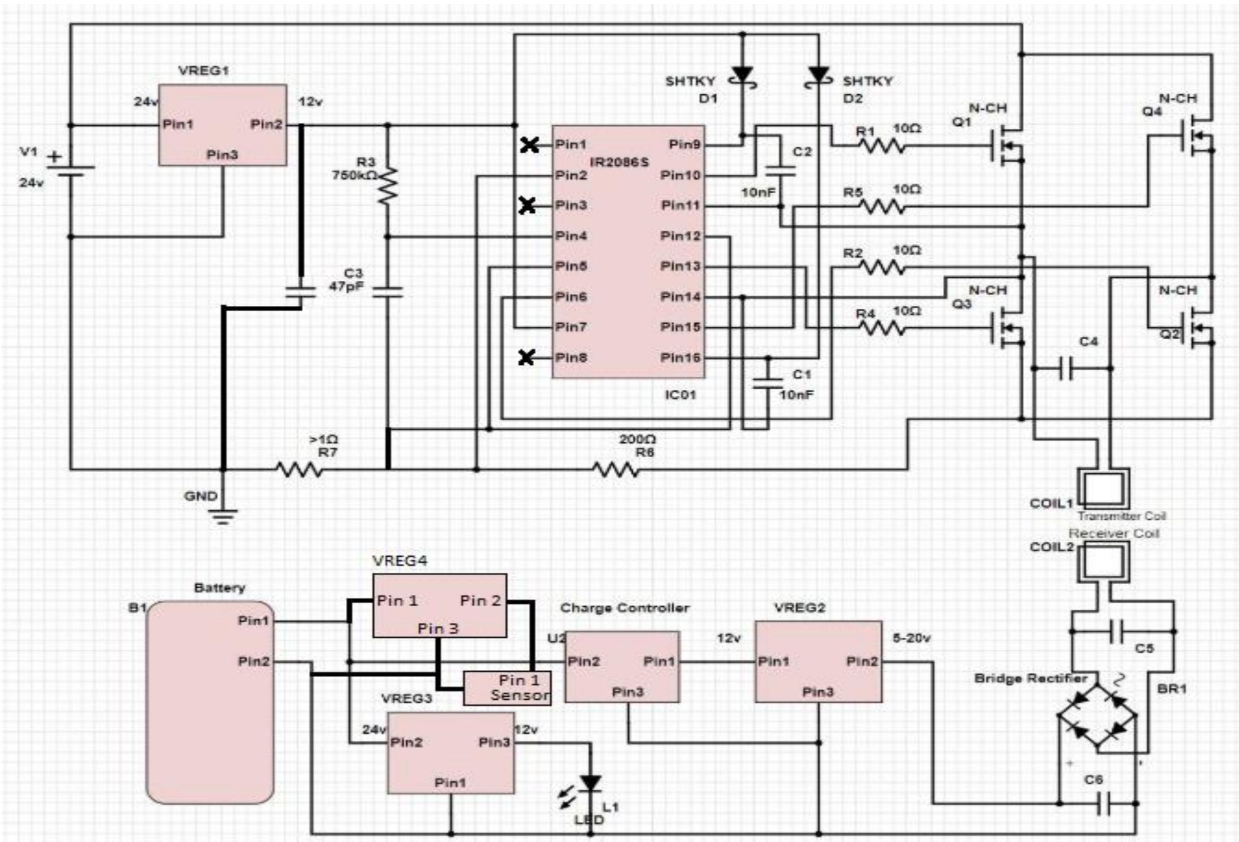
Due to the nature of our project, the space we will be working in is not only relatively small and limited, it is also set in a rough environment. For these reasons the system will need to be protected with a cover or other protective covering(s). When finished, our creation will need to be stable over long working hours and last longer than what is currently used in NCS systems. Another goal of ours is to follow the guidelines set by standards such as the OSHA standard and the NEC standard. Considering the power levels we will be working with and designing for, safety will be a top priority. More specifically, we will design as many safety features as possible into our project to prevent such catastrophes as fire or circuit shorting and destruction. Although cost will not directly be an issue, keeping costs low will be ideal to satisfy our client.

2.4 Previous Work and Literature

While developing our plan we looked online for papers that would be helpful to us calculating the technical parts of our project. In fact, there are companies that sell transmitting coils and provided a wide variety for various applications. Although there may have been and may be other projects that have done something similar to ours already, we have yet to find any sources and/or work of them. We did however find papers discussing power transmission efficiency as well as the equations needed to calculate the parameters and values of a hypothetical system (IEEE). Many smartphones use QI standard wireless charging nowadays and we have been following the news of these developments. One of the shortcomings of the QI standard is the required close range for power delivery. In summary, nearly all literature on wireless power transfer is done for small devices like smartphones or are simply for low power applications.

2.5 Proposed Design

In early development, we discussed a few ways about solving the issue, but each other idea we came up with did not pan out. A wired connection would not be possible, as the car wash arm spins constantly and wouldn't be able to untangle itself, and a tesla coil style of power transfer would be wasteful, dangerous, and expensive. So we decided to stick with the wireless magnetic induction method of power transfer. Below you can see the schematic of our system as we have determined thus far.



(*Figure 1)*

Transmitter Power: A 24 DC source is provided to us and located on the car washing machine. This can be seen on the top left hand side of the figure (VS). From there, the power flows to a voltage regulator (VREG1) which bucks the voltage down to a suitable 12 volts for the Integrated circuit (IR2086s). The 24 volt supply also connects to the H-Bridge MOSFETs on the top right hand side of the diagram. The power flow through the MOSFETs is controlled by the integrated circuit, and allows the direction of the current through the MOSFETs and subsequent coil (Coil1 middle right connected in parallel to C4).

Transmitter Control: Once the voltage is made suitable by the aforementioned VREG1, it is then used to supply the VCC of the IC. The resistor and capacitor, R3 & C3, which immediately follows VREG1 are sized to alter the output frequency of the IC. This output frequency of the IC is seen from of a square wave from its outputs on pins 6, 10, 13, & 16 on the diagram. For a more detailed look at what outputs come from this IC, please refer to our design document. These square waves are output in a way that cause the MOSFETs to alternate between their on and off states, and cause the current through the transmission coil (Coil 1) to change direction which creates an alternating current and alternating magnetic field.

Receiver Power: From Coil1, the changing magnetic field induces a current within Coil 2, which is used to power the receiving circuit. From Coil 2, the current passes by a capacitor C5 used to aid in resonating the coils, and then pass into a bridge rectifier to create a useable DC on the other end. The capacitor C6 (bottom right) helps smooth out the voltage from the rectifier and make it more suitable for the regulator it is attached to. At this point, VREG2 regulates and feeds a charge controller (bottom middle) which then feeds the batteries and all other voltage regulators that power the LEDs and sensor(s).

2.6 Technology Considerations

Limitations in budget motivated us towards using the QI standard for wireless charging and this method is quite delicate with range, which is usually between 2 to 5 millimeters. This is both a strength and weakness for us, because we need to place our wireless charging unit within the same range of what the QI standard often provide. However, the mounting location of our unit will be somewhere around the rotational rod of the robotic arm, which can occasionally tilt and move in two dimensions. So, one of the concerns and designing perspectives is that our charger should be able to tolerate such movements at a level in which it doesn’t allow the coils to touch each other or get separated more than the allowed range. The alternative wire option would be significantly simpler and more efficient, but the rotational movement of our powered device forced us to use the less efficient wireless approach.

2.7 Safety Considerations

While working on our components there of course will be some amount of danger to consider. For example, our wireless transmitter and receiver will be using AC to create a resonating magnetic field. This AC will be of a relatively high voltage that could be harmful to us and our equipment. The high power levels also pose a danger to our components. A shorted wire or poor layout could cause heating, fires, or explosions in certain circuits like capacitors. The environment in which our system will be located in will also be hazardous to the operators and equipment. Our coils and controlling circuits will be located high off the ground when installed so a person inspecting, repairing, or replacing the device could potentially slip and fall or be hurt from an electrical failure that stemmed from the harsh conditions (wet, soapy)

2.8 Task Approach

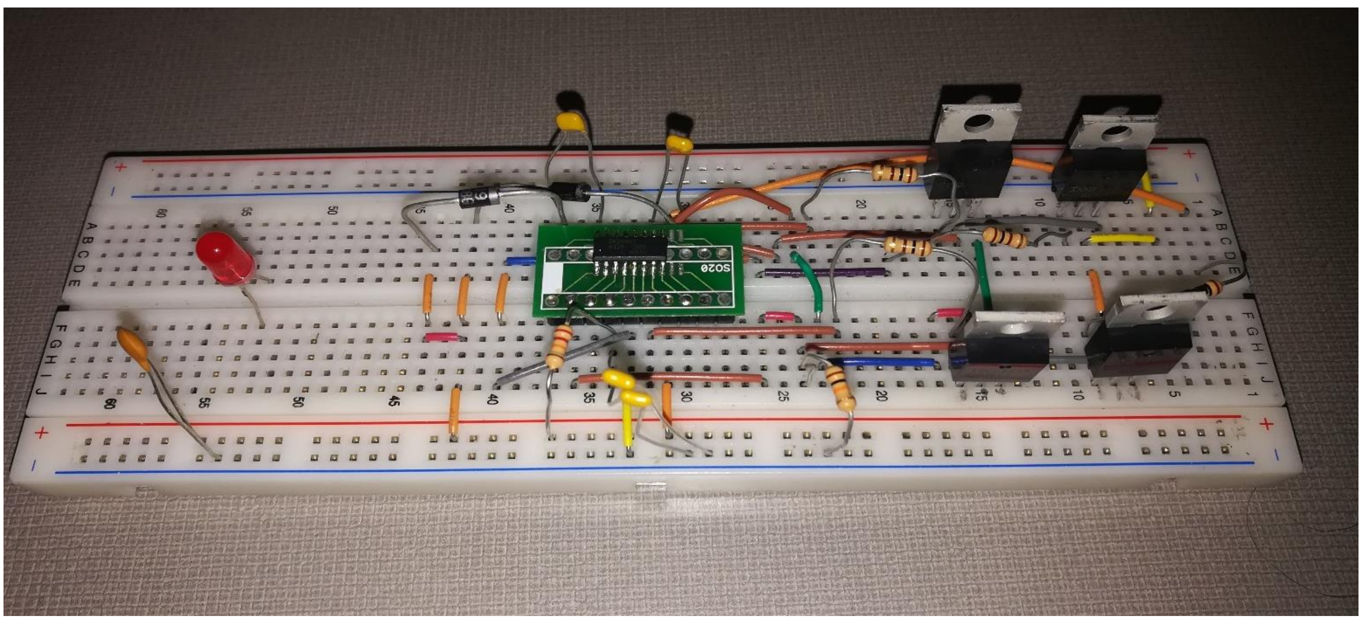
Our main approach was to start by first understanding what our client wanted in comparison with what they actually needed. From there, we have brainstormed ideas, and focused those ideas into the main points of our project. We then came up with a version one of a design and checked if it would work mathematically, then checked that it was physically and feasibly possible. We have made a few changes since the beginning and plan to make more as we continue. Our most up to date design is featured in section 2.5 of this report. Moving forward, we will approach our tasks from the mathematical side checked by multiple calculations, and then take various steps for testing to check our calculations.

2.9 Possible Risks and Risk Management

-If we end up needing to use pre-built ICs for frequency control of the coils and the battery, it may increase costs.
-If we choose to use one or two large batteries instead of eight or ten, it may not only increase costs but also it may make the system exceed the dimension limitations.
-If we create our own coils, loose connections and wrong geometry may affect the delivery efficiency and thermal safety.
-If our coils/system cannot deliver enough power to the batteries, the total ON time for the LEDs may have to be reduced.

2.10 Project Proposed Milestones and Evaluation Criteria

Our greatest milestone was the completion of our prototype, shown below in Figure 4. Our prototype, which was a complete high frequency H-Bridge circuit, was comprised of a MOSFET gate driver IC, its corresponding connection circuit, and a set of 4 MOSFETs. Some additional milestones accomplished include determining the battery type/brand, testing the H-bridge with LEDs to confirm the generated square wave, and testing the coils for power delivery in accordance with range and power intensity. Once we have all the needed components, we will compare our calculated results to the test results of our system.



(***Figure 2)***

2.11 Project Tracking Procedures

Keeping track of our progress will be based off of the arbitrary goals we set for ourselves. A majority of these goals can be found in our timeline laid out in section 3.1's figure 2a/b. Next semester, Spring 2019, will follow a similar structure. We will use this and other documentation to confirm we are on schedule to ensure our designs, and subsequent breadboard / PCB prototypes meet our functional requirements. First we want to get a working transmitter that can handle high currents, and confirm that the signal we can output from it is sufficient to transmit at least 2+ watts of power (ideally 24 watts as that is our goal). From there we then want to integrate voltage regulation for the transmitter's power source, and then begin creating our receiver prototype and check that it can simultaneously power the sensors, and charge the batteries. These milestones should be met at regular intervals that we set for ourselves to stay on track and will be modified or added as needed to this document.

2.12 Expected Results and Validation

To confirm that our designs are correct, our physical prototypes will be used to check and see if we have accomplished our goals or not. This will be done in a sort of step process. For example, when we test the H-Bridge, we did it only using a small supply voltage. Using higher voltages and currents could amplify any mistakes we make so keep things small is critical. By using scopes, we can confirm important voltage drops, voltage levels, and frequencies of our prototype. In our Transmitter, we will be looking for a high frequency voltage, and a changing direction of current across our transmitting coil. This can be seen in more detail on our design document's testing section. Once this is done, we can increase the power throughput and observe how to prototype operates under load as well as the increase in power transferred by the coil.

2.13 Test Plan

High Frequency H-Bridge Test:

Our H-Bridge has the following sub-components:

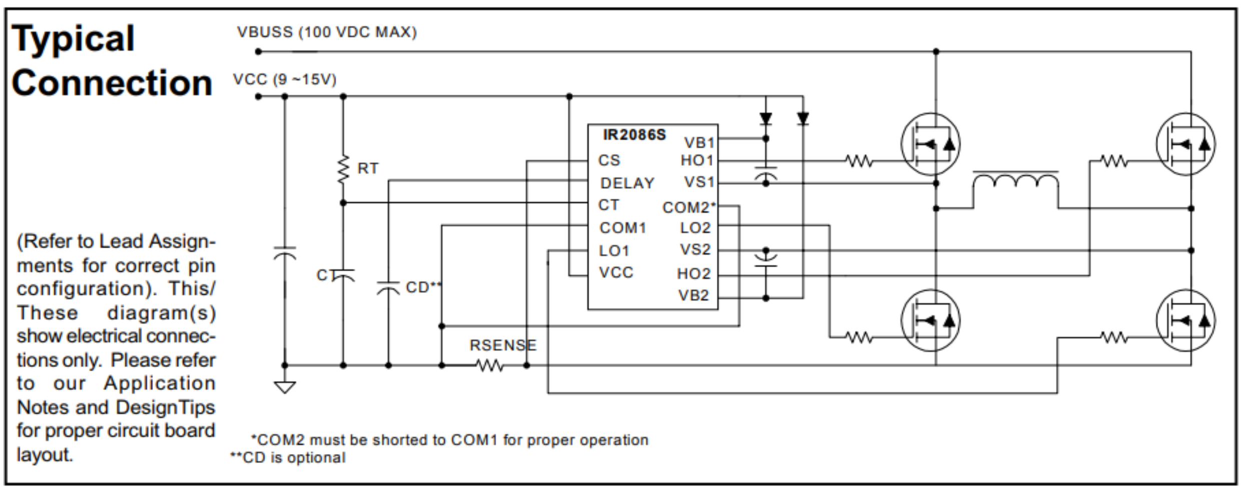
1. -High Frequency Power MOSFETs(H-Bridge)
2. -IR2086s(Oscillator/Gate Driver)

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

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

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

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



(Figure 3)

Coil Power Transfer Test:

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

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

H-Bridge & Coil Power Transfer Test:

The final test for our prototype would be to ensure that the power we generate from the H-bridge circuit can be used to power the coils. Ultimately we would hope for this power to be transferred as efficiently as possible. Ideally the power waveform generated from the H-bridge should be nearly the same as the output from the receiver coil. The steps to test the prototype are as follows:

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

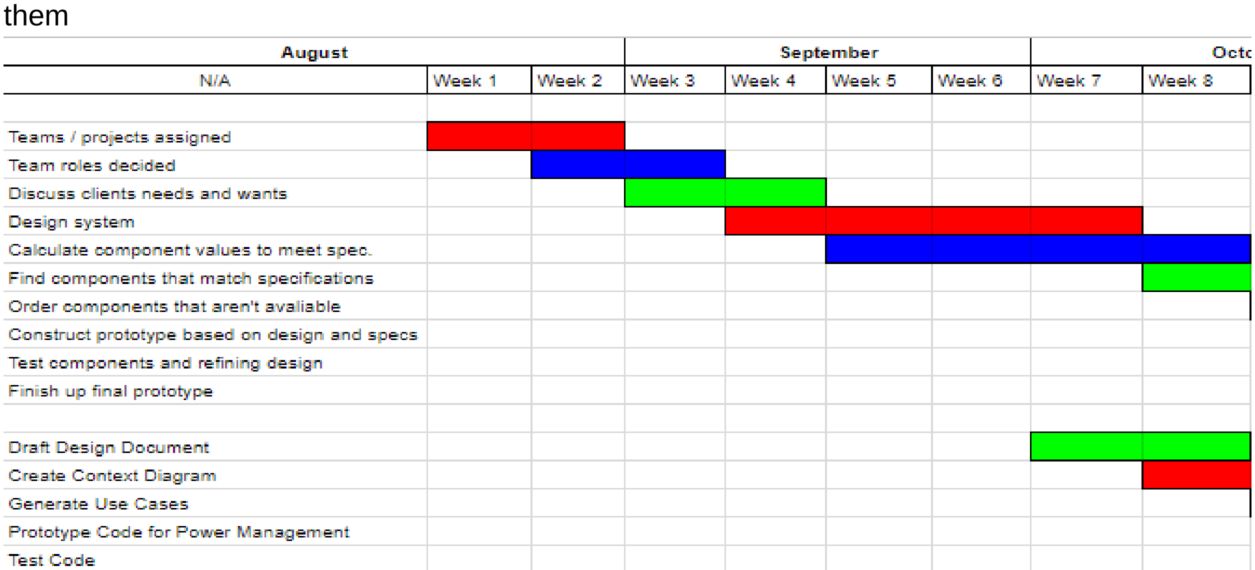
Additional Testing:

If time persists and the most crucial portion of our design works, we can test additional sections of our overall project. The next main sub-block of our project would be the full bridge rectifier. The rectifier would consist of 4 high frequency power diodes, which are very suitable for our application. The rectifier and everything else downstream of it has been used in many different areas in the industry. There are many references for using charge controllers, buck converters and charging batteries. The focus of this test document is mainly on what we were unsure could be done by our team: The generation of a high frequency and high power waveform, along with transferring that power wirelessly.

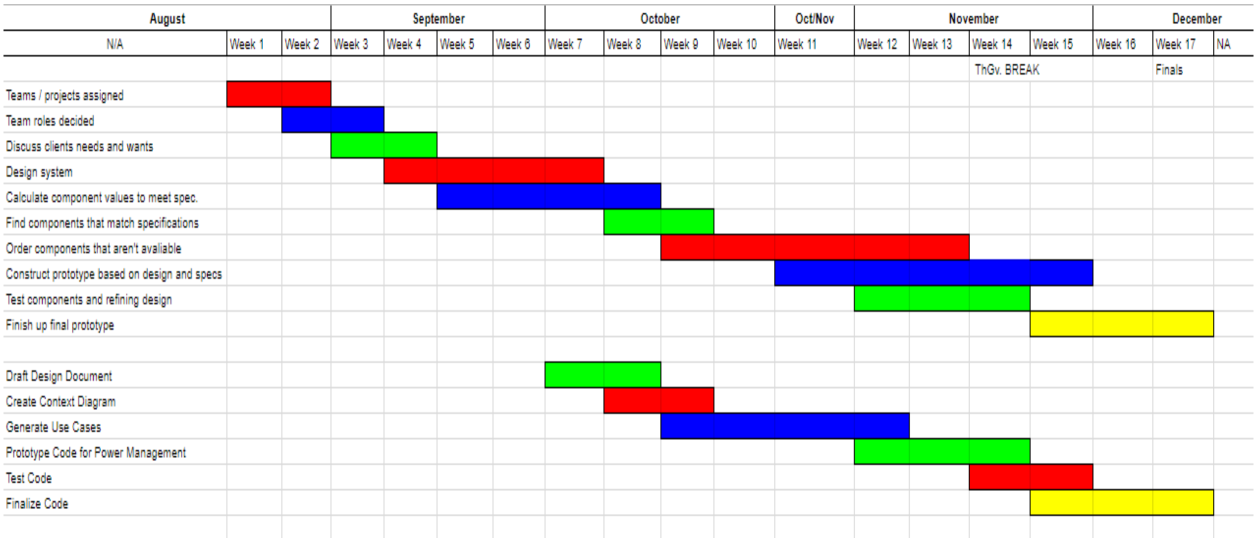
3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

Essentially, our work flow is planned out so that we have a basic idea of what we are doing, which is then refined into a more complex and clear picture that we then test and improve upon as we move forward. This timeline we have made, has been created such that we will have ample time to prepare and work in each of the important tasks and milestones as we encounter them



(Figure 4a)



(Figure 4b)

3.2 Feasibility Assessment

Our expectation is that the project would provide constant wireless capability for the sensor on the arm of the car wash successfully, but may not be able to provide enough power for the LEDs over long periods of time under heavy load. Expected challenges include; component availability with the desired ratings, dimensional limitations dictating component choices, reliability within the system regarding power delivery, charging capacity, unmatched frequencies of coils, etc.

3.3 Personnel Effort Requirements

Benjamin Gisler	Doruk Er	Kyle Henricksen	Miguel Hennemann
Hours : 6 Visit with client and discuss their wants and needs of the project. Had many questions answered as we toured their facility.	Hours : 6 Distinguishing the primary and the secondary focus of the project was instrumental. Consensus was to make sure of the sensor to be ON all the time and charge the LEDs as much as possible with the remaining capacity.	Hours : 6 Although controlling could be minimal, there is definitely potential for using more advanced logic in our system	Hours : 6+ A higher frequency within our coils would allow for better power transfer efficiency.
Hours : 4	Hours : 5	Hours : 3	Hours : 5

Assembled and tested H bridge. Looked up potential components for transmission.	Researched and eliminated options for frequency control of the coils by pulsating voltage and by using a pre-built frequency controller	Refined pseudo-code for Power management System.	Tested H-Bridge design in Coover Lab.
Hours : 6 Investigated how to find inductive values of coils which is needed for resonance calculations. Investigated power transfer feasibility	Hours : 5 Researched unknown factors for calculating the coil sizes and transmitting by resonance.	Hours : 5 Researched power management systems as well as basic circuit understanding.	Hours :5 Researched the concept and components involved with designing an effective wireless charging system.
Hours : 5.5 Assembled and tested H bridge. Looked up potential components for transmission. Roughly calculated values of coil(s) and developed design to base off of and start with	Hours : 5 Researched and eliminated options for frequency control of the coils by pulsating voltage and by using a pre-built frequency controller.	Hours : 5 Refined pseudo-code for Power management System.	Hours : 5 Narrowed down components necessary to build prototype. Discussed ordering coils with Wurth Electronics. Ordered MOSFETs, diodes and gate driver IC for testing.
FUTURE TASKS Hours : 16+ Test coil power transfer as well as powering coils via H bridge. Testing H-bridge with oscillator IC. **We will be working together doing this.**	Hours : 16+ Test coil power transfer as well as powering coils via H bridge. Testing H-bridge with oscillator IC.	Hours : 16+ Will observe and interact while tests are run to become more familiar.	Hours : 16+ Test coil power transfer as well as powering coils via H bridge. Testing H-bridge with oscillator IC
Hours : 6-14+ Refine our design and then test and document the results, making tweaks and changes along the way.	Hours : 6-14+ Prepare battery charging set up and circuitry.	Hours : 6-14+ Completely familiarizing with the electronics of the project as well as preparing code for future implementation.	Hours : 6-14+ Ensure prototype is functional and delivering expected results. Start planning for next semester's PCB design.

3.4 Other Resource Requirements

Most of the equipment that we need for measurement and simulation purposes are provided at our department labs such as; oscilloscopes, Multisim / EasyEDA, soldering iron and soldering equipment, breadboards, certain resistors/capacitors/transistors. Other specific components such as the coils, custom integrated circuits, diodes and custom H-bridges were ordered online from various distributors.

3.5 Financial Requirements

This project requires us to acquire specific types and amounts of circuits which do cost money. To facilitate our projects financial needs, our client has agreed to reimburse us for any funds we use to complete this projects. We are aiming to keep costs as low as possible so as to not financially burden our client any more than necessary.

4 Closure Materials

4.1 Conclusion

Our end goal is not only to create a safe, and efficient working system that our client can use, but also a system they will be happy with and that we can proudly say that we made. Form a more technical standpoint, making a system that can last for many months, even years with little maintenance and be reliable for the end user is what we are striving to provide. Not only does our system have potential for the specific car wash arm we are designing it for, it could theoretically be used on other car washes that the manufacturer develops, and also be updated with additional features if our client desires.

4.2 References

Bhutada, Manasi, et al. "Coil Design of a Wireless Power Transfer Charging System for a Drone - IEEE Conference Publication." *An Introduction to Biometric Recognition - IEEE Journals & Magazine*, Wiley-IEEE Press, 8 June 2015, ieeexplore.ieee.org/document/7816070.

4.3 Appendices

http://katalog.we-online.de/en/pbs/WE-WPCC-TRANSMITTER
https://katalog.we-online.de/en/pbs/WE-WPCC-RECEIVER