Wireless Recharging System

DESIGN DOCUMENT

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Table of Contents

1 Introduction 4

1.1 Acknowledgement 4

1.2 Problem and Project Statement 4

1.3 Operational Environment 4

1.4 Intended Users and Uses 4

1.5 Assumptions and Limitations 5

1.6 Expected End Product and Deliverables 5

2 Specifications and Analysis 5

2.1 Proposed Design 6

2.2 Design Analysis 7

3. Testing and Implementation 8

3.1 Interface Specifications 9

3.2 Hardware and software 9

3.3 Functional Testing 10

3.4 Non-Functional Testing 10

3.5 Process 10

3.6 Results 11

4. Closing Material 13

4.1 Conclusion 13

4.2 References 14

4.3 Appendices 14

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.

Figure 1: Proposed System Design
Figure 2: IR2086s IC Connection Diagram
Figure 3: Design Prototype
Figure 4: Test Load Waveform
Figure 5: Overcurrent Logic Waveform
Figure 6: Gate Voltage Waveforms

1 Introduction

1.1 Acknowledgement

We would like to thank our client NCS for their involvement in our project and their constant communication with us. We would also like to thank our advisor, Craig Rupp, for his words of wisdom, advice, encouragement, and overall contributions to our group. 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.

1.2 Problem and Project Statement

Our client NCS, desires a way to power sensors and LEDs on their machines such that they will no longer need to be powered by a replaced battery. Their current system needs to be routinely tuned up with a new battery which costs time and money. Unfortunately, the location of the sensors and LEDS doesn't allow for a simple wired connection, therefore a different method of power transfer and storage is required.

Our groups solution is to create a wireless power transfer system that can charge batteries so power can be delivered to the LEDs and sensors even if power is not being transmitted. By the end of this fall, we intend to have a working prototype that can transfer power from one coil to another as a proof of concept demonstration. From that point, we will further refine our electronics to be on custom made circuit boards and finalize the design of the electronics used to charge the batteries and power the LEDs/sensors.

Having this wireless system installed on a machine would allow not only for a more enjoyable experience for the end user, but also less work and maintenance for the operators of the machine.

1.3 Operational Environment

Our projects final product is intended to be used in the very damp wet environment of a car wash. We understand that this is a cause for concern as electronics are usually very susceptible to water and elemental damage, but we intend to account for this in our design. For example, a simple solution would be to cover our components in a layer of insulation to protect them, but this could make repairs on the electronics more difficult. Alternatively, we can create a container that would hold all the sensitive electronics and design it to be easily removed and opened for access to the electronics. We plan to choose a method of protection once we have a more clear idea of what electronics we will have and determine which method would be best at that point.

1.4 Intended Users and Uses

The very end user of our project will be the average person washing their car with a machine for NCS equipped with the updated hardware. Their car washing experience will give an impressive display of lights to accompany the washing of their car. A step above, the owners and operators of the car wash will not only have an impressive system that they can boast about to their customers, they will also no longer have to waste money replacing a sensor battery every few months, and can instead focus their work in other areas of their business. A final step above the car wash owners is our client, NCS. With an updated machine, they will be able to better sell their product(s) to more potential buyers and be in a better technological, and economical position than the competition.

1.5 Assumptions and Limitations

Assumptions: We are assuming a few variables while designing our system. Our system will be designed to operate under harsh operating cycles of one for 4 minutes then off for 3 minutes. We also are assuming the distance between our power transmission system's components will be between ¾ and ¼ of an inch. Estimating the power losses of our components is also something we are going to have to test to be sure of.

Limitations: We have a limited space to fit our components into and that may constrain the operating cycle times of our system. Our system will be only designed to fit into one machine, so some modifications would be necessary to put the system onto another machine. Our input power source will only be 24 volts DC, so we may not be able to get as much power into our system than if we had a different more powerful DC or AC source. The distances between our transmitting and receiving components may vary, causing inconsistent and dropping power transfer levels.

1.6 Expected End Product and Deliverables

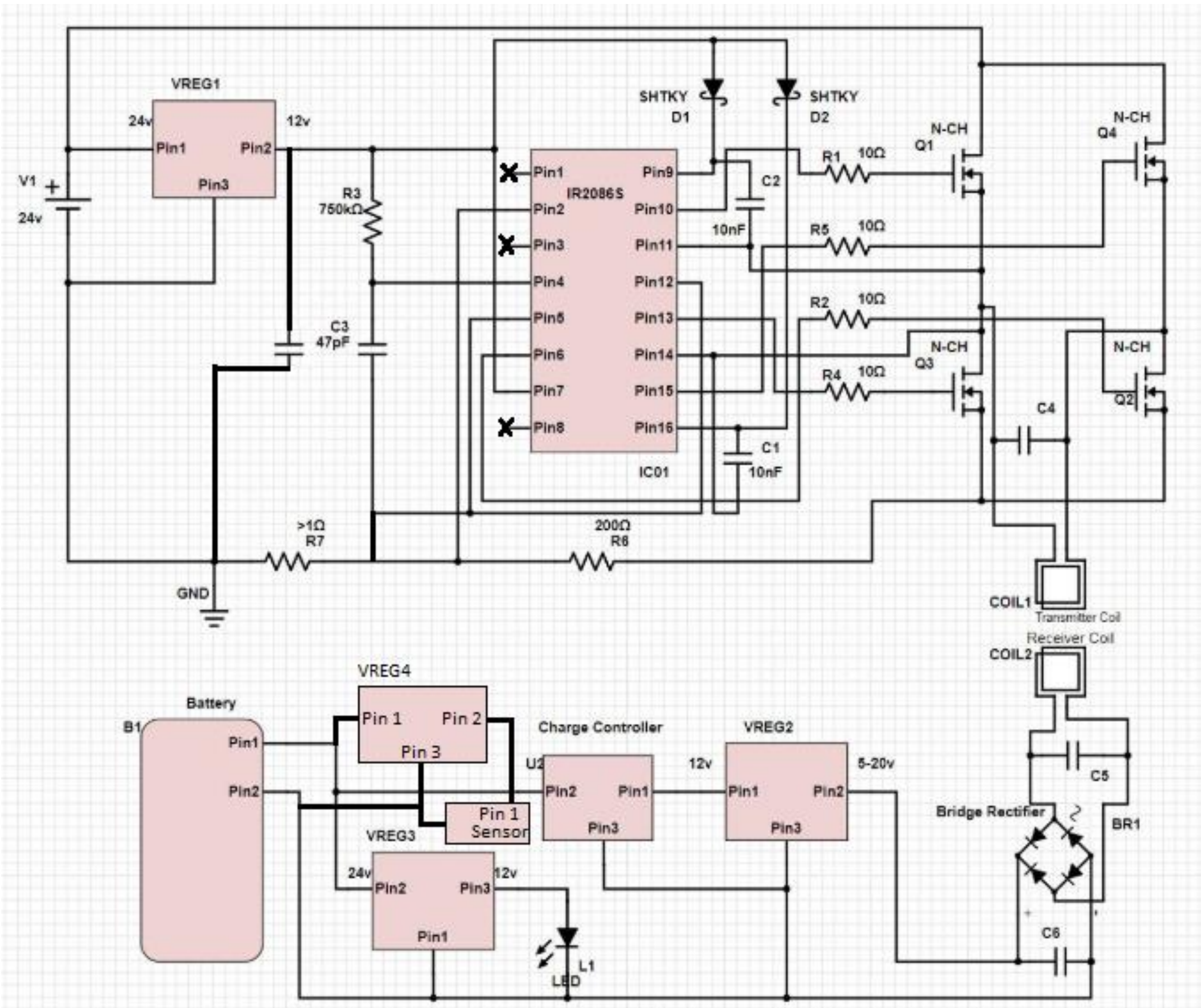
We aim to deliver a system that can provide a constant source of power to sensors, and make it simpler and easier to maintain it versus the current system. More specifically, we want will create two separate transmitting and receiving power modules that NCS can attach to their many machines as a replacement and upgrade to their current power systems. We are planning on getting the project's products ready and delivered to NCS by early May of 2019 with demonstrations.

2 Specifications and Analysis

2.1 Proposed Design

Our proposed designed (see figure one below) consists of 2 main components: The receiving circuit and the transmitting circuit. Since our power source on site is only 24v DC, we had to form our transmitting circuit with components that not only allowed for efficient power transfer, but also acted as an inverter to change our DC power into an AC signal. With this AC signal, we can vary a resistor R3 to get a desired high frequency 200 kHz for maximum efficiency. This high frequency is ideal for allowing the coils to resonate with each other (refer to page three for more information on magnetic resonance). The integrated circuit of the transmitting circuit is at its heart, and controls MOSFETS set up in an H-bridge configuration, making the DC inverting at high frequencies possible. Additionally, a voltage regulator is used to supply the IC with a safer voltage. The receiving circuit is much simpler, and only requires a few voltage regulators to supply the battery charger, and the other components of the system (LED strip and sensor).   The “X”s make no connection pins

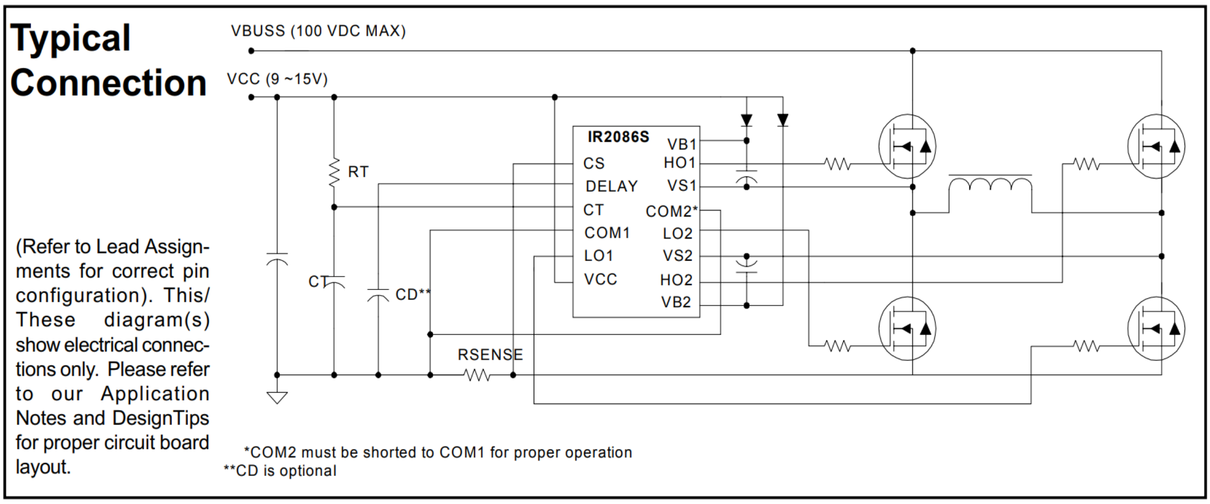
In regards to the problem of power management we have elected to use two Arduinos, one on the receiver side and one on the transmitter side. The receiver side microcontroller monitors the battery and its current charge, modulating the power to the various peripheries on the arm as necessary to conserve battery charge under load. The transmitter side microcontroller will receive information regarding the batteries current charge status and will also be informed by a sensor to detect if the transmitter is over the receiver. The transmitter will then use this information to determine if it will transmit power to the receiver.



(Figure 1)

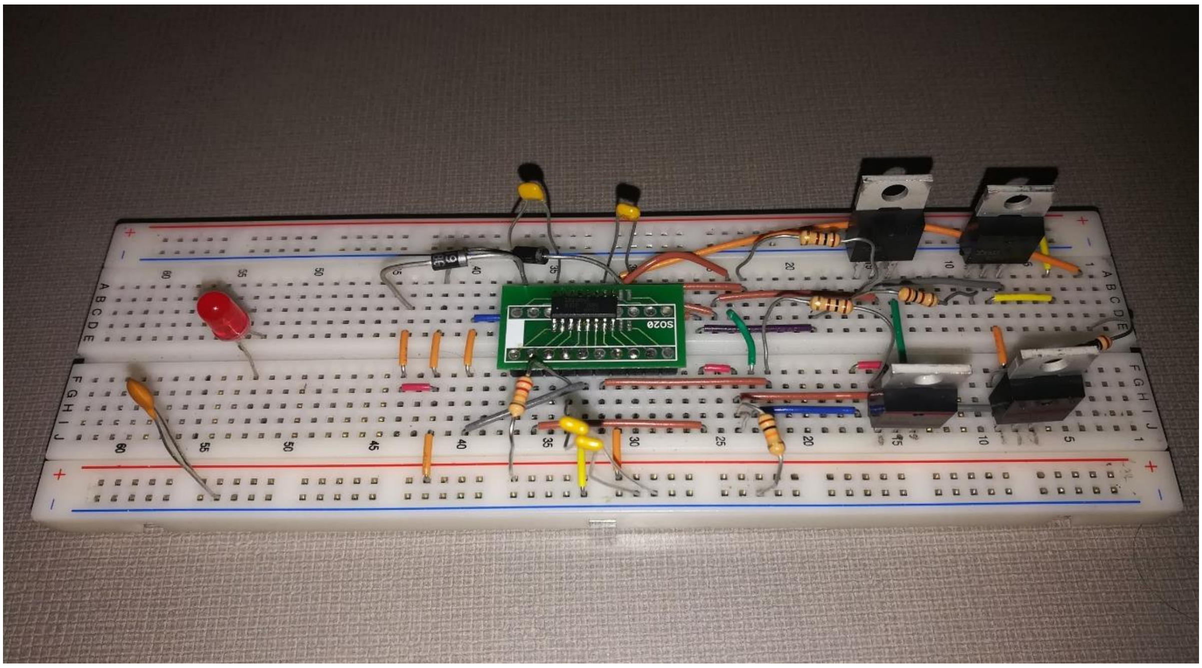
2.2 Design Analysis

The main goal we set for ourselves in the first semester was to ensure that the H-Bridge circuit was functional and that the coils could indeed transfer power. We started off by building the circuit dedicated to making the MOSFET gate driver IC functional, which is shown in Figure 2.



(Figure 2)

This was based on a recommended connection diagram provided by the manufacturer. The connection diagram included a number of resistors and capacitors to place at the pins of the IC in order for important parameters to be controlled. The H-Bridge circuit, which primarily consisted of a set of 4 MOSFETs, was then built. The H-Bridge circuit together with the IC would combine to be our high frequency/high power square wave generator. Figure 3 below depicts our design prototype.



(Figure 3)

Initially when we supplied the IC with an appropriate turn on voltage of about 10V, the gates of the MOSFETs did not give us the expected results. We pondered on this issue for days and decided to test the H-Bridge with a function generator, to determine if the IC was at fault. Through testing the H-Bridge alone, we found that the gate resistors were an issue and were too high of a value. These resistors affected the charge and discharge rates of the MOSFETs. We then lowered the value of the gate resistors to 10Ω, and since doing so, obtained the expected high frequency voltage signal at the gates of the MOSFETs. Currently our circuit has one problem. When testing the load of the circuit, which is depicted where the inductor on Figure 2 is located, we do not get our expected output. Some additional testing will need to be done in order to determine why we are not getting the expected output. In terms of testing the transmitter and receiver coils, the most ideal frequency to transfer power would be near 200kHz. This point was depicted on the datasheet as the Q-factor, which is where the transfer rate between the coils is most efficient. The coils are rated for over 40V, which is suffice for our application.

In regards to the Software design, we've mostly focused on the receiver side microcontroller as of right now. We've set up a small scale testing apparatus in which a small lithium-ion battery 3.7V with a power of 2.035Wh. The apparatus is a circuit that has some connections to the Arduino which is being used to read in the power drain from the battery based on whatever load its being put under. So far it's been tested using a few LEDs as the load, but it has been determined that this is too weak of a load to get results from the code in a testable and reasonable time frame.

3. Testing and Implementation

So far, we have been able to successfully test our H-bridge/transmitting circuit. These tests include testing and confirming output frequency, output voltages, and resonating frequencies of our coils. These make for an excellent stepping stone for further testing. At the moment, we have a few items that need to be tested during the first week or two of classes of spring 2019. The main area of testing we will be focusing on is power management and transfer. Below we will discuss testing Here are the items and circuits we plan to test:

1. Efficiency of voltage regulators on both the transmitting and receiving sides
2. Total power receiving side will consume underload
3. Rate/efficiency of power transfer of our coils and if it will be enough to satisfy receiver
4. Heat dissipation requirements and the best methods of cooling components.
5. Battery charging and power management systems (via microcontroller)
6. Ensuring that all the voltages levels in the circuit are at their nominal levels
7. Checking that the circuit protection aspect of our IC function properly
8. Voltage rectification and smoothing by bridge rectifier and its capacitor

A variety of methods will be used to make sure each of these areas are working correctly. For each of the points listed above, here are their respective testing procedures:

1. Use scope measurements and datasheets of the regulators to determine their power consumption and efficiency. From this information, we can judge whether or not the

component is operating correctly and if it will be able function without wasting too much power.
2. With a scope, we can more accurately see what voltages are being transferred and analyze how much power that voltage will allow us to receive. This test will also give us the amount of power we can expect we have to work with when charging the batteries.
3. Building off of the previous test, we will also be able to use a scope and test loads to find the efficiency values of our power transfer. From this we can estimate the power needed to make the entire system operate.
4. Using different types of heatsinks and temperature sensors, we can ensure that our components are kept cool. Once the efficiency of our system is found, we can reliable calculate a heat dissipation need and then meet that need with said heatsinks.
5. By using the datasheet/stats of our batteries, and measurement tools such as scopes and microcontrollers (Arduino) we can keep track of power consumption and amounts of power left in batteries. The battery charger will also need to be tested as while it operates alongside our power management circuit.
6. Using a scope will give us the most accurate and immediate feedback when checking voltages at strategical nodes. If we find irregular voltages levels, it could be a sign of a faulty component which we would replace as quickly as possible.
7. By sizing resistors to just the right amount, we can set up our transmitting circuit such that an unusual high current draw will deactivate the system, and prevent the IC from operating. Please refer to figure 2's Rsense, or figure 1 for a more detailed look
8. A scope can be used to ensure the operation of our bridge rectifier. The more DC like power we can get from the bridge rectifier, the better our components designed for DC inputs will operate, so smoother will be better.

3.1 Interface Specifications

For testing, we have been using typical lab equipment such as the multimeters and oscilloscopes. We have been using this equipment to actively monitor the various parameters of our circuit. Currently we have done some basic development and testing of microcontroller interfacing with our components. At its current stage, it is providing us with a way of seeing the current state of a circuit. For example, the Arduino we are using can take samples of the voltages at specific nodes of circuit and can determine the voltage drop, current flow, and power being used by said component. This data can then sent to a computer for further analysis. We plan to further develop this into a more advanced and dynamic control and communication system.

3.2 Hardware and software

The majority of our tests were done using the equipment provided by the university in the labs of Coover Hall. More specifically, we used DC power supplies, Scopes, and multimeters to confirm values and states of our components and circuits. We have made some of our own code for testing the viability of taking power measurements with an Arduino and so far our results look promising. Below are the components we tested during development and their relevance/use to our project.

H-bridge: Will provide the coils with high voltage/current for operation.

Transmitter/Receiver Coil: Will generate magnetic fields to transfer power.

Oscillator: Creates a square wave to control the H-bridge

Rectifier: Converts AC/time varying voltages to DC

Voltage Regulator(s): regulate voltages to our components like the oscillator and sensor

Battery Charge Controller: Ensures that the battery is charged at a stable and efficient rate

Arduino: microcontroller likely to be used in testing circuit responsiveness and responses. May also be used in development for a power management system.

3.3 Functional Testing

<u>MOSFETs</u>: Tested MOSFETs by creating H-Bridge and supplying gate signal using function generator. The goal was to determine if the MOSFETs could indeed be used in a high frequency application
<u>Gate Driver IC</u>: Despite having burnt 2 of our 4 circuits out, we have discovered much in the process. When testing, we now make sure to limit our power supplies' maximum current. This is done so that in the event of a short, we have some time to react before too much damage is done to our IC and/or other sensitive components.
<u>Transmitter and Receiver Coils</u>: (picture of scope output of coil(s) here?)
<u>Power Management System: </u>Tested Power Management System's code by creating a small scale. Using LED's and a small lithium-ion battery to draw from. This is extremely slow, so it was modified to us a more draining source like a small motor.

3.4 Non-Functional Testing

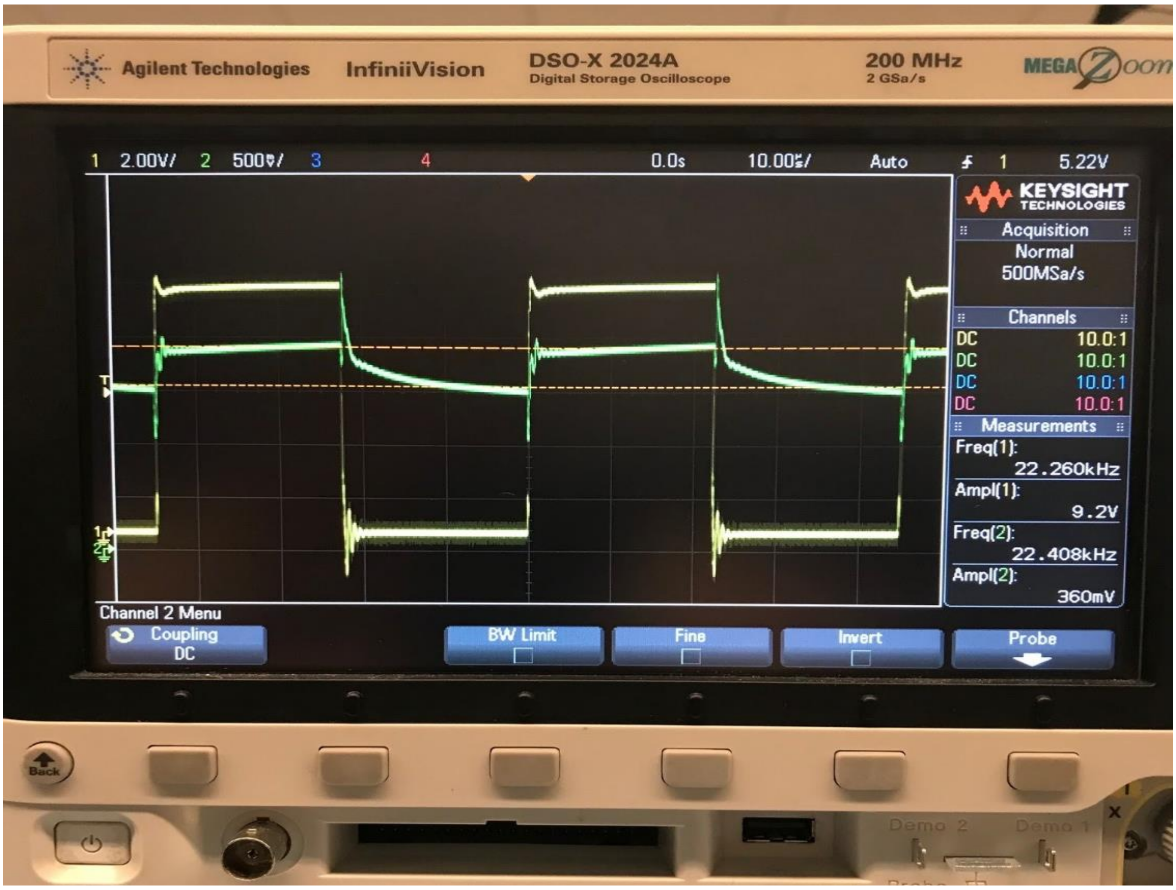
We have tested the thermal reliability of several types of LEDs and MOSFETs, and have been checking the datasheets of the best candidates for batteries and coils for compatibility. In terms of data security, we currently don't use any digital component that can be accessed remotely. However, we have been following the safety standards of IEEE with our design and test processes. In terms of efficiency, we are planning to test how much power is lost in our receiving system before making it to the battery. The efficiency the entire system is also important, as an inefficient system means a lot of power is wasted, and wasting power can cost a lot of money given enough time. Alongside efficiency, the reliability of our project will be crucial. The sensor(s) we plan to power are there for the safety of the machine and its operators/users so hiccups in our system will not be tolerated.

3.5 Process

In order to confirm that our H-bridge and Integrated circuit were working correctly, we mainly used an oscilloscope to confirm voltage levels and frequencies. First, we looked at what voltages and frequencies our components could operate at. These values we found by looking at the datasheets of the major components being tested, more specifically our IC and MOSFETS. Both of these are rated to handle high frequencies such as 200kHz. After we had connected the circuit accordingly, we used the scope to measure both the voltages being sent to our MOSFET gates and their frequencies (refer to figures one and two for diagram). Once we confirmed the voltages at the MOSFET gates were nominal, we then applied a separate voltage to the H-bridge and observed an oscillation that we would expect to see from an H Bridge. This confirmed to us that both the IC and the H-bridge MOSFETs were working as intended.

3.6 Results

We have been able to successfully run our IC and drive our H-bridge with it. Our initial test were done at a lower frequency, which is shown in figure 4. Figure 4 shows a test load being driven by our H-bridge. In this case, our test load was simply a resistor, and as you can see, the voltage levels change in accordance with the direction of power flow. More specifically, the green reading shows the voltage is higher when the side being measured is farther away from ground, and lower when it is closer. If you refer back to our design schematic, you will see an Rsense that helps both limit current and prevent the circuit from operating in the event of a short. When the green measurement is lower, the voltage drops because the power has already gone through the resistor before being measured by our probe, and the remaining voltage is dissipated across Rsense. (Figures 1 and 2 are helpful references)

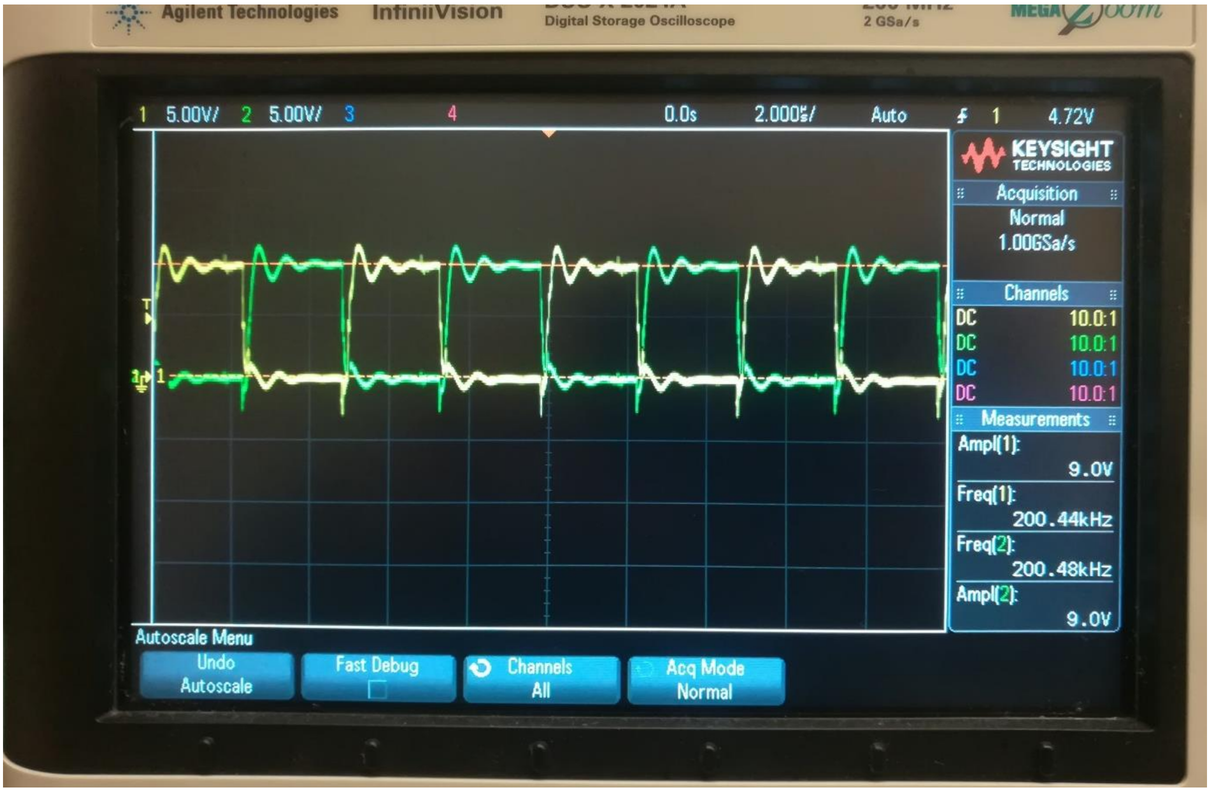


(Figure 4)

The next figure confirms that our overcurrent circuit works. When we increased our voltage enough or if we short our H-bridge, the voltage at the IC pin “CS” would rise above the allowed amount and would trigger the IC to stop outputting and wait for one period. What you can see in figure 5 is the IC turning on for a brief moment, then turning off when the voltage at “CS” stays too high for too long. This happens in an endless loop unless the input voltage to the H-bridge is lower or the resistive value to it is increased to dissipate more of the voltage.

(Figure 5)

Below is a high frequency test of our IC, confirming we should be able to drive our MOSFETS with a much higher frequency than the 22kHz seen in figure 4. Figure 6 shows a frequency of our gate voltage of 200kHz. This would be more ideal because our coils resonance frequency is much closer to 200kHz than 22kHz. We can use capacitors to help match the coil resonances the rest of the way.



(Figure 6)

A current issue we are in the process of resolving is one with our IC. It seems that when we ramp up its output frequency to 200kHz, one of its gate outputs drops to 50kHz when a load and power is supplied to it. Our current belief is that there may be something wrong with the IC or some simple wiring error. There is also a chance our break out SOIC PCB was damaged when we removed the previous burnt IC. In this case, we would likely solder a lead directly to the pin to ensure a proper connection.

4. Closing Material

4.1 Conclusion

Our hard work has paid off, giving us a working H-bridge and controller that will be critical in the functionality of our final product. We have determined most of the needs of our client, which is highly important in figuring out what actually needs to be accounted for. We also have designed both a block diagram and a conceptual diagram detailing all individual components and sub systems or our design. A prototype of the first half of the project has been completed and will be carried over, used and studied in the coming semester. Our goal for next semester is to not only complete the project, but more specifically to confirm both receiver and transmitter work as desired together and then put our components on custom PCBs.

4.2 References

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4.3 Appendices

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