



Design Document TMS: Transcranial Magnetic Simulation

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Project Plan V2

Dec 14 - 06

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1. SYSTEM LEVEL DESIGN

1.1 SUMMARY OF DEVICE

Our goal of this project is to create a high current pulse generator for the application of Transcranial Magnetic Stimulation (TMS). Currently, extensive research is being done in the area of TMS for many conditions that affect the brain. For instance, TMS is being used to treat depression, migraine headaches, as well as back and neck pains. Future research is exploring the possible uses in other applications like Alzheimer's disease, post-traumatic stress disorder (PTSD), Parkinson's disease, etc. Researchers are looking for a device that can produce the current needed to power a TMS coil and support deep brain stimulation to help treat and further understand these difficult brain conditions.

The magnetic fields used in TMS applications are pulsed at very short time intervals. A high current pulse is sent through an electromagnetic coil to create these fields. The goal of this Senior Design team is to create a device that can deliver such a pulse. This device will have controllable parameters (such as pulse width and amplitude) and will be able to manage our inductive load.

This document will cover the overall design process of our amplifier circuit. We have decomposed the circuit design into its basic parts; the power supply, power storage, switching device, and switching device control.

1.2 PROJECT REQUIREMENTS/SPECIFICATIONS

1.2.1 TOP LEVEL AMPLIFIER REQUIREMENTS

Functional requirements for amplifier shall:

- Create both mono-phasic and bi-phasic pulse waveforms
- Able to support 50 to 400 micro-second pulse width
- Output 1000 Amps both negative and positive
- Support 3 pulses with 1 microsecond intervals

Nonfunctional requirements for the system shall:

- Cost under \$500 dollars.
- Have a graphical user interface (GUI) utilizing MATLAB.
- Safe and easy to use.

1.2.2 TOP LEVEL INTERFACE REQUIREMENTS

The user interface requirements shall:

- Contain full control of device via MATLAB GUI
- Be able to select between mono-phasic and bi-phasic pulse waveforms via manual button controls on device
- Button to send 400 microsecond pulse manually.

The graphical user interface requirements shall:

- Control waveform pulse width
- Control waveform pulse type
- Control number of pulses sent and interval between them
- Discharge capacitors via button or upon exit of program
- Show pulse waveform via real-time current data
- Show charged capacitor real-time voltage data

1.3 FUNCTIONAL DECOMPOSITION

Our system can be described into four main parts the beginning of the circuit will be the power supply. This is where we generate our voltage for the power storage. We then use a microprocessor to control a high powered switch.

1.3.1 POWER SUPPLY

The power supply consists of transformer, voltage quadrupler, and filter. Our circuit begins with power from a standard wall outlet, which is adapted into wires using our power entry connector. Those wires are then attached to our 2:1:1 transformer that steps down the voltage and splits it into two halves (one for positive and negative rectification). The transformer has a current limiter located on the secondary side so that the circuit so that it doesn't draw over 15A. In addition we have a fuse on the primary side to ensure that the wall outlet is protected from the high currents in the circuit. When the voltage is stepped down it travels through our voltage quadrupler; this both rectifies our signal from AC to DC and amplifies our voltage to 240VDC. The voltage quadrupler we used consists of two Greinacher cells of opposite polarities to create positive and negative DC voltage. In effect, the input is increased by a magnitude of four. After this, to eliminate any rippling in the DC signal, we passed this through a resistor-inductor filter which stabilizes and creates a clean 200VDC. Notice that there is a 40V drop from the resistances of the voltage quadrupler and the filter.

1.3.2 POWER STORAGE

When the inductors are done filtering the voltage generated by our voltage quadrupler, it then charges the capacitors. The capacitors store up the voltage over small period of time which we have calculated to be around 50 seconds. They will then hold the voltage till a path to ground is created via high powered switch. The input from the user can choose to send a pulse on the casing or the graphical user interface (GUI) to discharge these capacitors for any given period of time. If the user is sending a pulse, the capacitors will quickly discharge into the inductive load via IGBT. To safely handle the capacitors, we implemented automatic capacitor discharge through the Arduino chip. We also allow users to safely discharge the capacitors through controls on the casing and GUI. These controls will flip a relay and discharge the capacitors safely into high power resistors instead of the inductive load.

1.3.3 SWITCHING DEVICE

The switching device will be two insulated gate bipolar transistors (IGBT). This component allows for very high power switching. These switching devices will control the type of signal our team wants to provide which will be either mono-phasic or bi-phasic. These pulse types mean that either a single positive current will be sent (mono-phasic) or two currents sent one positive and then after a very small delay the negative pulse will be sent (bi-phasic). Another feature with IGBT's is that they are very fast switching devices. Since we are dealing with pulse waveforms in the microsecond range this is essential to creating a clean square pulse. The IGBT's are rated for 10 microseconds which is quick enough to achieve the requirement of 50 to 400 microseconds pulse.

1.3.4 SWITCHING DEVICE CONTROL

As mentioned earlier our switching devices will be controlled by our Arduino Uno, which will determine what kind of signal will be generated either mono-phasic or bi-phasic and the duration of the pulse. The Arduino itself will receive input from either the casing or the GUI. The GUI will have a far greater amount of control than the manual control on the casing. Refer to section 1.2.2 for GUI requirements to view the functions extensive list of functions. The casing will only be able to send a simple 400 microsecond pulse that is either mono/bi phasic and safely discharge the capacitors after use.

2. DETAILED DESCRIPTION

2.1 SYSTEM DESCRIPTION

2.1.1 CIRCUIT CONCEPT

In order to create a circuit design we had to perform extensive surveying to gain a better understanding of how to implement a high current generator. We found that nearly all current amplifier circuits consists of large capacitors and inductors. We found that the idea is to store a lot of charge in a capacitor. Understanding the relationship between voltage and capacitance to be $Q=CV$, helped us determine how to achieve a large amount of charge. Figure 1 shows the analysis for how we determined the current through the inductor.

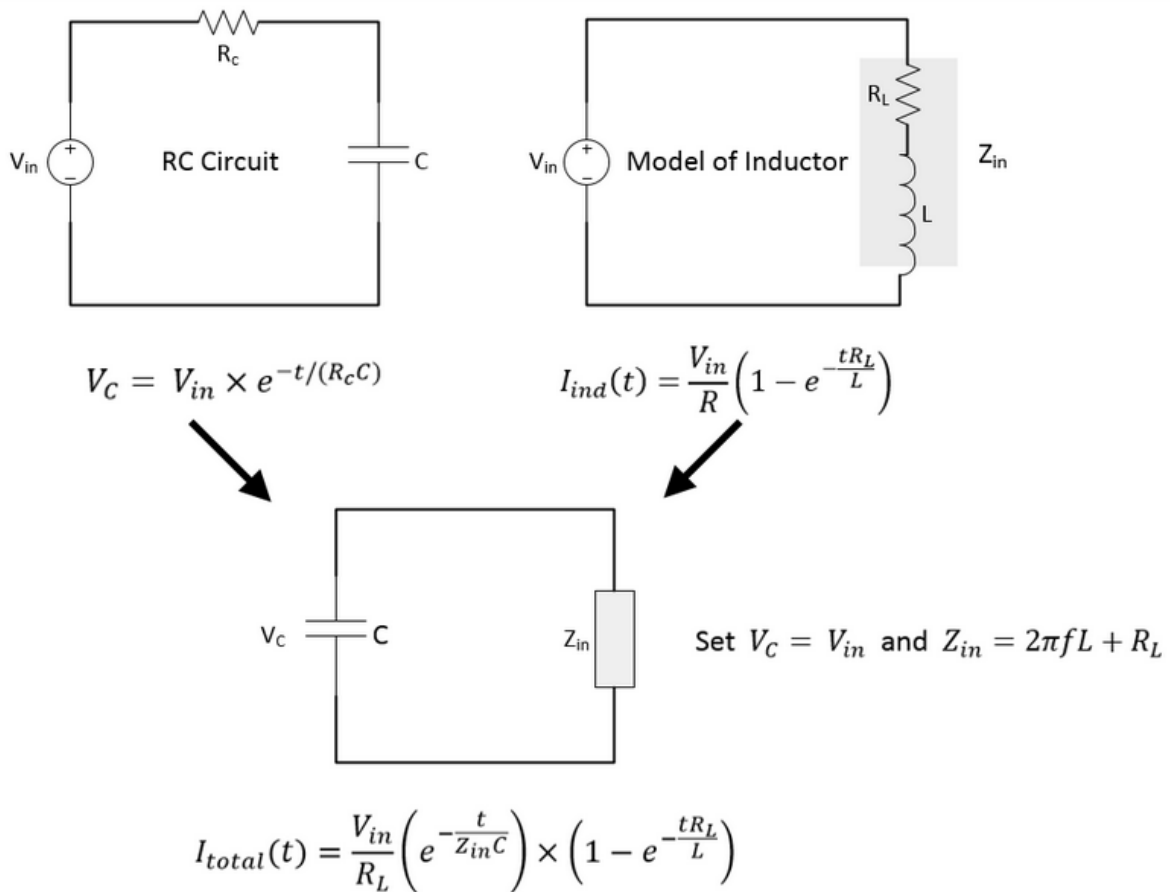


Figure 1: Circuit Analysis

This analysis was verified by applying the previous year's design to the equation. In doing this, the total current was calculated to be 510A. This is exactly what the last year senior design team observed at the output of their circuit. Knowing that this is correct, we choose the capacitor so that the cost would be minimized but the performance would remain. Since high voltage capacitors are expensive, we found it best to use only two (for positive and negative charge). We also minimized the capacitance since this variable also greatly effects cost. We also used the total current equation to make sure that our pulse will be quick enough to generate a minimum of 50 microsecond pulse. For this we assumed that the resistance of the inductor is 50 milliohms. Notice that the maximum current with this analysis is 4000A. The issues is that this is at time=0. In reality the inductor will immediately reduce this amount. We tested this analysis in Multisim and could conclude that this is indeed the right equation for characterizing the pulse amplitude. However, this does not include the negative edge analysis of the pulse. This analysis has been proven to be significantly more complicated due to the capacitance of the IGBT's. Per section 2.1.3 results, it can be seen that the output has a ripple after the waveform. We are currently working to reduce and characterize this rippling effect.

2.1.2 DESIGN OVERVIEW

With the concepts discussed in section 2.1.1 we designed our circuit to perform up to the requirements. This means producing mono-phasic and bi-phasic pulse waveforms with a minimum of 1000A output. To do this we created two branches of the circuit which both consist of three main sections: power supply, energy storage, switching mechanism. Controls will be used to send the pulse through the load. For the power source we intend to use a standard wall outlet and split the voltage using a 2:1:1 transformer. We then use a voltage quadrupler to rectify it into positive and negative DC voltages of +/- 200V. This voltage quadrupler also rectifies our voltage into a DC voltage. Since produces a rippling in the DC we send this through a filter using a resistor and inductor so we can get an even DC voltage as an output. The filtered voltage of +/- 200 voltages is then charges the capacitors for both positive and negative sides of the circuit. These banks will produce approximately 1000 Amps when they are discharged into our inductive load via IGBT control. The IGBT's allow us to control this high current to discharge the positive capacitor (mono-phasic) or discharge the positive then negative capacitors for bi-phasic. Our Arduino chip utilizes an IGBT driver for protection and is able to manage how long the IGBTs are conducting. The Arduino itself will be controlled by our MATLAB GUI to make the user interface easier for people who understand the layout of the GUI better than our button layout.

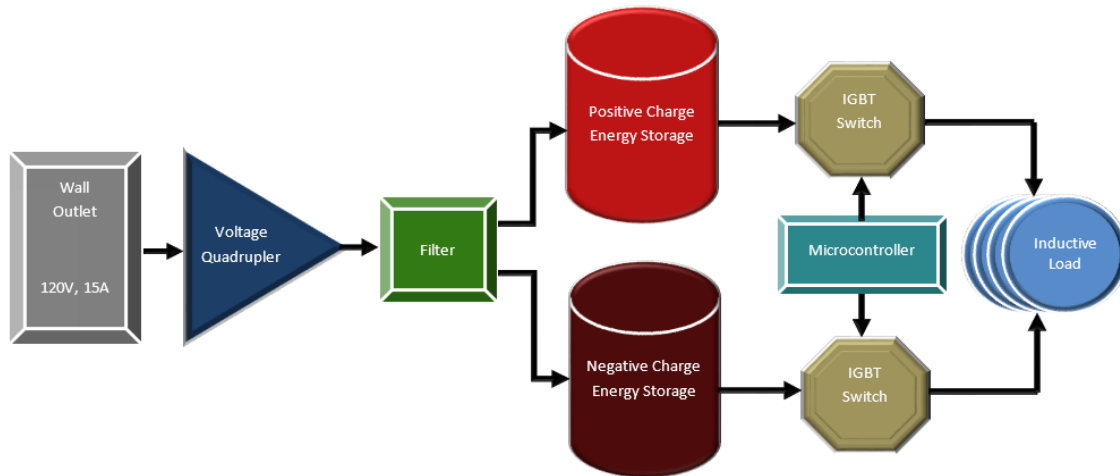


Figure 1: TMS Amplifier Block Diagram

From this block diagram you can see the key blocks that will be a major part of this circuit will be our transformer that will help us power the device and help shield the wall from the current surges due to the fuses on the primary coil and a current limiter on the secondary. Our voltage quadrupler is our second block that includes the use of diodes to rectify the circuit into DC voltage, and capacitors, inductors, and resistors to help filter and amplify the signal. The 10 millifarad capacitors are our most important part of this circuit since these will allow us to produce the 1000 Amps of current that is required to complete the specifications of the device. The two final important components that will be needed to complete the circuit will be our IGBTs that will control the massive current for mono/bi-phasic properties; these IGBTs will be connected to our Arduino. Our inductive load is the final component in this circuit design. This coil allows our team to create the electromagnetic fields that are required to use a TMS device. This load has the following parameters of 60 micro-Henrys with a resistance of 50 milliohms.

With the basic design for the circuit set, we had to find what the optimal components would be for the circuit. In order to make such a selection, we used the circuit analysis described in section 2.1.1 to find the cheapest capacitors. In addition, we performed wide spread searches for components of various suppliers to ensure the device could meet the budget.

2.1.3 DESIGN RESULTS

The full layout of our circuit is shown below and follows the diagram that is listed above. This circuit was created in Multisim. We first built the voltage quadrupler and filter and then kept adding onto the circuit as each section reached the desired output.

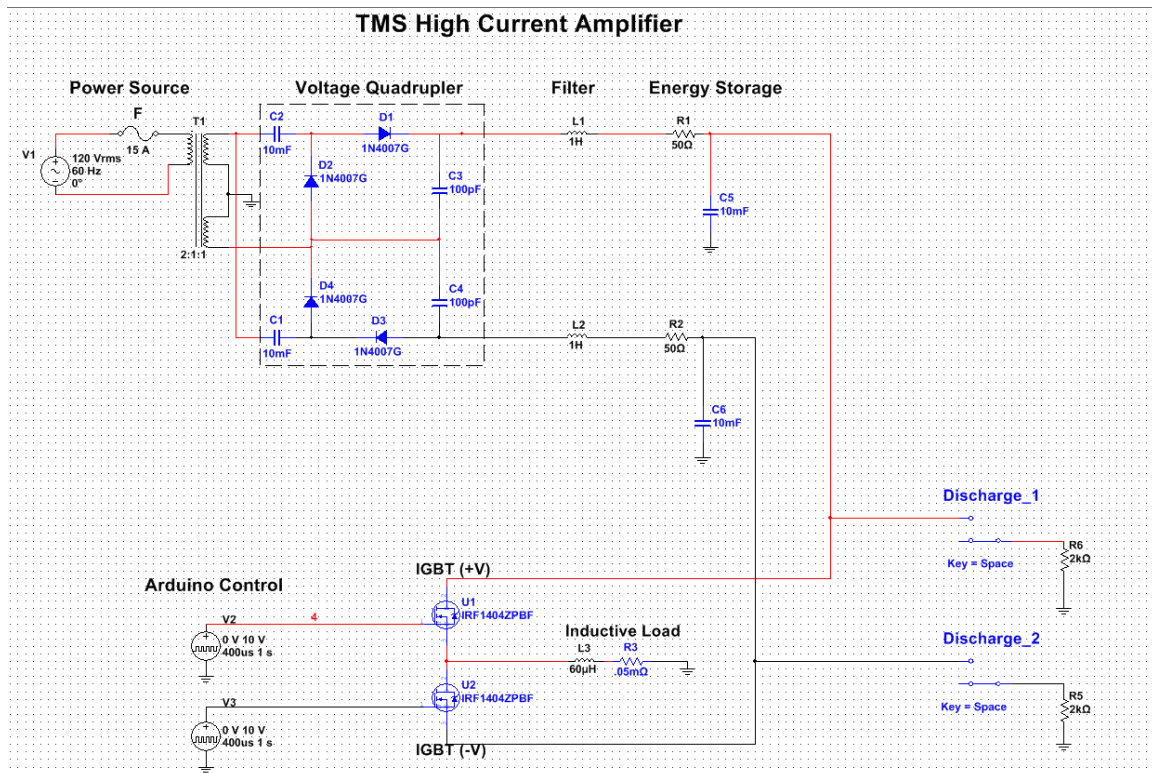


Figure 2: Multisim Circuit Design

Using the circuit that is highlighted in Figure 2 we have generated two outputs that fulfill the requirements that are outlined in section 1.2.1.

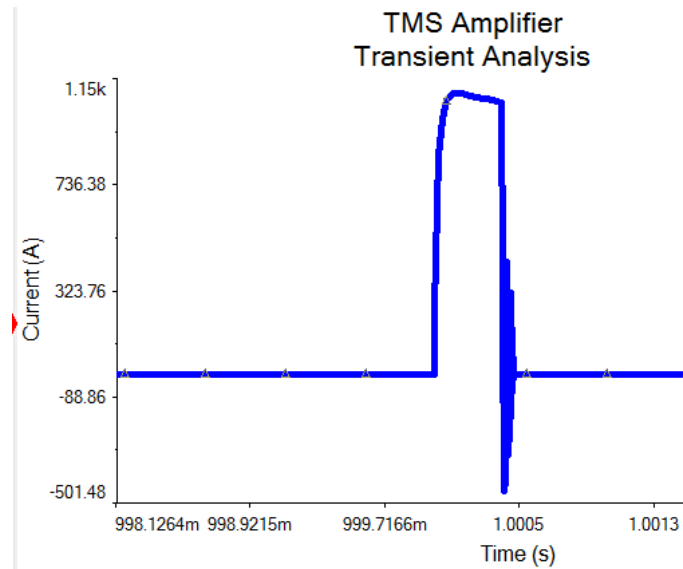


Figure 3: Mono-phasic Pulse

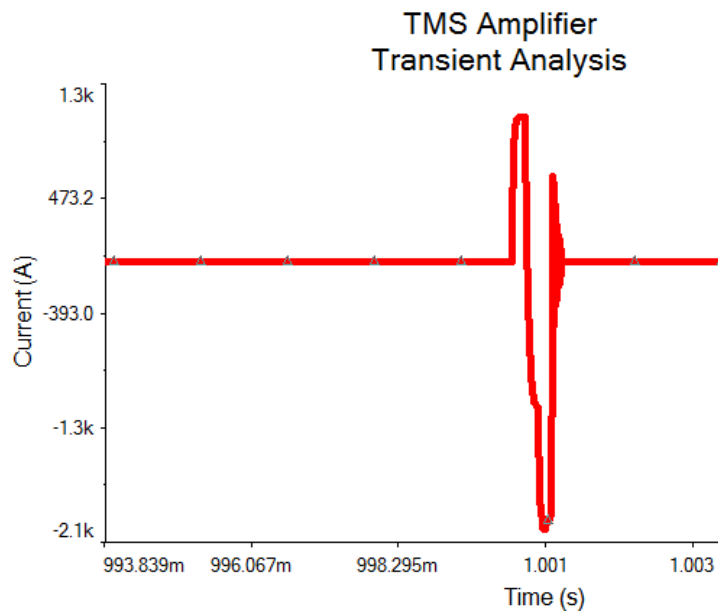


Figure 4: Bi-phasic Pulse

These graphs were generated using transient analysis in Multisim. It can be seen that the waveforms are up to specifications. The rise and fall time of the pulses are under the intended goal of 50 microseconds, and the pulse amplitude reaches the minimum of 1kA.

Notice that the output has a ripple after the waveform. We are currently working to reduce and characterize this rippling effect. With this circuit and the simulation results, we have moved on to the small/full scale building phase. We are in the process of ordering the parts to begin full scale fabrication. We also were able to build a simple small scale model of the circuit to verify that the simulation holds true.

2.2 USER INTERFACE

The microprocessor we choose for this project is the Arduino Uno. We favored this device because it is very easy to use and will provide all the control we need for this device. Using this microprocessor we can connect to a graphical user interface (GUI) using MATLAB. This provides explicit control of the pulse waveform. The user will be able to choose mono-phasic or bi-phasic wave types. They can also set the amplitude, pulse width, period, and number of pulses. In addition to the controls, current and voltage meters will be embedded into the circuit and provide data to the GUI for viewing. The GUI will also provide different ways to discharge the capacitors. As shown in figure 5 the GUI can also effectively discharge the capacitors with an installed button. Our team plans to implement a way for the capacitors to also be discharged with a time delay. This delay will take place if the capacitors are not discharged in a set amount of time. Our team is implementing this due to safety concerns. This GUI will create a user-friendly environment that will allow anyone to effectively control the output of this device. Other than the GUI we will provide labeled switches and buttons connected to the outside of the casing. These switches/buttons will include a power switch to turn on the circuit that will be connected to our power adapter device that will be plugged into the wall, a send pulse button, and a discharge button for the capacitors. A red LED will be placed above the discharge button to indicate that the capacitors are fully charged. The reason for these extra buttons on the casing is a safety protocol just in case that our GUI fails.

Since the GUI will be written in MATLAB, the code will be written using a procedural program design. This means that the code will represent data in variables and use them as arguments. The code will call a sequence of functions in order to implement code. This way our Senior Design Team can delegate tasks into individual functions. Each function will mainly control a feature that the GUI will handle. This process is favored in MATLAB code and will allow for easy addition of functions and code manipulation in the future. A prototype of our GUI is modeled below in figure 5. We intend to plot data gathered from the circuit on the right. Although this GUI is still under construction, we have been able to implement a simplified working model that can control several LEDs and read input data from the Arduino.

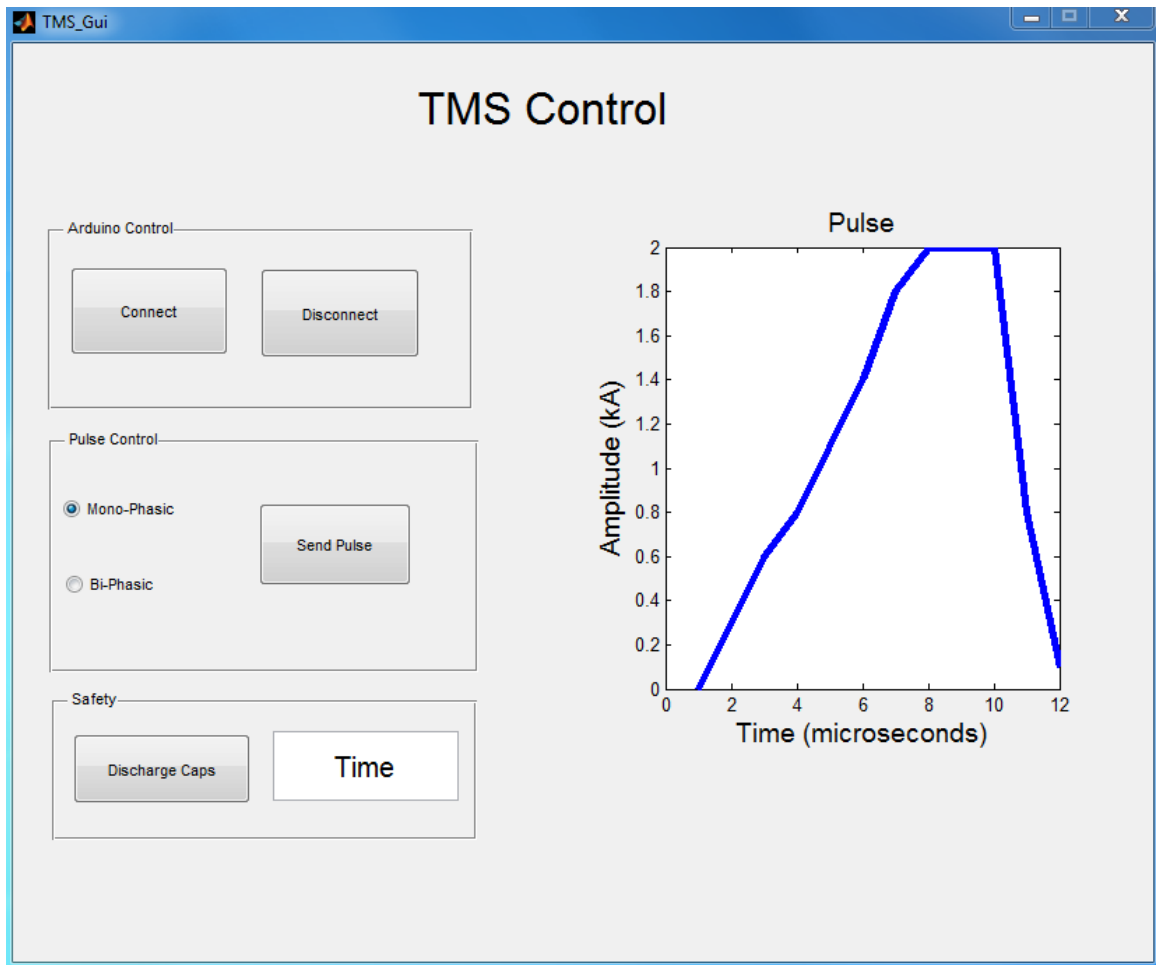


Figure 5: GUI interface

2.3 SIMULATION AND TESTING

The testing and simulation procedure can be seen in Figure 6. We created this procedure to ensure that the device is tested thoroughly and that the appropriate measures have been taken to fix potential problems.

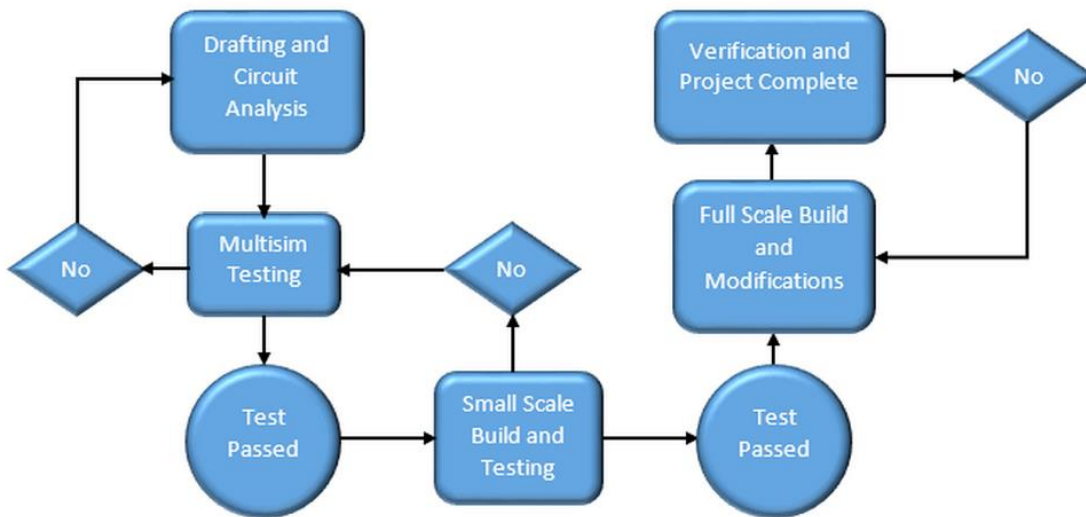


Figure 6: Testing Process Diagram

The first part of the design process requires drafting and analysis. This means creating the circuit and forming a foundation for the circuit design. Multisim then allows us to create any circuit design and thoroughly test it. We will measure all voltage and current input and outputs. When the desired output is achieved, we will create small-scale circuits using breadboards to verify that the simulation results hold true. If this is not the case, we will revert back to the drafting and circuit analysis and make the necessary changes in Multisim. When Multisim provided results that were favorable we modeled a small-scale circuit to ensure that the design will work before order the many expensive parts needed for this device. Once all bugs have been worked out, we move on to building and verifying the full scale model is working up to specs. Any problems at this stage will be resolved through full scale circuit modifications. Our group plans to test the circuit components before constructing the circuit. Once we fabricate the components together on PCB boards and get everything connected we will run extensive test to verify requirements. We will start to

optimize our circuit and make necessary changes to increase its functionality and reliability. To do this, we will be using high current probes, DMMs, and oscilloscopes to measure and record data. The data will be documented and analyzed in order to keep track of circuit modifications and performance. Once the functionality and all requirements have been met, the project will be deemed complete.

2.4 IMPLEMENTATION ISSUES/CHALLENGES

2.4.1 CAPACITOR ISSUES

Some of the issues our group encountered were how to create the required 1000 Amps while having our capacitors being a reasonable price and size. The reason as to why the possible capacitors were expensive was because of the high capacitance and the high voltage rating. We solved this issue by finding reasonable sized capacitors of 10 millifarads. Our team decided on this size of capacitor due to the amount of current that needs to be generated. The voltage rating on these capacitors is high which is found to be around 200 volts due to the high voltage from our voltage quadrupler. Our group managed to find the capacitors needed to make this circuit work, although we neglected to consider how large these could be. Our capacitors are around 4 inches tall and about 1.5 inches in diameter. This causes our circuit to become very bulky and increasingly difficult to arrange.

2.4.1 BURNING COMPONENTS

Due to working with high levels of current and voltage our group needed to find components that would not burn out quickly. This was seen in the last group's project where our advisor Robert was burning out components trying to work their circuit. Our group wants to avoid that happening so we researched and found various components that will be able to handle the amount of power the circuit creates.

3. PROGRAMS USED

3.1 MULTISIM

To start this design our team got familiar with using Multisim and to generate a circuit that will be used as our final design. Our team used Multisim to generate different types of prototype circuits to determine what would work to achieve our required parameters. We tested the voltage quadrupler separately and tested each additional section to ensure the circuit was functioning as anticipated. Our team designed multiple circuits before deciding on the final circuit that is highlighted in section 2.1 figure 2. This design is shown as a PCB board that is highlighted in section 3.2 in both figure 5 and 6.

3.2 ULTIBOARD PCB DESIGN

3.2.1 FILTER/AMPLIFIER BOARD

The device has two PCB boards to connect all the components with copper layering. We have created two boards in order to isolate the high current portion of the circuit. On one board we have our filter/amplifier with our voltage quadrupler, rectifier, and filters. The inductor filters are just attached to the board and will be connected by soldering the wires onto the copper lines. These will significantly reduce the rippling of the voltage quadrupler output.

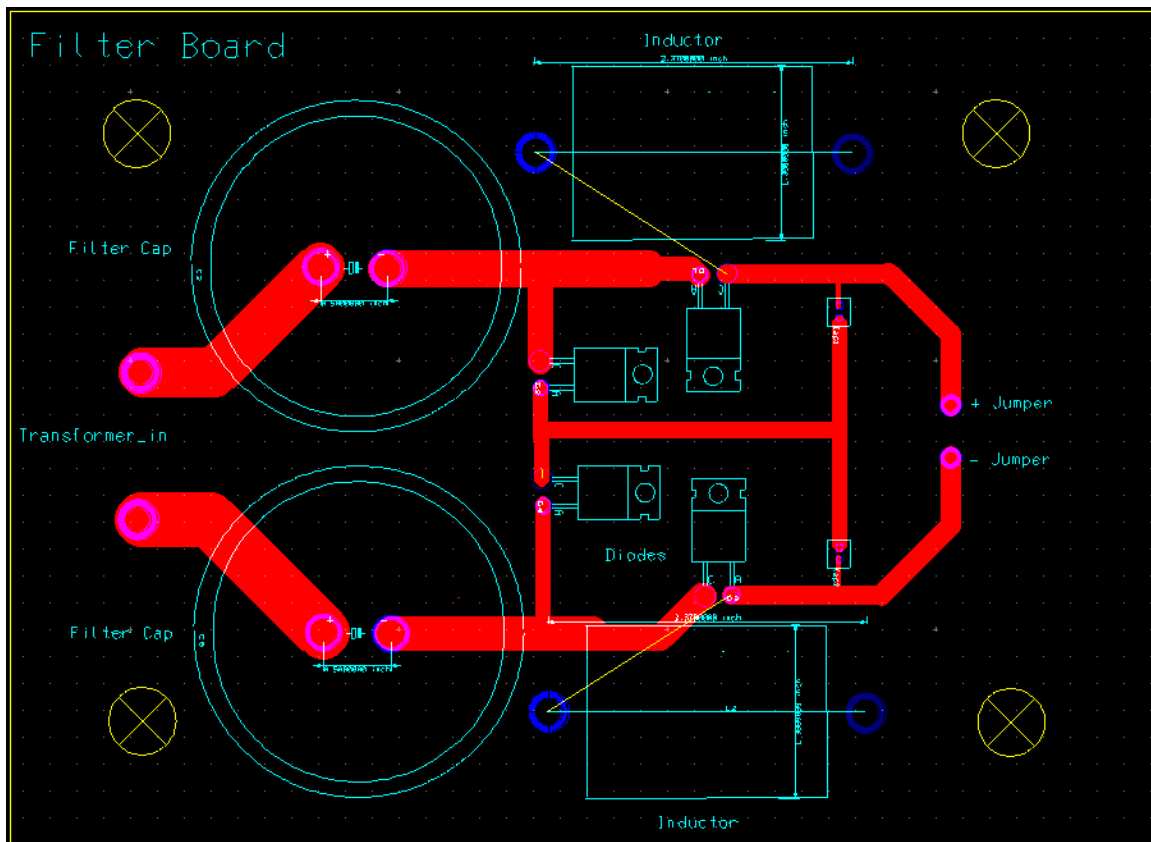


Figure 7: Filter/Amplifier Board

3.2.2 DISCHARGE BOARD

The second board that is being used is to hold our capacitors, discharge resistors, IGBT's, and the TMS coil. On this board we have some of our components being connected via jumper wires from the other board or the Arduino. The Arduino will be connected to the IGBT's via wires to be able to control the pulses. These pulses determine if we want to have either a mono-phasic or bi-phasic signal generated. The chip will also control the relays for discharging the capacitors. Our inductive load is located at the end of the circuit. This inductive load will be interchangeable for different coils. This will allow the user to test various coil design for TMS development.

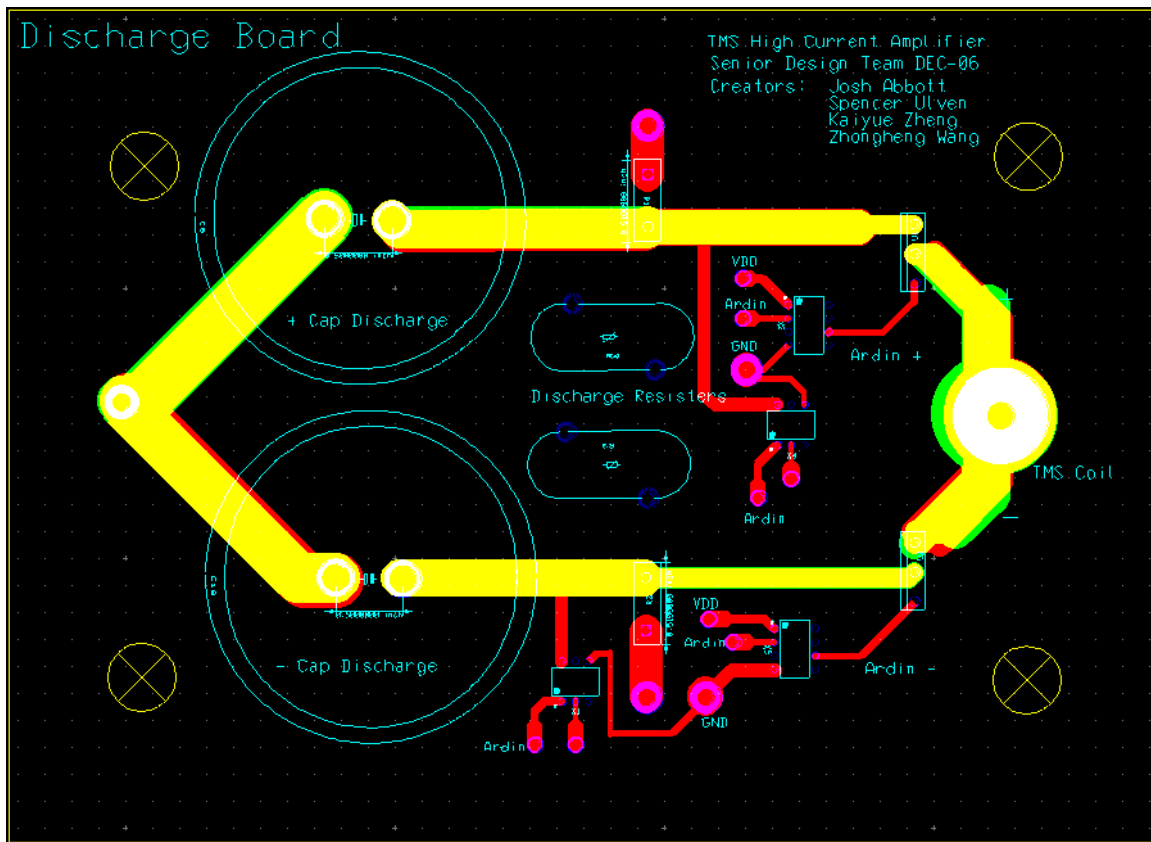


Figure 8: Discharge Board

The 3-D representation of both these boards are shown below to give the circuit a physical representation. However, figure does not have our exact measurements for each component. These boards simply give a general idea of how these boards will look like when fully fabricated.

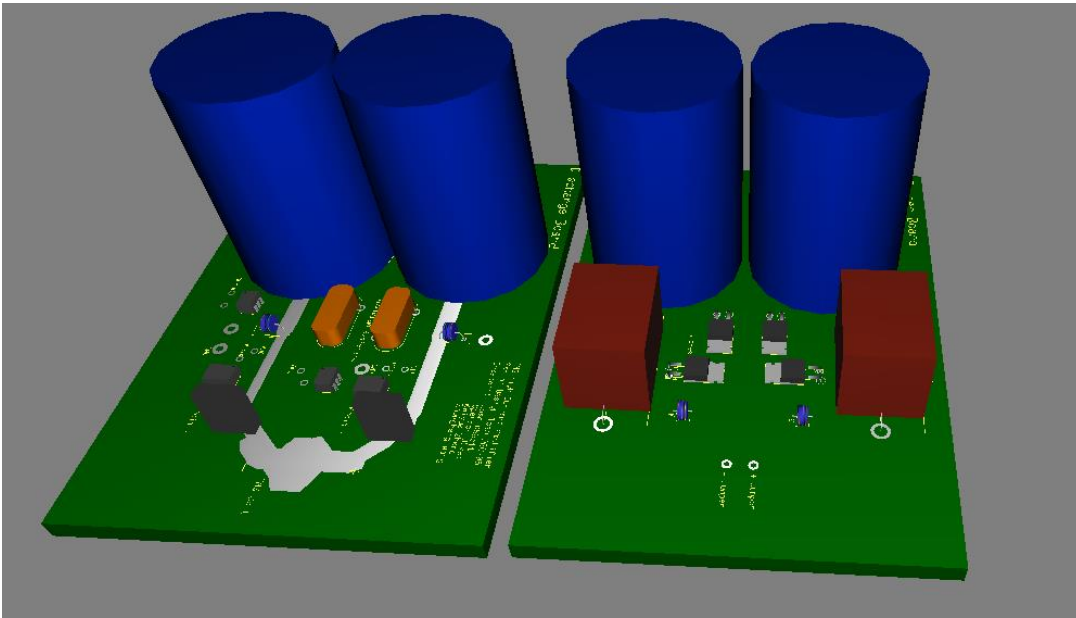


Figure 9: Ultiboard PCB Circuit Design 3-D

3.3 MATLAB/ARDUINO

As discussed in section 2.2, the GUI will be created using Arduino-MATLAB interface. The GUI will be constructed with the MATLAB's GUI builder. We chose MATLAB because it is a widely used software for researchers and can be easily modified for the user's preferences. By creating the GUI through MATLAB we can easily interface through serial communication to the Arduino chip. We can gather live measurements with the Arduino. MATLAB will allow us to make very fast matrix calculations with this raw data. So far we are not entirely sure how we will measure the current through the inductor. We are considering using a coil to measure the magnetic field and convert that into current. With this approach, having a quick software like MATLAB can help significantly in generating the necessary data.

In addition to MATLAB, the script writer for the Arduino will be used as well. Through the Arduino software, we can write code that will allow for MATLAB to control the chip as well as the manual controls located on the front of the physical device. We intend to use the Arduino by writing the C code that will fully control the circuit and implement various safety features. This means that whether the user wants to use the GUI or manually press the controls, the Arduino will handle all I/O.

4. CONCLUSION

The goal of this project is to create a device that could one day save lives and improve the quality of life for those of difficult circumstance. This device will one day help people with all the possible treatments that this device can provide. Our team has provided a descriptive process on how this circuit works and how to put this circuit together to create the specifications that are listed to create the magnetic field that will help potential patients.

5. APPENDIX

5.3 RESOURCES

To accomplish the goals of this project we had to use resources from our advisor and to other resources that we found ourselves. A comprehensive list is shown below:

Resources from Iowa State University:

- Iowa State University will provide a budget for the design, testing, and implementation of the design.
- Will fulfill all purchase orders.
- Will provide any tools needed for fabrication.

Resources from the group:

The resources we are using are the ones given to us by Robert. These resources show the group how TMS is used and what it is, the risks of using TMS and how to safely use these devices, and how it affects the body from high levels of electromagnetism due to the coils inside the devices. Basically the literature surveys helped the group better understand how these TMS devices work and the effect they can have on the people around them.

5.2 LITERATURE SURVEY

TMS Overview Document:

http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6695887&tag=1

Previous Design:

http://seniord.ece.iastate.edu/dec1306/uploads/1/8/1/8/18188693/dec13-06_design_doc_v2.pdf

Safety document:

http://bic.berkeley.edu/sites/default/files/Rossi_09_TMS_safety_review.pdf

Coils:

[Coil Link](#)

High Current Design

<http://www.ph.utexas.edu/~espg/paper/118.pdf>

High Current Design Theory

<https://www.jlab.org/ir/MITSeries/V5.PDF>

Electromagnetic Radiation

<http://advances.uniza.sk/index.php/AEEE/article/viewFile/473/263>

5.3 ACRONYMS

TMS Transcranial Magnetic Stimulation

GUI Graphical User Interface

PTSD Post-traumatic stress disorder