# Project Plan
# TMS: Transcranial Magnetic Simulation

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Project Plan V6

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# 1. SYSTEM OVERVIEW

## 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 researched 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, posttraumatic stress disorder (PTSD), Parkinson's disease, etc. Researchers are looking for a device that can produce the current needed to power the TMS coil and support deep brain stimulation to help treat 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, supply transformation, power storage, switching device, and switching device control.

The strengths of the device is that it could potentially lead to research that will change radically change the way doctors treat brain condition. In creating a cheap, high-powered TMS device, we can provide researchers a mean to develop this technology further. The weakness of this device is that it is a relatively new technology. Some of the risks associated with using such a process on someone can have negative effects. These effects are outlined in section in section 1.5.

## 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 GOAL

Our goal for this project is to create a high current amplifier that will support deep brain stimulation for TMS. We will improve on a previous semesters design while keeping the budget set at around $500. This means that our device needs to have higher current output, roughly 1000 Amps, and accurate control of the pulse while having the parts needed for a cost effective system. To reach these goals, thorough understanding of high current amplifiers and how to control pulse parameters is needed.

## 1.4 ENVIRONMENT OF OPERATION AND CONSTRUCTION

### 1.4.1 WHERE THE DEVICE WILL BE USED

The purpose of this project is for future research in the area of TMS. This means this specific device will be used in a laboratory. This project will have a potential of application of a low cost medical TMS device for use in hospitals but the design will focus on research applications.

### 1.4.2 WHERE THE DEVICE WILL BE CONSTRUCTED

Our team will be working with our advisor Robert Bouda. At first we had a bioengineering team which was responsible to create our inductive load but our team and advisor decided to create our own. We will create different types of inductive loads will be able to interface to the circuit. Our advisor brought this idea to us and we believe it might be a better solution than the bioengineering. The reason being is that we know the limitations and the inner workings of the amplifier. This give us the ability to design a coil that will best optimize the circuit for an effective magnetic field output. With the skill set on our team, we believe that the addition of another team to this project would slow and complicate progress.

The environment that we will be working in will be the TLA to use the computers to design the circuit using Multisim and to conduct research for anything that might leave us with questions. Other environments may include the high-speed engineering lab in Durham to create our PCB board and out adviser's lab in order to solder components to the board. We may also consider sending the PCB design to a company to fabricate offsite. One other lab we might utilize is the senior design lab, which has the necessary tools for creating the circuit as well.

## 1.5 COMPLICATIONS AND RISKS

### 1.5.1 AMPLIFIER AND CONTROL RISKS

Considering that this amplifier will be able to store and release large amounts of power. Keeping the system safe at all times is crucial for the users. Various components will be put in place to ensure the safety of the user of this device. Parts such as fans, fuses, proper grounding, and warning lights will be implemented into the design. Considering the high amount of heat that can be produced with this system, we plan on implementing a generous amount of ventilation that will be driven by two large fans. Warning lights to caution the user of high voltage/current will be created to also help minimize potential shock. In conjunction with the IEEE Code of Ethics, it is our responsibility to design a device that will keep the user safe while in operation.

In addition to making the actual circuit safe, we need to implement controls in order to ensure that the capacitors in the device are never discharged unintentionally. The capacitors in this circuit can hold a lot of energy even when the circuit is off. Since the circuit will be controlled through an Arduino, safe guards will be put in place so that the Arduino will discharge the capacitors for various situations. For instance, if the device has not been used for more than 5 minutes, we will employ an interrupt into the Arduino chip that discharges the capacitors. Other mechanisms to discharge the capacitor will include a button on the device and in the GUI.

### 1.5.2 BIOLOGICAL RISKS

Considering this project is focused on creating a device that will produce a large enough current to support deep brain TMS, some of the ethical issues surrounding such a system involve the side effects of using TMS on Humans. Per “Safety, Ethical Considerations, and Application Guidelines for the Use of Transcranial Magnetic Stimulation in Clinical Practice and Research,” document we have found that effects on TMS on people can create areas of risk. For instance in application of TMS it has been found that side effects such as, headaches, seizers, eyesight degradation, and tissue burning, although rare, can occur. The table below illustrates the current data reported on the use of existing TMS on patience. This table was provided by S. Rossi et al. / Clinical Neurophysiology which is included in section 5, Appendix.

| Side effect | Single-pulse TMS | Paired-pulse TMS | Low frequency rTMS | High frequency rTMS | Theta burst |
|---|---|---|---|---|---|
| Seizure induction | Rare | Not reported | Rare (usually protective effect) | Possible (1.4% crude risk estimate in epileptic patients; less than 1% in normals) | Possible (one seizure in a normal subject during cTBS) (see para 3.3.3) |
| Transient acute hypomania induction | No | No | Rare | Possible following left prefrontal stimulation | Not reported |
| Syncope | Possible as epiphenomenon (i.e., not related to direct brain effect) | | | | Possible |
| Transient headache, local pain, neck pain, toothache, paresthesia | Possible | Likely possible, but not reported/ addressed | Frequent (see para. 3.3) | Frequent (see para. 3.3) | Possible |
| Transient hearing changes | Possible | Likely possible, but not reported | Possible | Possible | Not reported |
| Transient cognitive/ neuropsychologial changes | Not reported | No reported | Overall negligible (see Section 4.6) | Overall negligible (see Section 4.6) | Transient impairment of working memory |
| Burns from scalp electrodes | No | No | Not reported | Occasionally reported | Not reported, but likely possible |
| Induced currents in electrical circuits | Theoretically possible, but described malfunction only if TMS is delivered in close proximity with the electric device (pace-makers, brain stimulators, pumps, intracardiac lines, cochlear implants) | | | | |
| Structural brain changes | Not reported | Nor reported | Inconsistent | Inconsistent | Not reported |
| Histotoxicity | No | No | Inconsistent | Inconsistent | Not reported |
| Other biological transient effects | Not reported | Not reported | Not reported | Transient hormone (TSH), and blood lactate levels changes | Not reported |

Table 1: Potential Side Effects of TMS

### 1.5.3 COMPLICATIONS OF PROJECT

With a device of this complexity various complications arise. A major complication is the fact that high current amplifiers on the market are usually over $1000. Having the ability to create such a high-powered amplifier with the $500 dollar budget could be an issue. The components in this design could cause problems as well since we are dealing with such high current. High current implies a lot of heat, and heat implies damage over time. Having the ability to create a robust circuit that will be able to operate under these conditions will be a challenging task.

# 2. DEVICE DESCRIPTION AND TESTING

## 2.1 SYSTEM DESCRIPTION

Since the TMS coil will need a current pulse to generate the magnetic field, our goal is to create a mono-phasic and bi-phasic pulse for a TMS device. Both mono-phasic and bi-phasic systems will consist of 6 main sections: power supply, voltage quadrupler, filter, energy storage, switching mechanism, and inductive load. A button will be used to trigger the pulse, sending out the pulse through the load. For the power supply we intend to take a standard wall outlet and split the voltage using the transformer. We then use a voltage quadrupler and rectify it into positive and negative DC voltages of +/- 200V. That voltage is then filtered using our inductor so we get an even DC voltage as an output. The filtered voltage is stored into our capacitor bank for both positive and negative sides of the circuit to create mono/bi-phasic waves. The banks will produce approximately 1000 Amps when they are discharged into the inductor via IGBT control. The IGBT's allow us to control this high current to produce either mono-phasic or bi-phasic. Our Arduino unit utilizes an IGBT driver for protection and is able to manage how long the IGBTs are conducting.

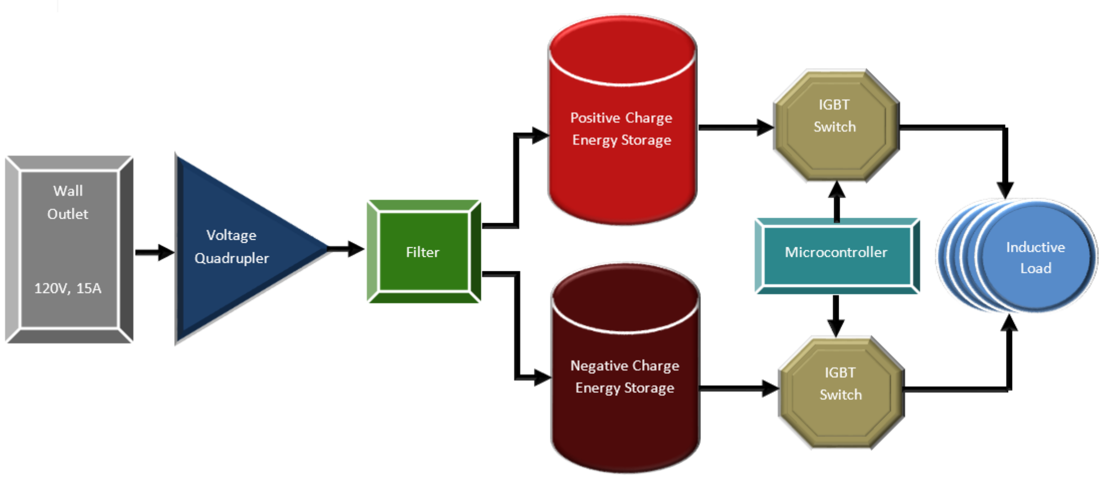


Figure 1: TMS Amplifier Block Diagram

From our block diagram you can see that our key components that will be a major part of this circuit. We will utilize a transformer that will help us power the device and help shield the wall from the current surges. In order to limit the current drawn from the wall outlet we are using a current limiter built with the transformer. Our voltage quadrupler basically will amplify the signal by a magnitude of 4. In addition to this, it also converts the AC voltage into DC. Since the output of the voltage quadrupler includes a small ripple signal, we use a filter to block this. Since the filter consumes some voltage, the input of the capacitors will be around 200V. Our capacitor bank is most likely our most important part of this circuit since it will allow us to produce the 1000 Amps of current that we need 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; these IGBTs will be connected to our Arduino and allow control through GUI or physical buttons on the device. The final component will be our inductive load which will consists of 60 micro-Henrys with a resistance of 50 milliohms.

## 2.2 USER INTERFACE

The microprocessor we choose for this project is the Arduino Uno. We favored this microprocessor 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.  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 switches connected to the outside of the casing and will label what each switch can do. Some of the switches we will have will be a power switch to turn on the circuit, discharge switches for the capacitors that will be one the GUI and will also be hardwired just in case of GUI failure.

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 out 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.

## 2.3 SIMULATION AND TESTING

The testing a simulation procedure can be seen in Figure 2. We created this procedure to ensure that the device is tested thoroughly and that the appropriate measures have been taken to fix potential problems.

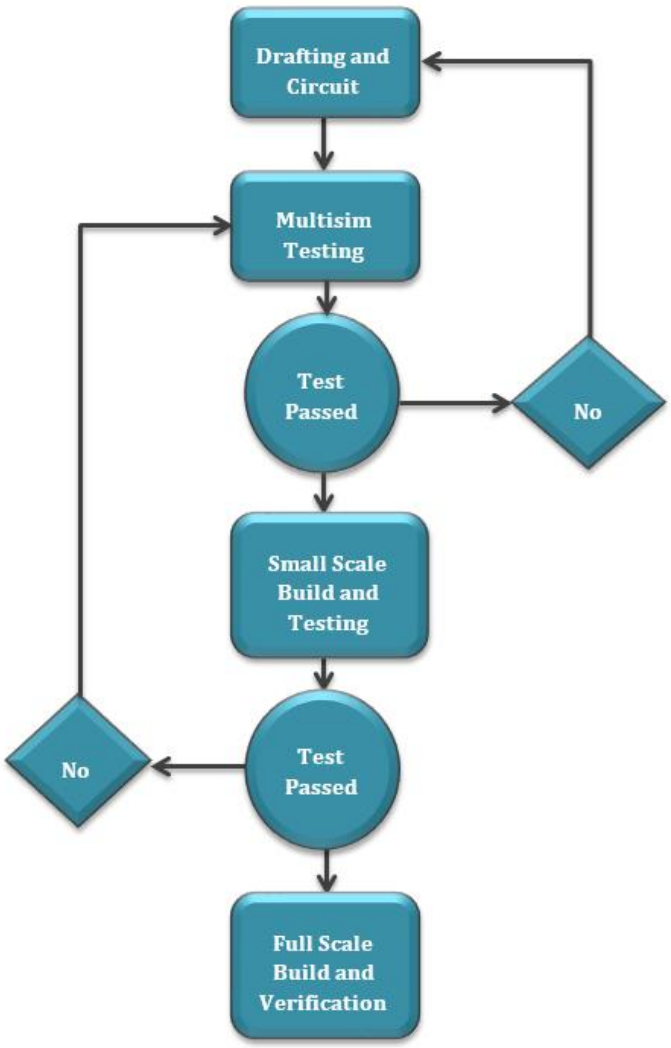


Figure 2: Testing Process Diagram

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. After Multisim we will model in the circuit small scale to ensure 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 is 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.

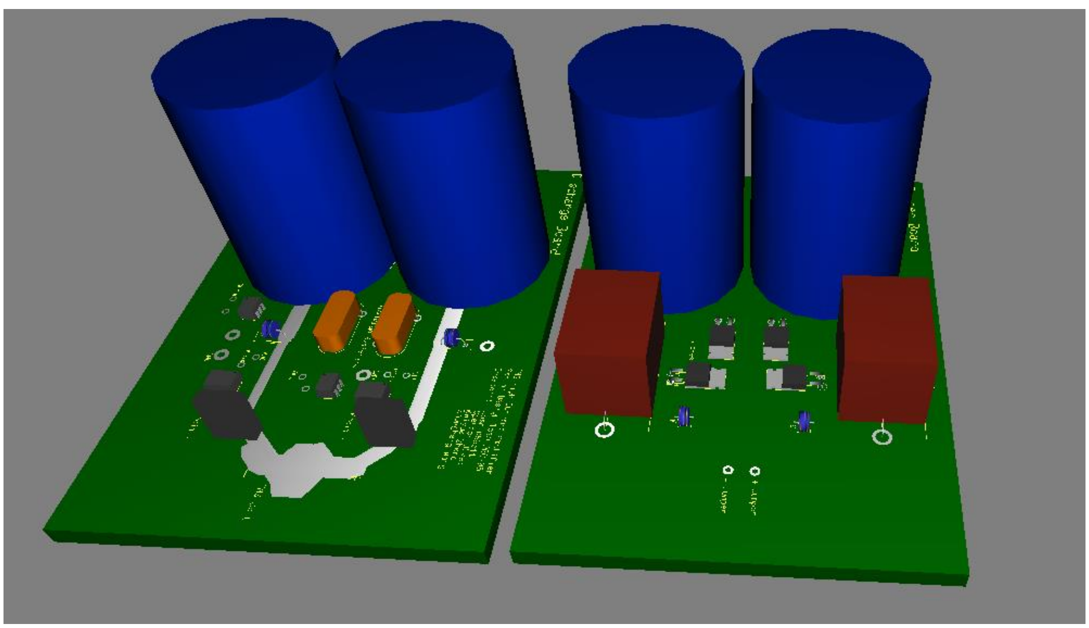

Figure 3: Ultiboard PCB Circuit Design

# 3. PROJECT DELIVERABLES

## 3.1 DELIVERABLES

The final product created by this senior design team will include a fully working mono/bi-phasic device. Our Arduino GUI will control the parameters of the pulse. A standard wall outlet that is 120 Vrms and 15 Amps will power the device. This device will safely produce 1000 Amps of current to be used on a TMS coil and fulfill all requirements outlined in section 1.2.

## 3.2 SOLUTION STATEMENT:

The way to deal with the high current is to create discharge buttons on for the capacitors that will not harm the user while using them. The discharge buttons will be located on the casing outside and will also be with our Arduino GUI. The problem with the high current from the capacitor can be solved by having a discharge switch that will connect the capacitor to a high rated resistor that can drain out the potential charge inside the capacitor. A way to fix the cost of the circuit is to research and find components that can be within our budget given to us and can be implemented easily in the circuit. The major component that will break the budget will be the IGBTs since they need to be highly rated due to the amount of strain that will be put onto them. Time can affect our group work due to having spent the first couple of weeks to better understand the material. This will take time to understand everything that will go into a TMS device and its circuitry.

## 3.3 CIRCUIT COSTS:

The cost for this circuit after finding all the components that we needed to create our requirements for this circuit was a total of $550.00. We created a bill of materials that listed out where all components we found were found at and how much they cost from that website. The biggest spenders of our budget were our 10mF capacitors with a 200V rating, our transformer, and our IGBT's because they needed to be rated high enough to not burn out from the high voltage and current running through the circuit. Although we have stayed under budget we have decided to use components that could possibly burn out since we have not tested these yet due to still making our PCB board so we have not implemented these into our design yet. We also may be making our own inductive load so that will be additional cost that will be calculated fall semester the development of the coil will begin. Figure 6 shows our bill of materials and the cost of each part.

| Quantity | Distributor part # | Distributor | Part | Model# | Unit Price | Total Price | Link | Comment |
|---|---|---|---|---|---|---|---|---|
| 4 | 493-7329-ND | Digi-Key | (4)Capacitor | LNR2D103MSE | $54.68 | $218.72 | Digikey Link | 10,000uF |
| 2 | 80-C315C101K2G | MOUSER | (2)Filter | C315C101K2G5TA | $0.36 | $0.72 | MOUSER Link | 100pF |
| 1 | AN-8475 | AnTek | Toroidal Transformer | AN-8475 | $84.00 | $84.00 | AnTek Link | 800VA 75V |
| 2 | 158SA-ND | Digi-Key | (2)Inductor | 158SA | $8.37 | $16.74 | Digikey Link | 1H |
| 2 | 684-MP9100-50 | MOUSER | (2)Resistor | MP9100-50.0-1% | $10.90 | $21.80 | MOUSER Link | 50Ohms |
| 4 | 71-RH0502K000FE02 | MOUSER | (4)Resistor (Cap Discharge) | RH0502K000FE02 | $4.25 | $17.00 | MOUSER Link | 2kOhms |
| 4 | 15ETH03PBF-ND | Digi-Key | (4)Diodes (Rectifier) | VS-15ETH03PBF | $1.54 | $6.16 | Digikey Link | 300V 15A |
| 1 | 747-IXXX300N60B3 | MOUSER | IGBT (Pulse Control) | IXXX300N60B3 | $24.30 | $24.30 | MOUSER Link | 600V 550A |
| 2 | 579-TC4420EOA | MOUSER | (2)IGBT (Driver) | TC4420EOA | $1.72 | $3.44 | MOUSER Link | 6A |
| 4 | 782-LH1500AAB | MOUSER | (4)Relay (Cap discharge) | LH1500AAB | $2.31 | $9.24 | MOUSER Link | 350V 150mA |
| 1 | 504-BK/MWO-15 | MOUSER | Fuse | BK/MWO-15 | $1.01 | $1.01 | MOUSER Link | 125V 15A |
| 2 | 576-03540101ZXGY | MOUSER | (2)Fuse Holder | 03540101ZXGY | $1.18 | $2.36 | MOUSER Link | 300V 15A |
| 1 | 612-R5BBLKREDFF1 | MOUSER | Button (ON-OFF) | R5BBLKREDFF1 | $2.53 | $2.53 | MOUSER Link | 250V(AC) 20A |
| 1 | #847781028362 | Superbrightleds | Button (Cap charge/discharge) | CPBT-SPR | $4.95 | $4.95 | Sbl Link | |
| 1 | EG1841-ND | Digi-Key | RockerSwitch(mono/biphasic) | R1966DBLKBLKCF | $1.74 | $1.74 | Digikey Link | |
| 1 | 1144-1033-ND | Digi-Key | Power Entry Connector | 06AE2 | $12.90 | $12.90 | Digikey Link | |
| 1 | 668933 | THE HOME DEPOT | Ground Bar | EC3GB27 | $12.54 | $12.54 | THD Link | |
| 1 | 995-AS32-10015 | MOUSER | Current Limiter | AS32 10015 | $6.52 | $6.52 | MOUSER Link | 120V 15A |
| 1 | 782-A000066 | MOUSER | Proccessor (Arduino UNO) | Arduino | $24.51 | $24.51 | MOUSER Link | 5V 40mA |
| 1 | N82E16835103052 | newegg | Cooling Fan | R4-S2S-124K-GP | $16.99 | $16.99 | newegg Link | Cooler Master 120mm |
| 1 | LED red diffused 20mm | gravitech | Warning LED | LED-RED-20MM | $1.95 | $1.95 | gravitech Link | 12V 50mA |
| 1 | #847781035971 | Superbrightleds | Button (Pulse control) | CPBT-SPG | $4.95 | $4.95 | Sbl Link | |
| | | | Case | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| | | | | | Total Cost | $495.07 | | |

Figure 6: Bill of Materials

# 4. PROJECT SCHEDULE

## 4.1 MONTH BY MONTH TASKS SCHEDULE

**Part 1 January through February 2014:**

January:

- Pick project and meet group, advisor, and client.
- Become familiar with group and set up times for future meetings.
- Brainstorm and research about TMS.

February:

- Start up web design for the HQ of our project.
- Research totem pole drivers, high current amplifiers, transformers, large capacitors, inductors, and power supplies.
- Refamiliarize with Multisim.
- Start working on MATLAB to Arduino GUI.

**Part 2 March 2014:**

March:

- Start implementing ideas into a final design on Multisim with mono/bi-phasic properties.
- Finalize MATLAB GUI that will control the pulses and mono/bi-phasic properties.
- Run tests and simulations of the circuit to make sure it meets the specifications listed.

**Part 3 Late March to mid April 2014:**

April:

- Identify any problems or errors and fix design.
- Redesign.
- Find optimal parts that will be needed for the circuit and create a bill of material that will be under budget.
- Using the parts found create an Ultiboard of the circuit with the dimensions from the parts listed.
- Order parts and Ultiboard system/PCB board that will implement components.
- Find the dimensions of the circuit and create casing

**Part 4 Mid April to end of spring semester 2014:**

May:

- Receive components and construct a prototype circuit within the casing and begin a testing phase with built circuit.
- Fix any problems with prototype.
- Start implementing our Arduino and other possible components needed after redesign process is finished.
- Prepare Reports and presentations for dead week.

**Part 5 Beginning of term to mid-September 2014:**
August:

- Our group will need to reacquaint ourselves with our circuit to be able to continue with project.
- After our group reacquaints itself with the project being another testing phase to make sure the circuit can still work.
- Redesign if necessary.

September:

- Gather feedback from client on possible adjustments.
- Continue testing the circuit and replace any burnt out components with more optimal components.

**Part 6 Mid-September to Mid November 2014:**
October:

- Continue with the fabrication of the circuit and finish the casing with implementing push buttons and a fan to make sure the circuit does not overheat.
- Continue testing the physical circuit and replace any burnt out components.

**Part 7 Mid November to Final presentation 2014:**
November:

- Work out any remaining problems with design.
- Add any new devices needed for design.
- Upgrade design.

December:

- Finish fabricating design to client specifications.
- Prepare final documents and Presentations.
- Present our design.

## 4.2 DESIGN SCHEDULE GANTT CHART

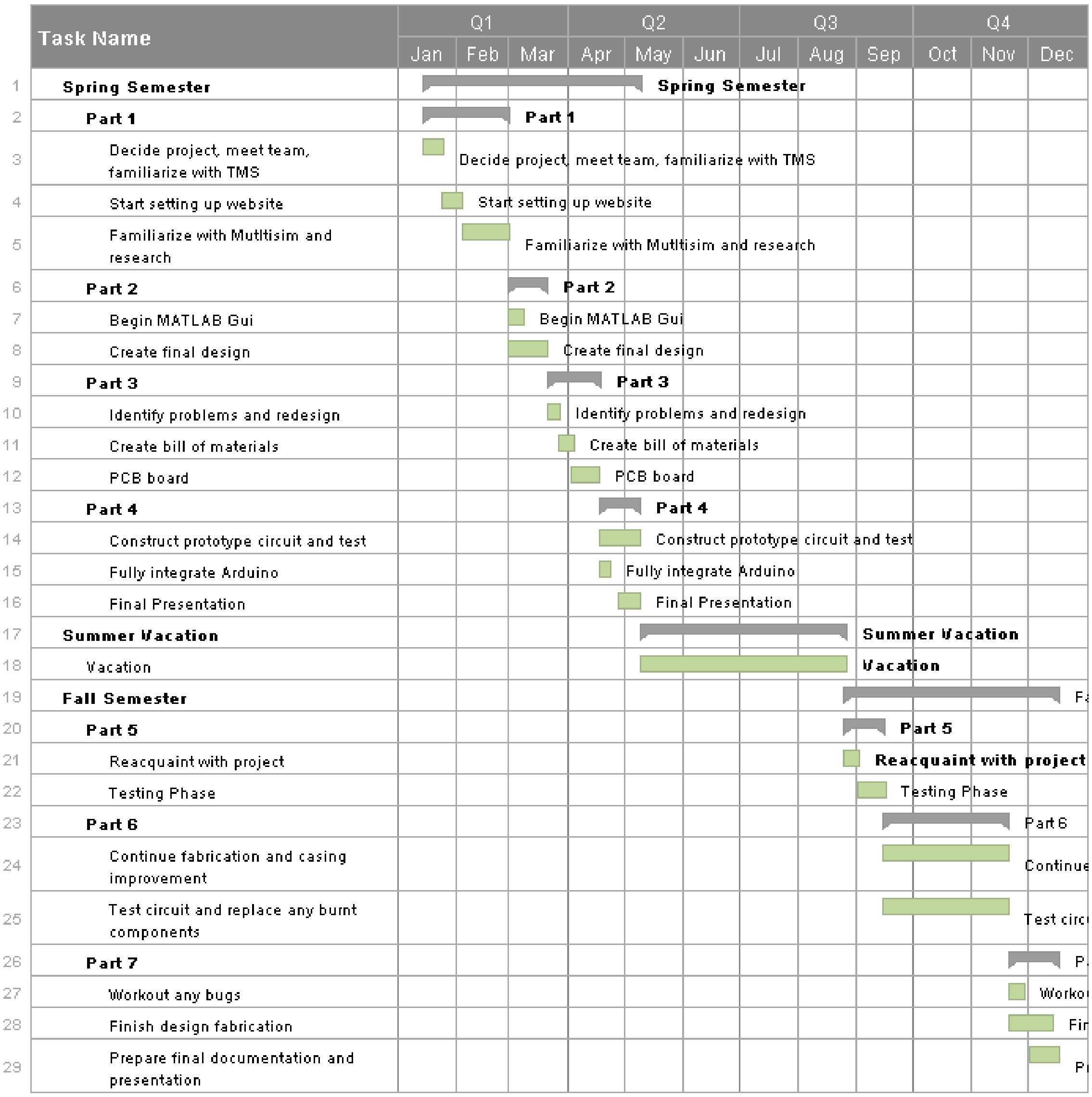


Figure 7: Design Schedule Gantt Chart

## 5. CONCLUSION

This project is to create a device that could one day save lives and improve the quality of life for those of difficult circumstances. The end goal of this project is to help people and use the skills and gifts of this team to help make a difference in the lives of those around us. Our goal is to provide a means for research to be done that will one day create treatments and therapies that will make tough modern day brain conditions treatable.

# 6. APPENDIX

## 6.1 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.

## 6.2 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

## 6.3 ACRONYMNS

| | |
|---|---|
| TMS | Transcranial Magnetic Stimulation |
| GUI | Graphical User Interface |
| PTSD | Post-traumatic stress disorder |