High Current Pulse Generator for the Application of Transcranial Magnetic Stimulation

PROJECT PLAN

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Table 1: Component List

List of Definitions and Acronyms

ETG: Electronics and Technology Group, Iowa State University

GUI: Graphical User Interface

IGBT: Insulated Gate Bipolar Transformer

TMS: Transcranial Magnetic Stimulation

Arduino: A popular microcontroller unit

1 Introductory Material

1.1 Acknowledgement

We would like to acknowledge Iowa State University for its financial assistance. This project would not be possible without their support. We would also like to acknowledge the invaluable technical assistance and guidance of the following individuals:

Dr. Mani Mina

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Neelam Prabhu Gaunkar

Priyam Rastogi

Thank you!

1.2 Problem Statement

This project aims to develop a high current pulse generator for the application of Transcranial Magnetic Stimulation (TMS). This technology is used to generate a pulsing magnetic field that can be focused on regions of the brain to treat various brain disorders. TMS has been studied for treatment of brain disorders since the mid 1980's and has been approved for the treatment of depression in the US since 2009 [1]. It is currently being researched for treatment of other disorders including schizophrenia and Parkinson's.

Currently, there is a need for a more cost effective and customizable pulse generator for use in basic research. Currently, approved commercial TMS units are very expensive and cannot be used with coils other than the closed, proprietary ones provided by the manufacturer. In recent years, different types of coils have been developed [2]. Moreover, different TMS coil have a tradeoff between focality and the depth of penetration [3]. By building and improving on past research and experimentation in this area, combined with innovations and original design, our team is aiming to meet this need for a robust, lower cost and flexible device that can be used with a variety of coils in a research setting.

This project will help to advance research in an area that has great social significance. Depression and other mental disorders are often treated with medication that causes dependency, is expensive, and has many negative side effects. TMS has already shown great promise in treating depression non-invasively and without medication. Additionally, the results of the treatment seem to be persistent, meaning the patient may not need to continue treatments after a few sessions. This technology shows promise for improving lives in a very real way, and we are eager to contribute.

1.3 Operating Environment

The intended operating environment for the final TMS device is a controlled one, due to its planned use in a research setting.

We do not anticipate or design for this device to be exposed to extremes in temperature, humidity, pressure, or particulates. The device is however likely be used for extended periods of time and by multiple users and in multiple physical locations (primarily labs). As a result, the device should be portable and robust enough to be easily moved from one location to another by 1 or 2 people without damaging the device or injuring the users.

The device will be designed to operate from standard 120 V wall power and will therefore be exposed to associated surge or power outage risks.

1.4 Intended Users and Intended Uses

Our primary intended users are researchers familiar with TMS technology working in a lab setting. Qualified students will likely also have access to the device under supervision or with training. The device is intended to be used under the control of a GUI to generate high-current pulses and vary the parameters of those pulses - pulse width, amplitude, total duration of operation.

A typical use case would involve a research attaching a compatible coil to the TMS device dependent on the size and shape of magnetic field needed for the research being done and test subject anatomy. The user will plug the device into a wall outlet, connect the device to a computer running Matlab and open the Matlab GUI provided. Once the GUI is up, the device is connected to the wall and the appropriate coil attached the user can operate the device via the GUI.

1.5 Assumptions and Limitations

Our TMS device is intended to be used under the following **limitations**:

- The total cost to produce the device shall not exceed $3000 dollars.
- The device shall support 1 coil type at a time. Multiple coils shall not be used simultaneously.
- The device shall <u>not</u> be used for TMS research on human subjects unless future approval is received.

Our TMS device was designed and made under the following **assumptions**:

- The device shall be used with US standard 120 V, 50-60 Hz wall current.
- The device shall be used only by or under the supervision of trained operators.
- The device shall be capable of sending pulses repetitively 10 pulses a minute.

- The device shall be capable of varying all pulse parameters described in section 2.2 Functional Requirements via the provided GUI.

1.6 Expected End Product and Other Deliverables

Pulse Generator Unit - Delivery May 2018

The pulse generator unit for the application of TMS shall be delivered in May of 2018. This shall include the following major components:

- Pulse generation circuitry
- Control circuitry
- Embedded microcontroller
- Cooling system
- Chassis box

These components shall be delivered assembled in the chassis box and capable of functioning as described in section 2.2 Functional Requirements.

Matlab GUI - Delivery December 2018

The final Matlab implementation of the Graphical User Interface (GUI) shall be delivered in December of 2018. This GUI shall allow control of all device operations and parameters as described in section 2.2 Functional Requirements.

Final Report - Delivery December 2018

A final report shall be delivered with the device in December of 2018. This report shall include a complete description of the device's design, test results, limitations and known issues, as well as any supplementary or supporting material and appendices.

2 Proposed Approach and Statement of Work

2.1 Objective of the Task

Our team is to design, build, and test a high current pulse generator for the use of transcranial magnetic stimulation coil testing.

2.2 Functional Requirements

The device shall be able to generate a pulse of current with an amplitude up to 2,000 Amperes. The pulse width shall be able to be modulated between 400 – 27 microseconds. It shall be able to produce up to 10 pulses per minute. The output waveform shall be biphasic. All the previously mentioned features shall be controlled using a GUI.

2.3 Constraints Considerations

The team shall create a graphical user interface to input the desired outputs from the machine. Standard IEEE code writing protocols shall be followed throughout the project.

2.4 Previous Work And Literature

In the past, other teams have developed and built plans for a TMS high pulse current generator. Their machine was designed to reach a peak current of 1000 Amperes, a pulse width between 50-400 micro-seconds, have an easy to use GUI, and a budget of $500 [4,5]. Our own project's objectives are mentioned earlier in section 2.2.

As our team researched past projects, we found the criteria that the teams had the most trouble meeting was cost and the size constraints of components causing safety concerns [4,5]. We are combating this by adding in gate checking throughout our circuit design phase.

In industry, there are several commercial options available. Magstim is the one our team is most familiar with. This machine can reach all our own objectives, however there is a reason we have been tasked with it. The short comings of using this machine in research are the high cost and difficultly of interchanging homemade coils. While our own circuit design will have very similar componentry and design as past projects, our project shall be able to reach higher current capability than past Iowa State projects and have an easier platform than Magstim to interchange various coil designs.

2.5 Proposed Design

The design shall consist of 3 sub blocks; the rectifying circuit, the power circuit, and the micro-controlling circuit. The rectifying circuit shall take in 120 Volts, 50-60 Hertz AC from a standard wall outlet and output a positive and negative direct current signal. Possible solutions for rectification include center trapped transformers and diodes. Transformers have the added benefit of isolating the machine from supply power.

The power circuit shall follow basic design ideas as presented in Polson's patent, Magnetic Stimulator for Neuro-Muscular Tissue. In which there is a storage device (capacitor) that delivers a high amplitude current pulse to the load using a switching device (thyristor) [6]. Past Iowa State University projects have made use of a IGBT in place of a thyristor [7]. As we developed our design, we had to choose an IGBT over thyristors because of availability.

Our design plan, as seen in figure 1, is based off Kirchhoff's Current Law: All currents entering a node must be equal to the currents leaving the node. The capacitor bank supplies equal parts of current across the node, so by having a switching component in series with each capacitor the amount of current through the switch would be only a part of what is seen at the load. To dissipate the current in the load, we introduce a diode and resistor pair in reverse polarity across the circuit. While delivering the pulse our diode is non-conducting, but when the switch is turned off, the load reverses polarity and turns our dissipation diode into a conducting path for our load current to flow through the resistor.

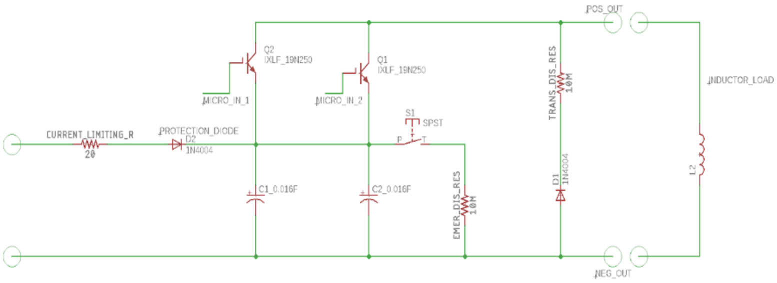

Fig. 1 Circuit Design

The micro-controlling circuit allows great control over our output waveforms. We shall be able to output square and sawtooth waveforms, with the ability to develop new waveform designs based on controller programming.

2.6 Technology Considerations

When choosing components, we must consider the limitations of each individual circuit component. We will be working with high currents and voltages in short periods of time, thus we need components that can sustain the currents and voltages without burning off. We also need to consider the costs. We have a budget, so we need the components that would work best inside our budget scope.

The switching device and capacitors are the highest costs as noted in past projects. We are reviewing different types of transistors, thyristors, and capacitors to choose the one that meets our requirements and is cost effective.

After reviewing several different types of transistors, thyristors, and capacitors based on the requirements previously defined in association with availability and cost we decided to use the ones found below in table 1.

Component	Model	Cost
IGBT	F6485-ND (Littlefuse)	$150.68
Capacitor	399-14357-ND (KEMET)	$60.89

Table 1

2.7 Safety Considerations

Due to the amount of current that will be going through the circuit, safety measures need to be taken. Since we're still in the process of designing the circuit and choosing the parts, this section has not been discussed extensively. However, after reviewing past projects, we've seen how some of them have open cabled freely hanging outside the black box, which is not safe as contact with a wire when the circuit is running is dangerous.

2.8 Task Approach

The method we are using to approach the project is to divide ourselves into teams and resolve individual issues. The following diagram (figure 2) shows the teams and the issue each team is currently working on. figure 3 displays our design process.

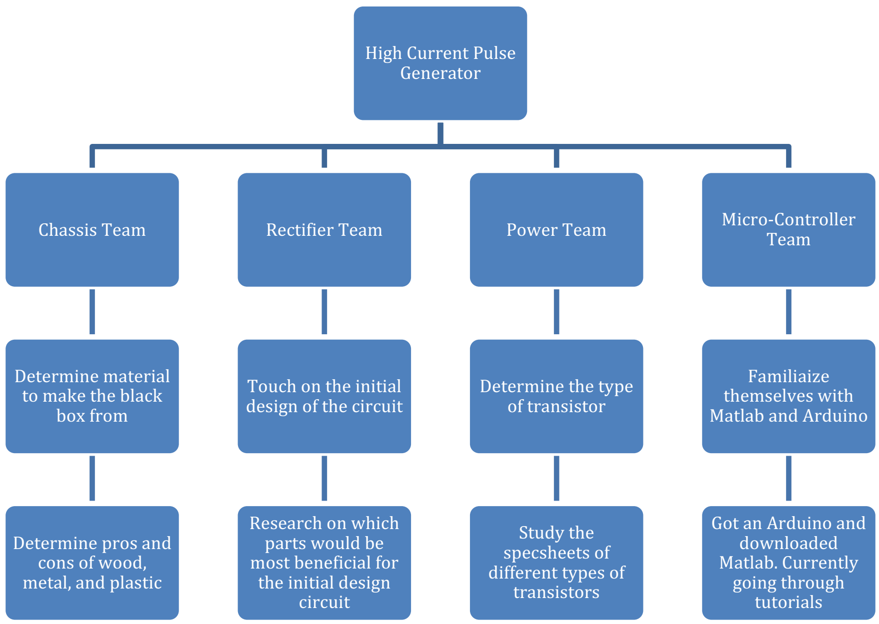

Fig. 1 Subteams

2.9 Possible Risks And Risk Management

The switching component can play a part in slowing the process of the circuit, due to the process of selecting one while having our budget in mind. It needs to be able to withstand a high drain to source voltage and the specified 2kA current.

On the meeting with our advisors the nature of the pulse was decided, that being a biphasic pulse. That means the cost would rise because we will need a switching component for each phase.

Our design includes capacitors that store the current until they're fully charged, at which time they would alert the microcontroller to open the gates and deliver current. In this situation we have the risk that the capacitors could contain some small amount of charge that we wouldn't know about which could cause injuries to anyone who comes into contact with it. A way we are managing this is figuring out a LED circuit that would be connected to the capacitors. When the capacitors have charge, even if minimal, we would be able to know by checking if the LED is lit up.

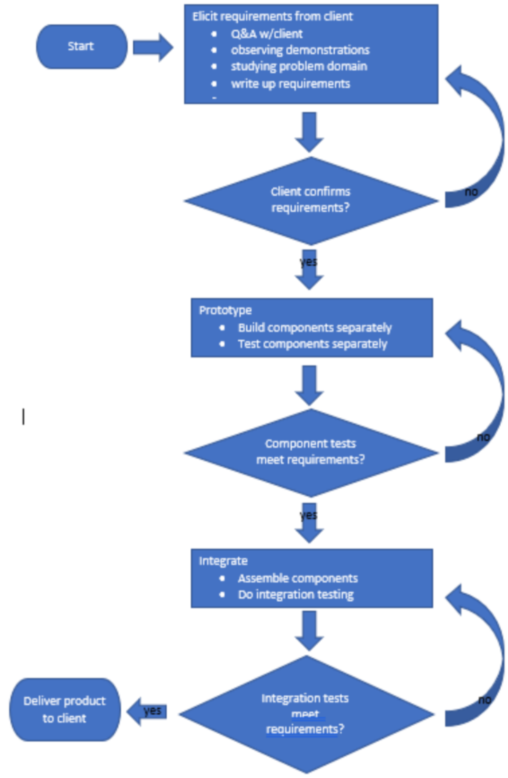

Fig. 3 Design Process

Another way we will be preventing potential injuries from users is using a "lockout tagout." That is, closing a lock on the circuit so no one can power the circuit without supervision. The team is planning on implementing a lock in the chassis box opening once we are done assembling so there is no unapproved contact with the circuit.

Regarding circuit risks, a way that we are protecting our project is by adding a discharging circuit part in the design. We are using resistors with high wattage that will be able to receive the full current and dissipate it, so none of the current is forced into an open IGBT or is sent back into the load.

2.10 Project Proposed Milestones And Evaluation Criteria

Our milestone for our Spring 2018 semester will be designing, ordering, and individually testing each of our design components. As a precaution we also simulated some of our circuits with P-spice and other circuit simulation software. Our major milestone will be testing everything separately to ensure that the current and voltage output is what we expect it to be. For our Fall 2017 semester, we plan on more extensive testing as to see what can be improved upon.

Testing in the spring will be for the main circuits individually to check if we meet the basic requirement. Testing here will be mainly for the output voltage and current using oscilloscope and multimeter. These tests are based off IEEE Standards [8].

For Fall Semester, our main job is to test the design of the negative section of the machine to make it biphasic. Because we are generating a high current and magnetic field, EMF will damage some parts if caution is not used. For that testing, we will likely be using a magnetic field meter. We will run our design for shorter periods at the beginning to keep inspecting parts for damage.

2.11 Project Tracking Procedures

The timeline in Section 3.1 will be followed to keep track of progress and make sure we are on track. At the beginning of each week, we meet and review our goals for the current week and do changes if needed. The following week, we first check our last week's goals to make sure they are met or rearrange the work if needed before planning for the current week and going over its goals.

As of now, we have been using the Gantt chart to check our progress. We had a few minor delays, but they have not impacted the project. By using our Gantt chart, we estimated the amount of time needed for each aspect of our project from designing to testing. Our progress has been smooth; we completed our design within schedule, ordered our parts before spring break, and began the construction of our device.

2.12 Expected Results and Validation

The project shall meet all requirements and specifications as defined in section 2.2. The desired weekly outcome is accomplishing all the goals discussed at the beginning of the week and reflecting on our knowledge and understanding in case we need to make changes in the future.

To verify that solutions work at a high level, we need to test it whether in simulation or physical testing depending on where we are in the project.

2.13 Test Plan

The main goal for our project is to get up to 2,000 Ampere in 400 micro-seconds. Testing this part will be relatively straight forward. We will use an oscilloscope to measure the current, frequency, and peak time

The second goal is make sure that the parts are not damaged by the EMF. For that, we will be using a magnetic field meter, and we will be testing the design for shorter times at the beginning, and then keep increasing the time. The goal is to try to prevent any damage before it happens or at least before affecting more parts.

3 Project Timeline, Estimated Resources, and Challenges

3.1 Project Timeline

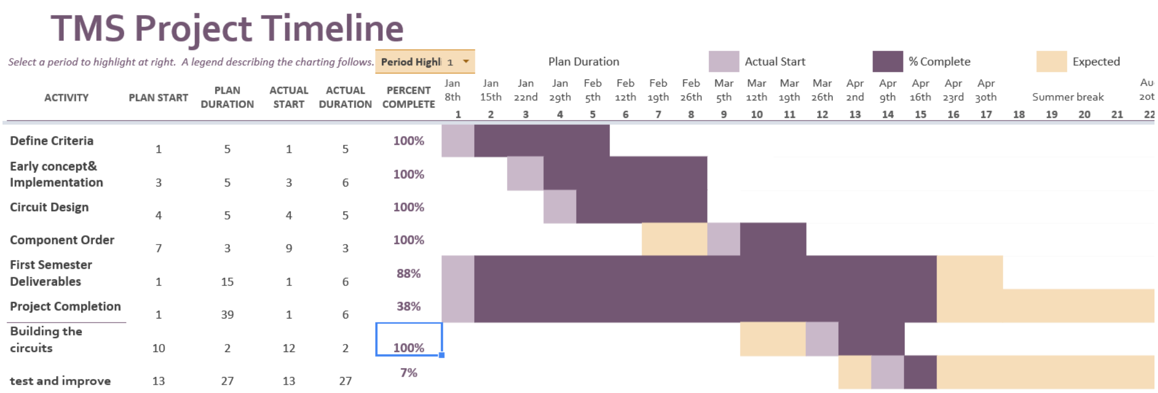

Fig. 4 Spring Gantt Chart

The figure above shows our team's Gantt chart. Due to the complex nature of our project, we decided to implement a general set of activities. Therefore, if something unexpected were to arise we can easily move more time to that specific topic. Based on our activities, we can easily show what has been completed and what hasn't been completed. We have a second Gantt chart that covers our work through the fall semester in the Appendix labeled figure 5.

Our criteria have been defined, our concept and implementation has been approved by our clients, the math and simulation of our circuit design has given us desirable results and our components have been ordered and delivered. As of now, we have begun the physical construction of the project. We plan on the building process being finished during this upcoming week. Afterwards, we will test and adjust our design if needed be.

The testing seemed to be were most teams in the past fell short, so our advisor is circumventing this by dedicated next semester to more extensive testing. With testing we hope to improve upon our design to make it as effective as possible.

For our upcoming semester we have designed another Gantt chart (figure 6 in Appendix). It resembles our semester 1 Gantt chart. Unlike figure 5, figure 6 is purely for the Fall semester.

3.2 Feasibility Assessment

Our project will concern all the objectives mentioned in section 2.2. Some past challenges that other teams seemed to face is the back feed of current and voltage through the circuit

[4]. We are currently designing solutions around this problem. Possible design solutions include using a switching device that can handle the peak current and voltages, as well as including a capacitor to absorb the charge.

3.3 Personnel Effort Requirements

Not yet applicable outside the typical research, readings and reflection done before each client meeting.

3.4 Other Resource Requirements

Apart from financial and material needs, our other resources include researching through reading papers as well as certain videos based on our subject, talking to and interviewing with professor/experts in this field, certain rooms for the group to work in and our advisors who are graduate students here at ISU that are enthusiastic about this project as well as hold high expectations of us. We will obtain our components and materials through the ETG.

3.5 Financial Requirements

It appears that our finances will be taken care of, so long as they are within reason. We plan our cost to be at $3000 in components. This will be split between the spring and fall semesters to make best use of our money if problems do arise.

4 Closure Materials

4.1 Conclusion

As stated previously there are commercial high current pulse generators available that meet the peak current and pulse width needs. However, they are costly and unable to easily support researcher's new coil designs. Our team will design, build and test a high current pulse generator that not only meets commercial benchmarks, but is economical, safe, and researcher friendly.

4.2 APPENDICES

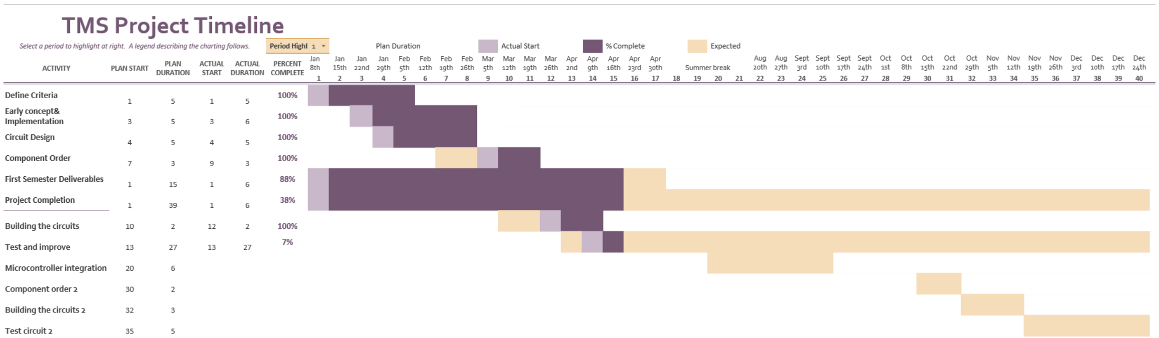

Fig. 5 Spring and Fall Gantt Chart

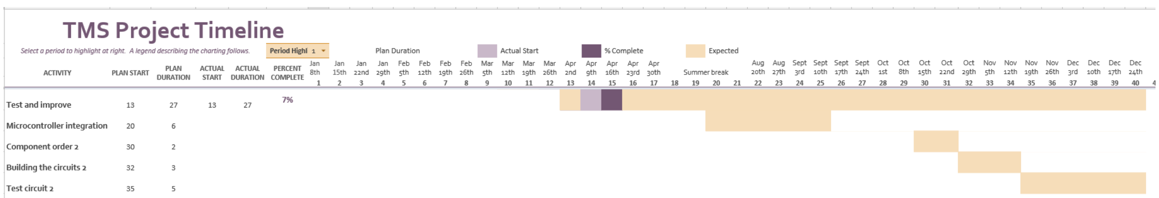

Fig. 6 Fall Gantt Chart

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