High Current Pulse Generator for the Application of Transcranial Magnetic Stimulation

PROJECT PLAN

Team Number: SD-04

Client: Dr. Mani Mina

Advisers:
Joseph Zambreno
J.P. Rakash
Dr. Mani Mina
Neelam Prabhu Gaunkar
Priyam Rastogi

Team Members & Roles:
Abdullah Bahashwan - Head of Rectification Circuits
Brian Kirkpatrick - Lead Circuit Designer
Curtis Richard - Team Leader
Jonathan Rothfus - Embedded Software Engineer
Tania Alvarado Carias - Head of Electrical Safety
Yan Wang - Head of Component Selection

Team Email: sddec18-04@iastate.edu

Team Website: http://sddec18-04.sd.ece.iastate.edu

Revised: 2/12/18-v1

Table of Contents

List of Figures

List of Definitions and Acronyms

Arduino: A popular microcontroller unit

ETG: Electronics and Technology Group, Iowa State University

GUI: Graphical User Interface

IGBT: Insulated Gate Bipolar Transformer

TMS: Transcranial Magnetic Stimulation

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

Dr. Joseph Zambreno

J.P. Rakash

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. It is currently being researched for treatment of other disorders including schizophrenia and Parkinson's.

At the moment 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. 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 this device being exposed to extremes in temperature, humidity, pressure, or particulates.

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 intended users are researchers familiar with TMS technology working in a lab setting.

Qualified students will likely also have access to the device.

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.

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 X 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 operating continuously for X minutes/seconds without cooling down.
- 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 of 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 [1,2]. 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 [1,2]. 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) [3]. Past Iowa State University projects have made use of a IGBT in place of a thyristor [4]. As we develop our design, the choice between thyristor and IGBT will depend on available components and their peak current and voltage specifications.

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.

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 1) shows the teams and the issue each team is currently working on. Figure 2 displays our design process.

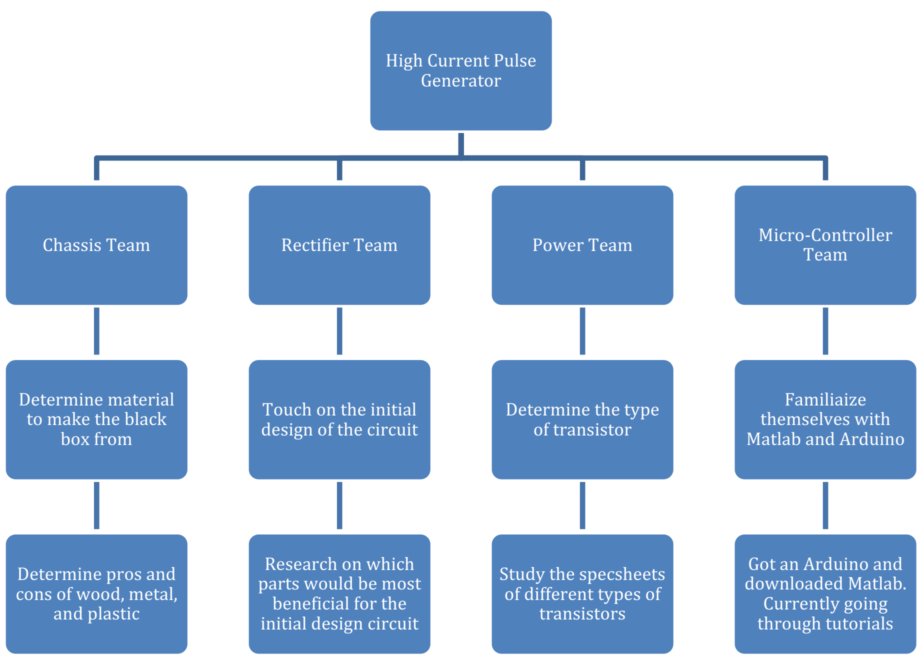

Fig. 1 Subteams

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 – we will need a switching component for each phase.

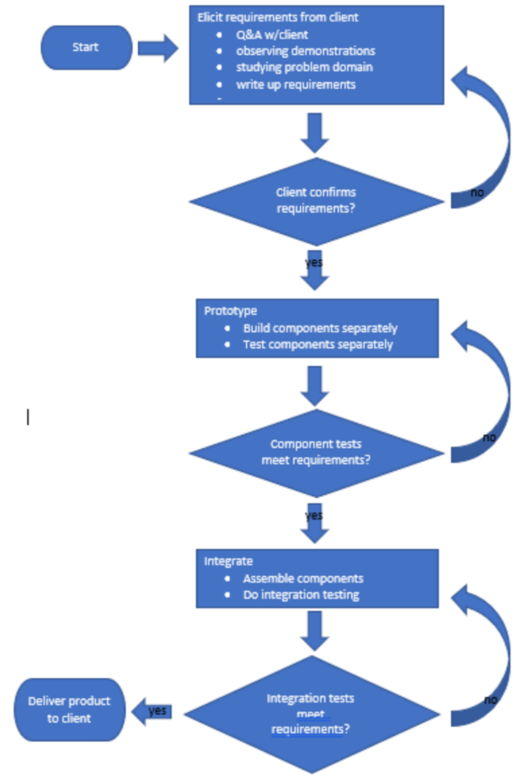

Fig. 2 Design Process

2.10 Project Proposed Milestones And Evaluation Criteria

For Spring Semester, the milestones are originating the design and simulating it. For that part, we will test our design mainly in simulation suing EAGLE PCB Builder. In the Spring Semester, we are also required to order and assemble the parts. The testing here 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.

For Fall Semester, our main job is to test the design a whole. Because we are generating a high current and magnetic field, EMF will damage some parts if cautions not used. For that testing, we will likely be using 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.

2.12 Expected Results And Validation

A desired outcome as a whole is a project meeting all requirements and specification and cost-effective. A desired weekly outcome is meeting all the goals discussed at the beginning of the week with more 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

Make sure to include at least a couple paragraphs discussing the timeline and why it is being proposed. Include details that distinguish between design details for present project version and later stages of project.

Our project has several different deliverables. Those being the defining the project objective, early concept and implementation, circuit design, ordering of components, assembly, and testing. These are noted in fig. 3 from the appendix. Most deliverables will be due during the first semester. The testing seemed to be were most teams in the past fell short, so our advisor is circumventing this by devoting the entire second semester to testing.

3.2 Feasibility Assessment

Our project will concern all of 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 [1]. 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. The design will need to be checked off by Dr. Mina before we can order the parts. Once our design is clearer, we will know a discrete monetary amount.

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

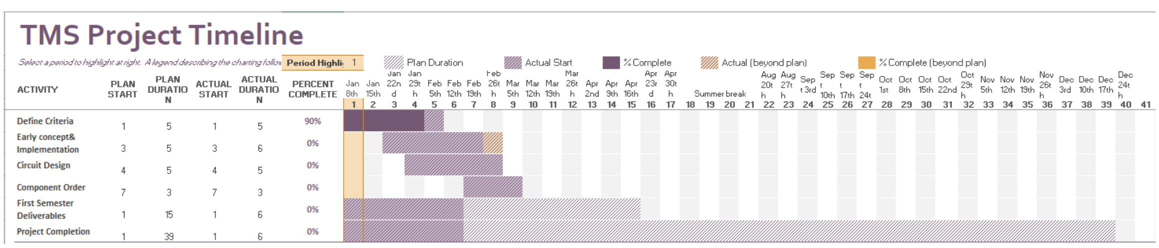

Fig. 3 Gantt Chart

4.3 References

[1] Spencer Ulven, et al. “TMS: Transcranial Magnetic Stimulation.”, unpublished.

[2] G. Bulleit, et al. “High Current Pulse Generator.”, unpublished.

[3] M.J.R. Polson. “Magnetic Stimulator for Neuro-Muscular Tissue.” U.S. Patent 5 766 124, Jun. 16, 1998.

[4] J. Selvaraj, et al. “Design of a Small sized High-Current Pulse Magnetic Field Generator for Transcranial Magnetic Stimulation of Small Animals.”, unpublished.