High Current Pulse Generator for the Application of Transcranial Magnetic Stimulation

DESIGN DOCUMENT

Team Number: SD-04

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LIST OF DEFINITIONS AND ACRONYMS

Arduino: *A popular microcontroller unit*

ETG: Electronics Technology Group at Iowa State University

EMF: Electromotive Force

GUI: *Graphical User Interface*

IGBT: *Insolated-gate Bipolar Transistor, primarily used as an electronic switch under the control of a switching signal, typically a voltage*

Matlab: *Scientific computing and scripting software providing a wide range of functionality*

Serial Connection: *A connection in which data is sent 1 bit at a time in series over a data channel*

TMS: *Transcranial Magnetic Stimulation*

1 Introduction

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. Joseph Zambreno

Dr. Mani Mina

Jayaprakash Selvaraj

Neelam Prabhu Gaunkar

Priyam Rastogi

Thank you!

1.2 PROBLEM AND PROJECT 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 fairly 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 OPERATIONAL 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 therefore be exposed to associated surge or power outage risks.

1.4 INTENDED USERS AND 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 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, 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 DELIVERABLES

Pulse Generator Unit - Delivery May 2018

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

- AC/DC rectification circuit
- Pulse generation circuit
- Control circuit

- Embedded microcontroller(s)
- Cooling system
- Chassis box
- Wall power cord

These components shall be assembled and delivered 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. This shall include all Matlab files and supporting documentation or instructional material needed for the user to install and configure Matlab and run the GUI program.

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, user guides, and appendices.

2. Specifications and Analysis

2.1 PROPOSED DESIGN

Our power circuit design can be split up into two different design ideas we call plan A and plan B. Originally our team put together design plan A based off ideas found in Polson's Patent, Magnetic Stimulator for Neuro-Muscular Tissue. In the design there is an electrical storage component, capacitor, and a switching device, thyristor, that controls the flow of current to an inductive load [1]. The design plan A can be seen in fig. 1. One of the other unique features of this design is the regenerative circuit. This portion of the circuit recaptures the electrical energy dumped into the load in capacitor storage, Cr, rather than having it return to the capacitors, Cs.
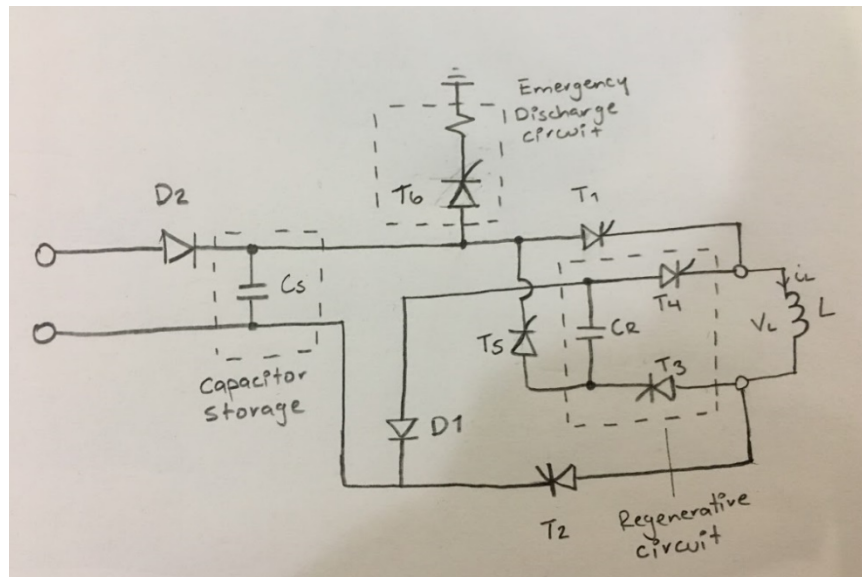

Fig. 1

The design plan A was dependent on having a thyristor that could handle the back EMF. We had chosen the thyristor IRK 230-20 for our design, and then began requesting quotes from several high-power electrical component suppliers. The most promising of the companies we were in contact with was 5S components, and still so

many problems arose with securing the part we decided to no longer go with a thyristor dependent design.

Design plan B, as seen in fig. 2, is based off Kirchhoff's Current Law: All currents entering a node must be equal to the currents leaving the node. The capacitor bank from design plan A was already supplying equal parts of current in parallel that would sum to the current across the node, so by having a switching component in series with each capacitor the amount of current the switch would see is less than what would be seen by the thyristor in design plan B (fig. 1.). This allows us to choose an IGBT like in the mouse pulsar design [2].

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 move through the resistors.

The circuit expectations laid out in section 1 are still met with design plan B, but we were unable to translate the regenerative circuit into our new design on such short notice. The decision was made to leave that portion of the circuit out, with the possibility we may return to the idea in the future after a working prototype has been established.
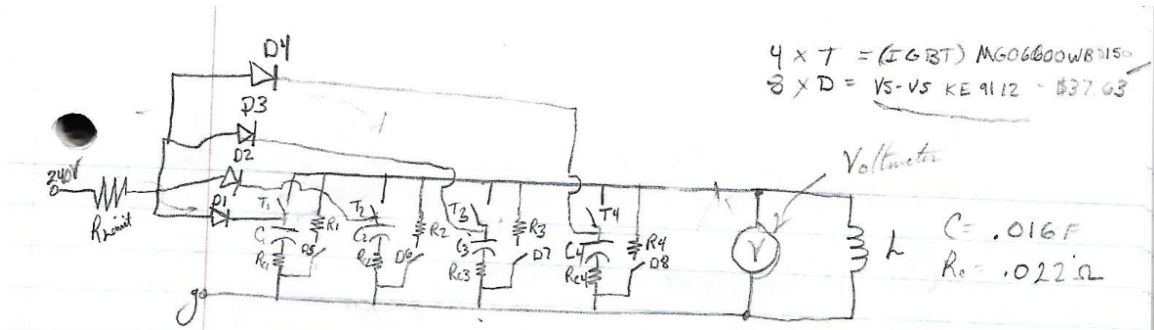

Fig. 2

2.2 DESIGN ANALYSIS– DISCUSS WHAT YOU DID SO FAR

As discussed before in section 2.1, the regenerative circuit may be added in the future after a working prototype. We expect other observations to evolve as we begin to assemble our circuit on March 23, 2018.

One of the strengths of design plan B is the "modularity". Each capacitor/switching line is equal to one resistor/diode dissipation line, both connected at the same node. We will build and test the circuit adding one capacitor/switch line at a time to our node. This will provide great safety as we test the circuit. By building and testing in this method we hope to avoid past team's shortcoming of overloading all their switching components at once [3,4].

3 Testing and Implementation

3.1 Interface Specifications

We are building user-friendly GUI that is used to choose parameters, such as waveform, frequency, current level, and others. While testing the GUI might be one of the easiest jobs in our project, it is going to be the most subjective part of the design. Our goal is to make the GUI as easy as possible to use not only by people with knowledge in electrical engineering or technology, but also by everyone who might use the divide. The best way to accomplish this is to assume that users of our project have a little experience with technology, so that they can still take a full advantage of the project. For people with more experience, using the design will then be easier for them.

3.2 Hardware and software

3.21 Hardware Testing

Eagle PCB has been used for simulation to verify our calculations and designs.

Multimeters and heat sensors will be used for testing after the design is built. While multimeters will be used to test the current and voltage levels in our design, the heat sensor will be used to make sure that capacitors and IGBTs do not heat up when the device is operating.

Our team will test the rectification, power, and microcontroller sections of the system separately before combining. The hardware sections (rectification and power circuits) shall be laid out on our chassis before assembly begins. This will allow us to look at any layout problems and adjust the chassis accordingly.

The power circuit will assemble one capacitor/IGBT module at a time. The system will be tested incrementally starting from 10 Vg for the IGBT and increasing by .5 V until the load current meets 500 Amps or failure occurs. The testing increments starting voltage for the IGBT comes from the IGBT datasheet [5]. In the case of failure, an upward boundary has been established that shall not be exceeded when testing the second capacitor module.

3.22 Microcontroller testing

3.2 A Matlab GUI Testing

Unit testing of the Matlab GUI will be done to ensure that each GUI element functions as intended. GUI elements include items such as buttons, plots, text entry fields, etc. Unit testing will be done with the Matlab IDE debugger, the Arduino and Matlab IDE serial monitors, and standard debugging methods such as print statements, etc.

Non-functional testing of the GUI will be conducted to ensure usability and robustness.

The serial communication between the microcontroller and Matlab shall be tested against data loss due to timing issues or buffer overflow.

3.2 B MICROCONTROLLER SIGNAL TESTING

The goal of the microcontroller is to interact with the circuit via digital and analog signals. Testing of all signals generated by the microcontroller will be done to ensure correct signal timing and waveform properties. The microcontroller signals under the control of software functions will be tested with the microcontroller isolated from any other hardware to verify that the correct signal is on the pins before integration testing.

The following properties of all signals generated by the Arduino will be tested for compliance with design requirements using an oscilloscope:

- Signal duty cycle
- Signal frequency
- Signal amplitude
- Pulse count per session/burst
- Rise time/slew

3.2 C MICROCONTROLLER/HARDWARE INTERFACE TESTING

After all software and signal tests have been performed in isolation and passed, the microcontroller will be tested in integration with various hardware components. Testing of the microcontroller control of hardware components will be done in a piecewise fashion to the extent that is possible, testing integration with one hardware piece alone before repeating with another.

The following microcontroller/hardware interfaces will be tested using an oscilloscope, multimeter or other standard lab electrical test equipment as needed:

Microcontroller/IGBT Interface: The microcontroller signal tested previously shall control the switching of the IGBT allowing current to flow through the circuit. The same basic properties listed above in "Microcontroller Signal Testing" shall be tested. In this case, the following properties of the output current pulse from the IGBT, under switching control of the microcontroller, shall be tested using an oscilloscope to verify compliance with design requirements:

- o Current duty cycle
- o Current frequency
- o Current amplitude
- o Current pulse count per session/burst
- o Rise time/slew

Microcontroller/Relay Interface: The microcontroller shall control charging of the capacitor bank via a relay. The operation of the relay under control of the microcontroller shall be tested using an oscilloscope or voltmeter.

3.3   FUNCTIONAL TESTING
Unit testing:
Microcontroller works correctly
The rectifier circuit delivers the 240 Volts signal needed
The power circuit has the correct behavior

Integration testing:
The microcontroller monitors the correct parts of the circuit and controls the IGBT's in the right manner.
The rectifier circuit takes the wall input signal and converts it to the desired output
The capacitors in the power circuit charge correctly with the signal sent from the rectifier circuit
The diodes in the power circuit activate and deactivate when anticipated with the signal form the rectifier circuit

Acceptance testing:
Test that the current pulse being delivered is the current expected
Check that the time the pulse is delivered is about 400 µs
Test the rise and fall times of the pulse are within 100 µs

3.4   NON-FUNCTIONAL TESTING

Usability testing:
The GUI is user-friendly and has all the controls our client expects to be able to modify
Any other external input control from the user works

Reliability testing:
The pulse magnitude does not change after several tests
The biphasic nature of the circuit does not affect the output in a negative way

Stability testing:
After being tested several times it does not experience a failure of some sort (i.e. some part burning off)
There are no unexpected fluctuations in the voltage or current at any part of the circuit

Security testing:
Discharges the energy efficiently
Alerts the user when it is not safe to touch

3.5   RESULTS

Results will be added when testing is complete.

4 Closing Material

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 REFERENCES

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

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

[3]   Spencer Ulven, et al. "TMS: Transcranial Magnetic Stimulation.", unpublished.

[4]   G. Bulleit, et al. "High Current Pulse Generator.", unpublished.

[5]   *Power IGBT Module*. MG06600WB-BN4MM. Littelfuse. Oct. 5, 2016

4.3 APPENDICES

We will have appendices once testing is complete.