

High Current Pulse Generator

Team DEC13-06

Final Report

Team Composition

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Table of Contents

Executive Summary	3
Requirements	3
Functional Decomposition	3
Detailed Design	4
Simulation and Testing	7

Executive Summary

Our goal of this project is to further research into high current pulse generators that could be used as for Transcranial magnetic stimulation (TMS). 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 inductive loads.

This document will cover the overall design of our circuit. We have broken down the circuit into its basic parts; the power supply, power storage, switching device, and switching device control. For each of these parts we have broken down our design choices and considerations.

Requirements

Functional

1. Control of pulse width and amplitude
2. Initial device capable of 25A monophasic
3. 400 μ s for maximum pulse width
4. Biphasic implementation
5. Higher current design or device

Non-Functional

1. Single device capable of monophasic and biphasic
2. The size and the weight of our machine would not be too big and heavy. It would be easy to move and carry.

Functional Decomposition

The basis of our design comes from the idea of storing a large amount of energy in a capacitor and being able to control its discharge through a load. Our system can be broken up into four parts: the power supply, energy storage, gate driver control circuitry, and the load. The power supply is a toroidal transformer and a 12V power supply. Our energy storage is capacitors for both the positive and negative sides. To control the pulse parameters, we are using gate drivers with an arduino to read the pulse. The load is where the pulse will be sent through. All of the parts will be gone into detail. From complications with our original design, the high side device configuration comes from our advisor Robert Bouda's research.

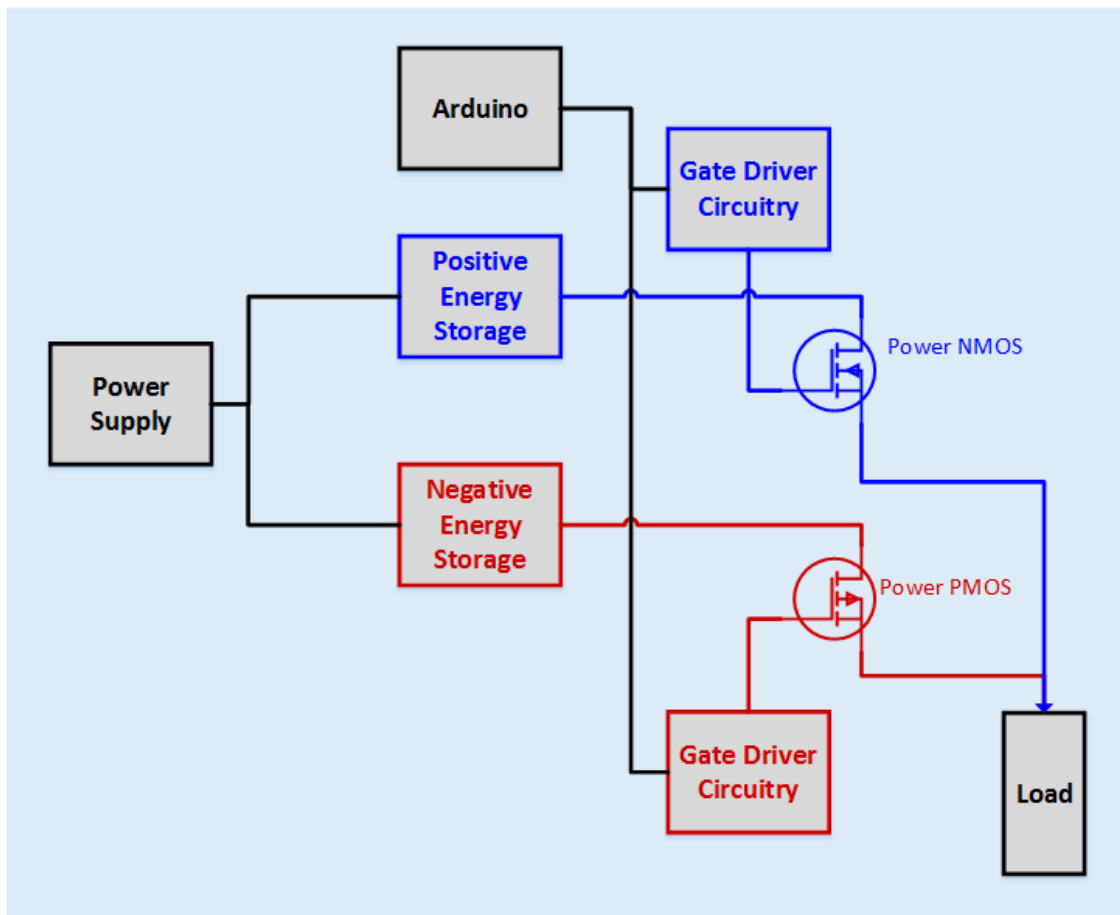


Figure 1: System level diagram.

Detailed Design

Input/Output

The device has seven inputs and one outputs. The inputs are the wall outlet for power, parameter controls, two buttons to discharge the capacitor, a secondary power switch used to turn on and off the transformer, and the button to initiate a pulse. The outputs are connections for the load device.

Inputs

- 120Vrms AC wall outlet
- Secondary power switch
- Capacitor discharge buttons (2)
- Pulse amplitude
- Pulse length control
- Pulse height control
- Pulse discharge button

Outputs

- Load

Power Supply

Our device is powered from a normal 120Vrms wall outlet. In our device we are using a toroidal transformer with a center tap to ground to have an output of 50 +/- right after the transformer. Power after the transformer is in AC, we have to convert it to DC. This is done by using two half wave rectifiers, one for the positive side of the pulse, and one for the negative side of the pulse. We are also using a 12V power supply to provide power for the arduino and gate driver board. The 12V power supply directly connects to the gate driver board, then routes to the arduino providing the arduino with power from the 12V power supply. Both the toroidal and 12V power supplies are connected to a secondary and main switch. The main switch turns on the 12V power supply, and the secondary switch turns on the toroidal. Both need to be turned ON for the system to work.

Storage

To store the power, we are using capacitors. For both the negative and positive sides of the pulse, each has three 8200 uF capacitors connected in parallel. To discharge the capacitors, we are using relays to resistors. Once the pulse is done running, there will be two buttons that will be needed to be pressed at the same time to discharge the capacitors. The buttons are then connected to the arduino which tells the capacitors to discharge whatever is left after the operation.



Figure 2 Capacitors connected in parallel

Gate Drive Circuitry

For the gate drive circuitry we came up with two different ideas that could worked together if the first one did not work. The first idea was to apply a DC voltage to the gate of the device. This DC voltage would need to be adjustable and the pulse length controlled through the arduino. To also help the overall design the gate drive circuits need to be simple and preferably run off one power supply. We first thought of using buck converters and ended up with a design that used a SEPIC and inverting buck-boost design.

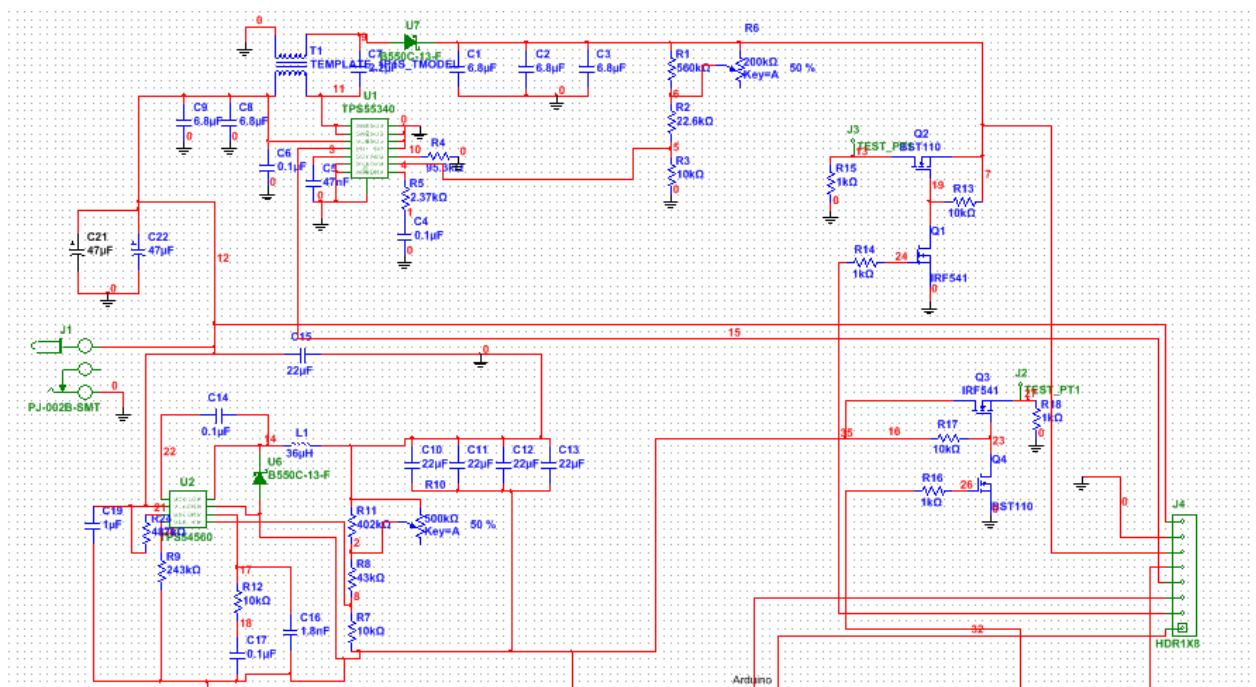


Figure 3 Gate driver circuitry in Multisim

The voltage input the convert board is 12V as this is also able to power the arduino. To have an adjustable pulse amplitude the positive supply needed to output 5 to 20V. The type of converter we are using is a SEPIC, or single ended primary inductor converter. This design allows an output voltage that can go above or below the input voltage. The converter we chose was a high current converter allowing up to 2A to be pulled at 20V and even higher current to be drawn when the voltage was lower. To make the output of this converter adjustable a potentiometer was added to the voltage feedback so that the output voltage could be changed by the user. The output voltage is also read by the arduino so that it can calculate the pulse amplitude.

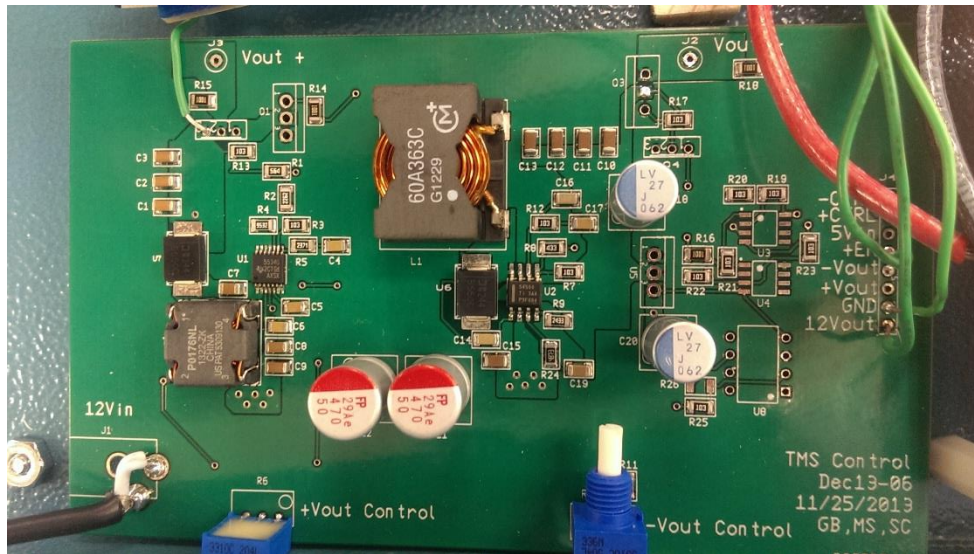


Figure 4 Sepic/Inv Buck Boost PCB

The negative gate voltage is created by an inverting buck-boost. This power supply design allows a positive input voltage with a negative output voltage. Similar to the sepic converter it runs off of 12V and output -5 to -20V. This converter is also a high current converter allowing more than 2A to be drawn at -20V. This converter also has a potentiometer added to the feedback to allow user adjustment of the output. With both of these converters the design let us control the pulsed gate voltage of the positive and negative MOSFETs.

Our second design and the design we are using is the isolated gate drive. The isolated gate drive works by using a transformer to electrically isolate one side of the circuit from the other. This allows the ground of the second side to be connected to the devices sources and accurately apply a V_{gs} to the device. This is the circuit we chose to use as it works without high side MOSFETs that have changing source voltages during the pulse.

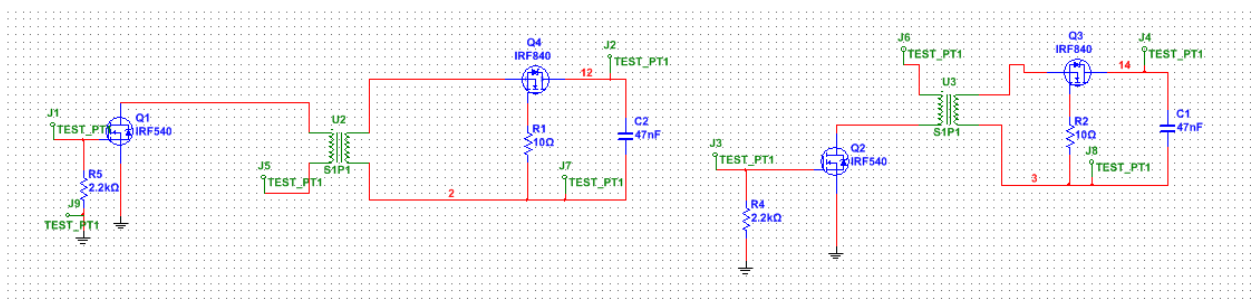


Figure 5 Isolated gate drive in Multisim

The circuit works by sending a square wave of the voltage we want on the primary side. This induces a similar voltage on the secondary side that is then stored in an external cap and the gate of the device. On the falling edge of the pulse on the primary side the gate and capacitor are discharged. By using this system the source voltage of the mosfets can change but the V_{gs} will stay the same. This system also works without first gate drive design. By using the SEPIC converter as the power supply for the primary side we are able to keep the easily adjustable amplitude of the pulse.

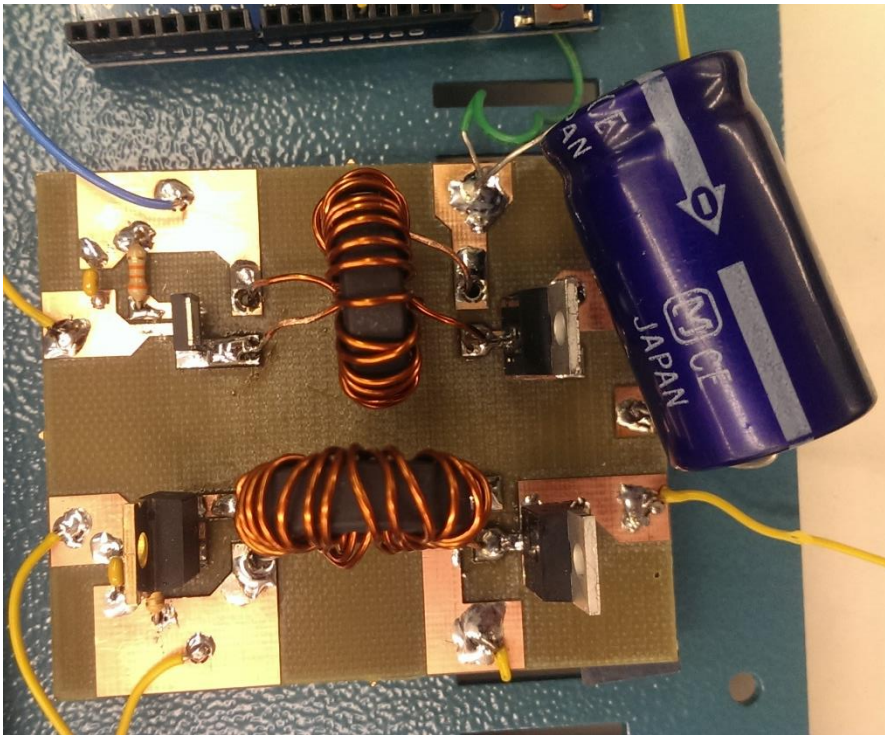


Figure 6 Isolated gate driver PCB

Arduino

The main purpose of the Arduino is to control the pulse width, monitor the converter circuit outputs to calculate amplitude, and to trigger the pulse itself. The secondary function of the Arduino is to discharge the capacitors once operation is finished.

- Digital input pins are used to sense a down press of either the pulse trigger or capacitor discharge push buttons
- Analog input pins are used to sense variable voltage from potentiometer knobs for pulse width and converter output, with the input readings converted to usable pulse parameters
- Digital outputs are used to trigger the pulse on the gate control circuitry and to enable relay-resistor circuits for capacitor discharging

MOSFET Board

The MOSFET board includes our power rectification and filtering, along with our two main switching devices. The inputs to this board are the positive and negative outputs of our transformer and these are filtered through a single wave rectification diode and have outputs to our capacitor banks. The two main switching devices are included on this board with the connection to the load. We choose to design this board this way so we can change out different parts of the circuit like the capacitors, gate drive circuitry, and the load.

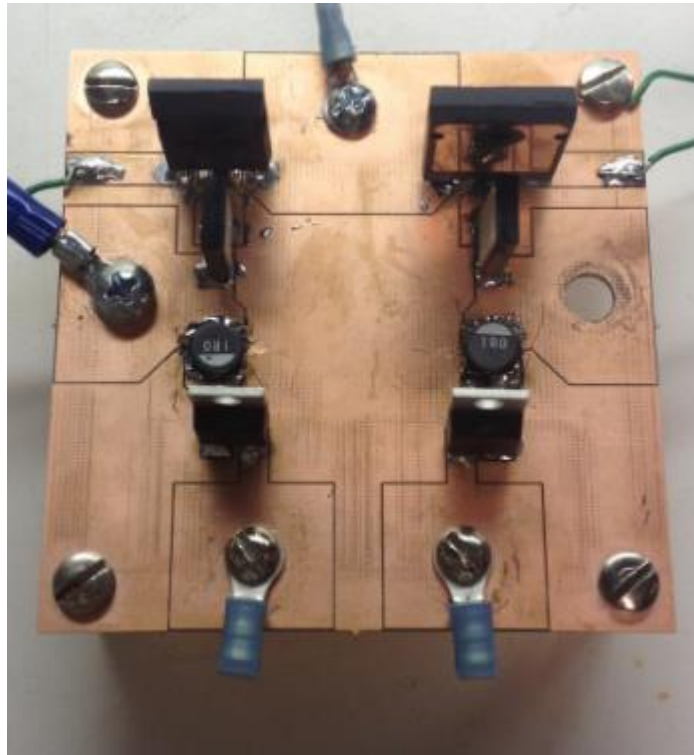


Figure 7 MOSFET PCB

Enclosure

A pre-manufactured metal enclosure was ordered to house the entirety of the circuit. A metal enclosure was desired to serve as an 'earth' ground for user safety. Other desired features included ventilation, two part top and bottom for easy access to components, and available panel space for circuit input. The complete list of external connections are the following:

- 1) Wall outlet to fused plugin
- 2) Secondary power switch for transformer
- 3) Two potentiometer knobs for setting pulse width
- 4) Two potentiometer knobs for converter output control
- 5) One push button for pulse trigger
- 6) Two push button system for discharging capacitors
- 7) Load output banana terminals

All PCB boards and other internal components are screw mounted or held on by an adhesive. Rubber stands for the enclosure to rest on were also added.



Figure 8 Device in enclosure

Simulation and Testing

Software: National Instruments (NI) Multisim

To simulate and test our design, we are using National Instruments (NI) Multisim software. Multisim is a very capable and widely used SPICE program. We have access to Multisim on the campus lab computers and also through remote desktop. The wide range of component selection and intuitive interface make it a very useful tool in our design.

Testing

Each section of the device was tested individually for functionality. Next was testing for each of the PCBS: capacitor bank, MOSFET, gate drive circuitry, and isolated gate drive.

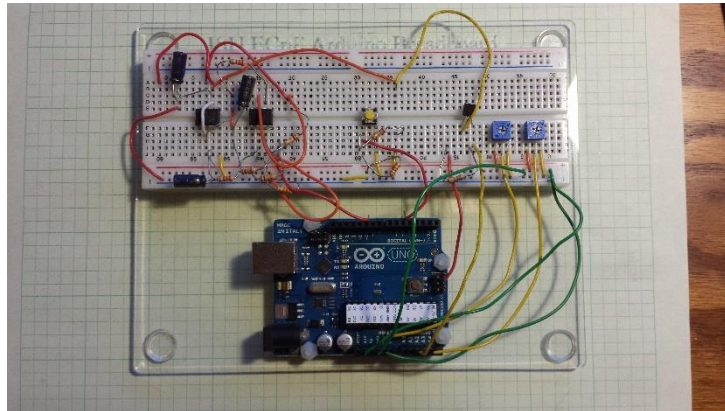


Figure 9 Testing of arduino

We started by testing the main MOSFET board with the capacitor bank attached. For our power supplies, we used the lab bench 25V power supplies instead of our transformer. Each side was tested independently to try and find any problems with our design.

Our testing with a DC voltage for the gate drive started by using a function generator as the gate drive source. Our load for these tests was a 5 ohm 5 watt resistor in parallel and a coil manufactured by us. In these tests in measuring voltages across the load and the gate voltage of the MOSFETS using an oscilloscope. From these tests we learned that a direct DC gate driving would not work as the voltage of the source of the device shifted too much.

Our second round of testing, we tested using the isolated gate drivers instead direct DC control. The overall setup was the same as before but we used a lab bench power supply to supply the primary side of the isolated gate drivers. With the isolated gate drivers, we were able to accurately control the voltage across the gate and able to measure the voltage with an oscilloscope. In these tests we were able to calculate the current through the load. With our coil's resistance being 50 milli ohms, our current through the load was 140 amps. These results were achieved using the positive side of the circuit.

Appendix

Operational Manual

- Make sure everything is in the enclosure
- Ground everything that needs to be grounded to the grounding chassis inside of the enclosure
- Plug a load into the output of the enclosure
- Connect an oscilloscope to the load to view the output
- Have both of the power switches OFF
- Plug in the power wire to the wall outlet
- Turn ON the main power switch
- Turn ON the secondary power Switch
- Press the pulse discharge button
- Observe output
- Turn OFF the secondary power switch
- Discharge capacitors by pressing both of the discharge capacitor buttons at the same time
- Unplug main power from wall outlet
- Clean up