High Speed Magnetic Field Pulser

Design Document

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Revised: 12/5/2021
Version: 1.0

Executive Summary

Development Standards & Practices Used

IEEE 370-2020 - IEEE Standard for Electrical Characterization of Printed Circuit Board and Related Interconnects at Frequencies up to 50 GHz

IEEE C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

Summary of Requirements

- Design and Create a Device that does the following:
  - Generates Magnetic Fields of 500 Gauss at minimum
  - Pulses with rise time of less than 100 ns
  - Programmable Control of the magnetic field generation
  - Uses a source voltage of, at most, 15 V (DC)
  - Size of the circuit board is no greater than 3.5” by 2”

Applicable Courses from Iowa State University Curriculum

- E E 201: Electrical Circuits
- E E 230: Electronic Circuits and Systems
- E E 311: Electromagnetic Fields and Waves
- E E 330: Integrated Electronics
- EE 333: Electronic Systems Design
- E E 414: Microwave Engineering
- E E 417: Electromagnetic Radiation, Antennas, and Propagation

New Skills/Knowledge acquired that was not taught in courses

- Component Procurement
- Client Relations
- Coil Designing
- Perfboarding
- PCB Designing/Soldering

Table of Contents

List of figures/tables/symbols/definitions

Figures:

Tables:

1 Team

1.1 Team Members

Abdulraheem Alqunais
Harith Arsyad
Tyler Bolton
James Camp
Ben Newell
Tom Zaborowski

1.2 Required Skill Sets for Your Project

- Circuit Design via Software
- Circuit Design Optimization
- Circuit Breadboarding
- Circuit Testing
- PCB Designing
- Soldering Expertise

1.3 Skill Sets covered by the Team

- Circuit Design via MATLAB
    - The team
- Circuit Design Optimization via ADS
    - James Camp
    - Ben Newell
- Circuit Breadboarding
    - The team
- Circuit Testing
    - The team
- PCB Designing
    - Tyler Bolton
- PCB Testing
    - The Team
- Soldering Expertise
    - The Team

1.4 Project Management Style Adopted by the team

The team adopted the Agile project management style for this project.

1.5 Initial Project Management Roles

- Meeting Facilitator
    - Tom Zaborowski
- Documentation Facilitator
    - Harith Arysad
- Circuit Testing Lead
    - Tyler Bolton
- Circuit Simulation Lead
    - Abdulraheem Alqunais
- Communications & ADS Testing Lead
    - Ben Newell
- PCB Design Lead
    - Tyler Bolton

2 Introduction

2.1 Problem Statement

The goal of the project is to design and fabricate a device that can speed up signals in optic cable applications via the use of high speed magnetic pulses and magneto-optic material. The device will be capable of producing magnetic field pulses greater than or equal to 500 gauss within 100 nanoseconds, will be powered by a source voltage of less than or equal to 15 Volts DC, and will be less than 3.5" by 2" in physical size. Given the design requirements and resources from the previous iterations of this project, we plan to create an improved design including a reduced rise time of 10ns, functional programmable control of the magnetic field generation, reduced overall noise, and increased stability.

2.2 Requirements & Constraints

Requirement:

- As set by the client:
    - Design and Create a Device that does the following:
        - Generates Magnetic Fields of 500 Gauss at minimum
        - Pulses with rise time of less than 100 ns
        - Programmable Control of the magnetic field generation
        - Uses a source voltage of, at most, 15 V (DC)
        - Size of the circuit board is no greater than 3.5" by 2"
- As set by the team:
    - Improve upon the design by the 2019-2020 Design Project Team

        - Design a PCB with no daughter board
        - Simulate if rise time and signal stability can be improved by the use of a GaN MOSFET transistor or other components/methods
        - Decrease the overall rise time to 10 ns
        - Reduce the noise in the resultant signal so the signal is stable for most of the pulse
    - Implement Team Specific Goals
        - Identify a range of frequencies for the device to operate at, and optimize the circuit design to operate at said frequency range
        - Implement the previous teams circuit design in ADS and Multi-Sim for future

Constraints:

- The source voltage of the circuit cannot be over 15 V (DC)
- Component purchasing must stay within the budget of $500

2.3 Engineering Standards

1. IEEE 370-2020 - IEEE Standard for Electrical Characterization of Printed Circuit Board and Related Interconnects at Frequencies up to 50 GHz

An important part of the project is to take a tested circuit on a breadboard and to print it onto a PCB for future testing. The standard here will establish guidelines for the group when it comes to design a PCB later on during this semester.

2. IEEE C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

Safety is an important aspect of this project that needs to be taken into consideration. Although the electromagnetic pulse generator is not very strong, it is crucial to understand what electromagnetic fields can do to humans when exposed to it during the group's testing phase of this project.

2.4 Intended Users and Uses

Uses: Implemented into existing networks decrease delay of signal
Users: Developers of medical/routing equipment and consumers of said equipment

The use of this product will be in addition to existing products. The intended immediate users will be companies that create medical or routing equipment and need this product to add to their product. Secondary consumers will be those that use the equipment that our product has been added to.

3 Project Plan

3.1 Project Management/Tracking Procedures

The project will require several circuit design iterations before a PCB circuit can be made. Likewise with the PCB, there could be some design iterations with that if the PCB does not deliver acceptable results. For this reason, an agile project management style fits what the project team is trying to do. Below is a diagram of the agile design process the team is hoping to implement.

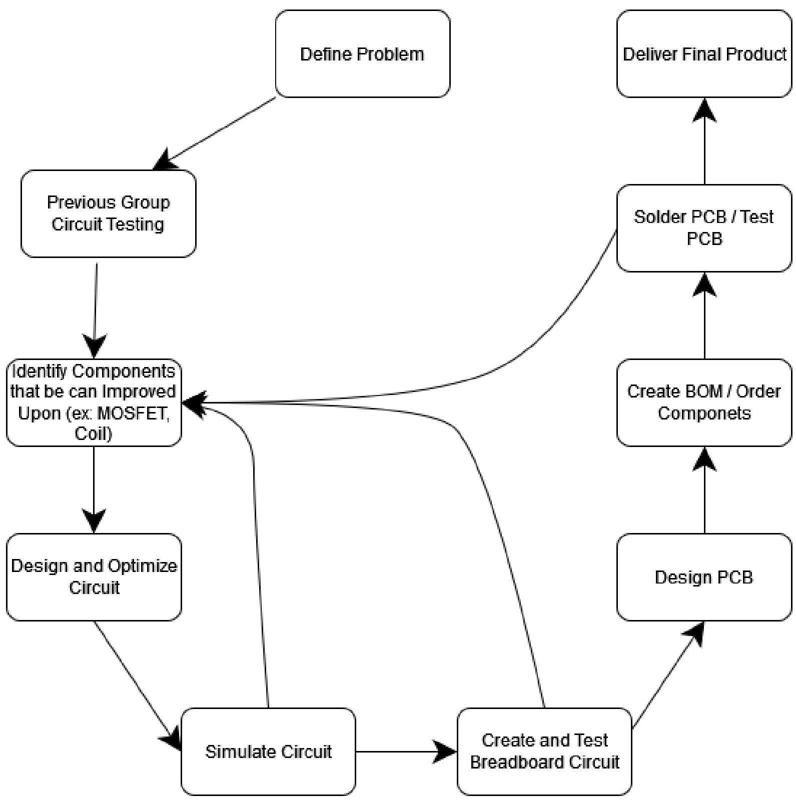


Figure 1: Group's Design Procedure Flowchart

The group utilizes Google Drive to keep all the files in one place. Google Drive is great because it is a cloud based database to keep all our files. We collaborate on any Office 365 type files at the same time. The group also uses Microsoft teams for file sharing with academic advisors. A new project management software tool we recently incorporated is Trello. It is a great tool to organize tasks along with splitting up tasks evenly.

3.2 Task Decomposition

Tasks

- Start of Project
  - Set up meetings
  - Contact Client
  - Research Documents and the Circuit from Previous Groups
  - Present Requirements and Timeline to Client
- Previous Circuit Simulations
  - Simulate the Previous Circuit with Multisim and ADS
  - Import PSPICE Models into Multisim
- Previous Circuit Improvements
  - Edit the Previous Group's Circuit or Design a New Circuit
  - Breadboard the Circuit Changes
  - Iterate Circuit Changes on the Breadboard until the Circuit Meets the Requirements
- Create PCB Prototype
  - Design the PCB
  - Create Bill of Materials
  - Order Parts and the PCB
  - Solder PCB
  - Test PCB

- Tom Zaborowski - Team Organizer, Multisim testing, PCB, and Circuit Testing
  - Facilitate team meetings
  - Circuit designing and testing through Multisim
  - PCB testing
  - Breadboard testing
- Ben Newell - Communications, Multisim & ADS Testing
  - Communicate regularly with faculty members and client to keep them up to date on current issues and progress made
  - Circuit testing in ADS to fine tune component values and component model selection
- James Camp - Multisim and ADS Circuit Testing
  - Create and design circuit in ADS that considers non-ideal and parasitic possibilities, innovate possible solutions
  - Test circuit to ensure correct response and intended outcome
- Abdulraheem Alqunais - Circuit Testing and Multisim Testing
  - Examine the operational and in-progress circuits.
  - Circuit testing using Multisim and modifying the circuit design to obtain the desired output
- Harith Arsyad - Weekly Reports and Multisim Testing
  - Set up the weekly report template for the group and write up the summary and pending issues every week.
  - Test circuit designs and multisim and find ways to iterate and improve the design.
- Tyler Bolton - Multisim Testing, Circuit Testing, and PCB Design

- Circuit simulation in Multisim and modifying the circuit to meet the requirements.
- Circuit testing on breadboard and PCB.
- Designing the PCB for the circuit in Altium Designer.

3.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

General Design Milestones & Metrics:

- Design and verification of the following fundamental requirements:
    - production of 500 Gauss magnetic fields
    - Pulses with rise time of less than 100 ns
    - Uses a source voltage of, at most, 15 V (DC)
    - Physical footprint no greater than 3.5" by 2"
    - Programmable Control of the magnetic field generation
- Goals to be looked at after fundamental requirements are met:
    - PCB with no daughter board
    - Decrease the overall rise time to 10 ns
    - Reduce the noise in the resultant signal so the signal is stable for most of the pulse

Communications:

- Meet with client and faculty at least once a week
- Client & faculty have access to all notable project documents as they are updated
- Weekly reports are shared with client the friday before they are due

Team Organization:

- Team meets once a week (not including client/faculty meeting) to discuss progress and issues

Component Model Research & Selection:

- Verification of optimal MOSFET, diode, capacitor, and resistor model selections
- Verification of optimal coil materials

Testing - Multisim:

- Simulate if rise time and signal stability can be improved by the use of a GaN MOSFET transistor or other components/methods

Testing - ADS:

- Implement and test previous teams circuits
- Verify and optimize component value and model selection through the testing of parasitics
- Identify a range of frequencies for the device to operate at, and optimize the circuit design to operate at said frequency range

Testing - Physical:

- Testing of previous groups design
    - Learn how to test for fundamental requirements
    - Gain a better understanding of how the device functions in non-ideal situations
- Testing of current/new designs
    - Verify that fundamental requirements are met

Design - Coil:

- The amount of turns in coil, coil length, and coil radius will be determined by following two equations when in the circuit designing and breadboarding phase of the project:

$$B = \frac{\mu N I}{\sqrt{l^2 + 4R^2}} \qquad L = \frac{\mu N^2 \pi R^2}{\sqrt{l^2 + 4R^2}}$$

Design - Layout:

- The PCB will be designed through Altium
- Similar components will be place in the same direction
- Components should be organized according to SMD PCB design rules
- Power, ground, and signals should be properly placed for a trouble-free path of travel
- Power ground and control ground should be separate
- Components should be spread out if possible to avoid heating issues.

3.4 Project Timeline/Schedule

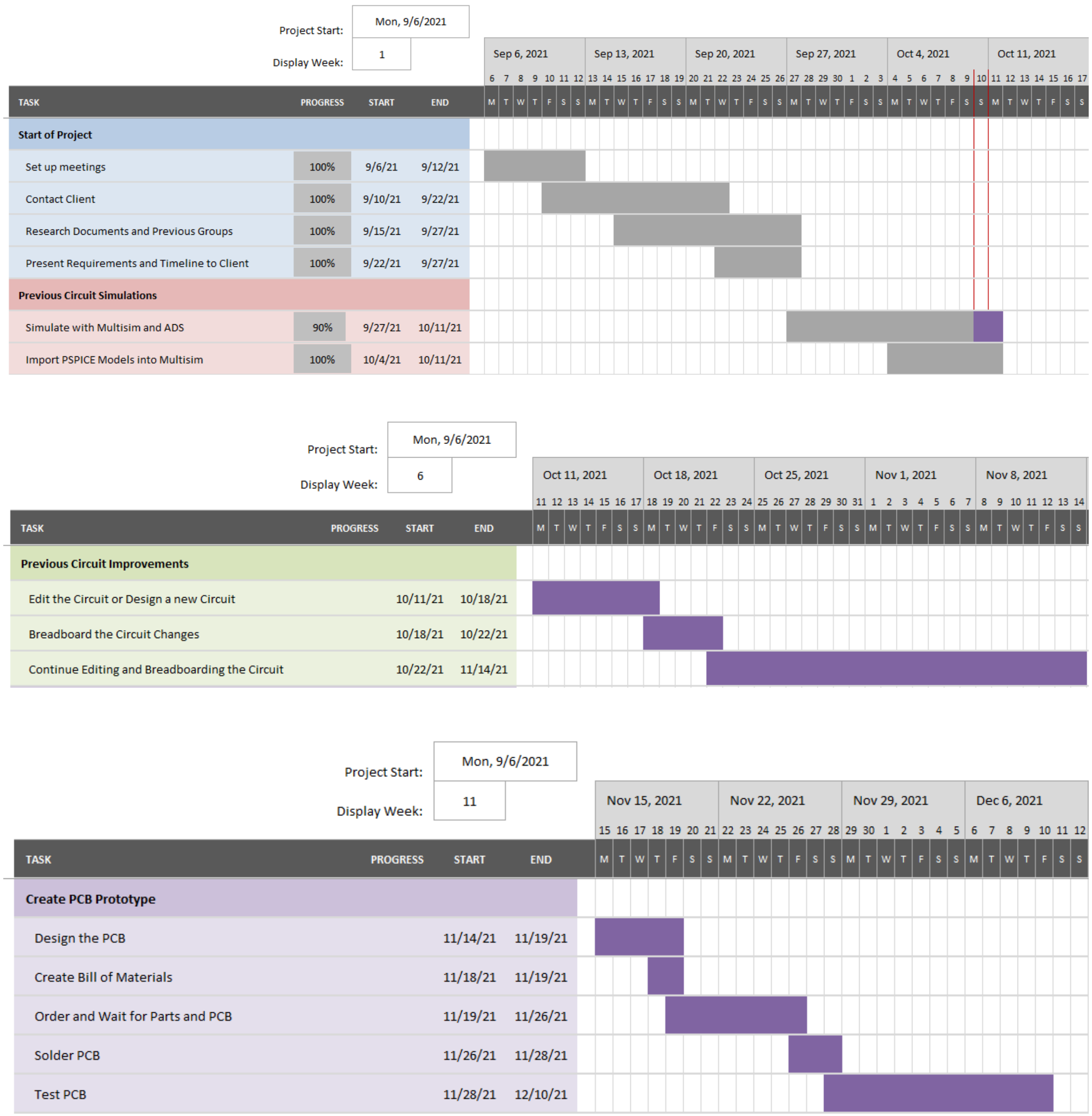


Figure 2: Project Timeline shown as a Gantt Chart

3.5 Risks And Risk Management/Mitigation

- **Ordering parts for the circuit:**
  - Components arriving late (0.5) - We should always assume the slowest shipping time and give our components at least 1 week extra to come in case any delays in shipping happens.
  - Parts not available (0.3)

- **Building the prototype circuit:**
  - Components we are using may burn (0.9) - This is highly likely and has happened to many teams in the past so we should make sure we order extra parts. We should also know the limitations of the component so we can prevent this from happening.
  - We might get shocked or burnt during testing (0.6) - We should follow proper lab procedure and understand how each machine in the lab works.
  - Final circuit may not meet functional requirements (0.6) - This is likely to happen since theoretical values won't match practical values. We should rigorously test our circuit in simulation, but computer analysis can only go so far so we should give enough time in the project timeline to build the prototype so we can troubleshoot any problems we get related to this.

3.6 Personnel Effort Requirements

There will be a breakdown of subtasks for each task on the Trello page. Each member of the team will be in charge of a subtask that they will choose to perform. Tasks will be evenly distributed to ensure that everyone on the team has contributed equally. The team will meet weekly. Individual progress updates and reflections will be shared during these meetings. Following these sessions, the team will assess progress and identify everyone's next steps for the week.

3.7 Other Resource Requirements

Table 1: Design Team's Resource Requirements and Method for Obtaining

Resource	Where/How Obtained
Software	
MATLAB	https://www.mathworks.com/products/matlab.html OR Access via ISU PCs
ADS	https://www.keysight.com/us/en/lib/software-detail/computer-software/pathwave-advanced-design-system-ads-software-2212036.html OR Access via ISU PCs

Multisim	Access via ISU PCs
Altium	ISU Keys
KiCad*	Free Download
Hardware	
Resistors	ISU ETG OR https://www.mouser.com/ OR https://www.digikey.com/en/products
Capacitors	ISU ETG OR https://www.mouser.com/ OR https://www.digikey.com/en/products
Diodes	ISU ETG OR https://www.mouser.com/ OR https://www.digikey.com/en/products
MOSFETS	ISU ETG OR https://www.mouser.com/ OR https://www.digikey.com/en/products
Copper Wire (Coil)	ISU ETG OR https://www.amazon.com/s?k=copper+wire&crid=1CR0JOB4HGRZB&sprefix=copper%2Caps%2C205&ref=nb_sb_ss_ts-doa-p_1_6
Soldering station	ISU TLA OR ISU ETG OR https://www.amazon.com/dp/B000AS28UC/ref=redir_mobile_desktop?_encoding=UTF8&aaxitk=affb4fdea8a0580208fffa11ab4f021e&hsa_cr_id=6323637260801&pd_rd_plhdr=t&pd_rd_r=

	adf1d9cc-f48b-4b96-9556-7f95cab3ebec&pd_rd_w=xKhOj&pd_rd_wg=jnKy3&ref_=sbx_be_s_sparkle_mcd_asin_0_title
Solder	ISU ETG OR https://www.amazon.com/MAIYUM-63-37-Solder-Electrical-Soldering/dp/B076QF1Y85/ref=sr_1_5?dchild=1&keywords=solder&qid=1633909617&sr=8-5
Flux**	ISU ETG OR https://www.amazon.com/s?k=flux&ref=nb_sb_noss
PCB	https://jlcpcb.com/ OR https://www.pcbway.com/
Ports	ETG OR https://www.digikey.com/en/products
Testing Equipment	
Oscilloscope	ISU Lab Spaces OR ISU ETG
Multimeter	ISU Lab Spaces OR Personal Multimeters
DC Power Supply (15V)	ISU Lab Spaces OR ISU ETG
Gauss Meter	ISU Lab Spaces

*If Altium is not available to use through Iowa State, KiCad will be used instead

* *Many solders have a flux core so buying independent flux may not be necessary

4 Design

4.1 Design Context

4.1.1 Broader Context

Table 2: Outline on Project's Broader Context

Area	Description	Examples
Public health, safety, and welfare	Work in this project could help very specific technologies that involve a fast switching magnetic pulse. Not only fast switching magnetic pulse but high speed technologies across many fields.	Improvement to medical equipment that utilize magnetic pulses for chronic headache pain. The most important improvement would be in switching for magneto-optic fiber-based technologies.
Global, cultural, and social	Hard to say if this technology will have an effect on cultural and social groups. On a global scale, this could improve circuit design that utilize a high speed pulse	Development of this would improve fiber technologies and medical equipment across the world.
Environmental	There is not a real big change to the environment with this development. Potential for increased communication infrastructure in lacking areas.	The implementation of this research would increase the use of fiber technologies over copper.
Economic	There is potential for less fiber networks because they need to achieve the same bandwidth. Such technology could also reduce the size of circuits that aim to achieve a fast pulsing magnetic field generator.	The product will cost less to make over similar solutions to real-life applications in the world.

4.1.2 User Needs

User Group 1: Communication Companies

Communication companies need a faster magnetic optical switch because they need a way to fix their bandwidth bottleneck with fiber-based technologies.

User Group 2: Academic Researchers

Academic Researchers need to find more solutions to making a fast switching magnetic pulse generator because they want to gain insight on what makes the rise and fall times of the magnetic pulse generator quick.

4.1.3 Prior Work/Solutions

Schematic of the circuits from the prior senior design groups were provided. Also, research papers and documents relating to the design topic: a high-speed magnetic field generator was supplied by our adviser. We tried to modify the (Sdmay20-39) design circuit by changing the capacitor and inductor values to analyze the result using Multisim simulation, specifically how these changes affect the current across the inductor, which is the magnetic field. Every member of the team modified the circuit's components and wrote a report about the findings. This was helpful to understand how the circuit functions and the key to knowing what to modify to enhance the previous group design.

The previous group met some of the requirements but with an unstable result. They generated a magnetic field of 500 gausses, Pulses with a rise time of 47 ns, and Used a source voltage of 25 V (DC)

What should be done: Generates Magnetic Fields of 500 Gauss at minimum, Pulses with rise time of less than 100 ns, Programmable Control of the magnetic field generation, Uses a source voltage of, at most, 15 V (DC), and Size of the circuit board is no greater than 3.5” by 2”

4.1.4 Technical Complexity

Provide evidence that your project is of sufficient technical complexity. Use the following metric or argue for one of your own. Justify your statements (e.g., list the components/subsystems and describe the applicable scientific, mathematical, or engineering principles)

1. The design consists of multiple components/subsystems that each utilize distinct scientific, mathematical, or engineering principles

The design consists of four subsystems that allow the coil to create an electromagnetic pulse. The four subsystems are the capacitors, the RL circuit, the switching MOSFET, and the pulse generator. To make the design work, we will need to apply principles of electromagnetic fields to obtain the required field strength from these subsystems. We will also need to apply properties of capacitors, inductors, MOSFETs, and the pulse generator.

2. The problem scope contains multiple challenging requirements that match or exceed current solutions or industry standards.

The electromagnetic pulse needs to be 500 Gauss, and this requires a large amount of current (~40-50A), and it will be a challenge to create a circuit and find components that will result in 500 Gauss. There were groups that worked on this project in the past, but none of them reached 500 Gauss.

4.2 Design Exploration

4.2.1 Design Decisions

List key design decisions (at least three) that you have made or will need to make in relation to your proposed solution. These can include, but are not limited to, materials, subsystems, physical components, sensors/chips/devices, physical layout, features, etc.

- Which MOSFET to use
- Design of the Coil (Single vs Helmholtz, material of the wire, number of turns, length)
- PCB layout / orientation

4.2.2 Ideation

For one design decision, describe how you ideated or identified potential options (e.g., lotus blossom technique). List at least five options that you considered.

- Which MOSFET to use:
    1. N-channel or P-Channel
    2. VDS rating of the MOSFET
    3. Max pulsed drain current
    4. Rise time of the MOSFET
    5. Material of the MOSFET

4.2.3 Decision-Making and Trade-Off

Demonstrate the process you used to identify the pros and cons or trade-offs between each of your ideated options. You may wish to include a weighted decision matrix or other relevant tool. Describe the option you chose and why you chose it.

In this project, we're iterating on previous groups' designs of a magnetic pulse generator and trying to improve upon their work. They've reached satisfactory characteristics, but we can further optimize the circuit such as reducing rise time and improving measurement accuracy. We are choosing our MOSFET options based on improving upon the functional requirements.

4. We are choosing n-channel MOSFETs because they have faster switching capabilities than p-channel. The tradeoff is that PMOS is cheaper since it's easier to manufacture and has higher yield.
5. We've found that using higher VDC means faster rise time for our magnetic pulse, but we are limited to 15V by the client requirements, so using a MOSFET rated above 15 V is needed.
6. The amount of current our MOSFET needs to handle will be based on the coil we use and we'll need to calculate that later on when we build our coil, but we can assume it has to be higher than 65A based on previous groups designs. Higher current means the transistors are more expensive and physically larger.
7. We are looking for a faster rise time in our MOSFETs, but it's hard to get this information since the conditions we are putting our MOSFETs in are very different from the conditions in the data sheet.

8 We are currently testing silicon MOSFETs only, but we are hoping to start testing with GaN MOSFETs since they are a lot faster than silicon, but costs a lot more.

4.3.1 Design Visual and Description

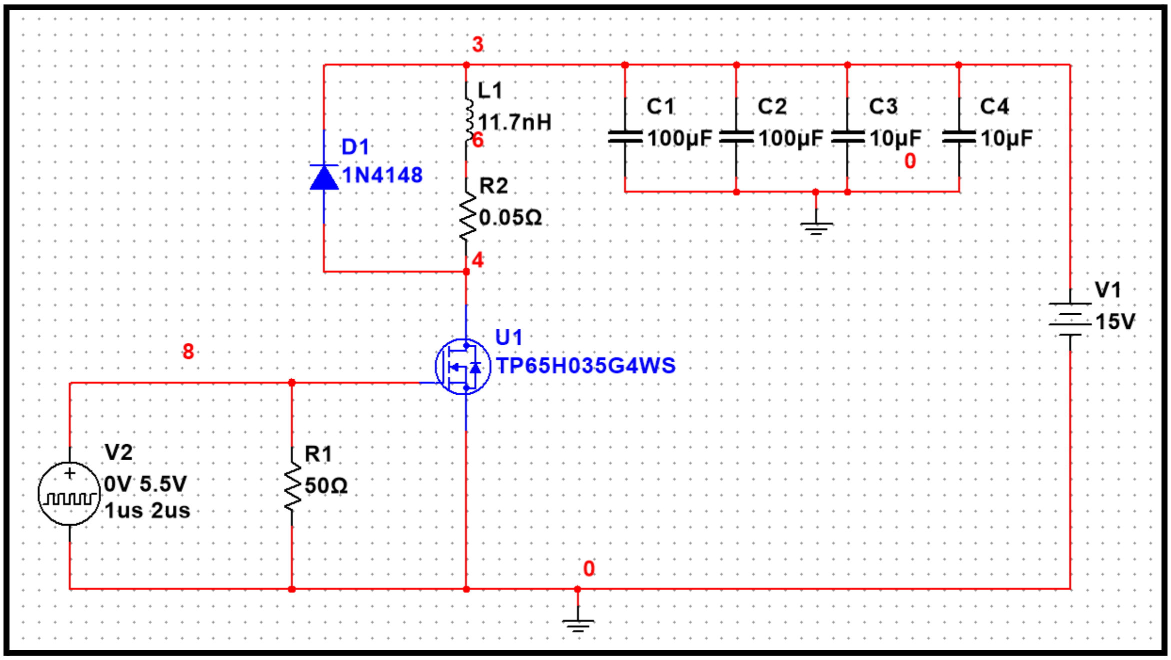


Figure 3: Circuit Design of the Magnetic Pulse Generator

This is a circuit diagram made by one of the team members in our group. The circuit design takes a large amount of influence from sdmay20-39 and sdmay21-41. The team plans on innovating this circuit. We hope to improve the rise time, the current spikes , and the overall stability of this circuit. As of now, they have taken steps to analyze every component of the circuit in order to understand how the component affects the waveform of the inductor. The team plans to now improve on this design in the upcoming weeks.

4.3.2 Functionality

The functionality of this technology is limited to only a couple real-world applications. The main application would be for a magneto optical switch in fiber-based network communication. The team intends to fulfill the requirement of making this pulser programmable. The user would have the option of changing the voltage sources that are connected to the circuit. The user would be able to change the pulse width, and the current amplitude of the magnetic field pulser through the voltage sources.

4.3.3 Areas of Concern and Development

We are still testing circuits from previous groups and iterating upon them to see how they behave, so our main concern at this point is being able to achieve a rise time of less than 100ns and a current strong enough to produce a 500 gauss magnetic field pulse. This can be done through simulation of the circuit and testing different components in the circuit.

After we are comfortable being able to deliver those crucial functional requirements, we can look into optimizing the circuit. Something we need to look at is adding some sort of filter so that there is less noise and oscillation in the simulation. The plan is to study the key factors of non ideal components and be able to replicate that in simulation. Only then can we start to look for ways to optimize our circuit and get less noise in our waveform.

The final crucial area of concern is to make sure that our final product is smaller than 3.5" by 2". This is something we have to worry about later in the semester, but we have to keep this in mind while we're designing our circuit. Once we start iterating and adding components into the circuit, we have to make sure that it will be small enough to meet this functional requirement

4.4 Technology Considerations

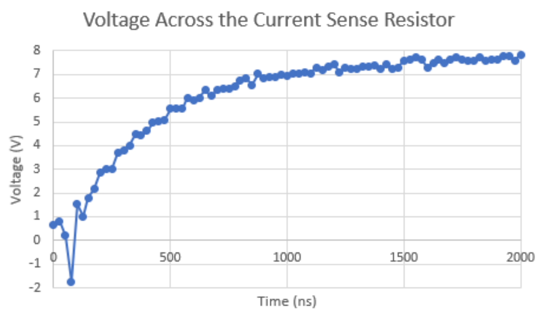
We have a lot of freedom in the technology we choose especially in the components we choose since we're building this from scratch. The biggest thing we have to consider is our testing equipment since it's the parts we have least control over. We are using what's available to us on campus and there are a few pieces of equipment and components creating a lot of problems.

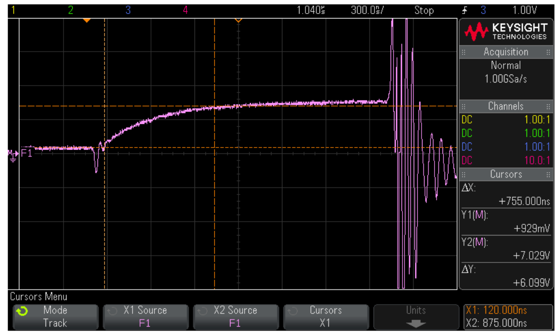
The first one is the function generator. The function generator provided to us on campus is great in general. It has a lot of customizability, and it's very reliable. The biggest problem we've found is that as we decrease the pulse width of our square wave into the nanoseconds range, we are getting a lot of noise from the function generator before it reaches steady state. This will only get worse the smaller we want our pulse width to be and a larger percentage of the pulse width will be noise. Another problem we encountered is the limit to the peak to peak voltage. Some of the designs we came up with have a required peak to peak voltage of 10Vpp or more. The function generator is limited to 10Vpp on high z. We've had to find more creative ways to reach the required voltage such as using a secondary DC input to further offset the pulse wave and get a higher peak voltage.

A component that is crucial in our circuit is the MOSFET. We have a lot of freedom in choosing our MOSFET, and there are a lot of MOSFETs on the market right now, but the better they get over the years, the better our design can be. We have a few fairly reliable MOSFETs that we've chosen already, but this design can only get better and faster as better MOSFETs are released in the future. For now, we've met the design requirements in the simulations and the rise time we need, but we can update this in the future and aim for much faster rise times.

4.5 Design Analysis

At the point this document has been revised, the team is still testing the breadboard design. The team has only done some preliminary testing with the first prototype. The team plans to do some more testing in the next semester before redesigning the circuit.





We measured the voltage across the 0.25Ω current sense resistor. We needed an average voltage of 7.2V across the resistor during the pulse. From the plotted data above, our prototype had a rise time of 755ns and an average voltage of 6.02V. Our prototype also had a large amount of flyback voltage after the pulse. The initial results are failing to meet the criteria of requirements given to the team .

4.6 Design Plan (NOT DONE)

1. Research previous senior design group circuits
2. Read academic papers on fast switching magnetic pulse generators
3. Find MOSETS and read their datasheets
4. Design a suitable coil for the circuit
5. Identify promising components for a magnetic pulse generator
6. Construct the circuit in Multsim
7. Simulate the circuit and analyze the transient
8. Construct the circuit on a breadboard and test the circuit
9. Design the circuit onto a PCB and test the PCB

5 Testing

5.1 Unit Testing

The team will be testing the strength of the magnetic field made by the inductive coil. This unit is measured in Gauss. There are many methods to test the magnetic field strength of the circuit. If possible, the team will utilize a Gauss meter to find the magnetic field strength. We will be using an oscilloscope to measure the voltage over the current sense resistor and the rise time of the pulses if a Gauss meter is not possible. From there, the team can use Ohm's law to find the current running through the current sense resistor which in result can let us know the current in the inductive coil we made. With the formula B = uNI, the magnetic field strength can be calculated.

5.2 Interface Testing

The first tool is software testing using NI Multisim and ADS. These two programs enable the team to simulate and modify the circuit by understanding the outcomes without the actual circuit elements and physical hazards. For example, many MOSFETs were tested to analyze the results without the need to physically have them. Some of these transistors are costly, and it is efficient to simulate the circuit first. Another example is that the circuit consists of a high current and high magnetic field of 500 gausses in the inductor. Thus, for safety reasons, the simulations are effective.

The second tool is hardware testing using lab equipment such as oscilloscopes and gauss Meter. The circuit should be built using PCBs with specific dimensions. After soldering the circuit, the team will debug the circuit to validate the design by analyzing the differences between the simulations' result and the built circuit to obtain the seeking High-speed magnetic field of 500 gausses and rise time of less than 100 ns.

5.3 Integration Testing

The design has four main components: the capacitors, the coil, the MOSFET, and the pulse generator. For integration testing, we plan to put the four components together as all four are needed to create the magnetic pulse. The capacitors provide the current required for 500 Gauss, the coil creates the magnetic field, the MOSFET opens and closes the path through the coil to ground, and the pulse generator controls when the MOSFET switches.

The circuit will be simulated, then tested. For our simulations, we use Multisim and ADS to simulate the circuit. During testing, we will supply the circuit with a power source and the pulse generator, and the circuit will be measured using an oscilloscope across a current sense resistor where the current can be calculated by dividing the voltage by the resistance. If the components were integrated together correctly, we would see that the MOSFET would open and close in response to the pulse at the gate and we would see a high (~40A-50A) amount of current through the current sense resistor.

5.4 System Testing

Before parts are purchased and a functioning prototype is built, the circuit design will be tested in Multisim to determine feasibility. A voltage probe will be placed to observe the voltage across the inductive load. The gate signal will be changed to different types of signals, using another voltage probe to observe the gate signal, and observed if a similar signal is achieved at the inductive load. The circuit design is considered successful once the signal across the inductive load resembles the gate signal in shape, and amplified in magnitude.

After the circuit is determined to be feasible, the circuit will be simulated in ADS to simulate parasitics in the circuit. This will utilize component datasheets and models (when available) created by manufacturers. The circuit will be changed to reflect parasitics present within the components. Similar to the system testing, voltage probes are used in the same places to observe the gate signal and the signal created at the inductive load. Then, the parameters of the inductive load, the capacitor bank, and other components that can be changed. Once the signal at the inductive load is considered satisfactory, the components used will be purchased and a prototype PCB will be created.

As a part of the PCB prototype, a magnetic coil will be built by the design team that will be used in place of the inductive load. Using an ammeter or a Gaussmeter, the magnetic field of the coil will be determined. When the coil produces a field strength of 100 Gauss, the coil satisfies the design requirements. Finally, the PCB will be tested similarly to the previous circuit simulations, aiming to have the signal across the coil be an amplified version of the signal at the gate of the transistor. The prototype is considered complete when this is achieved.

5.5 Regression Testing

Any new changes to the circuit will first be simulated through Multisim in order to ensure that the waveform of the inductor is still fulfilling the requirements given to us by ourselves and the clients. Once it passes the Multisim simulation tests, the newly changed circuit will be simulated through ADS in order to analyze the parasitics of the circuits. Once we determine from the simulation results that the parastics in the circuit will not harm the inductor waveform, the team will test the circuit on a breadboard to ensure it still meets the requirements. The oscilloscope will be used on the current sense resistor to find the magnetic field strength once the team is at the hardware portion of testing. The final test is to test the circuit on a PCB board with an oscilloscope in order to see if the circuit still meets the specifications made by the team and the client.

5.6 Acceptance Testing

We meet with the client every week on Mondays to report on our progress, and we also submit individual simulation reports to the client so that he can see how much we know and provide feedback on the project.

Some of the requirements like using a 15V DC supply voltage and keeping our circuit board smaller than 3.5” by 2” will be a constraint when designing the circuit itself and we can show our client that we meet this requirement by providing them with a schematic. Other requirements will be shown through simulation until we can actually build the circuit in real life and test it ourselves. An example of this is a rise time of less than 100ns. And then we also have to calculate our 500 gauss requirement and give that to the client to review. This can also be measured if we’re able to use a gaussmeter to measure the magnetic field strength.

5.7 Results

When testing the circuit prototype, we found that our observations did not meet the project requirements. From the 11.7nH inductor and the 0.25Ω current sense resistor on the circuit, we needed to see 7.2V across the current sense resistor for 500 Gauss. After applying the DC supply voltage and the pulse generator and placing probes to measure the voltage across the current sense resistor, we found that the pulse had a rise time of 755ns. Since the rise time was much longer than expected, we needed to raise the pulse generator’s pulse width to 2μs, and when we calculated the average voltage of the pulse, we found that it was only 6.02V, so the average magnetic field strength during the pulse was 418 Gauss. Additionally, we observed a significant amount of flyback voltage after the end of the pulse, even with the flyback protection, so it is likely our flyback diode is insufficient. The following two figures show the oscilloscope trace with cursors measuring the 10% to 90% rise time of the pulse and a plot of the oscilloscope trace during the pulse.

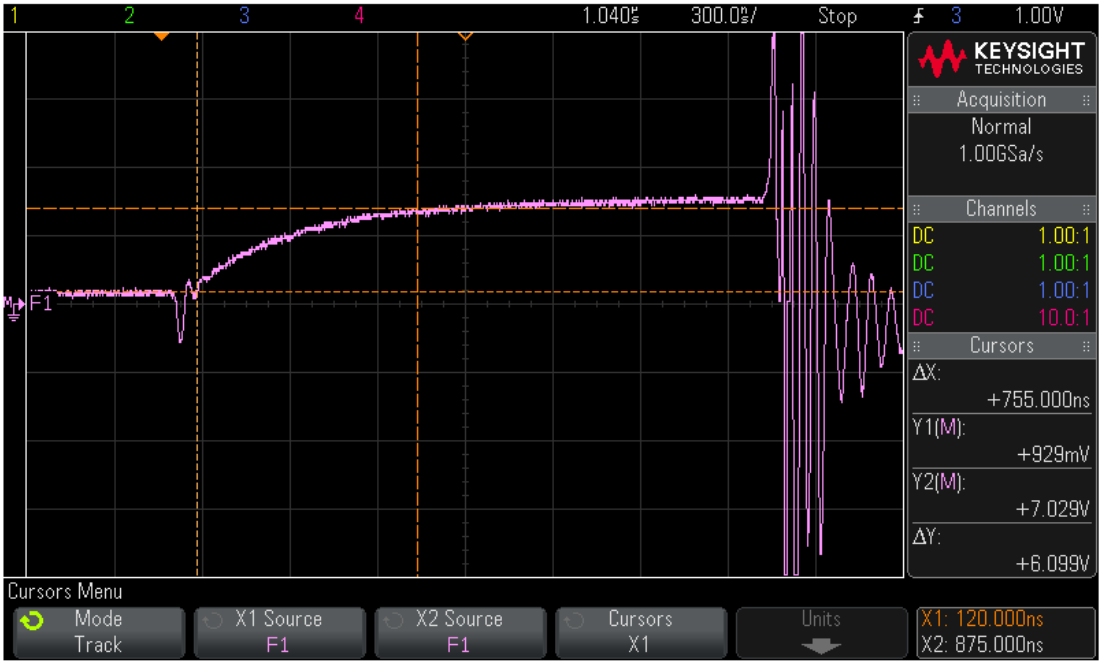


Figure 4: Oscilloscope Trace of the Resistor Voltage with Rise Time Measurements

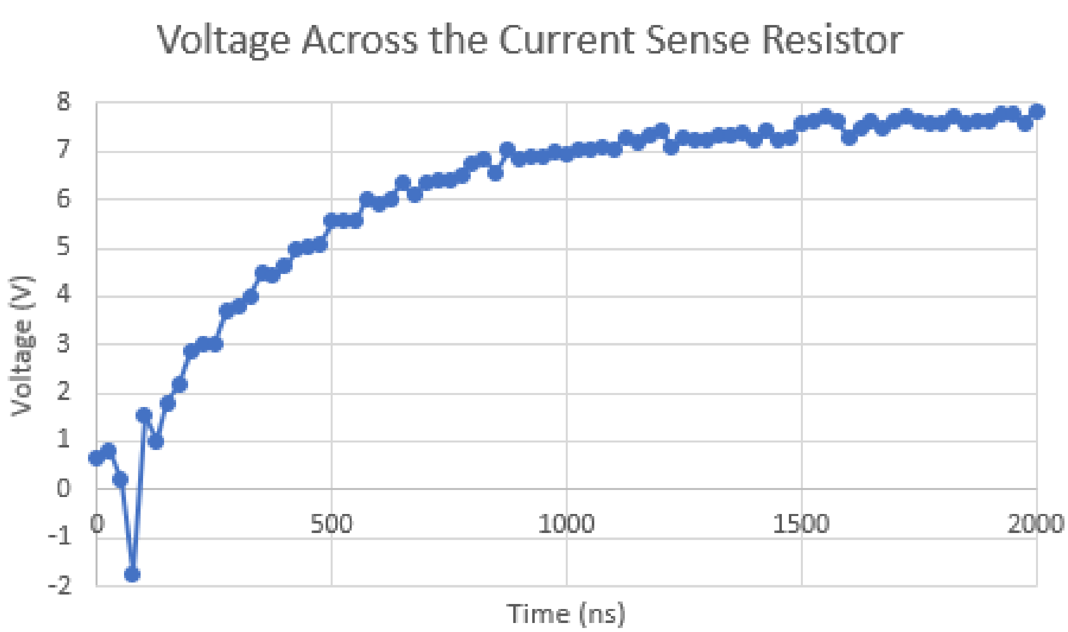


Figure 5: Plot of the Oscilloscope Trace During the Pulse

6 Implementation

We've already begun physical implementation of our design this semester, but we ran into a few issues where our physical implementation results were not even close to our simulated results. There is definitely some oversight and we'll have to revisit this in the next semester. The main things we think that could be causing this discrepancy is the components we're using and we've started to order new parts for the upcoming semester.

For now, we've only done physical implementation on a perfboard, so for our final design, we'll have to put the design on a PCB. After we're done building the design on a perfboard and getting satisfactory results, we can move on to PCB design since they cost a lot more to build.

7 Professionalism

7.1 Areas of Responsibility

Table 3: General Areas of Responsibility based on the IEEE Code of Ethics

Area of responsibility	**IEEE code of ethics**	**Differences between IEEE and NSPE**
Work Competence	#3, #5, #6: Engineers should improve their technical competence and only perform tasks in fields they are qualified in by training or experience. Engineers should also perform work that improves the application and understanding of technology. Engineers should perform honest work and should not be deceptive in claims or estimates from their work.	Both mention that engineers should perform only the work that they are competent at and work that is honest, but IEEE code of ethics adds that engineers should be maintaining and improving their competencies.
Financial Responsibility	#2, #3, #4: The code of ethics states that we should avoid conflicts of interest and disclose them to affected parties. This is a part of financial responsibility since conflicts of interest typically involve money and profits. The code also states that we should be honest in stating estimates.	Both say engineers should be honest people about the financials of a project, however, there are a couple small differences between the two. NSPE states to be financially honest to the company and clients to whom you are working for while IEEE states to be honest in claims made no matter

	It's important to make sure that a project is financially feasible and dishonesty in this will have very big consequences. Finally, the code mentions to reject bribery in all its forms.	what. IEEE also adds to avoid bribery and conflict of interests.
Communication Honesty	#3, #7: The code of ethics states that we should be honest and realistic when making claims and that it should be backed by data. It also states that we should seek, accept, and offer honest criticism of technical work. This is an important part of communication honesty and we should always be honest when talking to colleagues, clients, and others.	In the NSPE code of ethics, they go further and talk about how engineers shouldn't falsify their qualifications. They also talked about how engineers should only issue public statements in a truthful manner which is something that isn't touched upon in the IEEE code of ethics
Health, Safety, Well-Being	#1, #8, #9: Engineers are responsible for the well-being of themselves and others in the workplace by trying to avoid the injury of others. Engineers should treat everyone fairly in order to help protect the well-being of others. Lastly, Engineers should be responsible in making decisions that keep the public safe and out of danger.	There are no differences between IEEE and NSPE. Both hold health, safety, and well-being to a very high degree.
Property Ownership	#3, #5, #6, #7, #9: The IEEE Code of Ethics addresses property ownership by establishing respect for the property (both physical and intellectual) of engineers, their clients, and those they work with. The Code says that data should be respected, and not be lessened or heightened to imply something it isn't (#3). Additionally, the Code says that technology used should be understood so it isn't misused (#5) as to avoid the damage of physical or	The IEEE Code of Ethics covers this area sufficiently, but doesn't go into depth as to what may constitute personal ownership and the importance of ownership regardless of involvement in a project. The NSPE also gives engineers potential methods of dealing with breaches of personal ownership.

	intellectual property or persons (#5, #9). Finally, the Code emphasizes the importance of personal ownership of one's work, give proper ownership when in collaboration, and to accept any criticism when given (#7).	
Sustainability	#1: Engineers have the responsibility of making decisions that affect the health and safety of the public. This should include the sustainability of the environment because if the environment fails to be sustainable, the safety and well-being of the public is at risk.	NSPE does not address the Sustainability area of responsibility.
Social Responsibility	#4,#7,#8: Engineers should be treating all people fairly without engaging in discrimination of people's backgrounds. Also, they should aim to assist coworkers and colleagues in developing their skills in their professional care, and bribery should not be accepted in any form. Moreover, avoiding injuring people in any aspect such as reputation or employment by false action is a social responsibility	NSPE does not state how engineers should treat each other, nor how to improve coworkers' professional skills. However, both IEEE and NSPE stated to avoid injuring people in any form.

7.2 Project Specific Professional Responsibility Areas

Table 4: Areas of Responsibility and How they Apply to Design Team's Project

Area of responsibility	**How Does This Apply to Our Project?**	**Team Performance**
Work Competence	Work competence applies to our team's project. The team has spent several months now trying to learn about the fundamental parts to a magnetic field pulse generator. To prove our team has been increasingly competent, we were to	High

	send a weekly lab report on our new findings and discoveries to our advisor. With our newly learned concepts on a magnetic field pulse generator, we are designing and building our own magnetic field pulse generator.	
Financial Responsibility	Financial Responsibility is an important part of our project. With a budget of $500, it can be very easy to spend it all on various circuit components. When it comes time to breadboard the first circuit design, the team must only buy the components necessary for the circuit along with ensuring that the components are compatible with what we are doing. With this in mind, the team is keen on trying to go through the least amount of iterations needed in order to be financially responsible.	High
Communication Honesty	In our project, communication honesty is very important especially when it comes to talking to our client. We should always be honest and realistic about the project's timeline and our current progress. We should effectively communicate if we run into problems, delays, or anything else with our colleagues and clients. Our claims of whether our magnetic field generator meets the functional requirements should also be backed by data in simulation and testing.	High
Health, Safety, Well-Being	Health, Safety, and Well-Being is one of the most important areas of responsibility to take into account. This responsibility applies to the project across the board. The team's calculations are showing a current flow of 31 A in the circuit. The team is also utilizing a 15 VDC and 6 V pulse source at different parts of the circuit. The team is very mindful of the power going through the circuit and will take precautions to ensure the health, safety, and well-being of everyone in this project.	High
Property Ownership	Given that the group is in charge of applying academic research to create a device that hasn't been created before, it is important that ownership of the intellectual and physical properties are justly given. The group is in charge of understanding the academic research provided by our client, so that it can be properly applied to create our product. Additionally, our group will have to take ownership of our product and understand its capabilities, so when this product is presented, our group properly communicates the purpose and capabilities of our product. The team does a great job in this regard since we understand the importance of communicating progress to our client. This product will likely	High

	be used in academic research, and the consequences of over/under-stating the capabilities of our product can result in ruining someone else's research.	
Sustainability	Given the context of this project, this responsibility is something that does not apply greatly to the team. The team will make sure to perform certain actions throughout this project to be sustainable. Any kind of byproduct from shipped components will be disposed of in an orderly fashion. The team will also try to use power source generators when we only need them to ensure we are not wasting energy.	N/A
Social Responsibility	Social responsibility aligns with our project, specifically the environment of the team in which our team is diverse, and there are different backgrounds, and every member of the team treats the others fairly without discriminating against their background. Furthermore, the team is cooperative and seeks success. Therefore, the team members provide help to develop each member's professional skills.	High

7.3 Most Applicable Professional Responsibility Area

Work Competence has proven to be the most important factor in our project. This is because the project is highly technical, but hasn't provided much difficulty regarding other factors such as budget, safety, sustainability, etc. Our main process could be broken down into the following steps right now: theorize, research, design, test, share/discuss. It is critical that each member of the team is capable of carrying out these steps if we are to keep progressing towards an optimal design. Team members have shown that they are able to research effectively, understand difficult concepts, devise new innovative ideas/theories, and test these ideas through calculations and simulations. It is critical that team members are also capable of effectively sharing designs and teaching their findings to other members of the team as well as the client/faculty members. To show our progress such as new designs, breakthroughs, conceptual understandings, and general findings, we submit weekly reports to our project client and discuss these within our weekly meetings with him. It is vital during these meetings that we all have a fundamental understanding of important technical concepts like magneto-optics, magnetic fields, and circuit design, to list just a few. This allows us to generate productive discussions and questions that will help move the project forward.

8 Closing Material

8.1 Discussion

At the point this document has been revised, the prototype has been made on a perfboard and is currently being tested. The initial results are pointing to the first design failing the requirements.

The team will spend the next semester revising the prototype to eventually have it pass the requirements.

8.2 Conclusion

The team has taken all the steps needed to build a magnetic pulse generator circuit. Every member of the team took a considerable amount of time to learn about every function of a typical magnetic pulse generator circuit. From there, each member of the team made their own circuit to bring forward. As a collective, the team picked the best parts of each individual design and made a circuit. The circuit has been tested in both multisim and ADS for their transient waveforms. The waveforms show a rise time under 100 ns and a magnetic field strength of over 500 Gauss. The circuit is currently in the breadboard/perfboard phase of the project. The results are showing the need for improvements. The team plans to make more iterations in the design next semester until it passes requirements in the PCB testing phase. Although the team planned to have a PCB prototype of the project by the end of the semester, it did not get to that phase in the project yet. The circuit designing and simulations portion of the project took longer than expected. Coming up with original designs can be tough. Now that the team has gone through several design iterations, it gets easier to make original designs. The team plans to have a working PCB of a magnetic pulser generator by the end of May 2022.

8.3 References

IEEE 370-2020 - IEEE Standard for Electrical Characterization of Printed Circuit Board and Related Interconnects at Frequencies up to 50 GHz

IEEE C95.1-2019 - IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz

8.4 Appendices

8.4.1 Team Contract

Team Members:

1) Tom Zaborowski	2) Harith Arsyad
3) Ben Newell	4) Tyler Bolton
5) James Camp	6) Abdulraheem Alqunais
7)	8)

Team Procedures

1. Day, time, and location (face-to-face or virtual) for regular team meetings:

Mix of offline and online meetings through Discord. We are aiming for 6:00 on Sundays.

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face):
   We plan to have a few members meet with Mani in person to discuss project plans.

3. Decision-making policy (e.g., consensus, majority vote):
   Majority vote

4. Procedures for record keeping (i.e., who will keep meeting minutes, how will minutes be shared/archived):
   Google sheets and google docs. Ben will keep track of the meeting times.

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
   We aim to have 80% attendance.
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines:
   Everyone is expected to know the information they are assigned before they come into meetings. Make pairs (or a group of three) of people work on certain aspects of the project.
3. Expected level of communication with other team members:
   Everyone should be committed to communicating effectively every meeting. Everyone in the discord should reply if they are @'ed. Everyone should have their notifications on discord.
4. Expected level of commitment to team decisions and tasks:
   Everyone should strive to develop the best possible product.

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.):
   Ben and Tyler have stood out for having leadership qualities. The team has nominated them as our leaders.

   Ben - Client interaction

   Tyler – PCB design

   James, Harith – Testing

   Tom – Team Organization

   Abdulraheem - Testing

   *Even though these are what some of the members are assigned to do, there will be more roles to fill in the future and members will work in all sorts of roles in this project.

2. Strategies for supporting and guiding the work of all team members:
   Working in pairs will help to keep members on track. The pairs will keep each other in check.
3. Strategies for recognizing the contributions of all team members:
   People log their time working/researching and what they did for that time to contribute to the project. This will give us a better idea of who is working on what and how much effort is being put in.

Collaboration and Inclusion

1. Describe the skills, expertise, and unique perspectives each team member brings to the team.

   Ben – SPICE Simulators, Embedded systems, circuit design and testing, Electromagnetics, MATLAB, ADS

   Tyler – Schematic design, PCB design, circuit testing, PSpice, Multisim.

   Harith – MATLAB, SPICE and virtuoso simulation, C, power flow simulations, Electromagnetics

   James – MATLAB, CST Studio, C, Python, ADS, research experience.

   Tom – MATLAB, C, SPICE, VHDL. Embedded systems, experience in control systems, circuit design and testing.

   Abdulraheem - MATLAB, C, LTSPICE, Control signals and systems, Power systems

2. Strategies for encouraging and support contributions and ideas from all team members:
   Establishing rules for respect when it's time to have team meetings. Ownership and holding yourself accountable to your actions in order to support you and the people around you.
3. Procedures for identifying and resolving collaboration or inclusion issues (e.g., how will a team member inform the team that the team environment is obstructing their opportunity or ability to contribute?)
   Speak up if you see something that does not look right. Everyone needs to know that we are never attacking the individual in a debate but more debating the argument.

Goal-Setting, Planning, and Execution

1. Team goals for this semester:
   Research concepts to gain a full understanding. A proof of concept/ prototype by the end of the semester.
2. Strategies for planning and assigning individual and team work:
   Work will be split into groups according to everyone’s strengths

3. Strategies for keeping on task:
   The pair system will ensure that everyone keeps each other on track.

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
   First we should try to talk to each other about the issue.
2. What will your team do if the infractions continue?
   Members will bring this issue up to someone higher like a TA and then to Mani.

****

a) *I participated in formulating the standards, roles, and procedures as stated in this contract.*
b) *I understand that I am obligated to abide by these terms and conditions.*
c) *I understand that if I do not abide by these terms and conditions, I will suffer the consequences as stated in this contract.*
1) _____Tom Zaborowski______________________________ DATE _______9/17________
2) _____Ben Newell__________________________________ DATE _______9/17 ________
3) _____James Camp_________________________________ DATE _______9/17________
4) _____Abdulraheem Alqunais_______________________ DATE _______9/17________
5) _____Harith Arsyad_______________________________ DATE _______9/17________
6) _____Tyler Bolton_______________________________ DATE _______9/17________
7) ____ DATE __________________