High Speed Magnetic Field Pulser

Design Document

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Executive Summary

Development Standards & Practices Used

List all standard circuit, hardware, software practices used in this project. List all the Engineering standards that apply to this project that were considered.

Summary of Requirements

List all requirements as bullet points in brief.

Applicable Courses from Iowa State University Curriculum

List all Iowa State University courses whose contents were applicable to your project.

New Skills/Knowledge acquired that was not taught in courses

List all new skills/knowledge that your team acquired which was not part of your Iowa State curriculum in order to complete this project.

Table of Contents

List of figures/tables/symbols/definitions (This should be the similar to the project plan)

1 Introduction

1.1 Acknowledgements

Throughout the project Mani Mina, Wei Shen Theh, and Robert Weber have played an indispensable role. They were the pioneers of this project and provided us with not lonely technical insight but also structure and direction for the project.

1.2 Problem and Project Statement

Magneto optic switches are useful for fiber optic communication systems. Implementing these switches requires high speed magnetic pulsers. This project seeks to first understand the previous work that has gone into creating such devices and then implement an improved small scale design. More specifically, the project goal is to develop a magnetic pulser with magnetic flux density of 500 Gaus and rise time of less than 100 ns.

1.3 Operational Environment

The device will operate under stable conditions suitable for most electronics in terms of temperature, dust, and moisture. The primary environmental consideration will be the ambient electrical noise put off by local machinery or electrical equipment.

1.4 Requirements

Functional Requirements:

1. Magnetic flux density of 500 Gaus
2. Rise time of less than 100 ns
3. Programmable control of magnetic pulse generation

Other Requirements:

1. Total cost less than $1000

1.5 Intended Users and Uses

The user will implement this system in a fiber optic circuit that requires a faster response time than is currently available in systems similar in concept to the one being developed in this project. Currently, magnet-optic materials have extremely quick response times that are underutilized by the slow response of current systems.

1.6 Assumptions and Limitations

Assumptions:

- Used in a climate controlled environment amongst other electronics
- Is a component of greater electrical system

Limitations:

- Cannot be bigger than 2.5 x 3 inches
- Powered Externally
- Operates at 15V DC

1.7 Expected End Project Deliverables

Semester One:

1. Report of understanding of previous work
2. Functional simulation
3. Report of proposed improvements

Semester Two:

1. Prototype of design with improvements
2. Circuit diagram of design with improvements
3. PCB layout of design with improvements
4. Functional PCB that meets requirements

2 Project Plan

2.1 Task Decomposition

There are 2 classifications of tasks that will be completed that are distinct and related in their goal of completion of the project. The first are tasks that will be completed for the goal of improving our ability to complete a project in general and communicate the results and progress of the project: design reports, status reports, presentations, reflections, etc. The second are tasks that will be completed for the goal of producing the deliverables requested by the client: designing prototype, holding design reviews, and creating the prototype. Each of these types of tasks come with their own risks and challenges that will need to be overcome.

There are three main type two tasks:

1. Create a design version one of a design review.

This is the first major task of the project. In order to complete it the team will need to gain an understanding of the physics behind the circuit and create a design. Once the design is able to meet all of the requirements, it will be presented to our client and advisor. They will provide feedback and prompt a second round of revisions.

2. Update design for design review two

The second design will make improvements on the first and will culminate in the second design review. This design review will hopefully go well and send us forward to the prototyping task.

3. Create prototype of design

This task involves implementation of design that has been approved by the client and advisor.

2.2 Risks And Risk Management/Mitigation

For the first type of task the main challenge will come in the form of communication. Creating a design document or a presentation is not technically challenging, nor is it prone to being thrown off by external forces. The issue that way assise is each team member may not know their responsibilities and tasks may fall through the cracks. To overcome this issue there are three main channels of communication that the team will utilize to eliminate this miscommunication. The first is GitLabs issues which is where a complete description of each task will be laid out and responsibilities will be delegated. The second mode of communication is GroupMe and will be used for more quick informal messaging. Finally, Zoom will be used for video conferencing in which we will have 2 meetings a week, one to plan the tasks we are going to conquer this week and a second to go over the progress of the previous week's tasks with our client and advisor.

For the second type of task challenges come from internal and external sources. This means that the same challenges that faced the first type of tasks will still apply here and the same solution will be utilized to mitigate them. The external challenges are a lot more task dependent. In the initial designs of the prototype we will face the challenge of inexperience with the topic, none of the team members have direct experience working with a circuit like this one and will need to use our diverse electrical engineering backgrounds in order to create a fully realized design. Once the design is created, we will need to build the prototype. There are a number of challenges this task will face. First, due to the coronavirus, there may be lead time issues. There will not be a lot of time between the completion of the design and the creation of the prototype and we will not know what parts we need until the design is complete. To mitigate this we will stick to standard parts and preferably those available from the Iowa State parts shop. Second, there is a limited capacity on the lab use due to the coronavirus so physically building the prototype will also be difficult logistically. For this same reason, it will also be difficult to debug any issues that arise when the design is built. Mitigating this issue can be done by coming to the lab with a clearly thought out plan of attack to quickly complete all tasks.

2.3 Project Proposed Milestones, Metrics, and Evaluation Criteria

There are four key milestones in the project that will be completed in order to achieve success in this project. The two are to complete design reviews of designs that will theoretically meet all the requirements of the prototype. In the second design review the goal will be to have implemented all of the fixes and improvements proposed in the first design review. The final 2 milestones will be to create a working prototype that meets all specifications, hold another design review and then implement the improvements or fixes.

2.4 Project Timeline/Schedule

Week 5				
14-Sep	15-Sep	16-Sep	17-Sep	18-Sep
Monday	Tuesday	Wednesday	Thursday	Friday
Create Electrical Design				
				Bi-weekly Status Report Due

Week 6				
21-Sep	22-Sep	23-Sep	24-Sep	25-Sep

Monday	Tuesday	Wednesday	Thursday	Friday
Create Lighting Talk		Lighting Talk II		
Create Design document V1				Design Document V1

Week 7				
28-Sep	29-Sep	30-Sep	1-Oct	2-Oct
Monday	Tuesday	Wednesday	Thursday	Friday
		Electrical Design Review I		
				Bi-weekly Status Report Due

Week 8				
5-Oct	6-Oct	7-Oct	8-Oct	9-Oct
Monday	Tuesday	Wednesday	Thursday	Friday
Revise Design				
				Reflection: Areas of Professional Responsibility

Week 9				
12-Oct	13-Oct	14-Oct	15-Oct	16-Oct

Monday	Tuesday	Wednesday	Thursday	Friday
		Electrical Design Review II		
				Bi-weekly Status Report Due

Week 10				
19-Oct	20-Oct	21-Oct	22-Oct	23-Oct
Monday	Tuesday	Wednesday	Thursday	Friday
Build Proof of Concept				
Create Design Doc				
Create Lighting Talk		Lightning Talks: Technical Challenges		

Week 11				
26-Oct	27-Oct	28-Oct	29-Oct	30-Oct
Monday	Tuesday	Wednes day	Thursda y	Friday
Troubleshoot Proof of Concept				Finish proof of concept prototype
Design Doc V2				
				Reflection: Engineering Standards

Week 12				
2-Nov	3-Nov	4-Nov	5-Nov	6-Nov
Monday	Tuesday	Wednesday	Thursday	Friday
Create Presentation				
Create Final Design Document				
		Create Youtube Video		

Week 13				
9-Nov	10-Nov	11-Nov	12-Nov	13-Nov
Monday	Tuesday	Wednesday	Thursday	Friday
Finish Presentation	Practice Presentation			
Finish Final Design Doc	Revise Final Design Doc			
	Youtube			

	Video Due			

Week 14				
16-Nov	17-Nov	18-Nov	19-Nov	20-Nov
Monday	Tuesday	Wednesday	Thursday	Friday
Final Presentations to Panel				
Final Design Document Due				
Weekly Status Report Due				

2.5 Project Tracking Procedures

The project progress will be tracked using gitlab issues. We will adopt an agile-like approach in which we will move tasks across the board each week and present our progress to our clients. At the beginning of the week, the tasks that were completed in the previous week will be discussed amongst the members and we will prepare to present them to the client and mentor in the following day's meeting. Then we will og over the tasks that will be completed throughout this week. Finally, in the following meeting, we will present the tasks that were completed to the clients and receive feedback.With this feedback we will update the tasks that will be completed in that week.

2.6 Personnel Effort Requirements

For each task on the gitlab issues page there will be a breakdown of subtasks. Each team member will be responsible for declaring a subtask that they will complete. In smaller tasks one person will be asked to complete the entire task. In all cases effort will be taken to ensure that all team members have an even amount of work.

2.7 Other Resource Requirements

The resource that will be required will be determined by the parts in the final design. This is currently being developed.

2.8 Financial Requirements

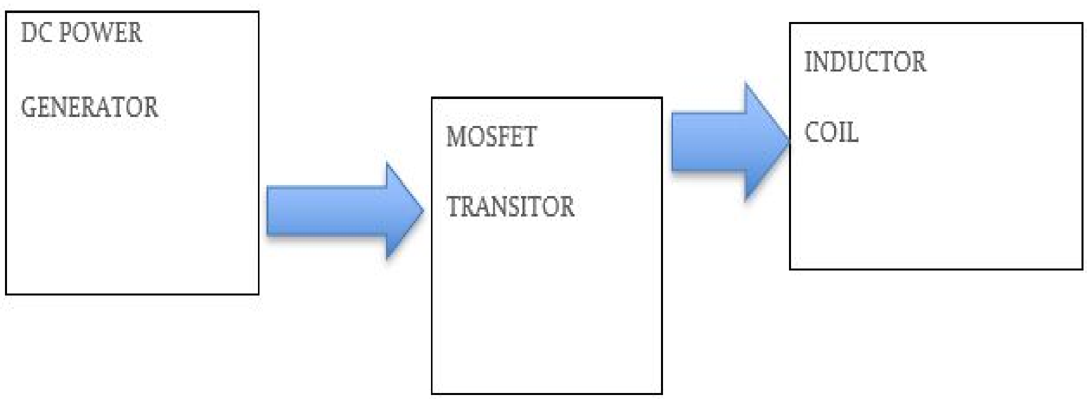
The total financial cost will likely be less than $100 as it is only one PCB will likely standard parts.

3 Design

3.1 Previous Work And Literature

A previous senior design group had done the same project before and during our meeting with our advisor, we were able to obtain some documents including a schematic done by the previous team. We then changed the capacitor and inductor value to perform a simulation using LT spice software. During our simulation, each member had a chance to play with component values to see how it affected the magnetic field(inductor current). Doing this helps us to understand how the circuit works and then come out with other solutions to improve a previous design.

3.2 Design Thinking

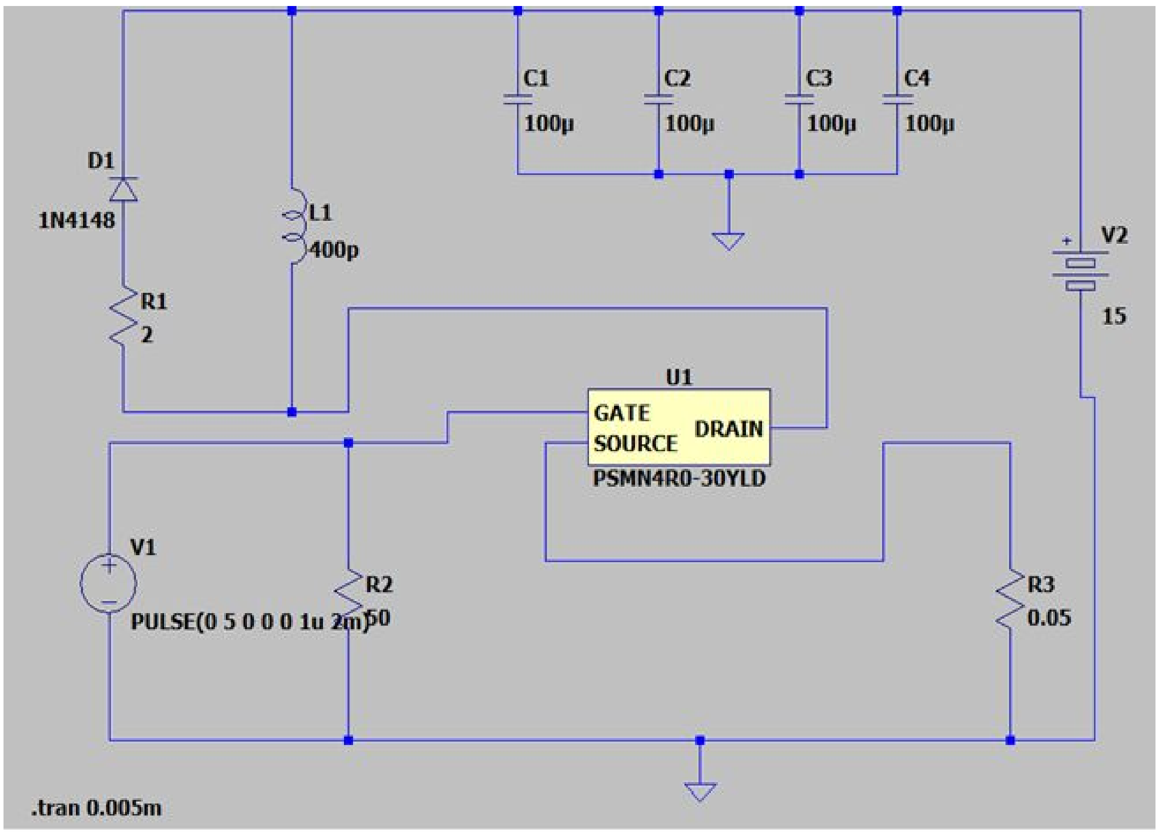


For this project, our goal is to design a magnetic pulse with magnetic field strength greater than 500 G pulse and time rise of 100ns. The circuit will have a MOSFET transistor and a small coil that will generate a magnetic field. We are using the same MOSFET that the previous team used for their design. There is also the resistor connected to the MOSFET source (Figure 1 – R3) to control the current through the inductor. Because we will need the inductor current value to calculate the magnetic field, this is nice path to track the require magnetic strength that we will need to meet our design requirement

We also added Capacitors in Parallel C1, C2, C3 and C4 to produce a high current through the inductor, we placed a diode D1 in series with the resistor to make our output stable. Another resistor is used to match the output impedance of the source. For this source, we are using a Pulse generator of (V1 = 0v, V2= 5v).

3.3 Proposed Design

Figure 1



Functionality (figure 1)

- The 2-ohm resistor R1 placed in series with the diode is used to dissipate some energy. Since there is a large amount of current flowing through the inductor, 2-ohm resistor is need to stabilize the circuit

- The resistor R2 is used to match the output impedance of the source. For this source, we are using a Pulse generator of (V1 = 0v, V2= 5v).

- The resistor connected to the MOSFET source (Figure 1 – R3) is used to control the current through the inductor. Because we will need the inductor current value to calculate the magnetic field, this is a nice path to track the required magnetic strength that we will need for our design.

- Capacitors in Parallel C_1, C_2, C_3 and C_4 are used to produce a high current through the inductor.

- The diode D_1 placed in series with the resistor R_1 is used to make our output stable. The diode can keep a constant voltage at the inductor, so the current through the inductor can be stable, so that the magnetic field pulse from the inductor will be better.

- The inductor is one of the most important components in our circuit. Our project requirements are to generate a magnetic field (B) pulse of 500 Gauss with a rise time of no more than 100ns. Combining these two requirements essentially defines our current and inductance by using the formula below.

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

B = magnetic field (Teslas) 1Tesla = 10000 Gauss

L = inductance (Henries)

μ = permeability of free space ($4\pi \times 10{-}7\ H/m$)

N = number of turns in coil , I = current through the coil (Amperes)

***l* = length of the coil (meters)**

R = radius of the coil (meters)

Throughout this semester we have used the same MOSFET that the previous team used for their design. Our future goal is to explore other MOSFET

3.4 Technology Considerations

The magnetic pulsers are already made and are available in the market. The previous design team had done a great job in successfully designing and producing fast magnetic pulser. However, there are issues regarding power dissipation and rise time of the circuit that makes it slightly inefficient. Our team goal is to improve the design and hopefully make it faster, stronger in terms of magnetic strength, and also reduce a rise time to 100ns. We are considering using another MOSFET to improve the power dissipation and rise time.

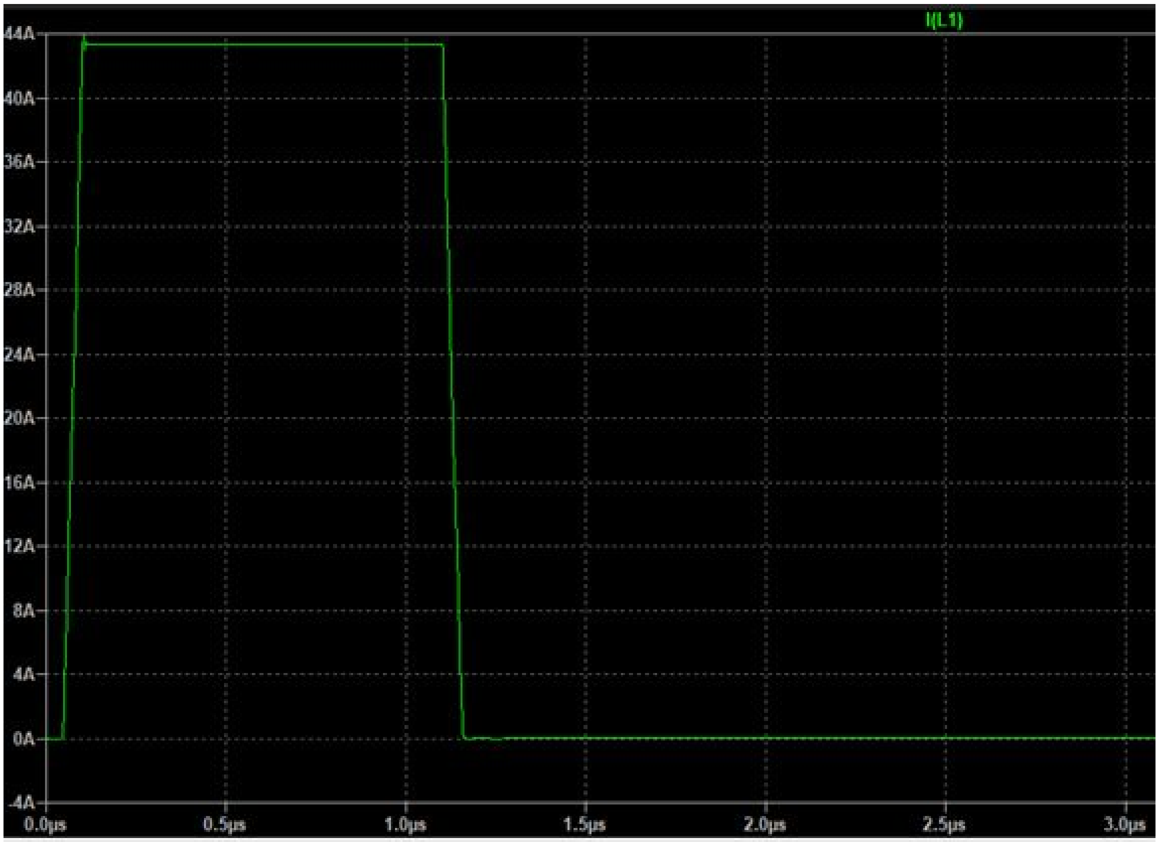
3.5 Design Analysis

After researching the concepts behind our circuit, we began simulating and completed a few simulations. To do this, we had to import the PSMN1R2-30YLD MOSFET made by NXP Semiconductors. This turned out easy for us since we are using LTSpice for the simulation. To gain a deeper understanding of the circuit's functionality, it was vital that we messed with components, changed simulation profiles, and used a variety of sources. This led us to really understand aspects of our circuit like why we need a diode, how does the MOSFET work and contribute to our goal, and how our inductance and capacitance values dictate the magnetic field output magnitude.

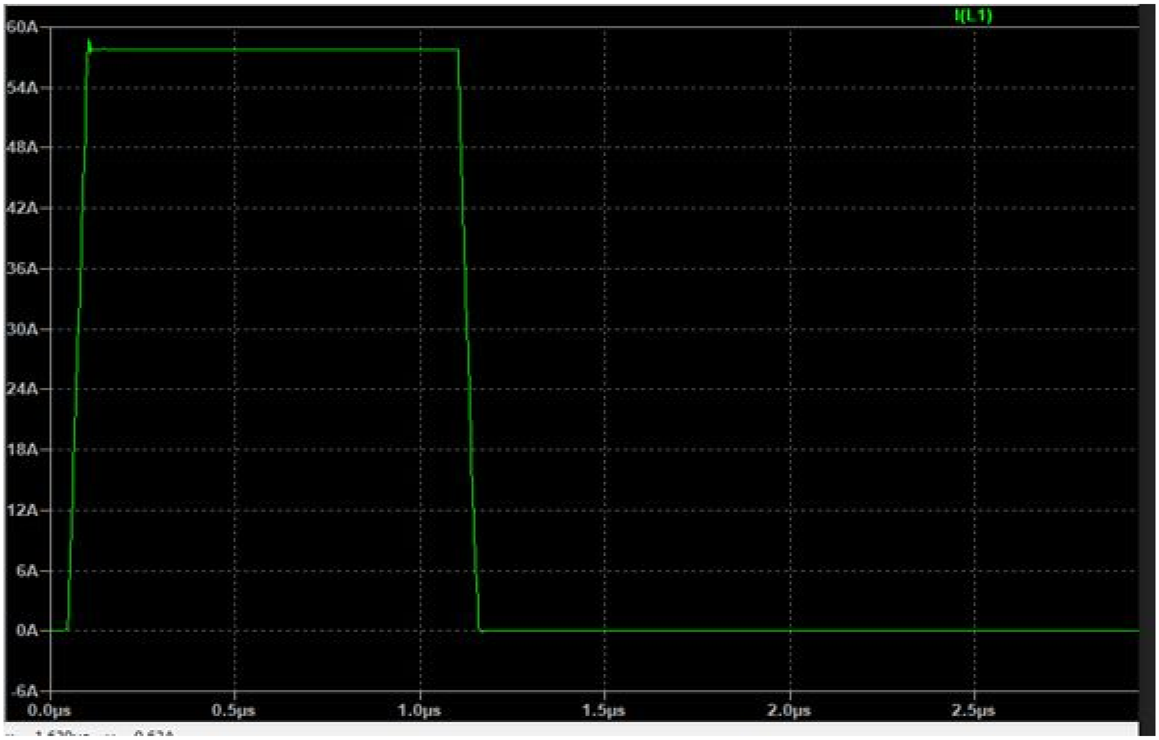
Throughout this experimental time, we recorded many scope images that show the behavior of the circuit configuration. In this section, we will outline a few of our most significant findings.

Result of simulations (please see the change of current IL of the inductor represent in y coordinate)

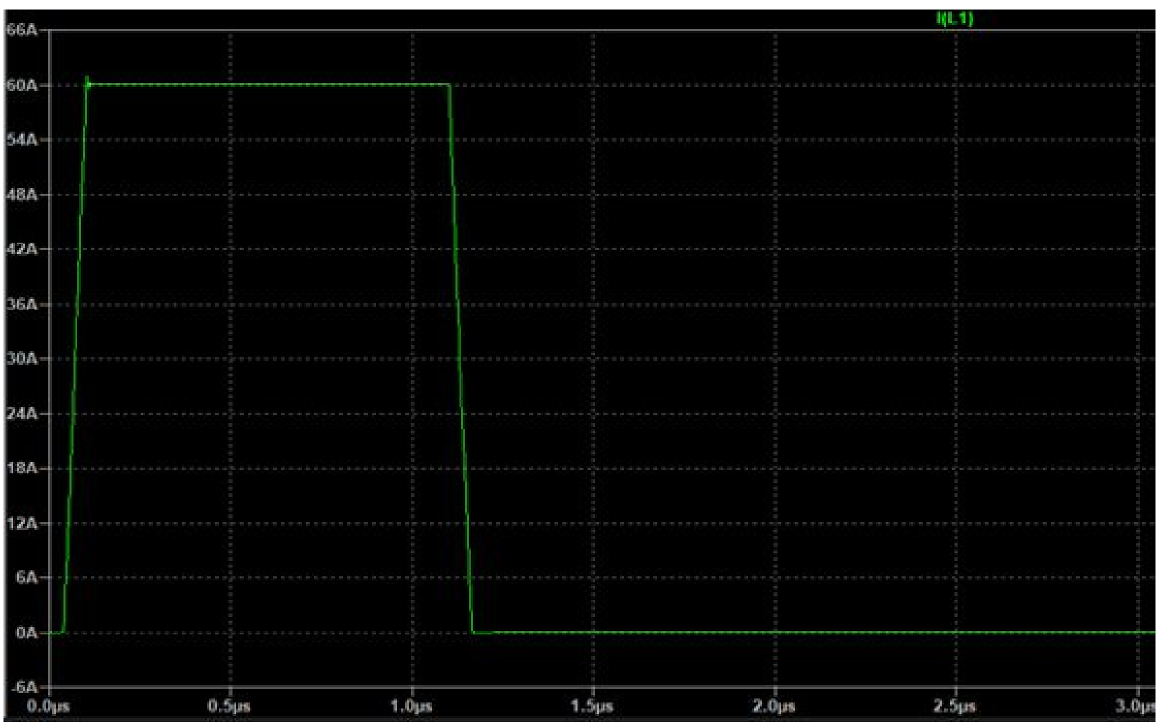
Simulation1 (standard value in circuit figure 1)



Simulation 2 (Increased the value of R3 from 0.05 ohm to 0.035 ohm)



Simulation3(Increased MOSFET VGS voltage to 6 v and rise R2 to 100)



Conclusion

In these graphs (Figure simulation 1 ,2 ,3), you can clearly see the difference between the current through the inductor. We can now achieve the desired current level by adjusting the value of R1 or Re and VGS. The inductor has a significant rise time of 1.2us. The design did not meet all requirements for this project. We still thinking about how to bring a rise time to 100ns

3.6 Development Process

The design and development of a low-cost magnetic pulse will follow three main processes: purpose of schematic, circuit simulation, and testing.

We start the design by reviewing a prepose schematic of a previous senior design team. We then changed the capacitor and inductor value to perform a simulation using LT spice software. After a few simulations we were able to obtain a required current need to generate a magnetic field. We are still working on how to reduce a rise time to 100ns. To reduce a rise time to 100ns we find that we have to use another MOSFET with low Qg.

After finding the desired MOSFET, we will be performing another simulation to see if it meet the requirements and move on PCB design . The last step will be the testing of our PCB design. We will be expecting our design to produce a strong magnetic field of 500 G with 100ns time rise.

3.7 Design Plan

The magnetic field pulser design will follow steps bellow:

1. Get required software (simulation and layout)
2. Learn how to use CAD software (simulation and PCB Layout).
3. Choose a suitable magnetic field component(inductor or etc..).
4. Create a field generation coil.
5. Choose a suitable MOSFET.
6. Choose suitable bypass and filtering capacitors.
7. Choose a suitable current-sense resistor.
8. Add miscellaneous passive and protection components if needed.

9. Manufacture PCB

4 Testing

4.1 Unit Testing

The units being tested in isolation are the components of our circuit that have an impact on the desired output and functional capabilities of the circuit. Specifically, these are the transistor, inductor, diode, resistors, and capacitors. Each of these components will be tested using software to discover their impact on the circuit as a whole. All of these components will be tested in software this semester and (hopefully) in hardware next semester. The results of these unit tests will be instrumental in the improvement of the circuit design, as well as serving as an essential method of attaining a greater understanding of magnetic field pulsers.

4.2 Interface Testing

Our group will conduct interface testing through the utilization of multiple software simulation tools and (possibly) hardware testing equipment. The software interfaces we are using are PSpice and NI Multisim, and the hardware interfaces we plan to use in the second semester (depending on the COVID-19 situation) are the Digital Multimeter, Oscilloscope, Function Generator, and Power Source.

To simulate our circuit, we have chosen PSpice and NI Multisim as our tools because of their simplicity and ease of access to these programs. The primary goals of our project for this semester is to recreate the original circuit and verify the experimental results through software testing and to gain an understanding of the functionality of the circuit design. Our first aim in software testing is to meet the project specifications by producing a magnetic field of 500 Gauss and a rise time of 0.1us. PSpice has all of the mechanisms that will facilitate this goal already integrated. We have figured out how to import MOSFET models, as well as other components we may need, into the design. This allows us to create our entire circuit within PSpice. We can now use the built in circuit simulation testing tools in PSpice to determine essential circuit values and confirm the viability of this project.

Once we were able to replicate the original circuit and validate the results of testing, we needed to obtain a more complete understanding of the circuit and how each individual component operates within it. To do this, we chose to use NI Multisim and work on a simpler version of a pulser. This software provided an environment where we were able to simulate different outputs of a pulser after changing various circuit components. By adding, removing, and altering different components, we were able to experimentally ascertain the purpose of each component. The reason we used NI Multisim over PSpice for this was because we were recommended to by our faculty mentor and an expert in the field of pulsers. This interface makes it easier for our group members to work separately, and it allows us to test different components slightly faster. Additionally, we may want to use NI Multisim in the future to transfer our virtual circuit to a PCB next semester.

We will do no hardware interface testing this semester, but we look forward to the possible opportunity to do so next semester. If we are able to gain access to the lab equipment, we will start by printing a PCB for our circuit (we have not yet determined which layout software we would use). After getting PCB and soldering in the necessary components, we would utilize the Digital Multimeter, Oscilloscope, Function Generator, and Power Source for hardware testing of the physical circuit. The results of this testing would likely be more prone to error, as real-life circuits operate in a non-ideal environment, unlike simulated circuits. We would use the results of the hardware test to determine if our design meets the project specifications, as well as gain insight into what may need to be altered to improve the functionality of the circuit.

4.3 Acceptance Testing

Acceptance testing will be broken down into two sections: functional testing and non-functional testing. Functional testing will be used to determine if the project specifications and requirements are all met, whereas non-functional testing will be used to evaluate other issues that come into play when actually implementing the circuit into real-world applications.

Our functional testing will be conducted both virtually and physically. We will utilize software testing, as previously mentioned, to ensure that the circuit is designed to output the specified Gauss value and rise time. This should be relatively easy under ideal conditions. Similarly, we will utilize hardware testing to ensure that the physical circuit passes its functional test. To be precise, we will use the oscilloscope to experimentally evaluate the rise time and the measured current through the inductor to calculate the Gauss value. The magnetic field value will take an extra step to calculate because it requires an equation. This equation consists of the variables B (magnetic field), u (the permittivity of free space), N (the turn density of the inductor), and I (the current through the inductor):

$B = uNI$

This calculation is relatively simple, but it is crucial in finding the Gauss value for both the software testing and hardware testing. It relates the current through the inductor directly to the magnetic field produced. The u value is simply a constant, but the N value is also important, as it can differ depending on the inductor chosen.

Our non-functional testing is not relevant as of right now, as our objectives this semester are to seek a better understanding of the circuit and to verify previous years' project findings. Next semester, if we are able to create a physical copy of the design circuit and test it we will also include non-functional testing. This will come in the form of evaluating different aspects of the design that could limit the applicability of the circuit. Some examples of this are the compatibility with magneto-optic (MO) material, power efficiency issues, and size of the circuit. These are the main areas of concern that were outlined by prior groups, so we will also examine these along with any other potential issues that we are able to identify after obtaining a better understanding of the circuit.

4.4 Results

The results we have found are listed in the table below, and they explain the impact a given component has on the circuit as a whole. These results were obtained through software testing in PSpice and Modelsim.

Components	Analysis Results	Conclusion
Transistor	Different transistors, specifically MOSFETs, provide shorter pulse width, low inductance, and have different gate capacitances.	MOSFETs do in fact work well for this project, but selecting which MOSFET to use can greatly impact the circuit.
Inductor	Low inductance will have high current and short pulse width.	A smaller inductor value is better for this project.
Capacitor	We failed to find a relation between the capacitors and the circuit output.	As of right now we are not sure about the capacitor impact, so we plan to do further testing. This may serve a

		purpose as a protection for the overall circuit.
Diode	The shape of the plot becomes somewhat misshapen if the diode is removed.	The diode operates as a stabilizer and needs to be present, especially if the inductance is high.
Resistors	We found that each of the resistors have some impact on the circuit, as if some are removed the plot becomes drastically distorted.	The resistors are essential, but they can be varied to some degree. However, at values too large or small, the circuit does not operate correctly.

We plan to conduct further testing to determine which values that we will use in the final product of our design. We learned a lot about how each of the components impact the overall circuit, and we will be delving more into the specific values that help us meet the required project specifications. With each iteration we will select more fitting components for our project, gradually polishing it into a final product. We will start with the more impactful components, such as the MOSFET and work our way down to the components that do not have much effect on the functionality, such as the capacitors.

5 Implementation

Describe any (preliminary) implementation plan for the next semester for your proposed design in 3.3.

6 Closing Material

6.1 Conclusion

Summarize the work you have done so far. Briefly reiterate your goals. Then, reiterate the best plan of action (or solution) to achieving your goals and indicate why this surpasses all other possible solutions tested.

6.2 References

List technical references and related work / market survey references. Do professional citation style (ex. IEEE).

6.3 Appendices

Any additional information that would be helpful to the evaluation of your design document.

If you have any large graphs, tables, or similar data that does not directly pertain to the problem but helps support it, include it here. This would also be a good area to include hardware/software manuals used. May include CAD files, circuit schematics, layout etc,. PCB testing issues etc., Software bugs etc.