High Speed Magnetic Field Generator

DESIGN DOCUMENT

Team: Sdmay20-proj39
Client: Iowa State University
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Zach Higgs – Team Lead
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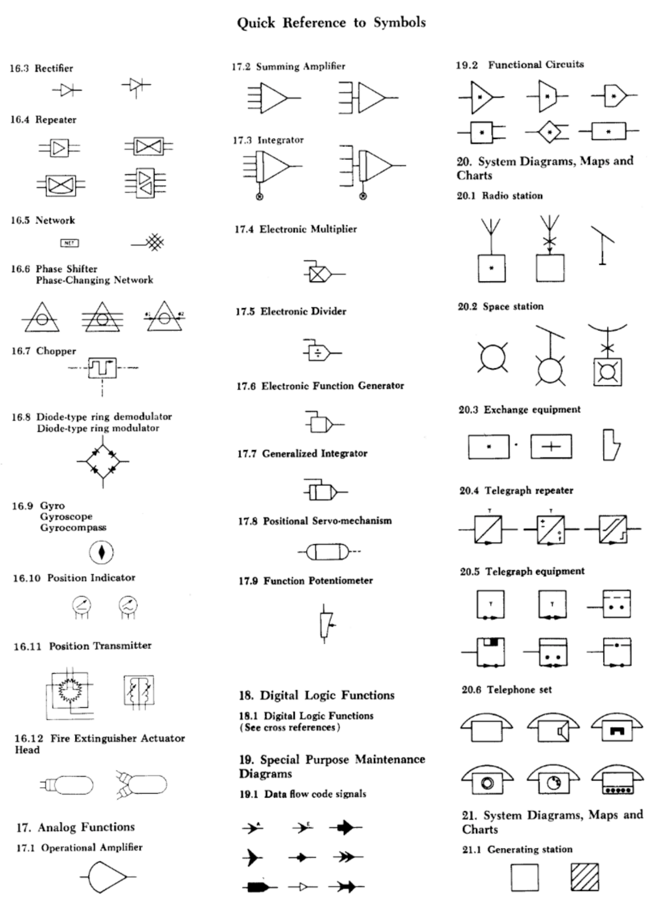
Executive Summary

Development Standards & Practices Used

- Electrical simulations
- Altium PCB Design and Schematic Capture
- Testing equipment: Oscilloscopes, Multimeters, Power supply, function generators
- PCB machining

Standard symbols:



Summary of Requirements

- Footprint smaller than 3.5” X 2”
- Final Product must deliver consistent results
- Developed on high end PCB
- Generate magnetic flux density of 500 Gauss
- Must have a rise time of 100 ns or less
- MO material must fit securely inside coil
- Must have an SMA connector attached

Applicable Courses from Iowa State University Curriculum

- EE 201
- EE 230
- EE 311
- EE330
- Engl 314
- Phys 222

New Skills/Knowledge acquired that was not taught in courses

- Magneto Optic material
- Faraday Rotation
- Bench testing complex circuits
- Finding parts based on required values

Table of Contents

1 Introduction

1.1 Acknowledgement

We would like to thank the following individuals for assisting us throughout this project. Doctor Mani Mina and Wei Shen Theh. Doctor Mina is the creator of the project and provides us with the space and materials we need to work on our project. Wei Shen is very knowledgeable about the project and has provided us continuous advice and information.

1.2 Problem and Project Statement

The goal of this project is to create a high-speed magnetic field generator with a magnetic flux density of 500 Gauss with a rise time of less than 100 ns. This generator will be used with electrical equipment such as network speed solutions and medical equipment. Though these systems work as they are now, there is always room for improvement which is where our project comes in. The use will be to create a magnetic field which will assist in changing polarity of a signal to alter data at any point along a fiber optic cable. Our proposal is to create a small PCB that can fit in this type of equipment while still completing the tasks stated above. We need to be able to fit a MO or Magneto Optic material inside of the coil as well. This project has great potential to optimize a lot of optic cable applications. By the end of this project we hope to have a small circuit board that (when powered) completes the above requirements.

1.3 Operational Environment

Our product is not planned to be used in any harsh environment. The only sort of environment we need to worry about is an electrically noisy one. If there is other machinery in the room where it is being used, we need to make sure it will not interfere with our product.

1.4 Requirements

Functional:

1. The product will generate a magnetic flux density of at least 500 Gauss
2. The product will have a rise time of 100 ns or less.
3. The pulse generated by the product must be able to be controlled.

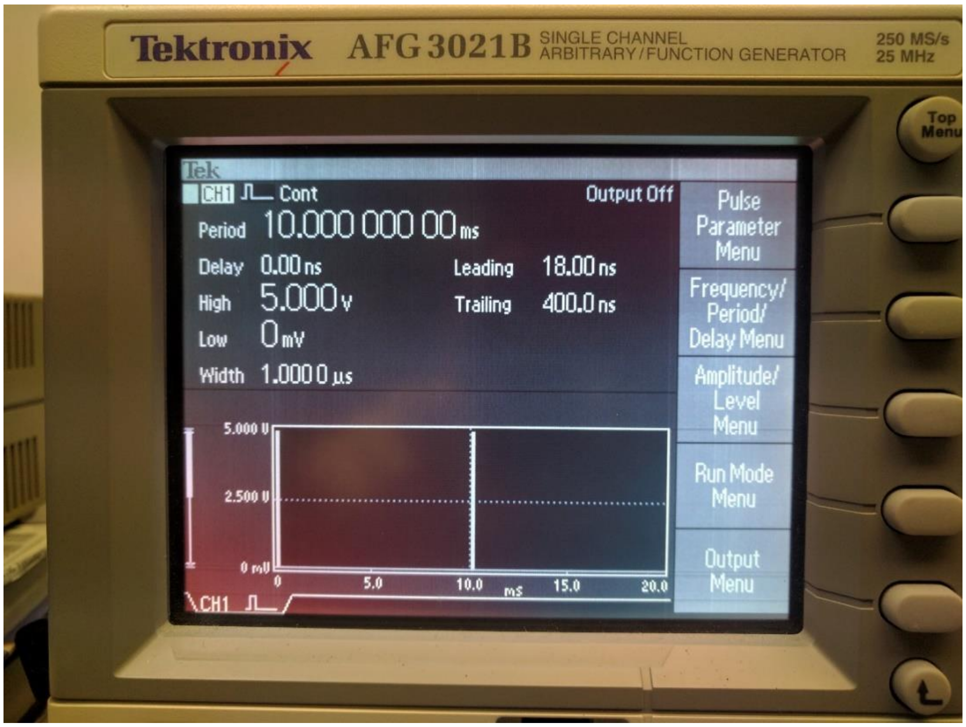
Non-Functional:

1. The product will be less than or equal to 3.5” X 2”

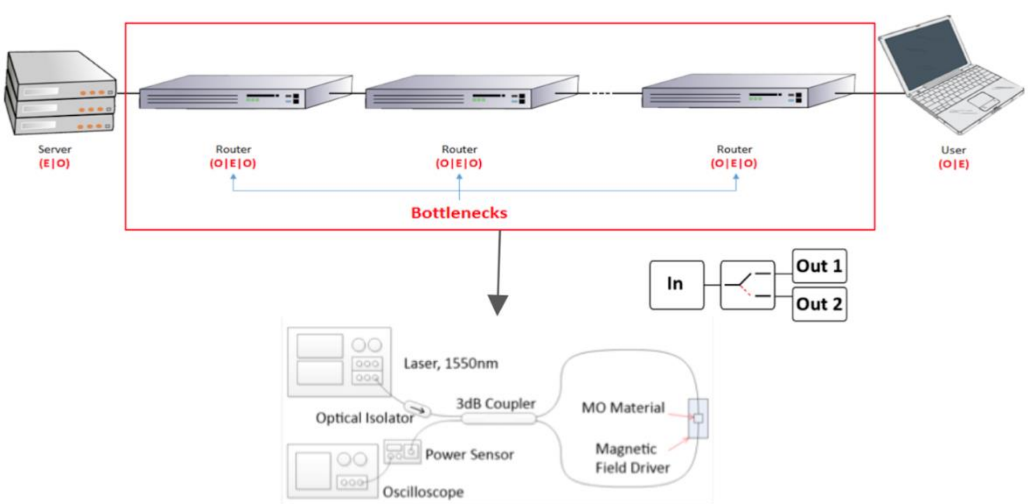
1.5 Intended Users and Uses

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.

Function Generator:



Application:



1.6 Assumptions and Limitations

Assumptions:

- This product will be used inside other equipment.
- This product will not be used in any harsh environment.
- This product will not be submerged.
- This product will not operate at high altitudes.

Limitations:

- The product must generate 500 Gauss to be able to correctly change the MO material.
- The product must have a rise time of less than or equal to 100 ns.
- The product will be powered by an external power supply.
- The product must be operated by a 15V DC supply.

1.7 Expected End Product and Deliverables

- If the end product is to be commercialized, the description shall be of the commercialized end product.
- It shall be in the form of a technical product announcement, as opposed to a product advertisement, and shall not include a list of technical specifications.
- Any other items that will be delivered to the client shall also be included and described unless their definition and description are obvious.
- Examples might include a household power supply to eliminate the need for batteries, a user's manual, or other project reports.
- There shall be at least a one-paragraph description for each item to be delivered.
- Delivery dates shall also be specified.

The end product will be a PCB with a coil that can generate a magnetic flux density of 500 gauss with a rise time of 100 ns. The product will be laid out on a professionally made PCB with an SMA connector. A datasheet will be included with the product showing input and output specifications as well as dimensions of parts for proper integration into other machinery. This product is not meant to be used in harsh environments and must be used to specified purposes.

2. Specifications and Analysis

2.1 Proposed Design

There is currently one primary design that will most likely be the one used. It is a design which was given to us by a team that worked on this design previously and it needs to be improved. They reached rise times of about 108nS, and we are here to make it much faster. We will need to test and measure many of the circuit's impedances to see what kind of parasitics we are working with, and by doing so, we will lower the rise time of the current in the inductor which generates the Gauss field.

We have also been looking into changing the given design completely. Currently a MOSFET is being used to drive the coil, but we want to go back a few steps and possibly redesign this idea. Possibly using other technology that will allow us for faster slew rates than those of MOSFETs.

There is also the problem of voltage input. We are limited at 15V DC, due to the client's needs, and we noticed huge improvements in rise time as the voltage increased. So, a new idea is to use the current technology with the same PCB and use a DCDC converter to boost the voltage to change the rise time as we desire. This could have stability implication, we with some smoothing capacitors we believe the idea could work. For now, we must apply this idea and test for quality and stability.

Another test that we want to conduct is on the MOSFETs themselves. There are many different types of MOSFETs that are composed of different materials. It is possible that different MOSFETs could work a lot better for our application. So even though voltage is probably the biggest improvement we can offer, changing the type of MOSFET could most likely cause just as much improvement.

2.2 Design Analysis

After talking with our clients, we have understood our requirements and we now know how to proceed with circuit designing. Our requirements are as follow:

- Achieve ~500 Gauss Electric Field within a coil
- Input one pulse with minimum 100nS rise time
- Only 15V power input

The most limiting item in the currently used circuit is the voltage supply. 15V is quite small and only allowed for a rise time of about 120nS, so if we were able to boost the voltage, we could easily decrease rise time by orders of magnitude.

Another factor that is most likely causing longer rise time is the MOSFET being used. After testing, it seems as of the MOSFET is not turning on fully and we can see on an oscilloscope in the form of two voltage slopes. At first the voltage rises fast, and at some point, the voltage changes its slope and slows the speed at which it's increasing. We want to make sure that the MOSFET will be constantly ON, and that the voltage slope we get is as high as possible.

After research and testing, we found that some MOSFET's really do change the rise time of the circuit. Some MOSFETs show a clear change while others are more subtle. We need to test them more to figure out the best MOSFET to use in our circuit. But there is the problem of unwanted oscillations. It seems that MOSFETs with higher gate capacitance will cause the output to oscillate and therefore make an unwanted slope to occur. There could be other ways to fix this problem, but we have not found one yet.

2.3 Development Process

At first, we were hoping to lower the amount of parasitic impedances and therefore lower the rise time significantly. But now we realize that this is not the most effective way. We could instead focus on other ways that would lower the rise time like a voltage increase by using a DCDC converter, turning on the MOSFET with a specialized MOSFET driver, and choosing the best type of MOSFET for our design.

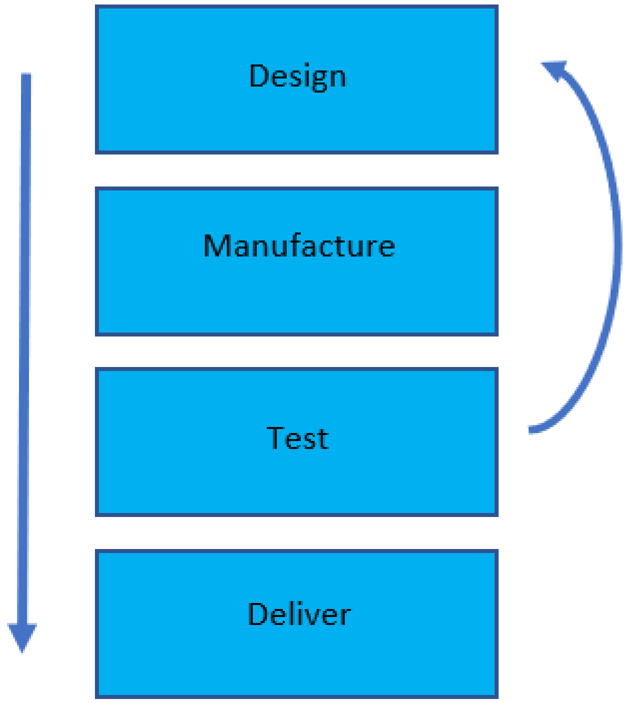
For parasitics, even though we try to maximize power in the form of voltage increase, parasitics are still involved. If we do not make sure to lower the impedance of the parasitics, the circuit will become unstable, and we will get bad ringing or oscillations at the output. And because this is a very quick process, we must make sure to design our PCBs in the most efficient way to lower parasitics and ensure a clean output.

If we want to design a new method of driving the coil other than using a MOSFET, we will need to follow a new set of directions. First, we will need to research the possible ways of driving the coil, then look for ways to implement the new items. And lastly, we will need to design board and test them. This will be a much longer process than the previous.

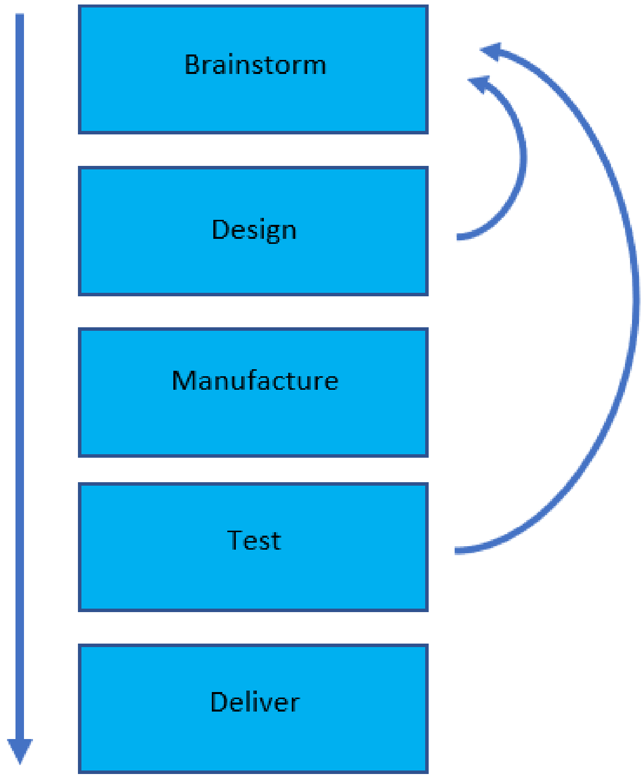
2.4 Design Plan

As previously discussed, there are two separate design plans that we can follow.

For basic MOSFET use, this flow chart will be used:



For a new design which does not include a MOSFET. New ideas and fixes will have to be constantly made:



3. Statement of Work

3.1 Previous Work And Literature

This project is a continuation of a few years of past senior design projects. The team from the previous year was tasked with developing a system that created a 500 Gauss field with a rise time of 100 ns. The advantages to work previously done on this project has provided us with a working circuit that generates a magnetic flux density of 433 Gauss with a rise time of 111 ns. While this helps in cutting our design work, we do need to find alternative solutions to aid in keeping the magnetic flux density around 500 Gauss as is but bring down the rise time.

3.2 Technology Considerations

- Alternative semiconductors with different Rs and gate Cap values.
    - Other MOSFETS may prove to be more efficient than current MOS in design. Looking to reduce gate cap and alternative Rs value.
- GaN MOSFETS
    - Determine if rise time is better than current MOS being used.

- Gate amplifiers
    - Possible replacement to current MOS to aid in overall rise time; may add more delay.
- Alternative Inductors
    - Test possible alternatives that aid in higher current values.
- Alternative Capacitors
    - Possibly aid cutting down overall rise time by altering layout/composition.

- Boost Converter
    - Find a chip that can be implemented before the MOS to boost input voltage from 15v to around 20v.
- Dual Coil System
    - If we were to implement two coils instead of one, we would drive them both and aid in decreasing inductance and possibly the rise time.

3.3 Task Decomposition

Team Member	Title	Tasks
Zack Higgs	Team Lead	• Maintain and schedule communication between members and external sources. • Manage and maintain meetings between members and stakeholders.
Jason Cheng	Technology Lead	• Develop and maintain PCBs and schematics. • Aid in creating of hardware. • Design and maintain team website and a consistent update of project.
Craig Philipp	Communications and Presentation Lead	• Develops and manages presentations. • Verify work is making progress for project. • Oversees individual and team reports.
Ben Colson	Test Engineer Lead	• Verify working and in progress circuits. • Creates plans for testing and verification. • Documents and organizes testing sessions for verifying functionality of circuits.

Harel Cohen	Hardware Lead	• Verifies hardware is ordered and any/all parts are accounted for. • Verifies all PCBs are accounted for and ready for testing. • Works with tech lead between revisions to organize prototypes and any updates.

3.4 Possible Risks And Risk Management

- Costs
  - Currently not concerned with the costs of overall project.
- Materials
  - Only concern pertains to obtaining parts in house to populate any physical prototypes.
  - If parts are not directly available, we will need to order the proper hardware and wait for its arrival for proper testing.
- Equipment
  - Training for use of Coover equipment.
  - This will hinder any physical prototypes being developed if access and proper training with equipment is not met.
- Knowledge
  - Need to obtain good understanding of overall project to ensure we have forward momentum with project.
  - Possible meetings with subject matter experts need to be scheduled to ensure we can have their knowledge to aid in possible improvements and understanding of the project.

3.5 Project Proposed Milestones and Evaluation Criteria

- Developed system performs with a sub 100ns rise time and generates a magnetic flux density with amplitude 500 Gauss.

- Develop working and testable Prototypes.

- Test prototypes to confirm and progress of rise time, and if not, what can be altered.

- Have consistent forward progress with design

3.6 Project Tracking Procedures

To ensure tracking of overall progress, the team will have consistent weekly meetings. These meetings will contain time for individual progress reports and reflections. Concluding these meetings, the team will determine if progress is being made and decided everyone's next step for the week. If no progress was made, we determine the cause of this and reflect on how to ensure forward momentum is sustained.

3.7 Expected Results and Validation

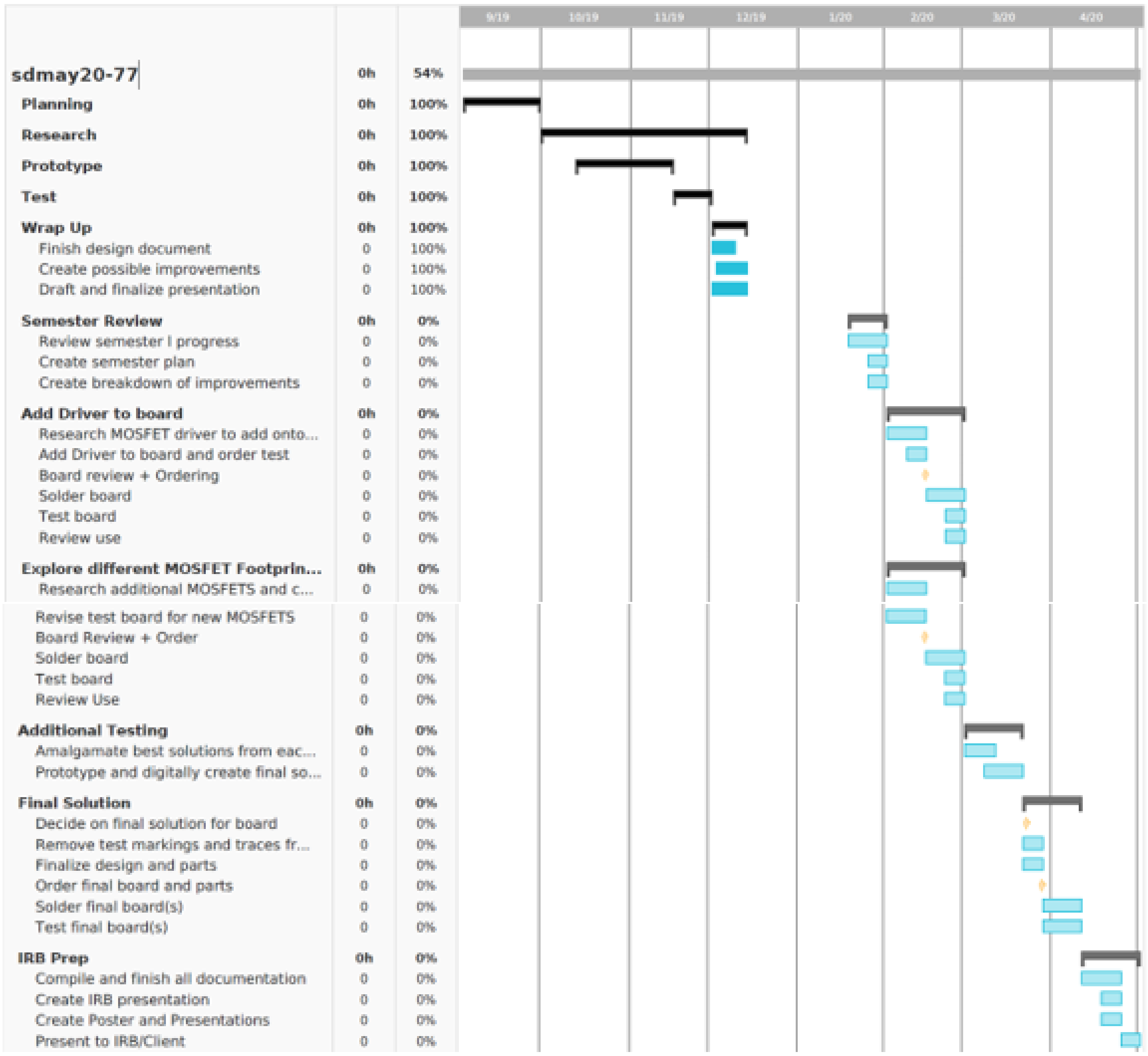
Desired Outcome:

- Design and test a working system that generates a flux density of amplitude 500 Gauss with a sub 100 ns rise time.

To ensure that solution to the design works, we will develop a working and testable prototype. This prototype will then be tested in its simulated environment.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline



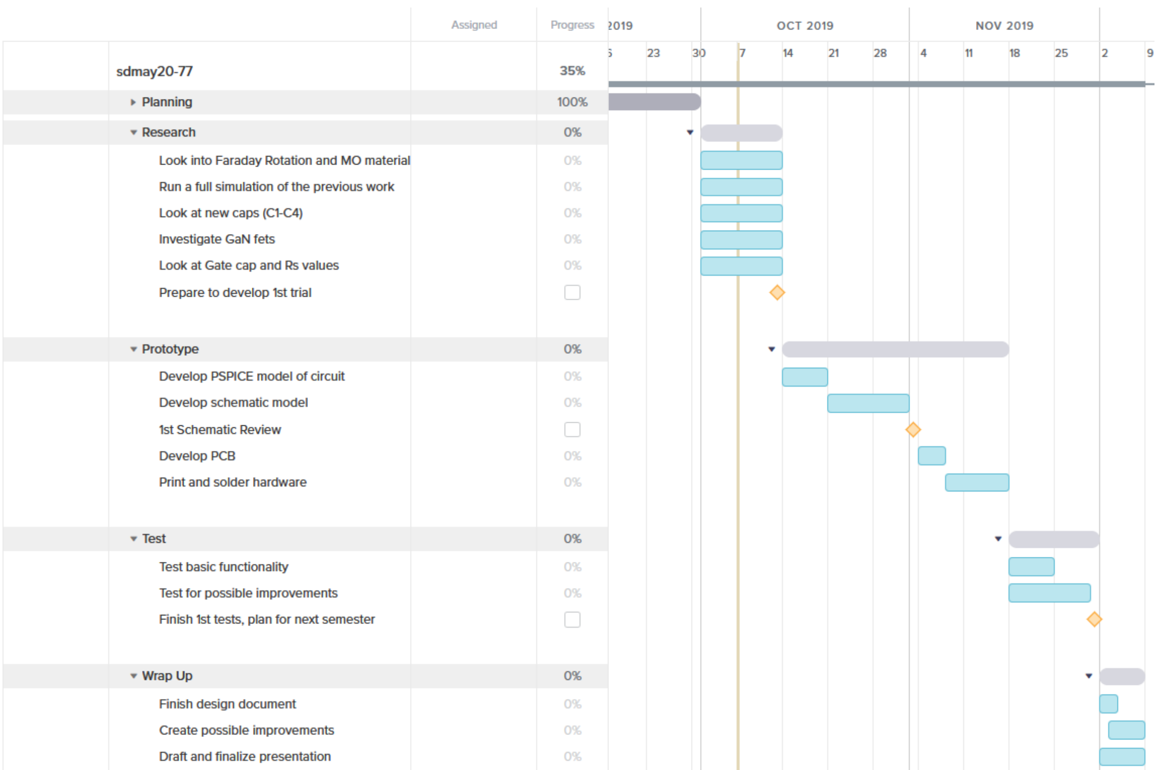
4.2 Feasibility Assessment

The project will be a circuit in the form of a PCB to generate a magnetic field for use in fiber optics. This project will iterate on previous designs, attempting to get a working circuit that meets minimum requirements necessary to be implemented in the full project. This will involve many iterations of the circuit, trying to find an ideal balance, both virtual and physical.

Problems will occur throughout the project. The project will involve iterating on a circuit and implementing parts that will have various tradeoffs. This will eventually lead to a group discussion over what tradeoffs must be made, and how to make them. In addition, as we get more advanced with the prototypes, it will be difficult to advance with our knowledge, so external resources will have to be consulted. The group must make sure to reach out to Dr. Mina, the group's sponsor, Wei-Shen, and other experts to understand and verify our understanding of the circuit, and the effects we will be having.

4.3 Personnel Effort Requirements

Each group member will be assigned an amount of responsibility as close to equal as they can manage. Each task currently noted below will be assigned accordingly.



4.4 Other Resource Requirements

- Machine shop access for the PCB prototypes
- PSPICE simulation software
- Altium Designer or equivalent to design schematics and PCBs

4.5 Financial Requirements

- ~$500 - Parts related to PCB and tests
- ~$100 - PCBs to test

5. Testing and Implementation

5.1 Interface Specifications

Our first testing tool is a software simulation tool called PSPICE. This simulation tool allows us to model our circuit's behavior to given inputs. In PSPICE, we can import non-ideal models for all components allowing us to predict how to circuit will behave in actual tests. Two of our main goal for this project is to design a circuit that can switch on a coil with a rise time of 100ns and produce a field of 500 gauss. PSPICE allows us to predict these specifications and verify that the circuit should theoretically satisfy our criteria.

After fabricating our circuit one of our first tests will be to measure the magnetic field of our coil. This is to meet our first requirement, of having a magnetic field of 500 gauss within our coil. One initial hardware interface we will be using is a multimeter to measure voltage across our current sense resistor. This is our 0.05-ohm current sense resistor.

Our group will also be using an oscilloscope to view the signal traces of the coil. Using this tool, we can verify that our rise time is less than or equal to 100 ns. An oscilloscope will also allow us to see the quality of the pulse. In the past, we have seen ringing on this line, and we should be able to view this on the oscilloscope.

5.2 Hardware and software

PSPICE:

PSPICE will be used to simulate the whole circuit and theoretically verify that all design specifications are met.

Advanced Design System (ADS):

Used to analyze the patristics of our circuit and to model the loss.

Multimeter:

This hardware tool will be used to measure supply voltages, check resistances, and read our current sense resistor

Oscilloscope:

The oscilloscope will be used to experimentally measure the rise time and signal integrity of the circuit. We will measure the rise time to verify that it is 100ns or less.

5.3 Functional Testing

Our functional test will require using both a multimeter and oscilloscope to verify our rise time and magnetic field. We will read the voltage over our current sense resistor, using ohm's law we can find the current through our inductor. Because devices in series have equal current, we can find our current coil by measuring the voltage over our 0.05-ohm current sense resistor. By knowing the current through the inductor, we can then find the magnetic field of the inductor. The magnetic field (B field) in an inductor: where mew is the permittivity of free space, N is the turn density, I is the current through the solenoid.

B= u NI

Using these three values we can experimentally calculate the magnetic field within our solenoid to verify that it is at least 500 Gauss.

To experimentally verify the rise time of the coil, we need to use an oscilloscope. Using an oscilloscope, we can view voltage vs. time, and plot the voltage of the inductor to verify that it reaches its correct value in less than 100ns. We will capture traces on the oscilloscope using the cursors to mark change in time.

5.4 Non-Functional Testing

After we receive our printed circuit boards (PCPs) we can test for power efficiency, size form factor, and compatibility with our magneto optic-material. We will also be looking to reduce any ringing on the signal which might not affect any functional tests immediately but might affect long term usability.

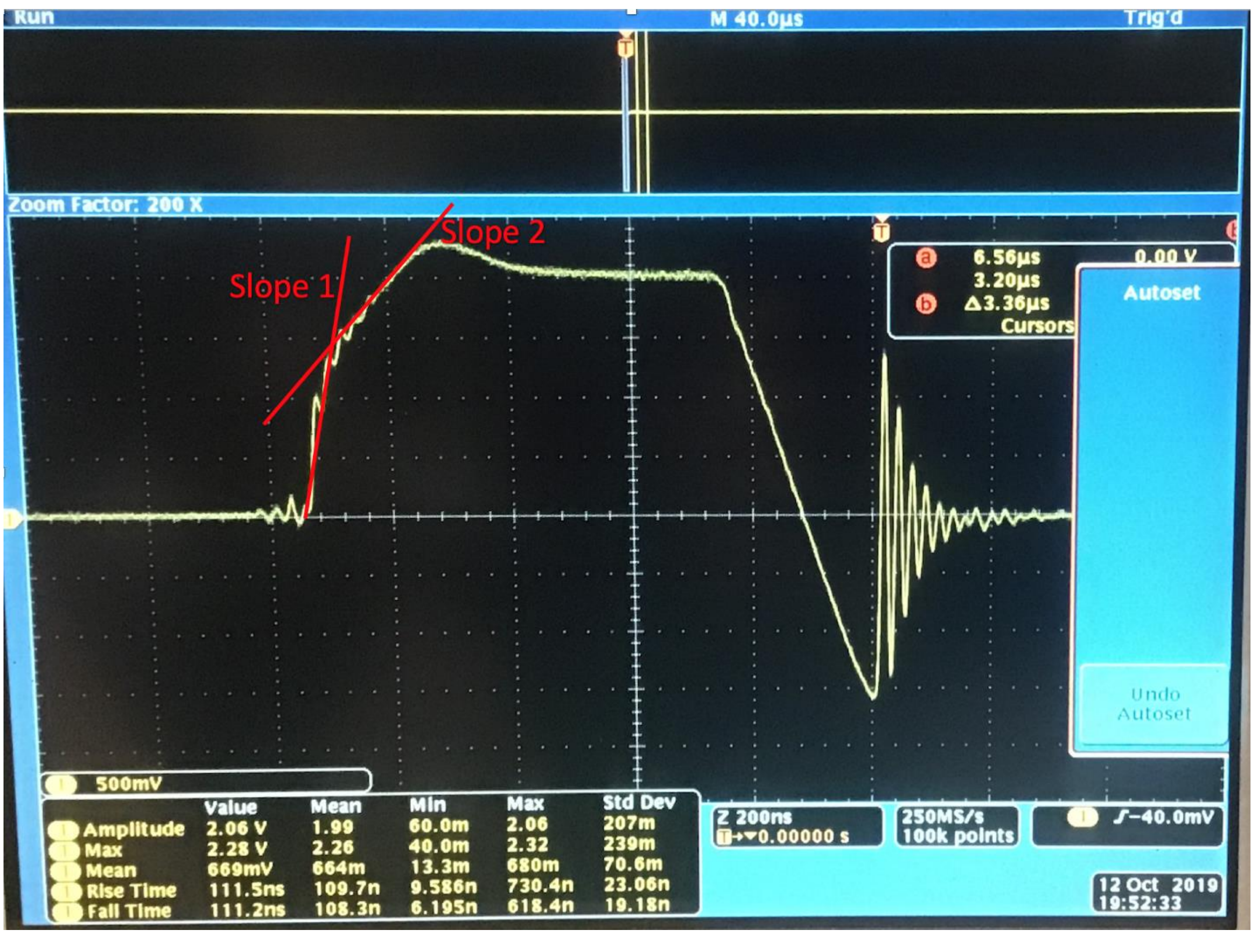
5.5 Process

At this stage in our testing we are running simulations to test different types of MOSFETS, inductor values, and voltage levels. We are changing each of these to reduce the rise time and increase the magnetic field within the inductor. The goal of these tests is to reduce the inductance of the solenoid, resulting in a reduction in rise time. To reduce the inductance of the solenoid the number of turns of the inductor must be reduced, resulting in a weaker magnetic field. Our hypothesis is that by increasing the supply voltage, the magnetic field and in result the current, will increase. The next step after successfully testing different MOSFETs, is to print PCBs and compare our theoretical results with our experimental results.

5.6 Results

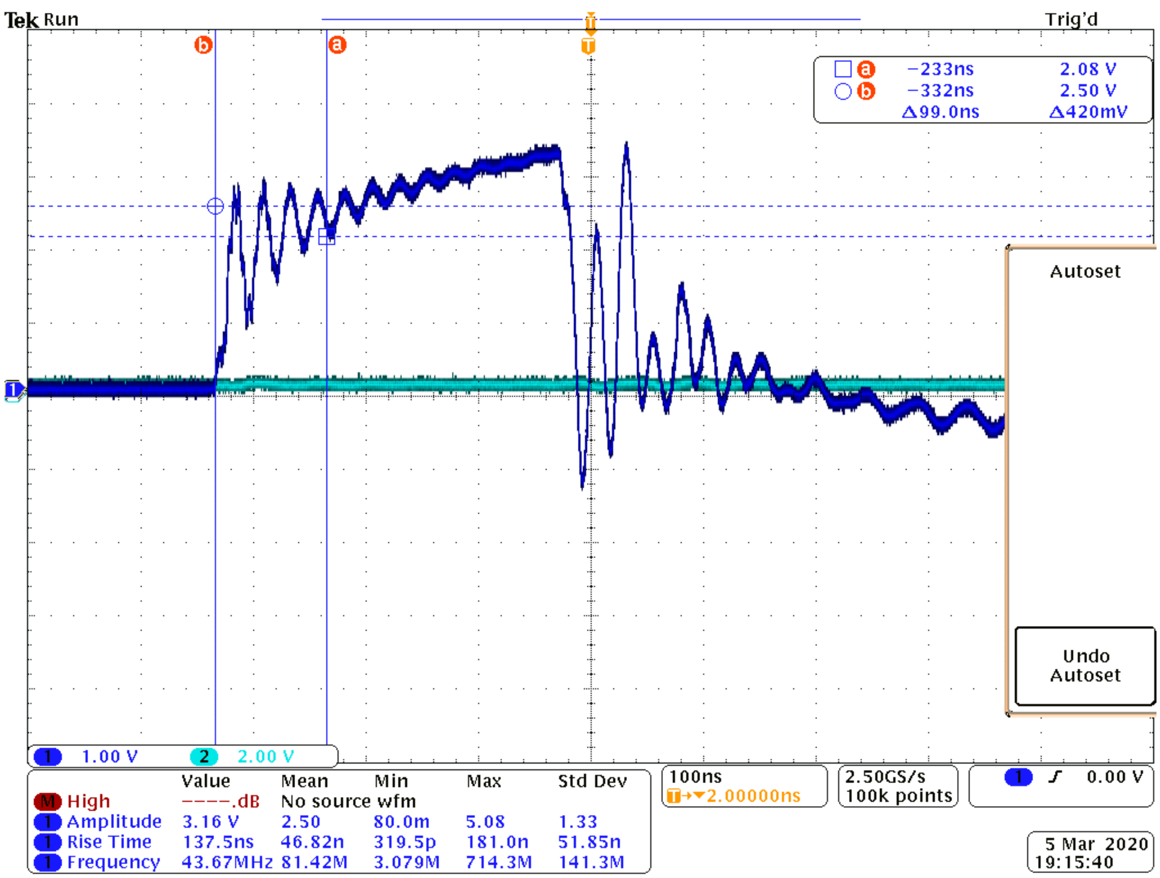
From the basic modeling and simulations using PSPICE we found our circuit to have a rise time of around 47ns, with one non ideal component. We use the CSD17322Q5A MOSFET first, this has a gate capacitance of 570 pF. Because of the gate capacitance, there is a delay between the green trace and the red, inductor voltage.

Since our last update, we have simulated different MOSFETs with different gate capacitance. The result of this is having a delayed output pulse, this pulse is simply shifted back. We have also tested the past circuit with added capacitance to fix several problems with our rise time wave form. During testing we have found our rise time to have two slopes (labeled as slope one and two). We are currently investigating why this is occurring. The two slopes could be a result of our main supply capacitors being drained. We will run an experiment where we add capacitance to the supply and observe the slopes. We also plan on running an Advanced Design System (ADS) transient simulation to observe how parasitics could change our circuit's behavior. This is important because higher parasitics could result in larger rise times.



There have been a few issues finding all the simulation modes of all the MOSFETS and diodes we want to try. Each one is made by a different company and not all the component's simulation files are downloadable online. We will be contacting the companies to request a PSPCIE simulation file.

Since our last update we have added a MOSFET driver to out system. This driver will drive the gate of out MOSFET with a higher voltage then our function generator can supply. The thought behind using this is that it will allow us to be sure that our gate turns on fully in a shorter amount of time. We were unsure of the outcome of this, but we gained some insight from running it. Before in person meetings were suspended, we were able to test this set up and gather some data.



This trace was captured using the SIRA28BDP-T1-GE3CT-ND MOSFET at a supply voltage of 25V and a gate voltage of 9.25V. The trace shows the voltage over our current shunt resistor. As previously calculated, the voltage must reach 2V to reach our desired inductor magnetic field of 500 Gauss. Using these parameters with the gate driver allowed us to achieve an unstable result. As seen in the initial part of this trace, the voltage of the trace oscillate at an extreme level. We think that these oscillations come from the initial gate having imperfections causing it to oscillate.

In the future, these oscillations need to be reduced and in order to achieve this, future groups could create their own PCB without a daughter board pulse using a more specific MOSFET driver to achieve a less noisy gate pulse.

6. Closing Material

6.1 Conclusion

We have talked to the client and figured out the uses for our product. Based on the information we have received, we conducted research based on past projects. We also have done outside research to understand our project better such as the concept of Faraday rotation and MO material research. Using this newly acquired information we started looking into ways we can improve our product to make the rise time faster than previous projects had made it.

Our plan is to continue to conduct research into different types of MOSFETs with different values of input and output capacitance so that we can continue to reduce our rise time while still holding our 500-gauss threshold. We are also attempting other methods such as using boost converters and MOSFET drivers to let us work with a higher voltage. We had created a timeline and planned to stick to it so we could have a finished product at the end of this cycle. Due to the unexpected changes the world is going through because of COVID-19, we have had to make a few changes and adjustments to the outcome of our project. We have not been able to do much physical testing since the university has gone online but we do have theories and we are continuing to test those. We were able to achieve a faster rise time; however, our output signal is not ideal. Currently, our team is researching to figure out just how we can fix this signal integrity.