

Building Blocks and Sub-Circuits with Magnetic Field Generators

Design Document

Team May23-29

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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

We would want to take the design of test fixtures, as well as methods and processes for ensuring the accuracy and consistency of measured data for signals with frequency content up to 50 GHz. Then we want to take the tested circuit and print it to our PCB with the frequency if needed 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

It is important that we are completing our project in a very safe manner. We want to make sure that safety is addressed and understand what the limit of frequency is of which we can be exposed to and what we should do if exposure does occur.

Summary of Requirements

List all requirements as bullet points in brief.

- To be able to understand high-speed circuits
 - build high-speed circuits
 - test high-speed circuits
 - measure high-speed circuits

Applicable Courses from Iowa State University Curriculum

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

- EE 333
- EE 311
- EE 324
- EE 224
- EE 201
- EE 417
- EE 330

- EE 230
- EE 475
- EE 438

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.

- Usage of the following programs
 - COMSOL
 - MATLAB (Mainly knowledge of EM)
 - Simscape
 - RF Block Set
 - NI Multisim
 - KiCad
 - CST
- Knowledge on couplers and waveguides
- Deeper understanding of electrical components (Such as inductors, and MOSFETs)
- Understanding of High Magnetic Field generators
- Understanding high level documentation and research articles

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Definitions

IEEE - Institute of Electrical and Electronics Engineers

MFG - Magnetic Field Generator

PCB - Printed Circuit Board

NI - National Instruments

VDC - Direct Current Voltage Source

G - Gauss

MO - Magneto-optic

ZVS - Zero Voltage Switching

1 Team

1.1 TEAM MEMBERS

MICHAEL LOPEZ - ELECTRICAL ENGINEER

ANDREW MURPHY - ELECTRICAL ENGINEER

WILLIAM NICHOLS - ELECTRICAL ENGINEER

STEVEN HYUNH - ELECTRICAL ENGINEER

UMAIR SARWAR - ELECTRICAL ENGINEER

1.2 REQUIRED SKILL SETS FOR YOUR PROJECT

- Circuit Design (MFG)
- PCB Design (MFG)
- MATLAB (Optical Switch)

1.3 SKILL SETS COVERED BY THE TEAM

- Circuit Design - Andrew Murphy and William Nichols
- PCB Design - Andrew Murphy and William Nichols
- MATLAB - Michael Lopez, Steven Hyunh, Umair Sarwar

1.4 PROJECT MANAGEMENT STYLE ADOPTED BY THE TEAM

Our team assigned tasks by group vote or volunteer. Our weekly tasks were typically assigned by our client, and initially the entire group was doing every task individually. Eventually, the team split up and each member focused on an individual part of the project, and took all the tasks in their area.

1.5 INITIAL PROJECT MANAGEMENT ROLES

Michael Lopez - Optical Simulator

William Nichols - Team Coordinator

Andrew Murphy - Electrical Circuit Design

Steven Hyunh - Electrical Circuit Tester

Umair Sarwar - Comsol Specialist

2 Introduction

2.1 PROBLEM STATEMENT

High speed magnetic generators are a useful tool in the communication and medical industry. There is a high demand to increase switching speed in routers which is the main application for our design. Our goal is to create a small, highspeed, magnetic pulse generator with a large magnetic flux density. We will be improving upon previous senior design projects by creating a smaller and more efficient design.

2.2 INTENDED USERS AND USES

A high-speed magnetic field generator can be used in many fields. Applications can be implemented in medical and communication industries. The goal is to achieve high signal integrity while increasing switching speed in electrical equipment. This increase in speed is important in communications to improve the magneto-optic switching used in routers. The medical industry also has uses for targeted magnetic pulses for applications such as transcranial magnetic stimulation. Secondary customers will be the users of products created by medical and communication companies.

2.3 REQUIREMENTS & CONSTRAINTS

Client Requirements

- Magnetic field strength greater than 500 G
- 15 VDC
- Rise time of the pulse is less than 100 ns
- Size of the PCB will not exceed 3.5" by 2"
- Develop a Optical System that relates to the Circuit System

Team Goals

- Improve upon past senior design projects
- Develop an optical system for simulation
- Utilize circuit simulation software and optical simulation software to develop our final product

Environmental Requirements

- Non-hazardous
- No electrical interference with device

Constraints

- Budget: \$500

3 Project Plan

3.1 PROJECT MANAGEMENT/TRACKING PROCEDURES

Our goal is to do a mix of agile and waterfall thought. We plan on researching our magnetic field generator then picking components that fit the specifications. Finally, we will test our circuit to see if it gives us the results that fit the parameters of the research. If we find our simulations to be unsatisfactory, we will go back to picking components and repeat the testing phase. This fits more of the agile project management style because we are going in circles in terms of development. When our Optical simulation is satisfactory, we will move onto PCB Design. This more coincides with the waterfall method as some parts of the timeline are linear. If our PCB design meets the specifications needed, we will go to final testing our PCB to see if our simulated design is what we expect. If not, we will go back to component selection and repeat the process until our PCB testing is to what we want. This will be a very similar process to our optical design with the only difference being instead of testing in multisim we will be testing in Simulink or other optical simulation software. This style then goes back into the agile method because we go back into a feedback design method. Essentially, there are aspects to this project that require us to use both the agile and waterfall methods due to the structure of this research project. Once we finish a particular portion, it will lead into the next portion, but the future parts cannot be done until the prerequisites of those portions are done. Below you will find our plan for senior design methodology to track progress.

We as a group have been using google drives as our project management tool. We have put a deadline for each person to complete their sides of the project and everyone can see when each person completes their part of the project. We also use Discord to manage our project management progress, communicating with each other and making sure we are on track with the project goals.

3.2 TASK DECOMPOSITION

In order to solve the problem at hand, it helps to decompose it into multiple tasks and subtasks and to understand interdependence among tasks. This step might be useful even if you adopt agile methodology. If you are agile, you can also provide a linear progression of completed requirements aligned with your sprints for the entire project.

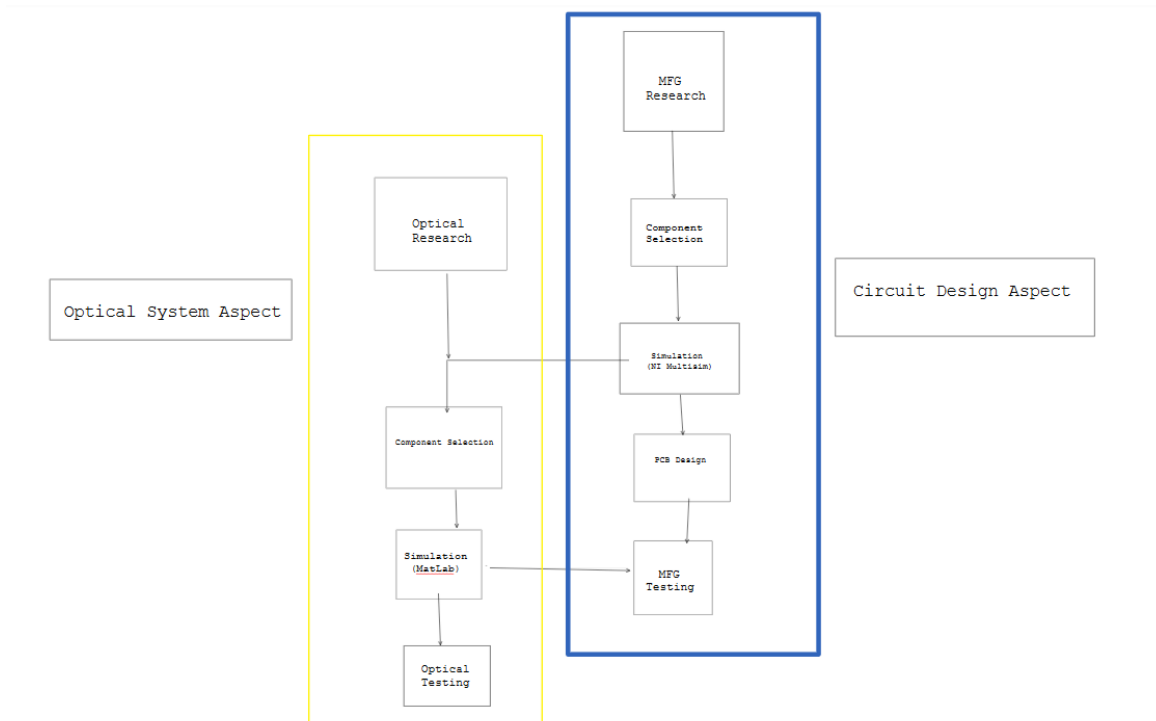


Figure 1: Task Decomposition of our project.

3.3 PROJECT PROPOSED MILESTONES, METRICS, AND EVALUATION CRITERIA

In an agile development process, these milestones can be refined with successive iterations/sprints (perhaps a subset of your requirements applicable to those sprints).

Milestone 1: Magnetic Field Generator (MFG) Research

Milestone 2: Selected MFG Components (Inductor, MOSFET, Capacitor, Diode, Resistors, etc.)

Milestone 3: Circuit Simulation Meets Desired Specifications (Rise time 100 ns, Gauss value 500, 15 VDC)

Milestone 4: Complete Optical Research

Milestone 5: Complete Optical Design for Simulation (Circuit Meets Expected Results)

Milestone 6: Complete Printed Circuit Board (PCB) design (3.5" x 2" PCB)

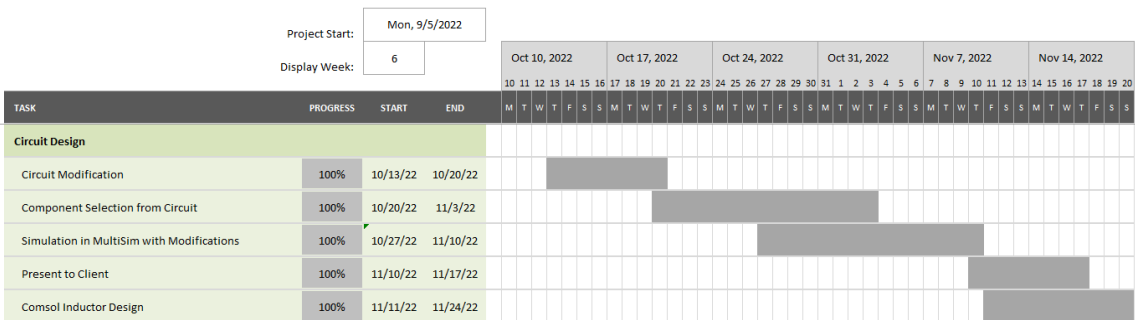
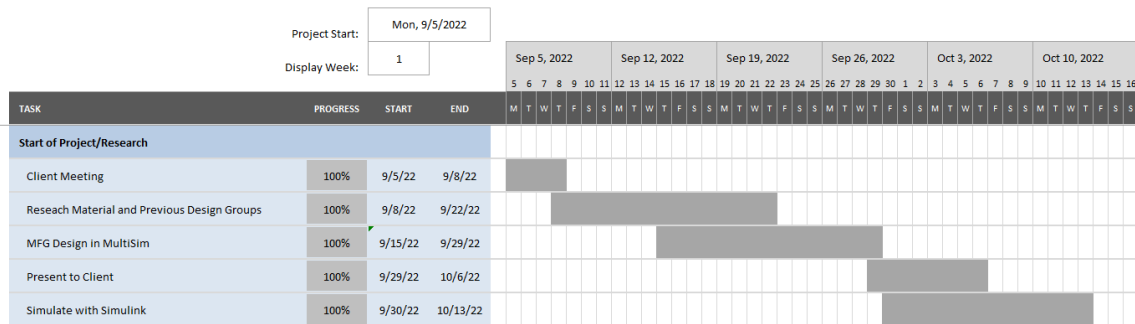
Milestone 7: Breadboard Testing (Real Circuit meets Expected Specifications)

Milestone 8: PCB Testing (PCB Circuit meets Expected Specifications)

Milestone 9: Develop Final PCB Circuit (Change from Through-hole to Surface Mount Components)

3.4 PROJECT TIMELINE/SCHEDULE

- A realistic, well-planned schedule is an essential component of every well-planned project
- Most scheduling errors occur as the result of either not properly identifying all of the necessary activities (tasks and/or subtasks) or not properly estimating the amount of effort required to correctly complete the activity
- A detailed schedule is needed as a part of the plan:
 - Start with a Gantt chart showing the tasks (that you developed in 2.2) and associated subtasks versus the proposed project calendar. The Gantt chart shall be referenced and summarized in the text.
 - Annotate the Gantt chart with when each project deliverable will be delivered
- Project schedule/Gantt chart can be adapted to Agile or Waterfall development models. For agile, a sprint schedule with specific technical milestones/requirements/targets will work.



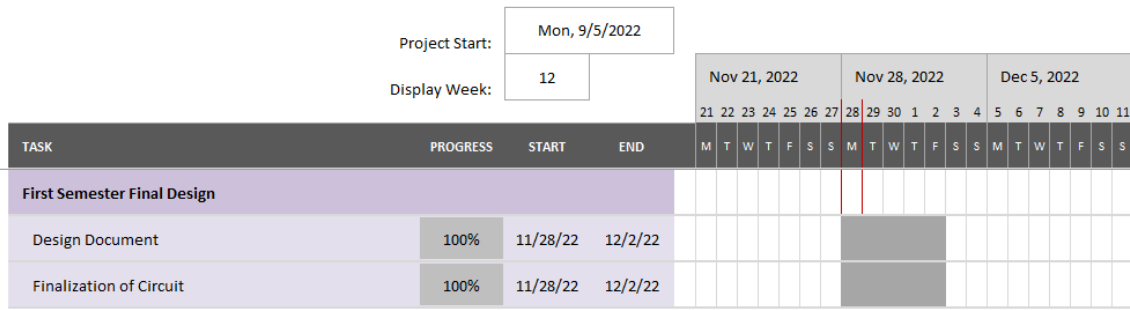


Table 1: Schedule Plan for work to be completed in Senior Design.

3.5 RISKS AND RISK MANAGEMENT/MITIGATION

Bodily Risks

- Shocked
- Team members will not interact with an active circuit.
- Burned (From Soldering Tools)
- Gloves will be worn when soldering to prevent burns.
- Bursting Solder in Eye
- Safety glasses will be worn by all team members while soldering.

Economical Risks

- Over Budget/Supply Chain
- Team will plan our testing carefully to avoid budget and supply chain issues
- Failed Equipment
- The team will use PCB sockets to quickly replace failed equipment.

3.6 PERSONNEL EFFORT REQUIREMENTS

Task	Time (Hours)
MFG Research	30-35
Optical Research	30-35
MFG Component Selection	15
MultiSim Simulation	15

PCB Design	5
Breadboard Testing	10
PCB Testing	10
Optical Simulation	20

Table 2: Time needed for our project.

Research will take the most time. This is because the team needs time to learn about the optical connections, and review magnetic fields. Component selection will take time as there are hundreds if not thousands of MOSFETs and diodes to choose from, but only a few will be useful in our circuit design. After we select components, we will likely use them in a simulation to make sure they will meet our expected design requirements and behave as expected. Once we have chosen all of our components, we will also take some time to optimize the circuit design by manipulating basic components such as resistors and capacitors. PCB design will take very little time, the main constraint is the maximum size set by the client. Breadboard testing is a simple yet important step in circuit design. We will want to buy and test all components of our circuit before committing to a PCB design. If our circuit design does not pass the design specs, we will need to perform a redesign of the circuit. Once the circuit passes the breadboard test, we can print the PCB. Once we receive the PCB, we will test it to make sure the circuit still meets our specifications. For the optical simulation we will spend more time as we are unfamiliar with optical simulation software. This section might take more time than expected because we will be learning the ins and outs of optical components from the ground up. Once we know more about the optical interaction, we can begin to start building our simulation. Once we have a successful MFG design and optical circuit design we can implement the MFG circuit into our optical circuit to experiment with our MFG design.

3.7 OTHER RESOURCE REQUIREMENTS

- 5 MOSFETS
- Coil of Wire (Inductors)
- 12 resistors
- 10 capacitors
- 6 Diodes
- 2 PCB
- 1 coupler
- 1 power sensor
- 1 optical sensor

- 1 oscilloscope
- Optical cable
- Laser source (1550 nm)
- MO material
- Solder material
- Soldering iron

4 Design

4.1 DESIGN CONTEXT

4.1.1 Broader Context

Area	Description	Examples
Public health, safety, and welfare	Medical Tools that use magnetic fields and magnetic pulses to get treatment. Our project can affect medical devices such as pacemakers and defibrillators.	TMS (transcranial magnetic stimulation) MRI (Magnetic resonance imaging)
Global, cultural, and social	Our magnetic field generator follows the guidelines of the IEEE Code of Ethics in every situation. We are carefully monitoring our situations each week and making sure that the project doesn't fail the Code of Ethics. Our product is a specific component that is used for companies that manufacture and design modems/routers	Modems from other companies such as Motorola, Netgear, Cisco-Linksys, Belkin, etc.
Environmental	It is possible that our product can interfere with other products that also have electrical circuits in the area. Also has an impact with energy usage.	Designing and laying out a plan about the products that are going to be inside a building and how they can come in contact with each other. For example, in a business area where electrical products are involved. We want to limit the amount of energy usage needed for our product.
Economic	Depending on the use of our project the cost will vary, but for the most part the cost will not affect product cost of existing devices. Since this project could eventually be a part of	Product needs to remain affordable for the target user. Keep the amount of energy the product needs to

	<p>a larger product like a router the cost for household users might go up. As the energy they need to keep the router running will cause the electricity to go up and then the cost they need to spend on the bills will increase</p>	<p>a minimum while still achieving the specification.</p>
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4.1.2 Prior Work/Solutions

Our project is very difficult to find on the market because it is a single component of a router. The goal of our project is to increase the speed of networks and optical switching in particular. Some routers today are capable of up to 6 GHz switching speeds. While we will not be able to achieve this speed, we are working on a circuit used for research purposes to achieve this in the future. One of the products on the market which might use our project is from netgear. <https://www.netgear.com/home/wifi/routers/nighthawk/>

This project has been assigned many times within the last decade. The main differences between our project and previous ones, is that we will use our MFG circuit in an optical system to test its functionality. While many projects in the past have successfully created a MFG circuit with a rise time of less than 100 ns, none have actually applied their design to an optical system or completely met the required specifications.

While research has been done in the past that can create very fast rise times, we will be achieving those rise times while simultaneously creating a large magnetic field. In some previous experiments performed by Mani Mina, rise times of 77 ns were achieved, but the magnetic field created was only 43.2 G in strength [2]. Our goal is to achieve a rise time of 100 ns with a strength of over 500 G, over 11 times the strength of this particular experiment. The optical simulation was also not done within the previous project groups as we are focusing our research towards optical networking. That said, this will improve research avenues and overall MFG simulation/functionality. The con is that it is not a perfect simulation, it only works under ideal conditions. So compared to other router circuitry, it will be very low leveled.

4.1.3 Technical Complexity

For technical complexity for this project, it hinges on two separate systems that require intense mathematics, High-level Physics, and problem-solving techniques. It's broken up into Circuit design, with a heavy emphasis on Electromagnetism, and Optical System knowledge. The Circuit Design requires knowledge on circuit analysis and electromagnetism as this circuit requires intense mathematics on steady state analysis of the desired output of the system. For example, the magnetic strength of the inductor must reach 500 G, the current through the inductor must reach around 50 amps and have a rise time of 100 nanoseconds. These conditions meet the current solutions standard of previous projects and research. Mathematical requirements are through number computation and equation manipulation. The engineering principles within this portion of the project involves fulfilling the set requirements from the client utilizing brainstorming of what type of components being used would fulfill the requirements of IEEE standards. It's important that none of the components will be destroyed within the

process so it involves trial and error of the number computations while continuously testing the circuit. The Optical System portion of the design process involves number computations, conversions, and software knowledge to accurately simulate the ideal values without creating an unstable system. There are no existing solutions to this process, so this portion must be made from scratch. This involves more of the engineering principles of brainstorming ideas to problem solve for a solution that could formulate the ideal circumstance for the number computations involved. As such, this will exceed the existing solution involving the optical system portion as it will scientifically and mathematically show how it fits within the overall process. The base requirement for this portion must accommodate for a 1550 nanometer wavelength sinusoidal input as this is the industry standard for communication devices such as routers. As such, this makes the problem challenging because there are no previous projects that have achieved this portion of the analysis.

4.2 DESIGN EXPLORATION

4.2.1 Design Decisions

In our project, the main design decisions that this project required are: the inductor, Transistor types; MOSFET or Bipolar Junction Transistor (BJT), resistor values, circuit type between Monophasic and Biphasic, and optical schematic. The inductor value dictates the magnetic field that the circuit is producing and the current required to produce it. The MOSFET/BJT changes switching speed and dictates the direction of the current within the circuit. The magnetic field strength and rise time generated by the inductor is the primary factor when deciding on components, meaning that everything surrounding these variables will change to compensate for it. The circuit type between Monophasic and Biphasic attempt to achieve the same goal but with different factors. For example, our transistor type could change based on if the circuit is a monophasic or biphasic circuit. So, while we have a choice between these components, they ultimately need to reach the goal of the project. Which is why these decisions are important for the project.

The decision surrounding the optical simulation gives us more freedom on how we can layout the simulation due to this being the first year in which they include this aspect to this project. The goal of the simulation is to replicate how our circuit is changing the fiber optic wire being manipulated by the circuit. In that regard, our client and advisor are unfamiliar with the software needed to fully simulate the optical portion of the project. We were given choices and decisions on which software to use and how to illustrate the optical portion. We were given choices between MATLAB/Simulink, Comsol Multiphysics, and Ansys Lumerical to fully simulate the optical portion of the circuit. We went with a combination of MATLAB/Simulink and Comsol. The Simulink is used to simulate how the optical portion is being affected by the circuit. Similarly, Comsol can be used to simulate the optical portion as well, but for this project, Comsol is being used to create 3-D models of our inductor to show the Magnetic field that is being generated. As mentioned, our client and advisor are unfamiliar with the software, so we are creating avenues for them to understand how the software is utilizing the data from the circuit generated to show how the optical portion is being affected in a detailed

manner. If we are successful, this opens up a new branch of research that can be explored for them in the future. However, this portion does rely on the circuit side of the project because these simulations are only for ideal cases, which means we need to finish the circuit portion before we can fully decide on the full general layout of the optical simulation.

4.2.2 Ideation

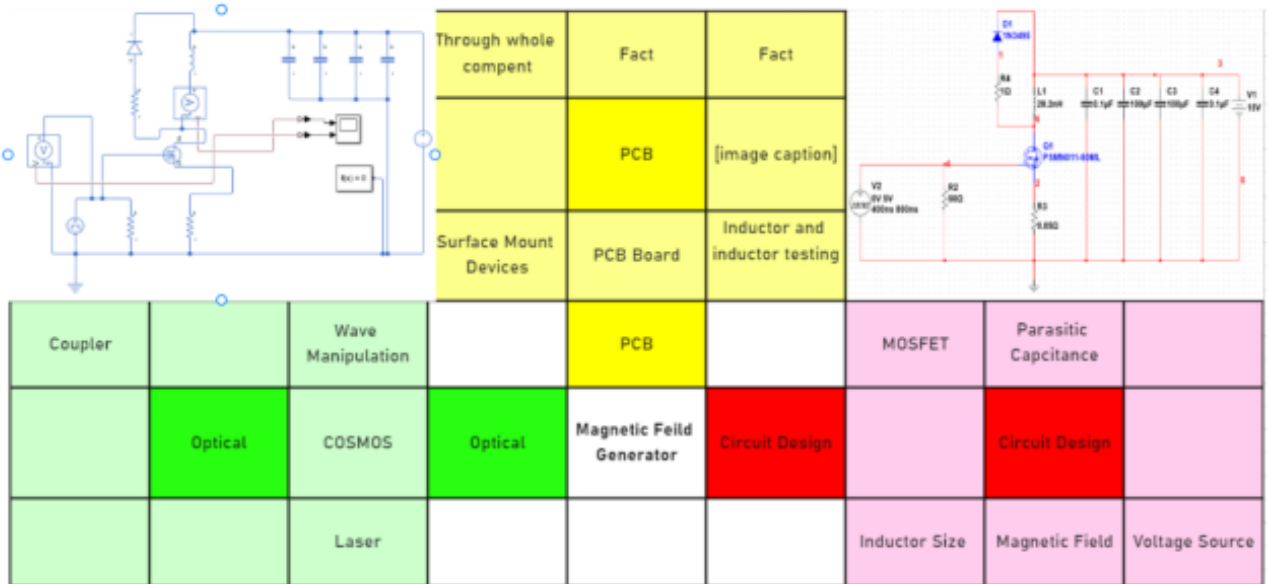


Chart 1: Gantt chart on idealization

4.2.3 Decision-Making and Trade-Off

For the pros to our circuit design, it was easier to decide what our MOSFET was going to be. Out of all the MOSFET we were going to choose from, we already knew what our criteria should be, all that was left was just process and elimination. The way we did this was to look up our ideal MOSFET on a website called “Digi key”. This website allowed us to choose from a wide variety of MOSFETS to choose from, not only that but we were able to enter our preferred values in the search bar. So searching for the ideal MOSFET to use in our simulated circuit design was not an issue. However, the cons when choosing our ideal MOSFETS was that most of the time, the MOSFET we wanted to use for our simulated circuit were either not available in the simulation for us to test our, or the item were sold out or completely discontinued. Due to this issue, it proved to be a lot harder in finding ourselves our ideal MOSFET.

Circuit Design		MOSFET Model
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Criteria	Weight	IPPO43NO3 LG	IPP8ONO4 S4L-O4	IPPO42NO3 LGXKSA1X	IPPO52NE7 N3G
Input Capacitance	2	1	2	1	2
Current Drain	5	5	5	5	5
Threshold VDS	5	5	5	5	5
Gate Threshold Voltage(min)	4	3	3	3	2
Risetime	3	2	1	1	1
Simulation	TBD				
Total	19	16	16	15	15

Table 3: List of Tradeoffs of each MOSFETs

When looking for the PCB, there were only 3 criteria we had to look for. Is the PCB within our price range? Is the quality high enough? Will we get the PCB in time? Since our budget for our project is \$500, looking for a PCB \$150 or less was our priority. We also had to make sure the quality of the PCB is good as well, otherwise it would've been a pain if the PCB breaks during the process. Finally, the time it takes for us to receive the PCB matters. No use working on our project if it takes 4 weeks to receive our PCB.

PCB		PCB website		
Criteria	Weight	4pcb.com	PCBway	Digi-key
Price	5	5	5	5
Quality	5	5	5	5
Ordering time	4	2	4	3
Total	14	12	14	13

Table 4: Tradeoffs ways to obtain our PCB

For the software, there were two criteria that mattered for this. Do we have experience in any of the software we've chosen? Does Iowa State offer it to us for free? Having experience with the software matters because it'll make the process much easier if we know how to use the software. ISU availability is also really important as it is convenient for us if we have access to the software without paying for it.

Software	Weight	Simulink	Comsol	Lumerical
Experience	10	8	4	0
ISU Availability	10	10	10	0
Total	20	18	14	0

Table 5: Optical Software Comparison

4.3 PROPOSED DESIGN

4.3.1 Overview

For our project we are making a magnetic field generator. The goal of our circuit is to run electricity through a coil of copper wire to generate a magnetic field. For this circuit we have many key components. We used basic circuit elements such as resistors to limit the flow of electricity and capacitors to increase the max current flow. We use a MOSFET transistor to switch our circuit on and off, which allows us to control the timing of the magnetic field with a voltage pulse source. This circuit will be used to magnetize magneto-optic material and will be used in the optical switching systems in wifi routers. Our goal is to reduce the switching speed of the magnetic field generation to 100 ns, and create a Printable Circuit Board (PCB) to place our circuit on.

4.3.2 Detailed Design and Visual(s)

For the Magnetic Field Generator (MFG) portion of our project, we are creating a class 1 MFG capable of reaching our peak circuit current in less than 100 ns. Our design has been limited in many ways by our client. We must use a 15 VDC source, create a magnetic field of 500 G, and solder our final design to a PCB no bigger than 3.5" x 2". A schematic of our circuit can be found in Figure 2.

In our circuit our two main components are the MOSFET and inductor. Starting with the inductor (L1), this component will be used to generate our magnetic field. It will be connected in series with our MOSFET (Q1), which will act as a switch to control the current flowing through the inductor. The goal of this circuit is to run as much current through the inductor as needed to produce the 500 G magnetic field. In order to create the large field, we will need an inductor large enough to generate the field, while also

being small enough to decrease the rise time below 100 ns. We will also run a current sensing resistor (R3) in series with the MOSFET to limit current flow, and allow us to measure the current in testing.

We will use a voltage generator to generate a pulse waveform (V2) to activate the gate of the MOSFET to initiate the current pulse through the inductor creating the magnetic field. The resistor R2 will act as a drain for the MOSFET gate to increase the charge dissipation of the gate, to decrease the circuit's fall time. Because the current going through our inductor will be larger than our VDC (V1) can handle we will be using large capacitors (C2 and C3) to supply extra charge for the duration of the current pulse. These capacitors will be recharged during the off period of the circuit. Lastly, we have the feedback loop featuring the diode (D1) and resistor (R4). This feedback loop will dissipate the backlash voltage induced by the inductor's resistance to voltage changes by allowing the backlash to flow to ground through the small capacitors (C1 and C4).

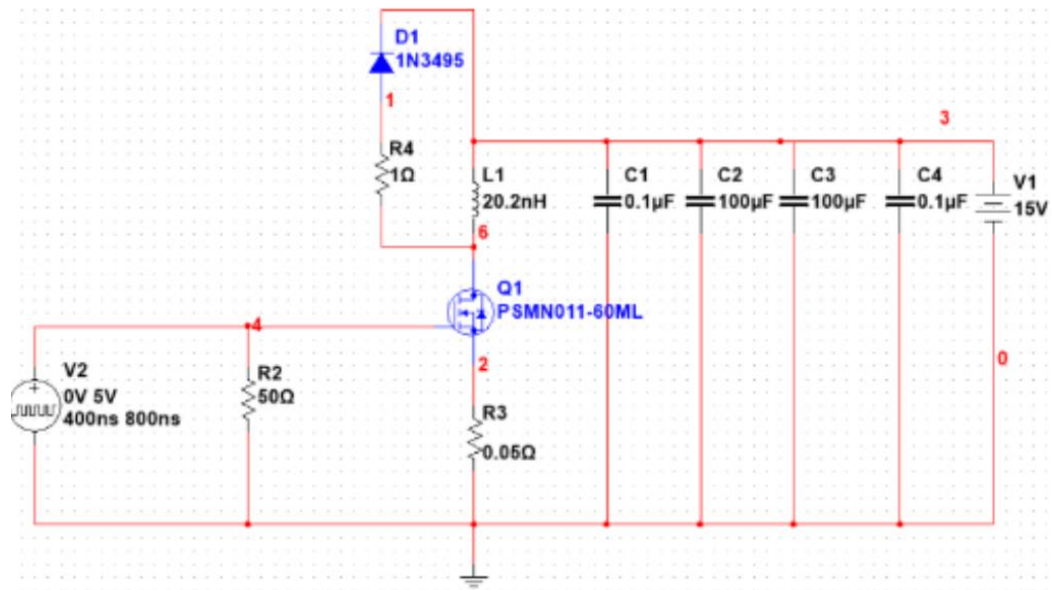


Figure 2: Schematic of MFG Circuit

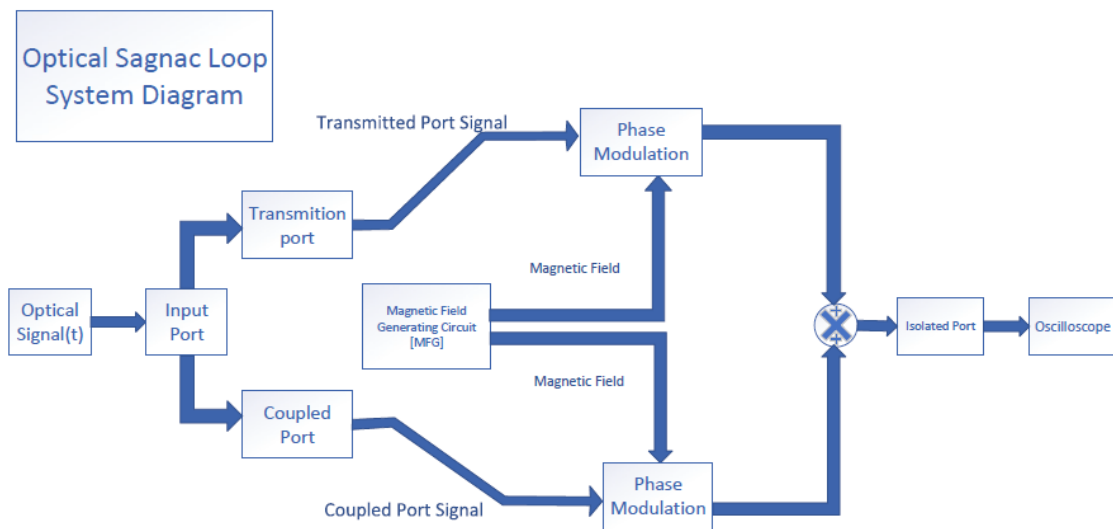


Figure 3: Optical Control System Diagram

As for the optical side of this project, we are currently attempting to create a simulation using Simulink and Comsol. In Simulink we will recreate our MFG circuit and try to convert the results into an optical signal (Figure 7). Because there is no good way to generate a magnetic field in Simulink, our team will be using Comsol to create a virtual inductor, and find the magnetic field density it produces (Figure 4). Hopefully, we will be able to use this simulation to better understand our optical system, and test it before building it next semester.

4.3.3 Functionality

This design is intended to be a single component of a router. Using the magnetic pulse generator, users will be able to generate electromagnetic pulses at high speeds for networks utilizing optical switching. This component would increase the speed of network processing in a router, creating a faster internet connection.

Our design would primarily be a component used by other companies for their products. This component would allow the router to linearly polarize incoming optical signals. This component allows the user to control the direction of the output. To summarize, the magnetic pulse generator would be implemented into the router allowing it to communicate at faster speeds. Then anyone that is connected to the router will have access to the internet at faster speeds.

4.3.4 Areas of Concern and Development

Our design meets the specifications that were given to us by our employer in simulations. We will still optimize our design until the end of the semester before we

initiate our build phase. One of our main concerns is power dissipation. We will be running high currents through our circuit which could cause overheating problems in some of our components, like the MOSFET. This could potentially destroy circuit components or even the PCB itself. Another concern we have is our implementation of our optical design, right now we are still researching how our magnetic field is going to interact with our optical components.

Overheating can be fixed by selecting more robust components that will allow us to handle larger power loads. The uncertainty with the optical portion of this project will hopefully be addressed in the coming weeks, by performing more research over break. We also plan on learning a new program over break to help confirm our results. We would be open to any advice from our client or advisors on potential problems with our initial design.

4.4 TECHNOLOGY CONSIDERATIONS

For our magnetic field generating circuit the main technology we rely on is a transistor. The transistor will be used as a switch to control the current flow through our inductor. There are many types of transistors, MOSFETs, BJTs, IGBTs, and for our circuit we decided to use a MOSFET. The main reason we chose a MOSFET was its high frequency switching capability. While BJTs and IGBTs are mainly used in high power situations, they lack the ability to achieve quick rise times. Another decision will be the type of MOSFET we choose. There are thousands of different designs for MOSFETs, and choosing just one will be difficult. We will need to consider dozens of different design parameters when choosing our device. Many different designs will be useful for our project and we will need to evaluate which one will be best for our purposes.

4.5 DESIGN ANALYSIS

So far in our project we have created a MFG Circuit in NI Multisim, an optical design in Simulink, a 3D inductor model in Comsol, and created a potential circuit on a breadboard. We have also simulated multiple different MOSFET's in our MFG circuit design. We have yet to decide upon a final MOSFET for our circuit. On top of the MOSFET choice, we also were testing different inductor values in Multisim that would work with our MOSFET selection.

Our proposed design from 4.3 does function properly. We have simulated it multiple times in MultiSim, and have even built a mock design on a breadboard. While many of our MultiSim simulations have met all of our specifications, due to multiple constraints, like available equipment, we have yet to create a breadboard test that meets all specifications. The main reason for this is that we are still designing and looking for primary circuit components: MOSFET and inductor. For the future we plan to keep experimenting and exploring different MOSFET's and inductors that can help us achieve our project requirements. Once we have selected our final components, we will order them to perform a breadboard test of our final circuit design. After we get a successful breadboard test that meets all specifications, we will import our circuit onto a PCB to use in our optical system.

5 Testing

5.1 UNIT TESTING

The main unit being tested in our circuit is our inductor. Specifically, we will be testing the magnetic field being created by our inductor. To test our magnetic field, we can do a couple of different methods. We can first simulate our inductor in a program called COMSOL. Which is a physics focus simulator that allows you to make multiple different types of physical components. While using COMSOL we can make our inductor and run a constant current through it to calculate our magnetic flux density (Figure 4). Before we test our magnetic field though we first have to make sure we have a constant stream of current running through our inductor. We can test this by hooking our circuit up to an Oscilloscope. We need to get a good steady current through our inductor to get a proper magnetic field. One other part of our circuit we are testing is our rise time.

5.2 INTERFACE TESTING

The interfaces used in this project consist of MATLAB, Multiphysics Comsol, NI Multisim, and KiCad. MATLAB sub-program called Simulink, which is a software that can handle or utilize large optical simulations and large-scale calculations. We also needed software that can verify/show our electromagnetic and optical portion of our system. Comsol can handle these various things to make the visualization feasible which was the main thing being tested. There was other optical simulation software such as Lumerical, but Comsol was the only software available to Iowa State University that was compatible with our needs. We needed software to verify our circuit design portion of the project that can handle all the parameters reasonably. Since we were already familiar with NI Multisim and it meets the requirements of the basic circuit design portions, simulating the currents and voltages of the circuit. While LTSpice can achieve a similar outcome, our unfamiliarity with the program made us go with Multisim.

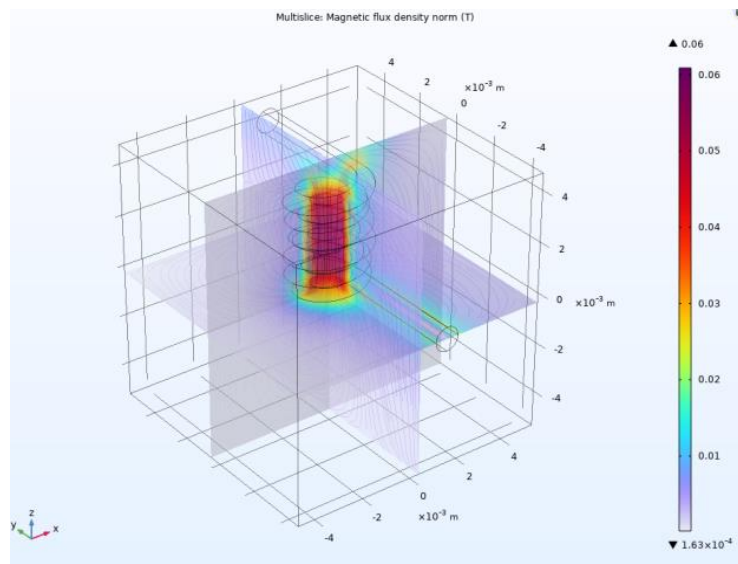


Figure 4: Magnetic Flux Density of Inductor

5.3 INTEGRATION TESTING

The start of our testing starts with our Multisim simulation. In Multisim we can first test the fundamentals of our circuit. We use Multisim to primarily test our rise time, and current draw from our inductor. We also tested both of these parameters through our breadboard testing. Which allows us to get a more realistic view of our current draw and rise time. One challenge in breadboard testing is measuring the magnetic flux density. We are currently looking into options, but it is not an easy task. One idea is to use a gauss meter, but we have not verified that this device will measure the exact value we are looking for. We can approximate the magnetic flux density using mathematical calculations.

$$B = \frac{\mu NI}{\sqrt{l^2 + 4r^2}}$$

B - Magnetic Flux Density

N - Number of Turns

I - Current

l - Length of the Inductor

r - Radius of the Inductor

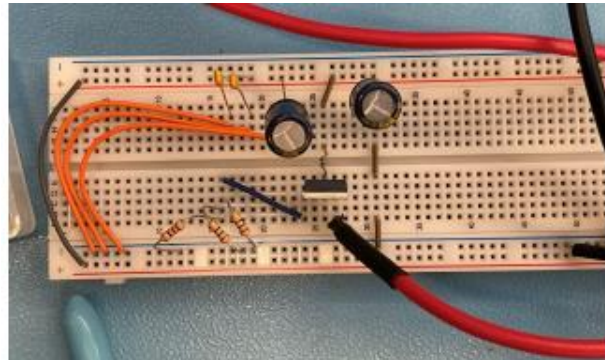


Figure 5: Breadboard Testing

5.4 SYSTEM TESTING

We can test our project using a variety of methods. For example, to test the magnetic field being created by our inductor, we can simulate the magnetic field in a program called COMSOL. COMSOL is a program that primarily focuses on the physics simulation of whatever item you are testing. If we want to test the magnetic field of the inductor, we would use COMSOL to run a simulation where we can have a current constantly flowing through the inductor, this way a magnetic field would be generated so we could measure it. Afterwards, to test the actual product itself, we would use the oscilloscope to measure the voltage across the resistor in our circuit. We can then derive the current waveform using Ohm's Law. Once we get a good steady current flowing through the inductor, we would then use another device known as the Gauss machine to test our magnetic field that is being generated by the inductor.

5.5 REGRESSION TESTING

We are ensuring that new additions don't break the old functionality by first taking the changes that we want to implement through Multisim. This means that any components that we are adding and or changing will first be simulated and verified that everything runs as expected with no errors. On top of the new changes, we might make we must still make sure that we are fulfilling the requirements of getting a peak circuit current of less than 100 ns and a magnetic field of 500 G. Once the simulation is correct and no issues are seen we will then implement the circuit onto a breadboard where we will test the circuit for the circuit current and the magnetic field. We will be using an oscilloscope to measure the current through the inductor and to find the magnetic field. Simulink and Comsol are being used for our optical side of the project, but we have not started hands-on testing so the process of new additions is much easier. We don't have to worry about breaking old functionalities because since our changes are simulated through Simulink, we will be able to get the results back within seconds and can alter design, if need be, without hassle. Similarly, when measuring the magnetic field in Comsol we can adjust components and if we run into an issue, we can alter them accordingly in-order to still get our expected results. In both of these simulations we still must make sure that we are abiding to the requirements and not breaking them.

5.6 ACCEPTANCE TESTING

For our project, we have very specific standards that need to be met for our design. For functional requirements, we must generate a magnetic flux density of over 0.05 Tesla, use a voltage source no greater than 15V, and create a circuit with a current rise time of less than 100 ns. For non-functional, we will have to solder our parts to a PCB no bigger than 3.5" x 2". All of these factors can be measured using various equipment: gaussmeter, oscilloscope, and ruler. Using such equipment, we can compute if we have reached our specific goals, or if more work is needed. We are also in weekly contact with our client, so as the project continues these requirements could change depending on our results.

6 Implementation

6.1 ZVS DESIGN

To start the second semester, we decided to improve our design further by implementing ZVS into our MFG design. ZVS is a technique to reduce the power loss from the MOSFET to prevent overheating and increase efficiency. We spent several weeks researching ZVS at the beginning of the semester and ended up using the design in figure 4. Our new design removes the feedback loop and instead dissipates the inductor's energy into the capacitor C4. This significantly reduces the power spike on the drain of the MOSFET which reduces switching losses. We also increased the series resistance of the circuit which will decrease the conduction losses within the MOSFET. This new circuit will also inherit the design constraints of the previous circuit and we plan to compare the two designs in the testing phase of the project.

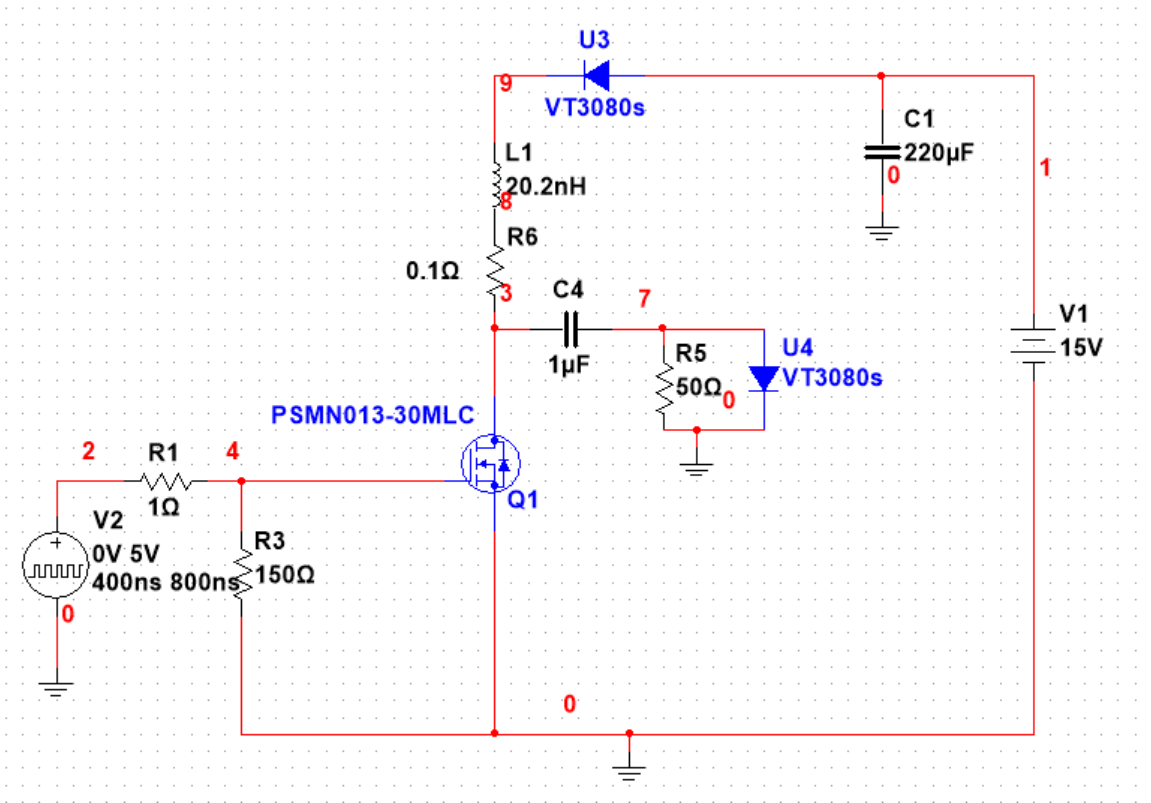


Figure 6: Multisim Implementation ZVS Circuit

6.2 BILL OF MATERIALS

Item	Manufacturer Number	Quantity	Price
MOSFET	CSD18504KCS	1	\$1.79
Resistor (100)	RR01J100RTB	2	\$0.64
Resistor (400m)	MP9100-0.40F-ND	4	\$64.80
Resistor (150, 1)	ETG	1/1	N/A
Diode	SBM1045VSS AY 00001	2	\$1.06
Terminals	ETG	3	N/A
Capacitor	ETG	3/1/2	N/A

(100u, 1u, 100p)			
PCB	JLCPCB	1	\$30.12
Total			\$98.41

6.3 PCB DESIGN

Once we were satisfied with our circuit design and parts selection, we started designing our PCB in KiCad. We decided to make two PCBs for this project to compare our two designs. The first PCB would be of our original MFG design and the second is the ZVS design. We added screw terminals to measure the voltage across our voltage sense resistors to make testing easier. Both boards were designed to meet the size constraints of 3.5" x 2".

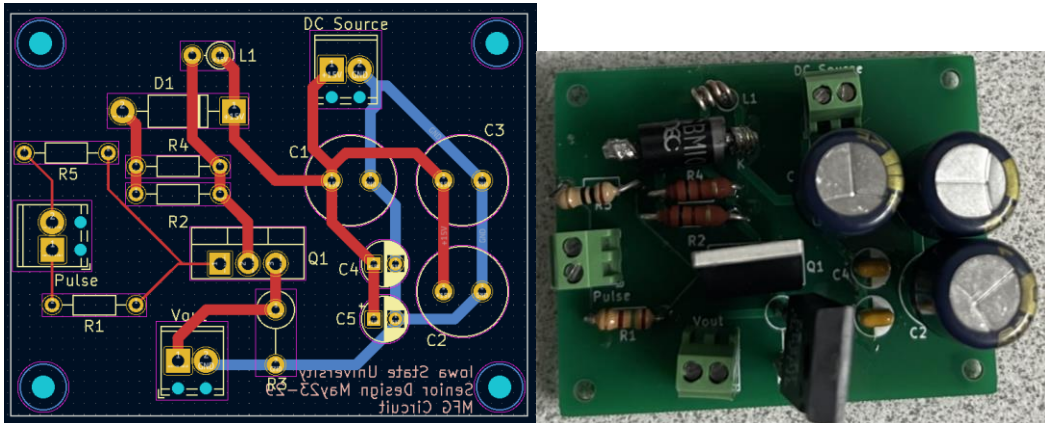


Figure 7: MFG Design

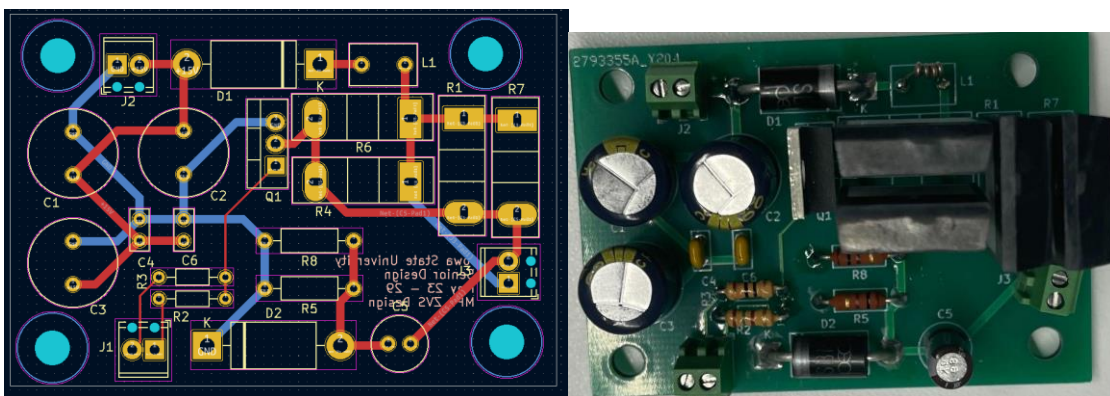


Figure 8: ZVS Design

6.4 FINAL PRODUCT RESULTS

After completing our PCB, we tested the final product to see if it met our specifications. We started by testing our MFG circuit. We measured the voltage across

the 0.05Ω resistor at various frequencies. For 1.25 kHz input we measured a current of 42.2 A, giving us a calculated Magnetic Flux density of 508 G. We also measured the rise time to be 96 ns. As we increased the frequency, the waveform continued to decrease in quality. Around 1 MHz the feedback on the circuit started to transfer over to the next pulse. Because of this the limit on this circuit is around 1 MHz.

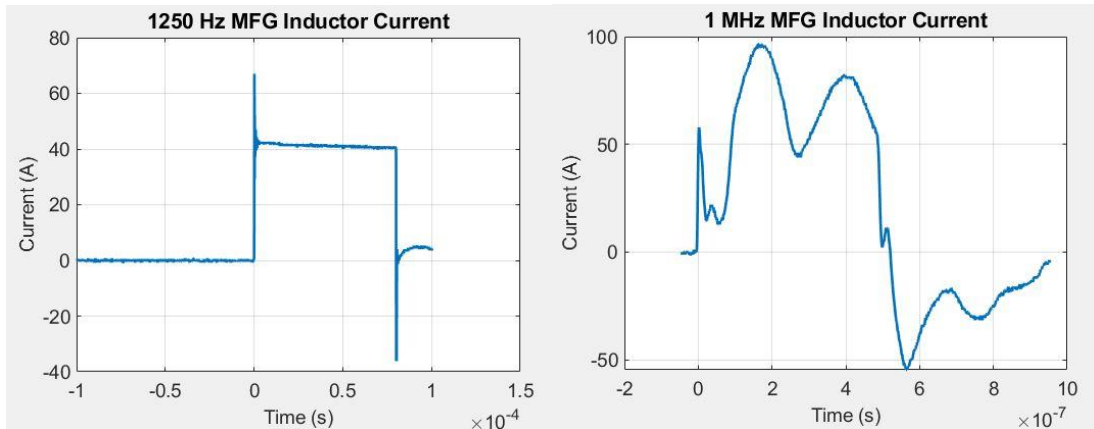


Figure 9: MFG Inductor Current

Next, we tested our ZVS circuit. We measured the voltage across the 0.1Ω resistor. Because neither side of the resistor was grounded, we had to measure both sides of the resistor and find the difference between them. We used MATLAB to perform the calculations. At 1.25 kHz we found the rise time to be around $1 \mu\text{s}$. This is much slower than our expected rise time. Another flaw with the waveform is that the current did not remain constant throughout the pulse, peaking around 50 A. As we increased the frequency the quality of the waveform remained constant. As we approached 1 MHz the rise time exceeded the pulse width which resulted in a decreased maximum current.

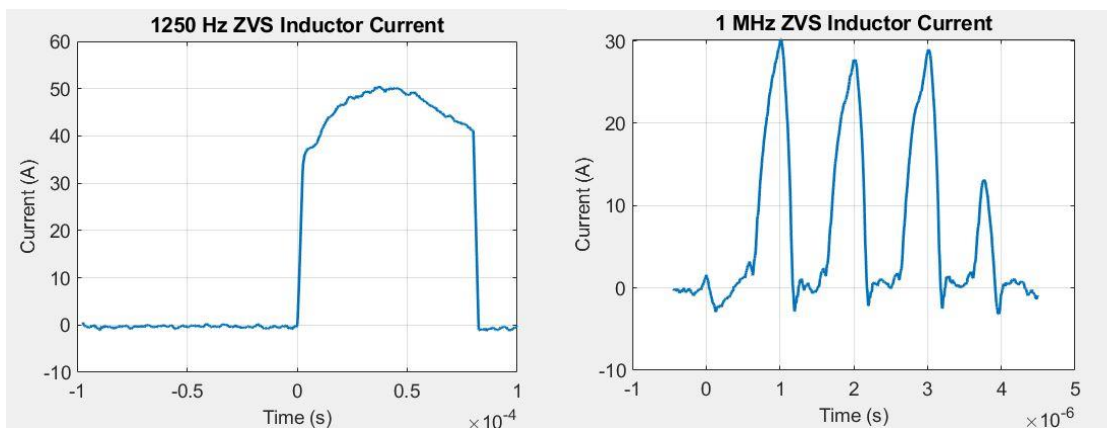


Figure 10: ZVS Inductor Current

Overall, our results were a success. We were able to make a MFG circuit that met our clients' specifications. While our ZVS design did not meet the rise time requirements, it did reduce the feedback after the fall time. The ZVS circuit also kept its signal integrity at higher frequencies while the MFG circuit did not. We showed that the ZVS circuit has the potential to surpass the original design with its ability to operate at higher frequencies.

6.5 MATLAB MACH-ZEHNDER SIMULATION

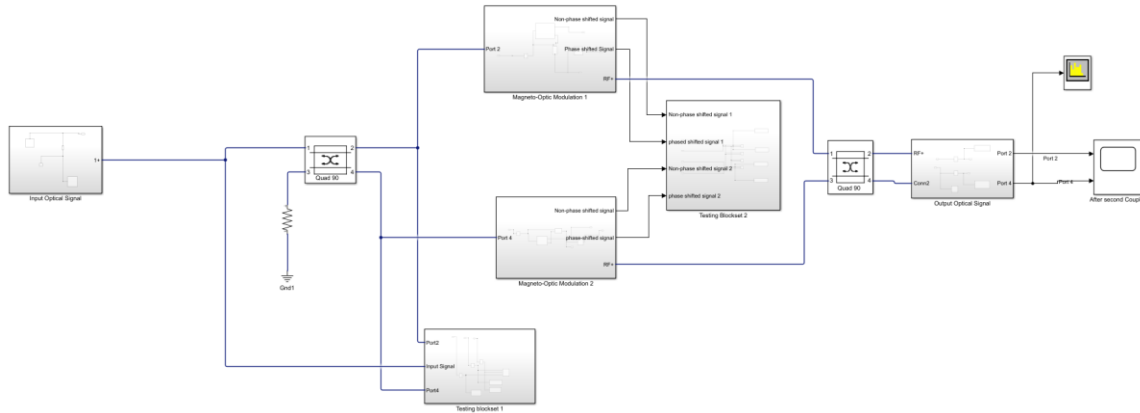


Figure 11: Mach-Zehnder Model

The original goal of the start of the semester was to design an optical system that could simulate the overall system and visualize the effects of the magneto-optic effect on our idealized signal. By utilizing the RF Blockset within MATLAB, we were able to accomplish our goal of using MATLAB to simulate the overall system and configure the RF Blockset for the uses of optics. From the start of the project, there was a learning curve on how to utilize simulink to the purposes of this project and to obtain correct values. The first semester and half of the second semester were researching optics and electromagnetism. The system utilizes a 1550 nm wavelength input and then is phased shifted based on the magnetic field density, the material, and the length for the magnetic field. We were originally tasked with making the Sagnac Loop in MATLAB, but were altered to make a Mach-Zehnder configuration instead due to implementation time constraints and lack of research. However, we were able to make a functional optical simulation for a Mach-Zehnder loop in MATLAB. We chose to make polar plots and 3-D plots for the simulation results as this is the easiest way to depict the changes and understand how the simulation works.

The RF Blockset in MATLAB breaks the signals into an inphase signal and quadrature signal. As such, using this complex band to create plots to show the phase shifted signals in results below. Ports 1 and 2 correspond to the inputs into the couplers, while ports 3 and 4 are the outputs to the couplers. The simulation computes a 36-degree phase shift for the simulation. This angle does not correspond to what the faraday rotator angle will be generated from this circuit. This is just an example and proof that the MATLAB RF simulation can be used for optical simulation of this project.

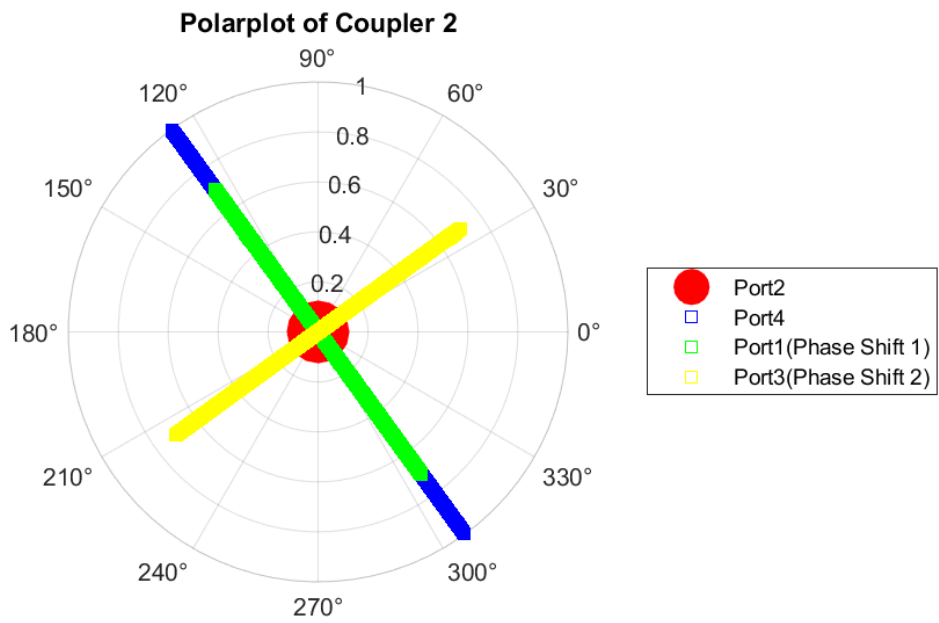
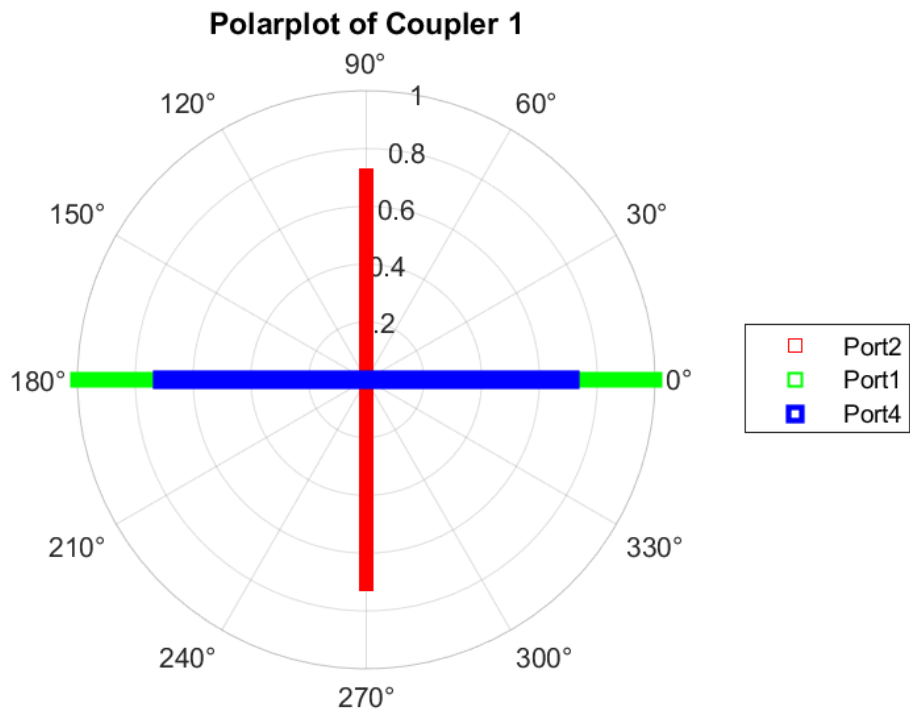


Figure 12: Polar Plots of Coupler 1 and 2

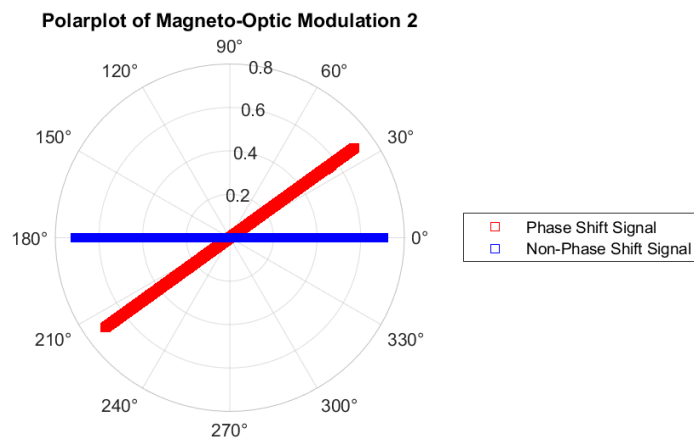
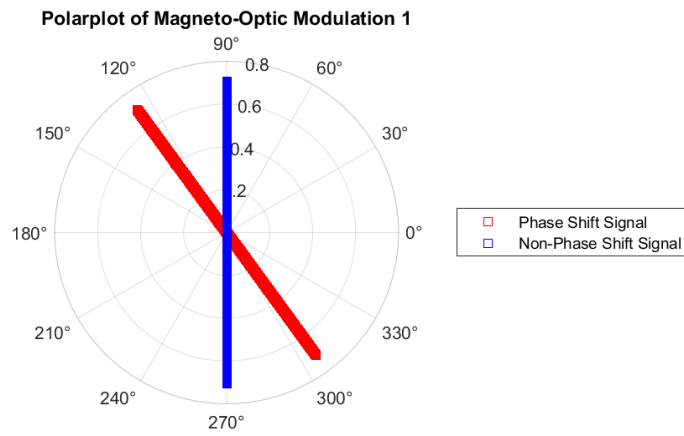


Figure 13: Polar Plots of Magneto-Optic 1&2

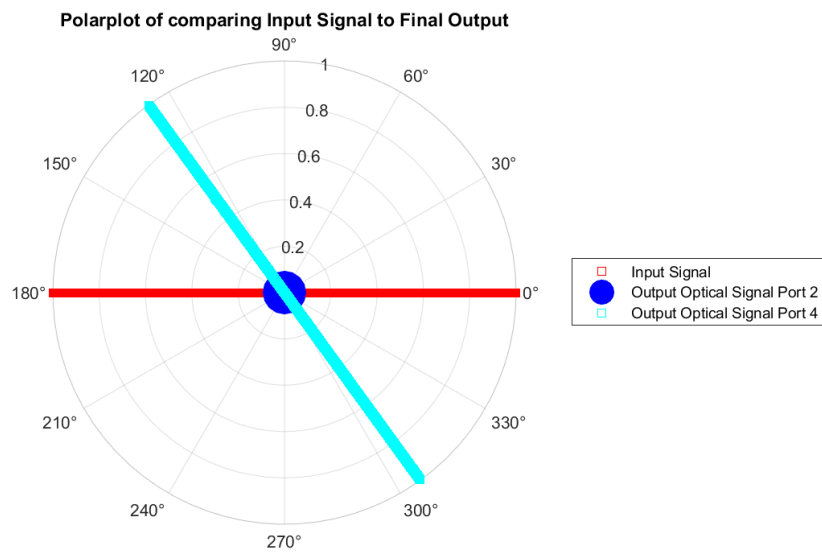


Figure 14: Polar Plot of comparing input signal to final signal

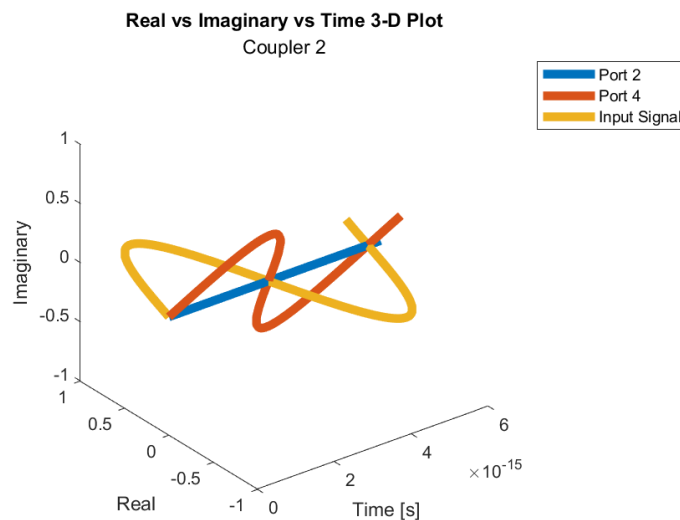
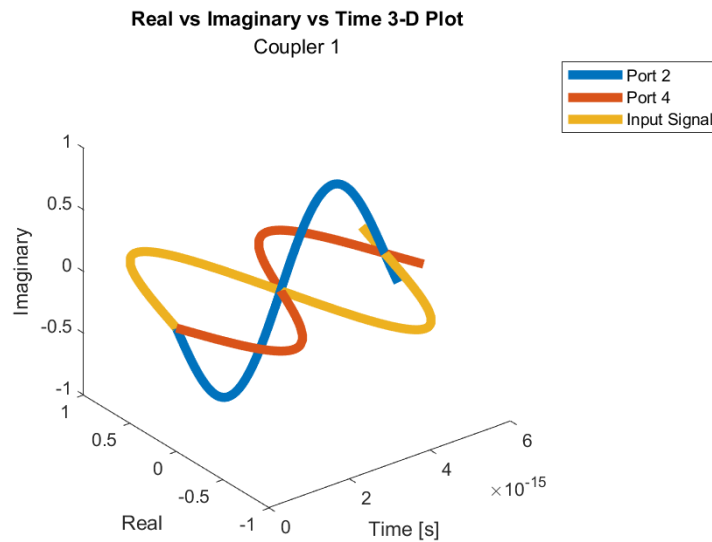


Figure 15: 3-D Plot of Coupler 1&2

6.6 COMSOL 2D SPIRAL COIL

For this semester we were given the task of designing and implementing two planar spiral coils. We were exploring different and potentially new ways that we can implement a coil into our design and a much smaller scale. In order for us to accomplish this we spent weeks of research on possible ways to model a spiral coil in COMSOL. After extensive research and multiple weeks of errors, we were able to create a 2D model as you can see in figure 16. On-top of creating the model we also wanted to view the magnetic flux density of the two planar spiral coils as shown in figure 17.

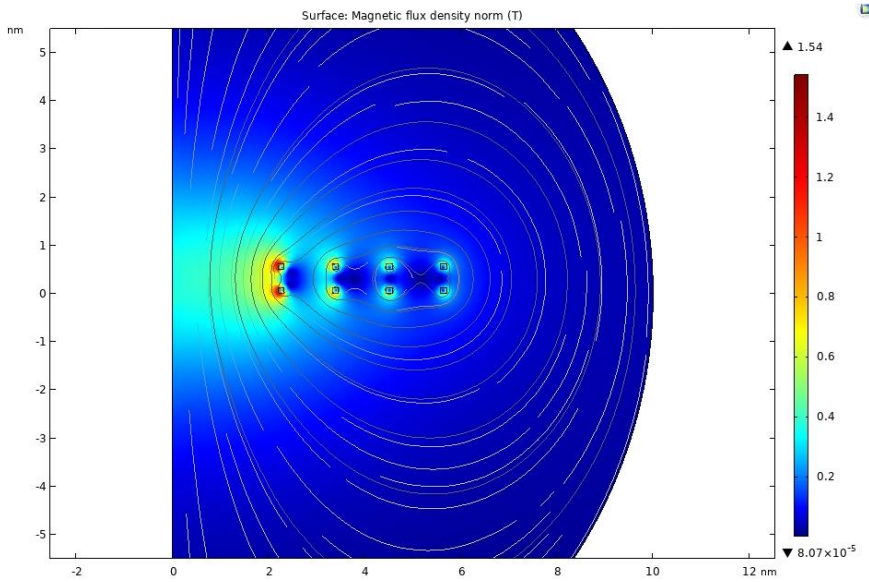


Figure 16: 2D View of Coils in COMSOL

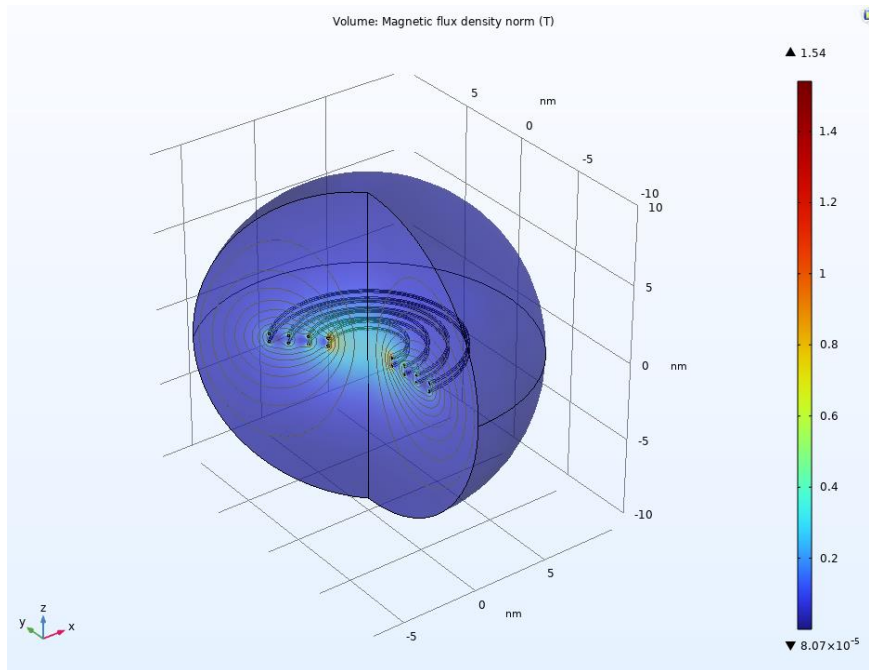


Figure 17: Magnetic Flux Density of two spiral coils in COMSOL

7 Professional Responsibility

This discussion is with respect to the paper titled “Contextualizing Professionalism in Capstone Projects Using the IDEALS Professional Responsibility Assessment”, *International Journal of Engineering Education* Vol. 28, No. 2, pp. 416–424, 2012

7.1 AREAS OF RESPONSIBILITY

Area of Responsibility	IEEE Code of Ethics
Work Competence	Engineers need to make sure that they are competent in technical knowledge for others but they also need to fulfill the necessary training/experience required for the positions.
Financial Responsibility	To make sure that they do not conduct themselves within bribery or other unlawful activities.
Communication Honesty	To be honest with their work and accept when they make mistakes or errors with realistic scenarios.
Health, Safety, and Well being	To make sure that they are not harming others in both being, property, or reputation.
Property Ownership	Make sure that the property is safe and uphold ownership.
Sustainability	Maintaining emerging technologies and upholding capabilities of technologies as an engineer.
Social Responsibility	Taking care of the public with various practices and to inform the public of possible dangers.

7.2 PROJECT SPECIFIC PROFESSIONAL RESPONSIBILITY AREAS

Area of Responsibility	Level of Performance
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Work Competence	Medium, We were paired with a project that wasn't within our expertise but we have been putting the effort to make up for our lack of expertise. For example, The coupler in our design is out of our expertise but we have been reading about and researching it.
Financial Responsibility	Low, we haven't made a bill of materials yet for how much the components will cost.
Communication Honesty	High, we have been constantly telling our client on what works and what does not work in terms of simulations. We have also been communicating when we can or cannot do something.
Health, Safety, and Well being	Medium, we have been testing our circuit and have blown components. It is still a work in progress.
Property Ownership	High, we have not copyrighted anything or done anything outside the bounds of research and integrity.
Sustainability	High, we have been working with new software that has been recently available and learning the ins and outs of it.
Social Responsibility	Low, we haven't considered the public within our project so this is low simply because we haven't done anything relating to social responsibilities.

7.3 MOST APPLICABLE PROFESSIONAL RESPONSIBILITY AREA

Our group believes that Work Competence is the most applicable area for our project. Without understanding the material of the project, we wouldn't have been able to get anything done. So, it is our responsibility to understand the material relating to the project.

8 Closing Material

8.1 DISCUSSION

Our team has met our requirements on our circuit design requirements. Which are the following: Have a magnetic field strength of 500 gauss, a rise time of 100 through the current going through our inductor, with a voltage source of 15 volts. We also made progress on a new MFG design utilizing zero voltage switching. While this new design did not meet the requirements set by our client, it did show potential as a design to pursue with future groups. Lastly, we made the foundations of an optical simulation in MATLAB. This simulation features the Mach-Zehnder loop, but can also be implemented in Sagnac and Semiconductor Optical Amplification (SOA) loops.

8.2 CONCLUSION

As a team we were able to successfully create a working PCB and optical simulation. While we did struggle and experience failure, we pushed through to meet our clients expectations. Overall, we learned a lot about long term design projects and gained a deeper understanding of engineering knowledge along the way.

8.3 REFERENCES

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9 APPENDICES

9.1 Operation Manual

Here are step-by-step instructions for measuring the MFG/ZVS circuit using a DC power supply, Waveform generator, and oscilloscope:

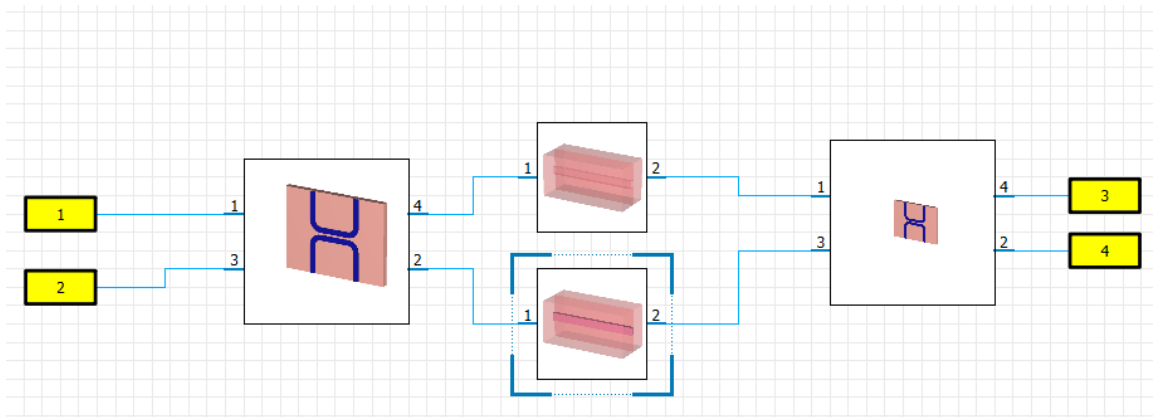
1. Turn on the DC power supply, waveform generator, and oscilloscope.
2. Attach three wires to the waveform generator: one wire on the 25-volt slot and 2 to ground. Attach another three wires to the waveform generator, same colors. Finally, attach two measuring probes to the oscilloscope.
3. Make sure the Waveform generator is set to High Z and in square-waves.
4. Set the waveform generator's voltage to 8 volts peak-to-peak and set the delay to 10% for 1.25kHz and 50% for 1MHz.
5. Hook the wire connected to ground from the waveform generator to your designated ground port on the breadboard.
6. Attach the positive and negative voltage source wires from the waveform generator to the positive and negative slots on the pulse wave block on the PCB.
7. Repeat step 6 with the DC power supply by attaching the red and black wires to the positive and negative side of the DC source block.
8. Grab any two wires and insert them into the Vout block on the PCB. Insert the other ends of the wires onto the breadboard.
9. Grab one or two probes (depending on what circuit you're measuring) and insert them next to the wires you inserted from step 8 from the PCB to the breadboard. Make sure to ground the probes as well.
10. Once everything is in place on the PCB and breadboard, set the oscilloscope to single.
11. Run the waveform generator and turn it off afterwards
12. Your results should appear on the oscilloscope.

Notes: These instructions may vary depending on the specific circuit and equipment you are using. Please follow the manufacturer's instructions and safety guidelines when using the electrical equipment.

9.2 CST Exploration

We explored the possibilities of using CST to help make a more realistic simulation of our Mach Zehnder Loop. We were unable to make a full development of our Mach Zehnder loop. There is a large potential to make our project into this program. With more knowledge on making waveguides and couplers our design would have been completed. Some of the components that we would need in order to create our Mach

For the coupler the main hiccup we had with the design was trying to understand how the different frequencies affect the specifications of the device. This goes with understanding the waveguide as well since making a 3D waveguide to our high-speed frequency ended up breaking the device. This might be due to a low amount of coddling between the devices. In figure 18 you will find an ideal set up for making our Mach-Zehnder loop in CST.



Mach-Zehnder loop would be the following: waveguides, couplers, and a magnetic optical material.

Figure 18: Mach-Zehnder Loop in CST

9.3 Team Contract

Team Members:

- 1) William Nichols
- 2) Steven Huynh
- 3) Umair Sarwar
- 4) Andrew Murphy
- 5) Michael Lopez

Team Procedures

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

Friday, 12:00-1:00 via Webex.

2. Preferred method of communication updates, reminders, issues, and scheduling (e.g., e-mail, phone, app, face-to-face): **E-Mail for informing the group and the clients. For just the group members we will use a snapchat group.**

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): **Each person will log their minutes individually through a google sheets document.**

Participation Expectations

1. Expected individual attendance, punctuality, and participation at all team meetings:
2. Expected level of responsibility for fulfilling team assignments, timelines, and deadlines: **All team members to meet all deadlines on all assignments.**

3. Expected level of communication with other team members: **Keep regular updates in the group chat of each team member's progress in the snapchat group mentioned above.**

4. Expected level of commitment to team decisions and tasks: **All team members are expected to participate in every team decision.**

Leadership

1. Leadership roles for each team member (e.g., team organization, client interaction, individual component design, testing, etc.): **Team Organization will be done by William Nichols, Client interaction will be done by Steven Huynh, Individual component design will be done on a case by case basis. Testing will be done by Michael Lopez and Umair Sarwar**
2. Strategies for supporting and guiding the work of all team members: **Team members will be supported throughout the entirety of the project.**
3. Strategies for recognizing the contributions of all team members: **Showing the minutes each person has worked on their individual parts of the project, as well as putting in what team member names to what they contributed to each section of the project.**

Collaboration and Inclusion

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

Umair Sarwar - Skilled in programming, simulink, electromagnetism, and COMSOL

Michael Lopez - Skilled in Control Systems, MATLAB/Simulink, Programming, and Signals

Steven Huynh - Skilled in Programing, simulink, had a summer internship for 2022

William Nichols- Skilled in circuit design and power system software PSS/E

Andrew Murphy - Skilled in circuit design with experience at two summer internships.

2. Strategies for encouraging and support contributions and ideas from all team members:

Helping them with their projects and showing them resources they could use to help guide them.

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?) **If any team member has concerns they will bring them up during team meetings.**

Goal-Setting, Planning, and Execution

1. Team goals for this semester: **What the client wants us to accomplish**
2. Strategies for planning and assigning individual and team work: **This will be discussed during client meetings.**
3. Strategies for keeping on task: **Strategies will be implemented by what works best for each individual team member.**

Consequences for Not Adhering to Team Contract

1. How will you handle infractions of any of the obligations of this team contract?
Rebellious team members will be approached by the team and advisor to discuss potential problems.
2. What will your team do if the infractions continue?
If more action is required, the team will approach the 491 professor for appropriate response.

- 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) William Nichols DATE: 11/29/2022
- 2) Umair Sarwar DATE: 11/29/2022
- 3) Steven Huynh DATE: 11/29/2022

4) Andrew Murphy DATE: 11/29/2022

5) Michael Lopez DATE : 11/29/2022