Fast, Compact, High Strength Magnetic Pulse Generator Project Plan 2

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1 Definitions

In the final revision of this document, there will be a comprehensive definition of terms to be included in this section.

2 Abbreviations

AC - Alternating Current

CAD - Computer-Aided Design

DC - Direct Current

LED - Light-emitting Diode

MO- Magneto-Optic

MOSFET - Metal-Oxide-Semiconductor Field Effect Transistor

PCB - Printed Circuit Board

TMS- Transracial Magnetic Stimulation

3 Introduction

3.1 Problem Statement

A solution for designing magnetic field generation devices for a small-scale, low power, and low cost has been difficult to achieve. Magneto-optic systems often use this form of technology as an alternative to a switch in optical communications. The switch required for these communication methods must be designed to be extremely fast and dynamic. The design of this switch to be integrated onto silicon-based technologies has become a challenge for our client.

3.2 Objective

In this project, we are designing and fabricating an electronic circuit to solve the stated problem for our client. This circuit will have a small coil that generates a pulsing magnetic field at very high amplitude very quickly. Our client is having difficulties in accomplishing this task with all design specifications included in the design.

4 System Description

4.1 Concept Sketch

Figure 1 shows a block diagram of the concept our team is implementing. This outlines our process of taking a DC source voltage to run through our circuit, which contains a magnetic pulse generator. This source voltage combined with the magnetic pulse generator will then create a one microsecond magnetic field pulse with strength of 500 Gauss.

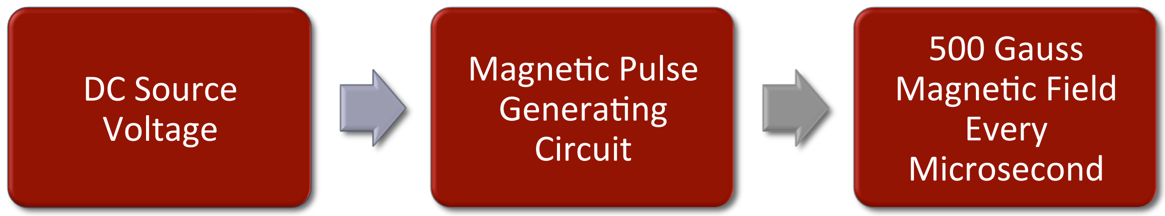

Figure 1: Block Diagram of Concept

4.2 Systems Level Diagram

Figure 2 shows the process our design team has cycled through to meet design specifications.

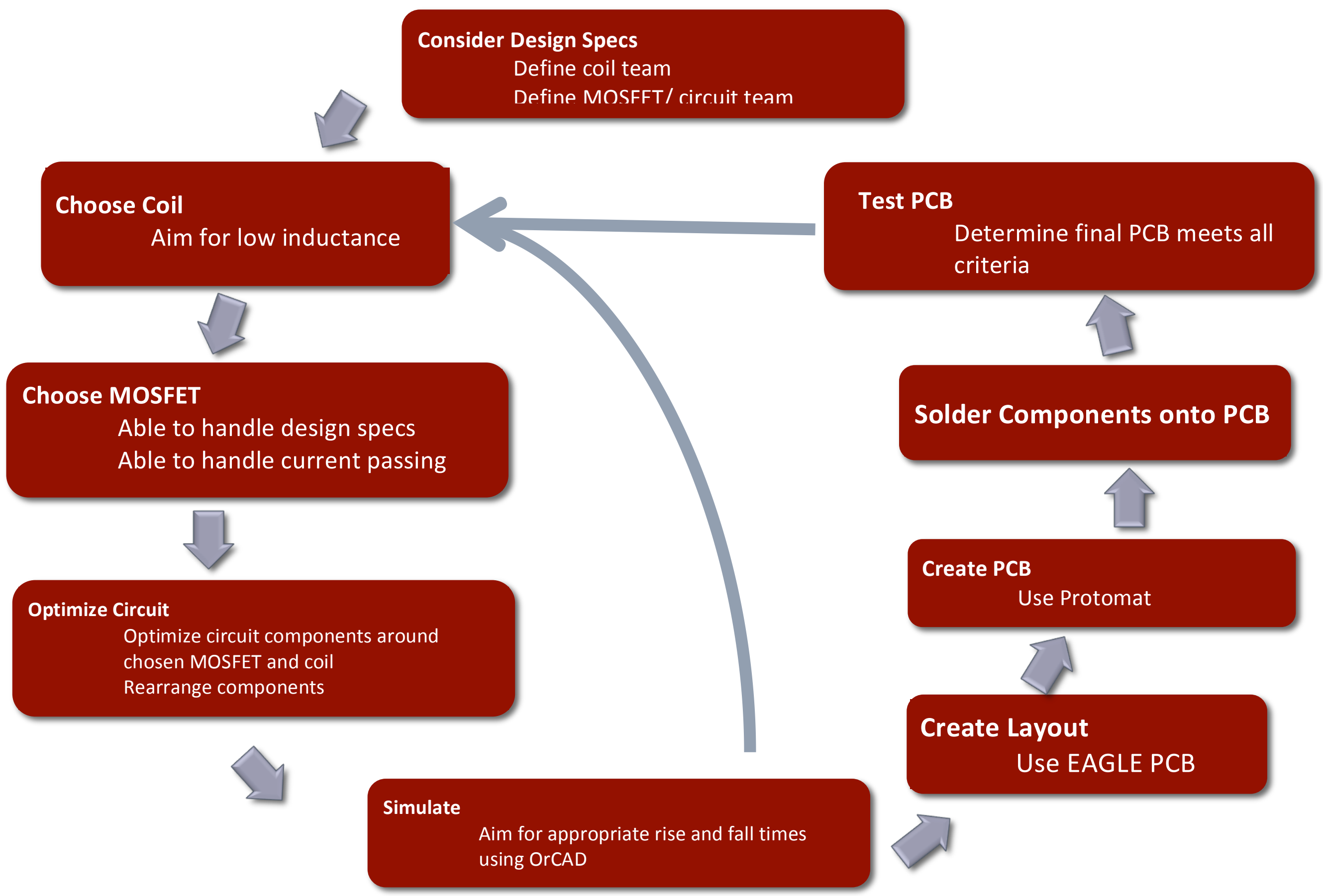

Figure 2: Systems Level Diagram

4.3 Process Details

In the next few sections, the design details for our previous project version, present project version, and future stages are explained.

4.3.1 Blinking LED

4.3.1.1 Schematic

After creating a schematic that meets ours parameter requirements, we created a PCB. To do this, we used Eagle PCB software created by Cadsoft. Eagle provides a simple layout editor, which provides us a platform to easily design a board that can be fabricated. The schematic and layout of the circuit was transferred to a GERBER file to fabricate the physical circuit in the workshop. The GERBER file was uploaded to the Protomat S62 to create the physical printed circuit board. To test the circuit, the parts will be bought online through www.digikey.com. We then soldered the components onto the PCB and concluded the circuit did in fact produce a blinking LED. The LED can be replaced by an inductor to obtain a magnetic field.

The circuit below was implemented in Eagle PCB, which was used as the schematic (Figure 3) and layout platform (Figure 5) for testing purposes.

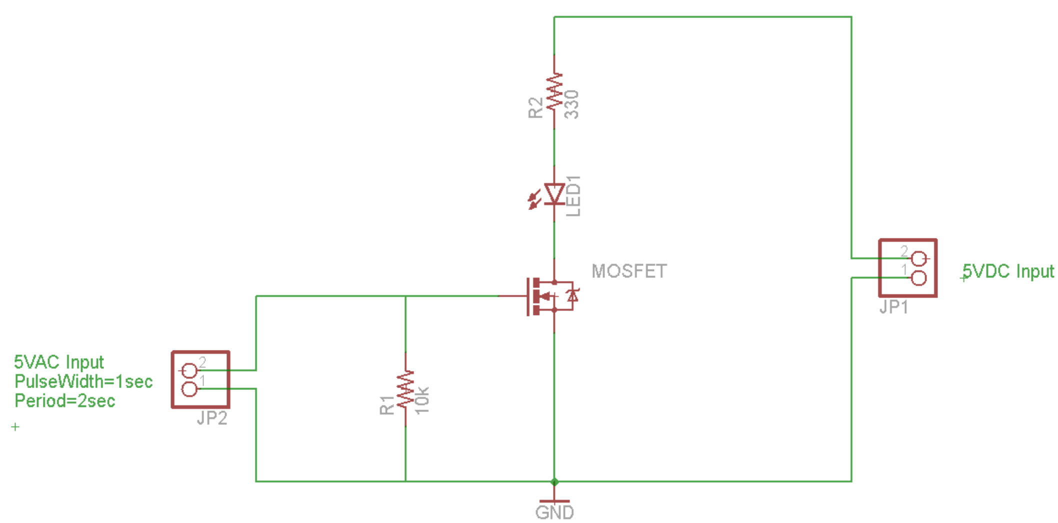

Figure 3: Eagle PCB Test Schematic

After future simulation and design, we concluded that this design will need to be more complex in order to meet requirements. Section 4.3.2 explains how we manipulated this design.

4.3.1.2 Computer-Aided Design & Printed Circuit Board

Figure 4 shows the layout of a basic circuit we used to test an LED blinking circuit with a SOT-23 packaged MOSFET. The circuit was shown previously in Figure 3. This was created using EaglePCB. The PCB pictured below in Figure 5 was created using the Protomat S62. This circuit will be very similar to the magnetic pulse generator circuit. Table 1 gives an accurate description of the PCB part. Figure 6 shows an image of the circuit components being soldered onto the PCB.

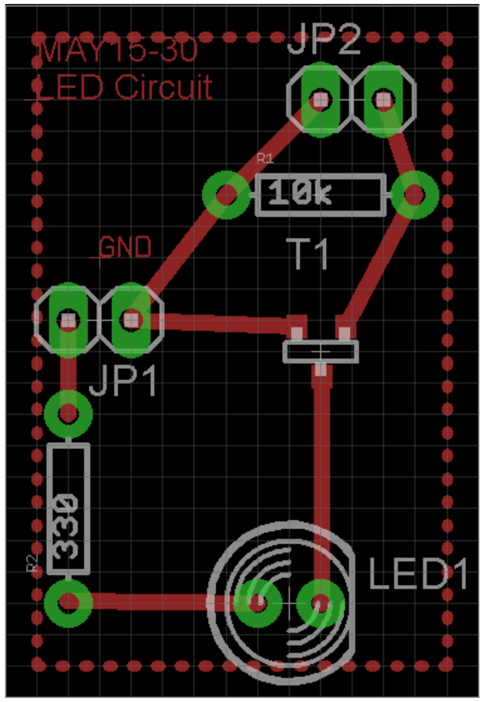

Figure 4: Eagle Layout

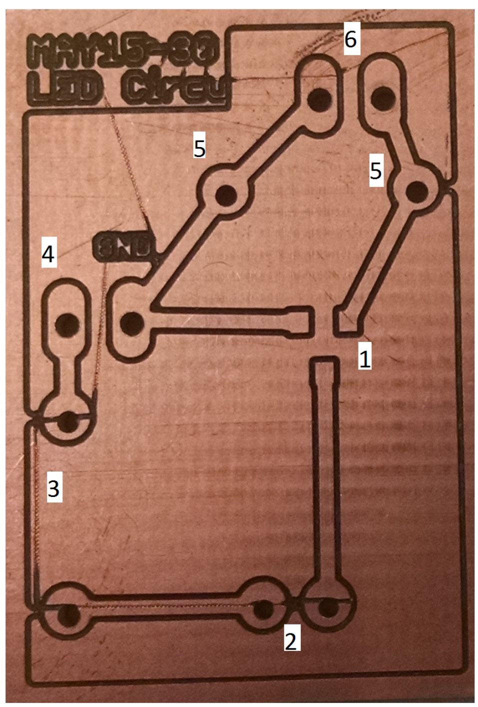

Figure 5: Protomat PCB Product

Table 1: Figure 5 Description

Item Number	Item Description
1	MOSFET SOT-23 Package
2	LED
3	330 Ohm Resistor
4	DC Input
5	10K Ohm Resistor
6	AC Input

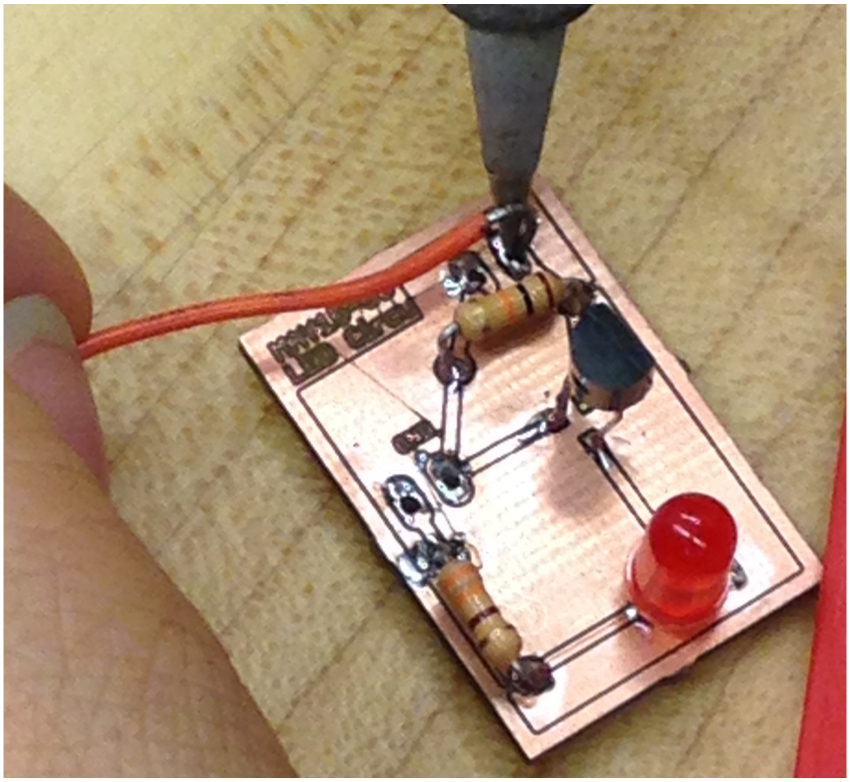

Figure 6: Soldering Components onto PCB

4.3.2 Current Protoype

4.3.2.1 Coils

The coil used in this project will have great impact on the final product. The coil's physical form will affect the inductance and fall time as well as other aspects of our circuit. For a coil design, a single short coil is being used for simulation. However, this may change to a Helmholtz design if we cannot achieve the fall time we desire for our circuit in future simulations. All specifications below assume we are using a single short coil design. Specifications include:

- Inductance generated by the coil must be low enough to allow for the 1 µs time restriction. The equation below shows the inductance (L) that the coil will create base on its physical features (length, radius, etc.)

$$L = \mu_0 \frac{N^2 * A}{l}$$

L - Inductance (Henries)
μ_0 - Permeability of free space ($4\pi \times 10^{-7}$ in m^2)
N - Number of turns in the coil (unitless)
A - Inner core area of the coil (πr^2 in m^2)
l - Length of the coil (meters)

- A soft MO material must be selected to be an inner core of the coil.

4.3.2.2 MOSFETs

A number of specifications are needed for the MOSFET in the design. For now, circuit simulations have consisted of one MOSFET. Calculations have proven that the current through the coil will be approximately 25 Amps. A MOSFET will be chosen based on the following:

- Drain to Source Voltage (Vdss) must be able to handle 15V or less
- Current channel must be able to handle the current load through the coil (approximately 25 Amps)
- Surface mount component

4.3.2.3 Simulation

OrCAD was used in the simulation and creation of the circuit. The MOSFET was chosen carefully as part PSMN0R9-30YLD from digikey.com. This MOSFET was chosen because it is the industry's first MOSFET to deliver the high frequency, low spiking performance usually associated with MOSFETs with an integrated Schottky diode. This MOSFET was designed for fast switching without having high leakage currents. Most importantly, this MOSFET meets design specs of being able to handle up to 15V and a large drain current in addition to being a surface mount component. In the final MOSFET selection we will have even more specifications to sort out.

Figure 7 shows two circuits on OrCAD that are similar to what our coil circuit will be. The only difference between the circuit on the right and the circuit on the left is the MOSFET. The circuit on the left the new MOSFET that we have chosen, and the circuit on the right has the MOSFET our team originally chose. After simulations and looking through the data sheets of various MOSFETs, we decided part PSMN0R9-30YLD was a better fit for our design.

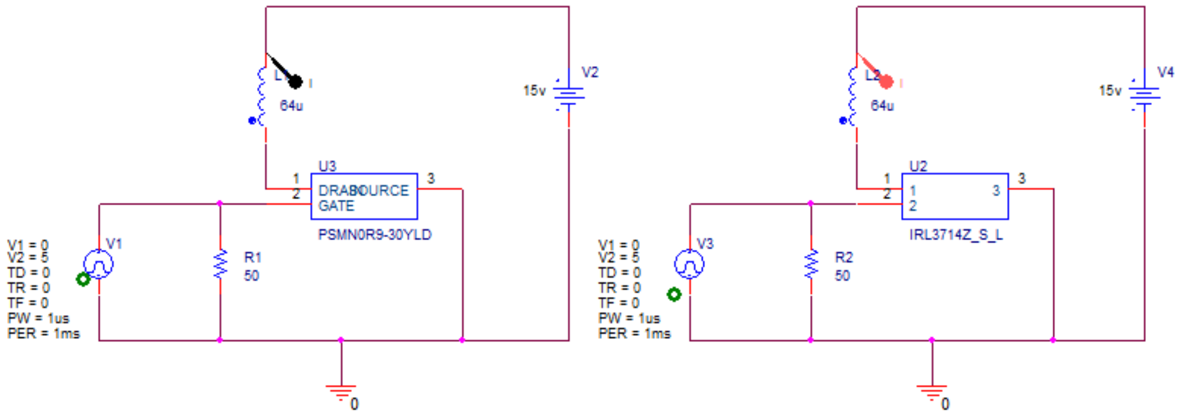

Figure 7: OrCAD Schematic

In Figure 8, a plot of currents through both inductors in the separate circuits is provided. For the new MOSFET, the pulses are visible as the black 14Amp pulses with a fairly sharp rise and fall time. Fast rise and fall times are central to the design of our circuit. The results for the old MOSFET can be viewed as the red line. You can see here that the red line has a lower peak value for current and also has a slower rise and fall time.

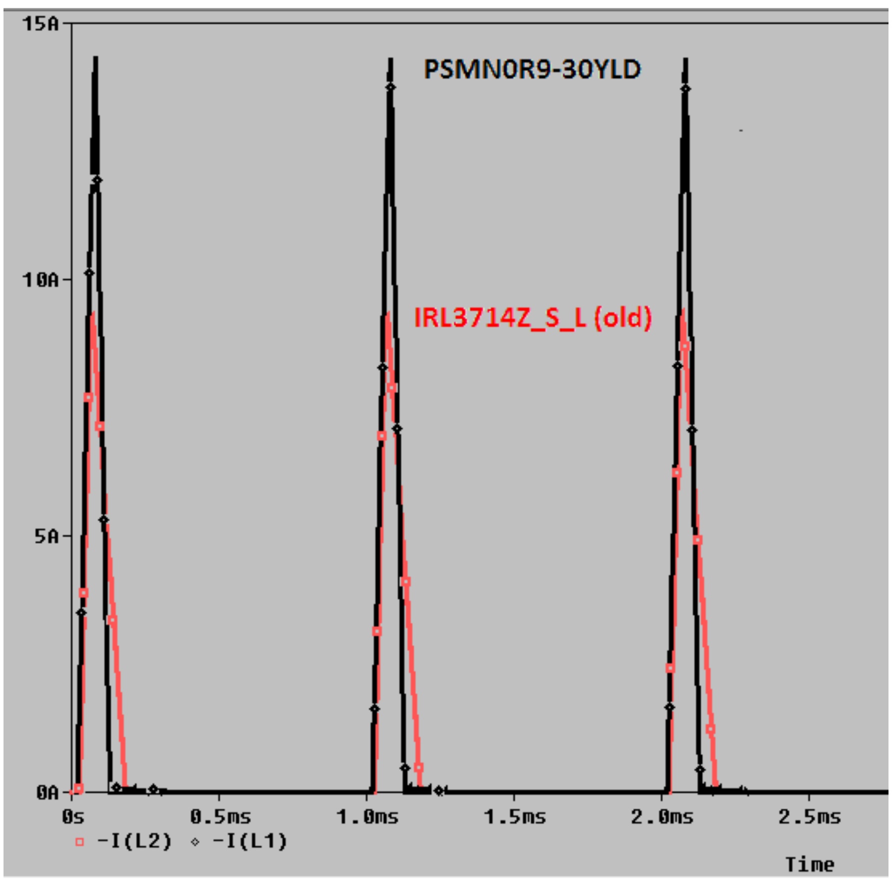

Figure 8: OrCAD Simulation

The next step for our current project version is to create a PCB for testing like we did with the blinking light circuit.

4.3.3 Future Project Version

In the future, we would like to explore how adding an MO material can improve the functionality of our circuit by assisting in creating a larger magnetic field. This may allow us to reduce our pulse width.

We will be updating our future circuit design with a large diode in parallel with the coil to prevent back EMF into the MOSFET. Capacitors will be added in series with our 15 Volt power supply to combat the inherent inductance of a long wire to a power supply and reduce switching time. We will also be adding a .25 ohm current testing resistor to have a way to test the current flowing through the inductor. This will be utilized to more accurately measure the magnetic field compared to a simple Gauss meter.

4.4 Functional Equipment

The only piece of functional equipment to be used in this project will be a function generator to produce a 15V DC supply.

4.5 User Interface for Marketable Applications

In terms of user interface for this project, we don't believe that we will require an input from a user in a marketable application. Once the PCB is hooked up to a power source, and the source is turned on, our circuit will do its job and generate magnetic pulses. We have discussed potentially inserting a switch in addition to the MOSFET we are using. It would be designed so that we could turn on the voltage source, and the circuit would only pulse if we flipped the switch (or pressed a button).

5 System Requirements

Our magnetic pulse generator is a simple notion that has two parts: a coil and a MOSFET that will act as a switch. While the idea is simple, the specifications make this project a challenge. Our team has divided up the work into a group working on the coil and a group choosing the MOSFET and circuit design. For the project to succeed, there has to be constant communication between the two groups. The physical specifications of the coil will affect the inductance of the circuit and, in doing so, will affect the fall time that the MOSFET (switch) will be able to give us.

5.1 Deliverables

5.1.1 First Semester

- Detailed design approach
- At least one prototype to show proof of concept

5.1.2 Second Semester

- Detailed design approach, schematic, and layout
- Professionally fabricated PCB with optional mechanical enclosure
- Precise project documentation
- Working final unit

5.2 Specifications

The new system designed during this project will be expected to meet the following criteria.

5.2.1 Functional Requirements

- Our circuit board will have dimensions of less than or equal to 3.5" x 2".
- The circuit must be able to create a magnetic field with strength of greater than or equal to 500 Gauss.
- The circuit must be able to generate the magnetic field every microsecond.
- We will use a DC voltage source of less than or equal to 15 Volts.

5.2.2 Non-functional Requirements

- In our final design, the circuit will be enclosed in some fashion.
- Our circuit design created in EAGLE PCB and tested will eventually be fabricated onto a PCB.
- Create a simple way to attach a DC voltage source to our circuit design.

5.3 Assessment of Proposed Solution

5.3.1 PCB Issues

As can be seen in Figure 5, the Protomat S62 damaged parts of the PCB by creating unpredictable, notched lines. After some required maintenance, our team will attempt to recreate the PCB damage free. If this cannot be attained in a prompt fashion, we will order the PCB from OSH Park (www.oshpark.com). By ordering from OSH Park the trade-offs made will be the time waiting for the shipment and cost, but in exchange the quality of the PCB will be higher.

5.3.2 Specifications Challenge

After completing the LED blink circuit and the first EMP generating circuit, we have a better picture of where we need to go, and what struggles we will be facing moving forward. From here on out, our goals are simply to optimize the circuit to meet the functional requirements. All of our calculations, to this point, have been in regards to meeting our field strength of 500 Gauss, so we believe we can easily meet this criteria. With this being said, we believe our biggest challenge is meeting the frequency requirement.

The variability in our project is high. The circuit can be designed using a wide array of coils. Our test plan will include testing with both the Helmholz coil and a single coil. During the second semester we can identify if using an MO material would be beneficial or not in conjunction with the coils and how it affects our magnetic field.

5.3.3 Other challenges and issues

The simulation of the first version of our circuit worked successfully. We implemented on Eagle then created a Gerber file to create the prototype. After talking to one of our advisors, he proposed we add capacitors, include an MAS connector to our circuit, and make some other changes. We will have to re-start the system analysis process again by considering the new remarks and what we have already done. One of the strengths to our current design is that we have a MOSFET that will work correctly, and we do not need to change it. This puts some ease on our project timeline. One of our weaknesses of our current design may be to find the correct values of the capacitors we should add to our circuit. The circuit will need to be simulated on OrCad to find the correct capacitor value that we need to use with our MOSFET and coil to have the desired current (around 25 amps). Once we figure that out, we would implement it on Eagle again and we will be able to create our new PBC using Protomat S62.

Extensive testing will need to be done to measure the magnetic field output for strength and consistency, voltage and current generation, inductive coupling, arcing, heat distribution, and how different magneto-optic materials affect all of these characteristics. This may be another challenge.

6 Test Plan

To achieve proper functionality, appropriate testing must be completed on the device. We have set up a process to ensure we test our device thoroughly throughout the design phase. Our testing process is shown below in Figure 9: Testing Procedure.

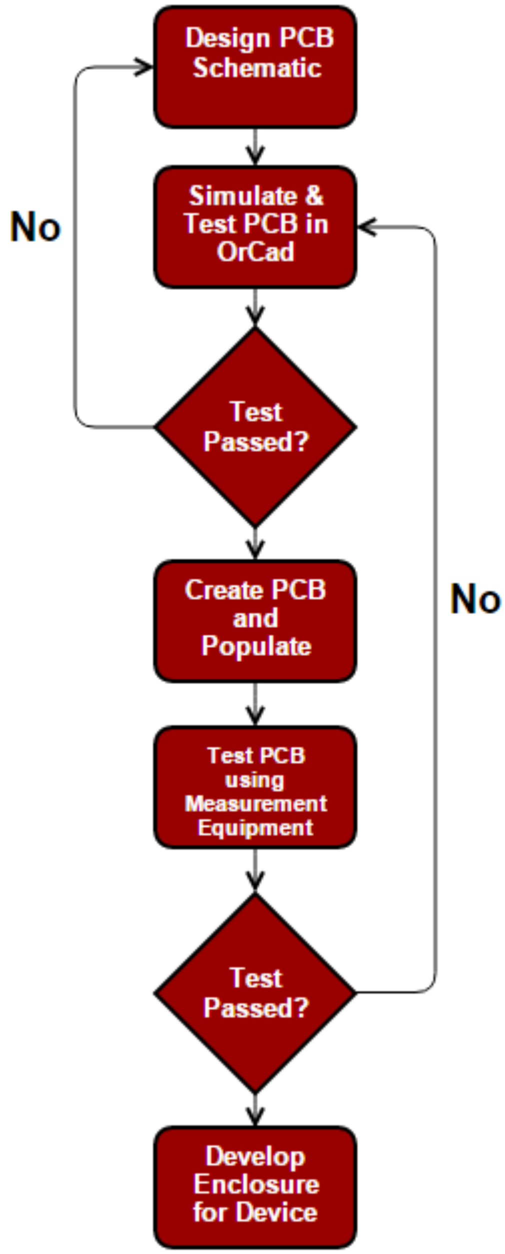

Figure 9: Testing Procedure

6.1 Functional Equipment

The requirements specified for our project will require us to use an oscilloscope, a function generator, a multimeter, and a gauss meter. The oscilloscope will allow us to ensure we are meeting our requirement of 1µs pulses. The gauss meter will assist in providing measurements of the magnetic field, which has a specified strength of 500 Gauss. This field strength will be verified analytically in conjunction with the multimeter.

6.2 User Interface Test Calculations

For testing purposes and calculations, our team has created multiple scripts to aid in our understanding of how our design is intended to run with the specifications we provide as a user. Understanding how to go back and forth from calculating current and magnetic field will help us when we need to optimize the circuit. With the scripts, we will be able to answer concepts such as how increasing the current affects how much magnetic field is generated.

1. MATLAB script that asks the user to input the number of turns, length, radius, *magnetic field (in Gauss)* and then calculates the current required to generate that field ***for a single short coil***.
2. MATLAB script that asks the user to input the number of turns, length, radius, *current (in Amps)* and then calculates the magnetic field required generated ***for a single short coil****.*
3. MATLAB script that asks the user to input the number of turns, radius, *magnetic field (in Gauss)* and then calculates the current required to generate that field ***for a Helmholtz coil***.
4. MATLAB script that asks the user to input the number of turns, length, radius, *current (in Amps)* and then calculates the magnetic field required generated ***for a Helmholtz coil****.*

6.3 Validation Test

- We shall verify using a standard ruler that the circuit board dimensions are less than or equal to 3.5” x 2”.
- We shall verify using a Gauss meter that the circuit generates a magnetic field with strength of greater than or equal to 500 Gauss.
- We shall verify using an oscilloscope that the circuit generates a magnetic field every microsecond.
- We shall verify using a multimeter our DC voltage source is less than or equal to 15 Volts.

7 Work Breakdown Structure

Each member of our group is expected to remain actively engaged in our project throughout both 1st and 2nd semesters. In order to ensure that the project plan is carried out effectively, we have assigned particular roles to each group member. Member roles include:

Team Leader: Communicate with advisor and client. Organize work needed to be completed. Lead team meetings.
Team Webmaster: Responsible for the project web design and maintenance
Team Communication Leader: Coordinate and finalize the weekly reports, project plans, design document, etc.
Team Key Concept Holder: Responsible to keep the newest idea, developments, and needed changes to be implemented
Team Commissioner: Accomplishes a particular action when a member of the team needs it completed

Because we have such a large, skillful group, we decided it would be best if we divided up the work into two separate teams:

The Coil Team: Look at the properties of inductors
The MOSFET Team: Look at the switching options for driving the inductor

Table 2: Team Breakdown

Team Member	Team Role	MOSFET/Coil team
Adam Kaas	Team Leader	Coil
Gregory Fontana	Team Co-Webmaster	MOSFET
Meiyong Himmtann	Team Co-Webmaster	MOSFET
Brittany Duffy	Team Communication Leader	MOSFET
Megan Sharp	Team Co-Key Concept Holder	Coil
Brandon Dixon	Team Co-Key Concept Holder	MOSFET
Alain Ndoutoume	Team Commissioner	MOSFET

8 Resource Requirements

At this point in the project, we have anticipated the required parts to complete the project. Each bill of materials is organized by prototypes use for hardware and software, testing prototype components, and final product components. We plan on creating at least three prototypes, so the total cost is subject to change, but will remain quite low.

Table 3: Prototype Hardware and Software

Item	Where to Obtain	Quantity	Cost Per	Total Cost
OrCAD Software	http://www.orcad.com	1	$-	$-
EAGLE PCB Software	http://www.cadsoftusa.com	1	$-	$-
MATLAB	http://www.mathworks.com	1	$-	$-
MOSFET	digikey.com	6	$0.50	$3.00
Resistor	digikey.com	10	$0.10	$1.00
Coil wire (3m)	Iowa State High Speed Systems Lab	1	$-	$-
Coil glue	Iowa State High Speed Systems Lab	1	$-	$-
Insta-set (fast dry glue)	Iowa State High Speed Systems Lab	1	$-	$-
Tweezers	Megan Sharp	1	$-	$-
exacto knife	Megan Sharp	1	$-	$-
Ruler	Iowa State High Speed Systems Lab	1	$-	$-
Balsa Wood	Iowa State High Speed Systems Lab	1	$-	$-
Charcoal (used for winding)	Iowa State High Speed Systems Lab	1	$-	$-
Sandpaper (for coil)	Iowa State High Speed Systems Lab	1	$-	$-
Soldering Station	Iowa State Parts Shop	1	$-	$-
Solder	Iowa State Parts Shop	1	$-	$-
PCB Fabrication	Iowa State Parts Shop	3	$-	$-
Total				**$4.00**

Table 4: Testing Prototype Components Cost

Item	Description	Quantity	Cost Per	Total Cost
Multimeter	Iowa State Senior Design Laboratory	1	$-	$-
Oscilloscope	Iowa State Senior Design Laboratory	1	$-	$-
DC Voltage Supply	Iowa State Senior Design Laboratory	1	$-	$-
Gauss Meter	Iowa State Senior Design Laboratory	1	$-	$-
Total				**$-**

Table 5: Final Product Cost

Item	Description	Quantity	Cost Per	Total Cost
MOSFET	digikey.com	10	$1.98	$0.50
Coil	Iowa State High Speed Systems Lab	1	$-	$-
Resistor	digikey.com	1	$0.10	$0.10
PCB Fabrication	oshpark.com	1	$10.00	$10.00
Total				**$10.60**

9 Project Schedule

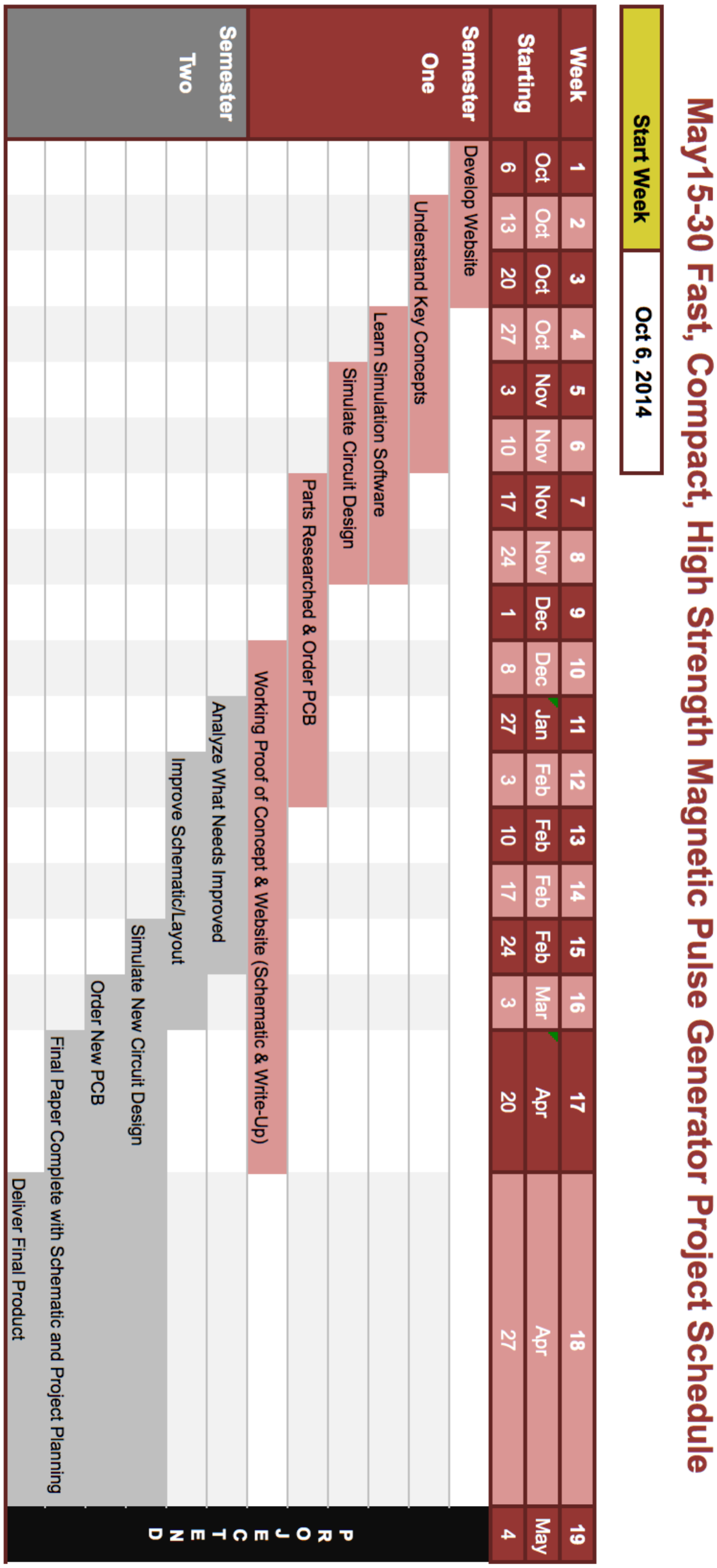

Figure 10: Project Schedule

10 Risks/Feasibility Assessment

10.1 Risks to the Project Timeline

One of the biggest risks that we may encounter during this project is receiving all parts of the project on time after we design our circuit and the ordering of the PCB. Our goal is to order the correct parts on digikey.com to minimize the probability of getting wrong parts. Another issue we may face is to make sure that our theoretical values match our practical values in the lab. We can only go so far with computer analysis in generating high magnetic fields. During testing in lab, components may burn; therefore, we should order enough parts in case of various incidents that can happen in the lab. The project is feasible in the frame time that we are expecting to deliver our final paper next semester, if any major incidents do not occur.

10.2 Physical Dangers

The largest physical risk is getting burnt while testing our circuit. Other risks include getting shocked by medium range voltages. Following proper lab procedure, such as turning off the power before we handle circuit components, will ensure that no one gets harmed.

11 Market/Literature Application

Our circuit design has many modern-day applications across a wide range of scientific tools. Similar circuits to our project can be used in the medical field such as transcranial magnetic stimulation and neuroscience. Transcranial magnetic stimulation is a noninvasive method to study the brain's functions and interconnections. It induces weak electric currents using a rapidly changing magnetic field. Future investigation is being done on how our circuit is applicable in other scientific technologies.

The concept of a magnetic pulse generator has been researched in the past. Looking what has been researched and published, parts of our project goals, such as a fast magnetic pulse generator or high energy have been designed previously. There are some patents on different designs and methods such as a Fast High Voltage Modulator Circuit, patented in 1997. This design included a transformer and three MOSFETs. The Fast High Voltage Modulator Circuit pulses at about 10 nanoseconds. In comparison to our design, the patented design is stackable and has more components. It also does not pulse as fast as what we would like our design to pulse at nor does it mention whether or not the design is compact or high strength.

12 Conclusion

At the end of the first semester, our system's functionality should be a circuit with a coil pulsing every microsecond providing at least 500 Gauss. Our first prototype is a major part in steps towards our final coil and circuit design. On the prototype, there is an LED that emits a visible pulse to see the designed circuit in action. Seeing the pulse through the LED, we know it is plausible to create a similarly designed circuit with a small coil in place of the LED. By continuing to research, design, and test, the end result will be a professionally fabricated working device pulsing every one microsecond at 500 Gauss.

12.1 Client

Iowa State University High Speed Systems Engineering Lab
Contact: John Pritchard

12.2 Team Information

Table 6: Team Contact Information

Team Member	Email Address
Adam Kaas	ajkaas@iastate.edu
Gregory Fontana	fontana@iastate.edu
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Brittany Duffy	baduffy@iastate.edu
Megan Sharp	megsharp@iastate.edu
Brandon Dixon	bmdixon@iastate.edu
Alain Ndoutoume	alain@iastate.edu

12.3 Advisors

Dr. Mani Mina (Senior Instructor, Dept. of ECpE) – mmina@iastate.edu
John Pritchard (Graduate Student) – johnp@iastate.edu
Robert Bouda (Graduate Student) - nybouda@iastate.edu