

# **Fast, Compact, High Strength Magnetic Pulse Generator Final Design Document**

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# 1 Introduction

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## 1.1 Project Summary

The goal of this project is to design and fabricate a relatively fast, compact, high strength magnetic pulse generator. As communication technology advances, the need for efficient, small-scale, low cost switches to place within these systems has steadily increased. This creates a problem in which a solution has yet to be achieved. The magnetic pulse generator we are creating for this project will address the need for economical, high-speed switches in various settings such as bio-medical therapy and magneto-optic systems.

## 1.2 Deliverables

The following are the deliverables over the course of the next two semesters.

### 1.2.1 *First semester*

- Detailed design approach
- A prototype to show proof of concept

### 1.2.2 *Second Semester*

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

## 2 System Level Design

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The systems level design summarizes the architecture, components, and requirements for the project.

### 2.1 System Requirements

Below, functional and non-functional requirements are listed.

#### 2.1.1 Functional Requirements

- The device shall generate a magnetic pulse of 500 gauss or greater.
- The device shall generate a pulse every microsecond.
- The device shall provide consistent results.

#### 2.1.2 Non-Functional Requirements

- The device shall be in an enclosure.
- The device shall have a DC source voltage of 15 volts or less.
- The device shall not exceed the dimensions 3.5" (L) x 2" (W).

### 2.2 System Analysis

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 magnetic field for one microsecond per millisecond period with strength of 500 gauss. In section 3, specifics within this diagram will be discussed.



Figure 1: Block Diagram of Concept

### 2.3 Functional Decomposition

Our magnetic pulse generator is a simple idea 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. We have divided up the work into a group working on the coil and a group working with the MOSFET and circuit design; however, 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 rise and fall time of the current through the coil. The major challenge will be to minimize the rise and fall times.

## 3 Detailed Design

### 3.1 I/O Specification

The input of the circuit is a DC source voltage that is 15V and a pulse generator to drive the MOSFET. The output is going to be a 500 gauss magnetic field produced for one microsecond per millisecond period.

### 3.2 Simulations and Modeling

Figure 2 shows our final circuit design which we simulated and modeled using OrCAD. In section 3.3, each individual component is discussed in detail.

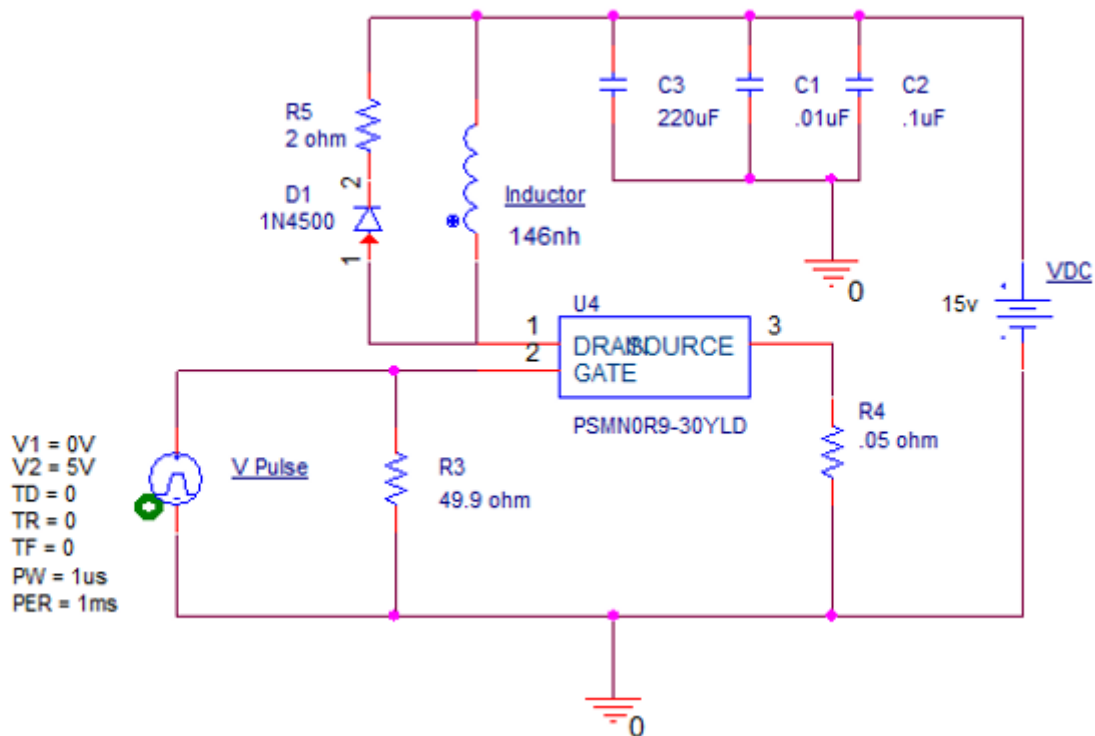


Figure 2: OrCAD Schematic

In Figure 3, a plot of the current through the inductor is provided. The pulse width is set to 1us, and the pulse period is set to 1ms. This gives us a duty cycle of 0.1% to ensure that our circuit will not over heat. The output shown in Figure 3 is not ideal because the pulse width is not 1us. This is caused by the inductor is not discharging fast enough. Ideally it should charge and discharge much faster.

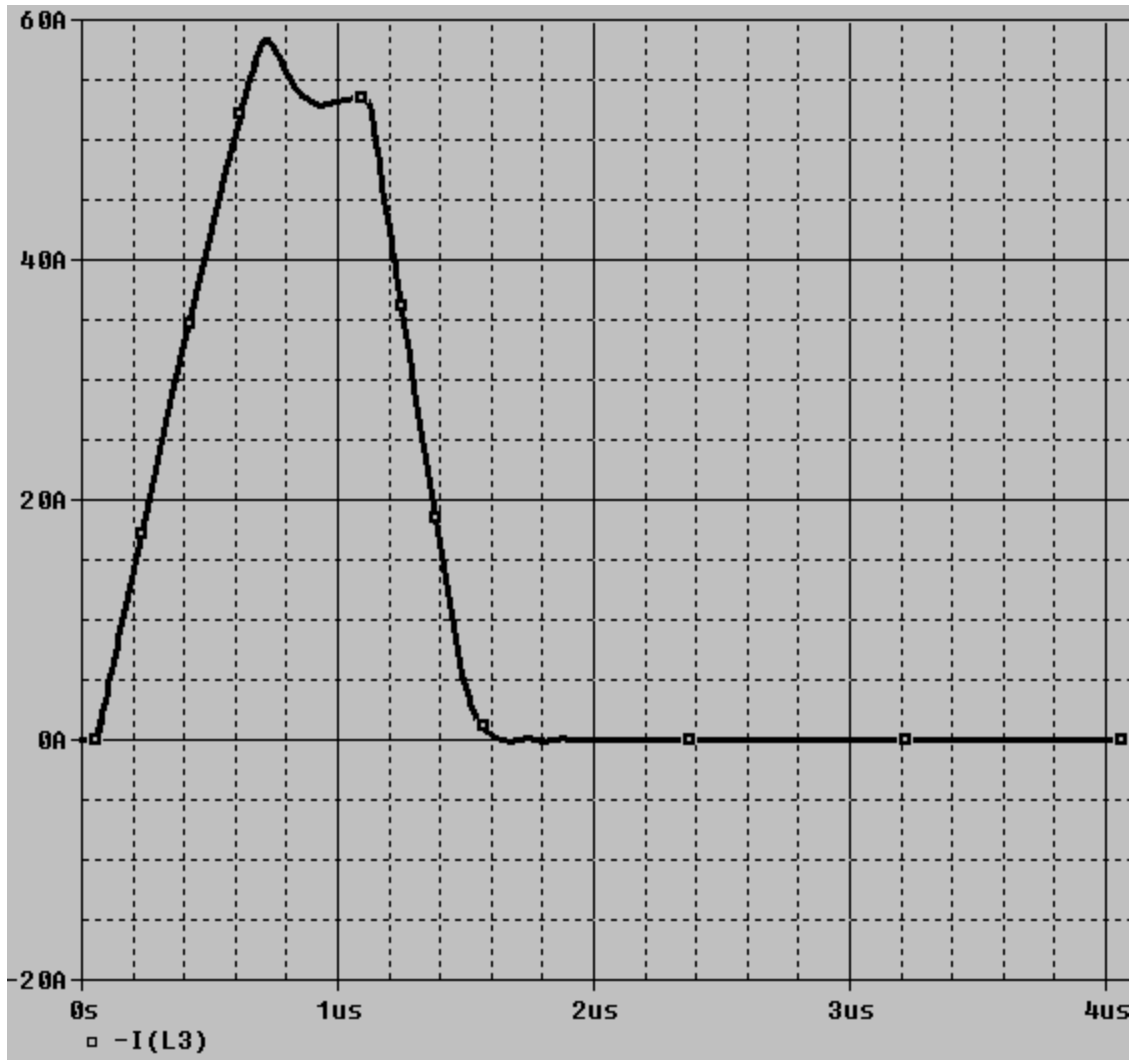


Figure 3: OrCAD Simulation

### 3.3 Hardware Specification

For hardware, our system can be described in five main parts: coil, MOSFET, diode, capacitors, and resistors. For preliminary purposes, the design is using one coil and one MOSFET. In the future, we may be using two coils and two MOSFETs in an edited circuit design.

#### 3.3.1 Coil

The coil used in this project will have great impact on the final product. We will try two different types of coils: a single coil and a Helmholtz coil. We will test both to see which yields the best results. The coil is a necessary part of the circuit because when current is put through the coil, this will generate the 500 gauss magnetic field. This magnetic field will be generated at the center of the coil. For the Helmholtz coil this means the magnetic field will be generated

between coil 1 and coil 2. We calculated the magnetic field for a single coil using the equation below:

$$B = \frac{\mu NI}{\sqrt{l^2 + 4R^2}} = 0.057865 \text{ Teslas} = 578.65 \text{ gauss}$$

We calculated the magnetic field for a single coil using the equation below:

$$B = \frac{\mu(0.7155)NI}{R} = 0.05 \text{ Teslas} = 500 \text{ gauss}$$

The resistance and the inductance will both affect the functionality of the coil. The resistance lowers the current which also lowers the magnitude of our magnetic field; therefore, the lower the resistance of the coil, the easier it is for the magnetic field to reach 500 gauss. Our team did a simple test by measuring the resistance of a five turn coil with an Agilent 4263 Model B LCR meter and measured resistance at 0.084Ω. Based on this, we expect our final resistance to be under or close to 0.1Ω. However, resistance of the coil is not something we have researched or tested in depth this semester. We have considered it negligible on existing OrCAD simulations. Once we have a working prototype, this will be something that we measure and include. The inductance can affect our rise and fall time. Since we have a requirement of a 1 μs pulse width and 1ms period, we have to take the coil inductance into consideration when working to achieve this. Coil inductance for the single coil is found using the equation below:

$$L = \frac{\mu N^2 (\pi R^2)}{\sqrt{l^2 + 4R^2}} = \frac{(4\pi \times 10^{-7}) 5^2 (\pi * (3 \times 10^{-3})^2)}{\sqrt{(1 \times 10^{-3})^2 + 4(3 \times 10^{-3})^2}} = 146 \text{ nH}$$

Coil inductance for Helmholtz coil is for using the equation below:

$$L = 2\mu(0.7155)N^2\pi R = 2(4\pi \times 10^{-7})(0.7155)(\pi(3 \times 10^{-3})^2) = 423.7 \text{ nH}$$

This semester we have calculated possible coil dimensions including theoretical inductances for both a Helmholtz coil and a single coil configuration. When constructing coils, we use a 6mm diameter (3mm radius). The length of a five turn coil is close to 1mm in length which can be used as a guideline to find the length based on the number of turns. Below are the coil calculations for each of type of coil.

Note: Here are relevant variables for this section:

μ: permeability of free space ( $4\pi \times 10^{-7}$ )

N: number of turn of a coil (dimensionless)

R: radius of a coil (meters)

l : length of a coil (meters)

L : inductance of a coil (henries)

B : magnetic field of a coil (teslas. 1 tesla=10,000 gauss)

I : current through a coil (amperes)



### 3.3.1.1 Single Coil

Figure 4 shows that 5 turns of the single coil provides 48.41 amps at 500 gauss. The script to generate this graph is shown in Figure 5.

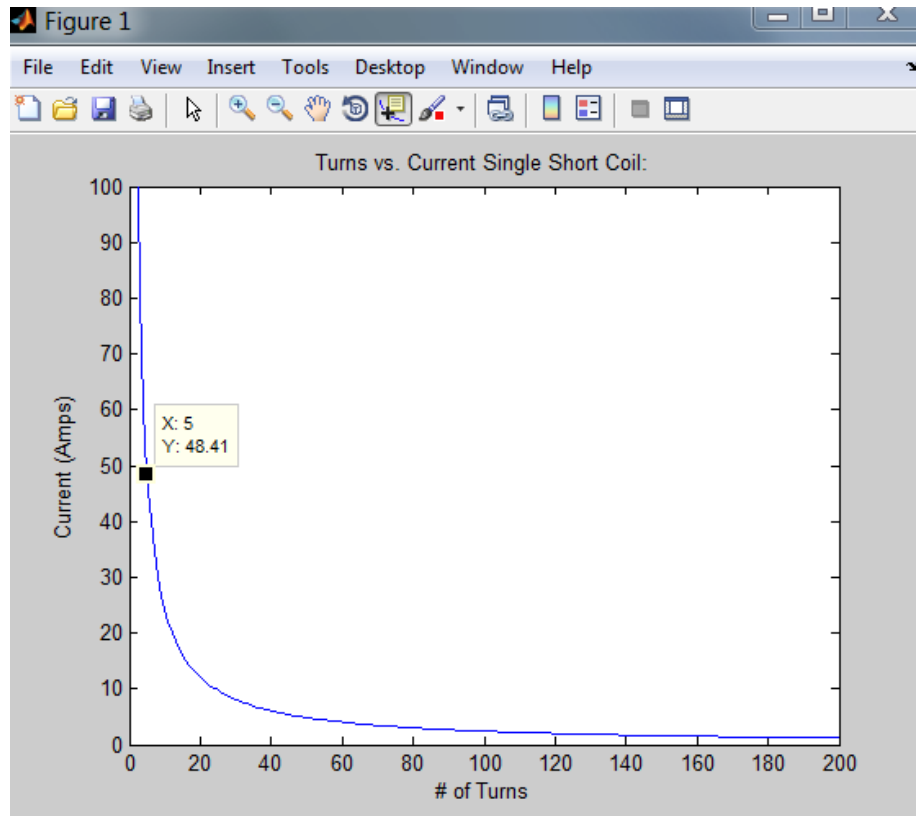


Figure 4 : Single Coil, 5 turns at 48.41 amps providing 500 gauss

```

I_vs_N_table_Single.m  I_vs_N_table_Helmholtz.m  +
1 -   num_rad = input('How many radii do you want to enter?');
2 -   r(num_rad)=0;
3
4 -   for k = 1:num_rad
5 -       r(k) = input('Give the first radius you want to graph (in mm.)');
6 -   end
7
8 -   N = [1:1:200];
9 -   I = zeros(1,200);
10
11 -  for j = 1:num_rad
12 -      for i = 1:1:200
13 -          I(i) = (0.05*r(j)*.001)/(N(i)*4*pi*10^-7*0.7155);
14 -      end
15 -      figure(j)
16 -      plot(N,I)
17 -      str = sprintf('Turns vs. Current Helmholtz Coil: R = %f', r(j));
18 -      title(str);
19 -      xlabel('# of Turns'); xlim([0,100]);
20 -      ylabel('Current (Amps)'); ylim([0,60]);
21 -  end

```

Figure 5: Script to Generate Figure 4

### 3.3.1.2 Helmholtz Coil

Figure 6 shows that 5 turns of the single coil provides 33.37 amps at 500 gauss. The script to generate this graph is shown in Figure 7 and has an inductance of 423nF. This inductance is higher than what we would want in a final design, however, the physical design of a Helmholtz coil may be more advantageous for some applications.

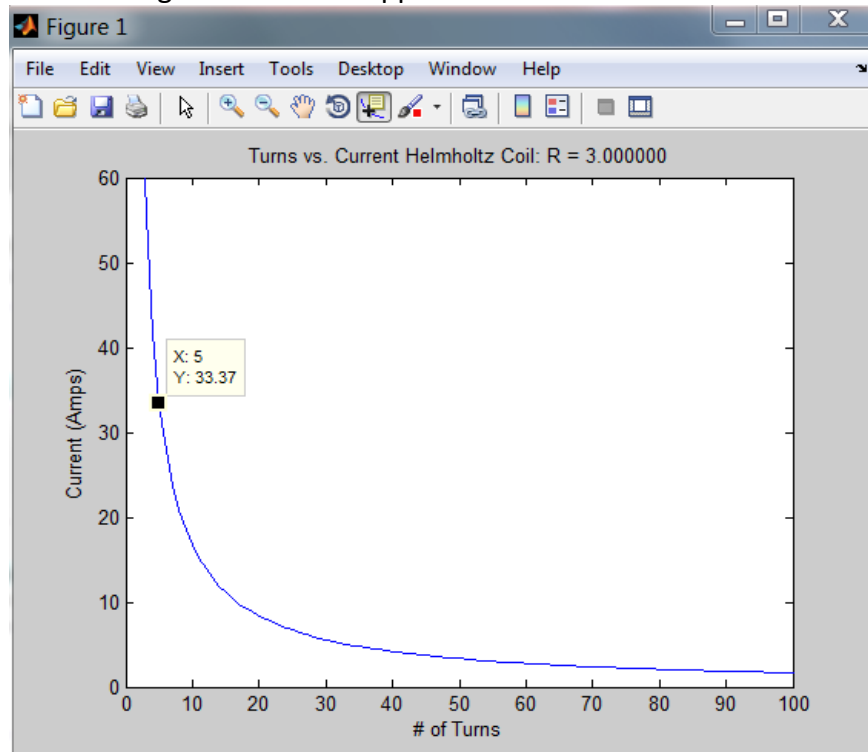


Figure 6: Helmholtz Coil, 5 turns at 33.37 amps providing 500 gauss

```

I_vs_N_table_Single.m  I_vs_N_table_Helmholtz.m  +
1  %num_rad = input('How many radii do you want to enter?');
2  %r_init(num_rad)=0;
3
4  %for k = 1:1:num_rad
5  r = input('Give the radius you want to graph (in m.)');
6  %end
7
8  l_init = input('What length do you want to work with (in m?)');
9  l = l_init;
10
11  N = [1:1:200];
12  I_s = zeros(1,200);
13
14  %hold on
15  %grid
16
17  %for j = 1:num_rad
18  for i = 1:1:200
19  I_s(i) = (0.05*sqrt(l^2 + 4*(z)^2))/((4*pi*10^-7)*N(i));
20  end
21  % figure(j)
22  plot(N,I_s)
23  str = sprintf('Turns vs. Current Single Short Coil:'); % R = %fmm, r(j));
24  title(str);
25  xlabel('# of Turns'); xlim([0,200]);
26  ylabel('Current (Amps)'); ylim([0,100]);
27  %end
28  %xlabel('# of Turns'); xlim([0,200]);
29  %ylabel('Current (Amps)'); ylim([0,100]);

```

Figure 7: Script to Generate Figure 6

### 3.3.2 MOSFET

As section 3.3.1 has shown, calculations prove that the current through the coil will be approximately up to 48.1 amps for the single coil meaning the MOSFET will need to handle at least a pulsing current of 55 amps, just in case. Most importantly, this MOSFET meets a number of design specs:

- Drain to Source voltage ( $V_{DS}$ ) must be able to handle 15V or more
- Current channel must be able to handle the current load through the coil (approximately 25 amps)
- Surface mount component

The MOSFET chosen was designed for fast switching. The chosen MOSFET for this circuit design includes the specs above as well as:

- N- channel, operates using a positive input voltage and faster switching
- Industries first MOSFET using Schottky technology to deliver high efficiency, low spiking performance without high leakage current
- Suited for high switching frequencies resulting in a soft-recovery
- Low parasitic inductance and resistance
- $V_{DS}$  rated up to 30 V
- Pulsed, peak drain current rated up to 1888 A
- More information: [http://www.nxp.com/documents/data\\_sheet/PSMN0R9-30YLD.pdf](http://www.nxp.com/documents/data_sheet/PSMN0R9-30YLD.pdf)

### 3.3.3 Capacitors

Capacitors near the voltage input hold a charge, effectively reducing the time it takes for the coil to get a current running through it by reducing the input inductance, and increasing the time taken between each pulse. Using our present calculations for the current and voltage, we have decided to use three capacitors of values .01uF, .1uF, and 220uF. The equations below gave us a minimum (base) value we could use for the total capacitance. This equation assumes that we have 25 amps of current in our inductor and a pulse width of 1us.

$$\frac{\text{Current} * \text{Pulse Width}}{\text{Voltage}} = \text{Capacitance}$$

$$\frac{25 \frac{\text{Coulomb}}{\text{second}} * 1 * 10^{-6} \text{seconds}}{15 \text{Volts}} = 1.67 * 10^{-6} \text{Farads}$$

For a circuit like ours, it's common practice to take this minimum value and multiply it by 100 or more. Our total capacitance used in our circuit is 220.11uF, which is roughly 130 times larger than our base value. The .1uF and 220uF capacitors we are using are tantalum capacitors, because their internal resistance is low.

### 3.3.4 Diode

EMF voltage occurs when the waveform generator goes from its upper voltage to lower voltage. In EMF voltage, the change in current over the change in time becomes negative. The inductance doesn't change, hence giving a negative voltage across the coil. Because the change in time will be very small, the magnitude of the negative voltage will be very large. Without a diode, this large negative voltage will reach the MOSFET and potentially ruin the MOSFET. We have chosen a large diode in parallel to the coil that prevents back EMF into the MOSFET.

Specifications include:

- Fast recovery time
- High reverse breakdown voltage
- Surface mount component
- More information: <http://www.digikey.com/product-detail/en/STTH3R02S/497-6085-2-ND/1653882>

### 3.3.5 Resistors

In our design we will be using a  $49.9\Omega$  surface mount resistor. Previously in our design we decided upon a  $50\Omega$  resistor, but in the end chose  $49.9\Omega$ . The  $49.9\Omega$  has enough power dissipation and lowered our cost by about \$14. Placing the  $49.9\Omega$  resistor provides expected results without having to worry about the  $50\Omega$  natural resistance of the waveform generator.

A  $2\Omega$  resistor is placed in series with the diode. This is because without the resistance, the current would continue to loop between the coil and diode because there is no place for the energy (heat) to dissipate. Because OrCAD makes all wire resistances ideal (zero), we may not need this  $2\Omega$  resistor in our physical circuit. The wires and connections may cause enough resistance for this energy to dissipate elsewhere.

Our design also contains a current sensing resistor with a value of  $0.05\Omega$ . Due to the difficulty of testing the magnetic field of our circuit, by placing a current sensor in our design, the current sensor will be a way to test that our design is producing a result by measuring the drain current through the MOSFET. If we are expecting to use 20-25A, we should expect to see a 1.00-1.25V drop across the resistor, thus changing our gate-to-source voltage from 5V to 3.75-4.00V. It is something we need to account for, and ideally we wouldn't have the resistor as part of our circuit. It is primarily for testing purposes.

## 3.4 Implementation, Issues, Challenges

### 3.4.1 Circuit

One of our main challenges for the circuit will be to develop quick rise and fall times in the current. Figure 3 clearly demonstrates the undesirable slow fall time effects and the challenges we will be facing as we continue to design this project.

After completing an LED blink circuit that could substitute the LED with a coil to generate a magnetic field 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 of a pulse generating once every microsecond.

### *3.4.2 PCB*

The layout for the PCB is created using Eagle PCB and then sent to a machine called the Protomat S62 that will then take that layout and etch it onto a copper board. Once the layout file is created using EAGLE it is then formatted to a Gerber file and sent over to the Protomat. The Protomat will then take the layout and etch it onto a copper board. Once the board has been etched it is ready for the circuit components to be soldered onto the top of the board. At our client's request, all the circuit components are surface mount.

### *3.4.3 Coil, MO Material, and Magnetic Field*

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 Helmholtz coil and a single coil. During the second semester, we will identify if using an MO material would be beneficial or not in conjunction with the coils and how it affects our magnetic field. For initial tests, we plan on using air for our material.

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 will be another challenge.

### 3.5 Testing Procedures

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 8.

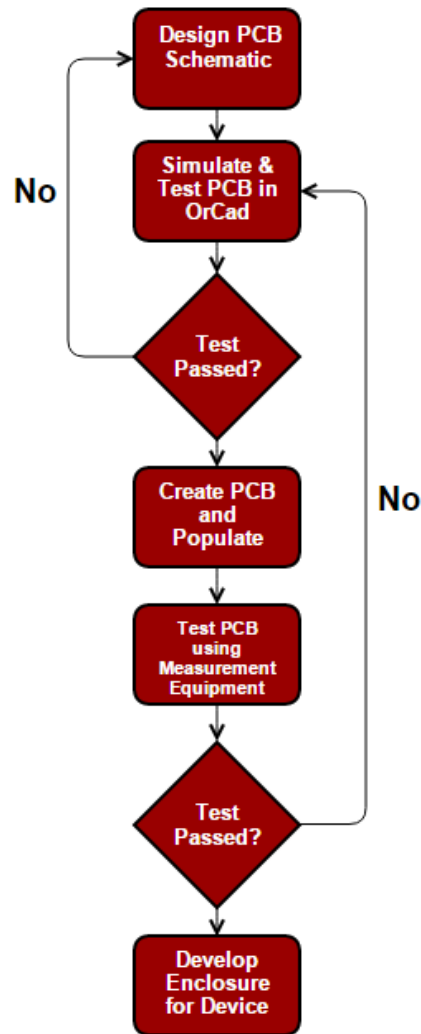


Figure 8: Testing Procedure

In order to test and develop the circuit, our team has created MATLAB scripts to calculate the magnetic field and current of different coil types. A PCB was designed and created by our team that will soon be tested with ordered components. See sections below for more information.

#### 3.5.1 Testing User Interface

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.

- 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**.
- 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**.
- 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**.
- 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**.

### 3.5.2 Eagle PCB Test

After creating a schematic that meets our 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 fabricate a board. 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, we ordered parts online through [www.digikey.com](http://www.digikey.com).

The circuit below was implemented in Eagle PCB, which was used as the schematic (Figure 9) and layout platform (Figure 10) for testing purposes.

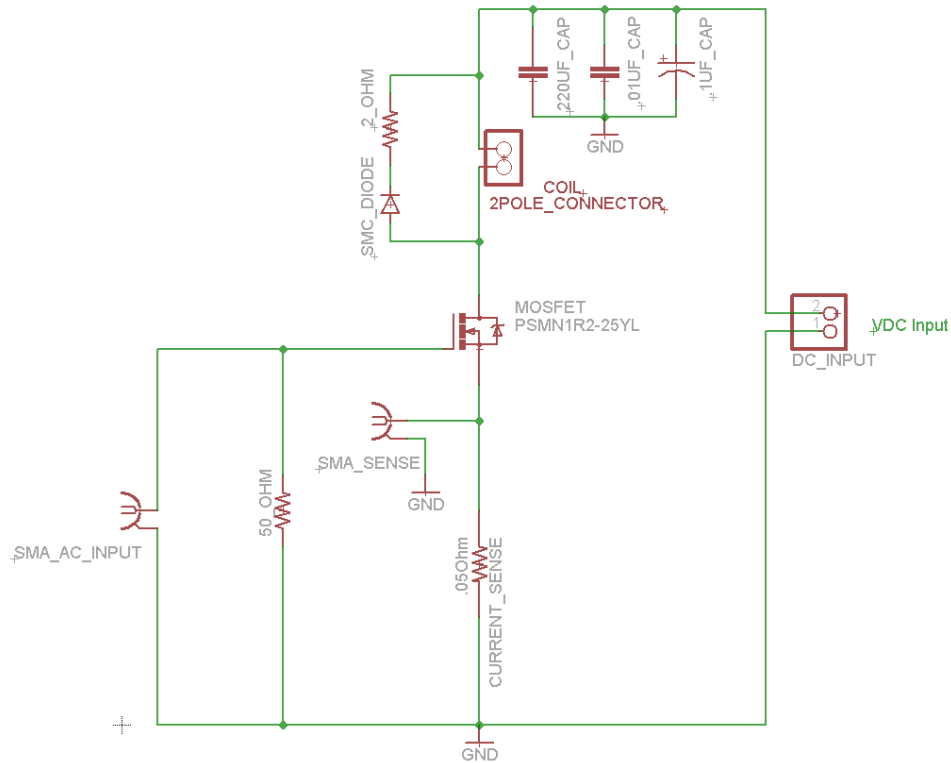


Figure 9: Eagle EMP Schematic

According to our simulations, the circuit depicted in Figure 9 should allow us to achieve our goals for the dimensions of the board, as well as creating a magnetic field of 500 gauss. For our final product, we will also need to achieve a one microsecond pulse width with 1 millisecond period, but that is something we will continue to look in to in the future. At this stage, we have moved on from our preliminary testing with a blinking LED circuit and are well on our way to completing the final design.



## 4 Computer-Aided Design & Printed Circuit Board

### 4.1 PCB Layout

Figure 10 depicts the layout of the board we are in the process of fabricating. The dimensions meet our specifications, measuring 1.49 x 1.30 inches. As can be seen, each component of the board is labeled to make it user friendly. The colored rectangle covering the majority of the board is a copper pour, which was done on both sides with the top layer represented in red and the bottom layer represented in blue. The point of these copper pours is to create ground planes on both sides of the board. This improves the functionality of our PCB because it allows us to remove traces that go to ground, as well as providing additional heat sinking.

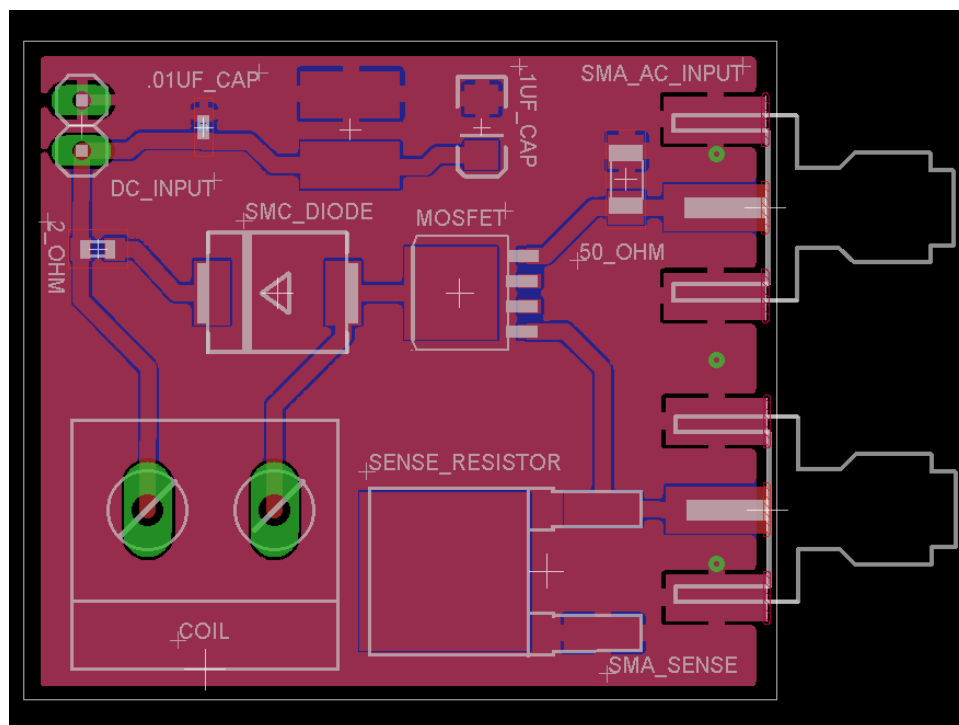


Figure 10: Eagle Circuit Layout

### 4.2 PCB Issues

When creating the PCB from the proposed Eagle layout, the Protomat S62 can damage the board, creating unpredictable, notched lines. These nicks and notched lines can affect the performance of the circuit, with a chance of disabling the circuit altogether. With our first circuit design, we were able to create a few damage free PCBs, enabling us to get our desired result. For time's sake, we have used the Protomat for our PCBs, and it has caused us very few problems. However, for our final circuit design, we will order the PCB from OSH Park ([www.oshpark.com](http://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 Resource Requirements

At this point in the project, we have anticipated the required parts to complete the design. Each bill of materials is organized by prototypes use for hardware and software, testing prototype components, and final product. Our team will create at least three prototypes before our final design is complete.

**Table 1: Prototype Hardware and Software Costs**

Item	Where to Obtain	Quantity	Cost Per	Total Cost
OrCAD Software	<a href="http://www.orcad.com">http://www.orcad.com</a>	1	\$-	\$-
EAGLE PCB Software	<a href="http://www.cadsoftusa.com">http://www.cadsoftusa.com</a>	1	\$-	\$-
MATLAB	<a href="http://www.mathworks.com">http://www.mathworks.com</a>	1	\$-	\$-
MOSFET	digkey.com	10	\$1.79	\$17.86
0.1uF Capacitor (Tantalum)	digkey.com	10	\$0.33	\$3.29
220uF Capacitor (Tantalum)	digkey.com	4	\$10.88	\$43.52
0.01uF Capacitor (Ceramic)	digkey.com	10	\$0.01	\$0.12
Diode	digkey.com	10	\$0.72	\$7.22
49.9Ω Surface Mount Resistor	digkey.com	10	\$0.10	\$1.00
0.05 Current Sense Resistor	digkey.com	2	\$9.13	\$18.26
Wire-to-Board Connector (30A/300V Rating)	digkey.com	2	\$1.04	\$2.08
Coaxial Connector	digkey.com	4	\$4.84	\$19.36
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	\$-	\$-
<b>Total</b>				<b>\$112.71</b>

**Table 2: Testing Prototype Components Costs**

Item	Description	Quantity	Cost Per	Total Cost
Multimeter	Iowa State Senior Design Lab	1	\$-	\$-
Oscilloscope	Iowa State Senior Design Lab	1	\$-	\$-
DC voltage Supply	Iowa State Senior Design Lab	1	\$-	\$-
<b>Total</b>				<b>\$-</b>

**Table 3: Final Product Costs**

Item	Description	Quantity	Cost Per	Total Cost
N-channel MOSFET	<a href="http://digikey.com">digikey.com</a>	1	\$1.79	\$1.79
Single Coil (Resistance Wire)	Iowa State High Speed Systems Lab	1	\$-	\$-
0.1uF Capacitor (Tantalum)	<a href="http://digikey.com">digikey.com</a>	1	\$0.33	\$0.33
220uF Capacitor (Tantalum)	<a href="http://digikey.com">digikey.com</a>	1	\$10.88	\$10.88
0.01uF Capacitor (Ceramic)	<a href="http://digikey.com">digikey.com</a>	1	\$0.01	\$0.01
Diode	<a href="http://digikey.com">digikey.com</a>	1	\$0.72	\$0.72
49.9Ω Surface Mount Resistor	<a href="http://digikey.com">digikey.com</a>	1	\$0.10	\$0.10
0.05 Current Sense Resistor	<a href="http://digikey.com">digikey.com</a>	1	\$9.13	\$9.13
Wire-to-Board Connector (30A/300V Rating)	<a href="http://digikey.com">digikey.com</a>	1	\$1.04	\$1.04
Coaxial Connector	<a href="http://digikey.com">digikey.com</a>	2	\$4.84	\$9.68
PCB Fabrication	<a href="http://oshpark.com">oshpark.com</a>	1	\$10.00	\$10.00
<b>Total</b>				<b>\$43.68</b>

# 6 Project Schedule

## May15-30 Fast, Compact, High Strength Magnetic Pulse Generator Project Schedule

Start Week **Oct 6, 2014**

Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Notes
Starting	Oct 6	Oct 13	Oct 20	Oct 27	Nov 3	Nov 10	Nov 17	Nov 24	Dec 1	Dec 19	Jan 27	Feb 3	Feb 10	Feb 17	Feb 24	Mar 3	Apr 20	Apr 27	May 4	
<b>Semester One</b>	Develop Website																			
	Understand Key Concepts																			
	Learn Simulation Software																			
	Simulate Circuit Design																			
	Parts Researched & Order PCB																			
	Working Proof of Concept & Website (Schematic & Write-Up)																			
	Analyze What Needs Improved																			
	Improve Schematic Layout																			
	Simulate New Circuit Design																			
	Order New PCB																			
	Final Paper Complete with Schematic and Project Planning																			
	Deliver Final Product																			
<b>Semester Two</b>																				

Table 4: Project Schedule

## 7 Conclusion

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At the end of this semester, we will have a functioning electromagnetic pulse generating circuit that can produce a one us pulse of 500 gauss with a period of one microsecond. To alter our original designs to function like an EMP generator, we have added capacitors, resistors, a diode to control back EMF to the MOSFET, and a coil. By continuing research, design, and test the end result will be a professionally fabricated working device.

### 7.1 Client

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

### 7.2 Team Information

Table 5: Team Information

Team Member	Team Role	Email Address
Adam Kaas	Leader	<a href="mailto:ajkaas@iastate.edu">ajkaas@iastate.edu</a>
Gregory Fontana	Simulator	<a href="mailto:fontana@iastate.edu">fontana@iastate.edu</a>
Meiyong Himmtann	Webmaster	<a href="mailto:himmtann@iastate.edu">himmtann@iastate.edu</a>
Brittany Duffy	Communication Leader	<a href="mailto:baduffy@iastate.edu">baduffy@iastate.edu</a>
Megan Sharp	Coil Designer	<a href="mailto:megsharp@iastate.edu">megsharp@iastate.edu</a>
Brandon Dixon	Layout Designer	<a href="mailto:bmdixon@iastate.edu">bmdixon@iastate.edu</a>
Alain Ndoutoume	Systems Leader & Commissioner	<a href="mailto:alain@iastate.edu">alain@iastate.edu</a>

### 7.3 Advisors

Dr. Mani Mina (Senior Instructor, Dept. of ECpE) – [mmina@iastate.edu](mailto:mmina@iastate.edu)

John Pritchard (Graduate Student) – [johnp@iastate.edu](mailto:johnp@iastate.edu)

Robert Bouda (Graduate Student) – [nybouda@iastate.edu](mailto:nybouda@iastate.edu)

## 8 Appendix

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### 8.1 Abbreviations

AC - Alternating Current

MO- Magneto-Optic

CAD - Computer-Aided Design

MOSFET - Metal-Oxide-Semiconductor Field Effect Transistor

DC - Direct Current

PCB - Printed Circuit Board

EMF- ElectroMotive Force

TMS- Transcranial Magnetic Simulation

LED - Light-emitting Diode