

Fast, Compact, High Strength Magnetic Pulse Generator Design Document

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1 Definition

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

MO- Magneto-Optic

CAD - Computer-Aided Design

MOSFET - Metal-Oxide-Semiconductor Field Effect Transistor

DC - Direct Current

PCB - Printed Circuit Board

LED - Light-emitting Diode

TMS- Transracial Magnetic Stimulation

3 Introduction

3.1 Project Statement

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 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.

3.2 Deliverables

The following are the deliverables of the project for the next two semesters.

3.2.1 *First semester*

1. Detailed design approach
2. Prototype providing proof of concept

3.2.2 *Second Semester*

1. Detailed design approach including PCB schematic and layout
2. Professionally fabricated, functioning PCB in an enclosure
3. Precise project documentation
4. Working final unit

4 System Level Design

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

4.1 System Requirements

Below, functional and non-functional requirements are listed.

4.1.1 Functional Requirements

1. The device shall generate a magnetic pulse of 500 Gauss or greater.
2. The device shall generate a pulse every microsecond.
3. The device shall not exceed the dimensions 3.5" (L) x 2.0" (W).

4.1.2 Non-Functional Requirements

1. The device shall be in an enclosure.
2. The device shall have a DC source voltage of 15 Volts or less.
3. The device shall provide consistent results.

4.2 Functional Decomposition

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.

4.3 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 every microsecond with strength of 500 Gauss. In the next section, specifics within this diagram will be discussed.

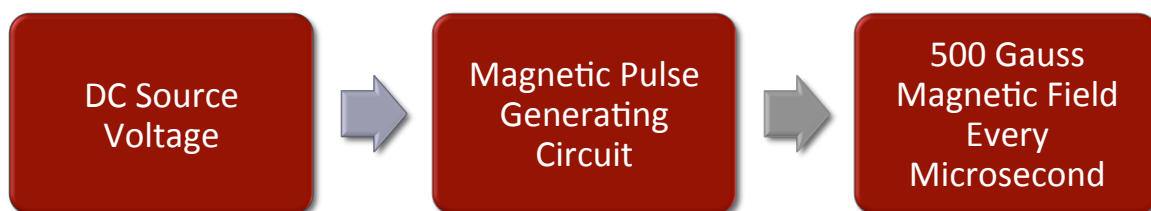


Figure 1: Block Diagram of Concept

5 Detailed Design

5.1 I/O Specification

In our circuit, the input is going to be a DC source voltage that is 15V or less. The output is going to be a 500 Gauss magnetic field. Our circuit was tested first with a resistor and an LED to make sure we have a current going through it. The resistor and LED are eventually going to be replaced by an inductor. The current going through the inductor will produce a magnetic field. Our final product will have the coil's magnetic field generating 500 Gauss.

5.2 Hardware Specification

For hardware, our main components consist of coils, MOSFETs, resistors, and diodes. For preliminary purposes, the design is using one coil and one MOSFET. In the future, we will be using two coils and at least two MOSFETs.

5.2.1 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 μ s time restriction. The equation below shows the inductance (L) that the coil will create based 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.

5.2.2 MOSFETs

A number of specifications are needed for the MOSFET in the design. For now, circuit simulations have consisted of one MOSFET. In order to choose the desired MOSFET, we must know the more information about the coil, such as the amount of current it will produce. Once we have gathered more information about the coil, 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
- Surface mount component

5.2.3 Resistors

Resistors will be used in our final circuit design. Specifications include:

- Value based on needs from coil and MOSFET components
- Surface mount component

5.2.4 Diodes

Diodes will be used in our final circuit design in order to avoid current leaking. Specifications include:

- Surface mount component

5.3 Simulations and modeling

OrCAD was used in the simulation and creation of the circuit. The MOSFET was chosen carefully as part IRL3714ZPbF from digikey.com. This MOSFET was chosen temporarily because its drain to source voltage can handle up to 20V. In the final MOSFET selection, we will have more specifications to sort out as well as making sure our MOSFET is a surface mount component. Figure 2 shows a blinking light circuit on OrCAD that is similar to what the coil circuit will be. The only difference between the circuit on the right and the circuit on the left is the value of the inductance. The circuit on the left shows an inductance of 10 μ H, and the circuit on the right shows a higher inductance of 100 μ H.

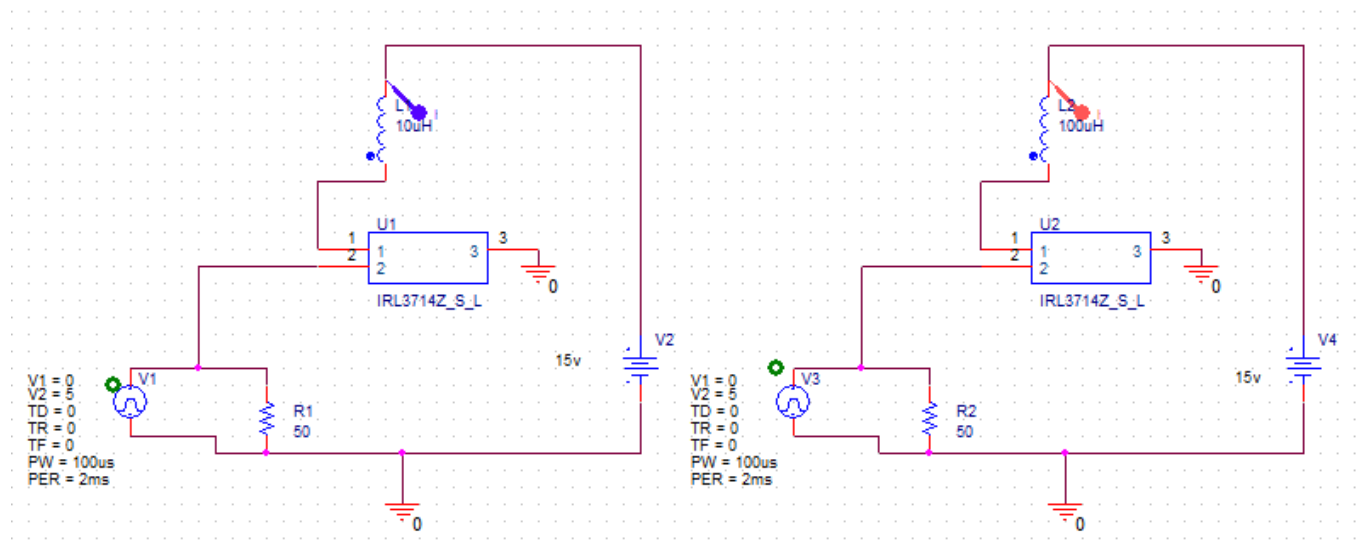


Figure 2: OrCAD Schematic

In Figure 3, a plot of currents through both inductors in the separate circuits is provided. For the low inductance circuit, the “blinks” are visible as the purple 65Amp pulses with a fairly

sharp rise and fall time. 65 Amps is an unreasonably high current for the coil. The results for the circuit with high inductance can be viewed as the red line. You can see here that the red line has a very gradual fall time, which is not ideal for our design.

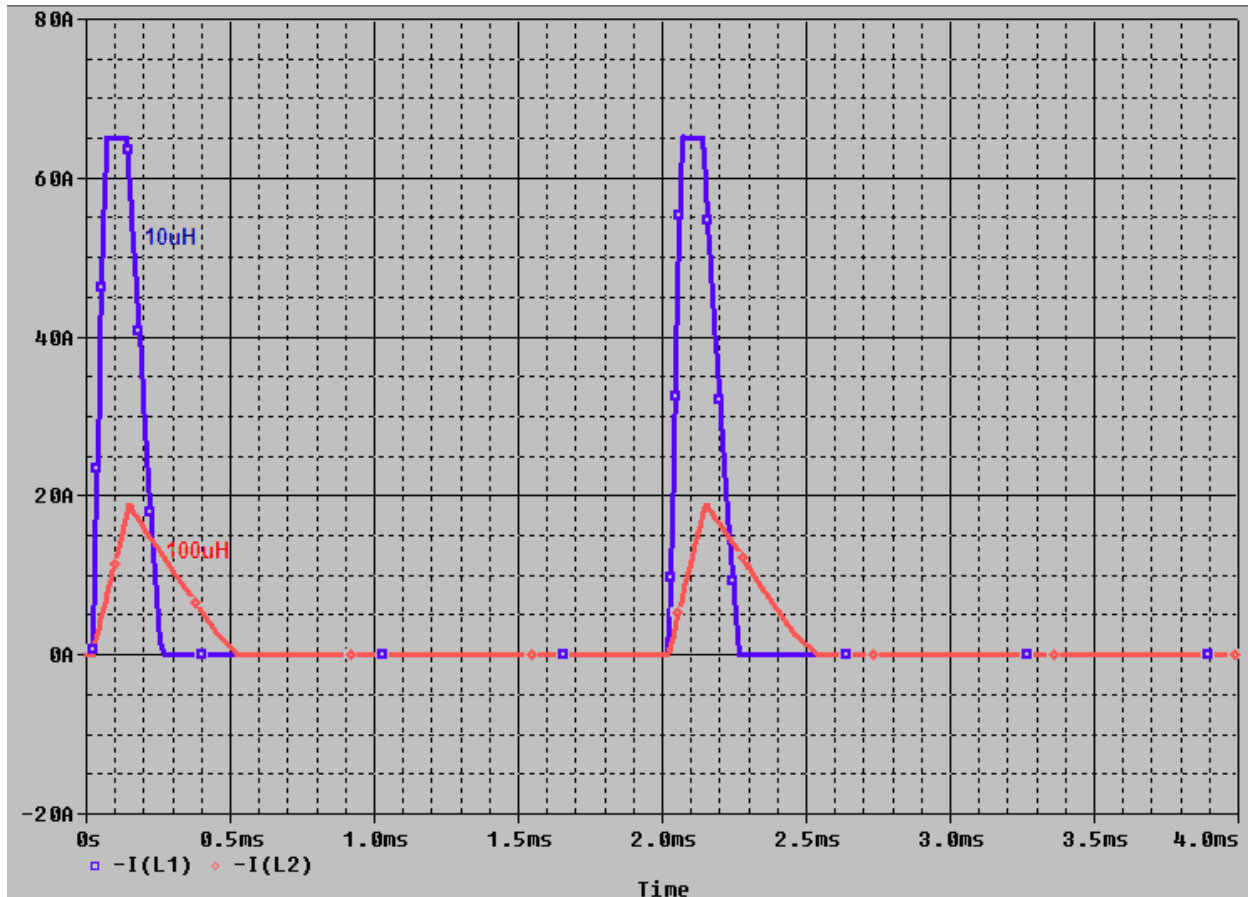


Figure 3: OrCAD Simulation

5.4 Implementation, Issues, Challenges

5.4.1 Circuit

As shown in section 5.3, one of our main challenges for the circuit will be to develop a moderately sized current through the inductor. Our aspirations of 25 Amps or less going through the coil is going to be difficult to achieve with a need of quick rise and fall time. Figure 3 clearly demonstrates the challenges we will be facing as we continue to design this project.

5.4.2 PCB

Learning how to use the Protomat S62 machine can be challenging when using it for the first time. The transfer of the file from Eagle to the Gerber file was a little challenging and time consuming. Soldering skills are important due to the small size of the board.

5.4.3 MO Material

Additional challenges faced by our team include considering the magneto-optic material at the center of our coil. This can have a large impact on the performance of our circuit. For initial tests, we plan on using air for our material. As stated by our client:

“Some of the challenges faced by small-scale systems with high field-strength requirements include (but are not limited to) geometric constraints, sufficient voltage and current generation, inductive coupling, arcing and heat distribution.”

These are all challenges we will have to consider as we progress through our design phase.

5.5 Testing Procedures

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.

5.5.1 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.

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**.

5.5.2 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 design a fabricatable 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, the parts will be bought online through www.digikey.com. The circuit should blink after soldering all the parts together. If the circuit works as designed, the LED can be replaced by an inductor to obtain the magnetic field.

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.

The circuit below was implemented in Eagle PCB, which was used as the schematic (Figure 4) and layout platform (Figure 5) for testing purposes.

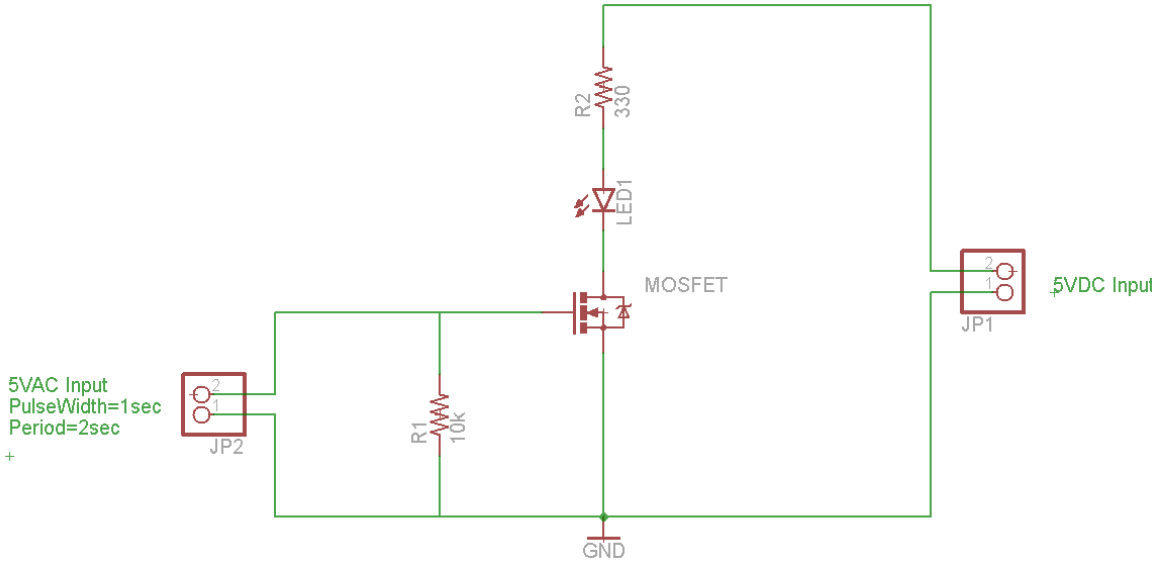


Figure 4: Eagle PCB Test Schematic

After future simulation and design, we expect this circuit to be a little more complex in order to meet requirements. A new PCB will be created to account for parts that will help contribute to attaining our goals.

6 Computer-Aided Design & Printed Circuit Board

Figure 5 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 4. This was created using EaglePCB. The PCB pictured below in Figure 6 was created using the Protomat S62. This circuit will be very similar to the magnetic pulse generator circuit.

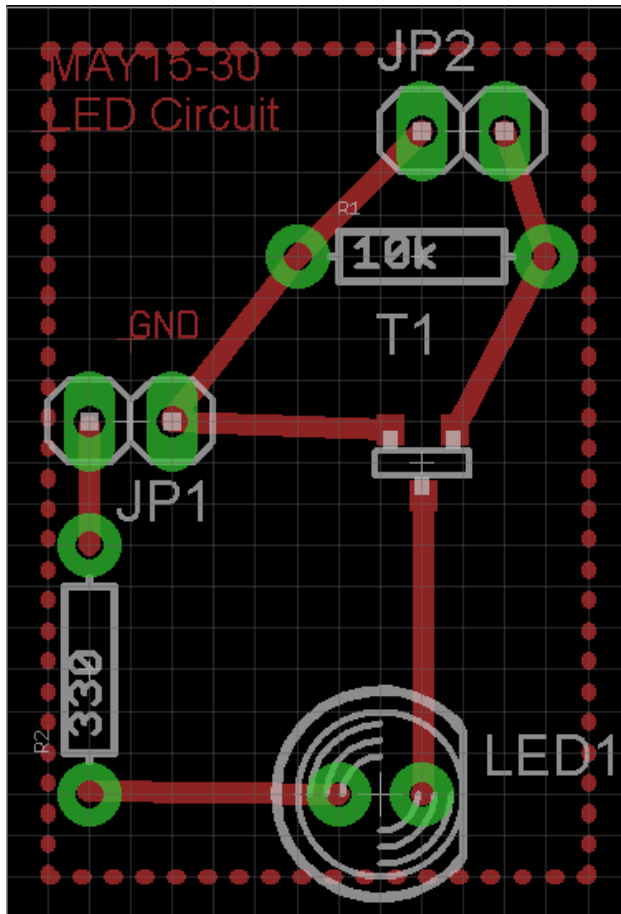


Figure 5: Eagle Circuit Layout

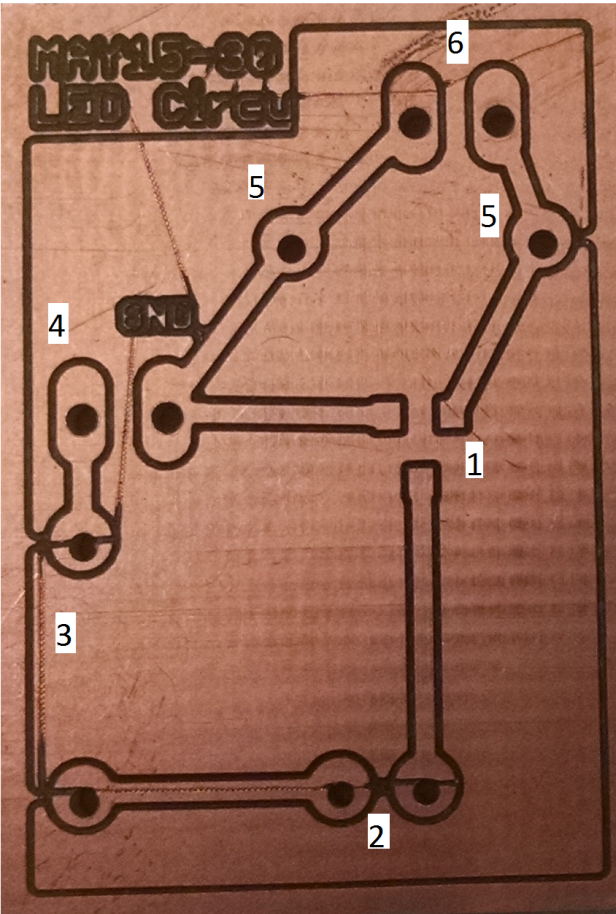


Figure 6: Eagle Circuit PCB

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

Table 1: Figure 6 Description

6.1 PCB Issues

As can be seen in Figure 6 as the unpredicted, notched lines, the Protomat S62 damaged parts of the PCB. 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).

7 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.

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	digkey.com	6	\$0.50	\$3.00
Resistor	digkey.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 2: Prototype Hardware and Software Cost

Testing Prototype Components

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 3: Testing Prototype Components Cost

Final Product

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

Table 4: Final Product Cost

8 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
Starting	Oct 6	Oct 13	Oct 20	Oct 27	Nov 3	Nov 10	Nov 17	Nov 24	Dec 1	Dec 8	Dec 15	Dec 22	Dec 29	Jan 5	Jan 12	Jan 19	Jan 26	Feb 2	Feb 9
Semester One	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																		
Semester Two																			

Table 5: May15-30 Project Schedule

P R O J E C T E N D

9 Conclusion

Overall, 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.

9.1 Client

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

9.2 Team Information

Team Member	Team Role	Email Address
Adam Kaas	Team Leader	ajkaas@iastate.edu
Gregory Fontana	Team Co-Webmaster	fontana@iastate.edu
Meiyong Himmtann	Team Co-Webmaster	himmtann@iastate.edu
Brittany Duffy	Team Communication Leader	baduffy@iastate.edu
Megan Sharp	Team Co-Key Concept Holder	megsharp@iastate.edu
Brandon Dixon	Team Co-Key Concept Holder	bmdixon@iastate.edu
Alain Ndoutoume	Team Commissioner	alain@iastate.edu

Table 6: Team Information

9.3 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