Fast, Compact, High Strength Magnetic Pulse Generator

PROJECT PLAN2

Team Number: DEC1622

Client: Iowa State University High Speed Systems Engineering Lab

Advisers: Dr. Mani Mina, Neelam Prabhu Gaunkar

Team Members
Team Leader: Wei Shen Theh
Communication Leader: JiaYu Hong
Webmaster: Wing Yi Lwe
Key Concept Holder: Aqila Sara Zulkifli

Team Email: dec1622@iastate.edu
Team Website: dec1622.sd.ece.iastate.edu

Contents

Abbreviations

EMF	- Electromotive Force
MO	- Magneto Optic
MOSFET	- Metal Oxide Semiconductor Field Effect Transistor
BJT	- Bipolar Junction Transistor
DC	- Direct current
PCB	- Printed Circuit Board
PSpice	- OrCAD Capture CIS

1 Introduction

1.1 Problem statement & purpose

The objective of this project is to design and fabricate a compact circuit that generates a high strength and high speed magnetic pulse. High speed technological systems such as fiber optics need fast optical switches during transmission of information. In our project, we will be designing a magnetic field generator that can be used to achieve faster switching based on the magneto-optic effect [1]. An example is shown below to further explain its applications.

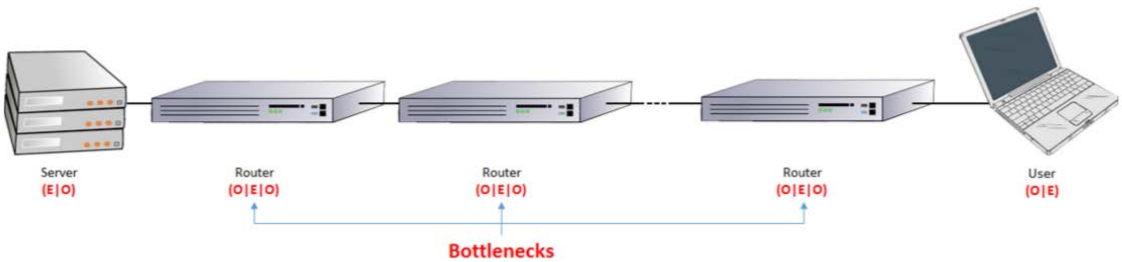


Figure 1: Simple fiber-optic network showing OEO interfaces

From the server, data is transferred from router to router until it reaches the user. At these routers, data, in the form of optical energy, had to be converted to electrical energy then back to optical energy before leaving the router. This creates a bandwidth bottleneck as electrical systems cannot match the bandwidth capabilities of fiber-optic ones. Hence, the generator we make can be used in a new optical router that can prevent the bottlenecks [1].

1.2 Goals

For this project, our goals is to provide:

1. Improved circuit design for magnetic field generation
2. Proof of concept prototype that can generate magnetic pulse in at least 1 microsecond and a magnetic field strength greater than 500 Gauss.

2 System Description

2.1 Previous work/literature

A previous group of undergraduate seniors have done this kind of project before and during our meeting with our adviser, we were able to see some example of prototypes done by them. We also read their documents [2] which includes their weekly reports, project plan, and design documents which were very helpful to our team. This helped us with our thought process briefly on how the circuit works, what we needed to emphasize when building the circuit and our design space variables (inductance value, MOSFET current output). Their design successfully meets the 1 microsecond and 500 Gauss magnetic field which we will strive to improve by the end of semester 2.

2.2 Concept Sketch

Figure 2 represents a simple diagram on how the circuit works. An input pulse will be fed into the system which will control the on/off of the MOSFET switch. The MOSFET of choice should display adequate switching speed to keep delay at a minimum. When the MOSFET is closed, the capacitors can quickly discharge to produce a high current which flows through the inductor. The inductor will then store the charge as magnetic field.

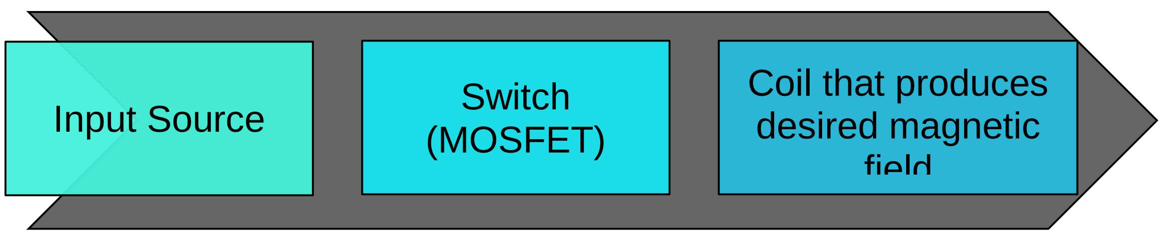


Figure 2: System Level Diagram

2.3 Systems Level Diagram

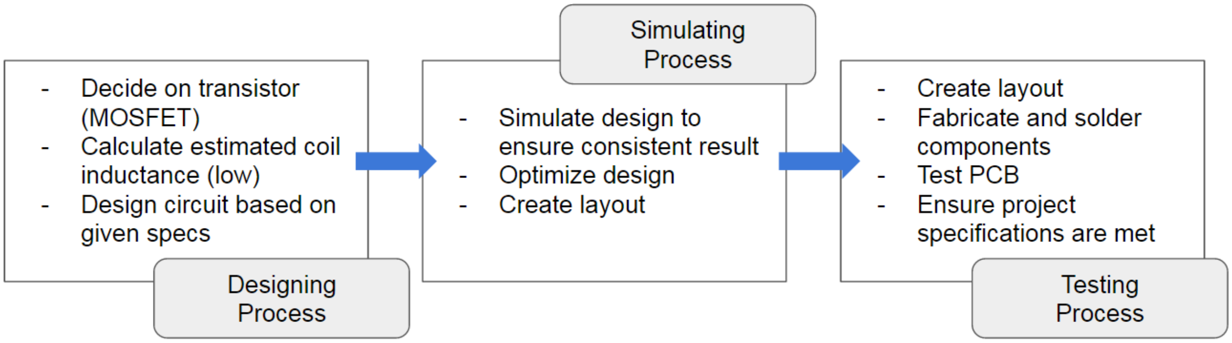


Figure 3: System level diagram

Figure 3 shows the team's three phases of the project; designing, simulating and testing. We are currently at the end of the second phase where the design of the circuit is being optimized by:

1. Searching for better MOSFET alternatives as our switch
2. Changing values of our circuits for the benefit of our understanding of how the circuit works (as mentioned in the design document)
3. Trying new circuits to compare their results which will be further explained below

2.4 Simulations

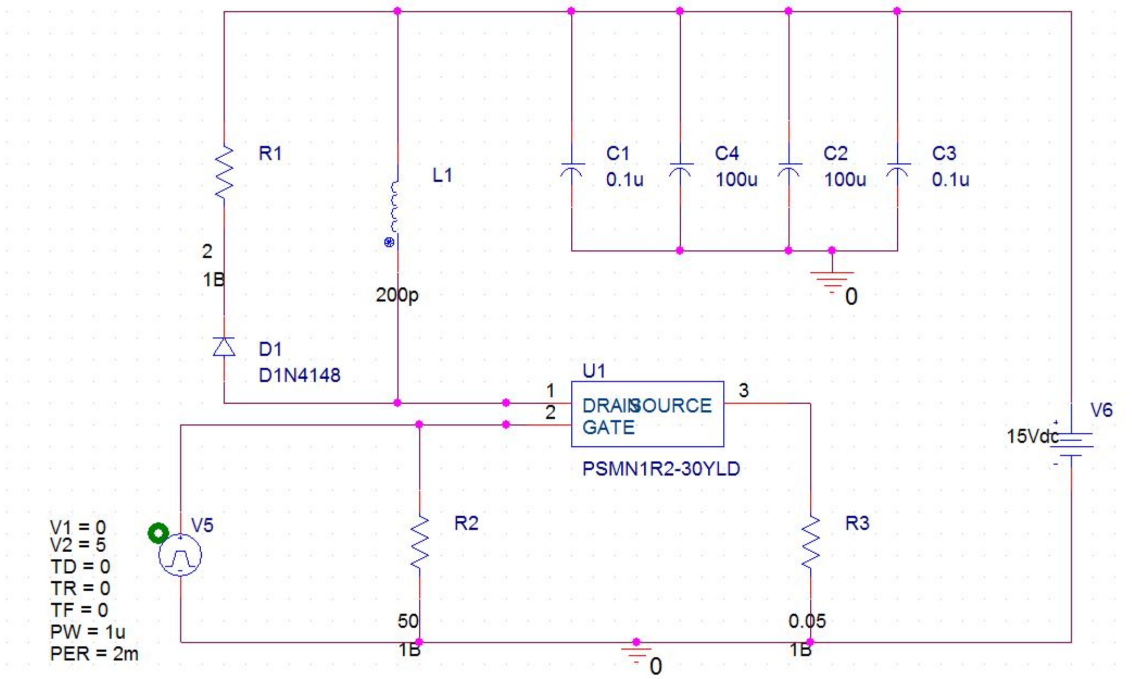


Figure 4: MOSFET Circuit

As shown in *Figure 4*, we used PSpice in the simulation and creation of the circuit. PSMN1R2-30YLD (U1) was used as the switch. This MOSFET was chosen because it was designed for fast switching without having high leakage currents. This is an n-channel MOSFET made by NXP Semiconductor with a rated Drain to Source Voltage (V_{dss}) of 30V and Continuous Drain Current (I_d) of 100A at 25°C.This is also a surface mount component. Since magnetic field strength is directly proportional to the current flowing through the coil (equation shown below), this circuit is specifically design to achieve an inductor current of 50A.

$$B = \mu \frac{Nl}{(l^2 + 4R^2)^{.5}}$$

R: The radius of the coil

l: The length of the coil

N: The number of turns of coils

2.4.1 Capacitor

For this circuit, four capacitors were connected in parallel. Two capacitors will have a much higher capacitance value (100uF) than the other two (0.1uF). The two larger capacitors will store energy so that there will be more current flowing through the inductor. While the smaller capacitors will act as a protector for the Vdc current since there are spikes showing up for the current through the inductor.

2.4.2 Diode

Instead of just flowing through the 2Ω resistor, the current needs to go through the inductor as well. Therefore, by putting a diode, it will help the current to go through the loop.

2.4.3 Resistor

A 2Ω resistor is placed in series with the diode 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.

Besides that, this design also used 50Ω surface mount resistor in the gate of MOSFET. This resistor is aimed at achieving maximum power efficiency into the gate of the MOSFET. According to EE 201 course, maximum power efficiency can be achieved when the two parallel resistors are of the same value .The reason that gate resistor is 50 Ω is to match a 50Ω from the function generator.

2.4.4 Inductor

The objective is to generate 500 Gauss magnetic field. Since the magnitude of the magnetic field is directly proportional to current (equation shown below), the magnetic field strength is higher when the current is high as well. We placed a current sensing resistor near the source of the MOSFET to act as a pull-down resistor (although not very effective since the resistance value is relatively low) and to help measure the current flowing through the inductor since the two components are connected in series. In addition, we will be focusing more on the current change while voltage is an observation reference.

$$B = \mu \frac{Nl}{(l^2 + 4R^2)^{.5}}$$

R: The radius of the coil

l: The length of the coil

N: The number of turns of coils

Using the method of controlled variable, we will explore how the value of the inductor affects overall performance.

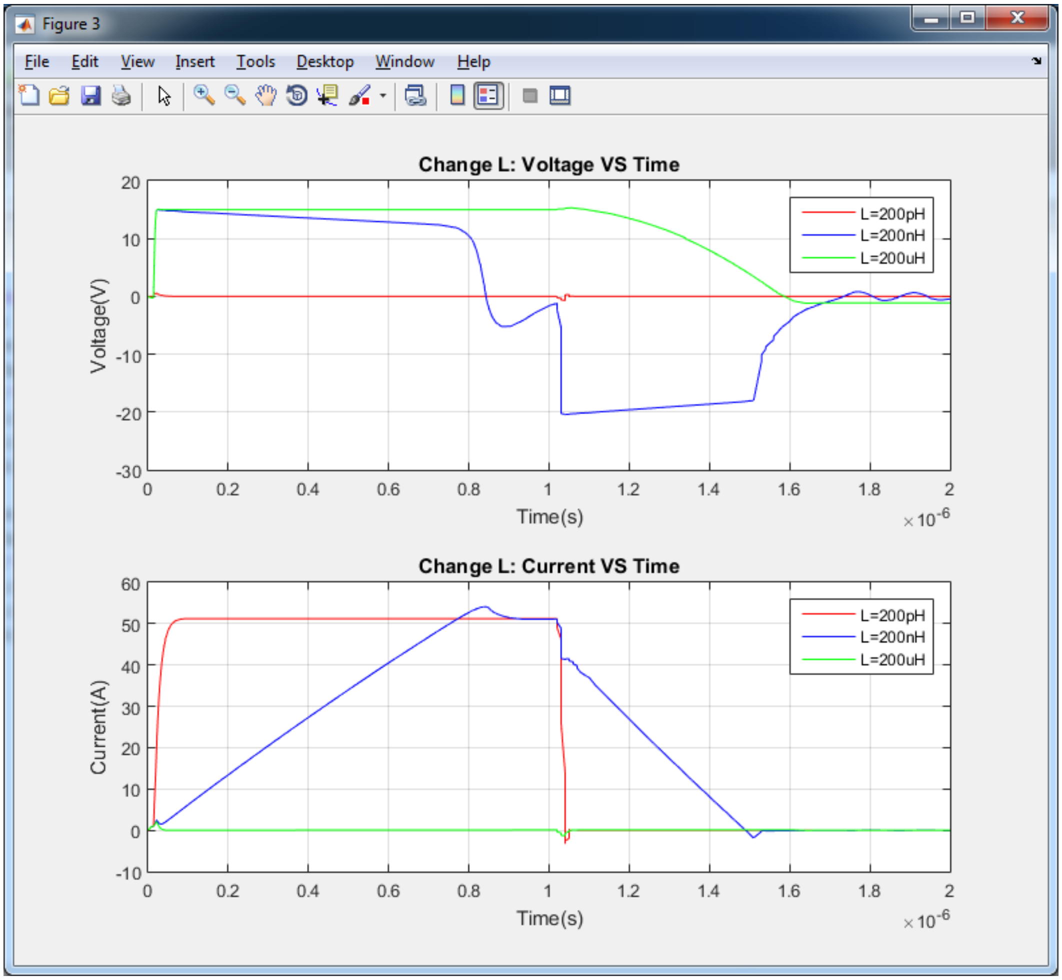


Figure 5: Values of voltage and current across inductor

Figure 5 clearly indicates that different values of inductor will affect the inductor current. The inductor current decreases with an increase in inductance. Here is an interesting result: when inductance is set as 200pH, the inductor current forms a nice pulse peaking slightly more than 50A; when inductance is increased to 200uH, the inductor current totally loses its pulse form and its magnitude is close to zero. Our assumption is a larger inductance will require a longer charge time. For a circuit with high inductance value and the input pulse is high (MOSFET is on), the inductor takes in charges hence maintaining the current close to zero. The pulse period is too short to fully change the inductor and the input pulse goes low even before it starts discharging hence maintaining the current near zero all the time. According to the law of conservation of energy (P = VI), a high current will require a low voltage to maintain the conservation of power energy. When L = 200pH, the inductor current is 50A, but the inductor voltage is low, which abides by the aforementioned conservation law.

2.4.5 Different Switch

We also tried a Darlington pair (MJD44E3T4) to act as a switch of the circuit. This is a NPN BJT made by ON Semiconductor with a rated Collector Emitter Breakdown Voltage of 80V and Collector Current (I_c) of 10A. BJTs typically display more favorable results compared to MOSFETs because of the lack of the small signal parameters r_Π (input impedance at base). However, BJT also has low collector current hence requiring a pair in a Darlington structure to boost up the current. The tradeoff is this structure consumes more power.

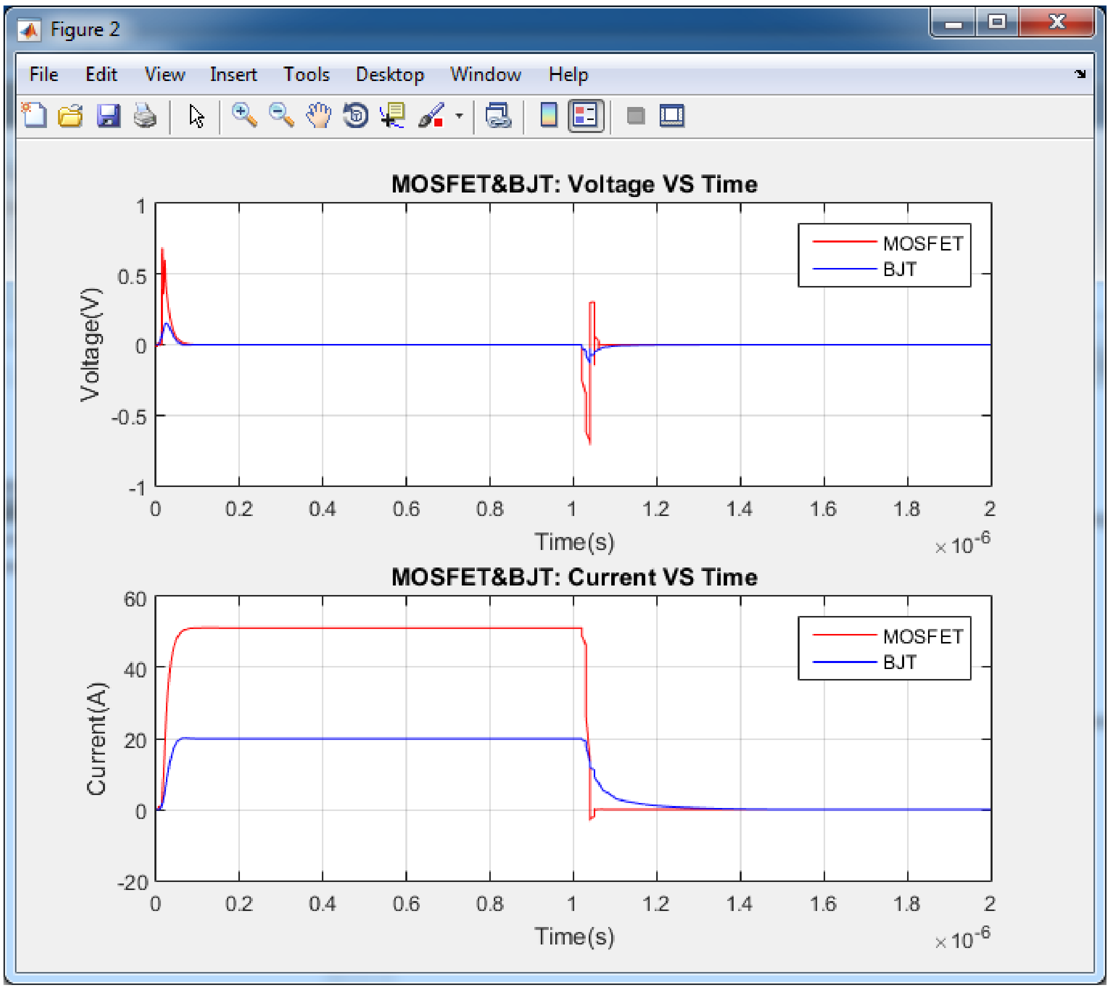


Figure 6: Voltage and current through the inductor using MOSFET and BJT

From the plot of *Figure 6,* we can observed that inductor current when using Darlington is less than half of a MOSFET circuit. In addition, rise and fall time of current pulse with MOSFET is much faster than Darlington.

3 Project Requirements

3.1 Deliverables

In two semesters, design and fabricate an electronic circuit with a small coil that can pulse magnetic fields with amplitudes of 500 Gauss at minimum in 1 microsecond.

Semester 1 - Provide a design approach and a prototype that can achieve at least 100 microsecond, 500 G pulses.

Semester 2 - Provide a working final device, professionally fabricated, that meets specifications.

3.2 Functional Requirements

1. Generate magnetic fields with an amplitude of 500 Gauss in 1 microsecond
2. DC power voltage supply of 15V or less
3. Final product connected to fiber optic ports at the input and output

3.3 Non-functional Requirements

1. Design dimensions: 3.5” x 2”
2. Fabrication process done on industrial grade PCB
3. Results not only meets requirements but remains consistent

4 Challenges

4.1 MOSFET

Our main challenge is to find a replacement for the MOSFET (PSMN0R9-30YLD) that has a high continuous drain current (Id) which is a crucial factor for a stronger magnetic field (Gauss). The MOSFET mentioned is no longer distributed by Digikey and the team has been searching for a replacement MOSFET that has similar specifications. Fortunately, we have found a MOSFET (PSMN1R2-30YLDX) that has the similar specifications needed which are:

1) Drain to Source Voltage of 30V
2) Current continuous drain (Id) of 100A

When tested, the simulation shows an output current that is slightly lower than the original MOSFET. However this should not be too much of an issue since we can design our coil accordingly with a reasonable radius and number of turns.

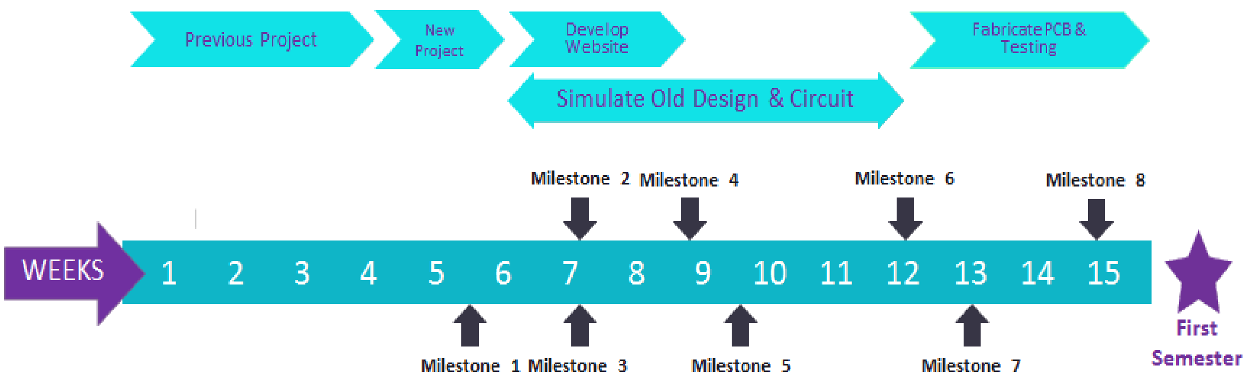
5 Resource requirements

Quantity	Digi-Key Part Number	Item Description	Cost Per Unit	Total Cost	Vendor	Link
10	497-6085-1-ND	Diode	$0.45	$4.50	Digi-Key	digikey link
3	MP725-0.050-FCT-ND	0.05Ω Current Sense Resistor	$9.37	$28.11	Digi-Key	digikey link
10	P2.2ECT-ND	2.2Ω Resistor	$0.10	$1.00	Digi-Key	digikey link
10	P49.9FCT-ND	49.9Ω Resistor	$0.10	$1.00	Digi-Key	digikey link
10	P422FCT-ND	422Ω Resistor	$0.10	$1.00	Digi-Key	digikey link
10	P1.3KECT-ND	1.30KΩ Resistor	$0.10	$1.00	Digi-Key	digi key link
10	P1.43KFCT-ND	1.43KΩ Resistor	$0.10	$1.00	Digi-Key	digikey link
100	160-1169-1-ND	Green LED	$0.14	$14.40	Digi-Key	digikey link
10	1276-2740-1-ND	0.01 µF Capacitor	$0.13	$1.30	Digi-Key	digikey link
10	399-3677-1-ND	0.1 µF Capacitor	$0.38	$3.80	Digi-Key	digikey link
10	399-5214-1-ND	100 µF Capacitor	$1.12	$11.17	Digi-Key	digikey link
10	490-1312-1-ND	0.01 µF Capacitor (Ceramic)	$0.01	$0.12	Digi-Key	digikey link
5	ED2675-ND	Wire-to-Board Connector (30A/300V Rating)	$1.13	$5.65	Digi-Key	digikey link
10	ED10561-ND	Wire-to-Board Connector	$0.55	$5.46	Digi-Key	digikey link
			Total cost:	$79.51		

Table 1: Cost Estimate (Semester 1)

6 Timeline

6.1 First Semester



Milestones:

1. Simulate simple circuit to explore how MOSFETs act as switches to generate continuous pulses.

2. Read documents from the previous team and additional electromagnetism materials, and explore multiple electronic design automation software for best options in fabricating PCB.

3. Simulate previous team's circuit and understand how it works.

4. Analyze the advantages and disadvantages of the previous team's design.

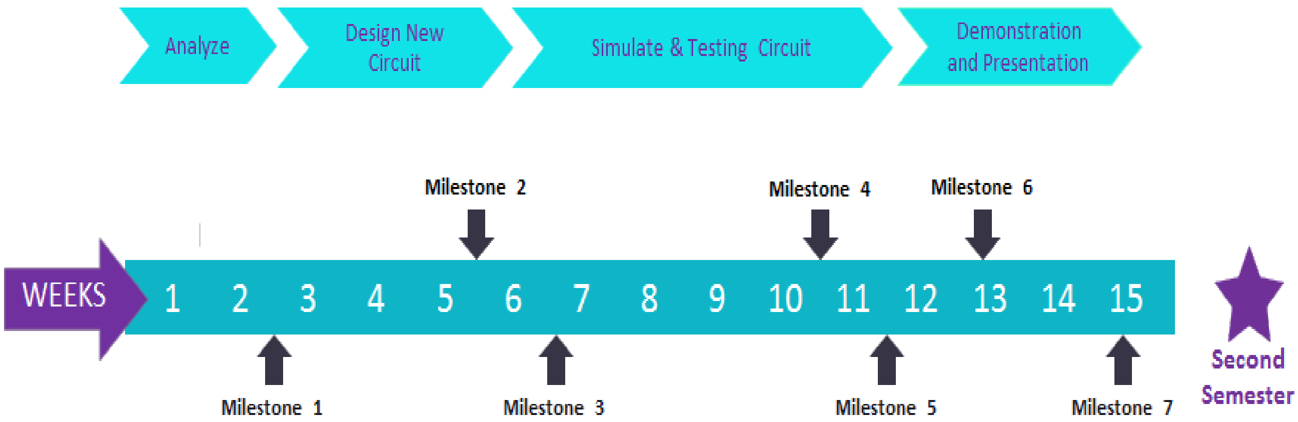
5. Do research to improve the circuit outcome. (Current phase)

6. Fabricate PCB board on campus and solder components onto the board.

7. Conduct trials and troubleshoot the board.

8. Verify board produces output as per specifications.

6.2 Second Semester



Milestones:

1. Analyze first semester circuit's advantages and disadvantages.

2. Do research and consult advisers to further improve the circuit performances.

3. Fabricate revised PCB and solder on components.

4. Test and troubleshoot revised circuit.

5. Verify final design produces outputs as per specifications or better.

6. Prepare final design for demonstration and presentation.

7. Demonstration and presentation to client.

7 Conclusions

The team has gone through considerable amount of simulations and designs in order to find one that will meet our specifications. This has allowed us to understand the basic design circuit for magnetic pulse generation. After obtaining the desired results, we will be able to move into the last phase of our project which is layout designing through Eagle PCB and fabrication of our prototype. As shown in our report, we are striving to obtain an output pulse widths of 1 microsecond although the requirements for this semester is 100 microseconds in order to help us realise our goals for the second semester which is to get it to be less than 1 microsecond. We also need to shift our focus to obtain enough magnitude of the magnetic pulse, 500 Gauss.

8 References

1. Pritchard, John. Mina, Mani, Robert, Narimdinda. N.p.. 2013. Mon. 4 Apr. 2016.<http://viewer.zmags.com/publication/17fde0ad#/17fde0ad/6>.
2. "May15-30." *May15-30*. N.p., n.d. Web. 19 Feb. 2016. <http://may1530.ece.iastate.edu/>.
3. Horowitz, Paul; Winfield Hill (1989). The Art of Electronics. Cambridge University Press. ISBN 0-521-37095-7
4. "Main Page." *High Speed Systems Engineering Lab RSS*. N.p., n.d. Web. 19 Feb. 2016. <http://wiki.eng.iastate.edu/high-speed-systems-engineering-lab/index.php/Main_Page>.
5. "EE 333 : Lab." *EE 333 : Lab*. N.p., n.d. Web. 19 Feb. 2016. <http://tuttle.merc.iastate.edu/ee333/lab.htm>.
6. "NI Multisim and Ultiboard Technical Resources." *Getting Started With NI Multisim*. N.p., n.d. Web. 19 Feb. 2016. <http://www.ni.com/multisim/technical-resources/>.
7. "Magnetic Field Generator Design for Magneto-Optic Switching Applications." *IEEE Xplore*. N.p., n.d. Web. 05 Apr. 2016. <http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6558961>.