EE 492 - Senior Design

High Speed Magnetic Pulse Generator

Final Report

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Introduction

Problem Statement

Magnetic field pulse generators have been used for various applications across many different electrical engineering disciplines. Technical requirements of generator systems vary based on the specific application. One of these applications is magneto-optical (MO) switching within fiber optic networks. These networks currently use optical switches and routers to direct signals to desired paths defined by electrical energy. During this process, the conversion from optical energy to electrical energy causes problems. Due to the different bandwidths between optical systems and electrical systems, the signal is not directed to its desired path as quick as needed. However, by utilizing the magneto-optic effect (Faraday effect), the router switching can be achieved without optical-electrical conversion and, consequently, without the high switching latency. One way of inducing the MO effect on the switching system is by applying a strong and quick magnetic field pulse. Past circuit designs have shown that it is possible to create pulse generators with relatively high power and speed. However, there is room for improvement in pulse strength, rise time, and power efficiency.

Project Purpose

The purpose of our project is to design and implement a circuit that generates a quicker, stronger pulse while also improving power efficiency. This would provide a more practical way to use magnetic pulse generators in optical switching.

Project Goals

The goals of this project are fourfold:

1. Gain a deep, applicable, and robust understanding of magnetic pulse generator concepts and circuit theory that will help us in our future careers and education.
2. Build a circuit that can generate a 500 Gauss magnetic field pulse with a rise of at most, 100 nanoseconds.
3. Identify a more effective method of directly measuring the current through the circuit coil

Design

System Requirements

Functional

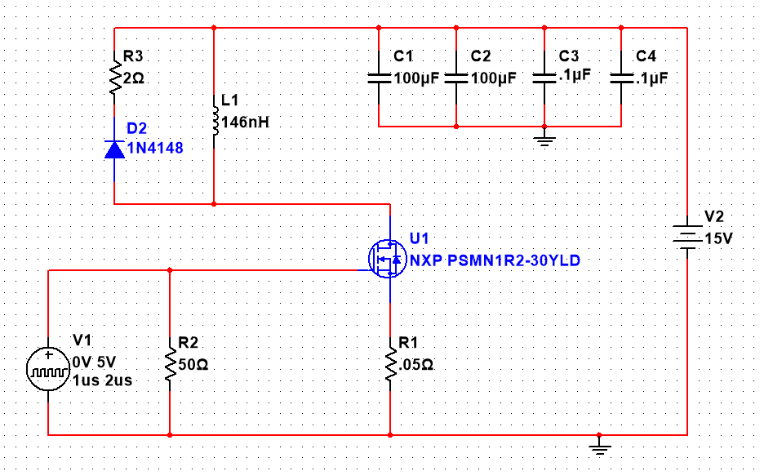
1. The product shall output a magnetic field pulse peaking at 500 Gauss with rise time of less than 100 ns
2. The DC power supply must not exceed 15 V
3. The transmitting coil must be fitted for the fiber optic cable

Non-Functional

1. The product must be on a PCB with a footprint of less than 3.5” x 2”
2. The product output must consistent
3. The product must be fitted in an insulating enclosure
4. The product must have quality soldering for long time using

Fundamental Design

Figure 1: Fundamental Circuit Design



Fundamental Components

Resistors

1. The 2 ohm resistor (Figure 1 - R3) placed series with the diode is used to dissipate some of the energy in its loop. Because there is such a large amount of current flowing through the inductor, this resistor is needed to stabilize the circuit.
2. The resistor in parallel with the pulse source (Figure 1 – R2) is used to match the output impedance of the source. For this source, we are using a Tektronix AFG 3021B function generator which has a 50 ohm output impedance. Matching this impedance is vital in order to prevent signal reflection. In other words, this causes all of the power output of the source to reach the gate of the MOSFET (ideal case).
3. The resistor connected to the MOSFET source (Figure 1 – R1) is used to control the current through the inductor. Because the inductor path can be characterized as an LR circuit, its current pulse characteristics can be controlled through R1. This resistor is also used to measure the current through the inductor (in series with the inductor when the MOSFET is “on” (see Future Work section).

Capacitors

In order to produce such a high current through the inductor, the circuit needs a dedicated capacitor bank. Our circuit contains a bank of four capacitors in parallel, creating 200.2 μF of energy storage. The two larger capacitors (C1 and C2) are primarily used to store the charge from the DC source that is eventually sent through inductor, creating the magnetic field. The two smaller capacitors (C3 and C4) act as protection against harmful current spikes. Because the DC source is only 15 V, this capacitor bank is essential in creating the necessary current flow through the coil.

Diode

The diode placed in series with the resistor can seem as a voltage regulator. We use this diode to make our output stable. The diode can keep a constant voltage at the inductor, so the current through the inductor can be stable, so that the magnetic field pulse from the inductor will be better.

Inductor

The inductor is one of the most important components in our circuit. When calculating the coil's specifications, we have referenced the bottom two equations. Our project requirements are to generate a magnetic field (B) pulse peaking at no less than 500 Gauss with a rise time of no more than 0.15 μs. Combining these two requirements essentially defines our current and inductance levels for us, therefore leaving us with specific coil dimensions. For further analysis on this concept, please refer to the Future Work section of this document.

$$B = \frac{\mu N I}{\sqrt{l^2 + 4R^2}} \qquad L = \frac{\mu N^2 \pi R^2}{\sqrt{l^2 + 4R^2}}$$

B = magnetic field (Teslas)

I = current through the coil (Amperes)

L = inductance (Henries)

l = length of the coil (meters)

μ = permeability of free space ($4\pi \times 10^{-7}\ H/m$)

R = radius of the coil (meters

N = number of turns in coil

MOSFET

Throughout all of last semester (EE 491) we used the same MOSFET that last year's senior design team used for this project. However, as we've moved further in the design optimization process, we have decided to test other

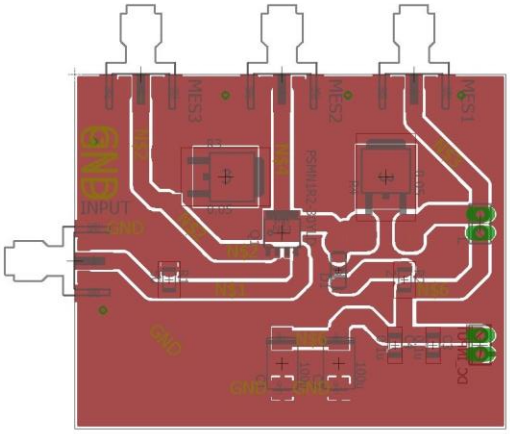
MOSFET options. For an in-depth explanation of our new MOSFET work, please refer to the “new MOSFET options” section of this report.

New Design Ideas

Current-Sense Resistor

The previous team’s circuit uses the resistor at the MOSFET source as a current-sense resistor. However, we believe that placing a small resistor in series directly next to the inductor would provide a more accurate way of measuring inductor current and, therefore, magnetic field strength. In the beginning of this semester, we worked on a test board layout that leaves two openings for resistors (figure 2): one next to the inductor and one connecting the FET source to ground. This gave us an easy way to test our hypothesis that the new resistor placement would lead to better test results.

Figure 2: New Current-Sense Resistor Layout



New MOSFET Options

Last year’s group used a different MOSFET with bigger resistance achieve a shorter rise time. We hope to find a new MOSFET with higher resistance, and lower input capacitance to achieve a shorter rise time. Also, we may have to modify other circuit components such as DC power level and/or capacitor bank.

Theory:

t (time constant) = L/R = RC

Rise time ~ 5t.

By keeping L constant, increasing R decreases t.

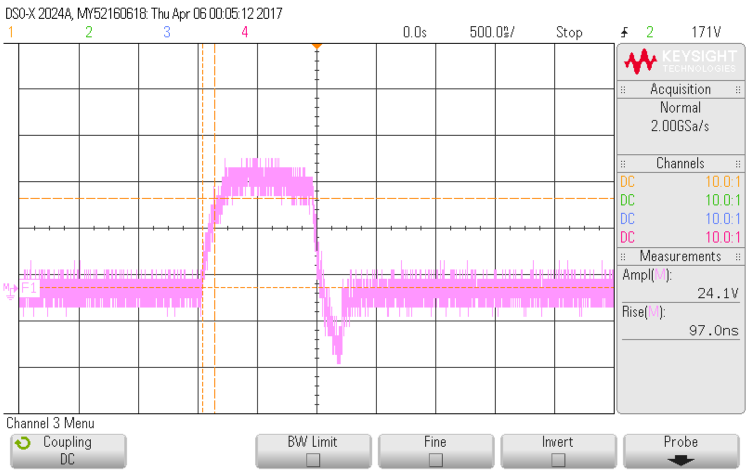
R = total series resistance of circuit = resistance of current sense resistor + MOSFET resistance

Three new MOSFETs are chosen by us: TI CSD17507Q5A; TI CSD18542KCS; TI CSD18563Q5A

Design Analysis

Current-Sense Resistor

This testing shows the difference between our old and new placements of the current sense resistor From the above results, we found in our new place of current-sense resistor (figure 3), it has a better performance than the old one (figure 4). First, the new one has a much shorter rising time than the old one. Second, from the waveform, we found the new current-sense decreased ringing at the end of the pulse by comparing the old current-sense resistor. This is a significant improvement from previous groups. We do observe some noise in the differential calculation, which could have a slight effect on results. However, we believe our results are significant because the pulse can now be measured in a more direct way and not through the MOSFET (which contains parasitic capacitance).


DSO-X 2024A, MY52160618: Thu Apr 06 00:05:12 2017

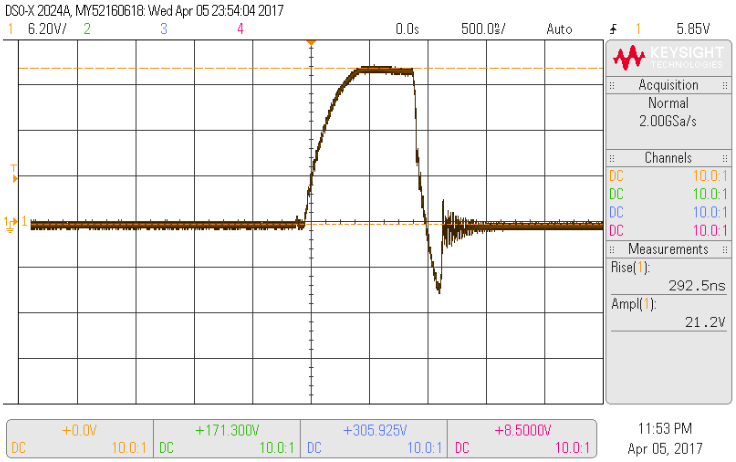
Acquisition: Normal, 2.00GSa/s

Ampl(M): 24.1V

Rise(M): 97.0ns

Figure 3: New Current-Sense Resistor Pulse Waveform

Figure 4: Old Current Sense Resistor Pulse Waveform



DSO-X 2024A, MY52160618: Wed Apr 05 23:54:04 2017
1 6.20V/ 2 3 4 0.0s 500.0ns/ Auto 1 5.85V
Acquisition
Normal
2.00GSa/s
Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1
Measurements
Rise(1):
292.5ns
Ampl(1):
21.2V
+0.0V DC 10.0:1
+171.300V DC 10.0:1
+305.925V DC 10.0:1
+8.5000V DC 10.0:1
11:53 PM
Apr 05, 2017

New MOSFET Options

In order to test new MOSFETs, we created two types of testing boards: solder-version and wire-version. For the smaller surface-mount FETs, we used the solder-version (figure 5) and for the larger through-hole FETs we used the wire-version board (figure 6). Please view the below table and waveform figures for results.

MOSFET	Input Capacitance	ON Resistance	Amplitude	Rise/Fall Time	Connection Type	Result
CSD 17507Q5A	**0.41nF**	**20mΩ**	**1.57V**	**9.5ns**	**Soldered**	**Figure 7**
CSD 18542KCS	**3.9nF**	**10mΩ**	**0.96V**	**756ns**	**Wired**	**Figure 8**
CSD 18563Q5A	**1.15nF**	**>25mΩ**	**1.62V**	**80ns**	**Soldered**	**Figure 9**

Figure 5: Solder-Version Testing Board

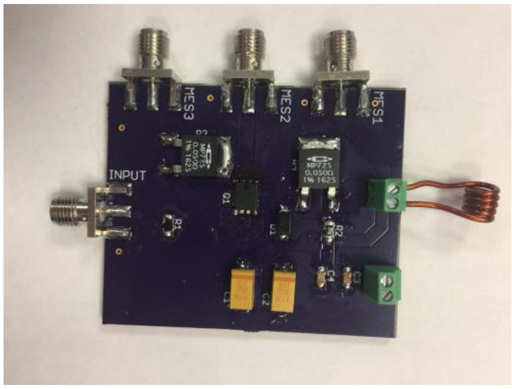


Figure 6: Wire-Version Testing Board

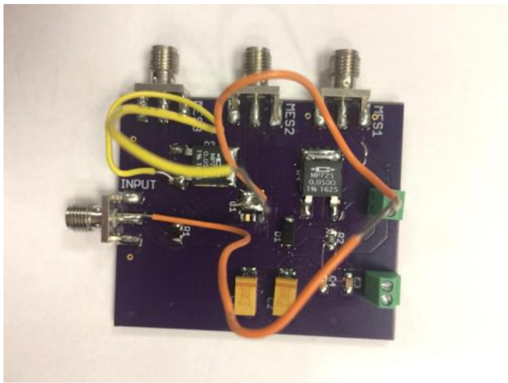


Figure 7: CSD17507Q5A

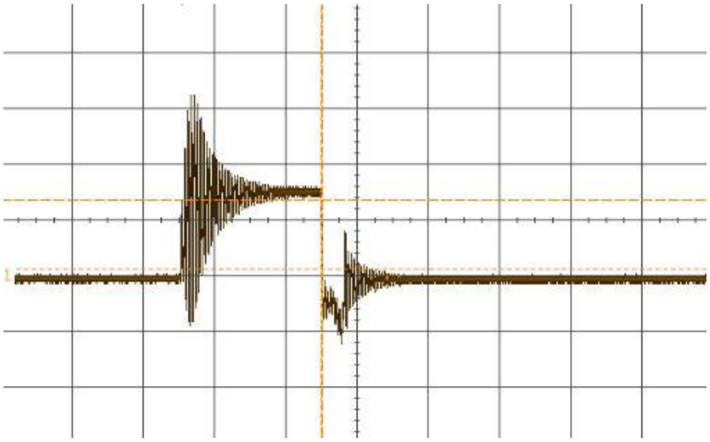


Figure 8: CSD18542KCS

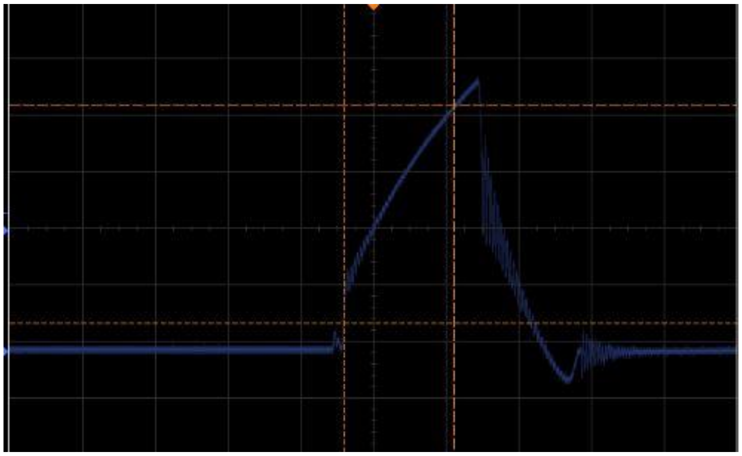
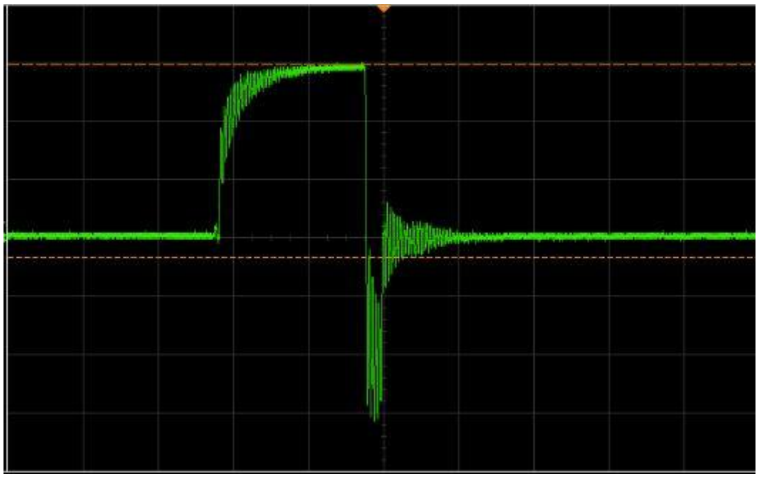


Figure 9: CSD17507Q5A



Future Work

1. Further MOSFET testing for:
    a. Less ringing
    b. Faster rise time
    c. Faster fall time
2. Filter out high-frequency noise in differential measurement
    a. Low-pass filter designed according to resonance frequency

Appendix I: Operation Manual

- Necessary equipment:
    - Function generator (Tektronix AFG 3021B)
    - DC Power Supply (Agilent E3631A)
    - Oscilloscope (Tektronix DPO 4032)
    - 4 50 ohm Coaxial Cables (with SMA adapters)
    - 2 banana-to-breadboard cables
- Testing Setup:

1. Connect coax cables to scope and function generator
2. Connect banana-to-breadboard cables to +25 (red) and GND(black) ports of DC supply
3. Turn on all equipment
4. Set DC power supply to +15V
5. Set function generator to:

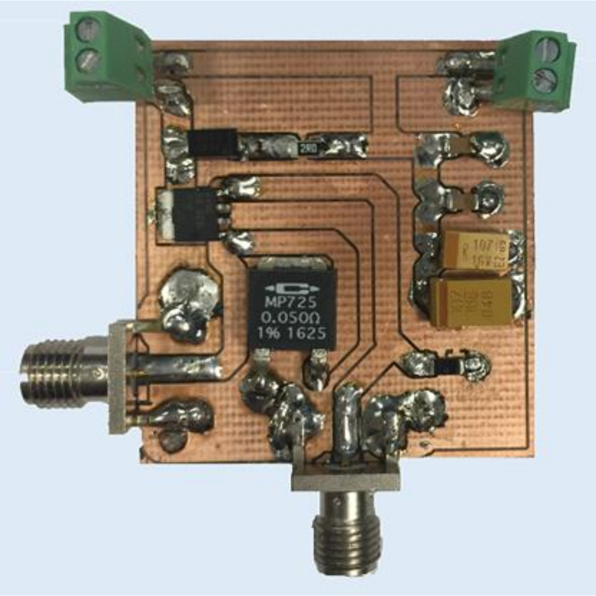
Period 1.000 000 00 ms
Delay 0.00 ns
High 5.000 V
Low 0 mV
Width 1.0000 µs
Leading 18.00 ns
Trailing 18.00 ns

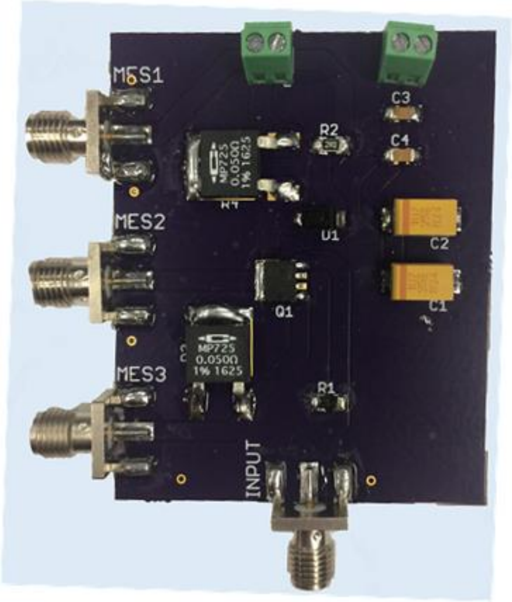
   a. Function = Pulse
   b. Period = 1ms
   c. Pulse Width = 1 us
   d. High level = 5 V
   e. Low level = 0 V
   f. Output Impedance = 50 ohm
6. Connect scope cables to board as follows:
   a. Channel 1 = MES1
   b. Channel 2 = MES2
   c. Channel 3 = MES3
7. Connect DC supply to port on board (see picture)
8. Connect function generator cable to INPUT port
9. Choose coil and connect leads to port (see picture)
10. Turn DC supply and function generator output “ON”

- Measurement Instructions:
   a. Autoscale scope
   b. Choose desired measurement:
      - Channel 3 = pulse measurement at current sense resistor at source of FET (figure 4 above)
      - MATH: Channel 1 - Channel 2 = differential pulse measurement (figure 3 above)
   c. Zoom and scale enough to see the full pulse (so that rise time can be calculated)
   d. Use “measurement” button to measure rise time, amplitude, fall time, etc.

Appendix II: Other Designs

First Design	Latest Design


MP725
0.050Ω
1% 1625


MES1
MES2
MES3
INPUT
R2
C3
C4
U1
C2
C1
Q1
R1
R4
MP725
0.050Ω
1% 1625