Independent Design Project

Coil-Gun Experiment

Electronics Lab

Instructor: Dr. Chad Davis

Course: ECE 3973-010

By: Ged Miller

Fall, 2022

Independent Design Abstract

For a long time, I have had an interest in electromagnetic propulsion, from maglevs to magnetic confinement. For this project, I would like to build a safe coil-gun to better understand the electromagnetic principles and also test how the material of the projectile can affect the coil-gun's attributes.

The coil-gun will need to meet three main requirements: a hall effect sensor to measure the magnetic field, there must be a timer circuit used between each shot, and the intensity of the electromagnetic field must be adjustable. These three constraints allow me to pursue a subject of interest whilst also implementing idea's learned in class.

The hall effect sensor will help gauge the strength of the electromagnetic fields produces. The output of the sensor will then be used in conjunction with MOSFETS to light up a green, yellow, or red LED to indicate the field strength.

The timer circuit will be used to delay firing speed so that the coil-gun's capacitors have enough time to recharge. The timer will ignore inputs from the trigger (most likely a switch) that are sent before the designated recharge cycle is complete.

Lastly, a potentiometer will probably be used to change the strength of the electromagnetic field.

Although a coil-gun is not unique, nor particularly hard to build, these circuit additions should add a complexity and relevance to course material that deems the project worthy.

Introduction:

This lab experiment aimed to create a coil gun with integrated sensors to test the strength of the force generated by the magnetic fields created whilst also testing how the dielectric constants of different materials affect how far the projectile is flung. The coil gun will have three primary interfaces that allow the user to collect data and adjust parameters. Potentiometers will be used to limit the voltage, thus allowing for the strength of the magnetic field to be adjusted. A timer circuit will enable the capacitor bank to have ample time to recharge. Lastly, a hall effect sensor and LEDs will be used to display the strength of the electromagnetic field generated.

Materials:

Component	Quantity
5” PVC Pipe	1
Breadboard	1
Electrical Tape	1
3” Steel L bracket	1
5’ 15 AWG Copper Wire	2
Steel BB’s	5000
Copper Plated Steel BB’s	5000
Lead BB’s	250
Tungsten Fish Weights	3
AA Batteries	5
AAA Batteries	5
9V Batteries	9
Hall Effect Sensor	1
Green LED	2
Red LED	1
Yellow LED	1
680Ω Resistor	5
2n7000	4
50kΩ Potentiometer	3
100uF Capacitor	1
0.1uF Capacitor	1
SPST Switch	1
555 Timer	1

Design:

A coil gun takes advantage of Lenz's Law, in which induced current flows in a direction that opposes the change that created it. This allows a ferromagnetic material to move when going through an electrically charged loop. The loop attracts the ferromagnetic material since the magnetic field flows around it. According to the right-hand rule, the force upon the material will be through the current loop, as shown in Figure 1. The design has three discrete circuits, the firing circuit, the magnetic field circuit, and the timer circuit.

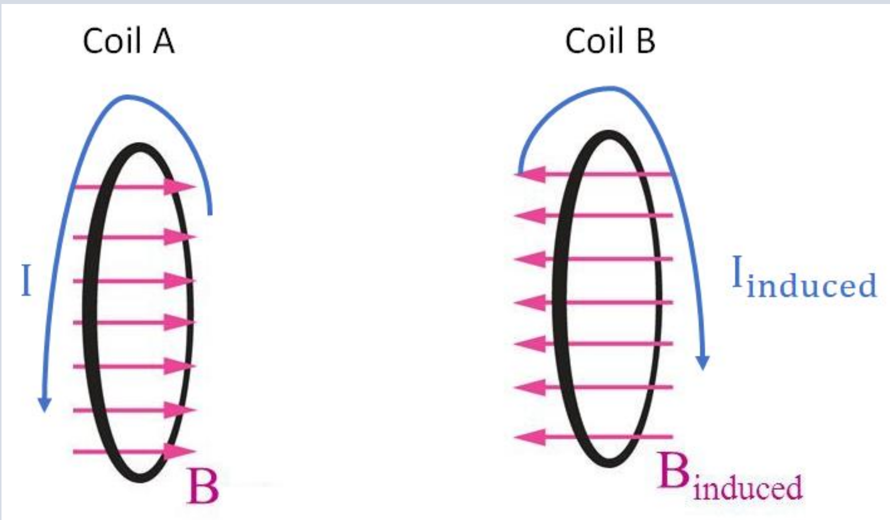

Figure 1: Altium.com Lenz's Law simulation.

The coil gun used 10 feet of 15AWG Copper wire, wrapped around a ½ inch in diameter PVC Pipe. The length of the copper coil is about 3 inches.

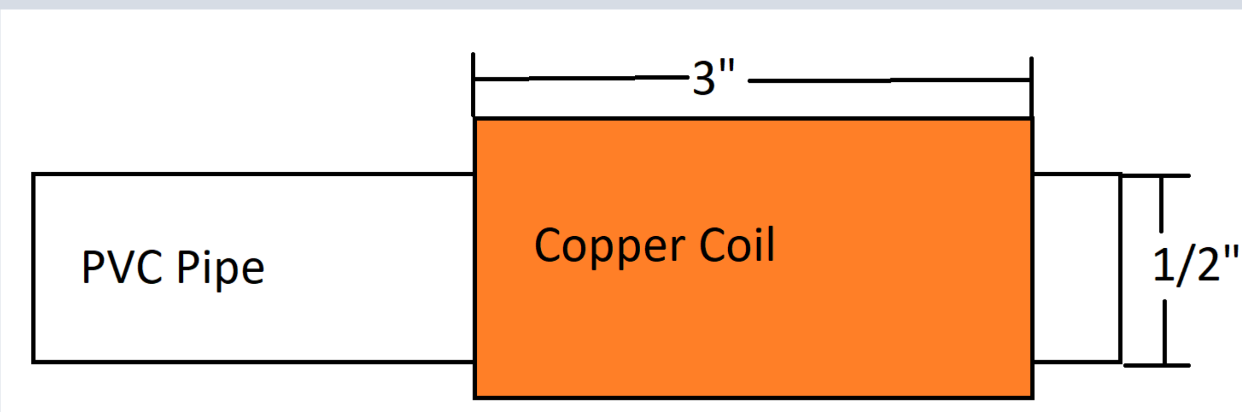

Figure 2: Copper coil wound around a PVC Pipe.

Firing Circuit:

Both ends of the coil are connected to the capacitor and switch, as shown in Figure 3. This allows the capacitor to charge and then discharge into the coil in a controlled manner. A potentiometer, MOSFET logic, and LEDs are then added to adjust electromagnetic field strength and collect data.

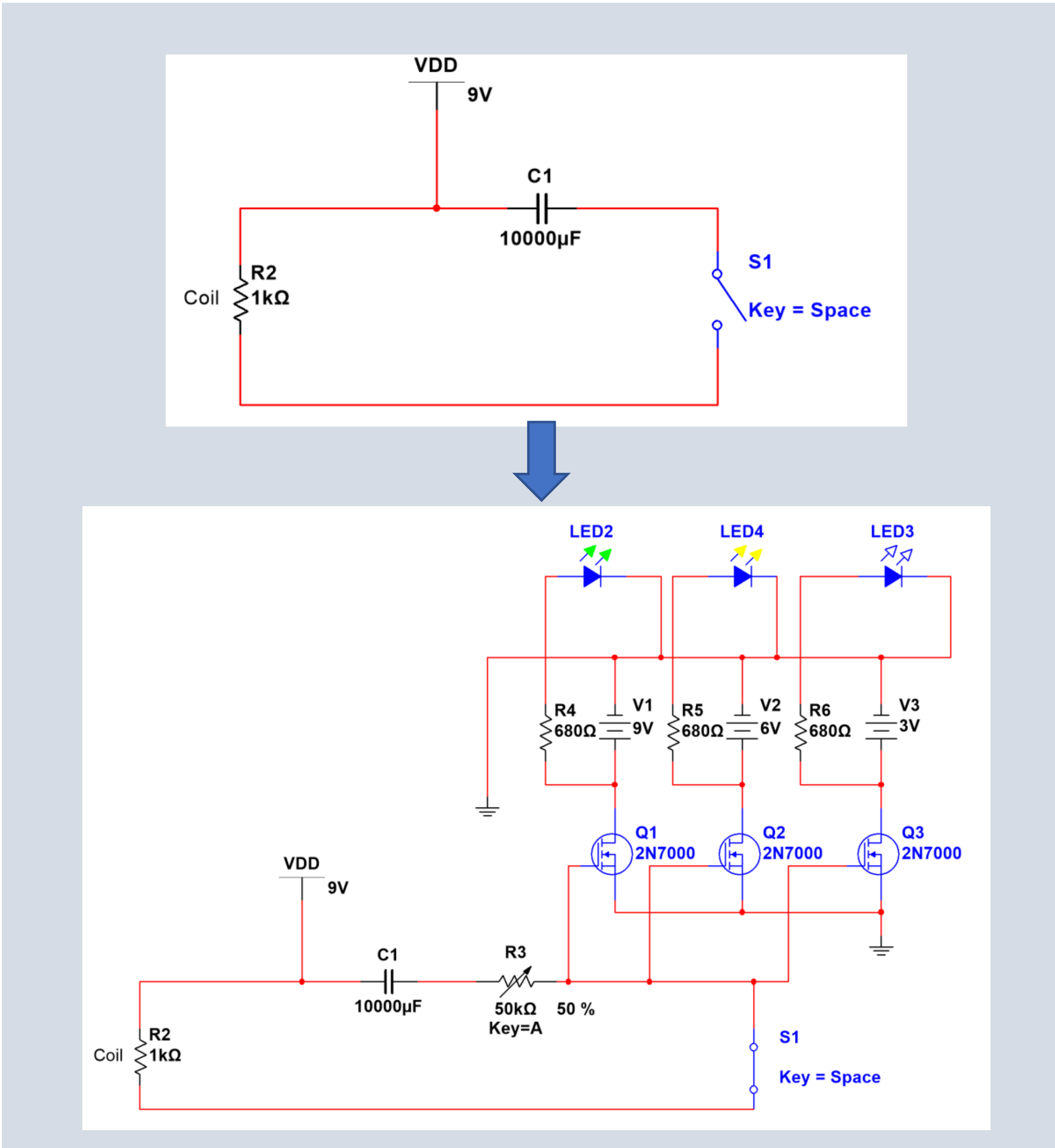

Figure 3: Coil circuit and coil circuit with integrated potentiometer and voltage readout.

Timer Circuit:

The magnetic field detection circuit only opens a switch to allow the coil gun to fire after sufficient time has passed, so the capacitor can fully recharge, as seen in Figure 4. Once the switch is pressed, a reset pulse could be sent back to the timer circuit; however, that was not originally intended. Potentiometers allow for the pulse time and pulse width to be adjusted for the recharging rate of the capacitor.

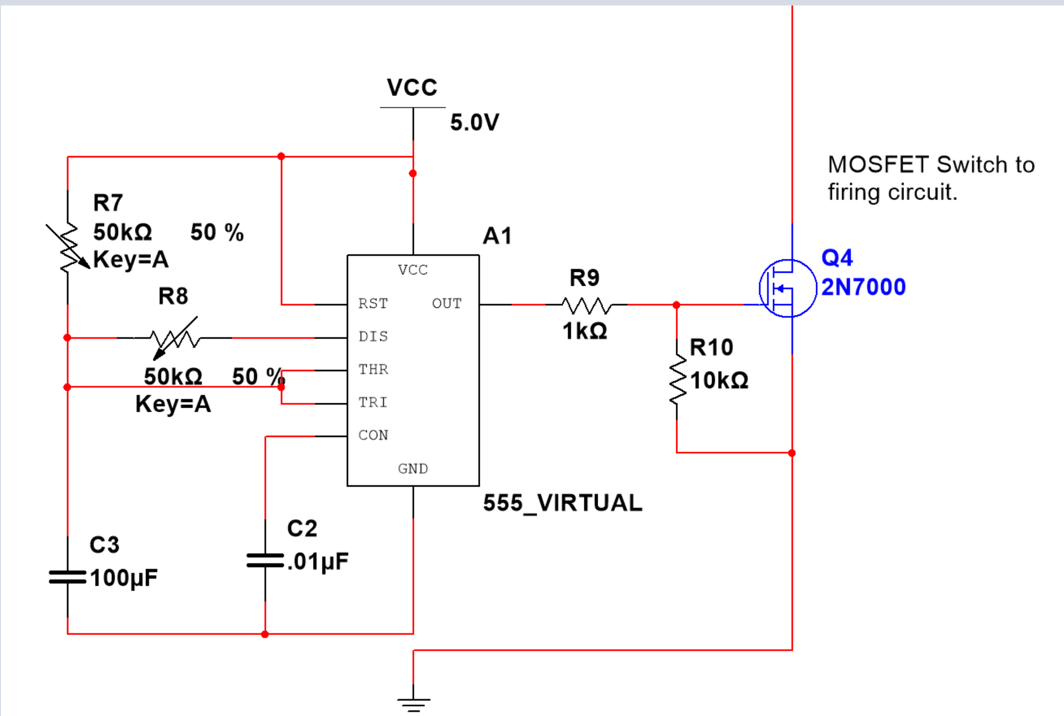

Figure 4: Timer circuit only allowing a shot after a specified time.

Magnetic Field Circuit:

The magnetic field circuit will trigger a green LED when a magnetic field is detected using a hall effect sensor as shown in Figure 5.

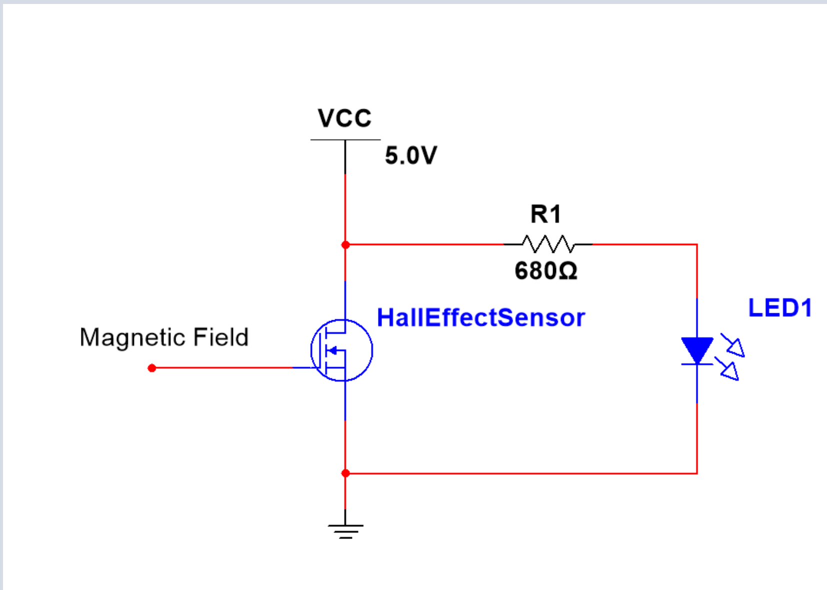

Figure 5: Simple circuit that detects a magnetic field.

Design Reliability:

Considering all components used, excluding the batteries, the chance of the coil gun not failing, as described above, over the course of a year is 99.413%.

Coil Gun Construction:

The coil gun's 10' of 15 AWG copper wire is wrapped around the ½" diameter PVC pipe and then covered in electrical tape. The ends of the copper cable are then soldered to breadboard wires. The three main circuits are created on a breadboard that is hot glued to the coil wrapped around the PVC pipe. The steel L-Bracket is then hot glued to the opposite side of the PVC pipe. The Hall Effect Sensor is also taped to the coil and connected to the breadboard using male-to-female connectors.

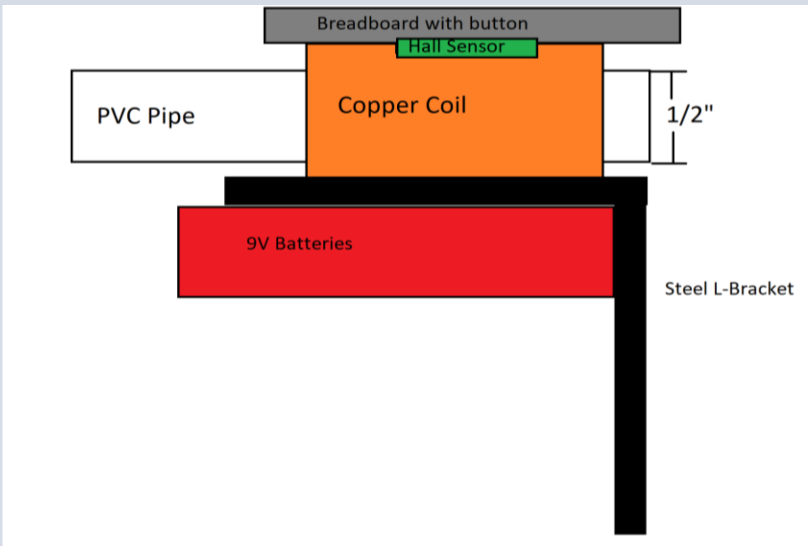

Figure 6: Coil gun schematic.

Results:

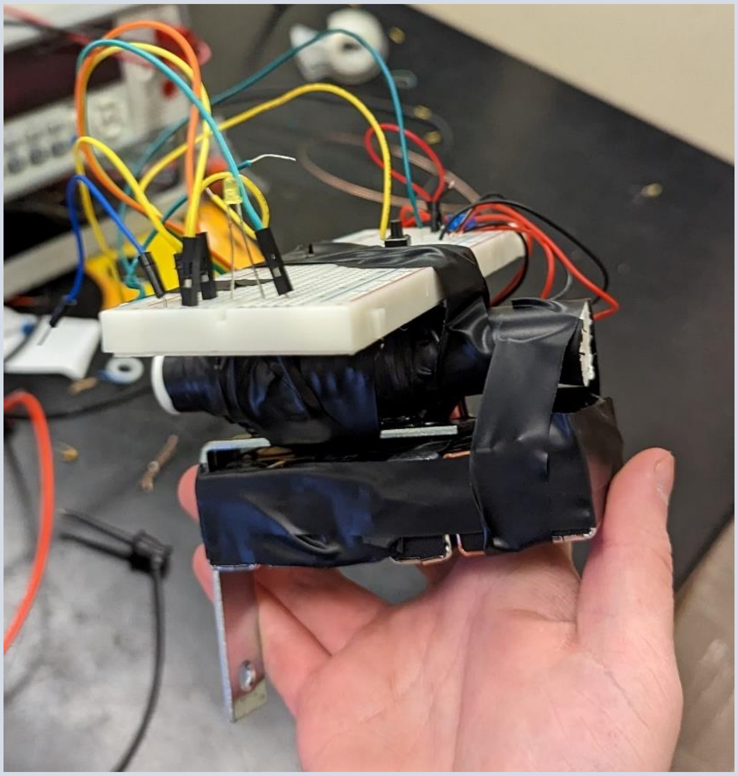

Figure 7: Prototype coil gun.

Testing was done throughout the process to ensure each component was working when constructing the coil gun. Initially, a large capacitor taken from the flash circuit of a disposable camera was used to discharge into the circuit, pushing a projectile. However, the capacitor took too long to charge, and due to the thickness of the copper wire, the capacitor lacked the voltage to create a meaningful magnetic field. This is because the field strength is affected by the number of rotations of a copper wire around a tube, the thickness of the wire, the voltage into the system, and the current into the system. If low voltage is used, a thin wire can be used, however, the number of rotations must be high. In this case, only a relatively thick wire could be used, so the low voltages that the capacitor outputted were insufficient to produce a meaningful electromagnetic field. A solution to this problem was to increase the amperage significantly. This was done by wiring five 9v batteries in parallel—wiring the batteries in series was also tried, however it didn’t not produce a noticeable magnetic field. The voltage regulator circuit was not able to handle the high amperages and voltages, the potentiometer burned out, so it could not be included in this simplified design.

The timer circuit would not be able to handle the high currents involved, even with the use of diodes, so it was not included in the simplified design.

The Hall Effect Sensor did not work as intended due to its properties; it only detects a rotating magnetic field. In the case of the coil gun, the magnetic field is not rotating so the sensor would either be left on or off.

The final design was greatly simplified compared to the idea outlined in the abstract. The main problem was the thickness of the copper wire used; it was hard to coil, required voltages that were too high and burned out the circuits, and 10 feet of the wire did not produce enough rotations to make a strong magnetic field. The simplified design was always on when the button was pushed, so it would attract an object, and then the object would get stuck in the magnetic field at the center of the coil. Increasing the projectile length did help to pull the projectile past the center point; however, the 3” long coil was too long for any object to traverse the entire length.

Projectile Results:

Several materials were used to test how a difference in the dielectric constant of metals affected the force upon an object. Since the coil gun did not work properly, other objects were tested.

The copper and steel BB pellets acted the same within the coil gun, slowly moving to the center of the 3” coil, at which point they stopped moving. The tungsten fishing weights were more attracted to the magnetic field than the BB pellets but barely moved. The lead BB pellets were not affected by the magnetic field, as expected. When sticking a AA battery into the coil, it was greatly attracted to the magnetic field; however, it also got stuck within the 3” coil. Taping batteries together, to make a longer projectile, produced a positive effect of up to 2 batteries attached head to toe. Any more batteries than two taped in such a manner would get stuck in the PVC pipe with no visible magnetic force upon them.

Conclusion:

Running a current through a coiled copper wire does induce a force upon a ferromagnetic material within the coil; however, optimizing this effect can be very difficult. Due to the use of unoptimized materials, mainly the 15 AWG copper wire, the circuits designed could not be safely implemented into the coil gun. Since a capacitor could not be used to activate and deactivate the coil, projectiles would be attracted to the center of the coil but not shoot out the other side since the magnetic field was still on. Due to the above failure, testing the effectiveness of different ferromagnetic materials within the magnetic field could not be effectively completed. With a high gauge wire, lower voltages could be used, allowing the designed circuits to be implemented and thus enabling the coil gun to shoot projectiles. In a future project, a higher gauge wire and larger capacitors will be used to safely optimize the strength of the magnetic field at low voltages.

References:

https://www.wikihow.com/Make-a-Coilgun

https://www.youtube.com/watch?v=id90kjYh-Qw&ab_channel=Electronoobs

https://www.electroschematics.com/electromagnetic-coil-gun/

https://www.britannica.com/science/Lenzs-law