School of Engineering

Grand Valley State University

EGR 214 – Laboratory #8

The One-Shot Door Lock

SWS Technical Paper #2

Objectives

- To design and implement a timed-pulse solenoid actuator

Pre-Lab Assignment

1. Read through the entire laboratory procedure.

Pre-Lab Deliverables

These deliverables are **due at the beginning of your laboratory period**. Your instructor will verify these deliverables as you enter the laboratory and will use them to construct your laboratory grade.

1. None for this lab.

Introduction

As suggested in a previous laboratory, a one-shot pulse generator can be used for disengaging a lock on a door when an access card is held up to a card reader. The actual lock mechanism is a *solenoid*, an electromagnet that can pull on a movable rod (also called an *armature* or *slug*) when it is engaged. The basic principle is as follows:

1. An electromagnet is formed by wrapping several turns of wire around a *core*. The core can be iron for greatest magnetic field strength, or just left empty (i.e., an *air core*) if the electromagnet is to be formed around another object. An example of an air-core electromagnet is shown in Figure 1.

Figure 1: Air-core electromagnet [1]

2. When current is passed through the coil, a magnet is created. The magnetic lines of flux circulate from the north pole to the south pole and pass through the core of the coil. Figure 2 shows a cross section of an energized coil and the resulting magnetic lines of flux.

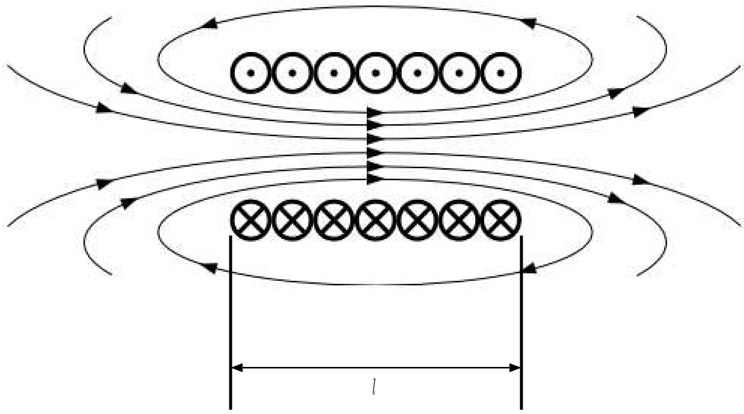


Figure 2: Wire wound in a coil around a core creates magnetic lines of flux inside the coil (shown with circulating lines with arrows) [2]. The figure shows the cross-section of a 7-turn coil. Circles with dots in the middle represent a cross-section of the coil wire in which the current is flowing out of the page, towards the reader. Circles with crosses in the middle represent a cross-section of the coil wire in which the current is flowing into the page, away from the reader. The dimension l represents the total length of the coil.

3. The magnet now created by the coil is capable of magnetizing the solenoid's movable armature, which must be made of ferromagnetic material such as iron, and turning it into a temporary magnet. This magnetized armature is now drawn towards the center of the coil as shown in Figure 3. If the current in the coil is left on indefinitely, the armature will come to rest in the center of the coil. In this way, the solenoid is actuated.

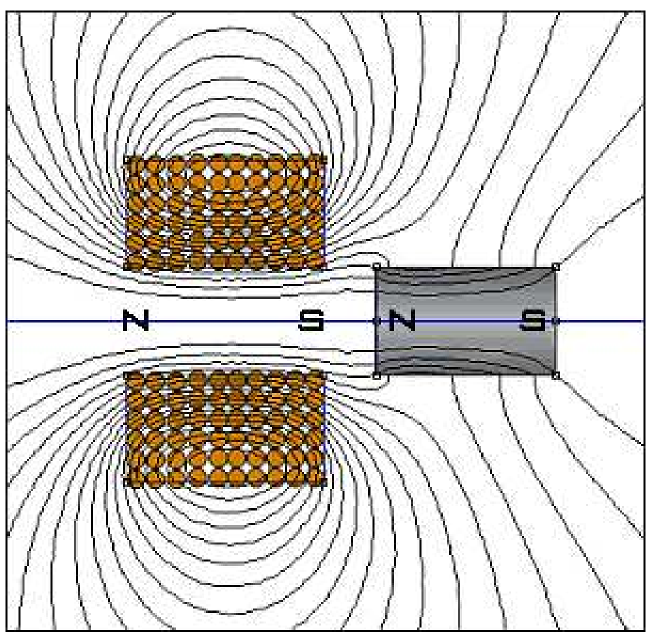


Figure 3: The magnetic field created by an energized coil can temporarily magnetize a ferromagnetic object so that it behaves as a magnet and is attracted towards the center of the coil [3].

Rather than relying on a temporary magnetization of the armature, an even stronger solenoid can be constructed using a permanent-magnet armature.

4. When the current in the coil is turned off, a spring mechanically pulls the armature back to its original position.

In this lab you will construct an electromagnet that is timed to generate a 3-second pulse to simulate the door lock mechanism described above.

Advice

As you work through this (and subsequent) laboratories, SHOW YOUR RESULTS TO YOUR INSTRUCTOR AS YOU OBTAIN THEM. Your instructor will be able to guide you towards the "correct" (or expected) results, thus saving you from having to re-do large portions of the laboratory.

Part I – One-Shot Pulse Generator **(estimated time: 45 minutes)**

The first task is to construct a one-shot pulse generator capable of generating a 3-second 10V pulse. The circuit of Laboratory #5 can be used with modifications for a 3-second pulse duration and to allow the pulse output to reach 10V.

Build this circuit and ensure that it works prior to proceeding to the next step. Keep good notes on your design procedure to help you in writing your paper.

- Include supporting derivations, schematic, procedural steps, and oscilloscope traces to justify your design.

Part II – Coil Characterization **(estimated time: 45 minutes)**

Obtain an electromagnet from your laboratory instructor. Your task is to characterize this electromagnet's inductance and resistance. Resistance can be measured directly with a DMM. Inductance should be measured according to the technique of Laboratory #6.

Ensure you document your procedure and observations carefuly to help you in writing your paper.

- Include supporting schematics, procedural steps, and oscilloscope traces to justify your estimate of the electromagnet's inductance and resistance.

Part III – Coil Driver **(estimated time: 90 minutes)**

The output current of the op-amp will not be nearly high enough to energize an electromagnet. While the op-amp is capable of sourcing 1-2mA comfortably, your electromagnet will demand approximately 100 times as much current.

We can use a MOSFET as a current amplifier by allowing it to switch the electromagnet current on and off under control of the one-shot circuit. Consider the circuit shown in Figure 4. A pulse from the one-shot circuit is used to turn a MOSFET on, and this MOSFET allows current to flow through the electromagnet represented by the inductance L.

Some additional design notes:

- The MOSFET should not be a 2N7000 as it is not designed for the 100mA-200mA of current we're going to need. Use an IRF540 or comparable power MOSFET (e.g., IRF520, IRL2703, NDP4060L, NDP6060L). All of these devices have the same pinout, shown below for reference:

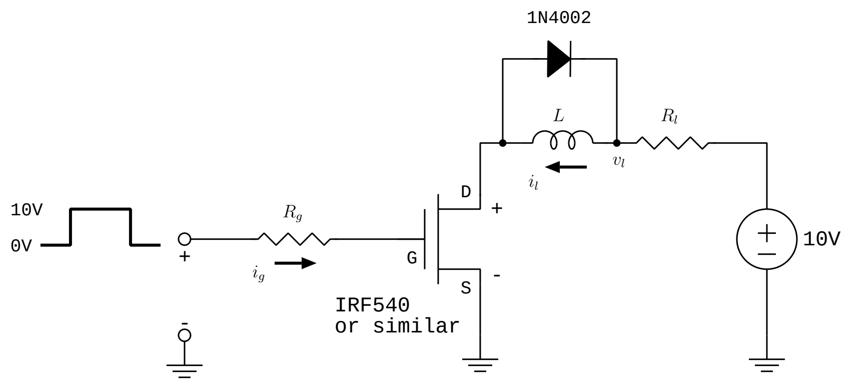
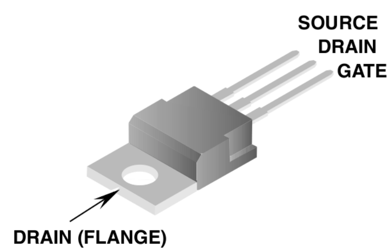


Figure 4: This circuit can be used to amplify the low-current output pulses of the one-shot generator to high-current pulses in an electromagnet (represented by the inductor L).



- The 1N4002 diode is not critical and you can use a 1N4001, 1N4004, etc. Can you explain why the diode needs to be there?
- The resistor R_l is intended to limit the current in the coil to the 100mA-200mA range. This resistor acts in series with the resistance of the electromagnet coil itself so the total resistance in steady state is $R_{coil} + R_l$ and the current in steady state will be $I = 10\text{V}/\left(R_{coil} + R_l\right)$. Also take the power dissipation of resistor R_l into account. In steady state, will a standard 1/4W resistor be acceptable?
- The resistor R_g is designed to limit the current leaving the one-shot op-amp. Remember that the gate of the MOSFET looks like a capacitor, and capacitors look like short circuits when they are not charged. Thus, right at the leading edge of the 10V pulse, the op-amp will be expected to source $I = 10\text{V}/R_g$ amps of current. The larger you make R_g, the less current will be demanded of the op-amp. Choosing $R_g = 10\text{k}\Omega$ for example will ensure that the op-amp current does not exceed 1mA.

Procedure

1. Choose the resistor R_l for coil current in the range of 100mA-200mA.
2. Build the circuit shown in Figure 4 and connect it to the one-shot pulse generator.
3. Obtain a permanent magnet from your instructor and use it to demonstrate to your instructor that your circuit works. Your electromagnet should be capable of lifting the permanent magnet from a work surface at a distance of approximately 1cm.

   A WORKING DEMONSTRATION IS REQUIRED!
4. Obtain a clear oscilloscope trace of the node v_l in the circuit of Figure 4 when the MOSFET turns on and when the MOSFET turns off.

- Include the two oscilloscope traces of the v_l node in your paper and explain their appearance with reference to the current amplifier schematic and circuit analysis theory.
- Explain the necessity of the 1N4002 diode in the circuit.
- Using your estimate of IRF540 gate capacitance from Laboratory #7, estimate how long it takes the IRF540 MOSFET to turn "on" and "off". Clearly show your derivation.

At The End Of The Laboratory

- Clean up your workstation, return all wire, components, etc. to the PROPER locations.
- Return the electromagnet and permanent magnet to your instructor.
- Disconnect all cables and return them to their PROPER locations.
- Turn off all test equipment and replace the cover on the oscilloscope.
- Make sure you clearly understand the laboratory deliverables and their due date.

SWS Technical Paper Requirements

Read this section carefully as it is different from that of previous laboratories.

You are to submit a full technical paper **by the beginning of your laboratory during the week of March 22-26**. Unlike previous laboratories, each student is to use the laboratory observations gathered as a group to write an **individual technical paper**. While it is expected that the data reported by two students in the same group will be the same, it is also expected that each student's paper is **individual work** and has no text, figures, schematics, etc. in common with the technical paper of any other student.

Your technical paper must contain a thorough discussion of your findings, including:

- Your name, the date, the laboratory number, your laboratory section, etc.
- Responses to the bulleted statements in the body of the laboratory procedure. Your responses should be woven into the narrative of the paper and not appear as isolated statements.

EACH STUDENT is responsible for handing in one technical paper.

References

1. `http://www.coolmagnetman.com/magelect.htm` – picture of air-core electromagnet
2. `http://en.wikipedia.org/wiki/Image:Solenoid.svg` – Image illustrating the magnetic field lines inside a solenoid. The image shown in Figure 2 was modified to add the dimension l.
3. `http://www.coilgun.eclipse.co.uk/images/theory_pages_images/general_diagrams/solenoid_bar_flux_diagram_1.GIF` – Image of ferromagnetic projectile being magnetized by a coil (from Coilgun Systems).

SWS Technical Paper Grading

Your first draft of the technical paper is due **at the beginning of your lab section** during the week of March 22-26. Your instructor will grade the paper as either ACCEPTABLE or NOT ACCEPTABLE and return it to you the week of March 29. If your paper is acceptable, your instructor will provide an initial grade, as well as comments and suggestions for improvement. The final paper will then be due the week of April 5. If your paper is not acceptable, you will not be allowed to hand in a final paper and will fail the SWS part of the course, thus will obtain an overall failing grade for the course.

The writing documents available on the course web site will be used as a standard for grading this paper:

`http://claymore.engineer.gvsu.edu/~steriana/214`

Specifically, the following documents should be referenced:

- SWS Scoring Criteria
- SWS Requirements
- SWS Writing Guidelines

Note that even though you are submitting a first draft, it is expected to be a complete paper, not a "work in progress". If your paper is missing major components or is clearly a poor effort, your instructor will consider it "not acceptable".

SWS Technical Paper Structure

Your paper must be submitted in a protected, bound enclosure such as a 1/2" 3-ring binder, 3-prong fastener portfolio, etc. The cheap, plastic-spine report covers are not recommended as they tend to fall apart fairly easily and can lead to lost pages.

- EVERYTHING in your paper must be computer-generated. Do not touch a pen or pencil to ANY part of your paper.
- Your paper must begin with a title page listing an appropriate title, your name, date, course number, laboratory section, and instructor name.
- Your paper must contain an Abstract that summarizes the entire paper, from introduction through conclusions, in one clear, concise paragraph. It is suggested that the Abstract is the LAST thing you write (how, otherwise, could you summarize a paper that hasn't been written?)
- Your paper must contain a Background (or Introduction) section that explains, in your own words, the relevant theory behind the laboratory experiments.
- Your paper must contain a Procedure section that concisely walks the reader through the steps you performed in the laboratory, and also presents measurements and observations as appropriate. You may, if you want, split this into a Procedure section and a Results section to separate your discussion of procedure from your presentation of measurements and observations.
- Your paper must contain a Discussion section that addresses some of the "big picture" issues (or, as the SWS Writing Guidelines document says, "a critical analysis of the results").
- Your paper must contain a Conclusions section that, in one paragraph, summarizes what you did in this laboratory and whether or not you were able to successfully complete the assignment (HINT: "no" is not an option).
- Your paper may contain one or more Appendices (not Appendixes) that contain large schematics, lengthy derivations, etc. that would not be appropriate for inclusion in the body of the paper.
- Other sections mentioned in the SWS Writing Guidelines document are optional (e.g., Future Work, Recommendations, etc.) and are not likely to be applicable to this paper.