ECE 203 – LAB 2
CONTROL FUNDAMENTALS AND MAGNETIC LEVITATION

BEFORE YOU BEGIN

PREREQUISITE LABS

• All 202 Labs

EXPECTED KNOWLEDGE

• Fundamentals of electrical systems

EQUIPMENT

• Oscilloscope
• Programmable Power Supply
• #1 Phillips Screwdriver

MATERIALS

• TIP-41A Power Transistor
• Large heat sink
• Fan
• Heat Sink Attachment Kit
• Heat Transfer Pad
• 1/4” by 5” fender bolt (fully threaded)
• Two 1/4” nuts
• Two ½” Inner Diameter 1¼” Outer Diameter nylon washers
• Magnet wire (140 feet)
• Three 741 op-amps
• Two IR photo-transistors IRD500
• IR photo-diode TLN110
• Wood Frame
• Four 1.5” Sheet Rock Screws
• Ferrous Globe or washer

OBJECTIVES

After completing this lab you should know:

• How to build a Magnetic Levitator
• The fundamentals of stability and negative feedback
INTRODUCTION

Stability is a fundamental part of control theory. In this lab we will be using the BIBO (Bounded Input Bounded Output) definition of stability. This means that if the input signal is bounded within a finite range, the output signal is similarly bounded within a finite range.

Feedback is also a fundamental part of control theory. The concept of feedback is relatively simple. When you take a shower, you control the temperature of the water based on your comfort level. If the water gets too hot or cold, you change the temperature to make it comfortable. Your skin senses the temperature of the water and provides a feedback signal, which is proportional to the temperature of the water. You compare the signal from your skin with some reference signal (your idea of what is comfortable) and you adjust the temperature accordingly. We can think of the difference between the sensed signal and the reference signal as an error that needs to be corrected. If you were to remove this feedback signal (disable your skin’s temperature sensing ability) you would not be able to effectively control the temperature of the water.

Many electrical and mechanical systems make use of control systems. These control systems can be found in everything from automobiles to electric guitar amplifiers. In this lab we will be investigating the control system for a magnetic levitator.

Theoretically, a person could suspend a metal object beneath an electromagnet without using a control system. All one would have to do is place the metal object in such a way that the magnetic force pulling upwards on the object exactly balances the downward pull of gravity. In reality, small variations in the magnet’s strength, air currents, and other disturbances would disrupt the balance. Either gravity or the magnet will win the tug-o-war and accelerate the object away from the critical balancing point. To overcome this problem, the strength of the magnetic field needs to be actively adjusted to compensate for the disturbances. A feedback control system can be used to accomplish this.

PRELAB

BUILDING THE MAGNET

The first step in this lab is to build the electromagnet. Begin by placing both washers and the nut on the bolt. Turn the nut until the washers are about 1 inch apart as in Figure 1.
Next, begin wrapping the wire around the bolt starting at the end closest to the nut and wrapping towards the round end of the bolt as in Figure 2. Be sure to leave at least 2 feet of wire before you begin wrapping around the bolt.

Continue wrapping wire until the outer layer of wire is even with the washers, as in Figure 3. Take your time wrapping the magnet. If you try to hurry, you will most likely tangle your wire and have to spend time straightening it out. Make your magnet wraps as tight and neat as possible. If the magnet is loosely wrapped, it will not be strong enough to lift the ball. You need to have at least two feet of wire remaining at both the beginning and end of your wrap job.
Next loosen the nut about ¼ inch and wrap the end of your wire once around the bolt as in Figure 4.

Finally, tighten the nut and washer down against your coil of wire as in Figure 5. This will hold the end of the wire so your coil does not unravel.
The wire that you are using has a thin layer of varnish insulation. Scrape the varnish off of the ends of your wire so that you can make an electrical connection to the wire.

**BUILDING THE FRAME**

Next you will need to assemble the wooden frame to hold your magnet and IR diodes. We will call the board with two holes the **IRD500 board**. You will be placing your IRD500 IR transistors into these two holes. The long board with one hole is the **TLN110 board**. You will be placing the TLN110 IR diode into this hole. The short board with the large hole will be called the **top board**. It will be used as the top of your frame. Figure 6 shows your completed frame.
Begin by screwing the four black screws into the tops of the IRD500 and TLN110 boards, two screws in each board. Figure 7 shows where to start the screws.

**Figure 7: Screw Placement for Side Boards**

Drive the black screws into the two small holes at the top of the side boards until the tip of the screw is \(1/8\)th inch beyond the back of the board as in Figure 8. Repeat this with all four screws.

**Figure 8: Screw Through the Board**

Next, place the top board upright on the table. Align one of the side boards above the top board. Tap the screws so that the side board is flat against the top board as in Figure 9.
Drive both of the screws into the top board.

Stand the two side boards up on end, holding their bottom ends flat against the table top. Slide them together until the screw tips are sticking into the top board and the two pieces of wood are flat against each other as in Figure 10. You may need to tap the screws to drive them into the top board. Aligning the pieces of wood in this way makes your frame stable and prevents it from rocking.
Finally, drive the final two screws all the way into the top board. You now have a completed frame.

Next, insert your electromagnet into the frame as in Figure 11. Place a long green wire from your wire kit through the lower diode holes and adjust the position of the magnet so that there is about \( \frac{1}{4} \) inch between the wire and magnet. Then remove the long green wire.

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**Figure 11: Complete Mechanical Construction and Magnet Placement**
LAB

ELECTRICAL ASSEMBLY

Answer Questions 1 – 2.

Your magnet should have a resistance less than 20 Ω and inductance around 5 mH. If you’re resistance is too high scrape the ends of the wire again and re-measure the resistance. If this does not help, remove some of your wire until the resistance is 20 Ω.

![Circuit Diagram]

Figure 12: Magnetic Levitator Circuit

Figure 12 shows the circuit you will use to control the power to your magnet. The TLN110 is an LED that emits photons in the infrared (IR) spectrum. The IRD500s are phototransistors that are sensitive to the infrared spectrum. They act like variable resistors that change their resistance based on how much infrared light hits them. The more incident infrared light, the lower their resistance. The TIP-41A is a power transistor capable of sourcing 1.5 amps. L1 is the lifting electromagnet.

Answer Question 3 – 5.

The circuit uses an infrared emitter (TLN110) and detectors (IRD500) to determine the position of the object. When the object gets too high, the circuit reduces the power to the magnet and the object moves downward. When the object gets too low, the circuit increases the power to the magnet and the object moves upward.
The IR detector labeled **Position** senses the location of the object and provides a voltage to Q1 proportional to the object’s position. Notice that the Q1 amplifier is configured as a high-impedance voltage follower. The position voltage is compared to the voltage from the **Reference** IR detector. Q2 amplifies the difference between the two signals (the error) and feeds the result into an RC network. The RC network is a filter that responds to certain frequencies more than others and helps the circuit respond more appropriately to changes in the object’s position.

Q3 is used as a non-inverting voltage amplifier with the gain controlled by a potentiometer. The transistor serves as a current amplifier and pulls current through the electromagnet. The diode (1N914) acts as a safety valve for the transistor. Recall that inductors respond slowly to sudden changes in current. When the transistor suddenly switches off, the diode provides a path for the excess current from the inductor so that it does not damage the transistor.

To distinguish between the IRD500 and TLN110 diodes, look into the top of the diode. The TLN110 IR diode has a small black square with two thin gold wires attached to it. The IRD500 has a larger black square with a single gold wire attached to it as in Figure 13.

![Figure 13: Diode Recognition](image)

All of the diodes have a flat spot ground into the side of the clear plastic casing. Refer to Figure 13 to determine which lead is negative (they are not the same.) Your circuit will only work if you have the negative leads attached to the more negative part of the circuit. Place the TLN110 through the TLN110 board. Place the **Position** IRD500 through the lower hole in the IRD500 board. Place the **Reference** IRD500 through the upper hole in the IRD500 board as in Figure 14. You will probably find it easiest to keep the diodes in their holes if you tape the leads to the boards. Be sure that the leads of the diodes do not touch each other.

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The pin-out for the TIP-41 transistor is shown in Figure 15.
Build the circuit in Figure 12. Power the op-amps with \( \pm 12 \) volts. You will need to set the power supply so that both output 1 and output 2 have a maximum current of 1.5 amps. **Do not connect the transistor at this time.** You first need to adjust several things in your circuit.

Measure the voltage on the + input of Q1. It should change to by several volts when you place your finger over the Position diode. If you get 11-12 volts even when you don’t interrupt the beam, check that you have the correct polarity on the TLN110. If you get a constant 9.2 volts whether or not the beam is interrupted, check the polarity on the Position IRD500. Record the voltage on the + input of Q1 when you are covering the position diode. Then record the voltage at the same point with the diode uncovered. Next, calculate the average of these two values. Next, check the voltage on the + input of Q2. Adjust the \( 100 \, k\Omega \) potentiometer until the voltage on the + input of Q2 is equal to the average value you just calculated. If you can’t get the voltage to the average, reposition the Reference diode and adjust the potentiometer again.

Next you will need to attach the heat sink to the TIP-41 transistor. Do this by placing the small screw through the heat sink, the Heat Transfer Pad (small gray rectangular piece of plastic), the transistor, and then through the small nut. Tighten the screw while holding the nut in place with your finger. **Your transistor can get HOT when your circuit is on!!!** Be careful not to touch it or the heat sink until your circuit has been off for several minutes. Use the fan to cool your transistor. Connect the black fan lead to \(-12\) V and the red lead to ground. **Be careful not to touch the turning blades of your fan.**

Turn off the power supply and place the transistor into your circuit. Turn the power back on. Adjust your \( 500 \, k\Omega \) potentiometer until channel 2 of your power supply reads 0.8 amps. This potentiometer controls the gain of your circuit. The current reading on channel 2 is a measure of your gain. Next, place your finger over the Position diode only. The current reading on the power supply should drop to 0.1 amps or lower. If the current remains high, you may have probably inserted the 1N914 diode backwards. The stripe on the diode should be closest to the +12 V power supply. If the circuit is wired correctly and still does not behave correctly, check the voltages on the inputs of Q2.

With the voltages set to the proper levels and the circuit behaving correctly, you are now ready to attempt levitation. Hold your hand flat open with the palm up. Place the globe or washer on your fingers and place the back of your hand against the table. Slide your hand into the wooden frame until the globe is under your magnet. Slowly move your hand up until the magnet attracts your globe. If you can’t get your globe to levitate after several tries, increase your gain slightly. If your globe begins slamming itself repeatedly against your magnet, decrease your gain.

Once you get your globe to levitate beneath your magnet, stand up and do a victory dance. Then sit down again because the lab is not finished.

**PARAMETER VARIATION**

The position of the globe is the output of this plant. The purpose of this lab is to investigate the effects of gain on the plant performance and stability.
Set your probe to 10x and your Oscilloscope Channel 1 coupling to AC. Use your oscilloscope to measure the voltage of the + input of Q1. This voltage is proportional to the position of the globe. You will notice that the voltage is oscillating. Slowly turn your gain potentiometer and observe what happens to the output of your plant.

For the purpose of this lab, the output of the plant will be considered unbounded if the globe touches the magnet or your lab bench.

**Answer Question 6 – 7.**

**FEEDBACK**

In this next section, you will be investigating the importance of feedback. The Position diode provides the feedback in this circuit. Breaking the circuit between Q1 and Q3 removes the feedback from the circuit.

**Answer Questions 8 – 9.**