Lab 5b: Magnetic Levitation (Week 2)

"Regardless what technology is, I like analog too." – Lou Gramm

1 Objectives

The goal of this lab is to design and implement an analog controller for the magnetic levitation system that you identified in last week's lab. Our aim is to design an analog compensator such that the open loop system's DC gain (which include the compensator gain and the plant) is 2 A/m and the compensator pole/zero ratio is approximately 20.

2 Equipment and Safety

Lab rules are the same as last week:

2.1 Lab Rules

- Safety glasses can be requested, if needed.
- The coils and black heat sink on the current amplifier can get very hot, please do not touch them.
- Before making any connections, make sure the polarity is correct.
- Be cautious before turning on any power supplies and double check all connections.
- If you are unsure about something, ask first!

2.2 Lab Equipment

Same setup as last week. In addition, you will have to use various circuit elements (op amps, potentiometers, resistors, ceramic capacitors) in order to implement your analog controller.

3 Pre-Lab

Recall the MagLev system from last week's lab and the values of the linearized model you have determined during the system identification.

1. Plot the root locus and frequency response of your system and explain what you see. Is the system stable or unstable?
2. We will be adding a controller of the form $G_c(s) = K_c \frac{1+s/z_c}{1+s/p_c}$ to improve the performance of our system. Depending on the pole and zero locations, the compensator can be referred to as either a Lead or Lag compensator. This will be elaborated upon in later classes.
3. Design a controller (ie. pick the location of z_c and p_c) such that the overall open loop system (including your controller) has
   - a DC gain ($K_c \cdot \frac{aK_aK_i}{K_x}$) of 2
   - a pole/zero ratio of 20

Hint: you may use any MATLAB tools that you find appropriate – `margin` or `sisotool` may help.

Observe that the DC gain of the transfer function $G(s)$ gives the DC gain from amplifier current δI to the voltage y at the photoresistor. Multiplied by K_a, we get the gain from amplifier voltage y_2 to photoresistor voltage y. You are solving for a controller of the form $G_c(s) = K_c \frac{1+s/z_c}{1+s/p_c}$. Recall that the transfer function of the plant is $G(s) = \frac{Y(s)}{V(s)} = \frac{aK_aK_i}{m\left(s^2 - \frac{K_x}{m}\right)}$, where

- $K_a = 2\,\mathrm{A/V}$ is the current amplifier's gain
- K_i (in N/A) and K_x (in N/m) are the parameters of the linearized plant that you measured during last week's lab.

4. Using your derivations from last week's Pre-Lab, calculate the values of R_1, R_2, and C to use in your circuit.

4 Lab

4.1 Controller Design Check-off

Present your data from the system identification performed in Week 1. In particular, show your values for the system parameters a, K_x, K_i, and a. Show the GSI your choices for R_1, R_2, and C, and the resulting controller.

4.2 Controller Implementation

Implement the controller and offset circuitry on one of the provided breadboards. The analog circuit is shown in Figure 1 on the last page of these instructions.

You will be using Analog Devices AD822 operational amplifiers. The AD822 is a dual precision, low power FET input op amp that can operate from a single supply of 5 V to 30 V or dual supplies of ±2.5 V to ±15 V. For a connection diagram, see Figure 2 on the last page. If you need more information, a data sheet is available at `http://www.analog.com/static/imported-files/data_sheets/AD822.pdf`.

You have both 1/4-turn and 10-turn potentiometers available. It is your choice which type to use – both work, but adjusting the gains on the sensitive 1/4-turn pots requires an extremely steady hand.

One possible procedure to balance the ball is the following:

1. Place the ball at the zero position. Adjust the potentiometer in the first op-amp circuit (magenta box) such that $y_1 = 0V$ at equilibrium.
2. Now remove R_3 to disconnect the current offset circuit from your controller. Adjust the potentiometer in the current offset amplifier such that the ball is just balanced by the electromagnet (i.e. has apparent weight ≈ 0). Now, re-install R_3 and slowly lower the stage.
3. If things do not work as expected, use general circuit debugging techniques. One easy thing you can check is whether your controller output changes significantly when you wave your hand across the light sensor.

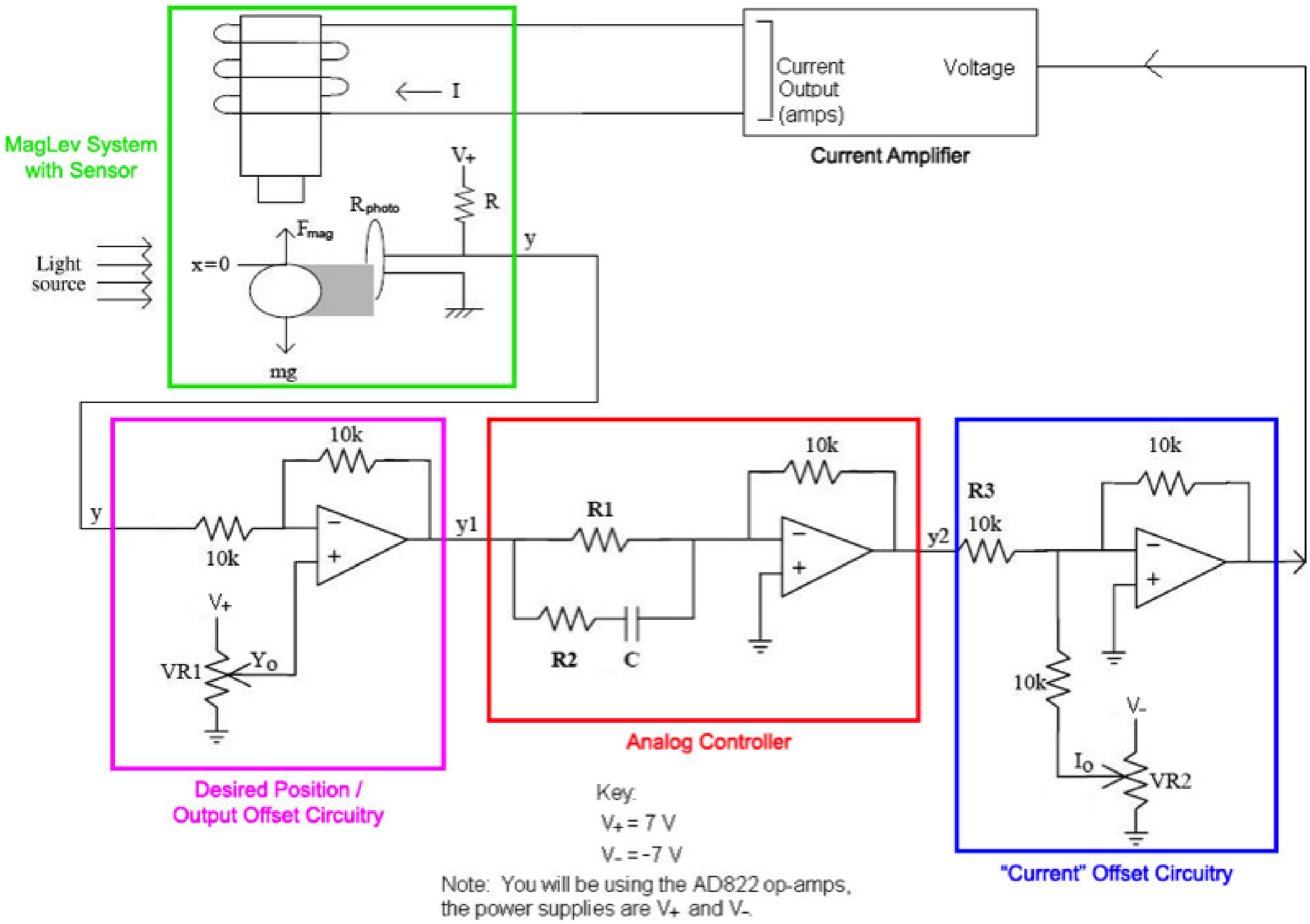

Figure 1: Block diagram of the magnetic levitation setup with circuit level details.

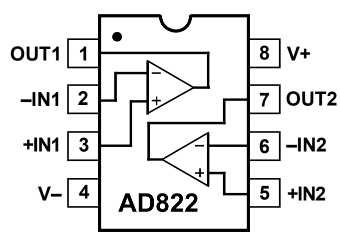

Figure 2: Connection Diagram AD822 OpAmp.

Alternatively, you can get a feel (literally) by holding the ball at the equilibrium and qualitatively trying to understand how the controller is reacting. Is it pulling too hard/not enough? Is it too jittery or is the controller output not making large enough corrections? Try to relate the behavior back to general system concepts such as gain and stability as well as your offset values. If necessary, re-system ID and re-design the controller.

4.3 Circuit Debugging

It is possible (probable) that your circuit will not work perfectly without careful construction and debugging. It is recommended that you test each piece of the circuit before connecting them. This both helps you to narrow down potential problems and protects the equipment. The following are some things to check during debugging:

- Sometimes resistors are placed in the wrong bin. Are you sure you selected the intended value? Resistor color codes can be found at `http://www.digikey.com/en/resources/conversion-calculators/conversion-calculator-resistor-color-code-4-band`
- Are the op-amps properly powered? Are the terminals connected in the correct positions for inverting or non-inverting?
- You have the transfer functions for each piece, so you can calculate the output voltage for a given DC input voltage. If you apply a sample voltage to the op-amp circuit, do the measured and calculated voltages match?

4.4 Lab Report Instructions

In addition to presenting your mathematical derivations from the week 1 pre-lab, please also do the following:

- Include the data you used to calculate K_i, K_x, and a and the plots of the data and linear fits.
- Include your strategy for the controller design, as well as your MATLAB code.
- Report what numbers you actually used for R_1, R_2, and C. If different from your intended design, how did the pole/zero ratio change and how did DC gain change? How does this affect the phase margin of your system?
- Describe your general procedure for getting the ball to levitate. Describe any difficulties you experienced while trying to do this.
- Include either a photo or video of your maglev working. (Video is preferred. Please upload to Youtube or any other streaming video service, and give us a link to the video. Make sure you put the names of your group members in the description!)