MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science
6.081—Introduction to EECS I
Fall Semester, 2006

Assignment for Week 10

- Issued: Tuesday, Nov. 7th
- Includes post-lab homework due before class on Tuesday, Nov. 14th

Getting a head with circuits

In all the previous labs, we have mostly abstracted away the electrical nature of the signals being processed and generated by the robot. In this laboratory you will design and build an electrical feedback system which controls a robot "head". In subsequent labs, you will put "eyes" on the head to help your robot "see". As with the previous labs, you will start by building a python tool to help you analyze circuits, and then you will use that tool to help you design an improved robot head controller. So this week you will be extending python code, analyzing an electromechanical system, and designing a circuit. Whew!

1. Preparation

1.1 Read this whole document!

Please read the entire section on the lab before coming to lab.

1.1. Exercises with the online tutor for November 9th

Use the online tutor to complete the problems due for November 9th.

2. To do in lab on November 9

Lab will start with a short mini-quiz that is based on the circuit problems you worked in the on-line tutor. After the quiz, you should work as part of a group with a single laptop and single robot head.

You will be extending the constraint resolver program for analyzing circuits by adding an op-amp model to the program. You can then use your augmented constraint resolver to help you design a circuit to control the motor.

2.1 Download and test the constraint system

The code for this lab is at the 6.099 web site on the calendar for this week. Download *resolver.tar* (or *resolver.zip*, if you prefer) again and unzip it. Make sure you can run one of the example files.

2.2 Add an op-amp model to the constraint resolver

In class we discussed the following operational amplifier circuit
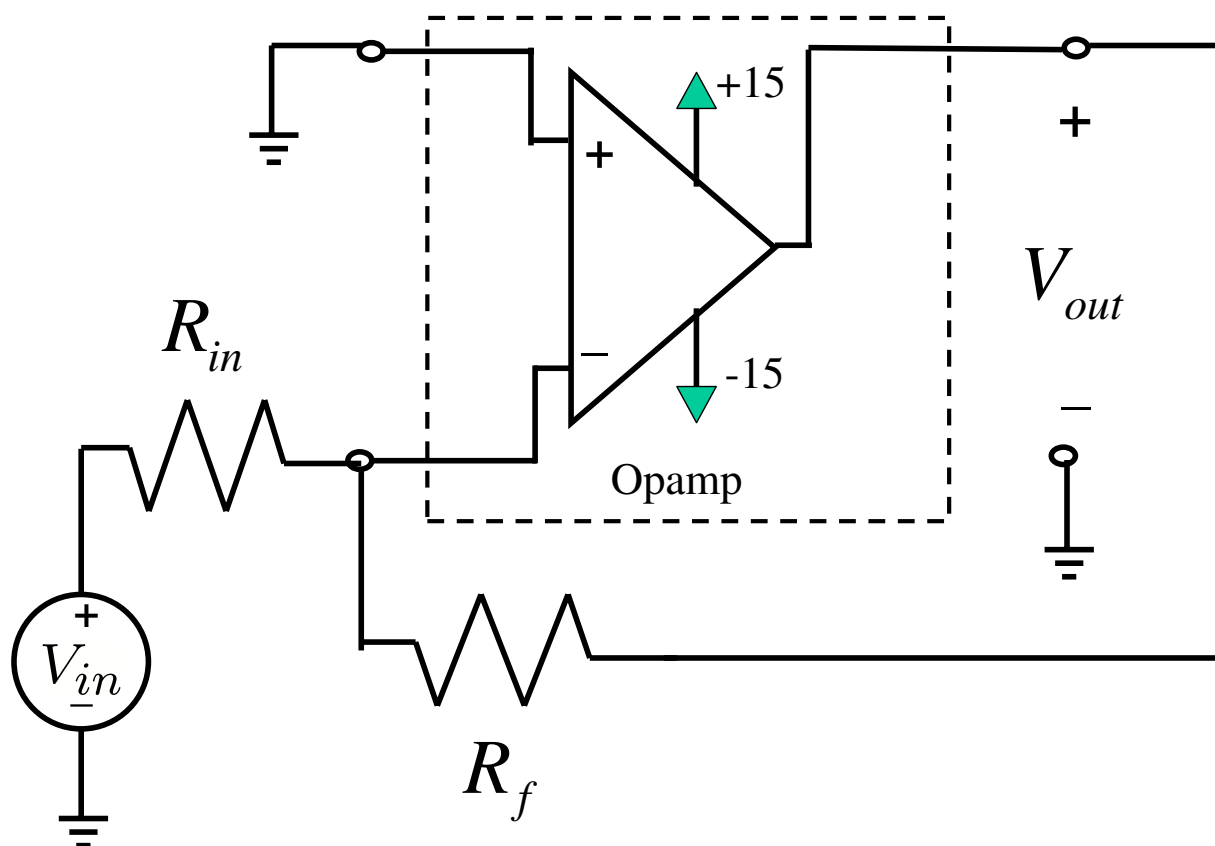
In order to simplify the analysis of the op-amp circuit, we assumed that $V_+ - V_- \approx 0$ and that no current enters the op-amp inputs. Using those assumptions, we determined that the relationship between V_{in} and V_{out} was

$$V_{out} = -\frac{R_f}{R_{in}}V_{in}.$$

The main reason we could assume that $V_+ - V_- \approx 0$ was that the op-amp was connected in a feedback configuration and the gain of the op-amp was very large. You will now investigate the accuracy of that approximation using the constraint resolver.

The abstract model we used for the op-amp was a voltage-controlled voltage source model, and using that model in the inverting amplifier yields a somewhat different looking schematic
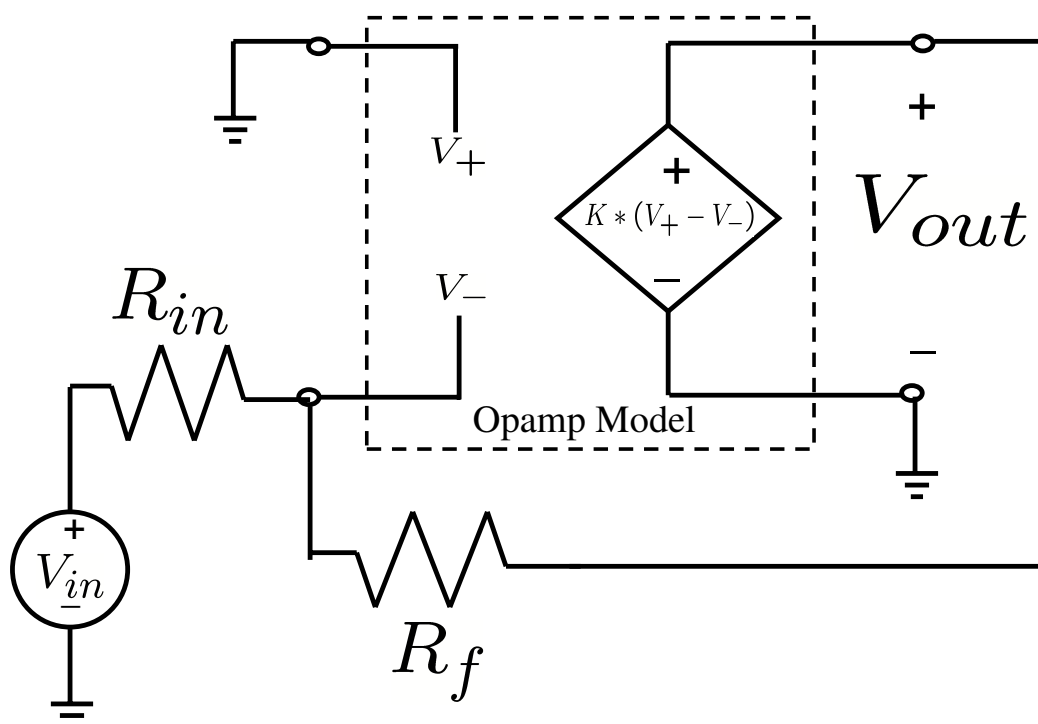
where the gain of the voltage-controlled voltage source, K, is a very large number. Please add this voltage-controlled voltage source model of the op-amp to the constraint solver, allowing K to be a parameter like resistance is for resistors. Keep in mind that this model has four terminals, but there is only one nonzero current. Therefore, your constraint should involve four voltages and one current. Please carefully consider what to do with the op-amp output current; note that the current is not used in the op-amp constitutive relations. What constraint will involve the op-amp current?

Test your implemenation by analyzing the inverting amplifier above using $R_{in} = 10,000$, $R_f = 100,000$, and the op-amp gain equal to $K = 1000$.

Finally, roughly determine the smallest value of op-amp gain, K, for which

$$\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$$

is accurate to within ten percent.

Checkpoint: 2:15 PM

- Demonstrate that the constraint solver correctly analyzes the op-amp.

- Know how small you can make the op-amp gain.

2.3 Try our robot head feedback circuit

The robot head is in four parts: the base (a big flat grey Lego plate), the circuit protoboard which is attached to the plate, the "head" which has a protoboard mounted on a rotating Lego platform, and a the motor driver which is connected by gears to the rotating head. In addition, there is a potentiometer (little blue thingy) on the bottom of the rotating head. The potentiometer shaft is connected to the head so that the shaft rotates with the head, and it is wired to the plate circuit board. The potentiometer is used to measure the head position, and when connected as shown in the following figure, the resulting circuit will act like a voltage divider.
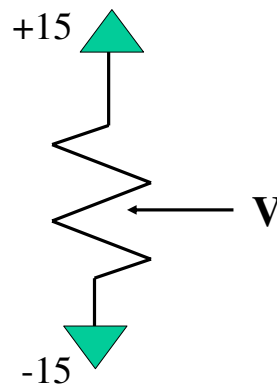
When the potentiometer is used to create a voltage divider, the resistors in the divider are related to head angle θ, see below, and so the voltage produced will be proportional to the head angle.

$$R_t = \frac{\theta}{2\pi} * 5K$$

$$R_b = \left(1 - \frac{\theta}{2\pi}\right) * 5K$$
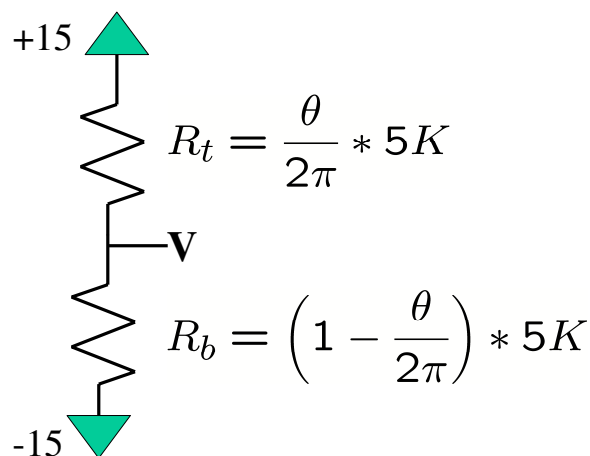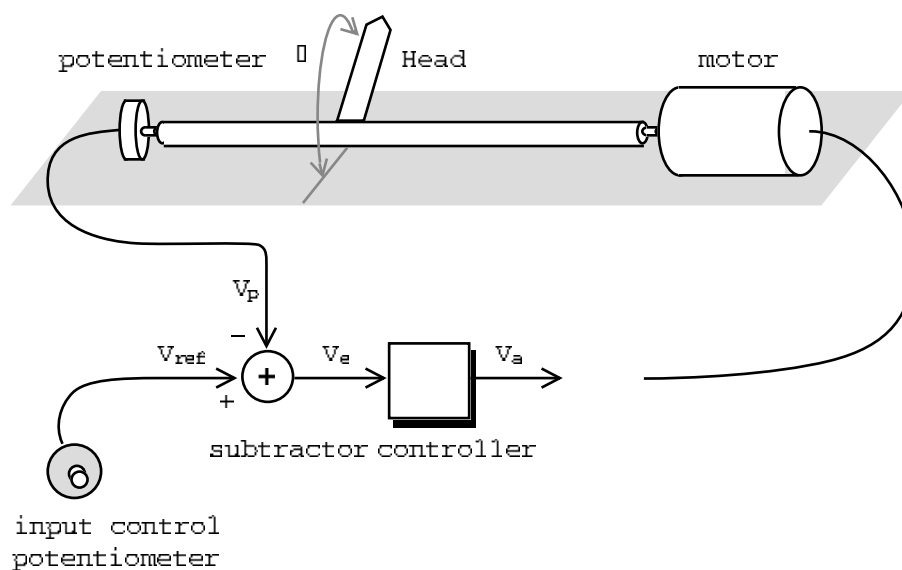
Above is a diagram of the robot head system that we will use. The mechanical portion of the system includes the rotating head, motor, and potentiometer. The head is connected by gears to the shaft of the motor and is directly connected to a potentiometer, so that the head, motor, and potentiometer all rotate in unison. The outer pins of the potentiometer are connected to -15 and +15 volts, respectively. Hence, as the head swings from one end of its range to the other, the voltage at the potentiometer's wiper (middle pin) swings from -15 to +15 volts. This voltage should be proportional to the angular position of the head θ. This *head-position voltage*, V_p, is fed back to the controller. The input to the system is V_{ref}, a voltage generated by another potentiometer. The voltage V_{ref} can be used to select a desired head position. The system is designed so that V_p tracks V_{ref}. Thus, the user controls the position of the arm by changing V_{ref}.

To see how this system works, suppose that initially V_p and V_{ref} are equal, and then V_{ref} is increased rapidly. Just after the increase, V_{ref} will be greater than V_p and so the error signal, V_e, will increase. Because V_e has increased, the controller output voltage V_a increases which increases the current to the motor windings I_a which causes the motor to rotate the head. The motor rotates the head, causing both the head and the potentiometer's voltage V_p to increase. The arm will continue to rotate until the error signal $V_e = 0$, and $V_p = V_{ref}$. That is, when the arm-position voltage equals the desired arm-position voltage. This sequence is reversed if V_{ref} is decreased rapidly. V_e becomes negative, generates a negative motor current, and the motor rotates in the opposite direction to reduce V_p to V_{ref}.

We have constructed the circuit for driving the head motor on the plate protoboard. The schematic diagram for the circuit is
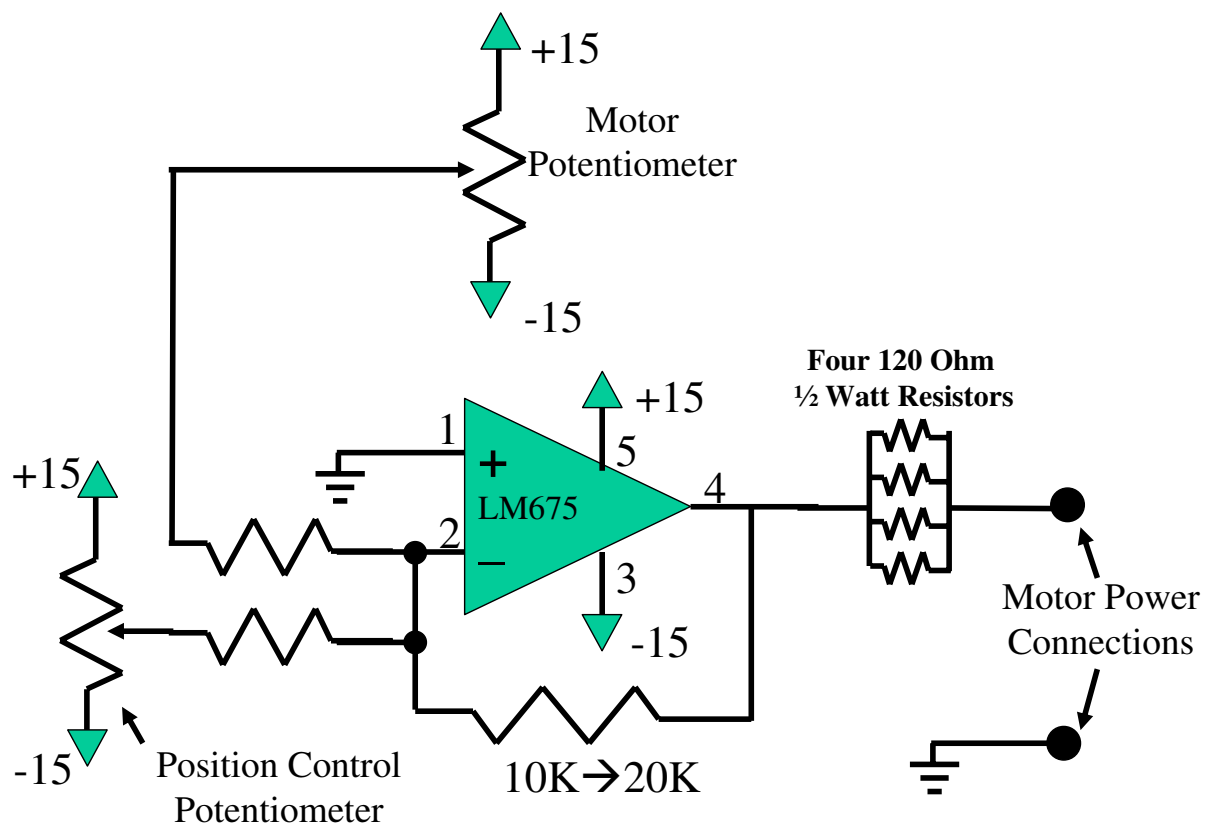
Motor Driver Circuit - Unmarked Resistors are 10k ohms

Make sure you understand how the driver circuit works and how connections are made using the plate protoboard. Then test that the circuit works by demonstrating that you can change the head position by turning the potentiometer shaft on the plate protoboard.
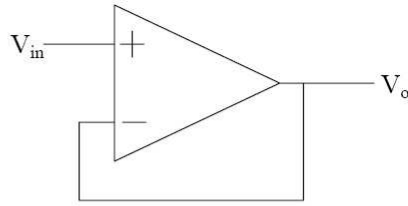
Checkpoint: 3:00 PM

- Demonstrate that you can control the head position.

- Demonstrate that you understand how the driver circuit works.

2.4 Change the power supply

For the next two sections, as a friendly reminder, here are some op-amp circuits that we learned about in class that you might find useful:
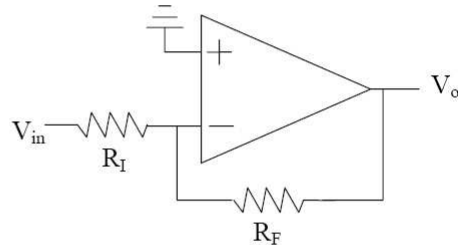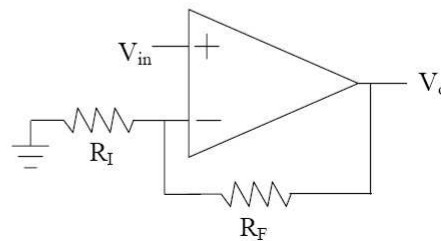
Voltage Follower

$$V_o = V_{in}$$

Inverting Amplifier

$$V_o = -\frac{R_F}{R_I} V_{in}$$

Non-Inverting Amplifier

$$V_o = \frac{R_F + R_I}{R_I} V_{in}$$

There is a problem in using the driver circuit for the robot head that you have been given. The robot only has $+12$ volts available, but the circuit on the protoboard requires a power supply with $+15$ and -15. We would like you to design a circuit that will drive the motor but only use a single twelve volt supply. Just using op-amps, you won't be able to increase the voltage range of your circuit past 12 volts, but fortunately the op-amps will run on $+6$ and -6. You will definitely need at least one more op-amp, and a number of additional resistors. Please do your design on paper, then demonstrate that the design works using the constraint resolver.

Checkpoint: 4:00 PM

- Be able to describe your circuit.

- Demonstrate that the circuit works using the contraint resolver.

Now, build your circuit on the protoboard and test it using just the $+15$ volt supply and ground from the project board to simulate having only the robot's power supply. If you turn the knob so that the line points straight up, the supply will be closer to $+12$ volts, but $+15$ is also close enough. The datasheet for the op-amp can be found on the course calendar; use it to figure out the pin configuration. When building your circuit, please clip the wires on the protoboard so that they are no longer than they need to be. This will make debugging your circuit easier. Before you connect things to power, double-check your connections, since it is really easy to blow up an op-amp. As a warning, your op-amp may get hot, so don't touch it when the circuit is on. Test that the circuit works by demonstrating that you can change the head position by turning the potentiometer shaft on the plate protoboard.

Checkpoint: 5:00 PM

- Demonstrate that you can change the head position by turning the potentiometer shaft, with your circuit powered only by connections to +15 and ground.

2.5 Increase the motor voltage range - Optional!

With our modified driver circuit for the robot head, the voltage across the motor ranges from negative six volts to positive six volts. To make the motor respond more quickly, we'd like to be able to put either positive or negative twelve volts across the motor. Still using a single +12 (or +15 volt supply, can you figure out how to double the range of voltage across the motor? Hint: right now, the voltage input to the motor is centered around +6 volts as a "virtual" ground. If we don't insist on having a fixed ground for the motor, but instead make the motor ground a second input that varies inversely (with respect to the +6 volt ground) with the voltage input, the voltage difference as seen by the two motor inputs can be doubled. If you're not sure where to start, take a look at the op-amp circuits that we learned in class, above. A tip: if you find that all you are doing with your +6 volt virtual ground is feeding it into the inputs of op-amps, do you still need the op-amp circuit from the previous section? What is the current (load) on the voltage divider providing your +6 volt virtual ground?

Optional Checkpoint: 5:00 PM

- Explain how your new circuit works, and demonstrate changing the head position.

3. To do before Tuesday November 14th

Write a description of your circuit. Give a complete schematic and describe how you derived the component values.

Concepts covered in this assignment

Here are the important points covered in this assignment:

- Learn to view circuits as constitutive relations and conservation laws.

- Explore the op-amp as an example of a more complicated circuit element.

- Learn how to design with op-amps.