

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
 Department of Electrical Engineering and Computer Science
 6.01—Introduction to EECS I
 Spring Semester, 2008

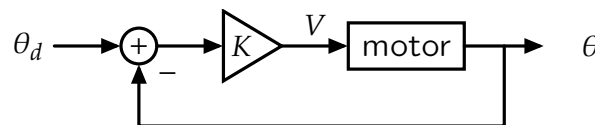
Assignment 8 Revised, Issued: Thursday, April 3

Revised Design Lab: Replaces only the design lab section of the original handout. There are post-lab homework problems in the original handout that you need to do.

Design Lab

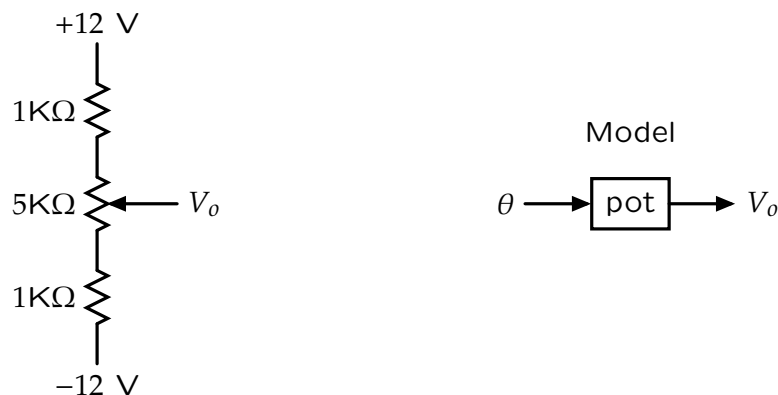
The goal of today's design lab is to build a circuit to control the position of a motor. In later labs, we will use this motor to turn the "head" of our robot.

At a high level, we can think of our motor controller as follows:



We wish to command a desired angle θ_d that is the input to a feedback loop that compares the desired angle to the measured angle θ . The difference is multiplied by a gain K to generate an output voltage V that will cause the motor to turn in a direction to make the measured and desired angles equal.

We cannot conveniently manipulate angles, so we will use potentiometers to convert the angle of their input shaft to a voltage. A potentiometer is a three terminal device. The resistance between the middle and bottom terminals increases in proportion to the angle of the input shaft (θ) and the resistance between the middle and top terminals decreases, so that the sum of the top and bottom resistors is constant (here it is $5\text{K}\Omega$). By connecting a potentiometer as shown below we can create a device that converts θ into a voltage V_o (measured relative to GND).



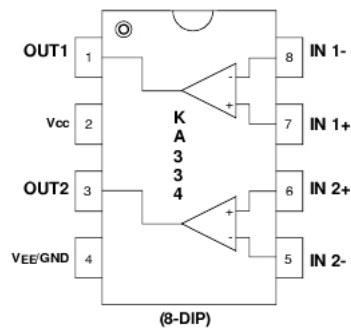
Question 11: Construct the circuit shown above (be sure to adjust the power supplies to $\pm 12\text{V}$ before connecting the circuit.) Mathematically determine the range of V_0 that the device can generate. Measure the range (relative to GND) and compare the measured and calculated ranges.

Question 12: Use the potentiometer from the previous question to drive the voltage input to the motor. Use a Lego motor with adaptor cable and breadboard adapter (6 pins). The motor is connected between pins 5 and 6 of the adaptor. Connect pin 5 to the output of the potentiometer and connect pin 6 to GND. How fast can you get the motor to turn? Explain.

Question 13: Use an op amp to buffer the output of the potentiometer (this is similar to what we did last week when we used an op amp as a buffer between two voltage dividers). Use one of the two op amps in the KA-334 package (see schematic below). Let $V_{cc} = +12\text{ V}$ (pin 2) and $V_{ss} = -12\text{ V}$ (pin 4). Compare the behavior of the motor now to its behavior in the previous circuit. Can you make it go in both directions?

Checkpoint: 30 minutes

- Show the potentiometer controlling your motor. Be sure it can go in both directions.



When we use the motor to position the robot “head,” we will only have access to a $+12\text{ V}$ supply (the robot does not have a -12 V supply). One way to get bidirectional turning from a single $+12\text{ V}$ supply is by generating a “virtual ground” that is midway between 0 V and $+12\text{ V}$.

Question 14: Reconnect power to the op amp so that it uses a single $+12\text{ V}$ supply, i.e., connect $V_{cc} = +12\text{ V}$ (pin 2) and $V_{ss} = \text{GND}$ (pin 4). Use a second op amp to generate a “virtual ground” signal. Modify your previous op amp circuit so that it uses the virtual ground to allow the motor to turn in both directions.

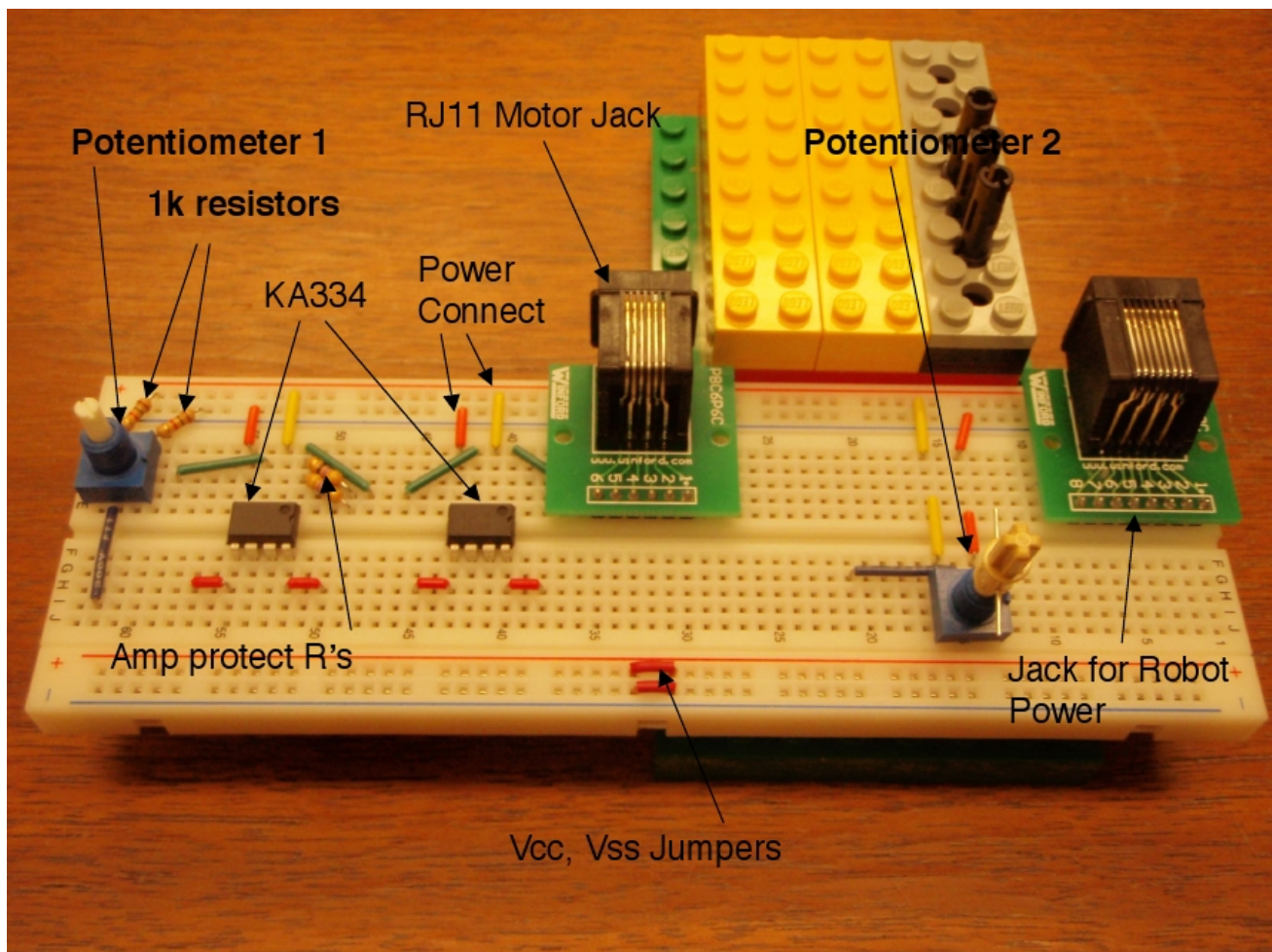
Be careful about the following:

- Your ‘virtual ground’ should be halfway between the power supply rails. (So that the power supply rails become ± 6 with respect to the virtual ground.)
- Henceforth, think of this as ground, think of what was formerly $+12$ as $+6$ (it is 6 volts higher than ground), and think of what was formerly 0 as -6 (it is 6 volts lower than ground). Remember that what matters is the relative voltages.

Checkpoint: 60 minutes

- Show the potentiometer controlling your motor, with a +6 and -6 supply. Be sure it can go in both directions.

For the remainder of today's lab, you will need a "head assembly," which you can obtain from the staff. These head assemblies have circuitry that is pre-built on the "bottom board." The "top board," which is mounted so that it can be swiveled by a Lego gear motor, has no circuitry on it right now. Examine and familiarize yourself with the circuitry on the bottom board (shown below). You will note that there are two KA334 op-amps, wired for power but not for input or output.



The photograph of the bottom board (above) shows the following:

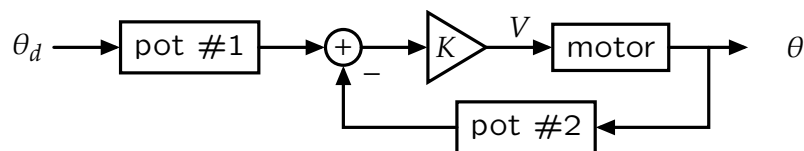
1. Potentiometer 1: This 'pot' is connected between the power supply and ground rails by two 1k resistors. The potentiometer has a total resistance of $5k\Omega$, just like the example you started this lab with.
2. Potentiometer 2: When you get the head assembly, this potentiometer will be connected to the bottom of the Lego motor. It is connected to the power and ground rails directly (not through resistors).

3. Two KA334 op-amps. As you can see, they are both connected to the power and ground rails. Two of the input pins (numbered 5 and 8) are connected by short red wires to rows of holes beyond the ends of the op-amps. This is just for your convenience in wiring. The other two input pins are unconnected. The two op-amp outputs (pins 1 and 3) are also connected to outboard rows of pins. Note that pin 1 of one of the op-amps is connected to two 47 ohm resistors in parallel. You should use that connection to the motor when it comes time to connect to the motor. **DO NOT DO THIS YET.**
4. There are two connectors from pins to cables. One of these is an RJ-11 like the one you have already used to connect to the motor. As you already know, pins five and six are the motor connections. The other cable connection accepts the RJ-45 cable that is on the robot, and is wired so that this board will get power and ground connections from the robot battery. For the moment you can ignore this connector and derive +12V and 0V from the same power supply you have been using.
5. Note that, on some but not all protoboards, the left and right power rails must be connected by jumpers. The jumpers for the bottom two power rails are shown in the photograph as VCC, VSS Jumpers. There must be similar jumpers for the top two power rails. The upper jumpers cannot be seen in the photograph because they are beneath the RJ-11 Motor Jack. **Please make sure that there are jumpers at the right spots beneath the RJ-11 connector.**

Be careful about the following:

- Check that the adapter for the head motor has been placed correctly on the protoboard (some of the pre-built units are incorrect). It should be located so that you can wire to pins 5 and 6. It is easily moved by unplugging it and plugging it in at some convenient location.
- When designing the op-amp circuit below, take advantage of modularity. Use the electrical operations of addition and/or subtraction.
- You should be able to do this using no more than 4 op-amps.
- Connect the black (reference) lead of your multimeter to your virtual ground, and make all measurements in reference to it.

Using potentiometers, we can redraw our block diagram as follows.



As before, we have represented the motor as a device that converts an input voltage to an output angle.

We will simply let the gain $K = 1$. So, to complete our motor controller, we must design a circuit to calculate v_1 , the voltage from potentiometer 1, minus v_2 , the voltage from potentiometer 2 (under the motor).

Question 15: Create the appropriate control signal:

1. Rebuild your circuit for creating a virtual ground signal on the bottom board of the head. Connect virtual ground to one of the supply rails. Connect your new +6 and -6 to the other two rails.
2. Design and draw the circuit diagram for an op amp circuit to compute $v_1 - v_2$.
3. Construct the circuit. Change the positions of the potentiometers and measure the change in output voltage that is produced. Can you set the potentiometers so that the output is +6? So that it is -6?

Question 16: Connect up the motor so that the feedback system drives the motor angle θ to equal θ_d . Does the motor turn to a stable position when you turn on power? Change the angle of potentiometer 1. Does the motor position change accordingly?

Please write up questions 14, 15, and 16 as shown above and not as shown in the *What to Write for PS 8* handout (due to changes in question wording).

Checkpoint: End of lab

- Show the potentiometer controlling your motor. Explain what's fundamentally different about the relationship between the pot and what the motor is doing, from what you did in the previous two checkpoints. The head should move smoothly and have a symmetric range of motion to the left and right.