MASSACHVSETTS INSTITVTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science
6.01—Introduction to EECS I
Fall Semester, 2007

Assignment 9b - Design Lab, Issued: Wednesday, Oct. 31st

To do this week

...in Tuesday software lab

1. Start writing code and test cases for the numbered questions in the software lab (in a previous handout). Paste all your code, including your test cases, into the box provided in the "Software Lab" (Part 9.1) problem on the on-line Tutor. This will not be graded.

...before the start of lab on Thursday

1. Read the lecture notes.
2. Do the on-line Tutor problems for week 9 that are due on Thursday (Part 9.2).
3. Read through the entire description of Thursday's design lab (this handout).

...in Thursday robot lab

1. Answer the numbered questions in the robot lab and demonstrate them to your LA.
2. Do the nanoquiz; it will be based on the material in the lecture notes and the on-line Tutor problems due on Thursday.

...before the start of lecture next Tuesday

1. Do the lab writeup, providing written answers (including code and test cases) for **every** numbered question in Tuesday software lab *and* this design lab handout.

On Athena machines make sure you do:
`athrun 6.01 update`
so that you can get the `Desktop/6.01/lab9` directory which has the files mentioned in this handout.

- You need the files **resolveConstraints.py, circuitConstraints.py, genKCL.py (your code) or genKCL.pyc (our code)** for the software lab, and may find them helpful for the circuit design lab.

During this design lab, if you are using your own laptop, download the files from the course Web site (on the Calendar page). Be sure you have `numpy` installed.

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 the constraint resolver, analyzing an electromechanical system, and designing a circuit. Whew!

Thursday's Robot Head Lab – Using Op-amp Circuits

For this lab you will need:

1. A robot head setup.
2. A voltmeter.
3. A project board with variable power supply.
4. A motor (in addition to the motor in the robot head) with a connector cable.

Examine your robot head and compare it to the picture in figure 1. The robot head is in four parts: the base (a big flat grey Lego plate), the circuit board which is attached to the grey plate, the swiveling "head" which has a circuitboard mounted on a rotating platform, and a motor that drives the rotating head. The picture in figure 1 also shows a motor connector cable, but that cable will not yet have been attached. The connector cable is attached to a separate free motor so you can run some initial experiments. The side view in figure 2 shows how the swiveling head is connected to the motor, and also how the motor is connected to the shaft of a blue position sensing potentiometer. The potentiometer shaft is connected to the head so that the shaft rotates with the head, and the potentiometer leads are connected the plate circuit board. The potentiometer is used to measure the head position. Note that one end of the potentiometer is connected to the positive supply and one end is connected to the negative supply. When so-connected, the potentiometer acts as an adjustable voltage divider, with the divider output being the center connection to the potentiometer as shown in figure 3.

As figure 3 indicates, the voltage at the potentiometer center connection (when measured with respect to ground) will be zero when the potentiometer is in its center position, and will be either the plus supply or the negative supply when the potentiometer is turned all the way clockwise or all the way counterclockwise. The voltage at the center connection of the potentiometer is then related to the shaft angle θ, and so the voltage produced will be proportional to the shaft angle.

The base circuit board is shown in figure 4 without the motor, swiveling head, and grey base plate. Notice the locations of the negative supply rail, the positive supply rail and the two ground rails. Also note that the circuit board has two potentiometers, the right potentiometer is used to sense motor position, the left potentiometer is for direct hand adjustment (by turning the white shaft). The circuit diagram for the entire circuit board is shown in figure 5.

Before using the robot head, adjust the variable power supplies on the project board to be +6 volts and -6 volts using your volt meter. Then connect project board ground, +6 volt and -6 volt supplies

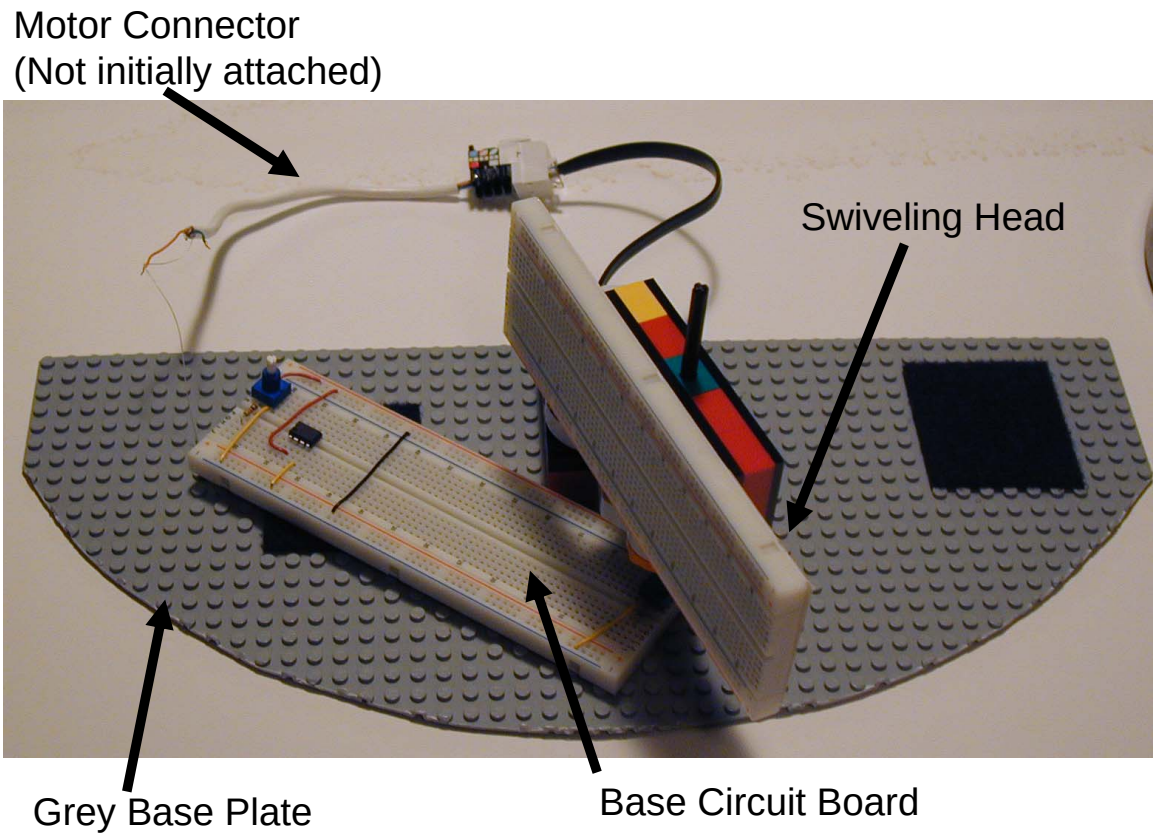


Figure 1: Robot Head, top view.

to the ground, Vpos and Vneg rails of the robot head base plate circuit board, respectively. Once the power supplies are connected, use a volt meter to measure the voltage between ground and the end of the 10k resistor in series with the left-side hand-adjustable potentiometer wiper. Notice how the voltage changes as you turn the shaft of the potentiometer. Note, you may have to swap leads on the voltmeter to make these measurements. Perform the same measurement on the right-side position sensing potentiometer, though you should turn the robot head to turn the potentiometer shaft.

Question 1. What range of voltages do you measure on the left-side potentiometer as you turn the shaft of the hand adjustable potentiometer?

Question 2. What range of voltages do you measure on the right-side potentiometer as you turn the robot head?

Question 3. Why are the two ranges different?

Next, connect the free motor (NOT the robot head motor) between ground and the end of the 10k resistor not connected to the left-side hand-adjustable potentiometer wiper, as shown in figure 6, and remeasure to voltage at the end of the 10k resistor.

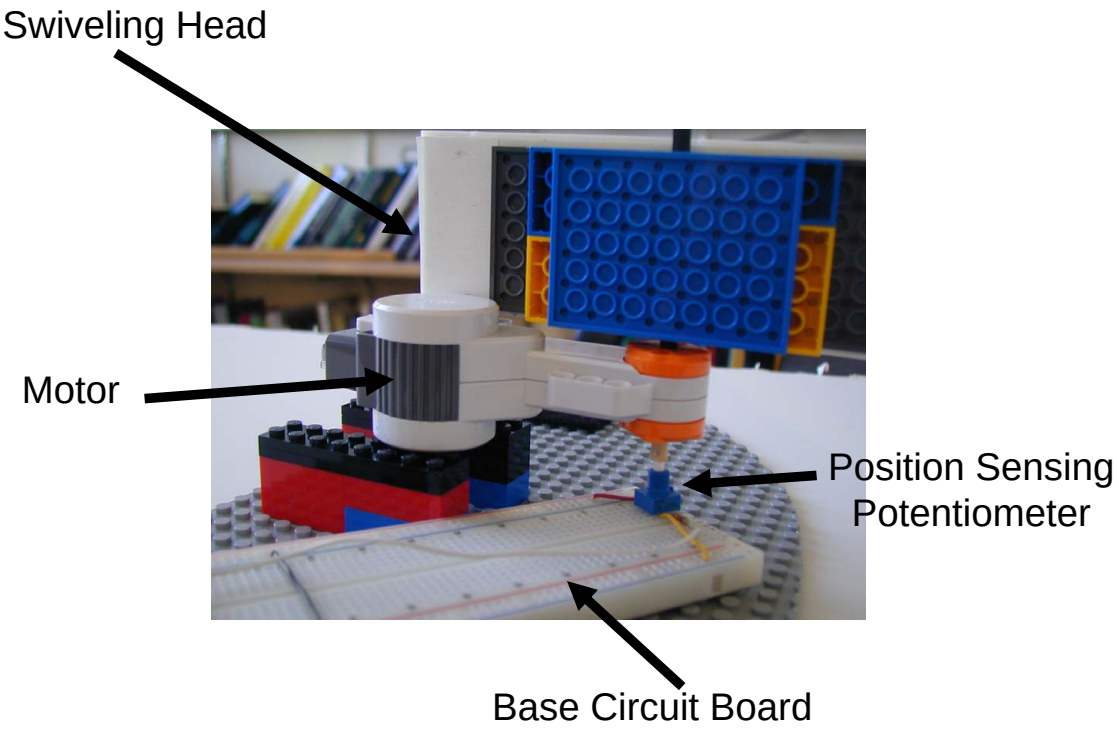


Figure 2: Robot Head, side view showing connection to sensing potentiometer.

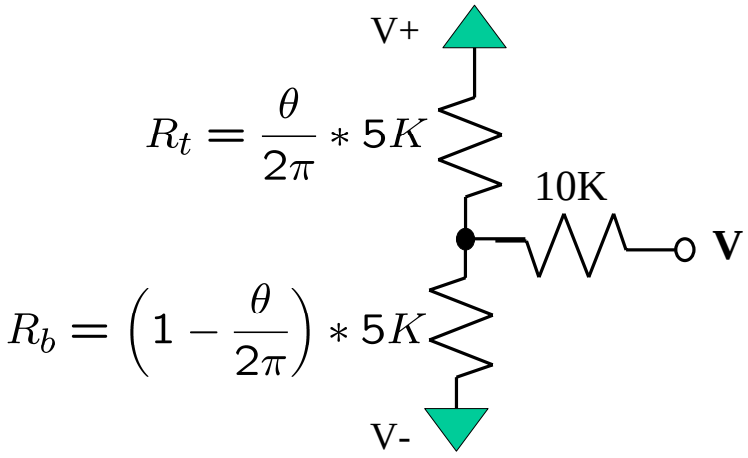


Figure 3: Circuit describing the relation between shaft angle and voltage.

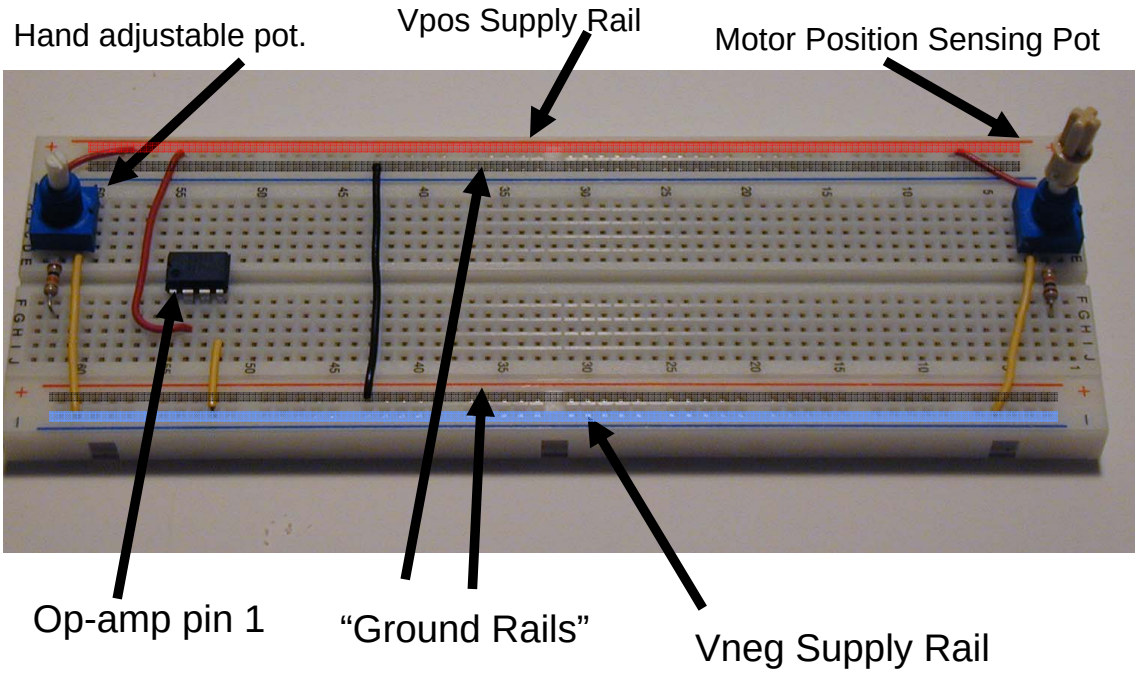


Figure 4: Base plate circuit board closeup

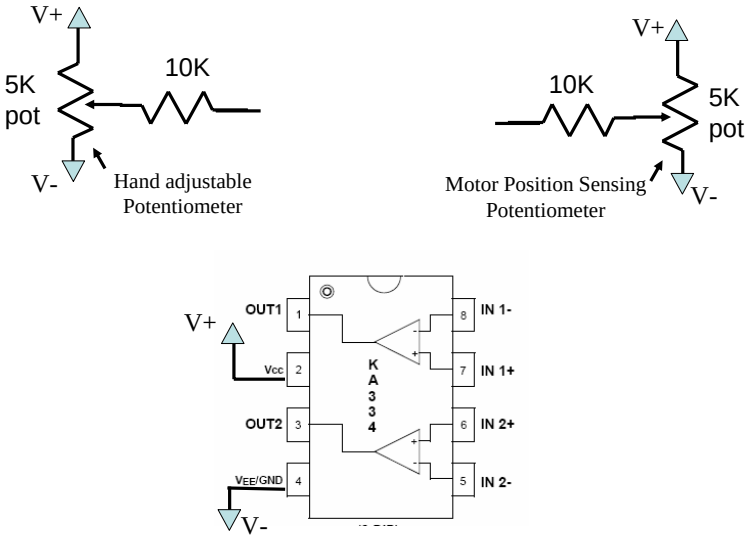


Figure 5: Circuit diagram for the base plate circuit board.

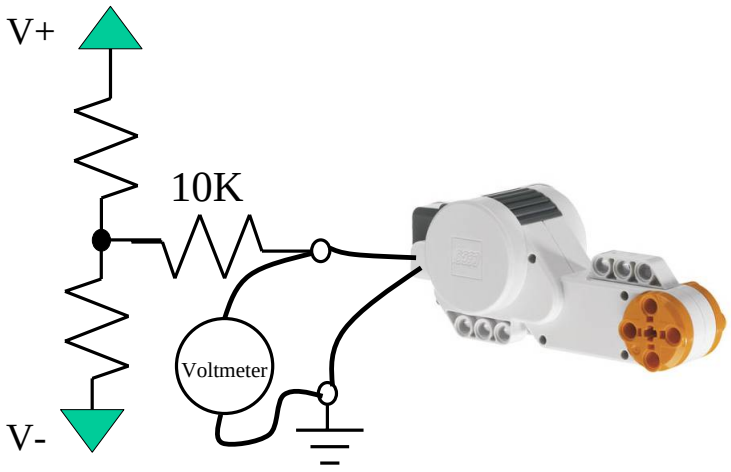


Figure 6: Circuit diagram for connecting the motor to the potentiometer

Question 4. What range of voltages do you measure as you turn the shaft of the hand adjustable potentiometer when the motor is attached?

Question 5. Explain your results.

Checkpoint: 10:30

- Demonstrate that you have adjusted the project board power supplies to plus and minus six volts.
- Demonstrate your voltage measurements.

Your circuit board has an op-amp, as show in figure 4, and its pin connection is show in figure 5. Design an op-amp circuit that will buffer the voltage from the hand-adjustable potentiometer circuit, and be able to drive the motor, as shown in figure 7.

Question 6. Describe your op-amp buffer circuit.

Question 7. When you use the buffer, what range of voltages do you measure across the motor as you turn the shaft of the hand adjustable potentiometer?

Question 8. What does the motor do as you turn the shaft of the hand adjustable potentiometer?

Question 9. What happens when you interchange the orange and green leads from the motor?

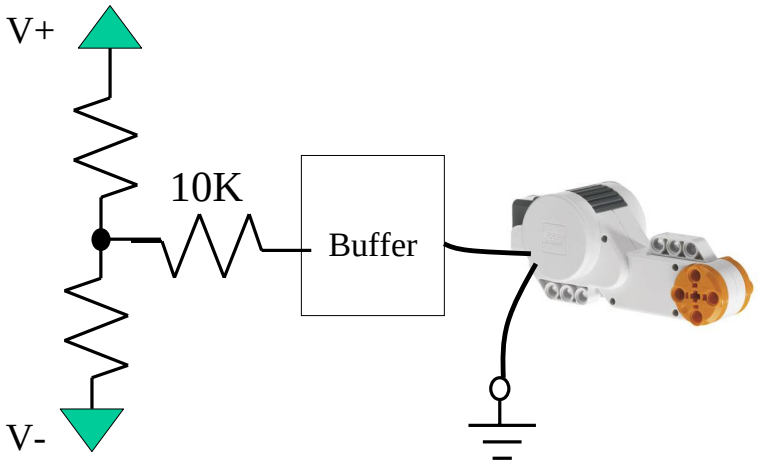


Figure 7: Circuit diagram for buffering the potentiometer voltage.

Checkpoint: 11:00

- Demonstrate your buffer circuit, and your voltage measurements.

Now design a circuit using the op-amp that produces an output voltage that is the negative of the sum of the voltages at the wipers of each of the two potentiometers, as shown in figure 8.

Question 10. Describe your op-amp summing circuit.

Question 11. For every position of the robot head, can you turn the left-side hand adjustable potentiometer so that the output of your circuit is exactly zero volts?

Checkpoint: 11:30

- Demonstrate your summing circuit, and your voltage measurements.

Move the motor connector from the free motor to the robot head motor, and connect the robot head motor to the output of your summing circuit so that you can use the hand-adjustable left-side potentiometer to control the position of the robot head. You may have to experiment with which motor lead goes to ground in order to get the circuit to work.

Question 12. Describe your circuit for controlling the robot head.

Question 13. Why does it matter when you interchange the orange and green leads from the robot head motor?

Question 14. Once you are sure your position control system is working properly, try increasing the variable supply voltages to +15 and -15. How does that impact the performance of your position control system?

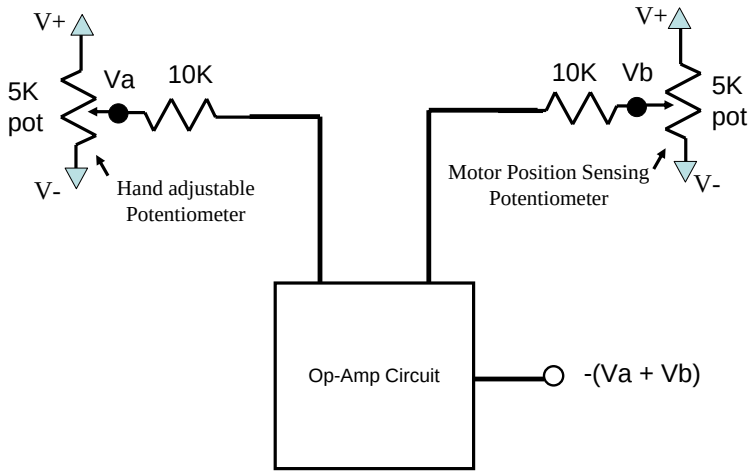


Figure 8: Circuit diagram for buffering the potentiometer voltage.

Checkpoint: 12:00

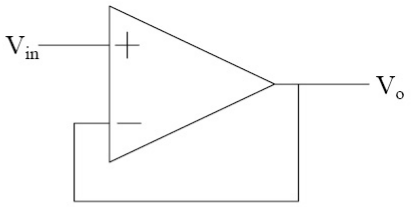
- Demonstrate that you can control the head position.
- Demonstrate that you understand how the driver circuit works.
- Demonstrate that you understand what happens when the orange and green wires connecting the motor to the driver circuit are swapped.

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:

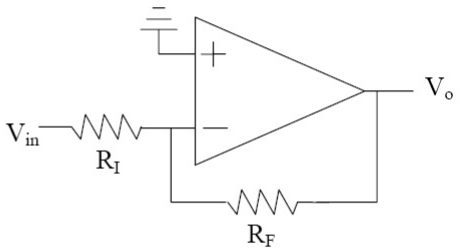
Voltage Follower

$$V_o = V_{in}$$



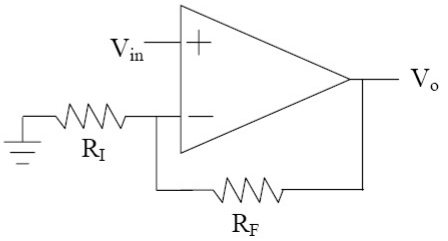
Inverting Amplifier

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



Non-Inverting Amplifier

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



There is a problem in using the above driver circuit for the robot head. The robot only has ground and +12 volts available, but the circuit on the project board requires a power supply with ground, +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 beyond 12 volts, but fortunately the op-amps will run on +6 and −6. You will definitely need to use at least the second op-amp, and a number of additional resistors. Please do your design on paper, then if you have time, demonstrate that the design works using the constraint resolver.

Checkpoint: 12:25 PM

- Be able to describe your circuit.

Build your circuit on the base plate circuit board and test it using just the +12 volt supply (adjust one of the project board supplies to generate ground and +12 volts) and ground. Test that the circuit works by demonstrating you can change the head position by turning the potentiometer shaft on the plate circuit board. When building your circuit, please clip the wires on the circuit board so that they are no longer than they need to be. This will make debugging your circuit easier.

Finally, you will be using your circuit in subsequent labs, please label your circuit board with your names!

Question 15. Give a diagram of your circuit for controlling the robot head with a single twelve volt supply.

Question 16. Please explain how your circuit works.

Checkpoint: 12:45

- Demonstrate that you can change the head position by turning the potentiometer shaft, with your circuit powered only by a single +12 supply.

Exploration - Increase the drive on the motor

It is likely that for your 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. Can you design a way to still use a single +12 volt supply, but increase 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 virtual ground) with the voltage input, the voltage difference as seen by the two leads connecting to the motor 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.

Post-Lab Writeup for Tuesday and Thursday's labs: Due before lecture on November 6th

All post-lab hand-ins should be written in clear English sentences and paragraphs. We expect at least a couple of sentences or a paragraph in answer to **all** of the numbered questions in both lab handouts (both Tuesday's software and Thursday's design lab).

We also want the code you wrote for Tuesday's or Thursday's lab (though there will not be much code to hand in for Thursday's lab).

Concepts covered in this assignment

Here are the important points covered in this assignment:

- Learn the constitutive relations and conservation laws for the op-amp model.
- Explore the op-amp as an example of a more complicated circuit element.
- Learn how to design with op-amps.
- Learn a little about analog feedback control.