

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

**Assignment 7, Issued: Tuesday, Mar. 18**

**Overview of this week's work**

**In software lab**

- Work through part 1 of this lab.

**Before the start of your design lab on Mar 20 or 21 Midterm**

**In design lab**

- Work through part 2 of this lab.
- There will be no nanoquiz or homework write-up due; but we will assign credit for both parts of this lab based on check-off sheets.

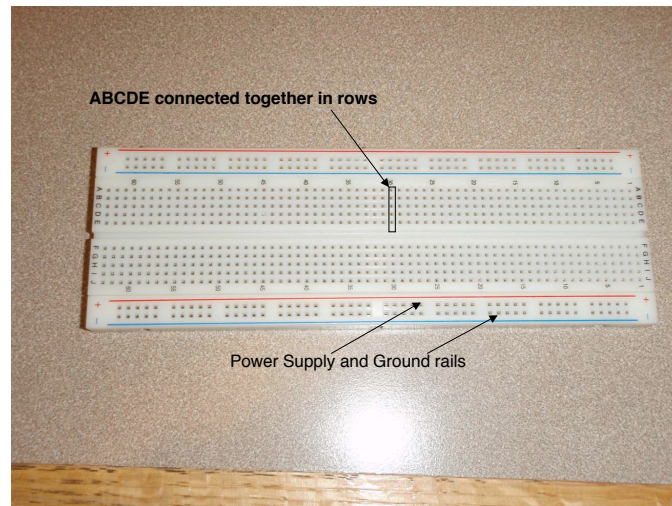


Figure 1: Protoboard

## Circuit Lab: Part 1

There are several exercises here, to be done in the two lab sessions this week. Please be sure to have done Exercise 6 before you leave the “software lab” of the week: the one on Tuesday or Wednesday that is 1.5 hours long.

The first thing you must do is become familiar with the prototyping board. You will be building your circuits on this card, an exemplar of which is shown in Figure 1.

The protoboard provides for easy and rapid prototyping of circuits: you can just plug in component parts and connect wires. Under each of the holes in the card are springy connectors. This particular card (which is just like the ones you will be using) has 63 rows of connections. Five holes on one side of a separator and five holes on the other side are connected together. The separator is there because we can plug in electronic components such as operational amplifiers, straddling the separator. You will notice the rows are numbered and the columns are labeled A-E and F-J (a little bit like airplane seating). There are two columns of holes on either side of the board, generally used for power supply and ground, and those holes are connected together along the red and blue lines. CAUTION: for some reason that none of us on the staff understand, the connection is broken between rows 31 and 33. Typical use of this thing requires that you ‘jumper’ (connect a wire) between the two ends of the power supply ‘rails’ and between the two ends of the ground ‘rails’ at those two rows. Failure to do this leads almost everyone to wonder why their circuit is not working. If you look carefully at the bottom of figure 9, you can see an example of these two jumpers as they should appear on your protoboard.

We will also be making use of a multimeter, used to measure voltage, current and resistance. Although some multimeters can measure frequency, temperature and other things, we will make use of only the elementary functions. You will also find it convenient to find a pair of ‘clip-leads’,

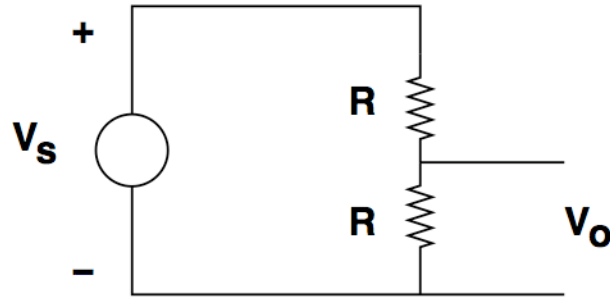


Figure 2: Voltage divider (schematic)

colorful wires with alligator clips at each end.

The multimeters all have two leads. One of them (the black lead) is plugged into a 'ground' or 'common' jack and the other (red) is usually plugged into a jack marked something like 'V- $\Omega$ -mA'. If you need to measure current higher than 100 or 200 mA, the red lead goes into another jack that is marked for that higher current.

The meters all have a control dial that selects what you are measuring. AC voltage is measured by setting the dial to one of the stops that have little tilde's (representing a sine wave). DC voltage is measured by setting the dial to one of the stops marked by a solid line over a dashed line. Resistance settings are marked by 'k $\Omega$ '. Most multimeters also have an 'off' position. Many, but not all multimeters will turn themselves off after being unused for some period of time, but it is best to set the dial to 'off' after you have made a measurement, to avoid exhausting the battery.

You will need to identify resistors. Almost all of the resistors we will be using are color coded, and some of us find those codes hard to read, so it is always best to verify the value of a resistor with a multimeter before using it. However, the color code consists of three bands around the resistor (you have to figure out which end is the first band). The first two are two digits of the value. The third band is a power of ten. The colors have meaning:

**0** black

**1** brown

**2** red

**3** orange

**4** yellow

**5** green

**6** blue

**7** violet

**8** gray

**9** white

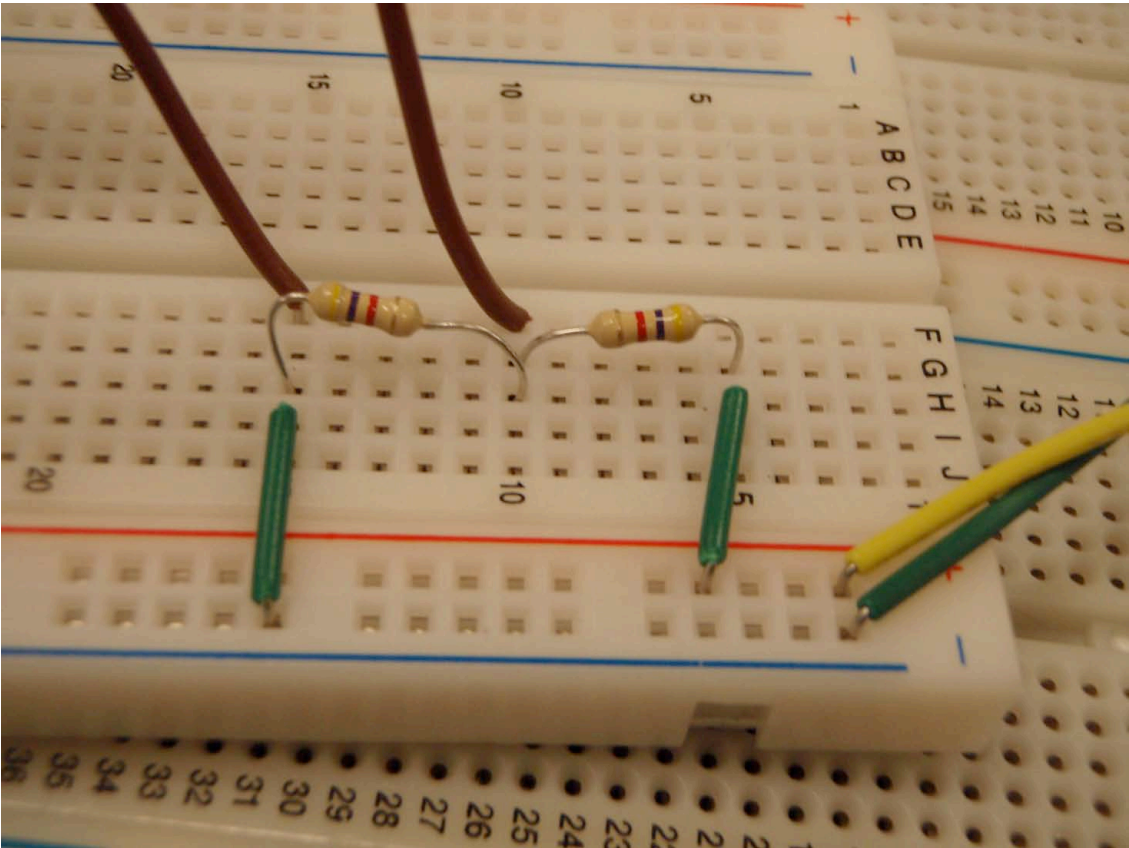


Figure 3: Voltage divider on protoboard

Thus a  $1,000\Omega$  resistor is marked by brown-black-red, meaning 1,0,2, or 10 times  $10^2$ .  $4.7\text{ k}\Omega$  is marked yellow-violet-red.

Most of the resistors you will encounter in the lab are rated for  $1/4$  watt, meaning you can dissipate  $250\text{ mW}$  under normal circumstances. If you dissipate much more than this the resistor will overheat and you may destroy it.

**Question 1: Measure Resistances** Find a few resistors of values of, say,  $1\text{k}$  ( $1000\text{ ohms}$ ) or  $4.7\text{k}$  ( $4,700\text{ ohms}$ ) and verify their resistance by using the multimeter. It is most convenient to connect clipleads to the probes of the multimeter and use the other end of the clipleads to grab the wires coming from the resistor. You will find that the resistors don't necessarily have exactly their stated value, but they are generally within a few percent.

**Question 2: Voltage Divider** Build up the circuit whose schematic is shown in figure 2 on your protoboard. The result might look something like the what is shown in figure 3.

What is built here is a simple voltage divider made up of two  $4.7\text{ k}\Omega$  resistors. Note the green wires that connect the right-hand lead of one resistor to the power supply rail and the left-hand lead of the other resistor to the ground rail. The green and yellow leads that go off the edge of the photograph are to be connected to ground and  $+12\text{ volts}$ , respectively. The two brown wires are a convenient way of connecting the clipleads from your multimeter to the resistive divider. Note that you will be using plastic-insulated wires, and to make connection with the protoboard, the power supply or almost anything else you need to 'strip' about a quarter of an inch of that plastic insulation from the end of the wire. We have tools that do this conveniently. Take care to take only the insulation and not cut off the end of the wire.

**Question 3: Adjust the power supply** Get out a power supply, plug it in, turn it on and adjust the positive supply to  $12\text{ volts}$ . Measure the power supply voltage with your multimeter.

Then connect your voltage divider to the power supply. What voltage do you expect to measure at the output of the divider? How close are you?

**Question 4: Limits to modularity** Now build a second voltage divider using two resistors of the same value as your first divider, taking the output of the first divider as the input to the second, as shown in figure 4. Is the output of this what you expect?

The problem here, which you should be able to explain quantitatively, is that by adding the second divider you put a resistance of  $2R$  in parallel with the lower resistor of the first divider, changing the divider ratio. To fix this, we could use an op-amp serving as a 'follower' or 'buffer' (the names are equivalent here). The schematic diagram for a unity gain follower is shown in Figure 5. We will learn more about this circuit (and other things you can do with operational amplifiers) very soon, but for now, we just accept the fact that  $V_{\text{out}} = V_{\text{in}}$  and the input draws no current (and so "looks like" a very large resistance).

The operational amplifier we will be using is the KA334, which has two op-amps in a single 8 pin DIP (Dual Inline Pin Package), that plugs into your protocard very conveniently. This kind of package, with pins at  $0.1''$  spacing, was once very common in electronics packaging. It has largely been superseded by surface mount parts now, however, as miniaturization has become more important. A wiring diagram of the KA334 part is shown in Figure 6. The power supply pins for this are pins 2 and 4, Pin 2 is connected to the positive power supply and pin 4 to the negative.

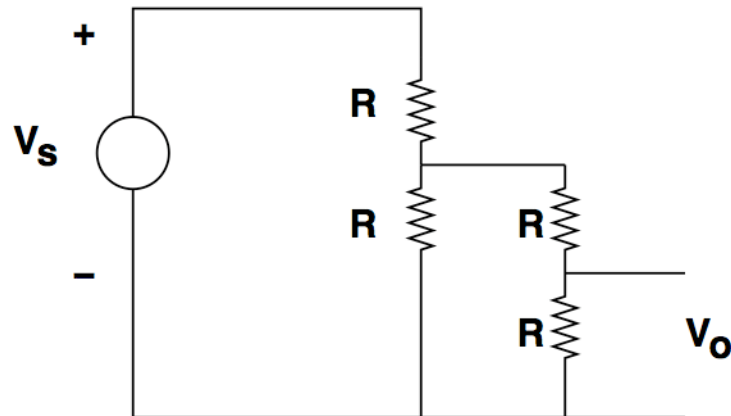


Figure 4: Two voltage dividers

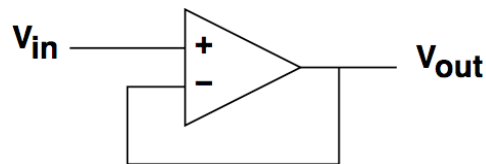


Figure 5: Op-amp wired as a follower

For our work we will use ground as the negative supply, so pin 4 is grounded and pin 2 is connected to +12 volts. NOTE: The power supply and ground connections are typically not shown in circuit schematics, but you **MUST** remember to make those connections or your op-amp won't work. Figure 7 is a schematic of one section of the KA334 wired as a follower, showing the power supply connection. You should use  $V_{CC} = 12V$  and  $V_{SS} = GND$ .

**Question 5: Use a KA334 as a buffer** Put a buffer in between the two resistive dividers, as shown schematically in Figure 8. **Whichever partner has done the least amount of actual circuit building so far should build this circuit.**

A picture of what your circuit should look like is shown in Figure 9. There is a brown wire running from the voltage divider output to Pin 7 of the op-amp (the positive input of one of the two amplifiers). A gray wire goes from the output of that amplifier (Pin 1) to the negative input (Pin 8), and the second divider is connected to that output point (Pin 1). Note green wires connecting pin 2 to the positive supply and pin 4 to ground. BE CAREFUL about the power supply. Reversing the positive and negative power supply leads will cause rapid failure of the amplifier. Two more things to note in this picture: red and black wires connecting the upper rails to the lower rails and two jumpers across that curious gap in the lower power supply rails.

These exercises with simple voltage dividers were principally to help you understand how to use the equipment in the laboratory, including the meters and the protoboards. Now we can go along and try something useful. Before you go home after the short lab session, you should make two simple measurements.

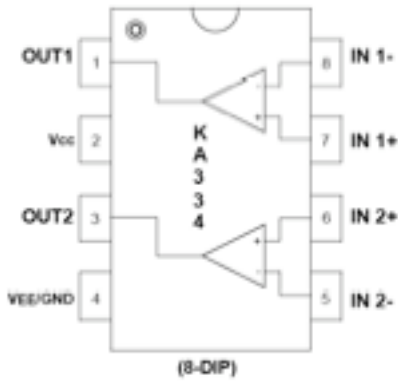


Figure 6: Pinout diagram of KA334. The 'dot' in the upper left-hand corner is visible on the top surface of the package.

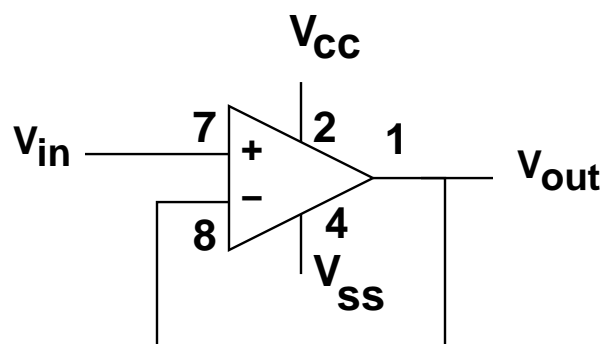


Figure 7: Schematic of KA334 wired as a buffer, with power supply pins shown



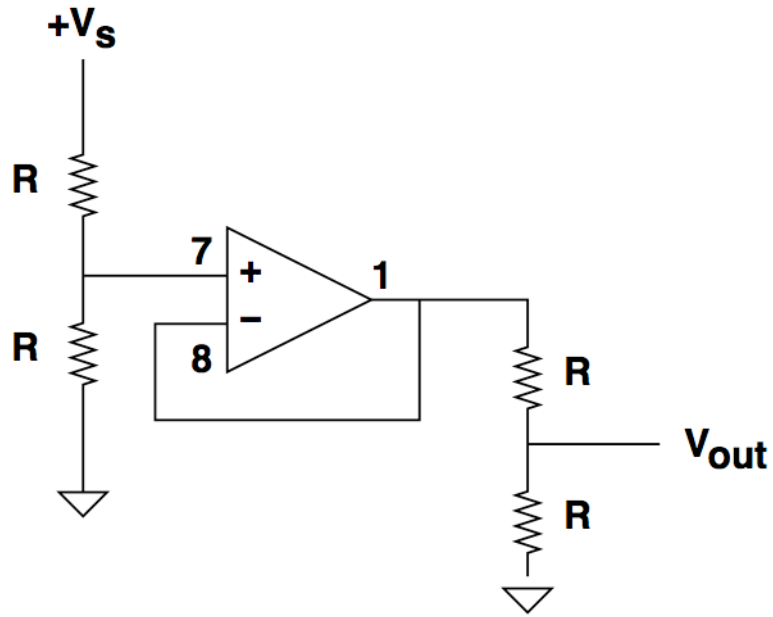


Figure 8: Two-stage, buffered voltage dividers

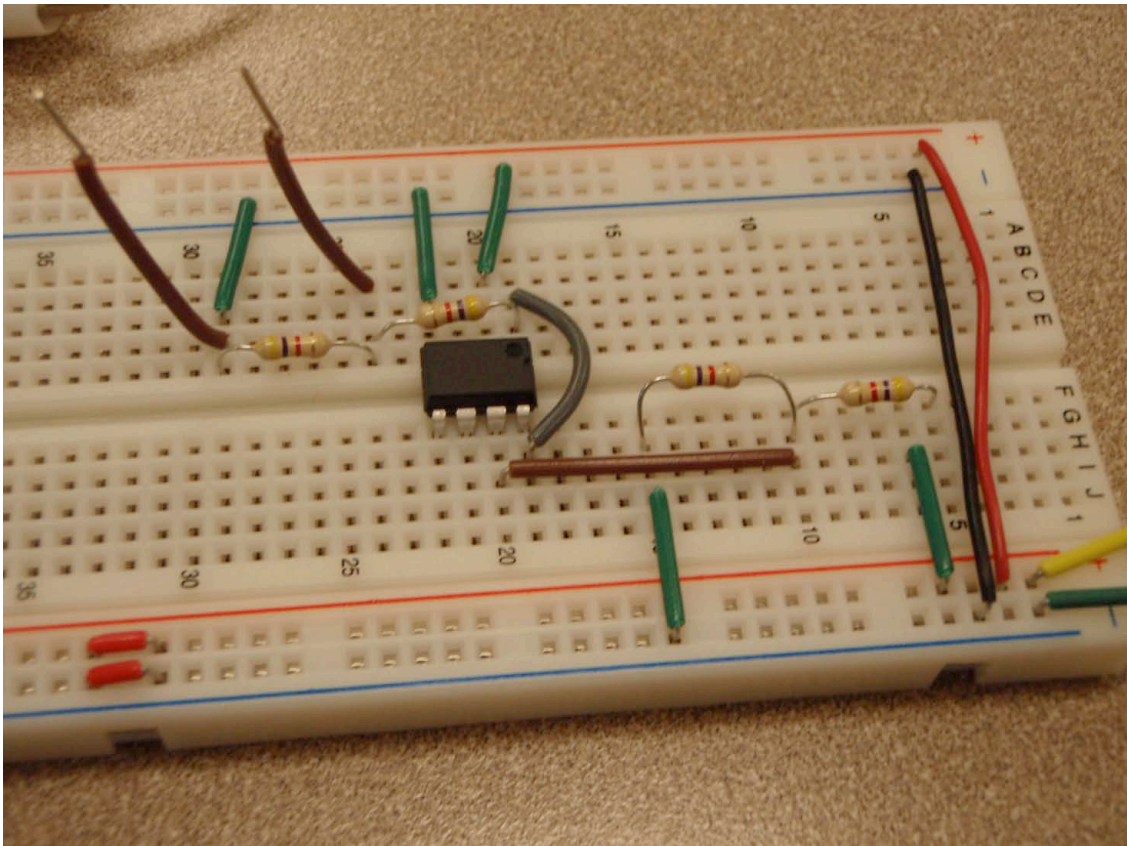


Figure 9: Protoboard with buffered voltage dividers



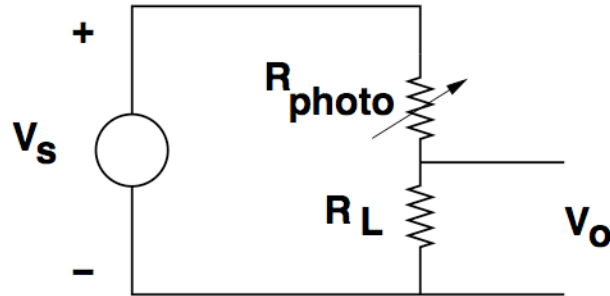


Figure 10: Light-sensing divider circuit

**Question 6: Photo-Resistor** Measure the resistance of one of the photoresistors we have available in the lab. You can just hook it up to a multimeter set to measure resistance. Note the resistance when the photoresistor is in the dark (cover it with something opaque. And note the resistance when a bright light is shining on the resistor.

To do something useful with these photoresistors, we will use them in simple voltage dividers, as is shown in Figure 10.

## Circuit Lab: Part 2

Do questions 7 and 8 at the beginning of the lab. If you want to get a bit ahead, you might try to do these two questions before you arrive in the lab.

**Question 7: Optimize the lower resistor value** Figure out what resistance  $R_L$  maximizes the voltage 'swing' from dark to light for this light sensing circuit.

**Question 8: Tailor the lower resistor to the Nidaq Box limits** We will want to measure the voltage output of this divider circuit with an analog to digital/digital to analog converter box (made by National Instruments) that we will refer to as the "Nidaq Box". The voltage input to this box should be limited to no more than ten volts. Calculate the value of  $R_L$  that should be used so that the voltage output of the divider does not exceed ten volts, when the divider is powered by a 12 volt source.

**Question 9:** Build the photosensing voltage divider Using the resistance you estimated as the optimal (or whatever standard value of resistance is closest), build the photosensing voltage divider of Figure 10. Power it up and measure the voltage out with a voltmeter. Cover the photoresistor with something opaque to put it in the dark and note voltage. Shine a bright light on it and measure the output voltage. Does it do what you predicted in Exercise 7?

Now we will learn how to connect your simple circuit to the computer, using the Nidaq box. For this exercise you will need to use one of our lab laptops, one of the Nidaq data acquisition boxes and a USB cable. When you connected the computers to the robots you used a long USB cable. We have short ones available that are more convenient to use and to put away. You should run `idle` from the `lab7` directory, which has the file `nidaq.py` (or `nidaq.pyc`) and the Unix executable `NIDAQserver`. Figure 11 shows the appropriate pins to use for the measurement. The connections

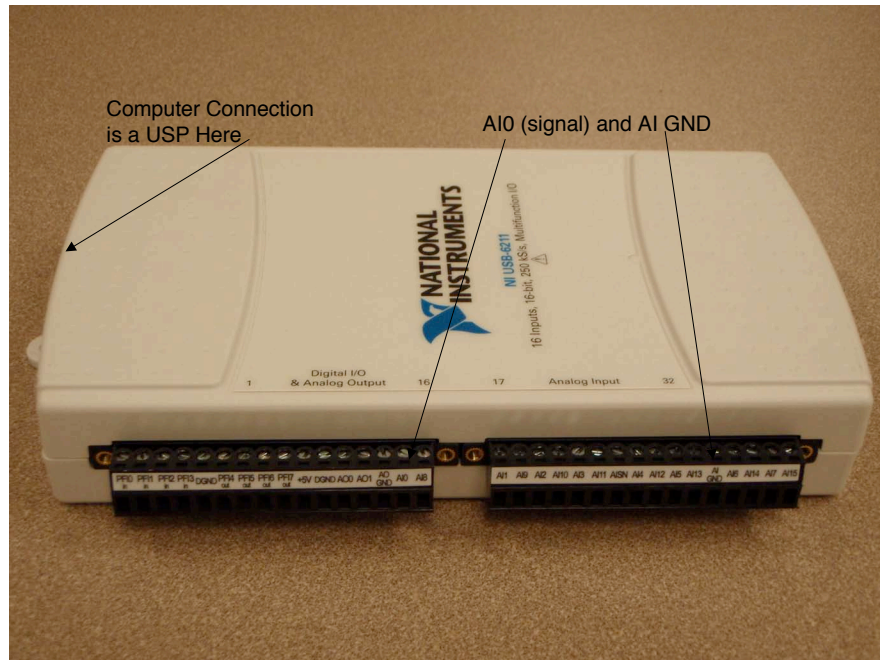


Figure 11: Data Acquisition Box

to the Nidaq A/D converter are screw terminals and you will need a fine tip screwdriver. Loosen the terminals, put the wire into the gap below the screw and tighten the screw. The wire should stay in when you do a 'pull test'.

The Nidaq digital acquisition box has sixteen analog inputs, marked AI0 through AI15. They are all referenced to AIGND. For the measurement of your voltage divider you should connect the output of the divider to pin AI0 and the ground connection to AIGND.

Within the file `nidaq.py`, there is a procedure called `initNIDAQ()` that returns procedure that, when called, returns a list of sixteen numbers, corresponding to the sixteen inputs, referred to GND. For example,

```
import nidaq
rp = nidaq.initNIDAQ()
while True:
    print rp()[0][0]
```

will repeatedly call the server, get those 16 numbers and print the first one (corresponding to the voltage between AI0 and AI GND).

**Question 10: Measure light with the computer**

Change the lower resistor in your divider to the value you calculated in Exercise 8. Connect the output of your divider to input AI0 of the Nidaq box. Observe what displays on your screen with the photoresistor covered and with the photoresistor in ordinary room light and with a bright light shining on it. Do you see what you expect?

**Question 11:** Set a threshold in your program, so that prints something special out when the photoresistor is illuminated by a bright light.

Now we want to move on to the next topic, which is those little motors sold by Lego that we will use in future labs to build servomechanisms. For this part of the lab you will need a motor, a cable and a plug that interfaces the motor and its cable to the protoboard. Note the Lego motor has a jack that looks very much like the RJ-11 used for telephones, but that has the locking clip offset to one side, so that an RJ-11 plug won't fit. However, we have cables that plug into the Lego motor at one end, and that fit into a standard RJ-11 plug at the other. We also have an adapter that is an RJ-11 jack mounted to a six pin arrangement that plugs into the protoboard. The motor winds up being connected to pins 5 and 6, which are labeled.

The first thing you should do is plug the cable into the motor and the adapter and plug the adapter into a convenient spot on your protoboard. Wire pins 5 and 6 to +12v and GND and turn on the power supply. The motor should turn at a fairly good speed.

**Question 12:** What happens when you adjust the power supply voltage?

**Question 13:** Disconnect the power supply and use your multimeter to measure the resistance of the motor.

Now set up to measure motor *current*. Your multimeter has a separate input marked something like "10 A", and you can run current through that input to the common connection point. You must also set the multimeter control knob to the 10A position. Put the multimeter in series with either pin 5 or pin 6.

**Question 14:** When you set the power supply to 12 volts and with the motor running unloaded (that is, nothing connected to the motor mechanical output), how much current does the motor draw?

**Question 15:** Try to slow the motor down by grabbing the rotating element. You may not be able to stop it, but you can 'load it' a bit. What does the current do?

**Question 16:** Given that you know the motor resistance and you also know how much current the motor draws when connected to 12 volts, you should be able to see that it is not behaving like a resistor. Propose a Thevenin equivalent circuit for the motor operating unloaded.

## Post-lab Homework

There is no post-lab homework this week because of the mid-term exam. Enjoy Spring Break.

## Concepts covered in this lab

- Familiarity with the prototype wiring system.
- Voltage, current and resistance measurement
- Operation of voltage dividers
- Familiarity with motors