# *Software* (hardware) *Lab 7* 6.01 – *Spring 2011*

Divide et impera

Work with a partner of your own choosing.

- **Using a lab laptop**: Log in using your Athena user name and password; in the terminal window, type `athrun 6.01 getFiles`. Work in the directory `Desktop/6.01/swLab07`.

- **Using your own laptop**: Download the zip file for software lab 7 from the *Calendar* tab of the course web page, unzip it, and work in the resulting directory.

You will also need:
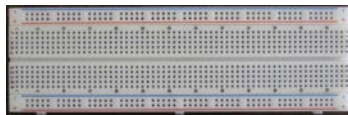
Proto board
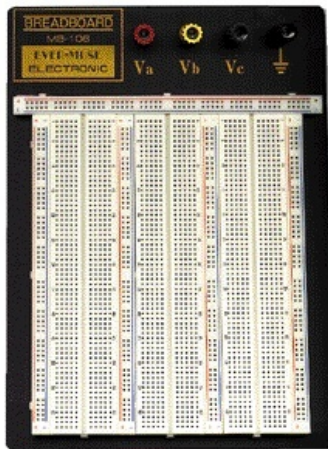
Power supply

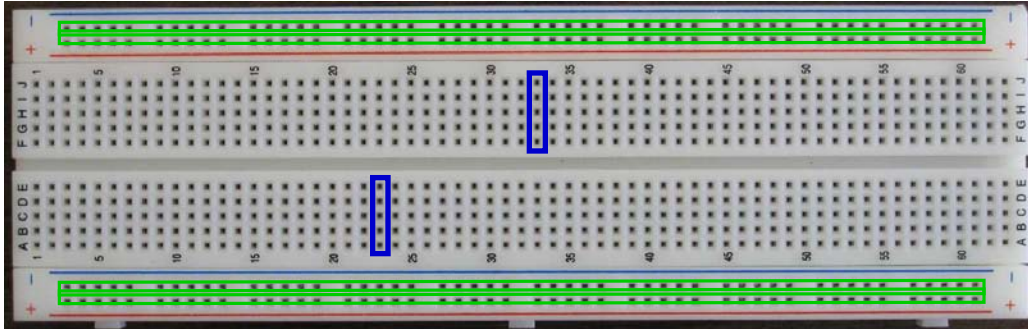

Four clip leads

Multimeter

Potentiometer

Four 1kΩ, one 100Ω, and one 10KΩ resistor

1kΩ = (brown, black, red); 100Ω = (brown, black, brown); 10KΩ = (brown, black, orange)

1   Getting started

In today's lab you will build some simple circuits and start learning how to use the 6.01 circuit simulator CMax.

We will build our circuits on a "proto board" like the one shown below.

The proto boards have holes into which wires and components can be inserted. Each column of 5 holes in the center areas is connected internally, as indicated by two representative vertical boxes (above). In other words, if you insert one end of one component into one of the holes in a column of 5, and then insert one end of a separate component into a second hole in the same column of 5, these two components are now connected by an internal wire that connects the 5 holes together. Holes in the top row (marked here with a red line, but sometimes indicated with blue instead) are connected internally (as are those in the second row, bottom row and next-to-bottom row), as indicated by the long horizontal boxes (above). These rows are convenient for distributing power (we will typically use $+10$ V) and ground.

*Use a **single, separate, proto board** as shown above for this lab. Do not use the proto boards that are attached to the power supply!!!*

It is conventional to use the top rail (which can be either red or blue) for positive supply voltages and the next rail (which can be either red or blue) for ground. Notice that the highest numbered column is on the right and the lowest is on the left.

Step 1.

- Connect the power supply terminals labeled $+15$V and **GND** to the power rails of your separate proto board using alligator clip leads. Connect the alligator clip to the proto board through short (less than 1") wires (from a wire kit); connect it to the terminal on the power supply by just sticking one 'jaw' of the alligator clip into the center of the terminal. **Don't unscrew the power-supply terminals.**

- Set the multimeter to measure voltage, and connect its probes to the power rails of the proto board using alligator clip leads, through short wires from a wire kit.

- Now, turn on the power supply and measure the power supply voltage with your multimeter. Adjust the positive supply to $+10$V. This step ensures that your setup will be delivering an appropriate amount of voltage to your protoboard.

2   Layout and Simulation

We will be using a simple layout and simulation tool, called *Circuits Maximus*, or "CMax" to its friends, to design and test circuits before constructing them. The following figure shows a screen-shot of CMax.

On Windows, you can run CMax by double-clicking on `CMax.py`. On a UNIX-based system, you can run CMax by using the terminal to navigate to the directory containing the file `CMax.py` and running "`python CMax.py`"
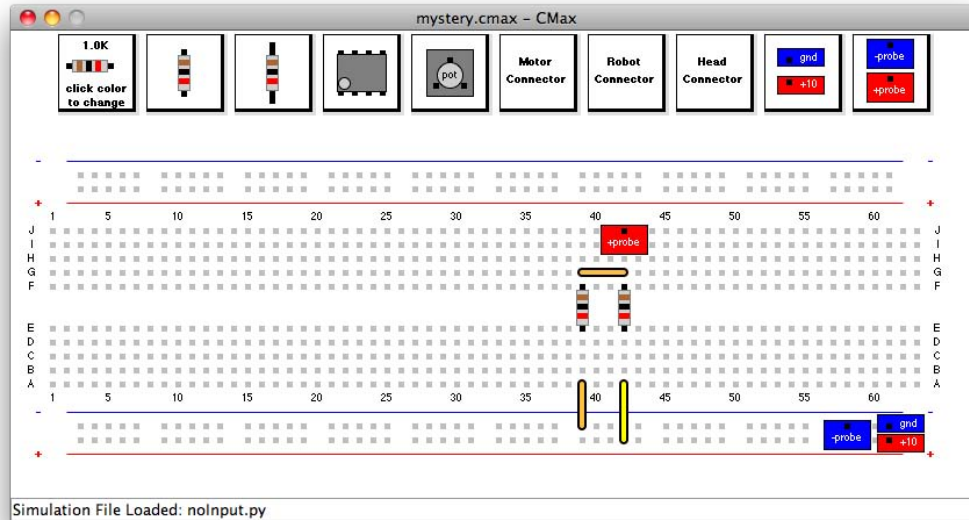
Step 2. Once CMax is running, select **File > Open** from the menu to open the file mystery.cmax.

**Step 3.** Draw a schematic diagram for the circuit shown in the CMax window.
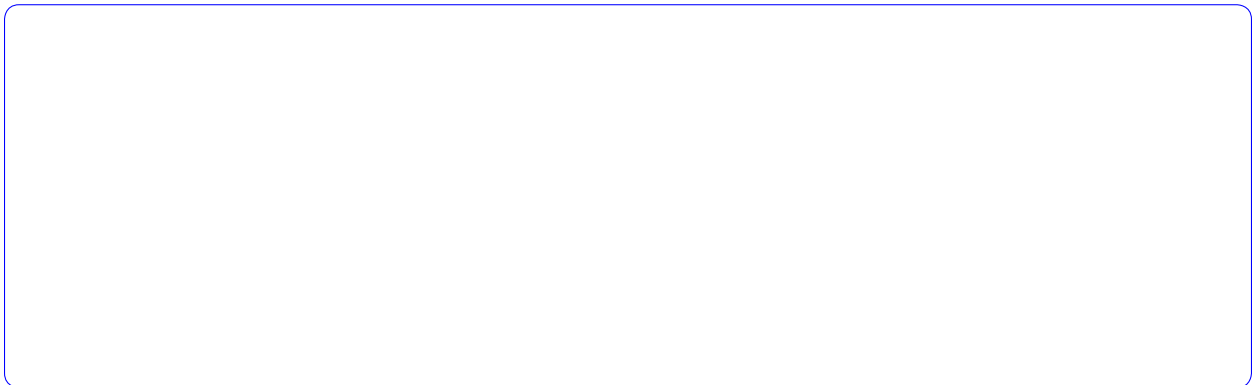
Step 4. Note the meter 'probes', attached to the ground rail and to location J42. Predict the voltage that will be measured across those two nodes in the circuit.

Step 5. Choose **Sim > Run Simulation** to make the simulator calculate the voltage across the probes. The result will be printed in a pop-up window. Do your calculations match the simulation?

3 Voltage Dividers

A voltage divider is a circuit that uses resistors to generate an output voltage that is a fixed fraction of the input voltage. The following figure illustrates a voltage divider as well as the resulting relation between its input voltage V_i and output voltage V_o:

$$V_o = \frac{R_2}{R_1 + R_2} V_i$$
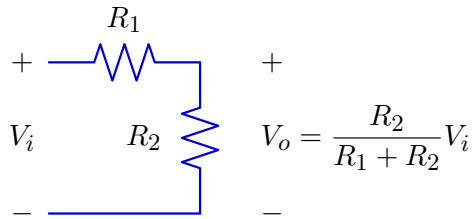
If $R_1 = R_2$, then $V_o = \frac{V_i}{2}$.

Can we cascade two divide-by-two circuits to produce a divide-by-four circuit? Consider the following design, where all of the resistors have $1\,k\Omega$ resistance.
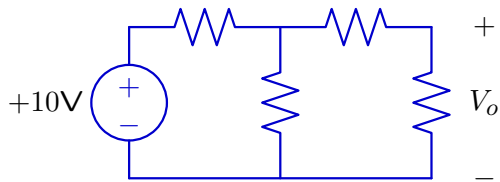
Step 6. Lay out this circuit using CMax. Documentation for CMax is available from the "Reference Material" page of the course web site.

Try to make your layout simple and clear. Use short wires oriented horizontally or vertically where possible. Try to avoid crossing wires, and do not run wires across other components! You will be using your layout as a guide to constructing a physical circuit. Jumbled wires are more difficult to construct correctly, and they are extremely difficult to debug!

Connect the "probes" so that they measure V_o. Choose **Sim > Run Simulation** to measure V_o. The value of V_o will be in the pop-up window.

Check Yourself 1. What is the simulated value of V_o?

$$V_o = \underline{\hspace{5cm}}$$

Check Yourself 2. Calculate V_o using circuit theory.

$$V_o = \underline{\hspace{5cm}}$$

Compare your result to that of the simulation.

Step 7. Lay out your circuit with physical parts. Make your physical layout look **exactly** like the CMax version. Trim the resistor leads so that the resistors lay flat against the proto board. (This step makes it easier to debug your circuit, by presenting a clean view of your components and their layout.)

> *Check Yourself 3.*   Measure V_o with your multimeter. Do you get the same voltage V_o? Exactly?

> *Checkoff 1.*   A voltage divider with equal resistors produces an output voltage that is half the value of the input voltage. However, two voltage dividers connected in cascade do not produce an output that is one quarter of the input voltage. Explain why.
>
> Show that your circuit looks **exactly** like the layout in CMax. Show the results from your circuit and simulation.

4 Potentiometer

A potentiometer (or pot) is a three-terminal device whose electrical properties depend on the angle of its mechanical shaft. The following figure shows a picture of the pot that we will use in lab (left), the electrical symbol used for a pot (center), and an equivalent circuit (right). The quantity α is in the range $[0, 1]$; Θ is the maximum turn angle of the pot, for example, $270°$, and $\theta = \alpha\Theta$ is the actual turn angle of the pot's input shaft.
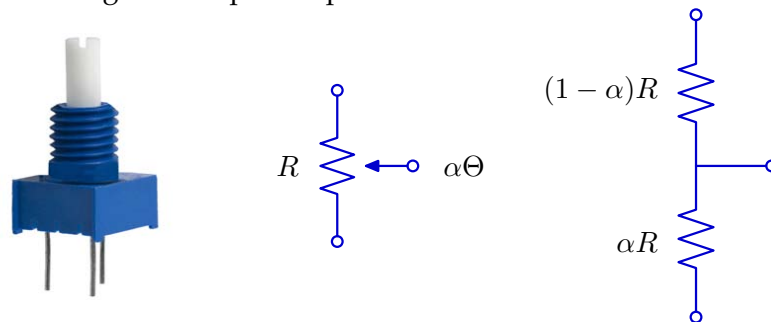
As the angle θ of the input shaft increases, the resistance between the bottom and middle terminals increases and the resistance between the middle and top terminal decreases. These changes in resistance occur such that the sum of the top and bottom resistors is constant. If you are interested in the internal construction of a potentiometer, look it up on a source such as Wikipedia. For our purposes, we will treat a potentiometer as a primitive element, which behaves as we just described.

By connecting a pot as a voltage divider (top terminal to a voltage source and bottom terminal to ground), the voltage at the middle terminal is made proportional to the angle of the shaft.

The pots we handed out in lab today have a total resistance of $5K\Omega$.

Step 8.   On your protoboard, wire a potentiometer to a $10\,V$ supply and ground. Notice that the leads are arranged in a triangle, with the base of the triangle parallel to one of the straight sides of the pot and the apex of the triangle near the middle of the opposite side. Connect power and ground to the two leads on the base of the triangle.

What are the min and max voltages at the middle terminal of the potentiometer?

Step 9. Adjust the potentiometer (the one you just put on your protoboard, **not** the knob on the power supply) so that the voltage on the middle terminal is 2.0V.

To what value of α does this correspond?

Step 10. Leaving the pot adjusted as it was in step 9, attach a 100Ω resistor between the middle terminal of the potentiometer and ground. Measure the voltage V_o at the middle terminal.

Step 11. Use circuit theory to compute the ideal value of V_o in this circuit.

Step 12. Leaving the pot adjusted as it was in step 9, remove the 100Ω resistor and attach a 10KΩ resistor between the middle terminal of the potentiometer and ground. Now what is the voltage V_o at the middle terminal?

Step 13. Use circuit theory to compute the ideal value of V_o in this circuit.

Wk.7.1.2   Complete this tutor problem based on your computations above.

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