

Design Lab 6: Divide et impera

You will need to use a computer capable of running python.

- **Athena machine:** Do `athrun 6.01` update and add `-f 6.01`.
- **Lab laptop:** Do `athrun 6.01` update.
- **Personal laptop:** Download design lab 6 zip file from course web page.

Code is in `~/Desktop/6.01/lab6/designLab/`.

To start, you will also need:

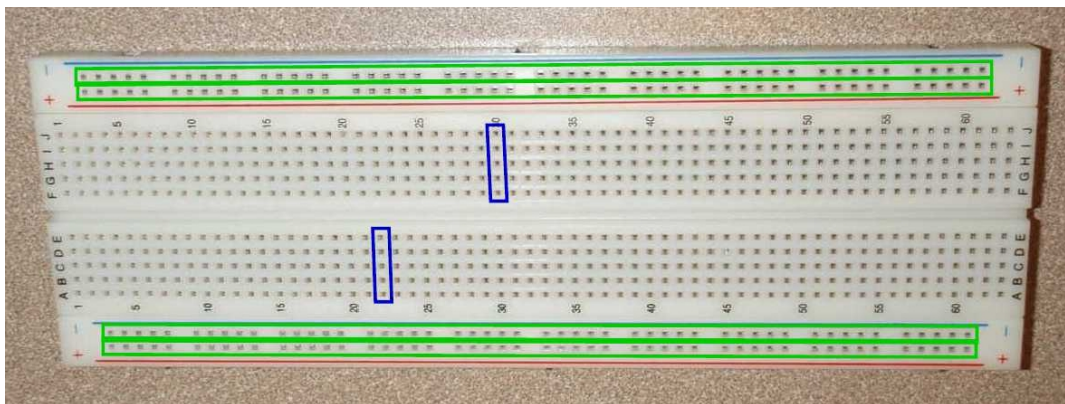
- power supply plus power cord,
- a *single, separate, proto board*,
- four clip leads,
- four $1k\Omega$ resistors, and
- a multimeter with two probes.

You can get other parts as you need them.

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

1 Proto Board

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). 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 is shown in the previous picture 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.

- Connect the power supply terminals labeled +15V 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.
- Set the multimeter to measure voltage, and connect its probes to the power rails of the proto board using alligator clip leads. Connect the alligator clip to the proto board 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 +10V.

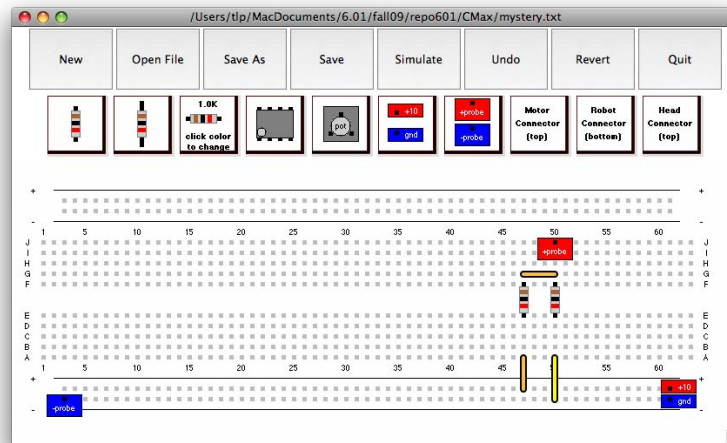
2 Layout and Simulation

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 screenshot of CMax. You can run CMax by going to a Terminal window, navigating to lab6/designlab and typing

```
> python CMax.py
```

Or, you can start Idle, open the file CMax.py and do Run Module. If you open CMax.py through Idle, close it down by killing Idle.

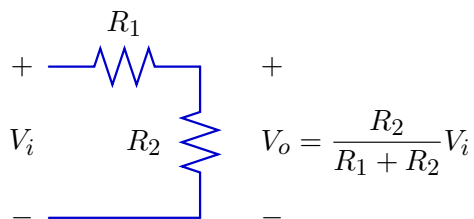
Once CMax is running, press the **Open File** button to open the file `mystery.txt`, which specifies the circuit shown below.



Check Yourself 1. Draw a schematic diagram for the circuit shown in the previous figure. Note the meter 'probes', attached to the ground rail and to location A50. Predict the voltage that will be measured across those two nodes in the circuit. Press the **Simulate** button (and choose the file `lib601/noInput.py`) to make the simulator calculate V_0 . The result will be printed in the window from which you started Python. Do your calculations match the simulation?

3 Resistor Dividers

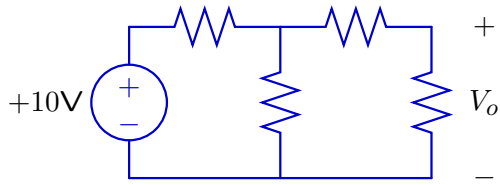
A voltage divider is a circuit that uses resistors to generate an output voltage that is a fixed fraction of the input voltage. The following figure illustrates a voltage divider as well as the resulting relation between its input voltage V_i and output voltage V_o :



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

3.1 Cascaded Dividers

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 $1\text{ k}\Omega$ resistance.



- Lay out this circuit using CMax. There is some documentation on how to use it in the **Robot Infrastructure Guide** on the course web site (Referenc Materials). 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 measures V_o . Press the **Simulate** button to measure V_o . The value of V_o will be typed in the window from which you started the program.

Check Yourself 2. What is the simulated value of V_o ?

$V_o =$

Check Yourself 3. Calculate V_o using circuit theory.

$V_o =$

Compare your result to that of the simulation.

Layout 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.

Check Yourself 4. Do you get the same voltage V_o ? Exactly?

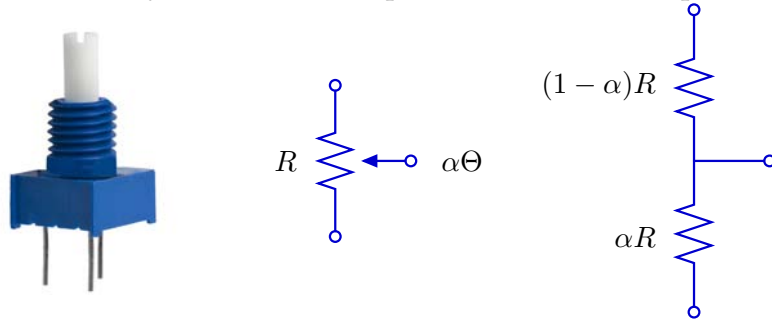
Checkoff 1.

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.

3.2 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).



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 so that the sum of the top and bottom resistors is constant. 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.

Check Yourself 5. Wire a potentiometer to a 10 V supply and ground. What are the min and max voltages at the middle terminal of the potentiometer?

- Start a new file in CMax and lay out your potentiometer circuit, connect the probes to measure the voltage at the middle terminal of the potentiometer (relative to ground). The potentiometers in CMax have a maximum resistance of (approximately) 5 k Ω .
- **Hold the Shift key and press Simulate**, then choose the `lib601/threeSteps.py` test. You should see two plots. The plot in blue shows the (simulated) values of α (which goes between 0 and 1). The plot in green shows the resulting voltage difference between the red and blue probes.

Check Yourself 6. What are the simulated values of the voltage, V_o , at the middle terminal for each of the values of α (0.25, 0.5, 0.75)? The graphs are a bit hard to read exactly, so estimate as best you can.

$V_o =$

Check Yourself 7. Calculate the values V_o using circuit theory.

$V_o =$

Compare your results to those of the simulation.

- In CMax, wire a resistor, R_L , that connects the middle terminal of the potentiometer to ground.
- Try values of the resistor of: 10 k Ω , 1 k Ω , and 100 Ω .
- Simulate the voltage, V_o , at the middle terminal for each of the resistor values. Use the lib601/threeSteps.py test.

Check Yourself 8. Calculate V_o as a function of R_L , for $\alpha = 0.5$, using circuit theory.

$V_o =$

Compare your result to those of the simulations.

- Build the circuit on your proto board; repeat the experiment.

Check Yourself 9. What are the measured values of the voltage, V_o , at the middle terminal for each of the resistor values?

$V_o =$

Checkoff 2. Explain your results to a staff member.

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6.01 Introduction to Electrical Engineering and Computer Science I
Fall 2009

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