Lab 3
Series and Parallel Circuits

Objectives

- *concepts*

  1. series and parallel resistor combinations
  2. voltage and current dividers

- *skills*

  1. analysis of series and parallel resistor combinations
  2. physical circuit construction, measurement and verification with theory
  3. design of a light bulb power circuit

Key Prerequisites

- Chapter 2 (Basic Laws)

Required Resources

- Circuit Lab Kit
- Laptops
- Circuit Construction Kit (DC) download
- Clothes pins (in Lab Kit)
- Aluminum Foil

Even such simple concepts as series and parallel resistor combinations find their way into practical circuit applications as we explore in the laboratory for this week.

Voltage dividers (series circuit), for example, can be used to convert a voltage from a high value to a low one for driving a load like a cell phone. Or, by selecting resistor values that are sensitive to environmental conditions, they can be used to convert things like temperature and light levels into an electrical signal which can be processed further.

In this lab you will build a simple voltage divider circuit that incorporates the human body as one of the resistors. This amounts to a simple “lie detector test” that you can use to amuse your friends. You will also build a simulation of a current divider circuit and verify the current divider equation on it. Finally, you will design a resistor network for powering a 1.5V light bulb from a 6 V source.

Vocabulary

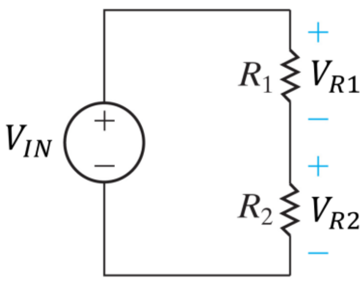
All key vocabulary used in this lab are listed below, with closely related words listed together:

Equivalent resistance, open circuit, short circuit, load effect

Discussion and Procedure

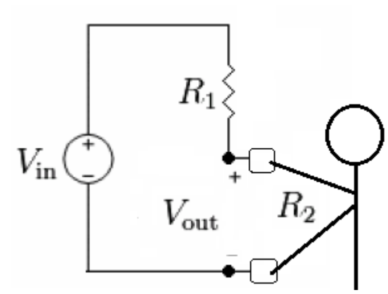
Part 1. Voltage dividers

A voltage divider is a linear circuit that produces an output voltage that is a fraction of the input source voltage. A simple voltage division can be achieved by using two series resistors, shown in the circuit below. The voltage V_{IN} drops across R_1 and R_2 in direct proportion to the resistor values, according to the following equations:



$$V_{R1} = \frac{V_{in} R_1}{(R_1 + R_2)}$$

$$V_{R2} = \frac{V_{in} R_2}{(R_1 + R_2)}$$



One application of voltage dividers is in circuits that sense the physical world. Replace R_2 with a resistor that varies based on some environmental parameter, such as temperature or ambient lighting, and you will be able to infer the quantity of interest just by measuring V_{out}.

One key quantity of interest in law enforcement is whether or not a subject is lying. It turns out that human skin resistance is a highly dynamic quantity, affected by subtle amounts of perspiration due to physical activity and emotional stress. If we insert a person into the circuit above in place of R_2, we will be able to read out a voltage that changes based on the "perspiration" state of the subject. By asking a series of more or less provocative questions, we may be able to determine if a subject is becoming emotionally upset, ("hot under the collar") and, possibly, lying.

Materials

- 4.7 kΩ, 10kΩ, and 100 kΩ Resistor
- Banana plug to alligator clip leads (2)
- Mini alligator clip leads (2)
- Large piece of aluminum foil, cut into 2 pieces
- Breadboard
- Digital Multimeter

Verifying a Two-Resistor Voltage Divider

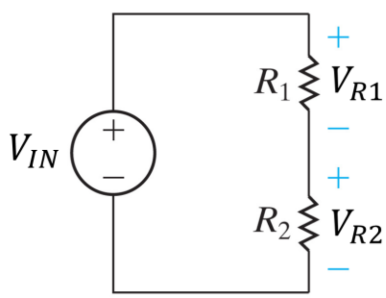
To begin, we are going to build and verify a voltage divider circuit made of two resistors in series. Then we will convert the circuit into a simple Lie Detector test, using our own body as one of the resistors.

1. Find the three resistors above and measure them with your Digital Multimeter (DMM) switched to Ohmmeter mode. Use the alligator clip leads to hold the resistor, and make sure your hands are not touching the alligator clips or the wire leads on the resistors.

   Record these values in Table 1 of your data sheet.

   Also use your DMM to measure the voltage of your 12V supply voltage, V_{IN}, and record below Table 1. You will use this value in the voltage divider formula.

2. Build the following circuit, using 4.7 kΩ for R_1, and 10kΩ for R_2. This is the same circuit you built in Lab 2, so if you like, you can pull up that handout if you need to see how to construct it.



3. Complete Table 2 in your datasheet by calculating the expected value of V_{R1} and V_{R2} using the voltage divider formula, and then measuring these values with the DMM. Then compute the percent error using the formula provided.

Constructing the Lie Detector Circuit

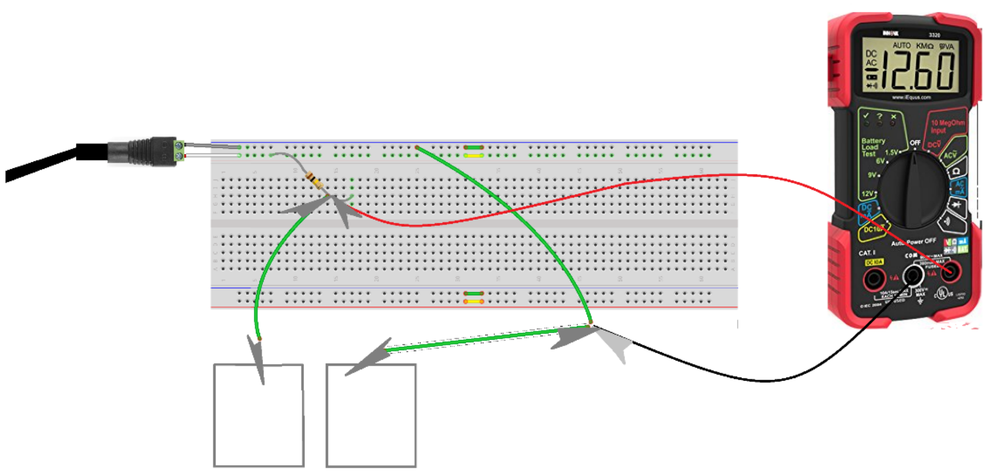
Now that you have a basic understanding of how a voltage divider works, you can begin the steps necessary to convert the circuit into a simple Lie Detector Test.

4. First, measure your and your partner’s “out of circuit” resistance by wrapping foil around each hand’s forefinger, twisting the ends, and holding them in place with clothespins. Then attach the DMM to the aluminum foil pads using the alligator clip leads. Switch the meter to Ohms, and measure the resistance of the test subject as indicated in the next figure.

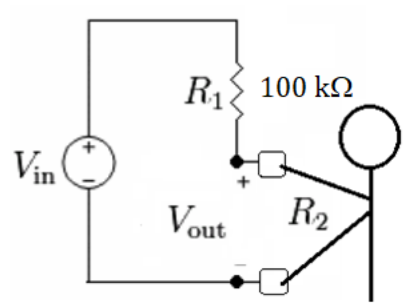
Measuring your body's resistance using an Ohmmeter connected to foil pads

Online students should grab a test subject from their immediate vicinity in place of a lab partner. For maximum effect, don't reveal the interrogation questions in advance.

5. Then build the circuit shown in the diagram below. Use the 100 kΩ resistor where indicated. You can add the extra alligator clips to the banana jack cables to make the cables that connect the aluminum foil pieces to short jumper leads coming out of the breadboard. You can use the third banana plug - alligator clip to connect the DMM ground to a jumper wire, as shown, and use the red DMM probe cable to measure the voltage Vout (this will require either pressing the red DMM lead into the 100 kΩ resistor lead, or finding a way to improvise a hands-free connection, say by wrapping a short jumper wire around the probe and connecting that into the node at which you are measuring Vout – as shown in the figure below).



6. Visually verify that your circuit, as constructed, correctly implements the following schematic, with the Voltmeter measuring V_{out}.



7. Switch the Multimeter into Voltmeter mode and connect it as shown in the drawing above. The black ground lead of the Voltmeter attaches to the ground line from the power supply through a regular breadboard wire, while the red lead of the Voltmeter attaches to the 100 k resistor. Plug in the 12V supply.

8. For each partner, measure the voltages requested in Table 3 of your data sheet. During interrogation, you may select from the suggested questions below.

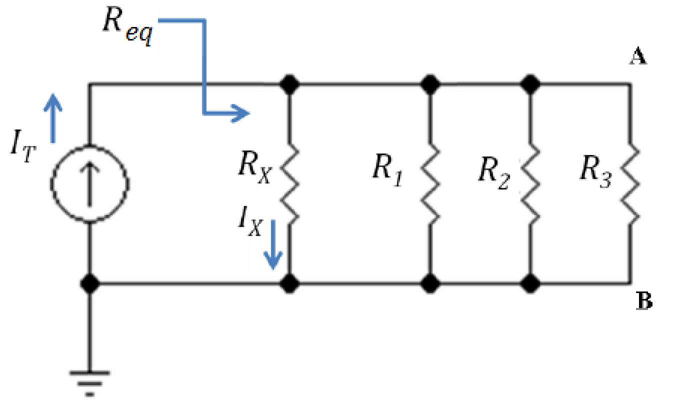
Suggested Questions

a) How old are you? Are you really _________ years old?
b) Have you ever broken the law?
c) Is your name __________ ?
d) Did you ever just copy the answer key instead of doing your homework?
e) Have you ever cheated on your partner?
f) Were you born in 1988?
g) Did you ever cheat on an exam?
h) Do you take classes at MPC?

9. Answer the **Lie Detector Circuit Questions** in your data sheet.

Part 2. Current dividers

We have seen how a voltage divider circuit involves a voltage drop taking place over one or more series resistances, and that the voltage across any of the series resistors is a fraction of the input voltage. A current divider, on the other hand, is a circuit in which a current source is fed into a number of parallel resistor branches, and each branch receives a fraction of the input current, which can be determined from the following equations.



$$R_{eq} = \frac{1}{\frac{1}{R_X} + \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$I_X = \frac{V_{AB}}{R_X} = \frac{I_T R_{eq}}{R_X}$$

Where I_X is the current through resistor R_X.

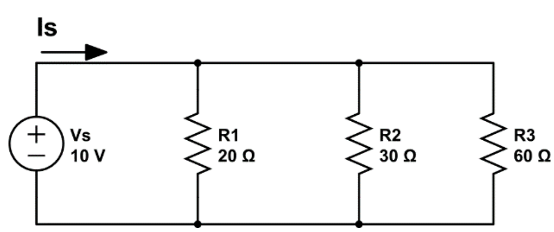
We can express the above relationships more simply if we first convert all resistance values (R) into conductance values ($G = 1/R$). In this case, the derivation mirrors the formula for voltage dividers:

$$G_{eq} = G_X + G_1 + G_2 + G_3$$

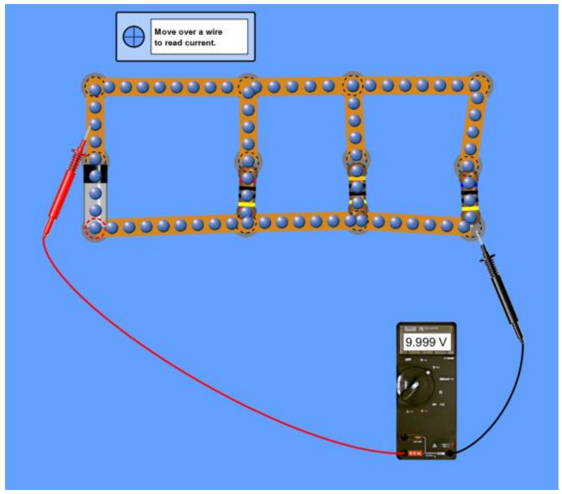
$$I_X = \frac{V_{ab}}{R_X} = \frac{I_T G_X}{G_{eq}}$$

Current Divider without a Current Source

The same current divider relation applies even when a circuit is driven by a voltage source. For example, in the circuit below, if we can determine I_s by some other means, we can use the current divider formula to determine the current through each of the resistors.



Simulate a Current Divider circuit in Circuit Construction Kit. We will explore current dividers using the circuit simulator Since we cannot easily access a current source physically, and it's somewhat cumbersome to measure current, download and run a version of Circuit Construction Kit (DC Only) on your computer.



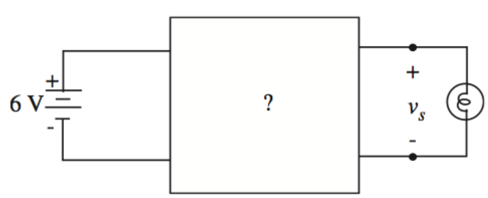
10. Use the parallel resistor formula to calculate the equivalent resistance of the 3 resistors, then use Ohm's law to find Is.

11. For Table 4, calculate the expected values of current through each resistor using the Current Divider Formula based on the value of Is you calculated. Then measure these quantities in your circuit simulation using the ammeter tool. Enter your results in the table below, and compute the percent difference between theory and experiment. (In this case, they should be exactly the same!)

12. Finally add a short circuit in parallel to the other three resistors. Record and interpret your results in the datasheet.

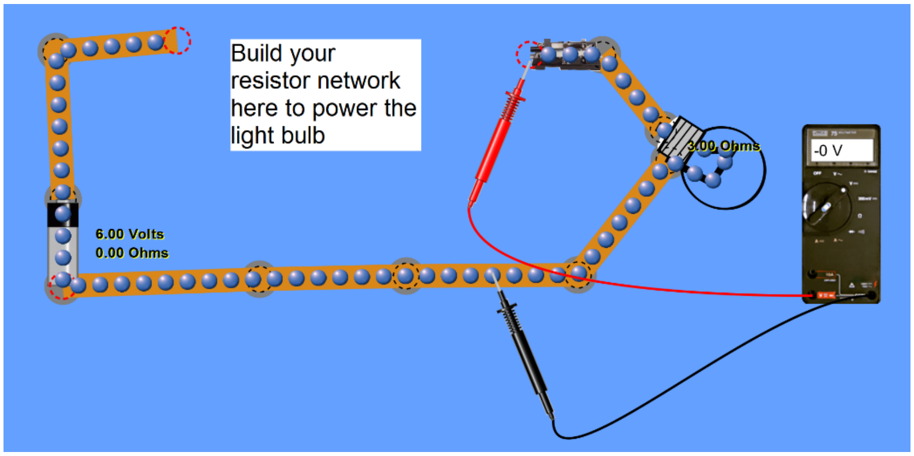
Part 3. Creative Challenge - Design a Resistor Network (adapted from edx.org's 6.002x class)

Suppose you have a 6-volt battery (assumed ideal) and a 1.5-volt flashlight bulb, which is known to draw 0.5*A* when the bulb voltage is 1.5*V* (see figure below). Design a network of resistors to go between the battery and the bulb to give *vs*=1.5*V* when the bulb is connected, yet ensures that *vs* does not rise above 2*V* when the bulb is disconnected.



Build the circuit in the simulator, adding the switch and voltmeter as shown. You can open and close the switch, observing the change in voltage, while running the simulation.

Your job is to design a resistor network so that Vs = 1.5V when the switch is CLOSED and Vs ≤ 2 V when the switch is OPEN.



When you find the solution, take a screen capture of the circuit with the switch OPEN (Vs ≤ 2V) and CLOSED (Vs = 1.5V), and copy it into your datasheet.