MODELING MEASUREMENT SYSTEMS USING VOLTAGE DIVIDERS

LAB 2 INTRO: MEASURING PROPERTIES OF VOLTAGE DIVIDERS, DEVELOPING MODELS OF MEASUREMENT DEVICES (DMM, SCOPE), BUILDING A VARIABLE VOLTAGE SOURCE

GOALS

In this lab, you will gain experience working with the prototyping board, which will be the main platform for building circuits for the rest of the semester. You will also learn how to refine you model of a circuit to include the measurement probes. Finally, you will use apply your knowledge of voltage dividers to build a dimmer switch.

Proficiency with new equipment:

- Prototyping board:
  - Set power rails on the board
  - Determine the connection layout on the proto-boards
  - Be able to assemble resistive circuits and measurement test points on the boards
- Potentiometers
  - Determine the connections on a 10-turn pot.
  - Use a pot to continuously control an output voltage.

Modeling measurement systems:

- Develop mathematical and schematic models of voltage dividers.
- Refine the voltage divider models to include the effect of the measurement probes.

Applications:

- Build a dimmer switch for a light bulb.

DEFINITIONS

Potentiometer (pot) – a three terminal resistive device that provides a variable resistance between the ends and the wiper connection.

USEFUL READINGS

1. FC Sections 2.1-2.3
2. H&H Section 1.03

LAB PREP ACTIVITIES

Answer the following two questions in your lab book. Scan the relevant lab book pages and turn in the pdf to D2L by midnight the day before your lab section meets. *Hint: if you read through the entire lab guide before you come to lab you will 1) be better prepared to ask questions / conduct the experiment, 2) see how the lab prep relates to the more challenging parts of the lab later. For example, completing the lab prep this week will allow you to construct the necessary models of voltage dividers and measuring probes very quickly during your lab session.*

Question 1	**Resistive Voltage Dividers (ideal power supply)** An ideal voltage source (no internal resistance) drives current around the loop of resistors shown in Figure 1 (a). a. Derive a formula for the current, I, and the output voltage, V_{out}. b. What is V_{out} if V = 10 V, R_1 = 2 kΩ, and R_2 = 1 kΩ ? c. Calculate the voltage V_{out} for the modified circuit shown in Figure 1(b) with R_3 = 10 kΩ and the other components unchanged.
Question 2	**Resistive Voltage Dividers (non-ideal power supply)** A non-ideal voltage source has an output impedance (resistance). First consider a supply with an output impedance 500 Ω. a. Draw a modified circuit diagram of Figure 1(a) to model the non-ideal voltage source as an ideal source with a series resistor. b. Derive a formula for the current, I, and the output voltage, V_{out} of the circuit you drew for Part (a) of Question 2. c. What is V_{out} if V = 10 V, R_1 = 2 kΩ, and R_2 = 1 kΩ ? d. An additional load is connected between V_{out} and ground in the form of the resistor R_3 as shown in Figure 1(b). Calculate the voltage V_{out} for this circuit (with the non--ideal power supply) and with R_3 = 10 kΩ.
Question 3	**Lab activities** a. Read through all of the lab steps and identify the step (or sub-step) that you think will be the most challenging. b. List at least one question you have about the lab activity.

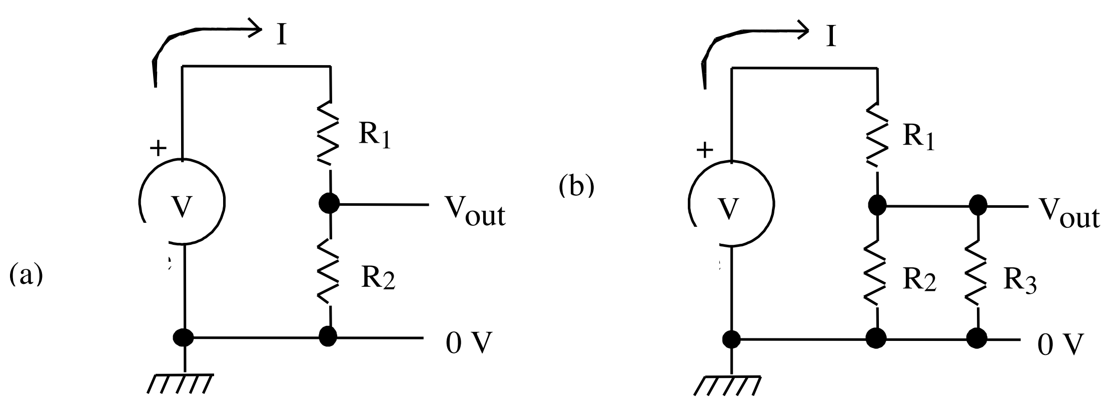

Figure 1) Voltage Dividers

REVIEWING LAB WRITEUPS

Step 0	**Review Approach and Expectations to Laboratory Notebook write-ups:** Lab1 Notebooks have been returned to you. These were graded leniently and future labs will be more strictly reviewed for completeness and correctness. a. Review the lab notebook write-up guidelines on the course website. b. Compare your write-up for Lab 1 with the Exemplar Lab 1 Write-up Shared in Lab. c. Identify 3 specific items / approaches that you will either keep or change for laboratory 2 (e.g. I will make sure to label my graphs and plot using the Mathematica guidelines provided).

SETTING UP YOUR PROTOTYPING BOARD

Most circuit designs are first tested using prototyping boards to allow for easy changes of components. Once the circuit works and meets the desired specifications, the circuit will often be built using more permanent methods such as soldering to a Vector board or to a printed circuit board. Present technology allows for anyone to cheaply design, layout, and have professional circuit boards printed. For example: http://www.expresspcb.com/

Step 1	**Test your prototyping board.** a. Your instructor will give your team a prototyping board to use for building your projects. Write your team member's names on it. Your team will use the same board all semester. An incomplete experiment can be left on the board and finished later. Store the board on the shelf labeled for your section. b. On the front panel, you will find: • BNC cable jacks that carry electric signals between your circuit on the board and the function generator and oscilloscope. • Colored banana jacks to bring in dc power for transistors or chips from an external power supply. • A precision 10 kΩ ten-turn potentiometer and several switches. • A wire or component on the board might be broken, or might break during the semester. Don't worry – you will be able to repair the board as you go. c. The circuit board contains arrays of holes, interconnected by buried conductors, into which components are plugged to build your circuit. In general, you can never be sure that any two contacts are really connected, or any wire is really continuous, unless you test it yourself, so get into the habit of testing things. d. Determine which holes on your protoboard are connected by using the DMM. Draw a diagram in your lab book of the connections. You can refer back to this diagram throughout the semester as you build new circuits.

Step 2	**Making power connections to your protoboard.** a. For essentially all circuits, you will need power connections (+15 V, -15V, ground). Connect the power supply to the panel using banana cables. b. **USE A COLOR CODE FOR THE POWER CONNECTIONS!** Typically black = ground, red = +15 V, and blue = -15V. Using a consistent color code will allow you and others to more quickly debug your circuits. You are also less likely to plug something in incorrectly and burn up a component. Write down your color code in your lab book. c. Once you have power connected to the front panel, use the wires soldered on the back of the connectors to make connections to the board (+15, -15, and 0V). The long rails that run the length of the board are best for distributing power to all of your components. Use these for only power or ground. d. Good electrical contact is essential when you plug in components or wires. Use only 22 or 24 gauge solid wire, not stranded wire. 22/24 gauge wire should make a good connection with the conductors inside the board without slipping out easily. Push in each wire until you feel the contacts grip. e. Reliable ground connections (0 V), readily accessible from any point on the board, are essential to the good functioning of most circuits. The front panel is the ground for your circuit board since the outside of the BNC connector connects the front panel of your circuit board to the ground of other instruments in your experiment.
Step 3	**Supplying power to the protoboard.** a. Turn on your DC power supply such that it produces +15 V and -15 V. Set the current limit to about 100 mA. This will reduce the amount of smoke released from your components when you happen to plug in the power incorrectly. Describe the procedure you followed to set the current limit. b. Measure the voltage on your protoboard rails using a DMM. You may need to use a wire to probe the voltage if your DMM probes do not fit in the holes. Always remember to measure voltages with respect to ground. Record the voltages in your lab book.

BUILDING AND TESTING VOLTAGE DIVIDERS

Step 4	**Fixed-value voltage divider - 1kΩ** *Components (resistors, capacitors, transistors, etc.) are available from the community stock. Take what components you need for the experiment.* a. Build a voltage divider similar to the one shown in Fig. 1(a) using resistors of around 1 kΩ. Draw a diagram of the circuit in your lab book. Make sure to label the resistors and record all measured component values and voltages. b. Measure each resistor with your DMM before inserting it into your circuit and record the value. Why should you measure component values before placing them in the circuit? c. Predict the output voltage you should measure based on your input voltage and resistance measurements. Include your calculations and numerical predictions in your lab book. d. Now, apply a DC voltage to the input and measure the output voltage of your divider, first using first your DMM and second using your oscilloscope with the minigrabbers. Record your measurements. (Do not have the DMM and the oscilloscope connected at

	the same time because each may perturb the measurement differently.) e. Compare the voltages you predicted to the voltages you measured. Does your model of the voltage divider agree with each of your measurements? Explicitly record what criteria you used to determine whether or not the model and measurements agreed. f. *Complete this step only if your model and measurements did not agree.* If your model and measurements did not agree, you will have to either refine your model or your experiment. Let's start by refining your model. Consider the input resistance of your measurement device. Draw a circuit diagram that includes that resistance. *HINT: You already worked with this circuit model in your prelab.* Derive an expression for the output voltage now including the unknown measurement device resistance. Use this new model to determine the input resistance of measurement device.
Step 5	**Fixed-value voltage divider – 1MΩ and 10 MΩ** a. Complete steps ***a-f*** of Question 4 for two additional voltage dividers, one using resistors ~ 1MΩ and one with resistors ~10MΩ. b. Using your refined model, you have determined the input resistance of both the DMM and scope. Specification or spec. sheets or data sheets can also be used to refine your model. c. Look up the input resistance of your DMM using the spec. sheets on the course website. Does the measured input resistance agree with the instrument specs? Explicitly record what criteria you used to determine whether or not the resistances agree. d. There is an easy way to determine the specified input impedance of the scope. Where can you find that information? Does the measured input resistance agree with the instrument specs? Explicitly record what criteria you used to determine whether or not the resistances agree.

APPLICATION EXPERIMENT: BUILD A CONTROLLABLE VOLTAGE SOURCE (DIMMER SWITCH)

You will now use your skills with building and testing voltage dividers to build a controllable voltage source using a potentiometer.

Step 6	**Determining the operation of a potentiometer.** a. The potentiometer on the circuit board panel has three connections. Two of the connections are at opposite end of a resistor. The third connection is connected to a sliding "wiper." Use the DMM to measure the resistance between all possible pairs of connections while turning the knob over its complete range. b. Draw a diagram of the pot including a model of the internal components and external connections using the resistance observations.
Step 7	**Build a variable voltage source / Using a pot to light a light bulb (Light bulb Dimmer)** a. Draw a circuit diagram that uses one pot to create a variable voltage divider. b. Derive an expression for the output voltage based on the input voltage and the two resistances. Are both resistances variable or is one fixed? c. Construct your voltage divider and use a scope to measure the output voltage. Do you need to include the scope input resistance in your model? Explain why or why not. d. Predict the maximum and minimum output voltage (when the wiper is at one end and then the other). e. Test your model by making measurements on the scope. Make sure to include the limits of the voltage source. Do your measurements agree with your predictions? Explicitly record what criteria you used to determine whether or not the model and measurements agree.

	f. Now connect a low voltage light bulb to the output. You may need to increase the current limit on the power supply to see visible light (Do not exceed 500 mA or your pot may burn out). Describe qualitatively the brightness of the bulb as the pot knob is adjusted. What is the minimum voltage needed to see the light bulb turn on? g. **Bonus question:** A good voltage source has very little (a few ohms) output resistance and thus very little power is dissipated in the supply. What is the output resistance of the circuit (including your power supply and external components) if it produces 10V? Would this circuit be good for creating a variable voltage source in the range of 5-10 V ? *HINT: Consider the power dissipated in the source.* Explain using your diagram, model, and values of resistance.