

# Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

*One Gradescope submission  
per group of 2 or 3 (add names)*

## LABORATORY 1: Basic Analysis and Engineering Practices

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## Getting Started!

### Lab Submission Instructions and Partners:

- 1) You can choose **up to two** people for a maximum group of three. Groups of 2 are acceptable. Working alone is discouraged but if necessary, it is possible. Remember, you will likely have to work with this person or persons for the rest of the semester.
- 2) Only one laboratory report is needed for each group. Make sure you include all group members' names on the front of the report. Also remember to add your partner(s) to Gradescope. (Only one person needs to submit it).
- 3) Please create a WebEx Teams space ***within the Intro to ECSE Team*** using your Last names, Alpha/Omega, and Section...for example, "Smith | Jones | Xu | Alpha | Sec 1"
- 4) You will work through each *core* lab section to learn some basic steps. ***Then you will prove specified concepts listed at the end of each section.*** This simply means that you will demonstrate how a specific concept works through clear and concise comparisons of mathematical analysis, simulation, and experimental measurements.

*The template for the Proof of Concepts document that you will submit can be found [here](#):  
Please answer any questions related to those concepts and provide mathematical calculation,  
simulation, and experimental data to support the proof of concept!*

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**Purpose:** The objectives of this experiment are to gain some experience with the tools we use (i.e. the electronic test and measuring equipment and the analysis software) and to gain some fundamental understanding of voltage dividers as both a mathematical concept and a component you can use. ***In ECSE Math is REAL and can reveal useful information OR be part of an entire system you can implement to solve problems! We start with simple division.***

**Student Preparation BEFORE doing this experiment:** (Students should be able to)

- Apply Ohm's Law to determine the current through a resistor
- Determine the values of series and parallel combinations of resistors
- Download and install software on a Windows machine

**Learning Outcomes AFTER doing this experiment:** (Students will be able to)

- Simulate a simple resistive voltage divider using LTSpice
- Build and test a simple resistive voltage divider
- Apply circuit reduction concepts to resistive circuits to simplify the analysis to a simple equivalent circuit
- Be able to build simple resistive circuits driven by constant voltages using a small breadboard
- Articulate a series of questions posed about simple circuits and answer the questions using data obtained from physical experiments.
- Demonstrate to themselves and others the difference between tinkering and engineering by answering the question "Is this right?" through documenting the comparison of mathematical analysis, simulation, and experiment to prove a concept or an idea!

**Software and Equipment Required:**

- LTSpice
- MATLAB
- ADALM2000 (M2K) board with Scopy or Analog Discovery with Digilent Waveforms
- Breadboard
- Several different resistors and wires from the parts kit (ADALP2000)
- Alpha Experiment: potentiometer
- Omega Exploration Optional!: resistive sensors, Arduino, push buttons or switches

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Learning from Proof of Skills applied to this lab:

### Professional Accountability:

- I can clearly document and compare a calculated, simulated, and experimental result to answer the question “Is this right?” for myself

### Circuit Simulation (LTSpice or equivalent):

- I can use operating point DC analysis to find voltages across a resistive circuit.
- I can step through parameters with parametric analysis to repeatedly measure voltages as I vary my resistance over a range of values.

### Experimental Measurement and Personal Instrumentation:

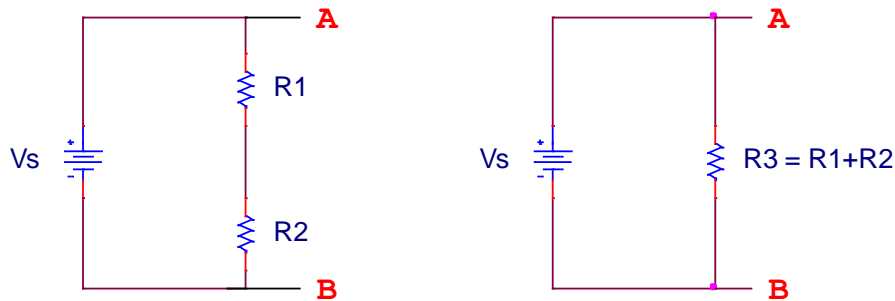
- I can use my instrumentation board’s function generator to create a DC, sinusoid, and pulsed signal and measure with its oscilloscope directly.
- I can build a resistive circuit and measure DC voltage across ONE resistor using a dc input source and vary dc voltage at least 3 times (-5, +5 and any voltage in between)

**PART A [Core] – Math as a Tool to Help You Understand...***Material covered: Resistor Combinations and Voltage Dividers*

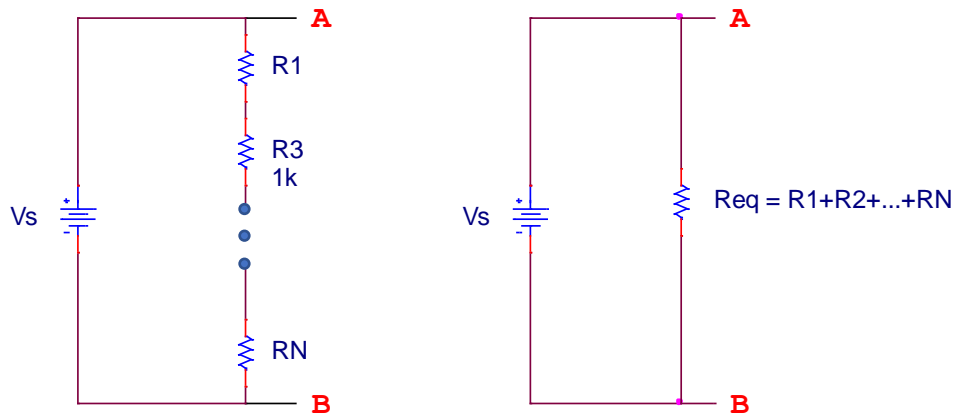
Background: Series and Parallel Circuits and Voltage Divider

*Series and Parallel Circuits:* A fundamental concept we need to understand in order to analyze the circuits we will build is how to mathematically combine resistances.

If any number of resistances are connected in series, you simply add them to find the total resistance,  $R_{Tot} = \sum_1^N R_i = R_1 + R_2 + \dots + R_N$ . This is summarized in **Figure 1** with two resistors in series. If we measure the voltage at nodes A and B (use the two leads of Channel 1 and Channel 2 of your instrumentation board) and apply Ohm's Law to get the current, the current will only be the same in the two circuits if they have the same equivalent resistance. In the figure, this is shown by the relationship  $R_3 = R_1 + R_2$  where  $R_1$  and  $R_2$  are in series and can be added to give a single equivalent value.

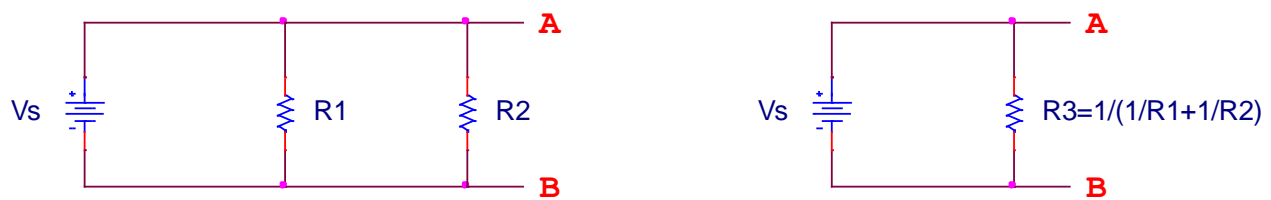
**Figure 1: Two Resistors in Series**

We can extend this to any number of resistors in series, as seen in **Figure 2**. The equivalent resistance is the sum of all the resistors in series.

**Figure 2: N Resistors in Series**

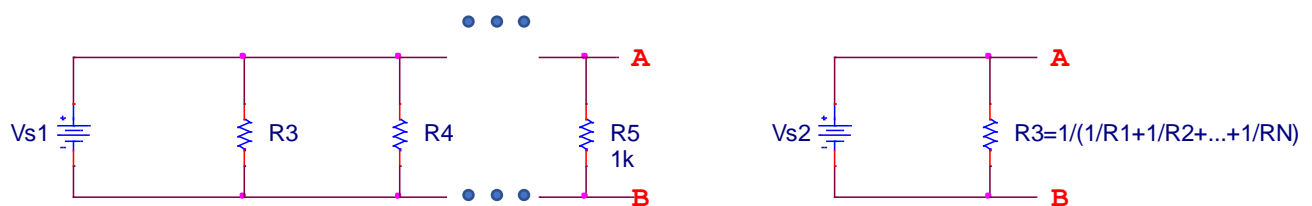
**Important Note: Two resistors are in series only if the end of one resistor is directly connected to one end of the other resistor. There cannot be anything else connected in between the two resistors.**

If any number of resistances are connected in parallel, we need to take the inverse of the sum of the inverses,  $R_{Tot} = \frac{1}{\sum_1^N \frac{1}{R_i}} = \left[ \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_N} \right]^{-1}$ . This is summarized in **Figure 3** with two resistors in parallel. If we measure the voltage at nodes A and B (use the two leads of Channel 1 and Channel 2 of your instrumentation board) and apply Ohm's Law to get the total current, the total current will only be the same in the two circuits if they have the same equivalent resistance. In the figure, this is shown by the relationship  $R_3 = \left[ \frac{1}{R_1} + \frac{1}{R_2} \right]^{-1}$ , where R1 and R2 are in parallel.



**Figure 3: Two Resistors in Parallel**

We can extend this to any number of resistors in parallel, as seen in **Figure 4**. The equivalent resistance is the inverse of the sum of the inverses.



**Figure 4: N Resistors in Parallel**

**Important Note: Resistors are only in parallel if both 'sides/ends' are connected together.**

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**Voltage Dividers:** In order to analyze the effect of the equipment, we need to understand a fundamental concept of circuit analysis called a voltage divider. When a voltage in a circuit is applied across two or more resistances, it divides up in a manner proportional to the magnitudes of the resistances. That is, a larger resistance will have a larger voltage drop across it and that voltage drop will be proportional to the magnitude of the resistance divided by the total resistance of a series circuit.

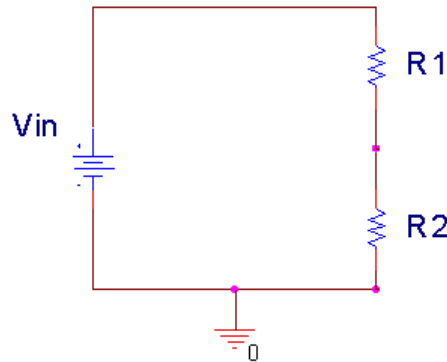


Figure 5

In **Figure 5** above,  $V_{in}$  is divided between  $R_1$  and  $R_2$ . Mathematically, this can be expressed as:

$$V_{in} = V_{R1} + V_{R2} \quad V_{R1} = \frac{R_1}{R_1 + R_2} V_{in} \quad V_{R2} = \frac{R_2}{R_1 + R_2} V_{in}$$

In the voltage divider circuit,  $R_1$  and  $R_2$  are in series. Using the series expressions on the previous page, we can determine the total resistance 'seen' by the source,  $R_{tot} = R_1 + R_2$ .

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Series and Parallel Circuits and Voltage Divider Experiment:

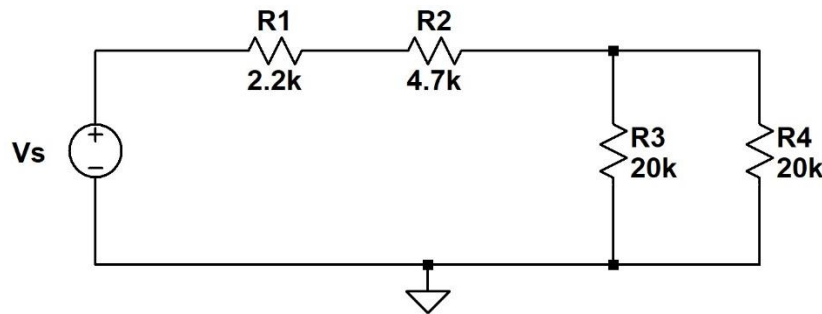


Figure A-1 Simulate this circuit using LTSpice

NOTE: YOU ARE FREE TO CHOOSE ANY VALUE OF RESISTANCES YOU WANT FOR THIS CIRCUIT. YOU CAN ALSO REARRANGE COMPONENTS IN THE CIRCUIT TO PROVE THE CONCEPTS IN THE CONCEPT LIST AT THE END OF THIS SECTION. JUST BE SURE TO SHOW YOUR SCHEMATIC IN THE PROOF OF CONCEPTS “BUILDING BLOCK” SECTION.

Use the circuit above (or a variation of it) to prove the concepts listed at the end of this part of the lab. Also include your answers to each of the questions below in the corresponding sections for your Proof of Concepts.

### Analysis

1. Which resistors are in series above? Which resistors are in parallel above?
2. Combine the two parallel resistors to make one resistor. Calculate the value.
3. Using the voltage divider equation calculate the voltage across  $R_1$  and  $R_2$ .
4. Using the voltage divider equation calculate the voltage across  $R_3$  and  $R_4$ .
5. Use Ohm's law to find the current through all resistors.
6. Using KCL, determine the relationship between the current through  $R_2$  and the current through  $R_3$  and  $R_4$ . (Write at least one equation that defines this relationship. Yes, there is more than one!)
7. Use these calculations, including values and equations, in the Proof of Concepts document under “Analysis” section for the appropriate concepts (list shown in Part A: Proof of Concepts list in the gray box below).

### Simulation (LTSpice)

1. Using LTSpice operating point DC analysis, find the voltage across each resistor and the current through each resistor. Label each voltage and current with the output results on the schematic showing only 3 significant figures.
2. Use the schematic as the “Building Block” portion in the Proof of Concept document for every Concept.



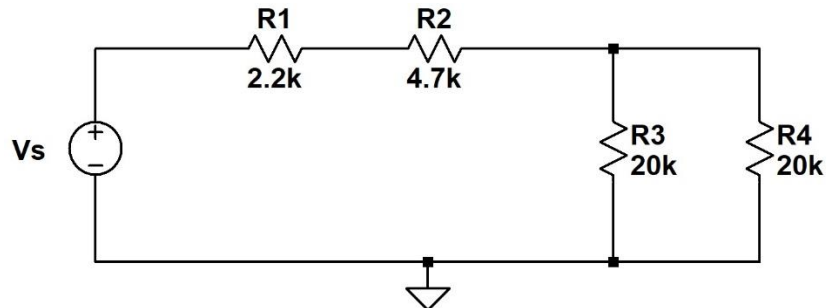
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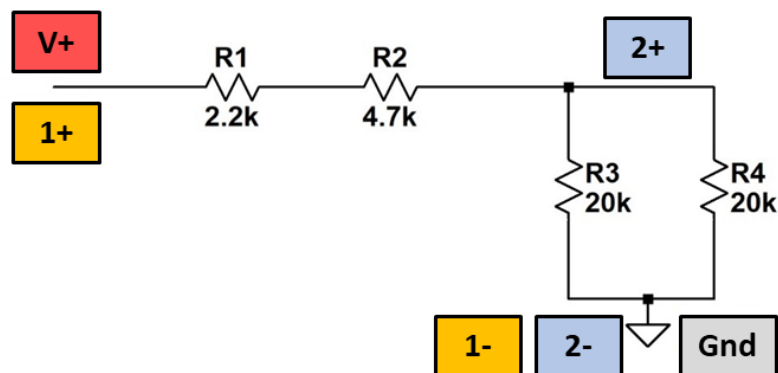
3. Use the appropriate LTSpice output as the simulation result under "Simulation" for each concept below.
4. **Optional:** Find at least one additional way to demonstrate voltage and current for resistor R1 using LTSpice simulation options (other than operation point DC analysis)

Experimental Measurement (M2K or Analog Discovery Board)



**Figure A-2:** Build this circuit with the exact values you simulated above (which could be different than these shown in the diagram above...as long as the built circuit, simulation, and calculations all match you are good to go!)

You should be able to quickly recognize the two resistors in series and the two resistors in parallel in the circuit shown in Figure A-2. Build the circuit on your breadboard and measure the voltage across the two resistors in series and across the two resistors in parallel. Figure A-3 is the same circuit as in A-2, but with the locations of the DC source ( $V+$ ) and measurement ( $1+/-$  and  $2+/-$ ) connections of your instrumentation board shown.



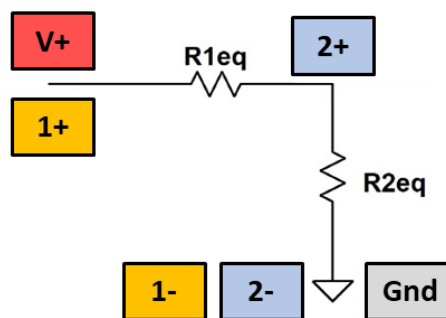
**Figure A-3:** The circuit from A-2, labeled with the locations of the leads from an instrumentation board

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- Set the positive DC supply (V+) voltage to 4V and record the voltage measurements from Channel 1 (1+/-) and Channel 2 (+/-) using the voltmeter tool.
- Determine the equivalent resistance of the two resistors in series and the equivalent resistance of the two resistors in parallel.
- Redraw the simplified circuit with the equivalent resistances. (You can place this in your Proof of Concepts document for concepts it applies to in the list below...)
- Considering the two equivalent resistances, find the closest valued resistors in your parts kit and build the simplified equivalent circuit. (Keep your above circuit and build the new circuit somewhere else on your breadboard.) Measure the voltage across the two equivalent resistors.



**Figure A-4:** The circuit from A-3 with R1, R2, R3 and R4 replaced by equivalent resistances

### Part A: Proof of Concepts List

1. Prove Ohm's Law, KCL, and KVL in a circuit.
2. Prove the concept of a voltage divider in a series circuit
3. Prove the concept of how current flows in a series circuit (same current through R1 and R2 for example? Or different current?)
4. Prove the concept of voltage across a parallel circuit (same voltage? Or different....)
5. Prove the concept of a current divider in a parallel circuit. *Hint: Try to search for this equation online. Use other current calculations and a simulation to confirm!*

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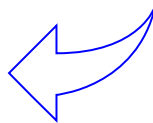
### Part B [Alpha/Omega] - Math as a COMPONENT you can use in a system....

*Material covered: Voltage divider applications and design*

#### Voltage Divider Applications and Design Background:

In the 2<sup>nd</sup> Year course that follows Intro to ECSE, ECSE 2010 Electric Circuits, we play a game called “Can a voltage divider save the world?” Each team comes up with as many real-world applications of a voltage divider as they can. As a class, the highest number of uses was 21.5 DIFFERENT ways a simple voltage divider can do real things in the world. You may choose to take the more defined Alpha experiment path to understanding the voltage divider as a useful component or explore on your own using the Omega design ideas below. Each path requires a Proof of Concept entry and full discussion.

### Choose Your Adventure! Alpha Experiments or Omega Exploration



#### Alpha Experiments

##### Potentiometers

1. Use LTSpice Parametric analysis in a simple voltage divider circuit
2. Find the potentiometer in your [ADALP2000 tool kit](#) and build your circuit on the breadboard. Measure with your instrumentation board.
3. Discuss how a potentiometer is a voltage divider and how it might be used in common everyday applications

***See below for more instructions***

#### Omega Exploration

Design your own voltage divider application circuit using one of the following:

- [Sensor \(Resistive\) Reading](#)
- [For programmers: Arduino + potentiometer...to LED or other!](#)
- [Push Button DAC \(for game controller or counter!\)](#)
- Other? Find another application and try it! Like [Timer Circuits](#)**

You should use your favorite search engine (Google, Bing, DuckDuckGo...) to help explore! Prove your design concepts! No instructions.

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Part B: Proof of Concepts List

- 6. Prove the Concept of a voltage divider in your application. *In your discussion, be sure to include if any failures occurred and speculate why they did. As an example, if you had trouble finding ways to accurately calculate values or simulate something, please state it.***

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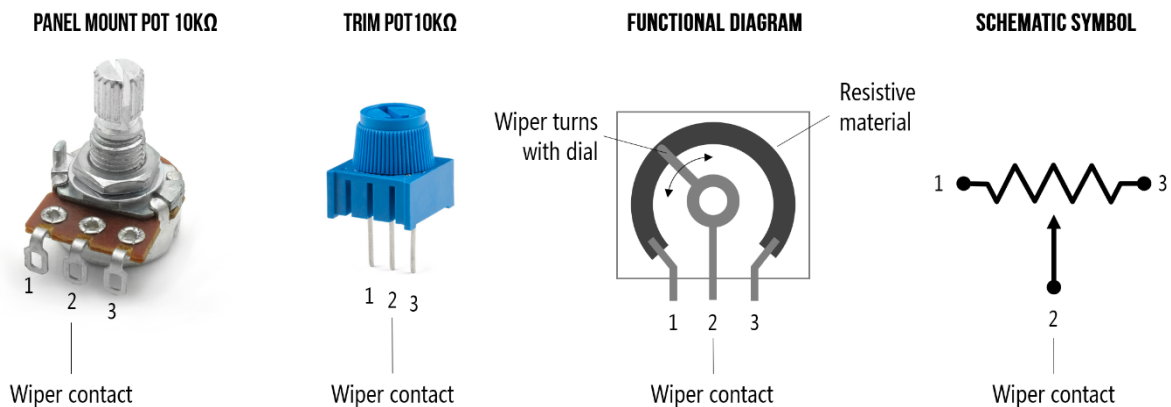
## Alpha Lab Experiment Guide

### Mathematical Analysis

1. Find the 10k $\Omega$  potentiometer in your [ADALP2000 parts kit](#) as shown in the picture below. A potentiometer is a variable resistor, whose resistance you can change by turning a dial. It has three terminals or “legs” (labeled 1, 2 and 3) and two variable resistances: R12, the resistance measured between terminal 1 and 2, and R23, the resistance measured between terminals 2 and 3. The resistance measured between terminals 1 and 3 will always be the maximum or total resistance of the potentiometer, which in this case will be 10k $\Omega$ .



### Typical connection pins



<https://makeabilitylab.github.io/physcomp/arduino/potentiometers.html>

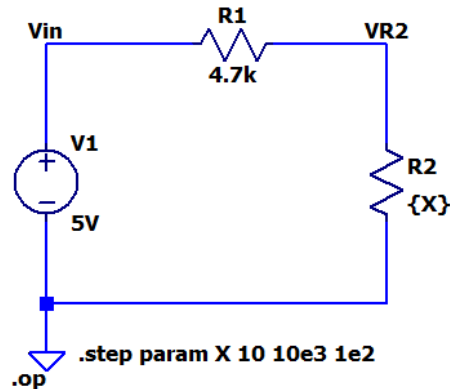
2. Using an ohmmeter (either use a multimeter – ask a TA if you don't have access to one), measure the maximum and minimum resistance of either R12 or R23 (whichever you plan to use in your circuit) by turning the dial all the way in both directions.

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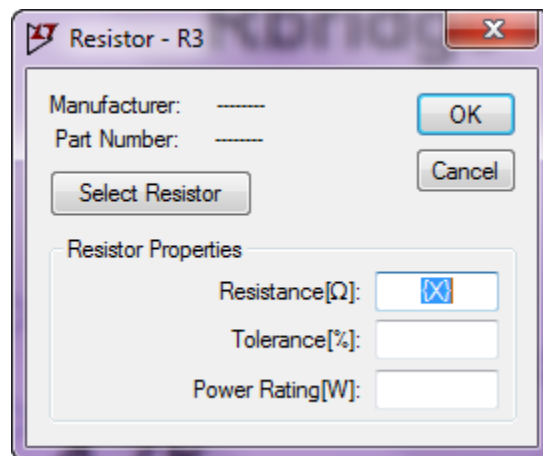
- You will use the circuit in Figure B-1 below for this Alpha Lab. R2 in the circuit below represents the potentiometer (either R12 or R23 – whichever you measured). Using circuit theory, calculate VR2 for the minimum resistance, maximum resistance, and three other resistances in between. You will compare this to simulations and experimental measurements.



**Figure B-1:** Series circuit containing a 4.7k $\Omega$  (R1) and 10k $\Omega$  potentiometer (R2).

Simulation (LTSpice): *Parametric Analysis:* The “.step” command performs repeated analysis while stepping through specified values of a model parameter, global parameter or independent source.

- Build the circuit in **Figure B-1** in LTSpice.
- Define the component parameter by right clicking a resistor in your circuit, i.e. resistor R2 and entering “{X}” for the value of resistance (as shown in the diagram below).



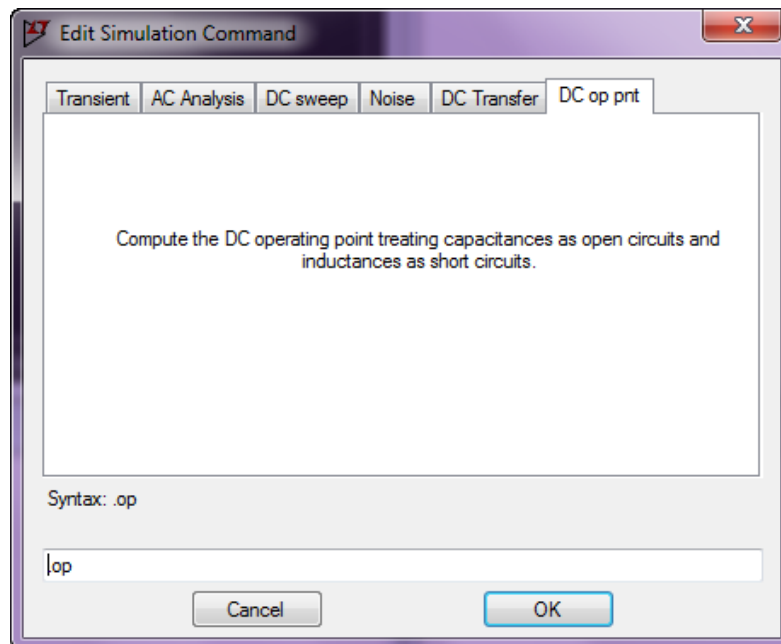
*Note: eventually you will have to build the circuit you designed and you will use a potentiometer with a range of resistances from 0 $\Omega$  to 10k $\Omega$  as your variable-valued resistor.*

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3. Add a “.step” command using a SPICE directive (press “s”) which specifies the steps for a parameter.  
*Example: “.step param X 1 10k 1k” steps the parameter X from 1 ohm to 10k ohms in 1k ohm increments.  
You may change the increments to a value that will give you more points.*
4. Add “.op” in the SPICE directive. (Click “.op” at far right on the toolbar and add “.op” to the text field in the box that pops up, then place it anywhere on the schematic)
5. Run the simulation (click the “Running man”), go to “DC op pnt tab” and click “ok”.



6. Run the simulation again. (click the “Running man”). The simulation pop-up window should show, but it won’t have any traces. However, the x-axis should show the range of resistor values you specified in the “.step” directive.
7. To specify a differential voltage probe across a resistor (for example R2 in **Figure B-2**), click the node to the left of the resistor (a red probe should appear), hold, then release the click on the node to the right of the resistor (a black probe should appear).
8. The trace V(N00x, N00y) for the voltage across your chosen resistor (i.e. VR2) should appear (where n is some number label of node). Label the trace directly on the diagram accordingly (i.e. “VR2”).
9. Pick points on the trace that correspond to the resistances you used for your calculations in the mathematical analysis section above and then compare them to the values you calculated via circuit theory.

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Measurement (M2K or Analog Discovery Board)

1. Build the circuit in **Figure B-1** on your breadboard. Remember that only two of the potentiometer legs should be connected to the circuit and that you should use the same two terminals as you measured for your mathematical analysis.
2. Measure the voltage across the potentiometer (VR2) for the five resistances you chose for your mathematical analysis. Using an ohmmeter, turn the dial on the potentiometer until the ohmmeter shows the resistance you want to set the potentiometer to, then plug it into the circuit, and measure the voltage across R2. Repeat this procedure for all five resistances. *Note: be careful not to touch the dial on the potentiometer as you're placing it into your circuit!*
3. Verify that your measured voltages agree with both your mathematical analysis and simulation results.



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### **SUMMARY of Concepts**

*Concept List that must be accounted for in your Proof of Concepts*

#### **PART A:**

1. Prove Ohm's Law, KCL, and KVL in a circuit.
2. Prove the concept of a voltage divider in a series circuit
3. Prove the concept of a how current flows in a series circuit (same current through R1 and R2 for example? Or different current?)
4. Prove the concept of voltage across a parallel circuit (same voltage? Or different....)
5. Provide the concept of a current divider in a parallel circuit. Hint: Try to search for this equation online. Use other current calculations and simulation to confirm!

#### **PART B:**

6. Demonstrate/Prove the Concept of a voltage divider in your application. *In your discussion, be sure to include if any failures occurred and speculate why they did. As an example, if you had trouble finding ways to accurately calculate values or simulate something, please state it.*

### **How You'll Be Graded (with Standards Based Assessment):**

You will be graded on the following Standards. Please ensure to achieve each standard. If you do not, you can resubmit to the missing standard to the end of the semester. CLEARLY mark the changes you make in you Proof of Concept submission by either Tracking Changes in Word or highlighting changes by writing comments in a different color and/or changing the color of the updated work.

## **Lab 01 Standards**

1. I can simulate a simple voltage divider circuit using LTSpice.
2. I can calculate and simulate series and parallel resistances that I combine.
3. I can build and test a simple voltage divider circuit on a breadboard and measure using my instrumentation board.
4. Alpha: I can connect a potentiometer to the right pins in my circuit.
5. Alpha: I can setup up, simulate and interpret parametric analysis in a circuit.
6. Alpha: I can discuss real-world applications of a potentiometer.
7. Omega: I can create a circuit schematic using LTSpice for my design exploration.
8. Omega: I can make appropriate assumptions to simulate values for my design exploration.
9. Omega: I can discuss and identify areas where I get stuck, I don't quite understand, or require more information.
10. I can demonstrate "good failure" whenever applicable by providing accurate results in my experience and speculating what went wrong.
11. I can identify non-idealities or unexpected results and attempt to explain why they may exist.
12. I can answer for myself "Is this right?" by comparing mathematical calculations to simulation and experimental results.
13. I can show plots and diagrams that are easy to read, scaled correctly and clearly labeled.
14. I can use consistent variable labels and component values in mathematical calculation, simulation, and experimental results for easy comparison.
15. I can accurately answer conceptual questions found throughout the lab.