

# 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

---

### Contents

Getting Started! .....	2
Lab Submission Instructions and Partners:.....	2
Purpose: .....	2
Student Preparation BEFORE doing this experiment: (Students should be able to) .....	2
Learning Outcomes AFTER doing this experiment: (Students will be able to) .....	2
Software and Equipment Required:.....	3
Learning from Proof of Skills applied to this lab: .....	3
PART A – Math as a Tool to Help You Understand.....	4
Background: Series and Parallel Circuits and Voltage Divider: .....	4
Series and Parallel Circuits and Voltage Divider Experiment:.....	7
Analysis .....	7
Simulation (LTSpice).....	7
Experimental Measurement (M1K or M2K or Analog Discovery Board) .....	8
Part A: Proof of Concepts List .....	9
Part B - Math as a COMPONENT you can use in a system.....	10
Voltage Divider Applications and Design Background:.....	10
<b>Choose Your Adventure! Alpha Experiments or Omega Exploration</b> .....	10
<b>Omega Exploration</b> .....	10
<b>Alpha Experiments</b> .....	10
Alpha Lab Experiment Guide.....	11
Part B: Proof of Concepts List .....	13
SUMMARY of Concepts.....	14
How You'll Be Graded (with Standards Based Assessment):.....	15

# Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

## 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 both 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 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!

**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 (aka breadboard).
- Articulate a series of questions posed about simple circuits and answer the questions using data obtained from physical experiments.

# Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

**ECSE-1010**

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

- 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
- ADALM1000 (M1K) board with Alice Source-Meter tool or ADALM2000 (M2K) board with Scopy or Analog Discovery with Digilent Waveforms
- Several different resistors and wires from Parts Kit (ADALP2000)
- Alpha Experiment: Potentiometer
- Omega Exploration Optional!: Resistive Sensors, Arduino, Push Buttons or Switches
- Breadboard

## 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:

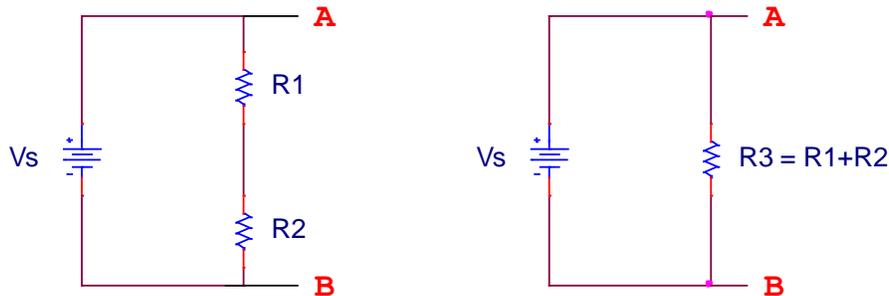
- I can use my instrumentation board’s function generator to **create a DC, sinusoid, and pulsed signal** and measure with its oscilloscope directly.
- I can **build a resistive circuit** and **measure DC voltage across ONE resistor using a dc input source** and vary dc voltage at least 3 times (-5,+5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

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

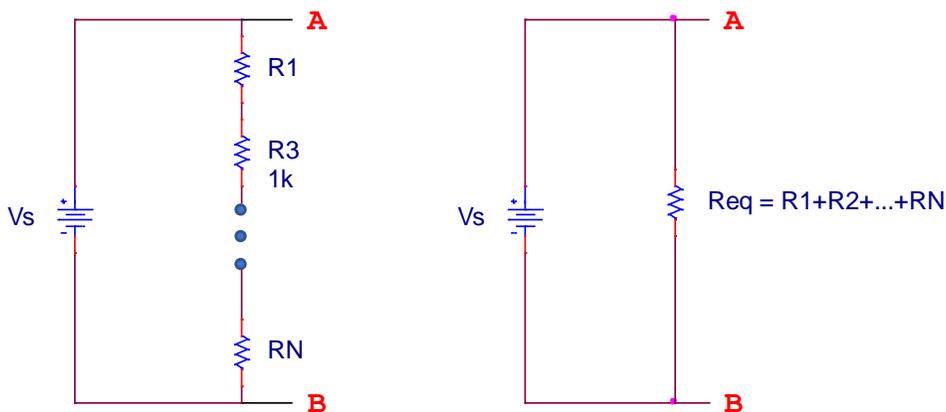
Background: Series and Parallel Circuits and Voltage Divider:

*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 the CH A and CH B/voltmeter) and apply Ohm's Law to get the current, for the current to be the same in the two circuits they must 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.

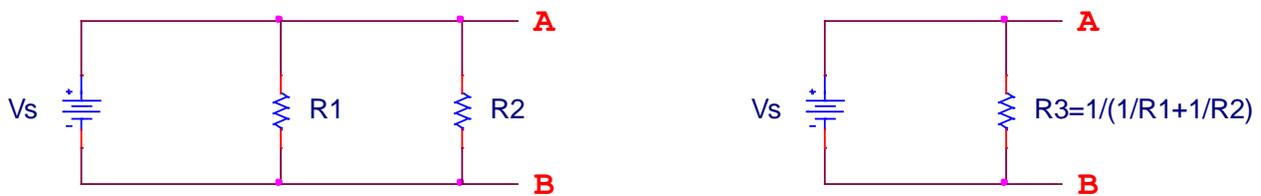
**Figure 1:** Two Resistors in Series

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

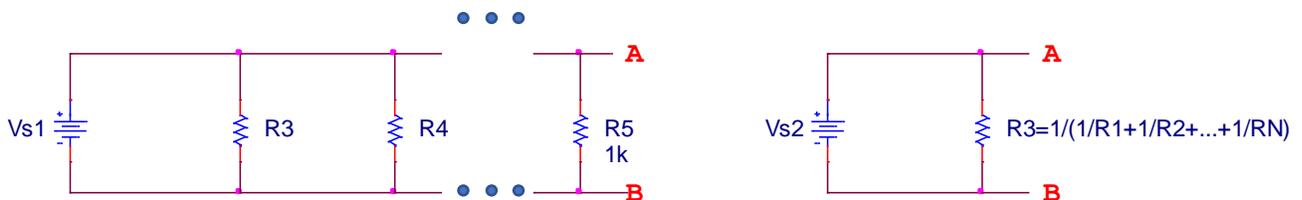
**Important note: Two resistors are in series only if the end of one resistor is directly connected to one end of the other resistor. There cannot be anything else connected in between the two resistors.**

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 CH A and CHB/voltmeter) and apply Ohm's Law to get the total current, for the total current to be the same in the two circuits they must 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.**

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

**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 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 circuit.

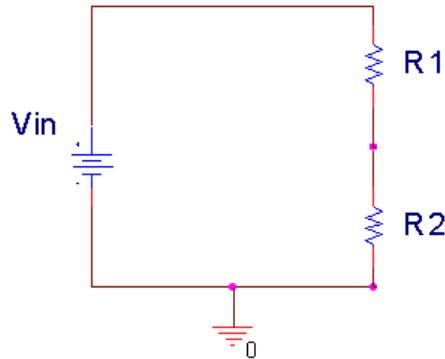


Figure 5

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

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

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,  $R_{Tot} = R_1 + R_2$ .

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

Series and Parallel Circuits and Voltage Divider Experiment:

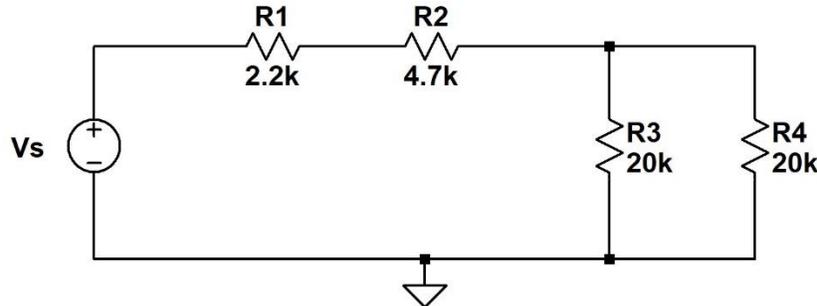


Figure A-1 Simulate this circuit using LTSpice

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.

In the above circuit, two of the resistors are in series and two of the resistors are in parallel.

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.
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  $R_1$  using LTSpice simulation options (other than operation point DC analysis)

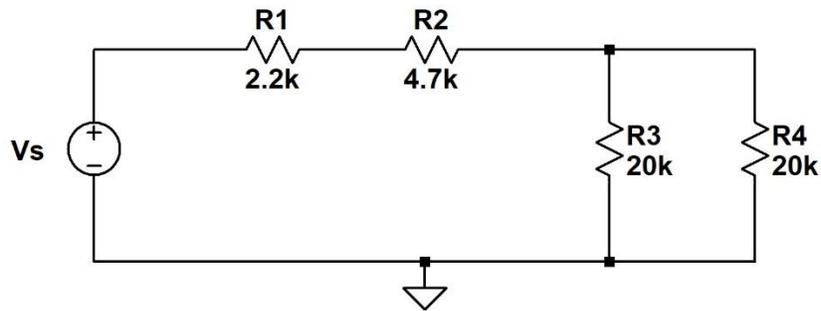
# Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

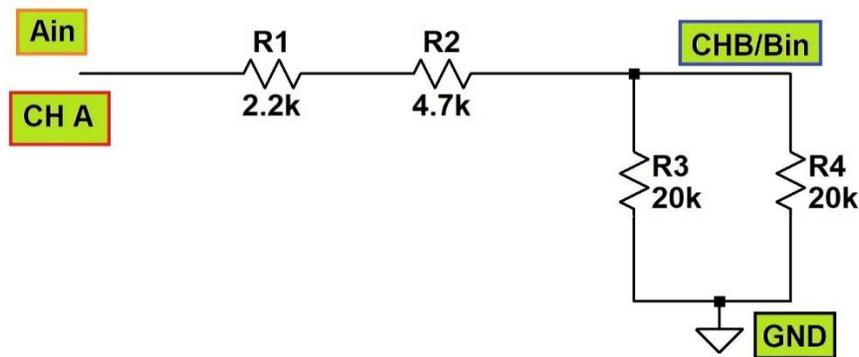
Experimental Measurement (M1K or M2K or Analog Discovery Board)

**Only instructions for M1K are shown below. Please see the [Self-Directed Skills Development Document](#) for introductory level instructions for the other instrumentation boards...**



**Figure A-2: Build this circuit with the exact values you simulated (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!)**

The circuit shown in Figure A-2 has a similar configuration to that on the previous page. You should be able to quickly recognize the two resistors in series and the two resistors in parallel. 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 with the M1K Board connections included.



**Figure A-3**

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

### ECSE-1010

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

- CH A should be in Split I/O mode. We are using it as a source *and* measuring-voltage unit.
- Set the CH A voltage to 4V and record the two voltage measurements, CA-V and CB-V meter using the Alice meter-source tool. Review experiment 5 video as needed.
- 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.

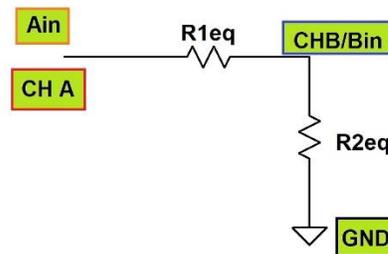


Figure A-4

#### 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!*

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

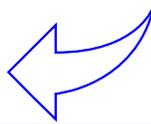
### Part B - Math as a COMPONENT you can use in a system....

*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 [ADALM2000 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.

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

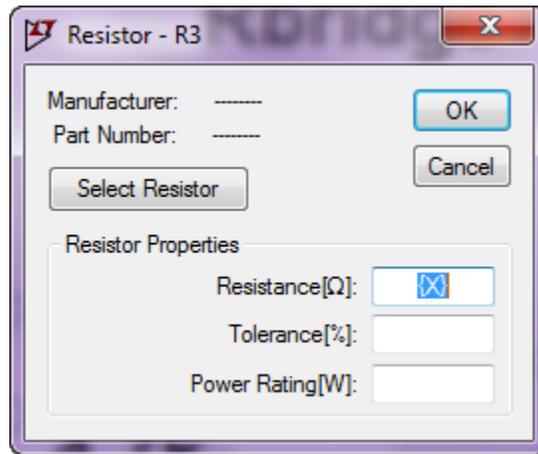
ECSE-1010

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

### Alpha Lab Experiment Guide

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

1. 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: Runknown is given the arbitrary value of 1k so the simulation can run.*

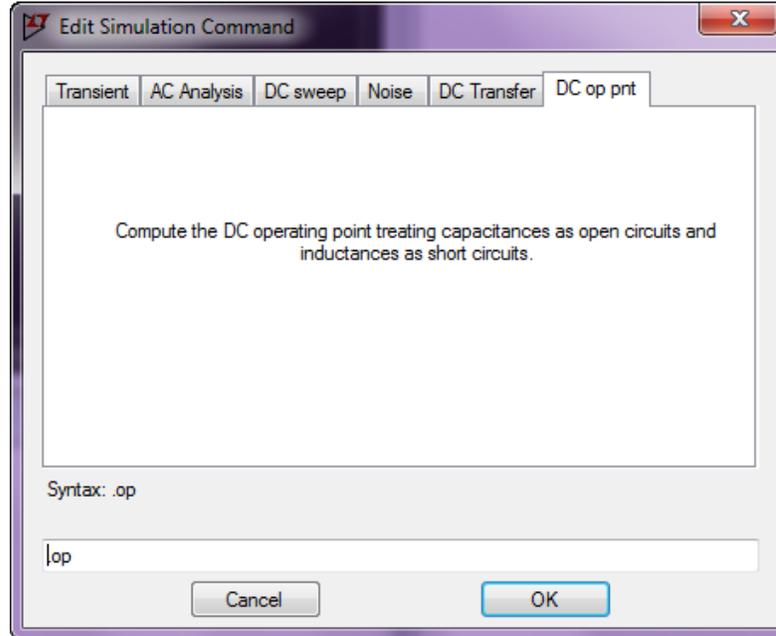


2. Add a .step command using a SPICE directive (press “s”) which specifies the steps for a parameter.  
Example: “.step param X 1 10k 1k” steps the parameter S from 1 to 10k in 1k increments.  
*You may change the increments to a value that will give you more points.*
3. Add .op in the SPICE directive. (Click “.op” far right on toolbar and add .op then place anyway on circuit)
4. Run the simulation (click “Running man”) go to “DC op pnt tab” and click “ok”

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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



5. Run the simulation again. (click "Running man"). The simulation pop-up window should show but without traces with resistor values as the x axis.
6. To specify the differential probes across Rbridge, click the node to the left of Rbridge (a red probe should appear), hold and click the right (a black probe should appear).
7. Probe the voltage across R1 and R2. The trace V(N00n, N00nx) for VR2 should appear (where n is some number label of node). Label the trace directly on the diagram as VR2.
8. Pick points on the trace and compare to calculated values of VR1 and VR2.

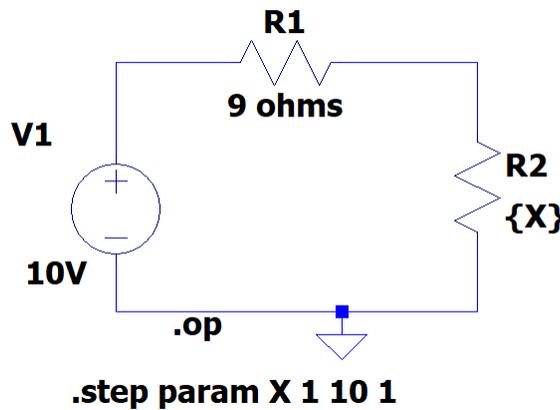


Figure B-1 This is an example circuit. You may make a more complicated circuit, change the values or change the configuration.

# Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

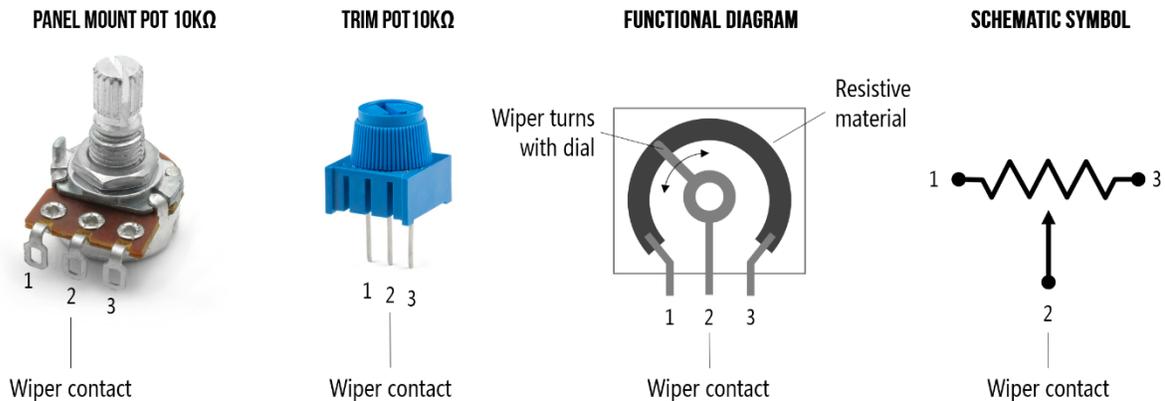
Measurement (M1K or M2K or Analog Discovery Board)

Only the M1K board has an ohmmeter tool. Borrow or ask TAs for another instrument if you need it!

1. Build the physical circuit using a 10kΩ Potentiometer in your [ADALM2000 parts kit](#) shown below, as shown in the picture below. Note, one leg of the potentiometer is floating. Turn the potentiometer until you get a specific voltage shown in your simulation. Once you find that value, use the [M1K Ohmmeter](#) to measure the resistance of the potentiometer (or another in the room). Be careful not to turn your potentiometer and make sure you disconnect the circuit so you don't measure the other resistors. Compare your result.



Typical connection pins



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

Analysis

1. Calculate values and compare with simulation and experiment using the voltage divider equation.

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.**

## Intro to ECSE Laboratories: Alpha Experiments and Omega Explorations

ECSE-1010

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

### **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.