THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

SCHOOL OF ENGINEERING AND APPLIED SCIENCE
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
ECE 2110: CIRCUIT THEORY LABORATORY

Experiment #4:
Voltage Division, Circuit Reduction, Ladders, and Bridges

EQUIPMENT

Lab Equipment	*Equipment Description*
(1) DC Power Supply	Keysight E36311A Triple Output DC Power Supply
(2) Digital Multimeters (DMM)	Agilent 34460A (DMM)
(1) Breadboard	Prototype Breadboard
(2) Test Leads	Banana to Alligator Lead Set

Table 1 – Equipment List

COMPONENTS

Type	*Value*	*Symbol Name*	*Multisim Part*	*Description*
Resistor	470Ω	R_1	Basic/Resistor	---
Resistor	560Ω	R_2	Basic/Resistor	---
Resistor	680Ω	R_3	Basic/Resistor	---
Resistor	750Ω	R_4	Basic/Resistor	---
Resistor	820Ω	R_5	Basic/Resistor	---
Resistor	910Ω	R_6	Basic/Resistor	---
Potentiometer	10kΩ	R_7	Basic/Resistor	---
LED Bar	Green	LEDs	LED/Bar_LED _Green_Ten	Bar of 10 Green LEDs

Table 2 – Component List

OBJECTIVES

- To calculate and measure the total resistance in a series/parallel circuit
- To calculate and measure the total current in a series/parallel circuit for a given applied voltage
- To calculate the expected total power dissipated in a series/parallel circuit from nominal and measured values
- To calculate and measure the voltage drop across and the current through all components of a series/parallel circuit
- To calculate the power dissipated by each component of a series/parallel circuit from measured data
- Design, build and test a voltage ladder
- Use a Wheatstone Bridge circuit as a detector of unknown resistances

INTRODUCTION

Voltage Division

The voltage divider circuit is one of the most important and fundamental circuits that you will encounter in Circuit Theory. There are countless applications for voltage dividers, and you will find that throughout the semester, many calculations become simpler if you see the circuit as a basic voltage divider. A **voltage divider** is a linear circuit whose output voltage is some fraction of its input voltage. In other words, a voltage divider allows us to turn a large voltage into a smaller one. **Voltage division** refers to the splitting of a voltage among the components of the voltage divider.

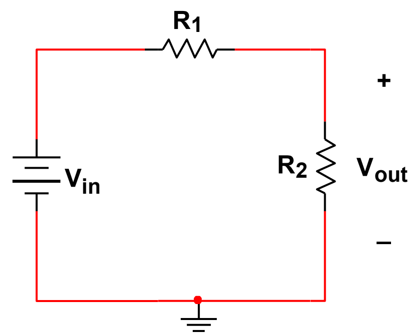

Figure 1 – Voltage Divider

$$Vout = \frac{R2}{R1+R2} * Vin$$

Equation 1 – Voltage Divider Equation

Potentiometer

A **potentiometer** is a passive device that acts as a **variable resistor** or **voltage divider**. Potentiometers have three terminals and some type of rotary component that can be turned clockwise and counter-clockwise to adjust the resistance. The resistance between the outer two terminals is constant and always equal to the nominal value of the potentiometer. The middle terminal is connected to the wiper shown in **Figure 4** that can be adjusted to change the resistance relationship between the two halves of the device. **Figure 2** shows the schematic symbol for a potentiometer, including the third middle terminal. Think of the potentiometer in **Figure 4** as two resistors connected in series with each other, R_1 between terminals A and W, R_2 between W and B, similar to the voltage divider of **Figure 1**. When the center dial is turned counterclockwise until it stops, R_1 would be 0Ω and R_2 would equal to the nominal value of the potentiometer. As the dial is turned clockwise, R_1 increases and R_2 decreases.

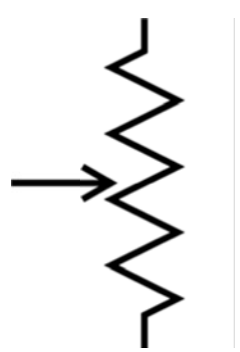

Figure 2 – Potentiometer Symbol

Figure 3 – Potentiometer

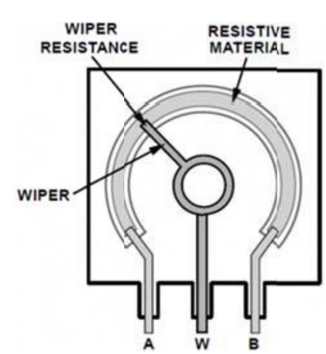

Figure 4 – Potentiometer Diagram

Voltage Ladder

A **voltage ladder** is a simple electrical circuit comprised of multiple resistors in series used to create multiple voltage points between 0V and the source voltage. Similar to a voltage divider, the source voltage is split across the resistors as determined by the ratio of the individual resistor to the entire equivalent resistance.

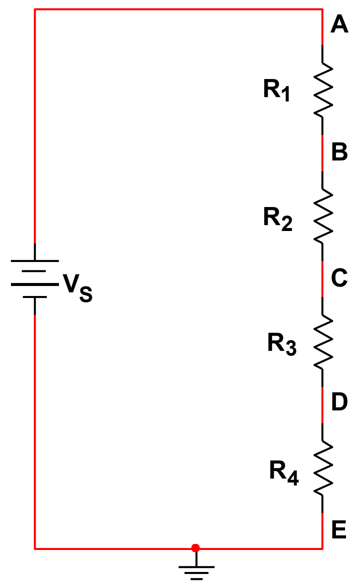

Figure 5 – Voltage Ladder

Wheatstone Bridge

A **Wheatstone Bridge** is an electrical bridge circuit used to determine and unknown resistance. The Wheatstone Bridge circuit consists of four resistances, three of which must be known and one that is unknown. By balancing the two legs of the bridge circuit and deriving the resistive relationship, the unknown resistance can be quickly determined. In **Figure 6**, R_X is the unknown resistance we are trying to find, R_3 is a variable resistor such as a potentiometer that we can adjust, and R_1 and R_2 are known resistances.

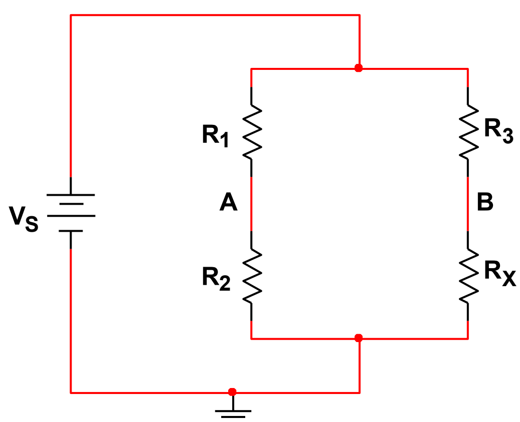

Figure 6 – Wheatstone Bridge

PRELAB

Part I – Simplifying a Parallel Circuit

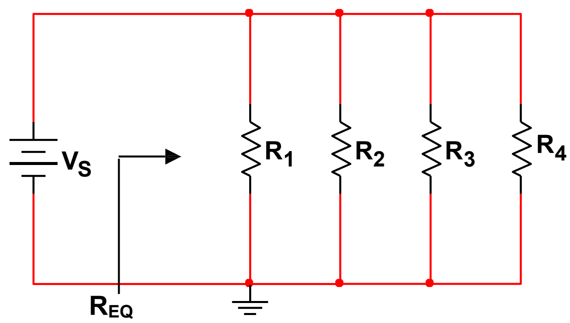

Figure P.1 – Parallel Circuit

1. **Simplify** the circuit in **Figure P.1** in order to find the voltage across, current through, and power dissipated by each resistor.
    a. **Find** the equivalent resistance $\mathbf{R_{EQ}}$ from the perspective of the voltage source V_S in **Figure P.1**. Leave your answer in terms of R_1, R_2, R_3, and R_4. ***Show all work.***
    b. **Calculate** the actual equivalent resistance $\mathbf{R_{EQ}}$ using the resistor values given in **Table 2**.
    c. **Calculate** the total **current** drawn by $\mathbf{R_{EQ}}$ and the total **power** dissipated by $\mathbf{R_{EQ}}$ assuming $\mathbf{V_S = 5V}$.
    d. **Calculate** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
    e. **Record** all of your results in **Table P.1**.
2. **Simulate** the circuit in **Figure P.1** in **Multisim**.
    a. **Find** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
    b. **Record** all values in **Table P.1**.
3. **Calculate** the **percent error** between your **calculated** and **simulated** results.
    a. **Record** the error in **Table P.1**.

Electrical Quantity		***Resistor***				
		R_{EQ}	***R_1***	***R_2***	***R_3***	***R_4***
***Voltage* (V)**	***Calculated***					
	Simulated					
	Percent Error					
***Current* (mA)**	***Calculated***					
	Simulated					
	Percent Error					
***Power* (mW)**	***Calculated***					
	Simulated					
	Percent Error					

Table P.1 – Prelab Data Table 1

Part II – Simplifying a Series Circuit

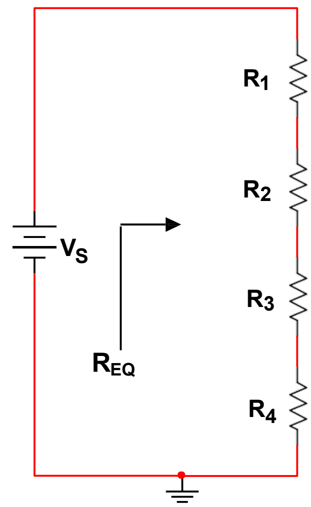

Figure P.2 – Series Circuit

1. **Simplify** the circuit in **Figure P.2** in order to find the voltage across, current through, and power dissipated by each resistor.
    a. **Find** the equivalent resistance R_{EQ} from the perspective of the voltage source V_S in **Figure P.2**. Leave your answer in terms of R_1, R_2, R_3, and R_4. ***Show all work.***
    b. **Calculate** the actual equivalent resistance R_{EQ} using the resistor values given in **Table 2**.
    c. **Calculate** the total **current** drawn by R_{EQ} and the total **power** dissipated by R_{EQ} assuming **Vs = 5V**.
    d. **Calculate** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
    e. **Record** all of your results in **Table P.2**.
2. **Simulate** the circuit in **Figure P.2** in **Multisim**.
    a. **Find** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
    b. **Record** all values in **Table P.2**.
3. **Calculate** the **percent error** between your **calculated** and **simulated** results.
    a. **Record** the error in **Table P.2**.

Electrical Quantity		***Resistor***				
		R_{EQ}	***R1***	***R2***	***R3***	***R4***
Voltage (V)	***Calculated***					
	Simulated					
	Percent Error					
Current (mA)	***Calculated***					
	Simulated					
	Percent Error					
Power (mW)	***Calculated***					
	Simulated					
	Percent Error					

Table P.2 – Prelab Data Table 2

Part III – Simplifying a Series-Parallel Circuit

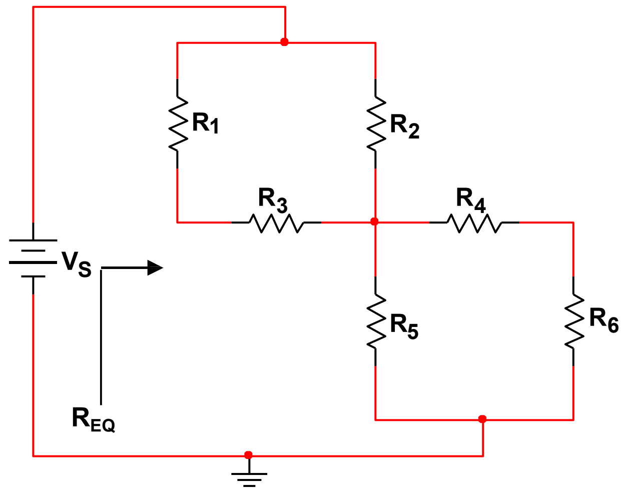

Figure P.3 – Series-Parallel Circuit

1. **Simplify** the circuit in **Figure P.3** in order to find the voltage across, current through, and power dissipated by each resistor.
   a. **Find** the equivalent resistance $\mathbf{R_{EQ}}$ from the perspective of the voltage source V_S in **Figure P.3**. Leave your answer in terms of R_1, R_2, R_3, and R_4. ***Show all work***.
   b. **Calculate** the actual equivalent resistance $\mathbf{R_{EQ}}$ using the resistor values given in **Table 2**.
   c. **Calculate** the total **current** drawn by $\mathbf{R_{EQ}}$ and the total **power** dissipated by $\mathbf{R_{EQ}}$ assuming **Vs = 5V**.
   d. **Calculate** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
   e. **Record** all of your results in **Table P.3**.
2. **Simulate** the circuit in **Figure P.3** in **Multisim**.
   a. **Find** the voltage drop across each resistor, the current through each resistor, and the power dissipated by each resistor.
   b. **Record** all values in **Table P.3**.
3. **Calculate** the **percent error** between your **calculated** and **simulated** results.
   a. **Record** the error in **Table P.3**.

Electrical Quantity		***Resistor***						
		R_{EQ}	R_1	R_2	R_3	R_4	R_5	R_6
***Voltage* (V)**	***Calculated***							
	Simulated							
	Percent Error							
***Current* (mA)**	***Calculated***							
	Simulated							
	Percent Error							
***Power* (mW)**	***Calculated***							
	Simulated							
	Percent Error							

Table P.3 – Prelab Data Table 3

Part IV – Wheatstone Bridge

The circuit below in **Figure P.4** is a **Wheatstone Bridge**. As discussed in the **Introduction** to this lab, the purpose of the Wheatstone Bridge is to use three known resistors (R_1, R_2, and R_3) to find an unknown resistance R_X. We need to generate an algebraic expression for resistor Rx in terms of the known resistors. Use the following steps to solve the bridge circuit for R_X:

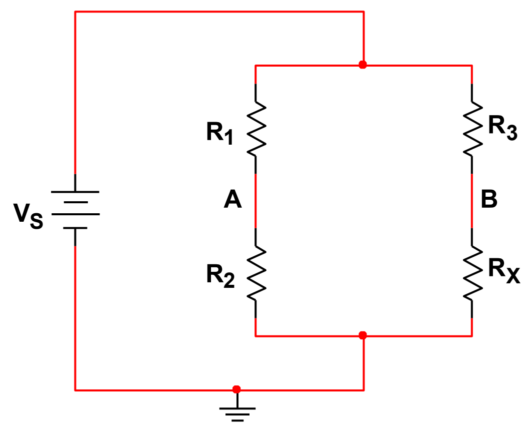

Figure P.4 – Wheatstone Bridge Circuit

1. **Solve** for $\mathbf{V_A}$ in terms of R_1, R_2, and V_S. ***(Hint:** V_A is just the voltage across R_2)*
2. **Solve** for $\mathbf{V_B}$ in terms of R_3, Rx, and V_S. ***(Hint:** V_B is just the voltage across R_X)* ***Note:** The bridge is said to be "balanced" when $V_A = V_B$.*
3. **Solve** for $\mathbf{R_X}$ by setting your equations for V_A and V_B equal to each other.
   ***Note:** V_S should drop out of the equation if you have done everything correctly*

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Lab

Part I – Parallel Circuit Measurements

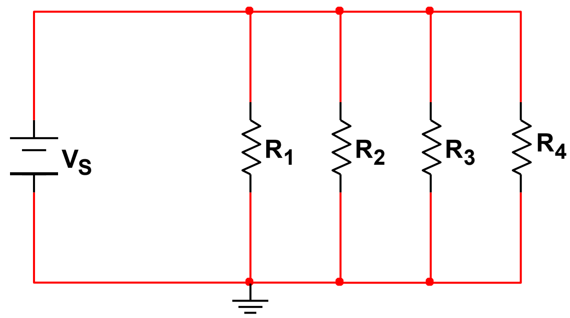

Figure 1.1 – Parallel Circuit

1. **Build** the circuit in **Figure 1.1** on a breadboard. **Before** connecting the power supply to the circuit, use the DMM to **measure** the equivalent resistance R_{EQ} of the circuit.
2. **Connect** the power supply ($V_S = 5V$) to the circuit.
3. **Measure** the **voltage across** each resistor and the **current through** each resistor with the DMM.
   Note: *Remember that it is impossible to measure the current across a resistor. You must use the DMM differently when measuring current. Ask your GTA if you do not remember how to do this.*
4. **Measure** the **total current** supplied by the power supply. To do this, break the circuit between the positive lead from the power supply and the rest of the circuit, insert the DMM in current mode, and record the reading.
5. **Calculate** the **power** dissipated by each resistor using the measured voltage and current.
6. **Record** all data in the **Measured** sections of **Table 1.1**.
7. **Compute** the **percent error** between your **calculated** and **measured** results and record it below.

Electrical Quantity		***Resistor***				
		R_{EQ}	***R_1***	***R_2***	***R_3***	***R_4***
***Voltage* (V)**	***Calculated***					
	Simulated					
	Measured					
***Current* (mA)**	***Calculated***					
	Simulated					
	Measured					
***Power* (mW)**	***Calculated***					
	Simulated					
	Measured					
***Percent Error* (%)**	***Voltage***					
	Current					
	Power					

Table 1.1 – Parallel Circuit Data

Part II – Series Circuit Measurements

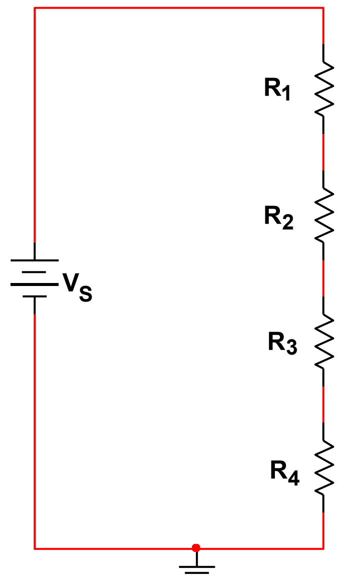

Figure 2.1 – Series Circuit

1. **Build** the circuit in **Figure 2.1**. **Before** connecting the power supply to the circuit, use the DMM to **measure** the equivalent resistance $\mathbf{R_{EQ}}$ of the circuit.
2. **Connect** the power supply ($\mathbf{V_S = 5V}$) to the circuit.
3. **Measure** the **voltage across** each resistor and the **current through** each resistor with the DMM.
4. **Measure** the **total current** supplied by the power supply.
5. **Calculate** the **power** dissipated by each resistor using the measured voltage and current.
6. **Record** all data in the **Measured** sections of **Table 2.1**.
7. **Compute** the **percent error** between your **calculated** and **measured** results and record it below.

Electrical Quantity		***Resistor***				
		R_{EQ}	R_1	R_2	R_3	R_4
***Voltage* (V)**	***Calculated***					
	Simulated					
	Measured					
***Current* (mA)**	***Calculated***					
	Simulated					
	Measured					
***Power* (mW)**	***Calculated***					
	Simulated					
	Measured					
***Percent Error* (%)**	***Voltage***					
	Current					
	Power					

Table 2.1 – Series Circuit Data

Part III – Series-Parallel Circuit Measurements

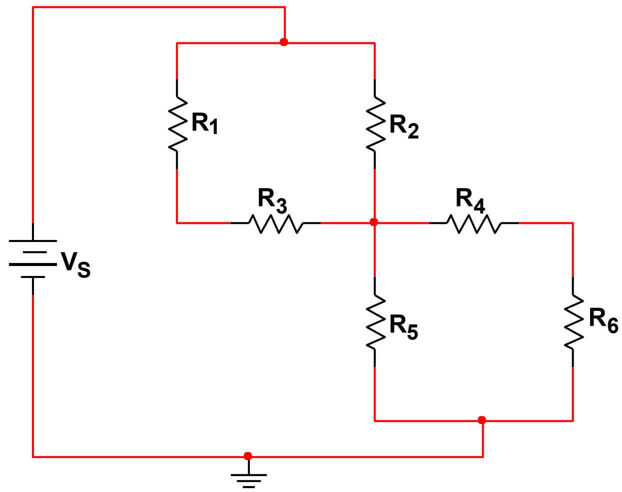

Figure 3.1 – Series-Parallel Circuit

1. **Build** the circuit in **Figure 3.1**. **Before** connecting the power supply to the circuit, use the DMM to **measure** the equivalent resistance R_{EQ} of the circuit.
2. **Connect** the power supply (V_S **= 5V**) to the circuit.
3. **Measure** the **voltage across** each resistor and the **current through** each resistor with the DMM.
4. **Measure** the **total current** supplied by the power supply.
5. **Calculate** the **power** dissipated by each resistor using the measured voltage and current.
6. **Record** all data in the **Measured** sections of **Table 3.1**.
7. **Compute** the **percent error** between your **calculated** and **measured** results and record it below.

Electrical Quantity		***Resistor***						
		R_{EQ}	R_1	R_2	R_3	R_4	R_5	R_6
***Voltage* (V)**	***Calculated***							
	Simulated							
	Measured							
***Current* (mA)**	***Calculated***							
	Simulated							
	Measured							
***Power* (mW)**	***Calculated***							
	Simulated							
	Measured							
***Percent Error* (%)**	***Voltage***							
	Current							
	Power							

Table 3.1 – Series-Parallel Circuit Data

Part IV – Design, Build, and Test a Voltage Ladder

In this part of the lab, you are asked to design a **voltage ladder** using the concept of **Voltage Division**.

Design Specifications:

- **P_{total}:** ≤ 86mW
- **V_S:** 5V ±5%
- **V_{AB}:** 1.724V ±5%
- **V_{BC}:** 0.345V ±5%
- **V_{CD}:** 1.724V ±5%
- **V_{DE}:** 1.207V ±5%

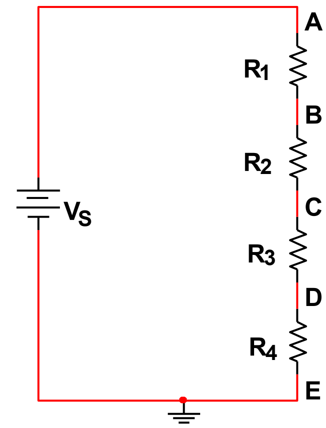

Figure 4.1 – Voltage Ladder

1. Using the circuit in **Figure 4.1**, find the appropriate values for R_1, R_2, R_3, and R_4 to build a voltage ladder that meets the **Design Specifications**. (***Hint:*** *A good first step would be to examine the relationship between Vs, P_{total}, and total current.)*

   Note: *R_1, R_2, R_3, and R_4 are for you to calculate. Do **not** use the values from **Table 2** that were used in earlier parts of this lab.*
2. **After** designing the voltage ladder, **build** it on a breadboard.
3. **Measure** the **voltage** drop across each resistor and **compare** it to the value in the specifications.
   a. **Record** your results in **Table 4.1**.
4. **Connect** the circuit to your green LED bar from points B, C, and D. **Wire** from nodes B, C, and D to the positive side (anode) of three individual LEDs in the bar (your GTA will assist you if necessary).
5. **Connect** the negative side (cathode) of the LEDs directly to ground. Vary the supply voltage from 0V to 6V (feel free to experiment).

   Question: What happens to the intensity of the LEDs as you vary the supply voltage? Do you notice a pattern?

Quantity	***Specified***	***Measured***	***Percent Error (%)***
P_{total}			
V_S			
V_{AB}			
V_{BC}			
V_{CD}			
V_{DE}			

Table 4.1 – Voltage Ladder Data

Part V – Wheatstone Bridge

In this part of the lab, the GTA will give you an **unknown resistor R_X**. You must build and use a Wheatstone Bridge in order to determine the value of the unknown resistance.

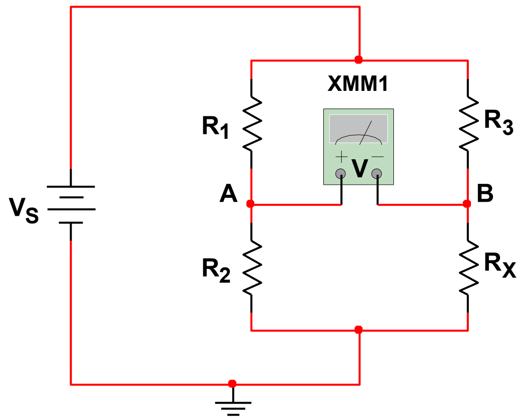

Figure 5.1 – Wheatstone Bridge

1. **Build** the Wheatstone Bridge in **Figure 5.1**. You will need the following components:
   - **R_1 = 2kΩ, R_3 = 5kΩ, R_2 = 10kΩ potentiometer**
   - **DMM** to measure voltage drop between nodes A and B (V_{AB})
2. **After** you have completed the setup, **connect** a **5V** supply for Vs.
3. **Record** the initial (unbalanced) value of **V_{AB}** in **Table 5.1**.
4. **Adjust** the potentiometer until the bridge is balanced. (***Hint:*** *Refer to* ***Part IV*** *of the* ***Prelab*** *to recall what balanced means for a Wheatstone bridge circuit.*)
   a. **Record V_{AB}** once the bridge is balanced in **Table 5.1**.
5. **Remove** the potentiometer from the circuit without adjusting it, and use the DMM to measure its actual resistance.
   a. **Record** the value of R_2 in **Table 5.1**.
6. **Measure** the exact resistances of R_1 and R_3 with the DMM.
7. **Use** the **measured values** for R_1, R_2, and R_3 and the expression you derived in **Part IV** of the **Prelab** to **calculate** the resistance of **R_X**. ***Show your calculations.***
8. **Remove R_X** from the circuit and use the DMM to measure its exact resistance.
9. **Compare** your calculated and measured results for the resistance of **R_X** by **calculating** the percent error.

<table>
<tr><th>Quantity</th><th>Measured</th><th>Calculated</th><th>Percent Error (%)</th></tr>
<tr><td>R_X</td><td></td><td></td><td></td></tr>
<tr><td>V_{AB} (unbalanced)</td><td></td><td colspan="2" rowspan="5">n/a</td></tr>
<tr><td>V_{AB} (balanced)</td><td></td></tr>
<tr><td>R₁</td><td></td></tr>
<tr><td>R₂</td><td></td></tr>
<tr><td>R₃</td><td></td></tr>
</table>

Table 5.1 – Wheatstone Bridge Data

POST-LAB ANALYSIS

For part 1 of the lab: Compare and contrast the calculated results from your prelab, to your Multisim simulations and finally to the DC measurements made in the lab itself. Show the percentage error in each case. Explain the differences between the calculated, measured, and simulated results then include a discussion on the reason for the discrepancies. Also explain the concept of tolerance in all the devices and equipment and how to compensate for the problem of inaccurate measurements.

For part 2 of the lab: Make sure to answer all questions asked in tandem with the lab instructions. Now that you have designed and observed the behavior of a voltage ladder / LED bar combination in detail, can you think of any applications for such a circuit? Name one or two possibilities in your report.

For part 3 of the Lab: Why does the bridge have to be 'balanced' in order to calculate the value of R_2? Does your calculated value for R_2 (from step 3 c) match your measured value of R_2 (from step 3 d), what is the % error? Research and explain several uses of the Wheatstone bridge.