THE GEORGE WASHINGTON UNIVERSITY

WASHINGTON, DC

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

Experiment #3:
Ohm's Law, Series, Parallel, and Series-Parallel Circuits

EQUIPMENT

Lab Equipment	*Equipment Description*
(1) DC Power Supply	KLY-2402000 Adjustable 3-24 V 2A DC AC adapter
(1) Digital Multimeter (DMM)	Harbor Freight Model 63759 Handheld Digital Multimeter
(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	750Ω	R_1	Basic/Resistor	---
Resistor	1.5kΩ	R_2	Basic/Resistor	---
Resistor	3kΩ	R_3	Basic/Resistor	---

Table 2 – Component List

OBJECTIVES

- To understand DC series, parallel, and series-parallel combination circuit
- To connect electronic devices on a breadboard
- To calculate DC voltage across resistors in a DC series circuit
- To measure DC voltage across resistors in a DC series circuit using a DMM
- To calculate DC current through resistors in a DC parallel circuit
- To measure DC current through resistors in a DC parallel circuit using a DMM
- To calculate DC current through resistors in a DC series-parallel combination circuit
- To measure DC current through resistors in a DC series-parallel combination circuit using a DMM
- To calculate the total power dissipated by each resistor in a DC series, parallel, and series-parallel combination circuit

INTRODUCTION

Ohm's Law

This lab will focus on **Ohm's Law**, one of the most fundamental laws governing electrical circuits. It states that voltage is equal to current multiplied by resistance. For a given current, an increase in resistance will result in a greater voltage. Alternately, for a given voltage, an increase in resistance will produce a decrease in current. As this is a first order linear equation, plotting current versus voltage for a fixed resistance will yield a straight line. The slope of this line is the conductance, and conductance is the reciprocal of resistance.

$$V = IR$$

Equation 1 – Ohm's Law

Resistors in Series

An important concept to understand in any electrical circuit is the difference between **series** and **parallel**. A **series** path is defined by a single loop in which all components are arranged one after the other. The **current is the same** at all points in the loop and may be found by dividing the total voltage by the total resistance. The voltage drops across any resistor may then be found by multiplying that current by the individual resistor value. The equivalent resistance of resistors in series is simply the sum of the resistances (see **Equation 2**).

$$R_{eq} = R_1 + R_2 + \cdots + R_n$$

Equation 2 – Series Equivalent Resistance

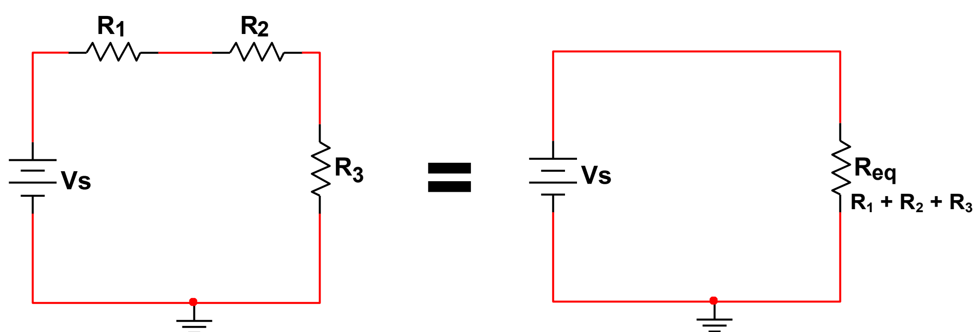


Figure 1 – Example Series Equivalent Resistance

Resistors in Parallel

Resistors in **parallel** share two common nodes. The **voltage** is the **same across all resistors** and will be equal to the applied source voltage. The total supplied current may be found by dividing the voltage source by the equivalent parallel resistance. It may also be found by summing the currents in all branches. The current through any resistor branch may be found by dividing the source voltage by the resistor value. The **current is the same** at all points in the loop and may be found by dividing the total voltage by the total resistance. The voltage drops across any resistor may then be found by multiplying that current by the individual resistor value. The equivalent resistance of resistors in parallel can be found by summing the reciprocal of all parallel resistors, then finding the reciprocal of that (see **Equation 3**).

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}}$$

Equation 3 – Example Parallel Equivalent Resistance

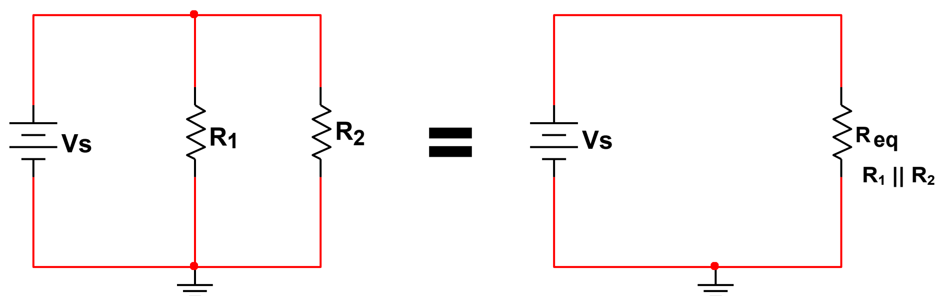


Figure 2 – Parallel Equivalent Resistance

Resistors in Series-Parallel Combination

Most circuits will use some combination of components connected in series and in parallel. Simple **series-parallel circuits** may be viewed as interconnected **series** and **parallel branches**. Each of these branches may be analyzed through basic series and parallel techniques such as the application of voltage divider and current divider rules. It is important to identify the simplest series and parallel connections in order to jump to more complex interconnections.

Measuring Voltage Across a Resistor

A Digital Multimeter (DMM) is a multi-use measurement device that we use in the lab to measure resistance, voltage, and current. The DMM was used in **Experiment #1** to measure the resistance of a resistor. In this lab, you will use the DMM to measure voltage.

Voltage is measured ***across*** an electrical device. **Figure 3** shows a series circuit with two resistors. After building the circuit on a breadboard, if we wish to measure the voltage across resistor R_2, we would do the following using the DMM:

1. **Set** the DMM to measure ***Voltage*** by selecting "**DCV**" on the DMM.
2. **Set** the DMM to the ***range*** we expect the voltage to be (uV, mV, V, etc.). Some DMM's will automatically adjust to the proper range when you measure.
3. **Attach** the positive lead coming from the DMM to the positive side of R_2 and the negative lead to the negative side of R_2.
    a. In this way, the DMM is measuring ***ACROSS*** R_2.
4. **Record** the value of the voltage measured on the DMM.

These are the four conceptual steps to measuring voltage. The exact procedure will be demonstrated and explained during the lab experiment. It is expected that you be familiar with these conceptual steps prior to the lab. If you do not understand these steps, be certain to discuss this with the GTA prior to the lab session.

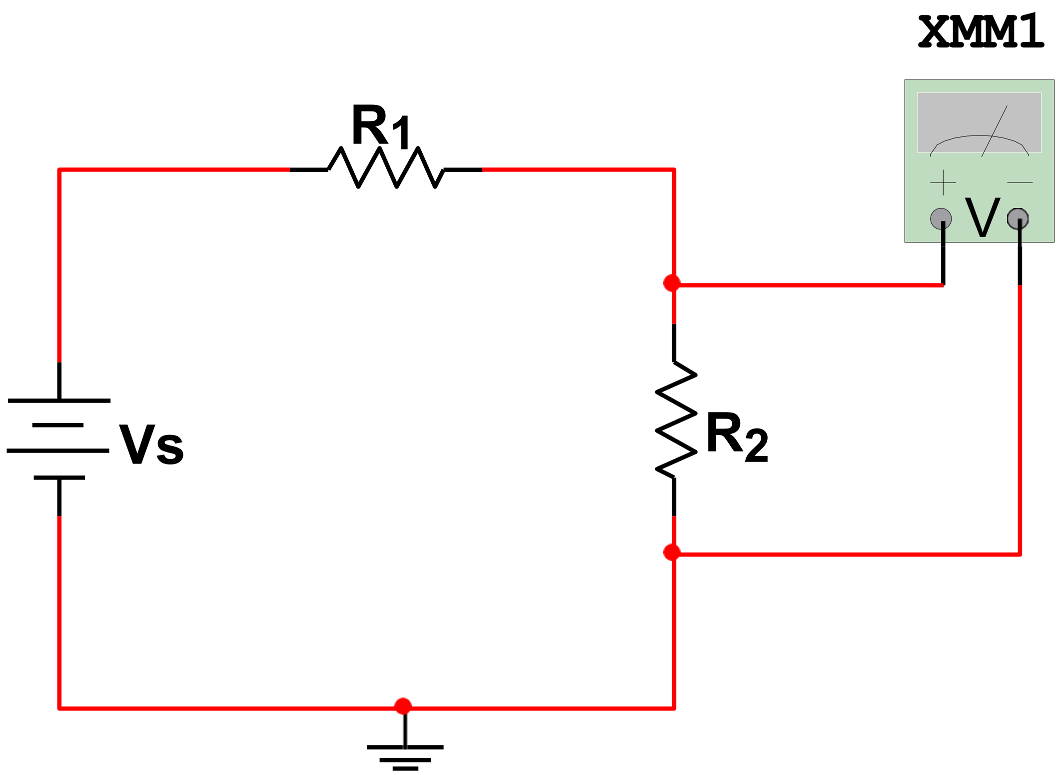


Figure 3 – DMM Measuring Voltage Across R2

Measuring Current Through a Resistor

Current is measured ***through*** an electrical device. It must be measured in an entirely different way than voltage is measured. **Figure 4** shows a circuit with two resistors. After building the circuit on a breadboard, if we wish to measure the current through resistor R_1, we need to BREAK the circuit where we wish to measure the current. We would do the following using the DMM:

1. **Set** the DMM to measure ***Current*** by switching to "**DCA**" (Amperes) on the DMM.
2. **Set** the meter to the ***range*** we expect the current to be: (uA, mA, etc.). Again, this is only if your DMM needs to be.
3. **Break the circuit** where we wish to measure the current.
   a. In **Figure 4**, we would **disconnect**/**break** the circuit between resistors R_1 and R_2.
   b. The DMM is then inserted **in series** between R_1 and R_2, allowing the current in the circuit to flow **through** the DMM, enabling it to measure the current.
   Note: *Because the DMM is in series, we know the current will be the same as it will be through R_1 and R_2.*
4. **Record** the value of the current measured on the DMM.
   a. This is the value of the current at all points through the entire series circuit.

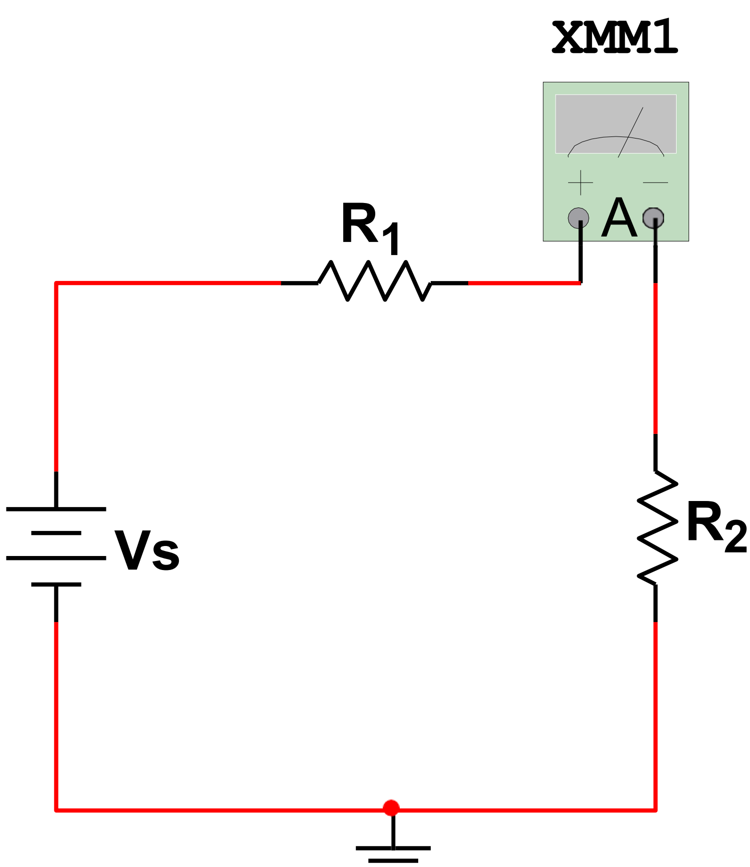


Figure 4 – DMM in Series Measuring Current Through Circuit

Introduction to the KLY-2402000 DC Power Supply

In previous labs, we have been able to use the AD2 to supply the voltages needed for our circuits. In this lab, we will see circuits that use more than the 5V the AD2 can supply, so we need to use an auxiliary Power Supply. In the tool kits, you have been supplied with 2 KLY-2402000 DC Power Supplies. This device is straightforward to use and can supply voltages greater than 5V. You will use these devices not only for this lab, but for future labs and the final project as well.

These power supplies come with special adapters, that allow us to probe wires into them so that we can attach the Power Supplies to our breadboard. To do this, simply take the adapter (shown in Figure 5), and unscrew the screws seen within. You do not have to unscrew them all the way, just enough to where you can fit a wire into the ports. The polarity on the adapter is labeled, and it is very important that you know which side positive and which side is negative, so that you do not damage any of the components within your circuit. It is recommended that you attach a red wire to the positive terminal, and a black wire to the negative, so that they are easy to distinguish. In Figure 5, you can see the wires already attached to this adapter.

After you have setup and attached the adapter, you can now connect this supply to the breadboard. The KLY-2402000 can supply 3-24V and up to 2A of current, so it is extremely important that you handle these devices with care, and always triple check your connections, and this supply can easily burn out capacitors and Integrated Circuit Chips, or IC's. To use this supply, you just simply plug it in, and there is a knob on the top that allows you to adjust the voltage. Turning it clockwise will increase the voltage, counterclockwise will decrease it and turn it off. Make sure to always have the supply plugged into your circuit before turning it on.

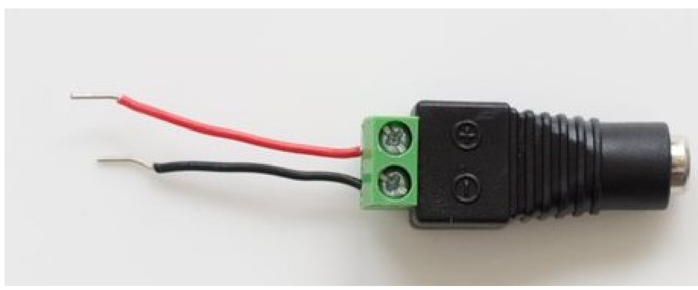


Figure 5 – Adapter Piece with Red Wire Attached to the Positive Terminal and Black Wire Attached to the Negative Terminal

Figure 6 – KLY-2402000 Power Supply

PRELAB

Part I – DC Series Circuit

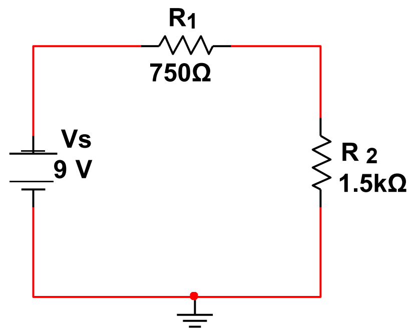


Figure P.1 – DC Series Circuit

Figure P.1 shows a DC circuit that has two resistors R_1 and R_2 connected in series with a DC Voltage Source.

1. **Analyze** the circuit in **Figure P.1**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **DC power consumption** of $\mathbf{R_1}$ and $\mathbf{R_2}$ (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 1.1** below.

Part II – DC Parallel Circuit

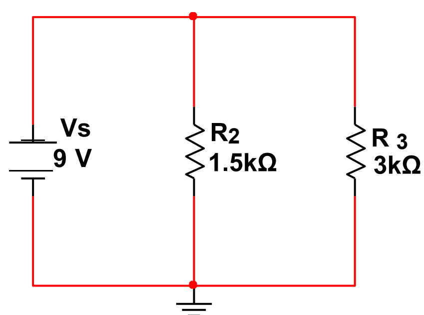


Figure P.2 – DC Parallel Circuit

Figure P.2 shows a DC circuit that has two resistors R_2 and R_3 connected in parallel with a DC Voltage Source.

1. **Analyze** the circuit in **Figure P.2**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **power consumption** of $\mathbf{R_2}$ and $\mathbf{R_3}$ (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 2.1** below.

Part III – DC Series-Parallel Combination Circuit

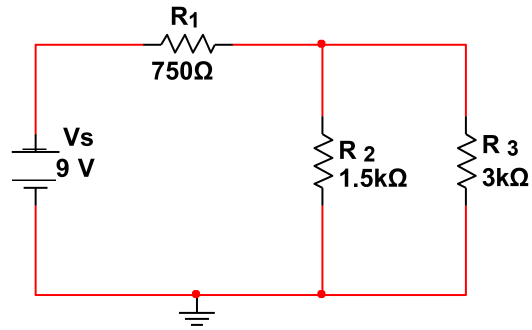


Figure P.3 – DC Series-Parallel Combination Circuit

Many circuits have a combination of series and parallel resistors. **Figure P.3** shows a DC circuit that has two resistors R_2 and R_3 connected in parallel with one another. R_2 and R_3 together are connected in series with resistor R1 and the DC Voltage Source.

1. **Analyze** the circuit in **Figure P.3**.
2. **Calculate** the nominal (expected) values for the **DC voltage**, **DC current**, and **power consumption** of $\mathbf{R_1}$, $\mathbf{R_2}$, and $\mathbf{R_3}$ (be sure to **clearly show all calculations**).
3. **Record** your results in **Table 3.1** below.

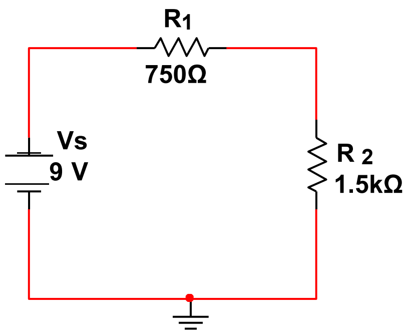
Part IV – How to Measure Voltage and Current

During the lab, you will build the three circuits you have analyzed in the prelab. You will then measure the **voltage across** and the **current through** each resistor to compare these experimental results to your calculated values. In order to make the measurements, it is **essential** that you know how to connect the measurement equipment to the circuits you will build.

1. **Review** the **Introduction** to today's lab and ensure you are familiar with the proper way to measure **voltage across** and **current through** resistors.
   Note: *It is imperative that you understand that you must change the way your DMM is connected to the circuit* ***before*** *switching between measuring voltage and measuring current. If you attempt to measure current across a resistor, you will pull a dangerous amount of current and likely blow the fuse on the DMM. Setting a* ***current limit*** *on the power supply will at least help to prevent blowing the fuse on the DMM.*
2. **Question:** What is the overload protection (maximum current allowed) for your DMM? Look up a specification sheet for your model to find the number. Make sure to include the name of your DMM along with its overload protection value.
3. **Redraw** the circuit in **Figure P.3** showing how you would attach the DMM to measure the current through R_2.

LAB

Part I – DC Series Circuit Measurements



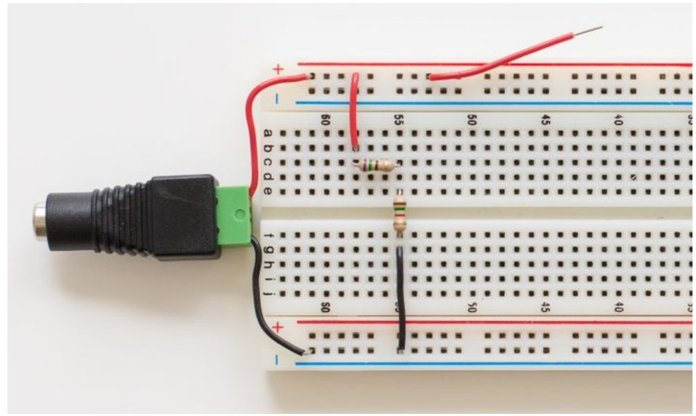


Figure 1.1 – DC Series Circuit

1. Build the DC Series Circuit in Figure 1.1 on your breadboard.
2. Plug in the DC Power Supply and set it to 9V.
3. **Measure** the **voltage across** R_1 and R_2 with the DMM and **record** it in **Table 1.1** using the following procedure (See Figure 1.1c):
    a. **Turn on** your DMM.
    b. Ensure the DMM is set to measure **DC** values and not AC.
    c. **Connect** the DMM to your circuit.
    Note: *Make sure the DMM is connected in **parallel** with the resistor across which you are going to measure the voltage!*
    d. **Record** the voltage in **Table 1.1**.
4. **Measure** the **current through** R_1 and R_2 with the DMM and **record** it in **Table 1.1(**See Figure 1.1d).
    a. **Disconnect** the alligator leads from your circuit before adjusting the DMM.
    b. **Switch** to the **A** on your DMM. You may need to adjust the range (to mA or uA) if needed.
    c. **Break the circuit** at the point you wish to measure current.
    d. **Connect** the DMM in **series** with your circuit as discussed in the **Prelab**.
    e. **Record** the current in **Table 1.1**.
5. Make sure to **turn off** your power supply when you are done taking measurements.
6. **Calculate** the **power consumption** of R_1 and R_2 from the measured DC voltage and DC current of R_1 and R_2 and **record** it in **Table 1.1**.

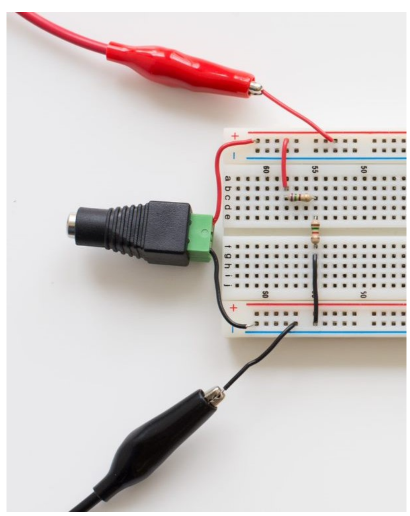


Figure 1.1b – Measuring the +9V

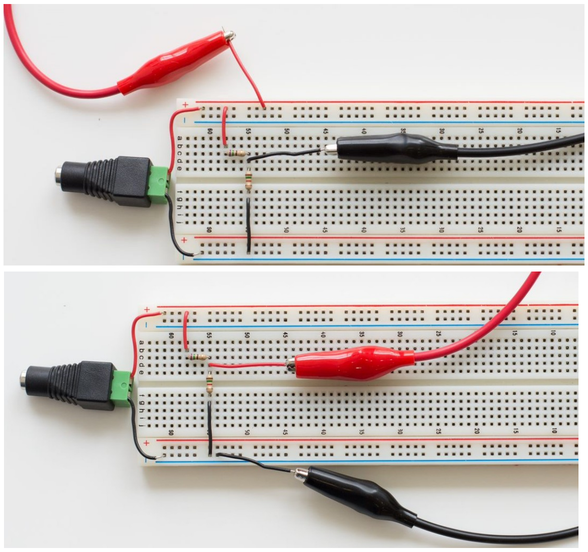


Figure 1.1c - Measuring Voltage Across the Resistors

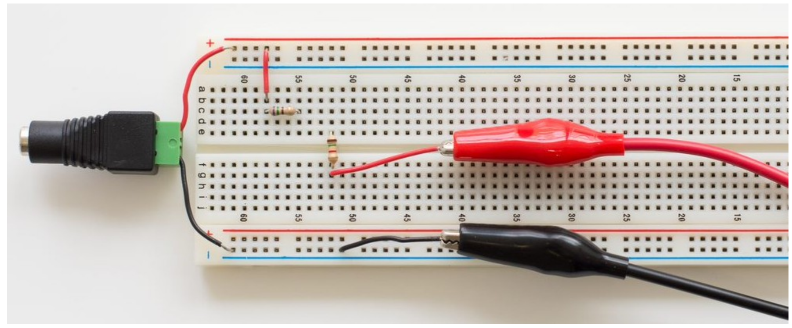


Figure 1.1d - Measuring Current in a Circuit

6. **Multisim Simulation**:
    a. **Simulate** the circuit from **Figure 1.1** in **Multisim**.
    b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.

    Note: *The GTA will give a brief overview of how-to setup the circuit in Multisim and perform the necessary analysis. You should be familiar with Multisim from the introductory labs, so this overview will be short and focused on the simulation itself. The analysis can be found under **Simulate** → **Analyses** → **DC Operating Point**.*

    c. **Record** your simulated results in **Table 1.1**.
7. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 1.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantity		***Resistor***	
		R_1	***R_2***
***Voltage* (V)**	***Calculated***		
	Measured		
	Simulated		
***Current* (mA)**	***Calculated***		
	Measured		
	Simulated		
***Power* (mW)**	***Calculated***		
	Measured		
	Simulated		
***Percent Error* (%)**	***Voltage***		
	Current		
	Power		

Table 1.1 – DC Series Circuit Data

Part II – DC Parallel Circuit Measurements

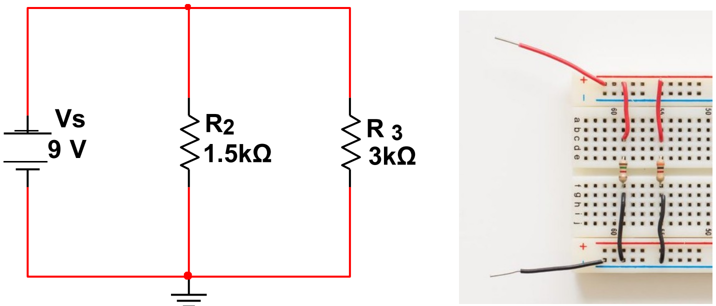


Figure 2.1 – DC Parallel Circuit

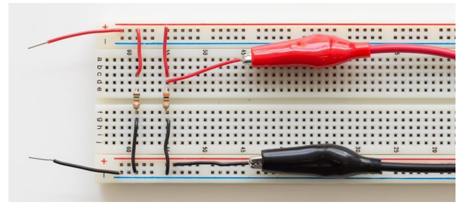


Figure 2.1b – Measuring Voltage

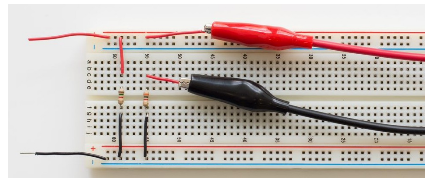


Figure 2.1c – Measuring current in one branch

1. **Build** the **DC Parallel Circuit** in **Figure 2.1** on your breadboard.
2. **Connect your DC Power Supply** to the circuit and set it to 9V.
   Measure the **voltage across** R_2 and R_3 with the DMM and **record** it in **Table 2.1**.
3. **Measure** the **current through** R_2 and R_3 with the DMM and **record** it in **Table 2.1**.
4. **Calculate** the **power consumption** of R_2 and R_3 from the measured DC voltage and DC current of R_2 and R_3 and **record** it in **Table 2.1**.
5. **Turn off** the DC Power Supply once you are done taking measurements.
6. **Multisim Simulation**:
   a. **Build** the circuit from **Figure 2.1** in **Multisim**.
   b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.
   c. **Record** your simulated results in **Table 2.1**.
7. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 2.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantities		***Resistor***	
		R_2	***R_3***
***Voltage* (V)**	***Calculated***		
	Measured		
	Simulated		
***Current* (mA)**	***Calculated***		
	Measured		
	Simulated		
***Power* (mW)**	***Calculated***		
	Measured		
	Simulated		
***Percent Error* (%)**	***Voltage***		
	Current		
	Power		

Table 2.1 – DC Parallel Circuit Data

Part III – DC Series-Parallel Combination Circuit

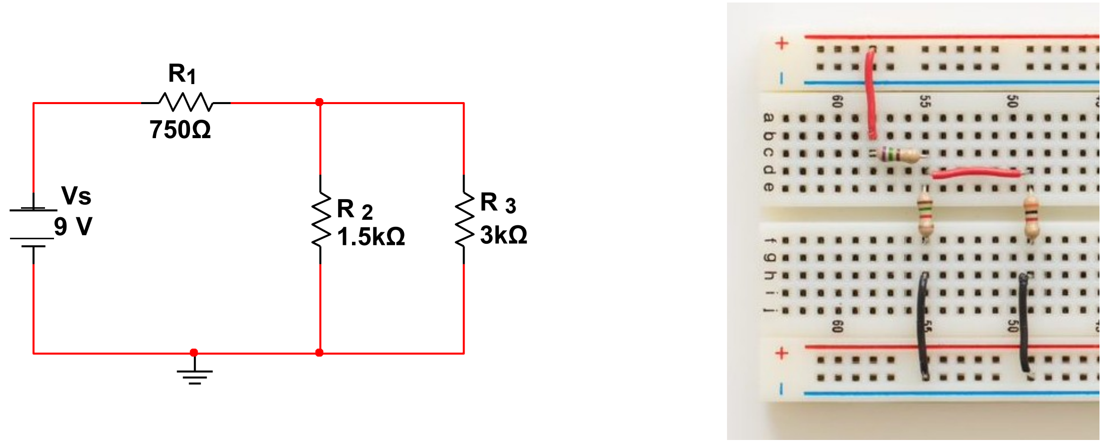


Figure 3.1 – DC Series-Parallel Combination Circuit

1. **Build** the **DC Series-Parallel Circuit** in **Figure 3.1** on your breadboard.
2. **Connect your DC Power Supply** to the circuit and set it to 9V.
3. **Measure** the **voltage across** R_1, R_2, and R_3 with the DMM and **record** it in **Table 3.1**.
4. **Measure** the **current through** R_1, R_2, and R_3 with the DMM and **record** it in **Table 3.1**.
5. **Calculate** the **power consumption** of R_1, R_2, and R_3 from the measured DC voltage and DC current and **record** it in **Table 3.1**.
6. **Turn off** the power supply once you are done taking measurements.
7. **Multisim Simulation**:
   a. **Build** the circuit from **Figure 3.1** in **Multisim**.
   b. **Find** the **simulated voltage**, **current**, and **power consumption** for each resistor by performing a **DC Operating Point Analysis**.
   c. **Record** your simulated results in **Table 3.1**.
8. **Calculate** the **percent error** between your **calculated** and **measured** results and **record** it in **Table 3.1**. Compare and discuss your results in the analysis section of the lab report.

Electrical Quantities		***Resistor***		
		R_1	***R_2***	***R_3***
***Voltage* (V)**	***Calculated***			
	Measured			
	Simulated			
***Current* (mA)**	***Calculated***			
	Measured			
	Simulated			
***Power* (mW)**	***Calculated***			
	Measured			
	Simulated			
***Percent Error* (%)**	***Voltage***			
	Current			
	Power			

Table 3.1 – DC Series-Parallel Combination Circuit Data

POST-LAB ANALYSIS

1. **Analyze** and **interpret** the data collected in **each** of the Data Tables throughout the lab. **Explain** any interesting pieces of data, outliers, or important considerations.
2. **Describe** the relationship between the total voltage and current in the whole circuit and the voltage across and current through every resistor in each part of the lab.
   a. **Part I – DC Series Circuit**
      i. Is the total voltage across R_1 and R_2 equal to the 9V source? Why or why not?
      ii. Are the currents flowing through R_1 and R_2 equal? Why or why not?
   b. **Part II – DC Parallel Circuit**
      i. What is the total current through the whole circuit? What are the currents through R_2 and R_3? What is the relationship between the total current and the currents flowing through each resistor?
      ii. What are voltages across R_2 and R_3? Are they equal? Why or why not?
   c. **Part III – DC Series-Parallel Combination Circuit**
      i. What is the mathematical relationship of the currents through R_1, R_2, and R_3?
      ii. What is the mathematical relationship of the voltages across R_1, R_2, and R_3?
3. **Compare** the **calculated** (nominal) results with the **measured** results in **Table 1.1**, **Table 2.1**, and **Table 3.1**. Be sure to complete the **percent error** section for each table and **analyze** the error. **Explain** any possible reasons for the error.