<u>EET 2035C – Electrical Circuits</u>

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Experiment 2

Series and Parallel Combination Circuits

Performed By:

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Submitted to:

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OBJECTIVE

The purpose of this lab experiment is to build and analyze series and parallel combination circuits for the purpose of observing current, voltage and resistance. These observations will be supported by foundational knowledge of Ohm's Law, KV, and KCL. Experimental measurements will be compared against theoretical and simulation data to ensure proper understanding of each.

LIST OF EQUIPMENT/PARTS/COMPONENTS

- 1 kΩ resistor (**R_1**)
- 330 Ω resistor (**R_2**)
- 470 Ω resistor (**R_3**)
- 560 Ω resistor (**R_4**)
- 1.5 kΩ resistor (**R_5**)
- 1 kΩ resistor (**R_6**)
- 1.5 kΩ resistor (**R_7**)
- 680 Ω resistor (**R_8**)
- 100 Ω resistor (**R_9**)
- DC Power Supply
- Multimeter (DMM)
- Breadboard Trainer

THEORETICAL BACKGROUND

Fundamental Instruments and Values

Much of this section follows information provided in Lab Report 1.

There are many measurements to be taken in this lab, including the resistance of resistors, potential difference, and current through components of a circuit. To measure the voltage across an individual component, a **voltmeter** must be attached to the respective component in parallel. The circuit, however, still functions normally, as the voltmeter has a large resistance value and only allows enough current to make a measurement, as the rest continues through the circuit. Voltage can also be measured regardless of whether there is a current flowing or not [1].

Alternatively, measuring the current through a component in a circuit requires the use of an **ammeter**, attached in series to the respective component. In contrast to a **voltmeter**, an **ammeter** requires current to be flowing through it in order to measure the current. It is important to take precautions to not place an ammeter in parallel to any components in a circuit, as it would receive the entire current of said circuit and blow the fuse of the **ammeter**.

In order to measure resistance of a resistor, an **ohmmeter** is used in either parallel or in series and does not require a current flowing through a component as it creates its own current, and measures using it.

For the purposes of this lab, a **Digital Multimeter**, or a **DMM**, will be used as it can act as all three aforementioned instruments. Alongside the **DMM**, the **Breadboard Trainer** will house the breadboard each of the circuits will be built on, and the power supply will be provided by a **Triple Power Supply**.

The theoretical **Resistance** of a resistor can be found by using the Color Code procedure, through analyzing **table 1** (read from left to right)

Table 1

Band Color	Digit	Multiplier	Tolerance
Black	0	10^0	
Brown	1	10^1	±1%
Red	2	10^2	±2%
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Gray	8	10^8	
White	9	10^9	
No Band			±20%
Silver			±10%
Gold			±5%

Formulas and Laws

There are a few formulas and theories that will assist in calculating various things throughout the lab. **Ohm's Law** is one such law, and states that the voltage through a component is equal to the current through the component multiplied by the resistance of the component [1].

$$V = IR$$

Also, **Kirchhoff's Voltage Law** states that the sum of each voltage drop through a circuit is zero, while the current is equivalent [1].

$$\sum_{k=1}^{n} V_k = 0$$

$$n = number\ of\ components\ in\ loop$$

Kirchhof's Current Law states that the current into a node is equal to the current out of it [1].

$$\sum_{k=1}^{n} I_k = 0$$

$$n = number\ of\ branches\ connected\ to\ a\ node$$

There are a few different methods to finding the **power absorbed** or **delivered** by an element of a circuit. Either the voltage and the current can be multiplied together (1), the current squared can be multiplied by the resistance of the element (2), or the voltage squared divided by the resistance of the element (3).

(1) $P = VI$

(2) $P = I^2R$

(3) $P = \frac{V^2}{R}$

In a **series** circuit, if only the voltage source V_S and all resistor values are known, the voltage of any component can be calculated using the **Voltage Divider** formula, which divides the voltage source by the value of every resistor in the circuit **except** the resistance of the component being measured [1].

$$V_x = V_s(\frac{R_x}{\sum_{k=1}^{n} R_k})$$

$$n = number\ of\ resistors$$

$$x = component\ being\ measured$$

In a **parallel** circuit, if only the total current I_T and all resistor values are known, the current through any component can be calculated using the **Current Divider** formula, which divides the total current by the value of every resistor in the circuit **except** the resistance of the component being measured [1].

$$I_x = I_T(\frac{R_x}{\sum_{k=1}^{n} R_k})$$

$$n = number\ of\ resistors$$

$$x = component\ being\ measured$$

In a **Series-Parallel** circuit, the equivalent resistance method can be used to calculate measurements for all components of the circuit. In this method, the circuit will be broken down to as few components as possible by combining resistors, and working backwards through the circuit following KVL, KCL, and Ohm's Law.

The DMM

The labelled DMM diagram is adopted from the following reference:

Ali Notash, "Current, Voltage and Resistance in Series and Parallel Circuits", in *EET 3081C – Circuit Analysis 1*, Florida: Valencia College, 2018.

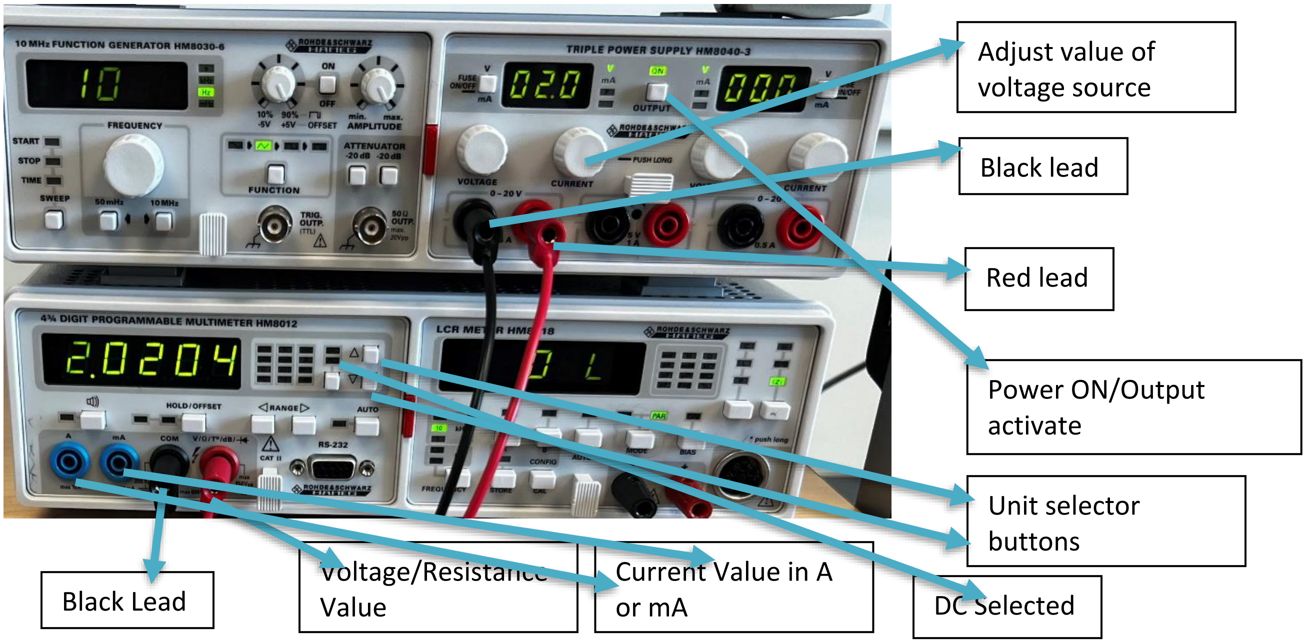

Figure 1

Labelled diagram of the DMM and Power Supply

PROCEDURE / RESULTS / OBSERVATIONS

Procedure is adopted from the following reference:

Prof. Ali Notash, "Current, Voltage, Power, and Resistance in Series and Parallel Circuits," in *Electrical Circuits Laboratory Manual*, 1st Ed. Florida: Valencia College, 2017, pp. 17-21.

Part 1 – Determining the Resistance of a Resistor & Ensuring Within Tolerance

Use the color code procedure to determine nominal values for R_1 through R_9. Record results in **Table 1**.

Measure the actual value for each resistor using the DMM, and record in **Table 2**. The resistors will plug into the DMM in the COM/Ω terminals and the DMM should be set to ohms.

Table 2

Resistor, R (Ω)	**$R_{1\&6}$**	**R_2**	**R_3**	**R_4**	**$R_{5\&7}$**	**R_8**	**R_9**	**R_T**
Nominal Value (Ω)	1000	330	470	560	1500	680	100	7140
Measured Value (Ω)	996.2	329.3	469.6	554.7	1.497k	672.0	98.9	7110.9

The following is an example of how the resistance of each resistor can be measured using the **DMM**:

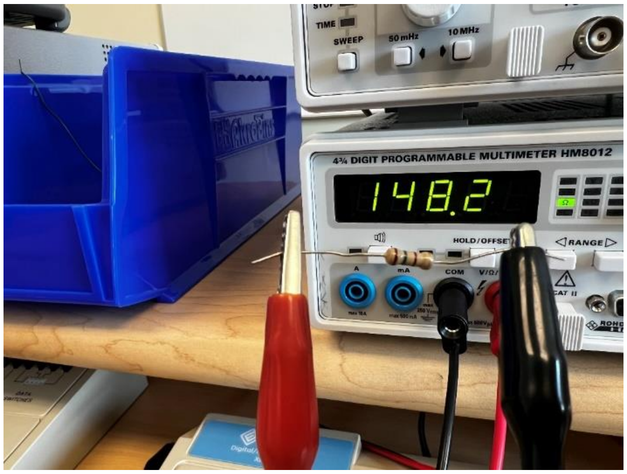

Figure 2

Depicting an example of how the resistance is taken on the DMM

Build the circuit found in **Fig. 3** on the breadboard.

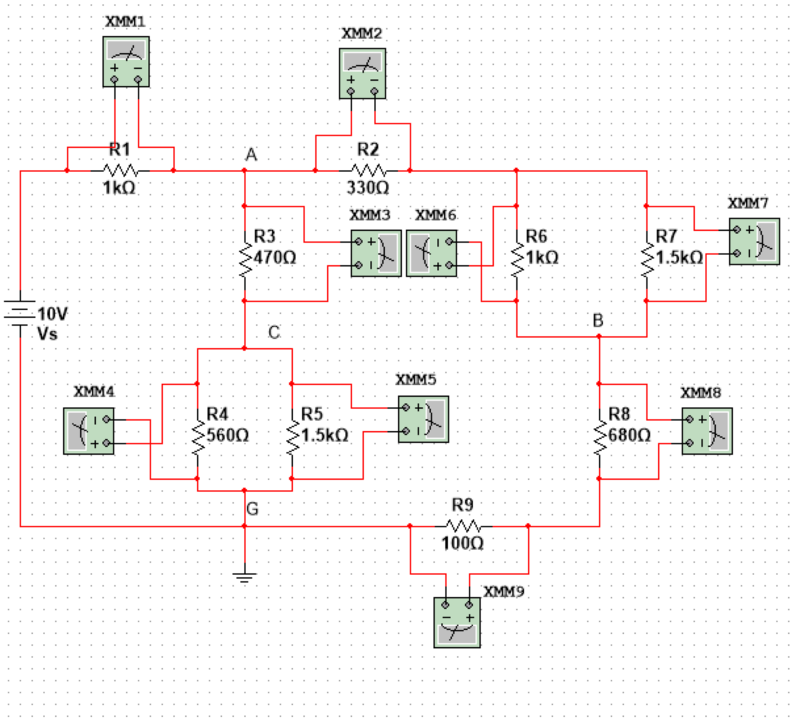

Figure 3

Multisim construction of circuit required for lab

Now, measure the voltage across R_1 through R_9, and record the results in **Table 3**.

Table 3

Resistor	Voltage (V)		
	Theory	Simulation	Measured
R_1	6.32	6.329	6.341
R_2	710m	708.44m	712m
R_3	1.97	1.966	1.974
R_4	1.709	1.705	1.702
R_5	1.709	1.705	1.704
R_6	1.29	1.288	1.298
R_7	1.29	1.288	1.298
R_8	1.46	1.46	1.454
R_9	0.215	214.679m	213.6m

The theory and simulation data for the above table is shown below.

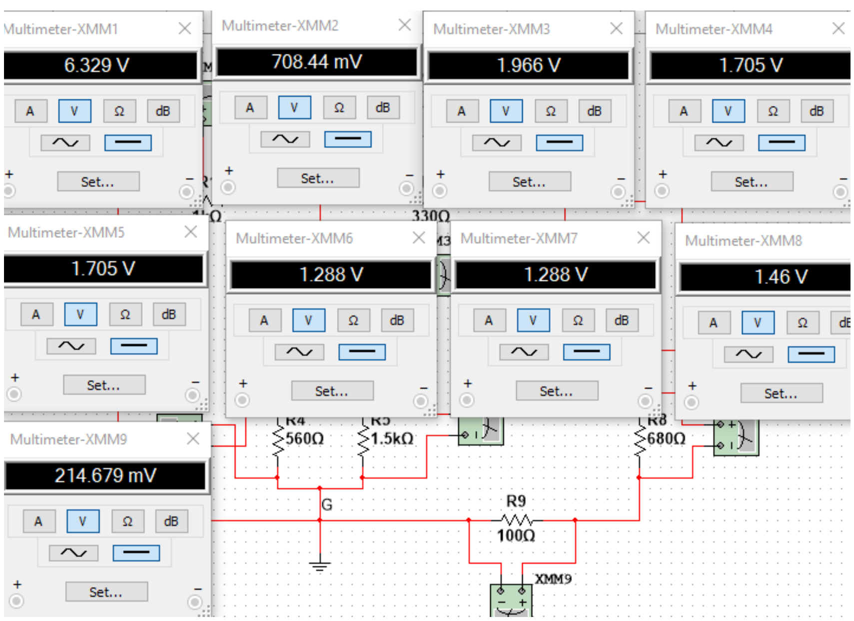

Figure 4

Depicting the multimeter values for voltages across R_1 through R_9

$$R1 = \frac{10}{1580.0309} = 6.32mA => 0.00632 * 1000 = 6.32V$$
$$Vs - VR1 = 3.68V$$
$$R(2(6||7)89) = \frac{3.68}{1710} = 2.15mA$$
$$R(3(4||5)) = \frac{3.68}{877.77} = 4.19mA$$
$$R2 = 0.00215 * 330 = 0.710V$$
$$R8 = 0.00215 * 680 = 1.463V$$
$$R2 = 0.00215 * 100 = 0.215V$$
$$R6 = 600 * 0.00215 = 1.2912 = R7$$
$$R4 = 0.00305 * 560 = 1.7095V = R5$$

Next, measure the voltage at points A, B, and C with respect to Ground and record the results in **Table 4**.

Table 4

Resistor	**Voltage (V)**		
	Theory	**Simulation**	**Measured**
V_A	3.671	3.671	3.68
V_B	1.672	1.674	1.6703
V_C	1.71	1.705	1.703
V_{AB}	1.99	1.997	2.009
V_{AC}	1.96	1.996	1.975
V_{BC}	-30.87m	-30.87m	-34.5m
V_{CB}	30.87m	30.87m	34.5m

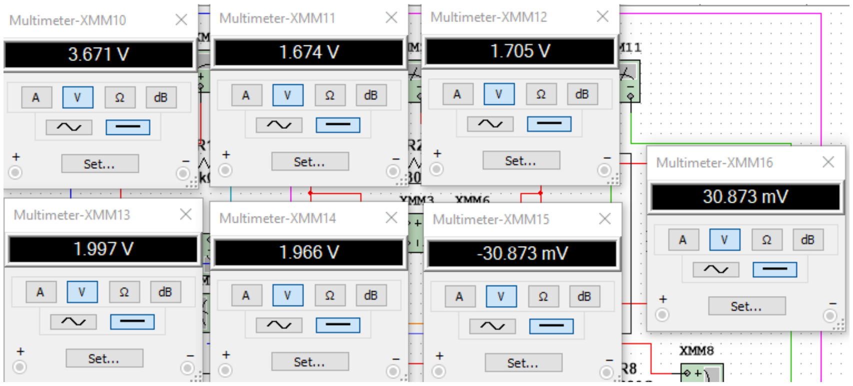

Figure 5

Multisim measurement of voltage at points A, B, and C with respect to Ground

$$VA = 10V\left(\frac{580.03}{1000 + 580.03}\right) = 3.671$$

$$VB = VA - VR2 + VR6 = 3.67 - 1.99 = 1.672V$$

$$VC = VR4 = VR5 = 1.71V$$

$$VAB = VA - VB = 1.99$$

$$VAC = VA - VC = 1.96$$

$$VBC = VB - VC = \ -30.87m$$

$$VCB = VC - VB = 30.87m$$

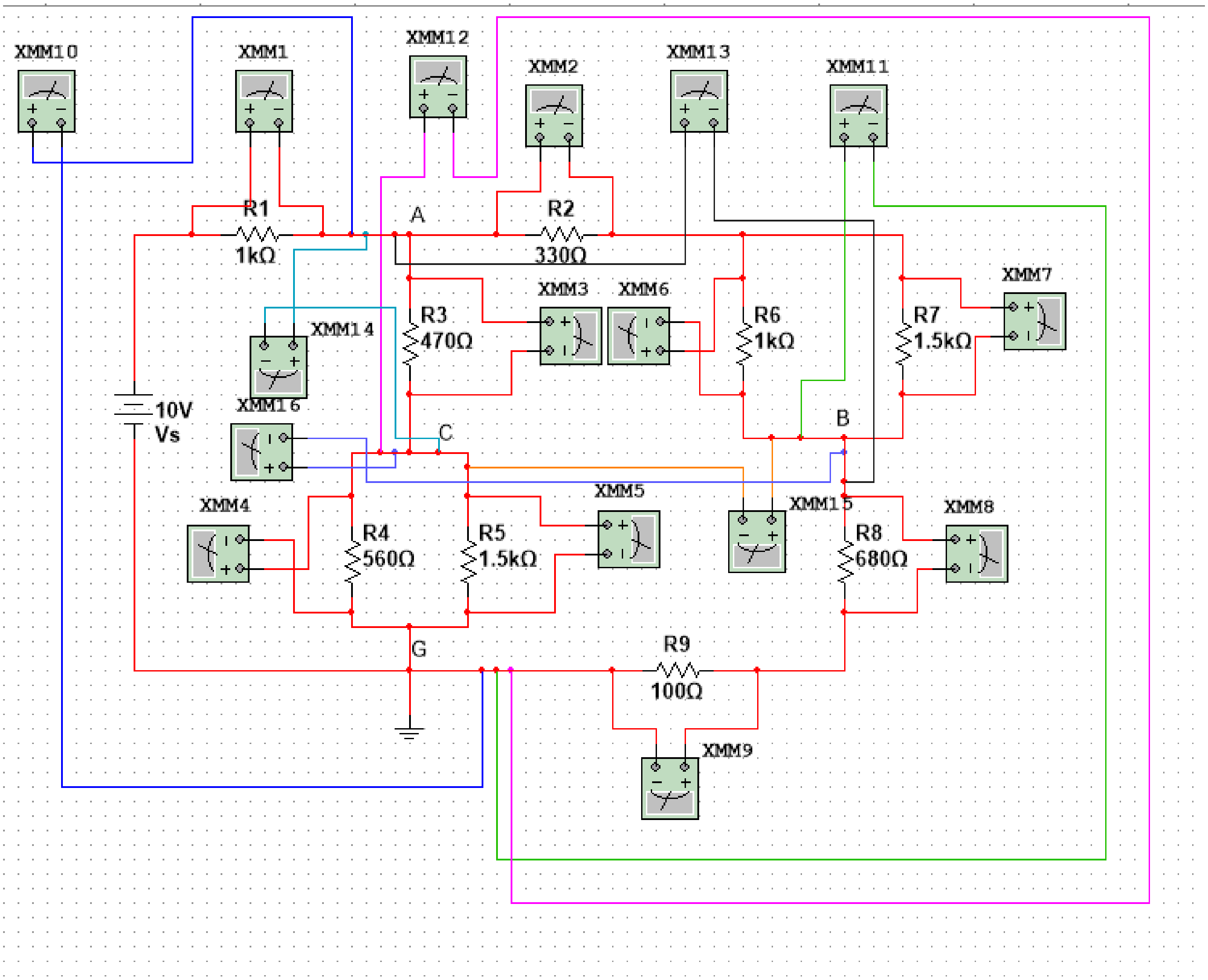

Figure 6

Depicting aforementioned Multisim circuit with added multimeters

Now, measure the current across R_1 through R_9 and record results in **Table 4**.

Table 5

Resistor	Current (mA)		
	Theory	Simulation	Measured
R_1	6.329	6.329	6.329
R_2	2.147	2.147	2.154
R_3	4.182	4.182	5.33
R_4	3.045	3.045	3.043
R_5	1.137	1.137	1.132
R_6	1.29	1.288	1.292
R_7	858u	858.712u	823.3u
R_8 & R_9	2.148	2.147	2.153

The theory and simulation data for the above table is shown below in **figure 7**.

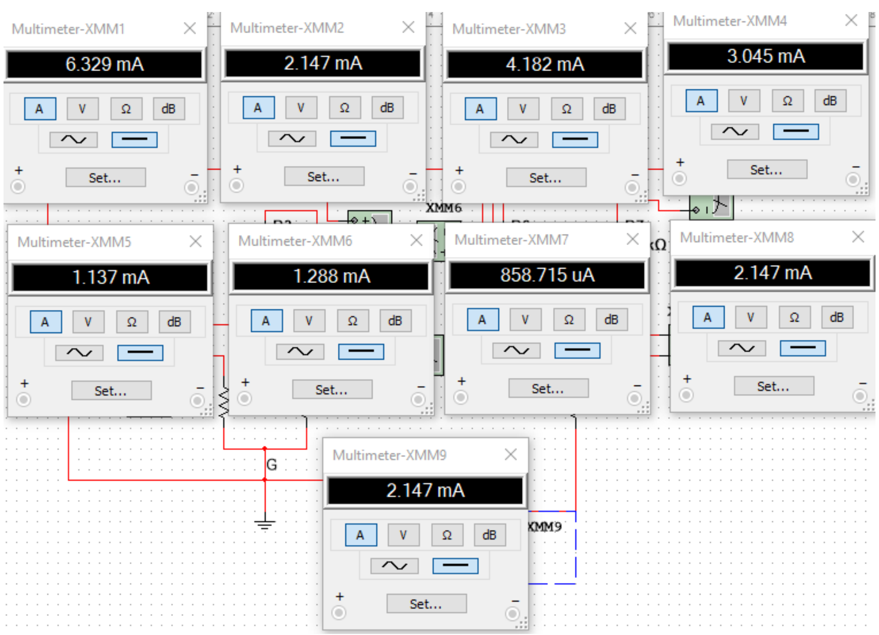

Figure 7

Multisim measurement of current across R_1 through R_3

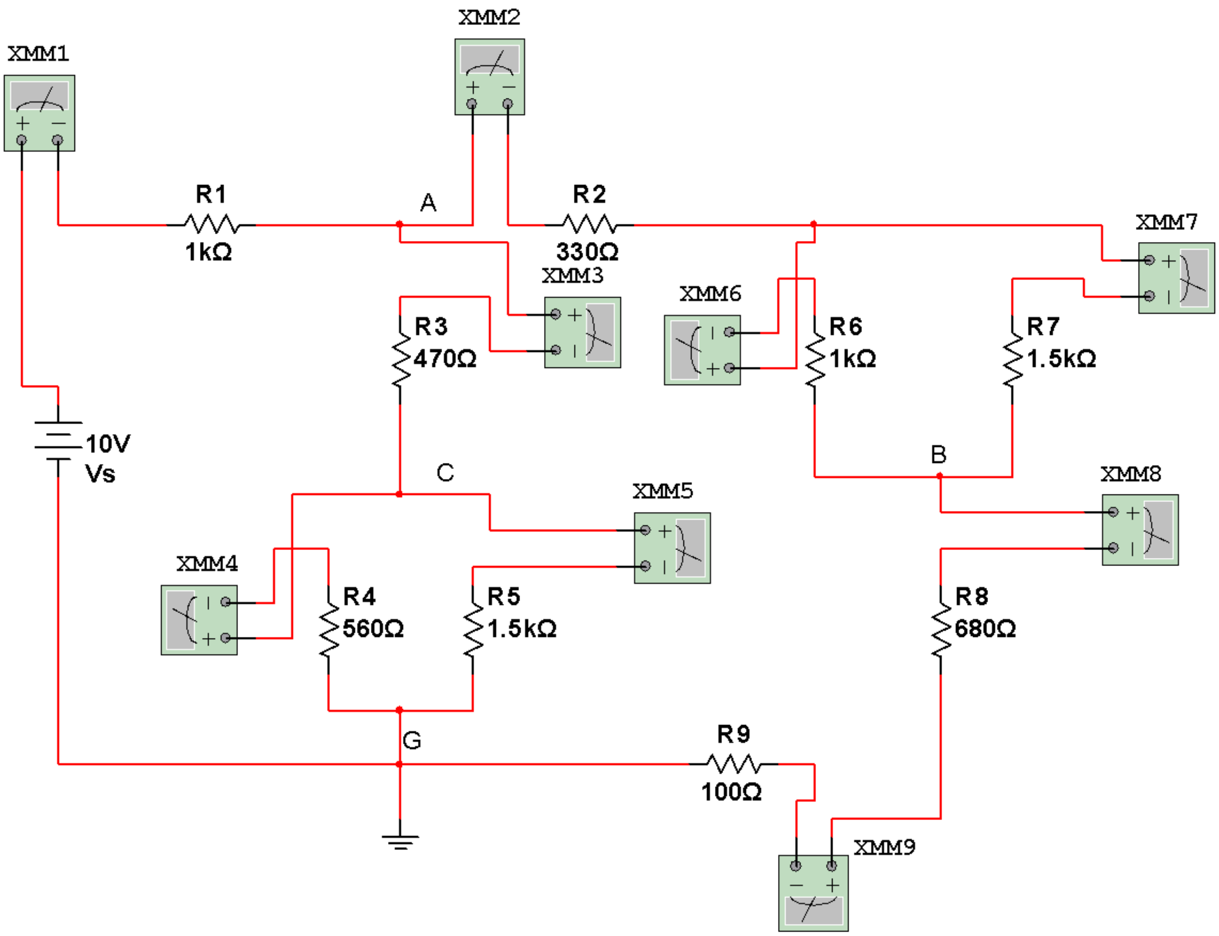

Figure 8

Multisim circuit depicting current across R_1 through R_9

Figure 9 depicts the constructed circuit, with power coming from the **DC Power Supply**

$$R1 = \frac{10}{1580.0309} = 6.32mA$$
$$R2, R8, R9 => Vs - VR1 = 3.68$$
$$= \frac{3.68}{1710} = 2.15mA$$
$$R3 = \frac{3.68}{877.77} = 4.19mA$$
$$R4 = 407.77 * 0.00419 = 1.7095$$
$$= \frac{1.7095}{560} = 3.05mA$$
$$R5 = \frac{1.7095}{1500} = 1.139mA$$
$$R6 = 600 * 0.00215 = 1.2912 => \frac{1.2912}{1000} = 1.29mA$$
$$R7 = \frac{1.7095}{1500} = 860.8uA$$

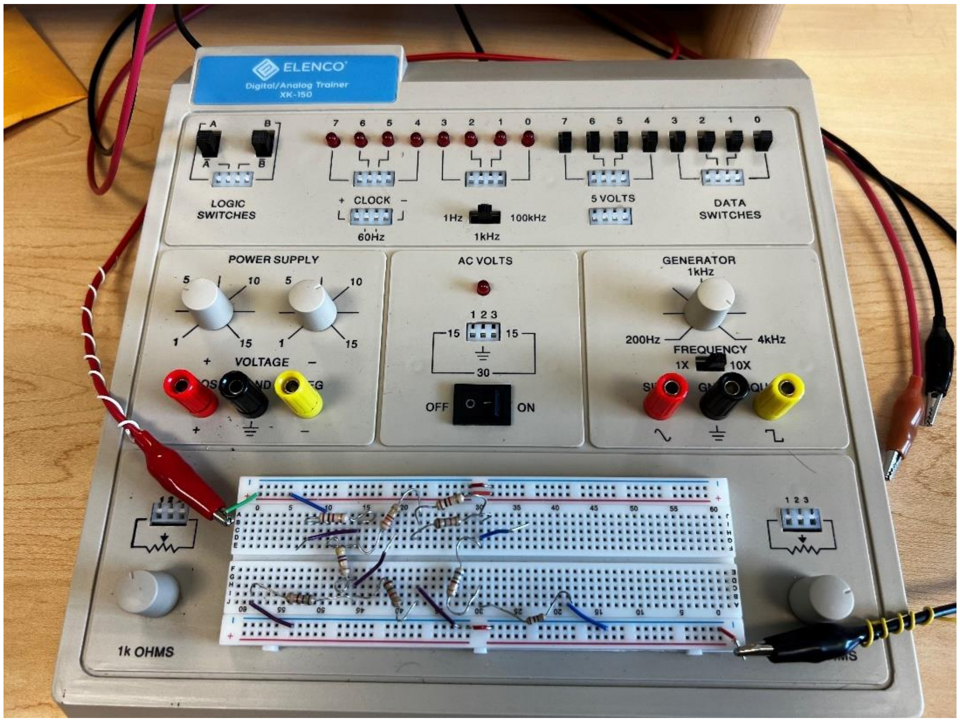

Figure 9

Aforementioned Multisim circuit constructed on breadboard

Open the $\mathbf{R_4}$ resistor and measure total potential difference through the circuit, then do the same to $\mathbf{R_5}$ and record results in **Table 5**.

Table 6

Without Resistor	Total Voltage R_1 (V)		
	Theory	Simulation	Measured
R_4	5.22	5.22	5.221
R_5	6.087	6.087	6.07

The theory and simulation data for the above table is found below.

$$No\ R4 = \frac{1}{\frac{1}{1970}+\frac{1}{1710}} = 915.407 = \frac{10v}{1915.407} = 5.22mA * 1000 = 5.22V$$

$$No\ R5\ \frac{1}{\frac{1}{1030}+\frac{1}{1710}} = 642.81 = \frac{10v}{642.81} = 6.09mA * 1000 = 6.087V$$

The answers here are different, as one of the two parallel branches (once the circuit has been broken down to three resistor equivalent values) changes from 1970 Ω to 1030 Ω.

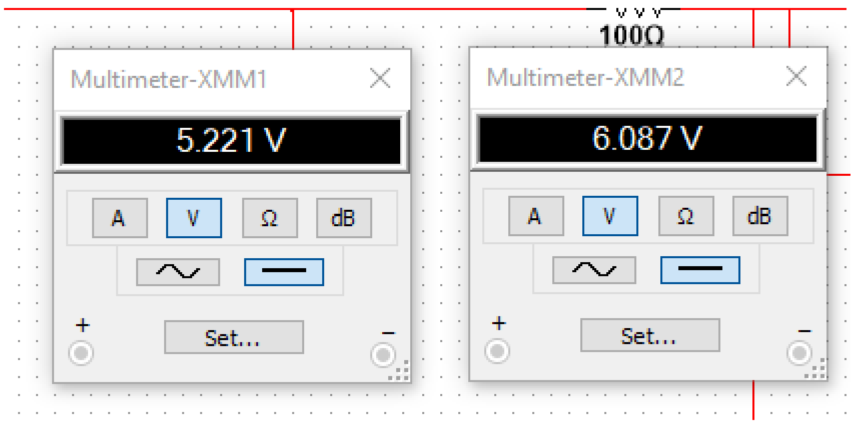

Figure 10

Multimeter voltage values for circuit without R_4 and R_5 respectively

We can see that the total potential difference through the circuit does change depending on the resistor remaining on the circuit. This is due to the total resistance of the circuit either increasing or decreasing.

Finally, find the total resistance of the circuit with the **power off**. Record results in **Table 6**.

Table 7

Total Resistance, R_T (Ω)		
Theory	**Simulation**	**Measured**
1580.02	1580.00	1574.00

The theory and simulation data for the above table can be found in **figure 11**.

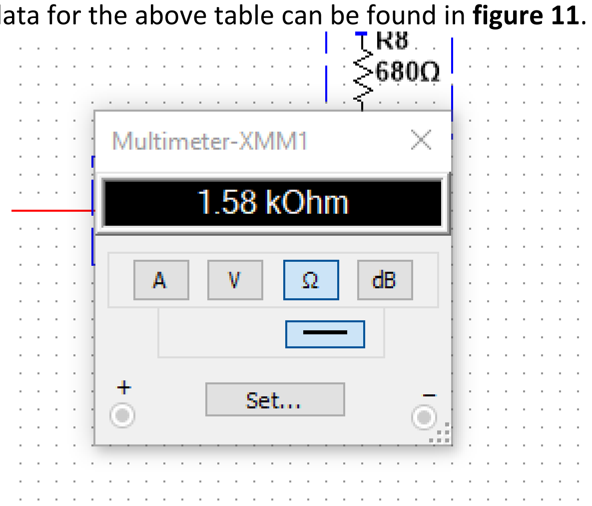

Figure 11

Multisim measurement for total resistance of the given circuit

$$R1 + (R3 + R4||R5) \ || \ (R2 + (R6||R7) + R8 + R9)$$

$$1000 + \left(470 + \left(\frac{1}{560} + \frac{1}{1500}\right)\right) \ || \ \left(330 + \left(\frac{1}{1000} + \frac{1}{1500}\right) + 680 + 100\right)$$

$$1000 + \left(\frac{1}{877.76} + \frac{1}{1709.99}\right) = 1580.02$$

Next, calculate the percent error for the measured **voltages** and **currents** obtained in all parts of the lab, using the following formula.

$$\%\ Error = \frac{Experimental - Theoretical}{Theoretical} * 100\%$$

Voltages across $\mathbf{R_1}$ through $\mathbf{R_9}$ (%):

$\mathbf{R_1}$	0.332278
$\mathbf{R_2}$	0.28169
$\mathbf{R_3}$	0.203046
$\mathbf{R_4}$	0.409596
$\mathbf{R_5}$	0.292569
$\mathbf{R_6}$	0.620155
$\mathbf{R_7}$	0.620155
$\mathbf{R_8}$	0.410959
$\mathbf{R_9}$	0.651163

Voltage at **A**, **B**, and **C** with respect to **Ground** (%):

$\mathbf{V_A}$	0.245165
$\mathbf{V_B}$	0.101675
$\mathbf{V_C}$	0.409357
$\mathbf{V_{AB}}$	0.954774
$\mathbf{V_{AC}}$	0.765306
$\mathbf{V_{BC}}$	11.75899
$\mathbf{V_{CB}}$	11.75899

Currents across $\mathbf{R_1}$ through $\mathbf{R_9}$ (%):

$\mathbf{R_1}$	0
$\mathbf{R_2}$	0.326036
$\mathbf{R_3}$	27.45098
$\mathbf{R_4}$	0.065681
$\mathbf{R_5}$	0.439754
$\mathbf{R_6}$	0.155039

R_7	4.044289
R_8 & R_9	0.232775

Current without R_4 and R_5 (%):

R_4	0.019157
R_5	0.279284

Total Resistance (%):

R_T	0.381008

Now, calculate the power delivered or absorbed by all circuit elements

Use the formula P = VI where P is watts, V is volts and I is amperes for any given component of the circuit.

Table 8

Resistor	Current (mA)	Voltage (V)	Power (W)	Power (mW)
R_1	6.329	6.341	0.04013219	40.13219
R_2	2.154	0.712	0.00153365	1.533648
R_3	5.33	1.974	0.01052142	10.52142
R_4	3.043	1.702	0.00517919	5.179186
R_5	1.132	1.704	0.00192893	1.928928
R_6	1.292	1.298	0.00167702	1.677016
R_7	0.8233	1.298	0.00106864	1.068643
R_8	2.153	1.454	0.00313046	3.130462
R9	2.148	0.2136	0.00045881	0.458813
Vs	-6.32	-10	0.0632	63.2

From the power calculations, the **Law of Conservation of Power** is evident, as the power nearly sums to zero for each circuit with marginal % error.

There is also % error between the theoretical calculations and measured values throughout the lab, which is likely due to differing tolerances from resistors practically, as well as potential human measuring error.

DISCUSSION

There are a couple of key details to ensure understanding of following this lab, such as KCL, KVL, and Ohm's law. Additionally, ensuring proper practices when conducting bench work, such as connecting voltmeters in parallel and ammeters in series, help to ensure accurate measurements and safe testing conditions. The theoretical results obtained in the lab largely matched the practical and simulation measurements, and the percent error calculations allow for understanding that in the real world, there are various factors that contribute to differing values (i.e. resistance tolerance values).

Using formulas such as the current or voltage divider can cut down immensely on necessary calculations for finding theory based data, however most theoretical measurements can be found by breaking down a series parallel circuit using the resistance equivalence method.

CONCLUSION

Part 1 of this report, allows for certification of resistance values, as well as the creation of a series-parallel circuit. Measurements of the voltage across each resistor, at each node, as well as the currents of these components are calculated and taken. It can hereafter be concluded through such measurements that Ohm's Law, KVL, and KCL are in effect.

In part 2 of the lab, certain resistors are removed from the circuit to observe its effect on the change in potential difference across the circuit. Here, it is clear that removing resistors from a circuit will increase the total potential difference. In this specific example, removing the 560 Ω resistor causes a lower increase in potential difference than removing the 1500 Ω resistor.

From part 3, power measurements were taken from each of the components of the lab, which allowed for the certification of the Law of Conservation of Power. Also, percent error was calculated for all measured/theoretical pieces of data. Through these findings it is evident that calculations and measurements were made properly, and that any error is likely do to realistic tolerance differences between digital resistors and physical resistors.

REFERENCES

[1] W. H. Hayt, J. E. Kemmerly, J. D. Phillips, and S. M. Durbin, *Engineering Circuit Analysis*, 9th ed. New York, NY: McGraw Hill, LLC, 2019.