Electrical Engineering
Lab 1 Report

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1 Objective

The aim of this experiment was to become proficient in using multimeters to measure voltage and current, as well as employing a potentiometer to determine internal resistance in various circuits. We investigated the relationships between electrical quantities and assessed measurement errors by comparing experimental data with theoretical values. In addition, we examine how different multimeters affect voltage and current measurements.

2 Theory

2.1 Ohm's Law

Ohm's law defines the relationship between voltage (V), current (I), and resistance (R) in a circuit:

$$V = I \times R$$

2.2 Experiment 1-Voltage Divider Formula

For two resistors R_1 and R_2 connected in series, the voltage divider formula is given by:

$$V_{\text{out}} = V_{\text{in}} \cdot \frac{R_2}{R_1 + R_2}$$

where:

- V_{in} is the total input voltage in the series resistors.
- R_1 and R_2 are the resistors in the voltage divider.
- V_{out} is the voltage across resistor R_2.

This formula is widely used in circuits to scale voltages and is essential in the design of analog circuits.

2.3 Experiment 2 - Current Divider Formula

For two resistors R_1 and R_2 connected in parallel, the current divider formula is expressed as:

$$I_1 = I_{\text{in}} \cdot \frac{R_2}{R_1 + R_2}$$

$$I_2 = I_{\text{in}} \cdot \frac{R_1}{R_1 + R_2}$$

where:

- I_{in} is the total current entering the parallel resistors.
- R_1 and R_2 are the resistances of the parallel resistors.
- I_1 and I_2 are the currents through the resistors R_1 and R_2, respectively.

2.4 Experiment 3 - Thevenin's Theorem

Thevenin's Theorem is a technique used to simplify complex linear electrical circuits. It states that any linear circuit containing voltage sources, current sources, and resistors can be reduced to an equivalent Thevenin circuit, which consists of:

1. A Thevenin Voltage Source (V_{th}) - an equivalent voltage source that represents the voltage that would be measured across the terminals of the circuit when no load is connected.

2. A Thevenin Resistance (R_{th}) — the equivalent resistance seen from the terminals when all independent voltage and current sources are deactivated (voltage sources become short circuits, and current sources become open circuits).

The Thevenin resistance R_{th} is the equivalent resistance observed from the terminals of the circuit after deactivating all sources.

2.5 Error, Relative Error, and Correction

- **Error**: $E = x_m - x_t$ where:
  - x_m: measured value
  - x_t: true value of the measurand
- **Relative error**:
$$e = \frac{E}{x_t} = \frac{x_m - x_t}{x_t}$$
- **Correction**:
$$C = -E = \frac{x_m}{x_t} - 1$$
- **Measurement of the output voltage** U_m (no-load voltage) of a linear (non-ideal) source:
$$U_m = \frac{R_{\text{IM}}}{R_{\text{IM}} + R_i} \cdot U_0$$
  where:
  - U_m: measured (indicated) value
  - U_0: true value (ideal VM, $R_{\text{VM}} = \infty$)
- **Relative error**:
$$e = \frac{E}{U_0} = \frac{-1}{1 + \frac{R_{\text{IM}}}{R_i}}$$
- For digital instruments: The error consists of the percentage of the reading plus uncertainty due to digital resolution, e.g., $\pm(0.1)$, where:
  - `rdg` = reading
  - `D` = digit = least significant digit of the reading

3 Materials and Equipment

- Digital Multimeter (Metrawatt 15S & Metrahit TRMS)
- Potentiometer
- Ideal Voltage Source
- Adjustable Voltage Source
- Resistors for Voltage Divider and Load Resistors (330 , 470 , 680 , 1 k, 2.2 k, 4.7 k, 10 k)
- Red and Black Connecting Wires
- Connecting Pins
- Electrical Circuit Board

4 Important Techniques for Using Instruments

- The multimeter should always be connected in parallel to the circuit when measuring voltage and in series when measuring current.

- The black wire should always be connected to the ground, and the red wire should be connected to the `mAVΩ` port.
  changing the settings between voltage and current modes, ensure that the probes are disconnected from the multimeter.

- Never connect an ohmmeter to a live circuit.

- Do not leave the multimeter in resistance mode when storing it.

5 Preparatory Work

- The circuits were first simulated using LTspice simulation software.
- The values to be measured in the lab were calculated beforehand by running LTspice simulations. This helped in identifying any errors made during the lab.
- Data tables were created in advance to streamline the experimental process.
- The procedure was carefully read and understood before beginning the experiment.

6 Experiment 1: Voltage Measurement

6.1 Experiment 1.1: Voltage Drop and No-Load Voltage

In this experiment, we measured voltage values using two different multimeters: the Metrahit 15S and the Metrahit TRMS.

First, we measured the open-circuit voltage across the terminals a and b using both multimeters. To obtain an open circuit, we disconnect the circuit from the potentiometer, leaving the voltage source V_1 as shown in the diagram below. We then measured the voltage across the terminals a and b (the open-circuit voltage) by adjusting the multimeter settings to measure the voltage.

Next, the probes were connected to the potentiometer, and we measured the voltage drop across terminals a and b using different instruments. The resistance was set to 10.1 k. All measurements are recorded in the table below.

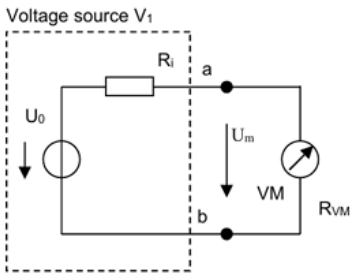


Diagram 1.1 Circuit set-up with an unknown voltage source in direct connection with the voltage meter

Multimeter Model	**Metrahit 15S**	**Uncertainty**	**Metrahit TRMS**	**Uncertainty**
Measured value	3.041V	± 0.060V	3.042V	± 0.060V

Table 1.1.1 No-load Voltage

Figure 1: Circuit diagram for current measurement.

Uncertainty: Metrahit 15S

The percentage error for the Metrahit 15S is calculated as:

$$\text{Percentage error} = 3.041 \times 0.01 = 0.03041\,\text{V}$$

This multimeter displays 3 decimal places. Therefore, the error due to the counts is:

$$\text{Error due to counts} = 3 \times 0.01\,\text{V} = 0.03\,\text{V}$$

Thus, the total uncertainty is:

$$\text{Total uncertainty} = 0.03041\,\text{V} + 0.03\,\text{V} = \pm 0.060\,\text{V}$$

Uncertainty: Metrahit TRMS

The percentage error for the Metrahit TRMS is calculated as:

$$\text{Percentage error} = 3.042 \times 0.01 = 0.03042\,\text{V}$$

This multimeter also displays 3 decimal places. Therefore, the error due to the counts is:

$$\text{Error due to counts} = 3 \times 0.01\,\text{V} = 0.03\,\text{V}$$

Thus, the total uncertainty for the Metrahit TRMS is:

$$\text{Total uncertainty} = 0.03042\,\text{V} + 0.03\,\text{V} = \pm 0.060\,\text{V}$$

Instrument	Resistance (Ω)	Voltage Drop (V)
Metrahit 15s	10.1k	3.011
Metrahit TRMS	10.1k	3.012

Table 1.1.2 Voltage Drop

6.2 Experiment 1.2: Internal Resistance R_i

In the next part of the experiment, we determined the internal resistance of the unknown source by applying the half-deflection method. We loaded the source with a power potentiometer R_p until the Metrawatt voltmeter 15S indicated half of the original (no-load) value. The values are clearly depicted in the table below. There was a small difference in the open circuit voltage measurement when we measured it for the second time using the Metrahit TRMS.

Afterward, we measured R_p with another multimeter and entered the values into a table.

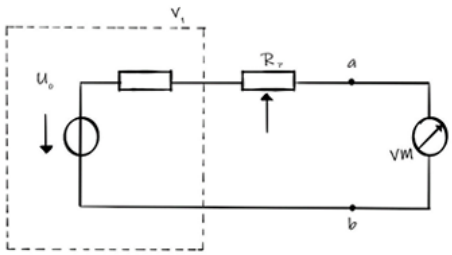


Diagram 1.2 Circuit set-up with an unknown voltage source connected to a power potentiometer and a voltage meter

Metrahit 15s: Open circuit voltage = 3.041V

Metrahit TRMS: Open circuit voltage = 3.038V

–

Instrument	Resistance (Rp) (Ω)	½ Open Circuit Voltage Calculated	Measured	Accuracy
Metrahit 15s	(9*10) +(10*1) + (10* 0.1) = **101**	1.5205	1.514	99.57%
Metrahit TRMS	(9*10) + (10*1) +(10*0.1) = **101**	1.519	1.514	99.67%

Table 1.2 Measured values using Metrahit 15s & Metrahit TRMS voltage meter

6.3 Experiment 1.3: Voltage Divider

In this part of the experiment, we used the digital voltmeter TRMS because it provided more precise voltage measurements. We connected terminals A and B to a fixed voltage of +5.0 V. Next, we measured the voltage drop across different terminals, as detailed below.

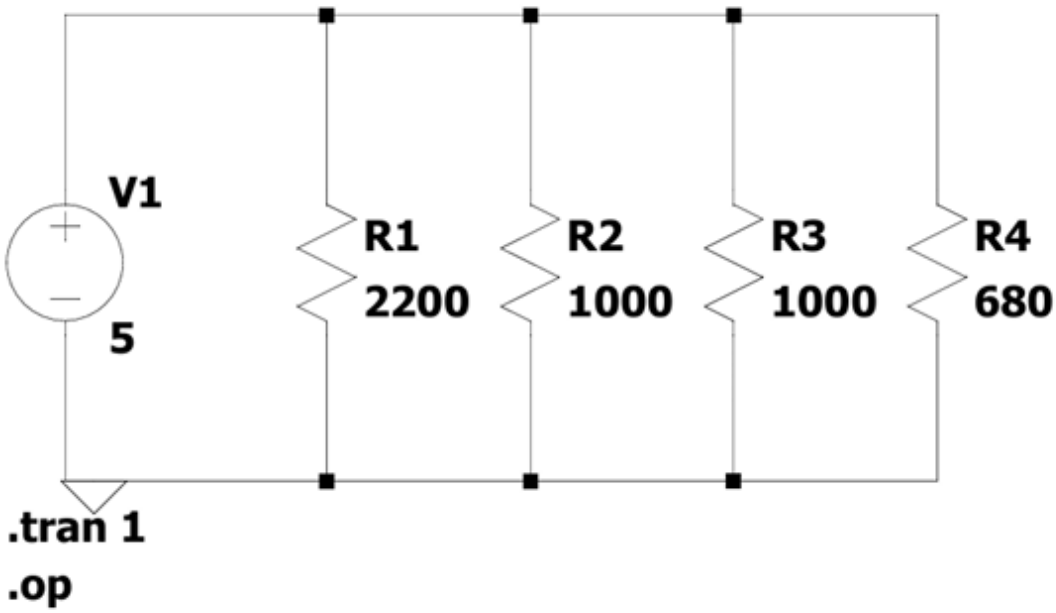
measure voltages in the expected range of 0 to 5.5 V

	C1-C2	C2-C3	C3-C4	C4-C5	C5-C6
Calculated	2.2V	1.0V	1.0V	0.47V	0.33V
Measured	2.200V	0.998V	0.996V	0.476V	0.327V
Relative error	0	-0.002	-0.004	0.0128	-0.0091
	C1-C3	C2-C4	C3-C5	C4-C6	
Calculated	3.2V	2.0V	1.47V	0.8V	
Measured	3.20V	1.996V	1.474V	0.801V	
Relative error	0	-0.002	0.0027	0.0013	
	C1-C4	C2-C5	C3-C6		
Calculated	4.2V	2.47V	1.8V		
Measured	4.19V	2.469V	1.801V		
Relative error	-0.0024	-0.0004	0.0006		
	C1-C5	C2-C6			
Calculated	4.67V	2.8V			
Measured	4.67V	2.799V			
Relative error	0	-0.0004			

Table 1.3 Measured and Calculated values across given points

7 Experiment 2: Current Measurement

In this experiment, we connected a 5.0 V voltage source to terminals A and B. The multimeter was then inserted in series between terminals A1 and A2 to measure the current. This measurement was repeated for each subsequent pair of terminals, such as C1-C2, and so on. Finally, the measured results were compared with the predicted values, and the relative error for each measurement was calculated.



Terminal Point	Calculated (mA)	Measured (mA)	Relative Error
A1-A2	19.6257	19.60	0.0257
C1-C2	2.27273	2.277	0.0043
D1-D2	5.0	5.017	0.0170
E1-E2	5.0	5.015	0.0150
F1-F2	7.35294	7.364	0.0111

Table 2 Measured and calculated values of currents in between given terminal points with its relative error

8 Experiment 3: No-Load Voltage and Internal Resistance

In this experiment, a variable voltage source was set to 8V to generate U_1. The 5V output of the voltage source was used to generate U_2. The circuit was assembled on the electrical board, as shown below, using resistors, wires, and connecting pins.

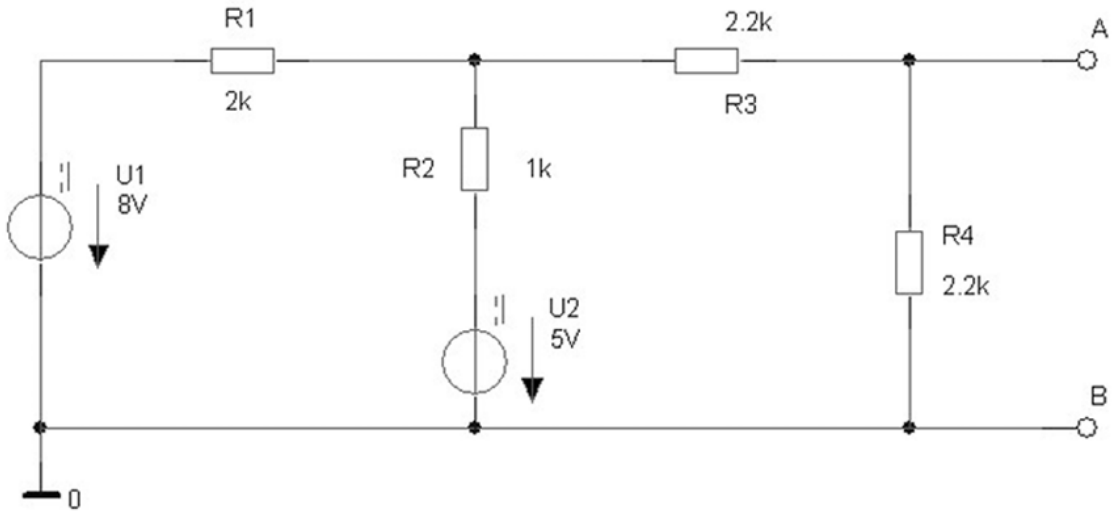


Diagram 3 Circuit board with 2 voltage sources

8.1 Experiment 3.1: Open Circuit Voltage

In this part of the experiment, we measured the open circuit voltage $U_0 = U_{AB}$ and determined the internal resistance R_i using the half-deflection method. The data collected in the lab is provided below.

- Measured open circuit voltage: 2.611 V
- Calculated open circuit voltage: 2.60526 V

To find the internal resistance R_i using the half-deflection method, we calculated half of the open circuit voltage as follows:

$$\frac{1}{2} \times 2.611 = 1.3055\,\text{V}$$

Next, the potentiometer knobs were adjusted until the voltage on the multimeter displayed the calculated half of the open circuit voltage, which allowed us to determine the internal resistance.

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8.2 Internal Resistance Calculation

The internal resistance R_i is calculated as follows:

$$R_i = 1 \times 1000 + 2 \times 100 + 3 \times 10 + 5 \times 1 + 10 \times 0.1 = 1236\,\Omega$$

8.3 Experiment 3.2: Proving the Equivalence of a Linear Voltage Source

In this part of the experiment, a load resistor was connected to the terminals A and B of the circuit as shown in the figure above. We measured the current and voltage values for the following load resistances:

- $R_{L1} = 470\,\Omega$
- $R_{L2} = 4.7\,\mathrm{k}\Omega$
- $R_{L3} = 10\,\mathrm{k}\Omega$

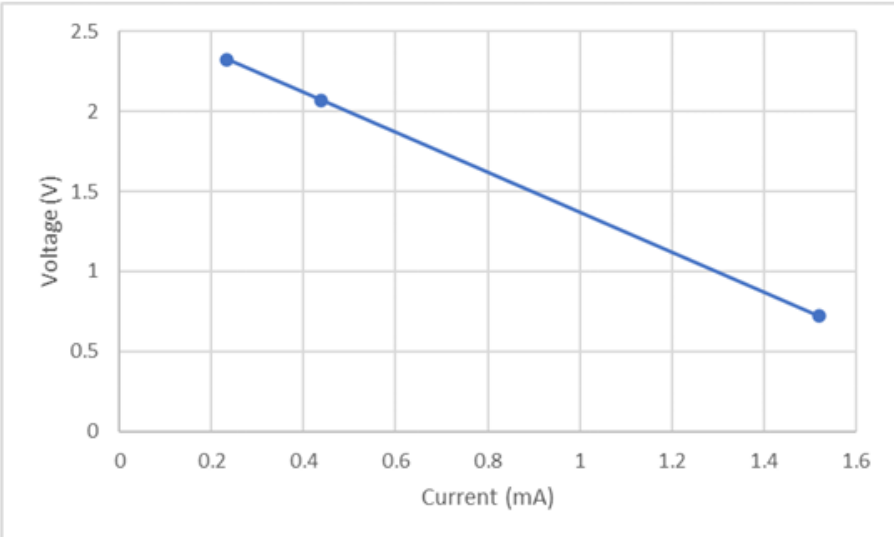

Diagram 3.1 U = f(I) of the voltage source based on these three data points

Resistance	Measured		Calculated	
	Voltage(V)	Current (mA)	Voltage(V)	Current (mA)
470 Ω	0.7193	1.521	0.714088	1.51934
4,7 k Ω	2.068	0.438	2.05976	0.438247
10 k Ω	2.322	0.233	2.31687	0.231687

Table 3.2.1 Measured and calculated values of Voltage and Current in given Resistance

Next, we connected the same three load resistors to a simple linear voltage source. The voltage source was adjusted to U_0 and a potentiometer was set to $R = R_i$. The potentiometer was then connected in series with the voltage source. This configuration should be equivalent to the circuit with two voltage sources, as shown in the circuit diagram above.

We applied our understanding of creating equivalent sources and used Norton's and Thevenin's theorems to calculate the voltage and current values.

Finally, we compared the measured values with the calculated results and determined the relative error for each measurement.

Resistance	Measured	
	Voltage(V)	Current (mA)
470 Ω	0.7293	1.535
4,7 k Ω	2.085	0.441
10 k Ω	2.340	0.235

Table 3.2.2 Measured values of Voltage Current in given Resistance in Equivalent source

9 Conclusion

The experiments conducted revealed that it is impossible to replicate a theoretical circuit with 100% accuracy in practice. This limitation arises due to the inherent resistance in materials used to build the circuit, causing some energy loss in the form of electrical potential. The only way to achieve an ideal circuit is through the use of superconductors. As Alexander Tsirlin explains in his lecture notes *Superconductivity I* from Leipzig University: "A superconductor is a material with outstanding conducting properties, as its resistivity drops to zero below a certain critical temperature T_c." In the controlled conditions of a typical laboratory, with ordinary materials and temperatures, achieving such ideal conditions is not feasible.

Additionally, although Thevenin's theorem allows us to simplify a complex circuit into an equivalent one with similar properties, practical limitations arise. Physical factors such as the lengths of circuit branches contribute to small energy losses, meaning the simplified circuit values will approximate but not perfectly match those of the original physical setup.

This experiment provided valuable practical experience in measuring voltage, current, and resistance using multimeters across various circuit configurations. We observed that professional-grade multimeters, though more expensive, are essential for industrial and precision environments due to their higher accuracy, dependability, and features like auto-ranging and low tolerance errors (e.g., $\pm 0.1\%$). Regular calibration of these devices is crucial for maintaining long-term accuracy.

Furthermore, in cases where a specific resistor value, such as 2k, was unavailable, we successfully applied the theory of resistors in series by substituting two 1k resistors to achieve the desired total resistance. This demonstrated the practical application of theoretical principles.

To improve future experiments, we plan to transition to recording data in Excel instead of MS Word. Excel offers superior tools for organizing, analyzing, and presenting data efficiently, which will enhance the overall accuracy and effectiveness of our experimental results.

10 Appendix

Nahvi, M., Edminister, J. A. (2017). Schaum's outline of electric circuits (6th ed.). McGraw-Hill Education.

Figure 2: Metrahit TRMS

Figure 3: Metrawatt 15S