1 Introduction

A potentiometer is an electrical component that functions both as a variable resistor and as a voltage divider. It allows for the precise adjustment of electrical resistance and the control of output voltage in a circuit. The aim of the experiments detailed in this report is to analyze the behavior and characteristics of the potentiometer in various circuit configurations.

2 Background/Theory

A potentiometer is a resistor that has three terminals. Two of the terminals constitute the full resistance value, while the third one is a sliding contact. Figure 1 displays the different contacts of the potentiometer [1].

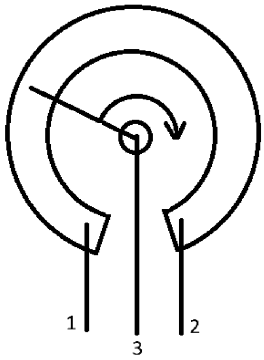


Figure 1: Drawing of a potentiometer with labeled terminals

The resistance between terminals 1 and 2 is constant, while the resistance between 1 and 3 is determined by equation 1 [1]:

$$R_{13} = kR \tag{1}$$

Since the potentiometer can be used as a voltage divider, the value of the potential difference between terminals 1 and 3 will be determined using equation 2 [1]:

$$V_{13} = kV_{tot} \tag{2}$$

When adding a load resistor in parallel to terminals 1 and 3, the voltage across them can be calculated using equation 3 [1]:

$$V_{13} = \frac{kR_L}{R_L + k(1-k)R_P}V \tag{3}$$

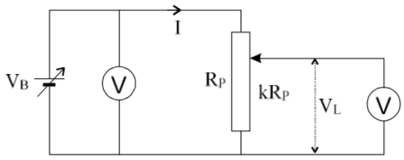
3 Methods & Materials

All circuits in the experiments were assembled using the provided connection boards. The electrical measurements, including voltage and current, were performed using the AM-520 HVAC multimeter for precision. A 10-turn potentiometer with a total resistance of 1 kΩ and a resolution of $\Delta k = 0.001$ was used to vary resistance and control output voltage. The power supply consisted of two 1.5V batteries connected in series. Fixed resistors of 1 kΩ and 510 kΩ were utilized as load resistors, along with a decade resistor to provide adjustable resistance for certain measurements.

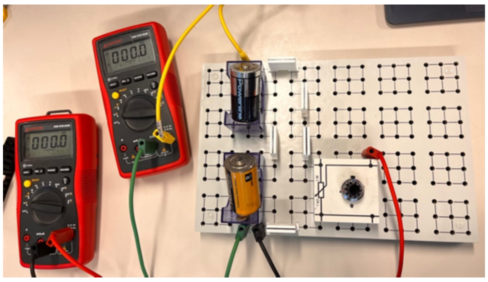
3.1 Experimental Set-Up unloaded potentiometer

An unloaded potentiometer circuit comprises a voltage source and a potentiometer. Measurements are taken for both the voltage supplied by the power source and the potential difference established between terminals 1 and 3. In the unloaded potentiometer circuit, measurements are conducted incrementally by varying the parameter k from 1 to 0.1.

Figures 2(a) and 2(b) display both the electrical diagram, and a picture of the physical set-up of the circuit.



(a) Circuit diagram of unloaded potentiometer circuit [1]



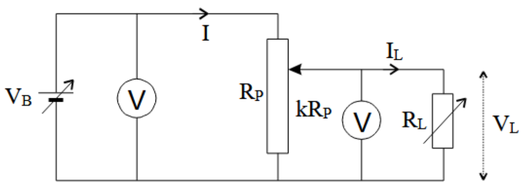
(b) Picture of the unloaded potentiometer circuit

Figure 2: Electrical schema and physical set-up of the unloaded potentiometer circuit

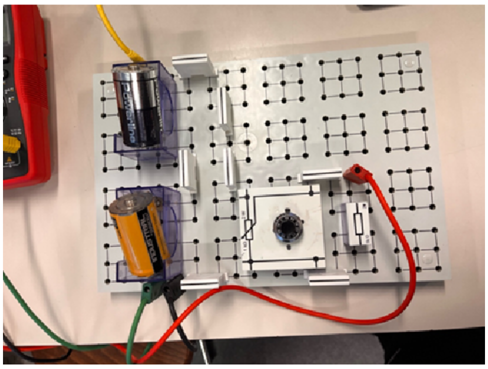
3.2 Experimental Set-Up with fixed resistor

The experimental set-up for the second experiment mirrors that of the first, with the key distinction being the addition of a load resistor connected in parallel across terminals 1 and 3. Specifically, a 510 Ω resistor and a 1 kΩ resistor are incorporated to introduce varying load conditions.

Figures 3(a) and 3(b) display both the electrical diagram and a picture of the physical set-up of the circuit.



(a) Circuit diagram of the loaded potentiometer circuit [1]



(b) Picture of the loaded potentiometer circuit with fixed resistance

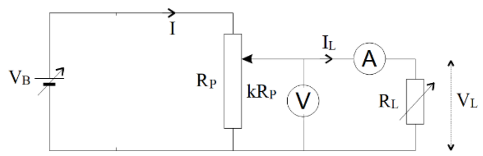
Figure 3: Electrical schema and physical set-up of the loaded potentiometer with fixed resistance

3.3 Experimental Set-Up with fixed load current

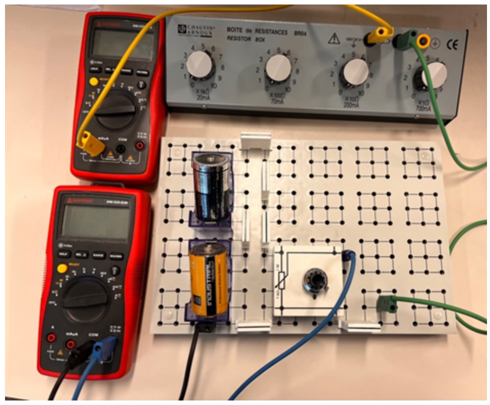
The set-up for the third experiment omits the voltmeter measuring the power source, replacing it with an ammeter in line with the load resistor. The load resistor being used becomes a decade resistor.

The experimental flow is also changed, as now with a change in the k-value, the decade resistor is adjusted in order for the current load to remain the same, then the resistance of the decade resistor, and the voltage drop is measured.

Figures 4(a), and 4(b) display the circuit diagram and picture of this experiment.



(a) Circuit diagram of the constant current load circuit [1]



(b) Picture of the constant current load circuit

Figure 4: Electrical diagram and physical set-up of the constant current load circuit

4 The Unloaded Potentiometer

4.1 Measurement Results

Table 1 presents the measured voltage values ($V_{unloaded}$) corresponding to the different values of the parameter k, alongside the theoretical voltage values ($V_{expected}$) and the associated measurement error ($\Delta V_{unloaded}$) for the unloaded potentiometer circuit. Additionally, the voltage of the battery was measured and obtained a result of ($V_{cell} = 2.959 \pm 0.028$) V. The calculated error is based on the multimeter's error of reading [2].

Table 1: Measured and expected voltage in terms of the parameter k of the potentiometer

k	$V_{unloaded}$ (V)	$\Delta V_{unloaded}$ (V)	$V_{expected}$ (V)
0.1	0.302	0.006	0.296
0.2	0.594	0.006	0.592
0.3	0.890	0.009	0.888
0.4	1.184	0.011	1.184
0.5	1.481	0.013	1.480
0.6	1.776	0.015	1.775
0.7	2.076	0.018	2.071
0.8	2.365	0.020	2.367
0.9	2.663	0.024	2.663
1.0	2.957	0.025	2.959

4.2 Graphs

Figure 5 illustrates the relationship between the measured voltage as a function of the parameter k in the unloaded potentiometer circuit.

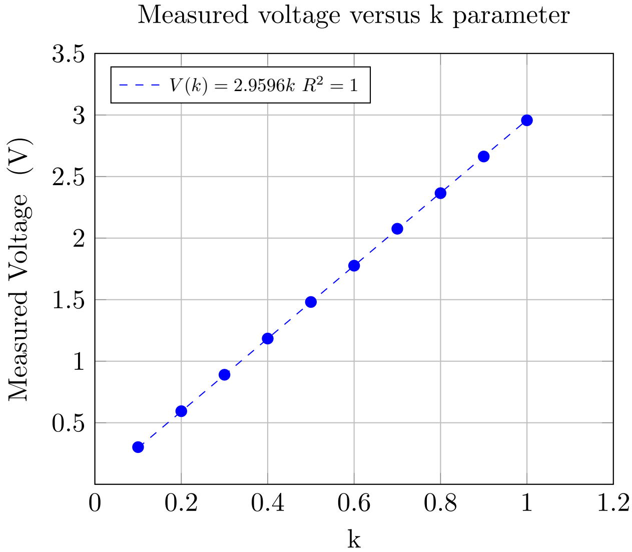


Figure 5: Measured voltage (V) drop in terms of the k parameter

4.3 Discussion

The goal of this experiment was to determine the effect of modifying the parameter k of the potentiometer on the voltage load. The graphical representation of these values in Figure 5 demonstrates the linear relationship between the k-value and the voltage drop across the potentiometer. This relationship is consistent with the theoretical formula presented in equation 2. The slope of the linear relationship, approximately 2.9596, corresponds to the total voltage supplied by the circuit (approximately 2.960V), reinforcing the expectation that voltage is directly proportional to the k-value in an unloaded potentiometer configuration. Analyzing the difference between measured and expected voltage, the results show strong agreement, with discrepancies falling within the calculated measurement error. These minor deviations can be attributed to potential inaccuracies in measurement or the inherent precision limits of the multimeter. Furthemore, the total voltage supplied by the circuit expected from the theoretical formula is strongly related to the one recorded by measuring the power source ($V_{cell} = 2.959 \pm 0.028$), further confirming the accuracy of the data.

5 Potentiometer loaded with fixed resistor

5.1 Measurement results

Table 2 presents the measurements for k, including the unloaded potentiometer value and the values corresponding to both loads, $1k\Omega$ as load 1 and 510 Ω as load 2. The table provides both the measured V_{L1} and V_{L2} values, and theoretical values V_{L1t} and V_{L2t}, along with the calculated percent deviations PD_1 and PD_2.

Table 2: Measured and theoretical voltage for 1 kΩ and 510 Ω load values in terms of k

k	$V_{unloaded}$ (V)	V_{L1} (V)	V_{L1t} (V)	PD_1 (%)	V_{L2} (V)	V_{L2t} (V)	PD_2 (%)
0.1	0.302	0.274	0.271	9.27	0.253	0.254	16.23
0.2	0.594	0.514	0.510	13.47	0.451	0.457	24.07
0.3	0.890	0.739	0.734	16.97	0.628	0.640	29.44
0.4	1.184	0.957	0.954	19.17	0.809	0.820	31.67
0.5	1.481	1.184	1.183	20.05	0.993	1.012	32.95
0.6	1.776	1.433	1.431	19.31	1.210	1.230	31.87
0.7	2.076	1.717	1.712	17.29	1.470	1.493	29.19
0.8	2.365	2.039	2.040	13.78	1.801	1.828	23.85
0.9	2.663	2.448	2.443	8.07	2.268	2.284	14.83
1.0	2.957	2.952	2.959	0.17	2.948	2.959	0.30

5.2 Graphs

Figure 6 illustrates the relationship between the voltage across the load resistor and the parameter k, comparing the experimental results with the corresponding theoretical values. Additionally, it presents the voltage drop across the unloaded potentiometer for reference.

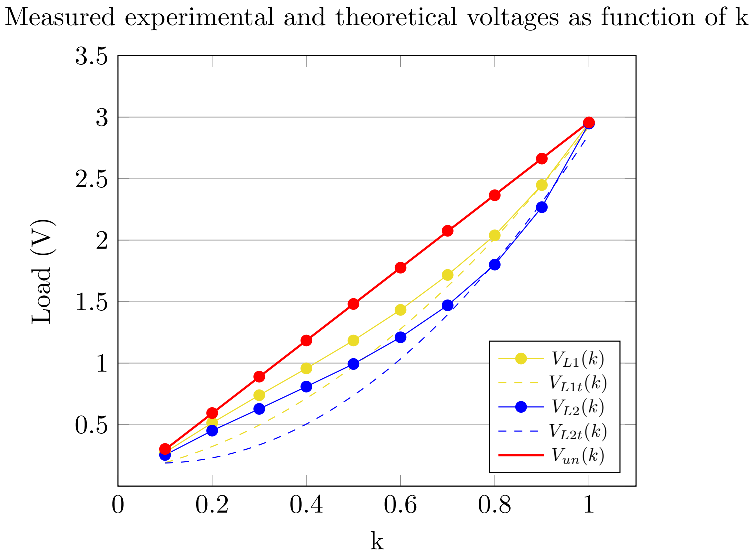


Figure 6: Measured experimental and theoretical voltages in fixed resistor circuit for load 1 and load 2 as a function of k

Furthermore, Figure 7 displays the relationship between percent deviation and the k parameter

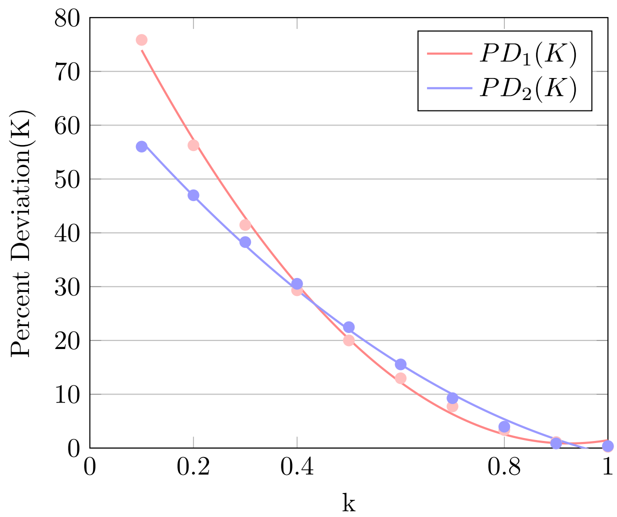


Figure 7: Percent deviation in terms of k

5.3 Calculations

To calculate the theoretical load, equation 3 is used. Using k = 0.5 and R_L = 543 Ω the following calculation is made:

$$V_{13} = \frac{kR_L}{R_L + k(1-k)R_P} \cdot V = \frac{0.5 \cdot 543}{543 + 0.5(1-0.5)1001} \cdot 2.959 = 1.012 \text{ V}$$

Using the user manual of the multimeter, ΔV, ΔR_L, ΔR_P can be determined [2]:

$$\Delta R = \frac{R}{100} + 2LSD \tag{4}$$

$$\Delta V = \frac{0.8V}{100} + 1LSD \tag{5}$$

$$\Delta R_L = \frac{543}{100} + 2LSD = 5.46 \ \Omega$$

$$\Delta R_P = \frac{1001}{100} + 2LSD = 10.02 \ \Omega$$

$$\Delta V_P = \frac{0.8 \cdot 2.959}{100} + LSD = 0.00616 \text{ V}$$

To calculate the error values of V_{th}, the following formula is used [3]:

$$\frac{\Delta V_{th}}{V_{th}} = \sqrt{\left(\frac{\Delta V_P}{V_P}\right)^2 + \left(\frac{\Delta R_P}{R_P}\right)^2 + \left(\frac{\Delta R_L}{R_L}\right)^2} \tag{6}$$

Calculating this value for $k = 0.5$, $R_L = 543 \ \Omega$:

$$\Delta V_{th} = 0.77\sqrt{\left(\frac{0.00616}{2.959}\right)^2 + \left(\frac{10.02}{1001}\right)^2 + \left(\frac{5.46}{543}\right)^2} = 0.011 \text{ V}$$

The error for the measured voltage will be calculated using equation 5:

$$\Delta V = \frac{0.8 \cdot 0.993}{100} + LSD = 0.0109 \text{ V}$$

Therefore, in standard notation the results for V_{th} and V_L are:

$$V_{th} = (1.012 \pm 0.02) \text{ V}$$
$$V_L = (0.993 \pm 0.02) \text{ V}$$

5.4 Discussion

This experiment aimed to analyze the voltage across the potentiometer when loaded with parallel resistors of 1 kΩ and 510 Ω. According to Figure 6, the relationship between the k-value and load voltage follows a non-linear trend, especially at lower k-values. Additionally, Figure 7 highlights that the percentage deviations show a more pronounced variation at lower k-values. For instance, at a k-value of 0.5, the percentage deviation was 20.05% for the 1 kΩ load and 32.95% for the 510 Ω load. These values suggest potential systematic errors, possibly due to human intervention or equipment inconsistencies at lower values.

These deviations are notable but fall within a plausible range given the potential loading effects and measurement uncertainties. As the k-value increased, the percentage deviation decreased, with minimal deviations observed at k = 1.0, where deviations were 0.17% for the 1 kΩ load and 0.30% for the 510 Ω load.

Such deviations can be attributed to loading effects, the influence of connection resistance, and inherent limitations in the precision of the multimeter. Despite these discrepancies, the general trend of the measured values aligns with theoretical expectations. The similarity in the overall behaviour of the experimental and theoretical graphs (Figure 6) confirms that the theoretical model accurately represents the system's behavior, particularly at higher k-values where deviations diminish.

6 Potentiometer with fixed load current

6.1 Measurement results

Table 3 displays the values for V_{th}, V_L, PD_1, PD_2, and $V_{unloaded}$:

Table 3: Measured and calculated values for the third experiment

K	$V_{unloaded}$ V	V_{L_1} V	V_{th_1} V	PD_1 %	V_{L_2} V	V_{th_2} V	PD_1 %
0.1	0.302	0.108	0.116	64.24	N/A	N/A	N/A
0.2	0.594	0.257	0.271	56.73	N/A	N/A	N/A
0.3	0.890	0.431	0.467	51.57	0.029	0.046	96.74
0.4	1.184	0.654	0.703	44.76	0.194	0.222	83.61
0.5	**1.481**	**0.968**	**0.979**	**34.64**	0.430	0.478	70.97
0.6	1.776	1.214	1.294	31.64	0.755	0.813	57.49
0.7	2.076	1.554	1.650	25.14	1.156	1.230	44.32
0.8	2.365	1.925	2.047	18.60	1.639	1.726	30.70
0.9	2.663	2.340	2.482	12.13	2.192	2.302	17.69
1	2.957	2.786	2.959	5.78	2.838	2.959	4.02

6.2 Graphs

Figure 8 represents the load voltages, both theoretical and measured, in terms of the k-value:

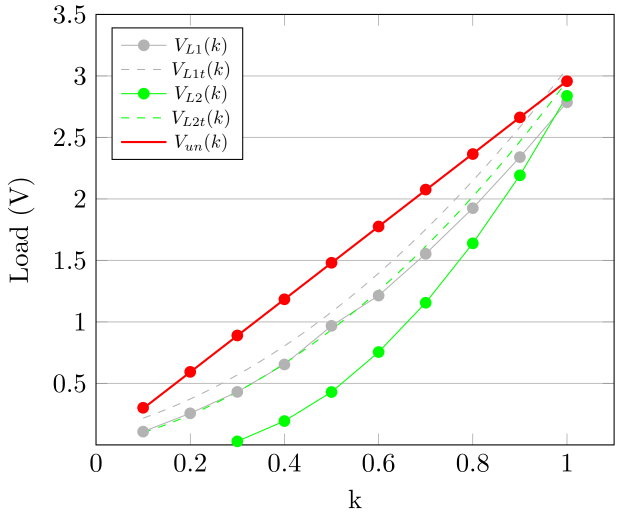


Figure 8: Loads in terms of k

Figure 9 represents the two percent deviations in terms of the k-value.

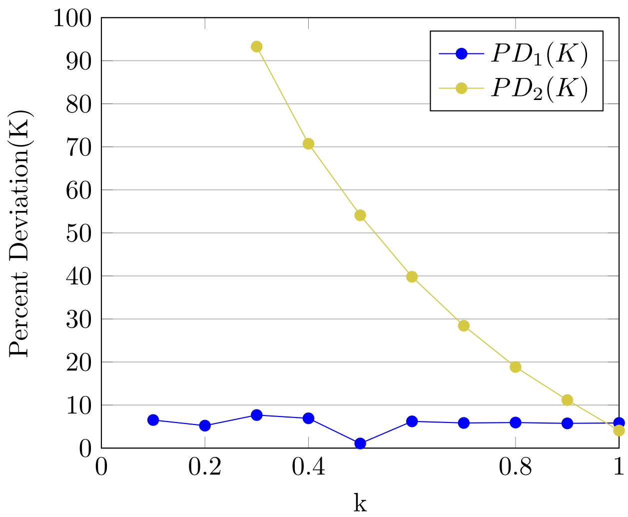


Figure 9: Percent deviation in terms of k

6.3 Calculations

Due to the variable resistance of the decade resistor, R_L at $k = 0.5$ will be 480 Ω.

Firstly, using equation 3, the theoretical load can be calculated:

$$V_L = \frac{0.5 \cdot 480}{480 + 0.5(1 - 0.5)1001} \cdot 3 = 0.979 \text{ V}$$

Using the values highlighted in table 3, the sample error calculations can be made.

Using equations 4 and 5, the calculations for ΔR, and ΔV are:

$$\Delta R_L = \frac{480}{100} + 2LSD = 4.8\ \Omega$$

$$\Delta R_P = 10.02\ \Omega$$

$$\Delta V_L = \frac{0.08 \cdot 0.968}{100} + 0.008 = 0.01557 \text{ V}$$

Using equation 6, the error for the theoretical value can be found:

$$\Delta V_{th} = 0.979\sqrt{\left(\frac{0.01557}{0.968}\right)^2 + \left(\frac{10.02}{1001}\right)^2 + \left(\frac{4.8}{480}\right)^2} = 0.021 \text{ V}$$

Therefore the load values in standard notation are:

$$V_{th} = (0.979 \pm 0.021) \text{ V}$$
$$V_L = (0.968 \pm 0.016) \text{ V}$$

6.4 Discussion

In this experiment, a constant current load was analyzed. Significant deviations from theoretical predictions were observed, especially at lower k-values. Firstly, the values for the fixed 4mA current did not coincide with the theoretical values. This is likely due to the effect of the internal resistance of the batteries on the rest of the circuit. Typical batteries have an internal resistance of around 0.2 Ω at room temperature [4]. Thus, when decreasing both the potentiometer's k-value and the decade resistor, the internal resistance had a greater impact since the external resistances were smaller. Internal resistance is also likely the cause of the discrepancy in the first current load. However, since the external resistances were larger, the overall effect of internal resistance was less pronounced.

Furthermore, the percentage deviation discrepancies could be attributed to the circuit construction method. Since the connections were more exposed compared to a traditional circuit, external interference may have skewed the results. This suggests that ensuring better connections and minimizing external interference would enhance measurement accuracy.

7 Conclusion

This study explored the relationship between the potentiometer's k-value and the resulting voltage in various circuit configurations. The unloaded potentiometer demonstrated a clear linear correlation, aligning well with theoretical expectations. When introducing fixed resistors, deviations were noted, particularly at lower k-values, due to loading effects. In the fixed load current experiment, internal battery resistance and circuit construction impacted measurement accuracy. While theoretical predictions provided a solid foundation, practical factors introduced measurable deviations, emphasizing the importance of considering real-world conditions in experimental analysis.

8 Bibliography

References

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