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.

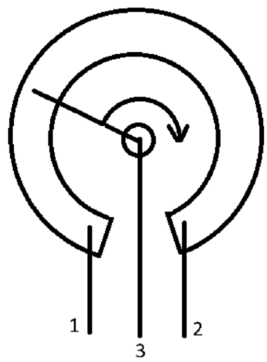


Figure 1: Drawing of a potentiometer
with labeled terminals

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 [1]:

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

3 Methods & Materials

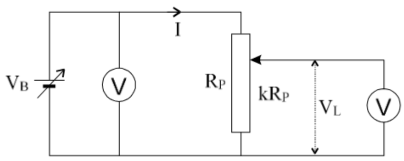
All circuits in the experiments were assembled using the provided connection boards. The electrical measurements, including voltage and current, were performed using the AM-520 HVAC multimeter for precision. A 10-turn potentiometer with a total resistance of 1 kΩ and a resolution of $\Delta k = 0.001$ 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

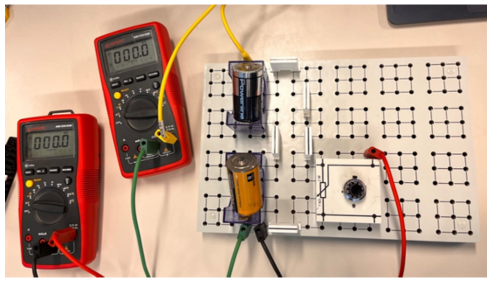
An unloaded potentiometer circuit comprises a voltage source and a potentiometer. Measurementeasurements are taken for both the voltage supplied by the power source and the potential difference established between terminals 1 and 3.

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]



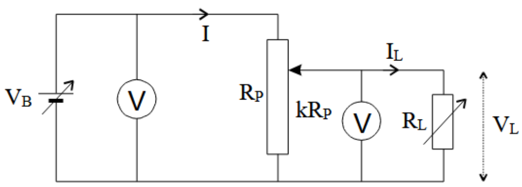
(b) Picture of the unloaded potentiometer circuit

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

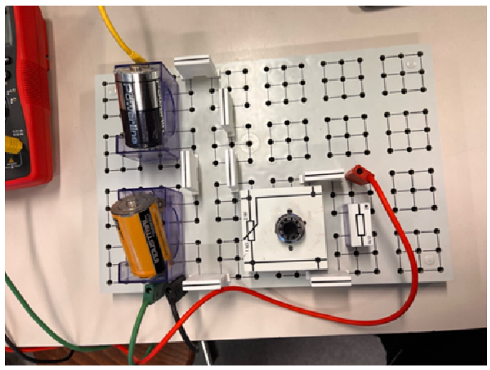
3.2 Experimental Set-Up with fixed resistor

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

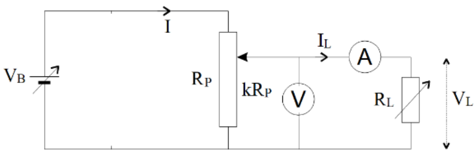
Figure 3: Electrical schema and physical set-up of the loaded potentiometer with fixed resistance

3.3 Experimental Set-Up with fixed load current

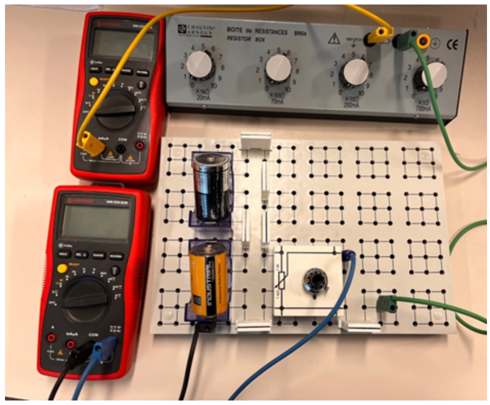
The set-up for the third experiment omits the voltmeter measuring the power source, replacing it with an ammeter in line with the load resistor. The load resistor being used becomes a decade resistor.

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.

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.

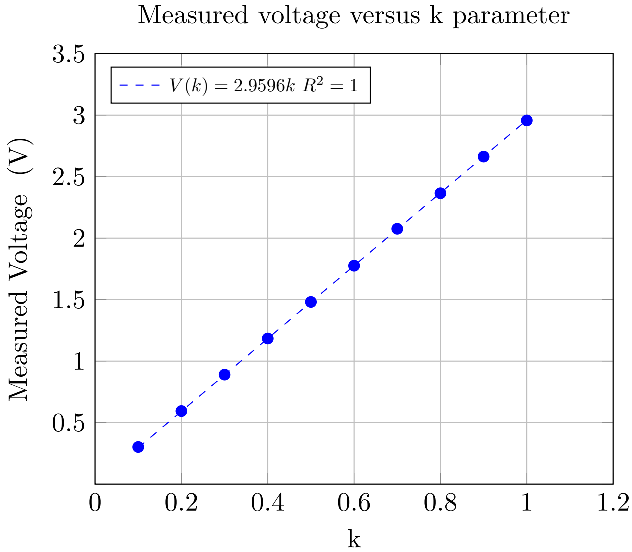


Figure 5: Measured voltage (V) drop in terms of the k parameter

4.3 Discussion

The main goal of this experiment was to determine the effect of changing the k-value of the potentiometer on the voltage load of the varying resistance. When looking at the graphical representation of these values seen on figure 3, we see a linear relationship between the k-value and the voltage drop on the potentiometer.

Analyzing the difference between the measured and expected voltage, we see that the measured values are accurate, as the difference between them and the expected values falls within the measurement error.

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.

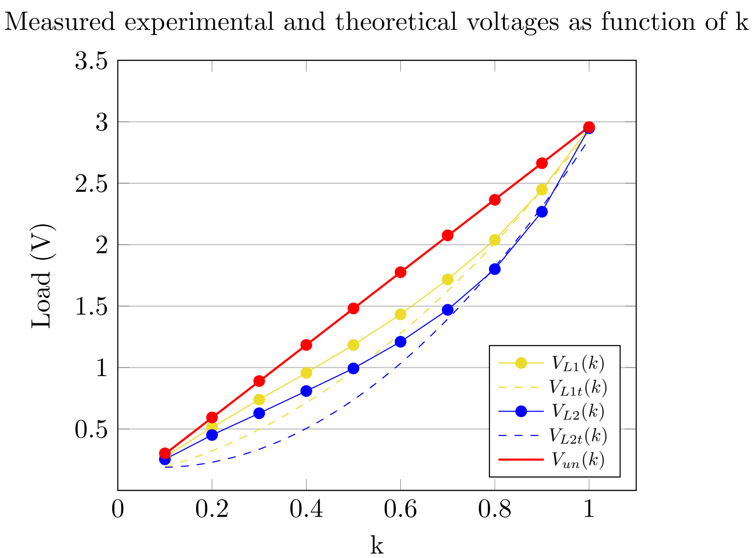


Figure 6: Measured experimental and theoretical voltages in fixed resistor circuit for load 1 and load 2 as a function of k

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

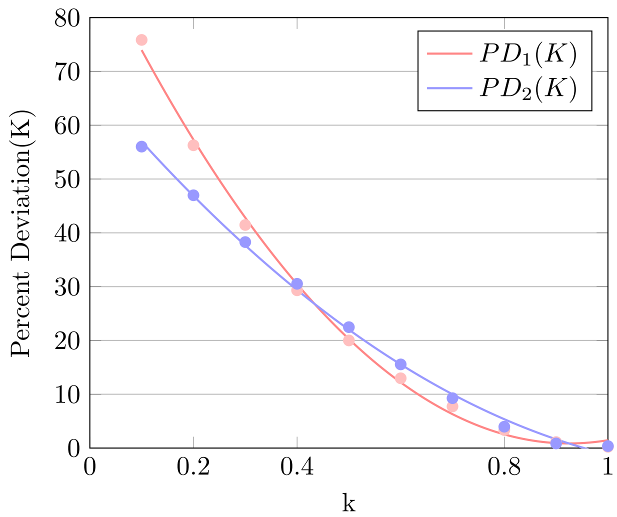


Figure 7: Percent deviation in terms of k

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

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:

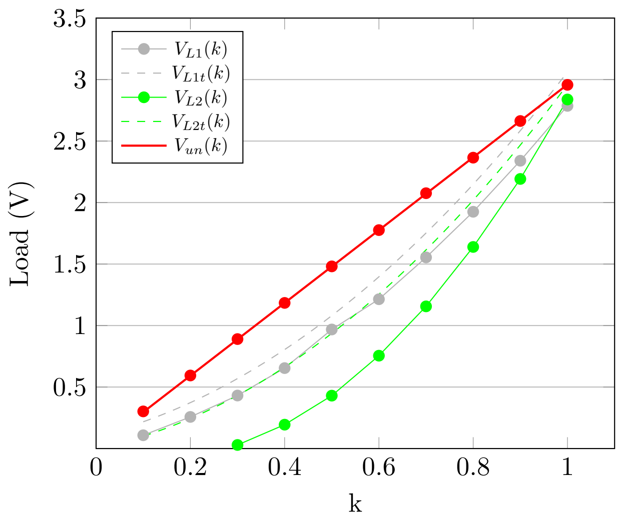


Figure 8: Loads in terms of k

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

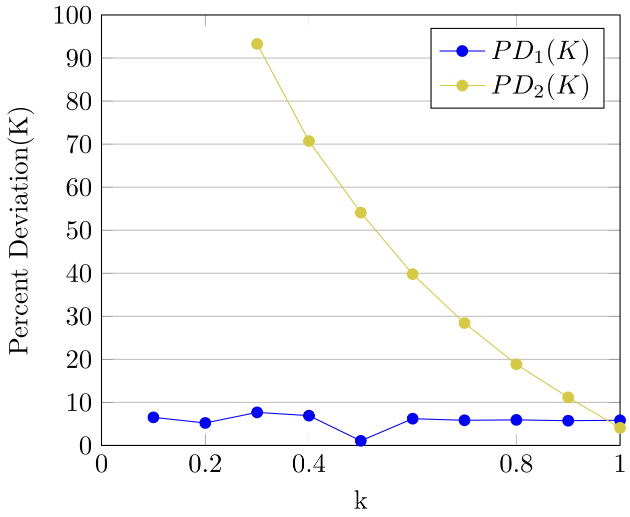


Figure 9: Percent deviation in terms of k

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

Firstly, the values for the fixed 4 mA current did not coincide with the theoretical values. This is likely due to the effect the internal resistance of the batteries has 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 caused more of an effect, 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 bigger, this has less of an overall effect.

The percent deviation discrepancies could be attributed to the interference of the circuit building method. Since the connections are more exposed than on a traditional circuit, interference can skew the results.

7 Conclusion

8 Bibliography

References

[1] J. Loeckx, “2 potentiometer 21-22.”

[2] “AM-500 Multimeter,” Dec. 2019. [Online]. Available: https://www.amprobe.com/wp-content/uploads/2019/12/AM-500_DIY-PRO_Digital-Multimeter_Manual.pdf

[3] L. Deneyer and J. Loeckx, “Uncertanty analysis(2024, 1st semester),” 2024.

[4] E. LLC, “Battery internal resistance,” 2005.