# Wrocław University of Science and Technology

ELECTRIONIC MEASUREMENTS
LABORATORY REPORT

Chair of Electronic and Photonic Metrology
ELECTRIONIC MEASUREMENTS LABORATORY

Theme of class: RESISTANCE MEASUREMENT

Group no: 1

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# Contents

# 1 Introduction

## 1.1 Theory

Resistance can be measured using two methods: direct or indirect.

**Direct**

To take a direct measurement, the measured component must be connected to the ohmmeter as shown in Fig. 1. The component cannot be connected to a circuit, and must be passive and linear. A linear component isn't influenced by other parameters and will not change its value over time.

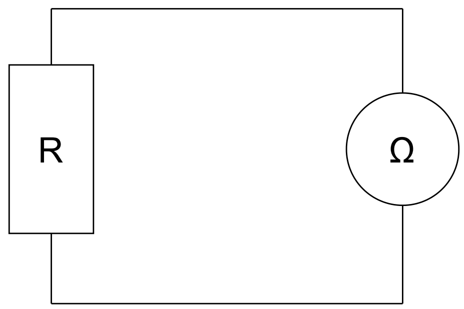


Figure 1: Direct resistance measurement schematic

**Indirect**

Resistance is measured indirectly using the ammeter-voltmeter method. Figures 2, 3 show different ways of implementing said method. In both instances, the resistance is calculated using the Ohm's law: $R = \frac{U}{I}$.

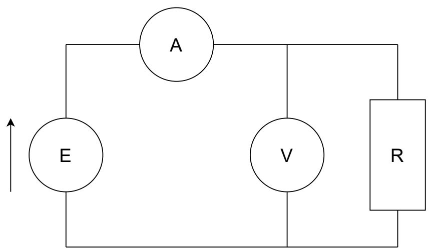


Figure 2: CVM (circuit with correct voltage measurement)

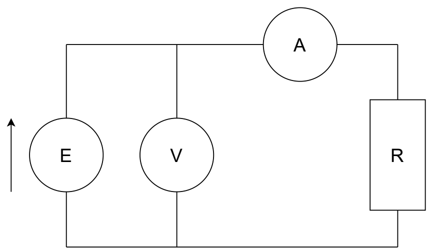


Figure 3: CCM (circuit with correct current measurement)

The method error is calculated using the following formulas:

- CVM: $\Delta_m R = \frac{-R_m^2}{R_V - R_m}$, $\delta_m R = \frac{-R_m}{R_V}$;
- CCM: $\Delta_m R = R_A$, $\delta_m R = \frac{R_A}{R_m - R_A}$;

The CVM circuit should be used for small resistances and the CCM circuit should be used for big resistances. The following equation describes the threshold resistance for which the choice of the circuit doesn't matter: $R_{thr} = \sqrt{R_V \cdot R_A}$.

## 1.2 Equipment

The following devices were used during the laboratory:

- power supply: DF1730SB3A;
- digital meter: Agilent 34401A;
- decade resistor: DR4b-16;
- digital meter: UT803;
- linear resistor;
- diode resistor.
- analog voltmeter: LM-3;
- analog ammeter: LM-3.

# 2 Experiment

## 2.1 Direct resistance measurement

We measured the resistance of linear resistors ($R_2, R_4$) and a diode ($D$). Measurements were taken for three different ranges and both polarities. Tab. 1 shows all of the measurements along with the final results.

| $R_x$ | $R_m[\Omega]$ | $R_r[\Omega]$ | Accuracy | $\Delta_{res}[\Omega]$ | $\Delta R[\Omega]$ | $\delta R[\%]$ | $R \pm \Delta R[\Omega]$ |
|---|---|---|---|---|---|---|---|
| Positive polarity | | | | | | | |
| $R_2$ | 424.4 | 600 | $0.8 + 3$ | 0.1 | 3.6952 | 0.870688 | $424.4 \pm 3.7$ |
| $R_4$ | $OL$ | 600 | $0.8 + 3$ | 0.1 | | | |
| $D$ | $OL$ | 600 | $0.8 + 3$ | 0.1 | | | |
| $R_2$ | 420 | 60000 | $0.5 + 2$ | 10 | 22.1 | 5.261905 | $420 \pm 23$ |
| $R_4$ | 2650 | 60000 | $0.5 + 2$ | 10 | 33.25 | 1.254717 | $2650 \pm 34$ |
| $D$ | $OL$ | 60000 | $0.5 + 2$ | 10 | | | |
| $R_2$ | 400 | 600000 | $0.5 + 2$ | 100 | 202 | 50.5 | $400 \pm 202$ |
| $R_4$ | 2600 | 600000 | $0.5 + 2$ | 100 | 213 | 8.192308 | $2600 \pm 213$ |
| $D$ | $OL$ | 600000 | $0.5 + 2$ | 100 | | | |
| Negative polarity | | | | | | | |
| $R_2$ | 424.4 | 600 | $0.8 + 3$ | 0.1 | 3.6952 | 0.870688 | $424.4 \pm 3.7$ |
| $R_4$ | $OL$ | 600 | $0.8 + 3$ | 0.1 | | | |
| $D$ | $OL$ | 600 | $0.8 + 3$ | 0.1 | | | |
| $R_2$ | 420 | 60000 | $0.5 + 2$ | 10 | 22.1 | 5.261905 | $420 \pm 23$ |
| $R_4$ | 2650 | 60000 | $0.5 + 2$ | 10 | 33.25 | 1.254717 | $2650 \pm 34$ |
| $D$ | 42.69 | 60000 | $0.5 + 2$ | 10 | 20.21345 | 47.349379 | $42.69 \pm 20.22$ |
| $R_2$ | 400 | 600000 | $0.5 + 2$ | 100 | 202 | 50.5 | $400 \pm 202$ |
| $R_4$ | 2600 | 600000 | $0.5 + 2$ | 100 | 213 | 8.192308 | $2600 \pm 213$ |
| $D$ | 178400 | 600000 | $0.5 + 2$ | 100 | 1092 | 0.612108 | $178400 \pm 1092$ |

Table 1: Direct resistance measurements (for: $R_m$ – measured resistance, $R_r$ – range, Accuracy: ± (a% of reading + n – number of uncertain digits), $\Delta_{res}$ – resolution, $\Delta R, \delta R$ – limiting error)

Example calculations for $R_r = 600\,\Omega$ ($R_2$, positive polarity) are shown in the equations below.

$$\Delta R = \frac{a}{100\%} \cdot R_m + n \cdot \Delta_{res} = \frac{0.8\%}{100\%} \cdot 424.4\,\Omega + 3 \cdot 0.1\,\Omega = 3.6952\,\Omega \tag{1}$$

$$\delta R = \frac{\Delta R}{R_m} \cdot 100\% = \frac{3.6952\,\Omega}{424.4\,\Omega} \cdot 100\% \approx 0.870688\% \tag{2}$$

## 2.2 Indirect resistance measurement

### 2.2.1 Analog

For analog measurements we used 0.5 accuracy class devices. The voltmeter had a $\frac{1000\,\Omega}{\mathrm{V}}$ internal resistance and the ammeter had a $\frac{23}{I_r[\mathrm{mA}]} + 0.004\,\Omega$ internal resistance.

The measurements for the CVM circuit are broken into Tables 2, 3, 4, 5 and the CCM circuit measurements are broken into Tables 6, 7, 8, 9. Example calculations for the measurement of $R = 100\,\Omega$ using the CCM circuit are shown in Equations 3 - 18. Since the calculations for the CVM circuit only differ in how the method error is obtained, they are not included in this report.

| $R_{thr}[\Omega]$ | $R_x[\Omega]$ | $\alpha$ | $\alpha_{max}$ | $V_r$[V] | $V_m$[V] | $\Delta V$[V] | $\delta V[\%]$ |
|---|---|---|---|---|---|---|---|
| 25 | 30 | 48.5 | 75 | 7.5 | 4.85 | 0.038 | 0.773196 |
| 48 | 100 | 48.5 | 75 | 7.5 | 4.85 | 0.038 | 0.773196 |
| 76 | 300 | 48.5 | 75 | 7.5 | 4.85 | 0.038 | 0.773196 |
| 152 | 1000 | 48.5 | 75 | 7.5 | 4.85 | 0.038 | 0.773196 |
| 240 | 3000 | 48.5 | 75 | 7.5 | 4.85 | 0.038 | 0.773196 |

Table 2: CVM for $E \sim 4.8\,\mathrm{V}$ ($R_{thr}$ – threshold resistance, $R_x$ – true resistance, $\alpha$ – actual needle swing, $\alpha_{max}$ – maximal swing, $V_r$ – range, $V_m$ – measured voltage, $\Delta V, \delta V$ – limiting error)

| $\alpha$ | $\alpha_{max}$ | $I_r$[A] | $I_m$[A] | $\Delta I$[A] | $\delta I[\%]$ |
|---|---|---|---|---|---|
| 37 | 75 | 0.3 | 0.148 | 0.0015000 | 1.013514 |
| 50 | 75 | 0.075 | 0.05 | 0.0003750 | 0.750000 |
| 43.5 | 75 | 0.03 | 0.0174 | 0.0001500 | 0.862069 |
| 56 | 75 | 0.0075 | 0.0056 | 0.0000375 | 0.669643 |
| 57.5 | 75 | 0.003 | 0.0023 | 0.0000150 | 0.652174 |

Table 3: CVM for $E \sim 4.8\,\mathrm{V}$ ($\alpha$ – actual needle swing, $\alpha_{max}$ – maximal swing, $I_r$ – range, $I_m$ – measured current, $\Delta I, \delta I$ – limiting error)

| $R_m[\Omega]$ | $\Delta R[\Omega]$ | $\delta R[\%]$ | $R_m \pm \Delta R[\Omega]$ | $R_V[\Omega]$ | $R_A[\Omega]$ |
|---|---|---|---|---|---|
| 32.770270 | 0.585509 | 1.786709 | $32.8 \pm 0.6$ | 7500 | 0.080667 |
| 97 | 1.477500 | 1.523196 | $97.0 \pm 1.5$ | 7500 | 0.310667 |
| 278.735632 | 4.558066 | 1.635265 | $279 \pm 5$ | 7500 | 0.770667 |
| 866.071429 | 12.496014 | 1.442839 | $866 \pm 13$ | 7500 | 3.070667 |
| 2108.695652 | 30.056711 | 1.425370 | $2109 \pm 31$ | 7500 | 7.670667 |

Table 4: CVM for $E \sim 4.8\,\mathrm{V}$ ($R_m$ – measured resistance, $\Delta R, \delta R$ – limiting error, $R_V$ – internal voltmeter resistance, $R_A$ – internal ammeter resistance)

| $\Delta_m R[\Omega]$ | $\delta_m R[\%]$ | $c[\Omega]$ | $R_c[\Omega]$ | $R_c \pm \Delta R[\Omega]$ |
|---|---|---|---|---|
| $-0.143814$ | $-0.004369$ | 0.143814 | 32.914084 | $33.0 \pm 0.6$ |
| $-1.270971$ | $-0.012933$ | 1.270971 | 98.270971 | $98.3 \pm 1.5$ |
| $-10.758996$ | $-0.037165$ | 10.758996 | 289.494628 | $289 \pm 5$ |
| $-113.067199$ | $-0.115476$ | 113.067199 | 979.138627 | $979 \pm 13$ |
| $-824.772090$ | $-0.281159$ | 824.772090 | 2933.467742 | $2933 \pm 31$ |

Table 5: CVM for $E \sim 4.8\,\mathrm{V}$ ($\Delta_m R_m, \delta_m R_m$ – method error, $c$– correction factor, $R_c$– corrected resistance)

| $R_{thr}[\Omega]$ | $R_x[\Omega]$ | $\alpha$ | $\alpha_{max}$ | $V_r$[V] | $V_m$[V] | $\Delta V$[V] | $\delta V$[%] |
|---|---|---|---|---|---|---|---|
| 25 | 30 | 48.5 | 75 | 7.5 | 4.85 | 0.0375 | 0.773196 |
| 48 | 100 | 48.5 | 75 | 7.5 | 4.85 | 0.0375 | 0.773196 |
| 76 | 300 | 48.5 | 75 | 7.5 | 4.85 | 0.0375 | 0.773196 |
| 152 | 1000 | 48.5 | 75 | 7.5 | 4.85 | 0.0375 | 0.773196 |
| 240 | 3000 | 48.5 | 75 | 7.5 | 4.85 | 0.0375 | 0.773196 |

Table 6: CCM for $E \sim 4.8\,\mathrm{V}$ ($R_{thr}$ – threshold resistance, $R_x$ – true resistance, $\alpha$ – actual needle swing, $\alpha_{max}$ – maximal swing, $V_r$ – range, $V_m$ – measured voltage, $\Delta V, \delta V$ – limiting error)

| $\alpha$ | $\alpha_{max}$ | $I_r$[A] | $I_m$[A] | $\Delta I$[A] | $\delta I$[%] |
|---|---|---|---|---|---|
| 37 | 75 | 0.3 | 0.14800 | 0.0015 | 1.013514 |
| 49 | 75 | 0.075 | 0.04900 | 0.000375 | 0.765306 |
| 37 | 75 | 0.03 | 0.01480 | 0.00015 | 1.013514 |
| 47 | 75 | 0.0075 | 0.00470 | 0.0000375 | 0.797872 |
| 41 | 75 | 0.003 | 0.00164 | 0.000015 | 0.914634 |

Table 7: CCM for $E \sim 4.8\,\mathrm{V}$ ($\alpha$ – actual needle swing, $\alpha_{max}$ – maximal swing, $I_r$ – range, $I_m$ – measured current, $\Delta I, \delta I$ – limiting error)

| $R_m[\Omega]$ | $\Delta R[\Omega]$ | $\delta R$[%] | $R_m \pm \Delta R[\Omega]$ | $R_V[\Omega]$ | $R_A[\Omega]$ |
|---|---|---|---|---|---|
| 32.770270 | 0.585509 | 1.786709 | $32.3 \pm 0.6$ | 7500 | 0.080667 |
| 98.979592 | 1.522803 | 1.538502 | $99.0 \pm 1.6$ | 7500 | 0.310667 |
| 327.702703 | 5.855095 | 1.786709 | $328 \pm 6$ | 7500 | 0.770667 |
| 1031.914894 | 16.212087 | 1.571068 | $1032 \pm 17$ | 7500 | 3.070667 |
| 2957.317073 | 49.914485 | 1.687830 | $2957 \pm 50$ | 7500 | 7.670667 |

Table 8: CCM for $E \sim 4.8\,\mathrm{V}$ ($R_m$ – measured resistance, $\Delta R, \delta R$ – limiting error, $R_V$ – internal voltmeter resistance, $R_A$ – internal ammeter resistance)

| $\Delta_m R[\Omega]$ | $\delta_m R$[%] | $c[\Omega]$ | $R_c[\Omega]$ | $R_c \pm \Delta R[\Omega]$ |
|---|---|---|---|---|
| 0.080667 | 0.002468 | −0.080667 | 32.689604 | $32.7 \pm 0.6$ |
| 0.310667 | 0.003149 | −0.310667 | 98.668925 | $98.7 \pm 1.6$ |
| 0.770667 | 0.002357 | −0.770667 | 326.932036 | $327 \pm 6$ |
| 3.070667 | 0.002985 | −3.070667 | 1028.844227 | $1029 \pm 17$ |
| 7.670667 | 0.002601 | −7.670667 | 2949.646407 | $2950 \pm 50$ |

Table 9: CCM for $E \sim 4.8\,\mathrm{V}$ ($\Delta_m R_m, \delta_m R_m$ – method error, $c$– correction factor, $R_c$– corrected resistance)

$$V_m = \alpha \cdot \frac{V_r}{a_{max}} = 48.5 \cdot \frac{7.5\,\mathrm{V}}{75} = 4.85\,\mathrm{V} \tag{3}$$

$$\Delta V = \frac{cl \cdot V_r}{100\%} = \frac{0.5\% \cdot 7.5\,\mathrm{V}}{100\%} = 0.0375\,\mathrm{V} \tag{4}$$

$$\delta V = \frac{\Delta V}{V_m} \cdot 100\% = \frac{0.0375\,\mathrm{V}}{3.85\,\mathrm{V}} \cdot 100\% \approx 0.773196\% \tag{5}$$

$$I_m = \alpha \cdot \frac{I_r}{a_{max}} = 49 \cdot \frac{0.075\,\mathrm{A}}{75} = 0.049\,\mathrm{A} \tag{6}$$

$$\Delta I = \frac{cl \cdot I_r}{100\%} = \frac{0.5\% \cdot 0.075\,\mathrm{A}}{100\%} = 0.000\,375\,\mathrm{A} \tag{7}$$

$$\delta I = \frac{\Delta I}{I_m} \cdot 100\% = \frac{0.000\,375\,\mathrm{A}}{0.049\,\mathrm{A}} \cdot 100\% \approx 0.765306\% \tag{8}$$

$$R_m = \frac{V_m}{I_m} = \frac{3.85\,\mathrm{V}}{0.049\,\mathrm{mA}} \approx 98.979\,592\,\Omega \tag{9}$$

$$\delta R = \delta V_m + \delta I_m = 0.773196\% + 0.765306\% = 1.538502\% \tag{10}$$

$$\Delta R = R_m \cdot \frac{\delta R_m}{100\%} = 197.959\,184\,\Omega \cdot \frac{1.538502\%}{100\%} \approx 3.045\,606\,\Omega \tag{11}$$

$$R_V = \frac{1000\,\Omega}{\mathrm{V}} \cdot V_r = \frac{1000\,\Omega}{\mathrm{V}} \cdot 7.5\,\mathrm{V} = 7500\,\Omega \tag{12}$$

$$R_A = \frac{23}{I_r[\mathrm{mA}]} + 0.004\,\Omega = \frac{23}{750} + 0.004\,\Omega \approx 0.310\,667\,\Omega \tag{13}$$

$$R_{thr} = \sqrt{R_V \cdot R_A} = \sqrt{7500\,\Omega \cdot 0.310\,667\,\Omega} \approx 48\,\Omega \tag{14}$$

$$\Delta_m R = R_A = 0.310\,667\,\Omega \tag{15}$$

$$\delta_m R = \frac{R_A}{R_m - R_A} = \frac{0.310\,667\,\Omega}{197.959\,184\,\Omega - 0.310\,667\,\Omega} \approx 0.001572\% \tag{16}$$

$$c = -\Delta_m R = -0.310\,667\,\Omega \tag{17}$$

$$R_c = R_m + c = 98.979\,592\,\Omega + (-0.310\,667\,\Omega) = 98.668\,925\,\Omega \tag{18}$$

# 3 Conclusion

## 3.1 Direct measurement

Linear resistor behave similarly for both polarities and the meter only displayed an "OL" error message when the chosen range was too small.

A diode is constructed to only allow current to flow in one direction and, ideally, has infinite resistance in the other direction. We believe that is the reason why the meter displayed an "OL" message for the positive polarity and numerical values for the negative polarity. It remains unclear to us why the numerical values of the same diode differed for different ranges, with one "OL" message within them. The most likely explanations are either human error or the meter influencing the component.

## 3.2 Indirect measurement

Digital measurements showed the expected circuit behavior - once the threshold resistance had been reached, the results became unreliable for incorrectly chosen circuits. Analog measurements didn't seem to be influenced by an incorrect choice of circuit and returned correct values regardless of the resistance threshold; we do not yet know why.