

# Wrocław University of Science and Technology

## ELECTRONIC MEASUREMENTS LABORATORY REPORT

Chair of Electronic and Photonic Metrology  
ELECTRONIC MEASUREMENTS LABORATORY

Theme of class: RESISTANCE MEASUREMENT

Group no: 1

Students:

1. Paulina Nowak 251002
2. Ivan Melnyk 275510
3. Stanislav Kustov 275512

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Lab assistant: mgr inż. Krzysztof Adamczyk

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# 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.

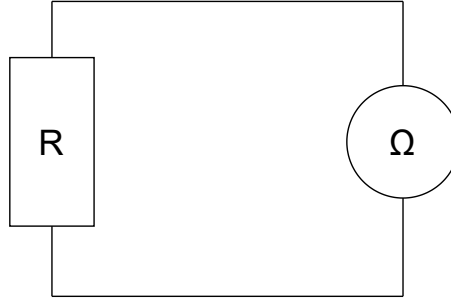


Figure 1: Direct resistance measurement schematic

### 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:  $R = \frac{U}{I}$ .

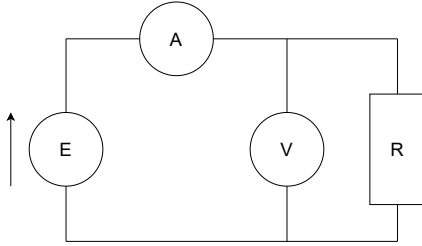


Figure 2: CVM (circuit with correct voltage measurement)

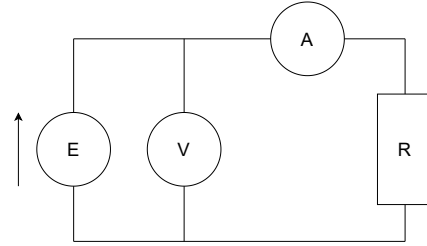


Figure 3: CCM (circuit with correct current measurement)

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 ± 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 ± 23
$R_4$	2650	60000	0.5 + 2	10	33.25	1.254717	2650 ± 34
$D$	OL	60000	0.5 + 2	10			
$R_2$	400	600000	0.5 + 2	100	202	50.5	400 ± 202
$R_4$	2600	600000	0.5 + 2	100	213	8.192308	2600 ± 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 ± 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 ± 23
$R_4$	2650	60000	0.5 + 2	10	33.25	1.254717	2650 ± 34
$D$	42.69	60000	0.5 + 2	10	20.21345	47.349379	42.69 ± 20.22
$R_2$	400	600000	0.5 + 2	100	202	50.5	400 ± 202
$R_4$	2600	600000	0.5 + 2	100	213	8.192308	2600 ± 213
$D$	178400	600000	0.5 + 2	100	1092	0.612108	178400 ± 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.

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

$$\delta R = \frac{\Delta R}{R_m} \cdot 100\% = \frac{3.6952 \Omega}{424.4 \Omega} \cdot 100\% \approx 0.870688\% \quad (2)$$

### 2.2 Indirect resistance measurement

#### 2.2.1 Analog

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

surement 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  $E \sim 4.8\text{ V}$  ( $R_{thr}$  – 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  $E \sim 4.8\text{ V}$  ( $\alpha$  – 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  $E \sim 4.8\text{ V}$  ( $R_m$  – 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  $E \sim 4.8\text{ V}$  ( $\Delta_m R_m, \delta_m R_m$  – 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  $E \sim 4.8\text{ V}$  ( $R_{thr}$  – 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  $E \sim 4.8\text{ V}$  ( $\alpha$  – 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  $E \sim 4.8\text{ V}$  ( $R_m$  – 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  $E \sim 4.8\text{ V}$  ( $\Delta_m R_m, \delta_m R_m$  – method error,  $c$  – correction factor,  $R_c$  – corrected resistance)

$$V_m = \alpha \cdot \frac{V_r}{\alpha_{max}} = 48.5 \cdot \frac{7.5\text{ V}}{75} = 4.85\text{ V} \quad (3)$$

$$\Delta V = \frac{cl \cdot V_r}{100\%} = \frac{0.5\% \cdot 7.5\text{ V}}{100\%} = 0.0375\text{ V} \quad (4)$$

$$\delta V = \frac{\Delta V}{V_m} \cdot 100\% = \frac{0.0375 \text{ V}}{3.85 \text{ V}} \cdot 100\% \approx 0.773196\% \quad (5)$$

$$I_m = \alpha \cdot \frac{I_r}{a_{max}} = 49 \cdot \frac{0.075 \text{ A}}{75} = 0.049 \text{ A} \quad (6)$$

$$\Delta I = \frac{cl \cdot I_r}{100\%} = \frac{0.5\% \cdot 0.075 \text{ A}}{100\%} = 0.000375 \text{ A} \quad (7)$$

$$\delta I = \frac{\Delta I}{I_m} \cdot 100\% = \frac{0.000375 \text{ A}}{0.049 \text{ A}} \cdot 100\% \approx 0.765306\% \quad (8)$$

$$R_m = \frac{V_m}{I_m} = \frac{3.85 \text{ V}}{0.049 \text{ mA}} \approx 98.979592 \Omega \quad (9)$$

$$\delta R = \delta V_m + \delta I_m = 0.773196\% + 0.765306\% = 1.538502\% \quad (10)$$

$$\Delta R = R_m \cdot \frac{\delta R_m}{100\%} = 197.959184 \Omega \cdot \frac{1.538502\%}{100\%} \approx 3.045606 \Omega \quad (11)$$

$$R_V = \frac{1000 \Omega}{V} \cdot V_r = \frac{1000 \Omega}{V} \cdot 7.5 \text{ V} = 7500 \Omega \quad (12)$$

$$R_A = \frac{23}{I_r[\text{mA}]} + 0.004 \Omega = \frac{23}{750} + 0.004 \Omega \approx 0.310667 \Omega \quad (13)$$

$$R_{thr} = \sqrt{R_V \cdot R_A} = \sqrt{7500 \Omega \cdot 0.310667 \Omega} \approx 48 \Omega \quad (14)$$

$$\Delta_m R = R_A = 0.310667 \Omega \quad (15)$$

$$\delta_m R = \frac{R_A}{R_m - R_A} = \frac{0.310667 \Omega}{197.959184 \Omega - 0.310667 \Omega} \approx 0.001572\% \quad (16)$$

$$c = -\Delta_m R = -0.310667 \Omega \quad (17)$$

$$R_c = R_m + c = 98.979592 \Omega + (-0.310667 \Omega) = 98.668925 \Omega \quad (18)$$



### **3 Conclusion**