Wrocław University of Science and Technology

ELECTRIONIC MEASUREMENTS
LABORATORY REPORT

Chair of Electronic and Photonic Metrology
ELECTRIONIC MEASUREMENTS LABORATORY

Theme of class: DC CURRENT MEASUREMENT

Group no: 1

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Contents

1 Introduction

1.1 Theory

Electric current can be measured in two ways: directly or indirectly. To make a direct measurement, the meter must be connected to the circuit in series. An ideal meter should have a zero internal resistance as not to impact the current flowing through; in reality, meters will always have a non-zero resistance creating a voltage drop.

The systematic error of current measurements $\Delta_m I$ can be calculated using formulas shown in Eq. 1, 2 (for: I_A – measured current, R_A – internal ammeter resistance, R_C – circuit resistance).

$$\Delta_m I = -I_A \cdot \frac{R_A}{R_C} \tag{1}$$

$$\delta_m I = -\frac{R_A}{R_A + R_C} \tag{2}$$

1.2 Equipment

The following devices were used during the laboratory:

- power supply: DF1730SB3A;
- analog ammeter: LM-3;
- digital meter: Agilent 34401A;
- decade resistor: DR4b-16;
- resistance standard: product name unknown.

2 Experiments

2.1 Direct current measurements

For direct measurements the meter was connected to the circuit in series (Figure 1). Measurements were taken for varying circuit resistances.

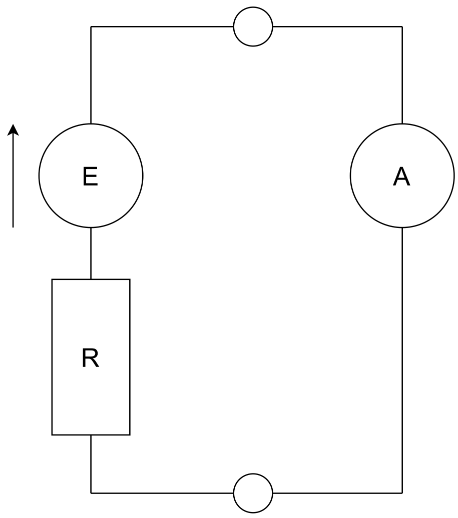

Figure 1: Direct current measurements schematic

2.1.1 Analog measurements

The ammeter which we used for analog measurements had a 0.5 accuracy class and a $\frac{23}{I_R[\mathrm{mA}]} + 0.004[\Omega]$ internal resistance (for: I_R – range).

The measurements along with the results are split into Tables 1 and 2; Tab. 1 contains the measurement results with only the limiting error applied, whereas Tab. 2 shows the final results which include the systematic error.

$R_C[\Omega]$	α	α_{max}	I_r[mA]	I[mA]	ΔI[mA]	δI[%]	$I \pm \Delta I$[mA]
10	66	75	150.0	132.00	0.7500	0.56819	132.0 ± 0.8
30	45	75	75.0	45.00	0.3750	0.83334	45.0 ± 0.4
100	67	75	15.0	13.40	0.0750	0.55971	13.40 ± 0.08
300	45.5	75	7.5	4.55	0.0375	0.82418	4.55 ± 0.04
1k	34	75	3.0	1.36	0.0150	1.10295	1.360 ± 0.016
3k	12	75	3.0	0.48	0.0150	3.12501	0.480 ± 0.016
10k	5	75	3.0	0.20	0.0150	7.50001	0.200 ± 0.016

Table 1: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: R_C – circuit resistance, α – actual needle swing, α_{max} – maximal swing, I_r – range, I – measured current, ΔI –absolute error, δI – relative error)

$R_A[\Omega]$	$\Delta_m I[\text{mA}]$	$\delta_m I$	$c[\text{mA}]$	$I_C[\text{mA}]$	$I_{exp}[\text{mA}]$	$I_C \pm \Delta I[\text{mA}]$
0.15734	-2.07681	-0.01550	2.07681	134.07681	130.00	134.1 ± 0.8
0.31067	-0.46601	-0.01025	0.46601	45.46601	43.33	45.5 ± 0.4
1.53734	-0.20601	-0.01515	0.20601	13.60601	13.00	13.61 ± 0.08
3.07067	-0.04658	-0.01014	0.04658	4.59658	4.33	4.60 ± 0.04
7.67067	-0.01044	-0.00762	0.01044	1.37044	1.30	1.370 ± 0.016
7.67067	-0.00123	-0.00256	0.00123	0.48123	0.43	0.481 ± 0.016
7.67067	-0.00016	-0.00077	0.00016	0.20016	0.13	0.200 ± 0.016

Table 2: Current measurements for $E \sim 1.3\,\text{V}$ (for: R_A – internal ammeter resistance, $\Delta_m I$ – systematic error, $\delta_m I$ – relative error, c – correction factor, I_C – calculated current, I_{exp} – expected current)

Example calculations for $R_C = 300\,\Omega$ are shown in the equations below.

$$I = \frac{\alpha \cdot I_r}{\alpha_{max}} = \frac{45.5 \cdot 7.5\,\text{mA}}{75} = 4.55\,\text{mA} \tag{3}$$

$$\Delta I = \frac{I_r \cdot cl}{100\%} = \frac{7.5\,\text{mA} \cdot 0.5\%}{100\%} = 0.0375\,\text{mA} \tag{4}$$

$$\delta I = \frac{\Delta I}{I} \cdot 100\% = \frac{0.0375\,\text{mA}}{4.55\,\text{mA}} \cdot 100\% \approx 0.82418\% \tag{5}$$

$$R_A = \frac{23}{I_R[\text{mA}]} + 0.004[\Omega] = \frac{23}{7.5\,\text{mA}} + 0.004\,\Omega \approx 3.070\,67\,\Omega \tag{6}$$

$$\Delta_m I = -I_A \cdot \frac{R_A}{R_C} = -4.55\,\text{mA} \cdot \frac{3.070\,67\,\Omega}{300\,\Omega} \approx -0.046\,58\,\text{mA} \tag{7}$$

$$\delta_m I = -\frac{R_A}{R_A + R_C} = -\frac{3.070\,67\,\Omega}{3.070\,67\,\Omega + 300\,\Omega} \approx -0.01014 \tag{8}$$

$$c = -\Delta_m I = -(-0.046\,58\,\text{mA}) = 0.046\,58\,\text{mA} \tag{9}$$

$$I_C = I + c = 4.55\,\text{mA} + 0.046\,58\,\text{mA} = 4.596\,58\,\text{mA} \tag{10}$$

$$I_{exp} = \frac{V}{R_C} = \frac{1.3\,\text{V}}{300\,\Omega} \approx 0.004\,33\,\text{A} = 4.33\,\text{mA} \tag{11}$$

2.1.2 Digital measurements

Digital measurements were made using a multimeter. Its internal resistance, accuracy, and burden voltage for each range are available in the device manual; for our calculations we chose the least precise accuracy value that is guaranteed to work for one year after device calibration.

The measurements along with the results are split into Tables 3 and 4; Tab. 3 contains the measurement results with only the limiting error applied, whereas Tab. 4 shows the final results which include the systematic error.

$R_C[\Omega]$	Accuracy	I_r[mA]	I[mA]	ΔI[mA]	$\delta I[\%]$	$I \pm \Delta I$[mA]
10	$0.050 + 0.005$	100	86.4317	0.04822	0.05579	86.43 ± 0.05
30	$0.050 + 0.005$	100	37.9869	0.02400	0.06316	37.987 ± 0.024
100	$0.050 + 0.005$	100	12.8199	0.01141	0.08900	12.820 ± 0.012
300	$0.050 + 0.020$	10	4.43229	0.00422	0.09512	4.432 ± 0.005
1000	$0.050 + 0.020$	10	1.34645	0.00268	0.19854	1.346 ± 0.003
3000	$0.050 + 0.020$	10	0.45049	0.00223	0.49396	0.4505 ± 0.0023
10000	$0.050 + 0.020$	10	0.13522	0.00207	1.52907	0.1352 ± 0.0021

Table 3: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: R_C – circuit resistance, Accuracy: $\pm$ (a% of reading + b% of range), I_r – range, I – measured current, ΔI –absolute error, δI – relative error)

$R_A[\Omega]$	$\Delta_m I$[mA]	$\delta_m I$	c[mA]	I_C[mA]	I_{exp}[mA]	$I_C \pm \Delta I$[mA]
6	-51.85903	-0.37501	51.85903	138.29073	130.00	138.29 ± 0.05
6	-7.59739	-0.16667	7.59739	45.58429	43.33	45.584 ± 0.024
6	-0.76920	-0.05661	0.76920	13.58910	13.00	13.589 ± 0.012
10	-0.14775	-0.03226	0.14775	4.58004	4.33	4.580 ± 0.005
10	-0.01347	-0.00991	0.01347	1.35992	1.30	1.360 ± 0.003
10	-0.00151	-0.00333	0.00151	0.45200	0.43	0.4520 ± 0.0023
10	-0.00014	-0.00010	0.00014	0.13536	0.13	0.1354 ± 0.0021

Table 4: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: R_A – internal multimeter resistance, $\Delta_m I$ – systematic error, $\delta_m I$ – relative error, c – correction factor, I_C – calculated current, I_{exp} – expected current)

Example calculations for $R_C = 300\,\Omega$ are shown in the equations below.

$$\begin{aligned}\Delta I &= \frac{a}{100\%} \cdot I + \frac{b}{100\%} \cdot I_r = \frac{0.050\%}{100\%} \cdot 4.432\,29\,\mathrm{mA} + \frac{0.020\%}{100\%} \cdot 10\,\mathrm{mA} = \\ &= 0.002\,216\,145\,\mathrm{mA} + 0.002\,\mathrm{mA} = 0.004\,216\,145\,\mathrm{mA} \approx 0.004\,22\,\mathrm{mA}\end{aligned} \tag{12}$$

$$\delta I = \frac{\Delta I}{I} \cdot 100\% = \frac{0.004\,22\,\mathrm{mA}}{4.432\,29\,\mathrm{mA}} \cdot 100\% \approx 0.09521\% \tag{13}$$

$$R_A = \frac{\text{burden voltage}}{I_R[\mathrm{mA}]} = \frac{0.1\,\mathrm{V}}{10\,\mathrm{mA}} = \frac{0.1\,\mathrm{V}}{0.01\,\mathrm{A}} = 10\,\Omega \tag{14}$$

$$\Delta_m I = -I_A \cdot \frac{R_A}{R_C} = -4.432\,29\,\mathrm{mA} \cdot \frac{10\,\Omega}{300\,\Omega} \approx -0.147\,75\,\mathrm{mA} \tag{15}$$

$$\delta_m I = -\frac{R_A}{R_A + R_C} = -\frac{10\,\Omega}{10\,\Omega + 300\,\Omega} \approx -0.032256 \tag{16}$$

$$c = -\Delta_m I = -(-0.147\,75\,\mathrm{mA}) = 0.147\,75\,\mathrm{mA} \tag{17}$$

$$I_C = I + c = 4.432\,29\,\mathrm{mA} + 0.147\,75\,\mathrm{mA} = 4.580\,04\,\mathrm{mA} \tag{18}$$

$$I_{exp} = \frac{V}{R_C} = \frac{1.3\,\mathrm{V}}{300\,\Omega} \approx 0.004\,33\,\mathrm{A} = 4.33\,\mathrm{mA} \tag{19}$$

2.2 Indirect current measurement

To take indirect current measurements, we added an extra resistance standard to the circuit (Figure 2) and measured the voltage drop across it Voltage was measured with a digital multimeter, connected to the circuit in parallel. Measurements were taken for varying circuit and resistance standard values and current was calculated using Ohm's law.

The measurements along with the results are split into Tables 5, 6 and 7; Tab. 5 and 6 contain the measurement results with only the limiting error applied, whereas Tab. 7 shows the final results which include the systematic error.

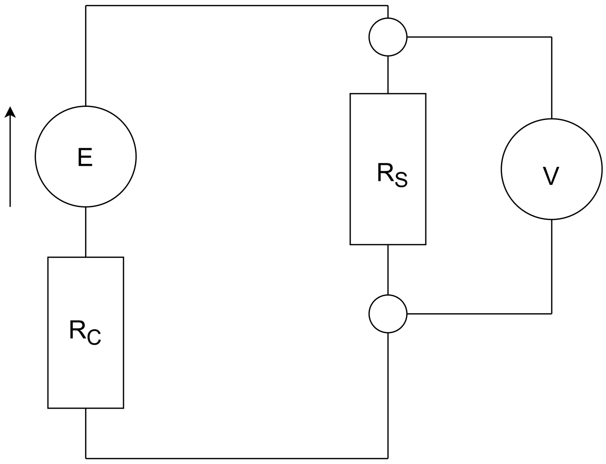

Figure 2: Indirect current measurements schematic

$R_C[\Omega]$	Accuracy	V_r[V]	V[V]	ΔV[V]	δV[%]
10	0.0035+0.0005	10	1.22609	0.00009294	0.00757801
100	0.0040+0.0007	1	0.675053	0.00003401	0.00503696
1000	0.0040+0.0007	1	0.122755	0.00001192	0.00971040
10000	0.0050+0.0035	0.1	0.013375	0.00000417	0.03116744
10	0.0040+0.0007	1	0.658095	0.00003333	0.00506368
100	0.0040+0.0007	1	0.122238	0.00001189	0.00972653
1000	0.0050+0.0035	0.1	0.013369	0.00000417	0.03118016
10000	0.0050+0.0035	0.1	0.001348	0.00000357	0.26458615
10	0.0035+0.0005	10	1.33556	0.00009675	0.00724375
100	0.0035+0.0005	10	1.22532	0.00009289	0.00758057
1000	0.0040+0.0007	1	0.673799	0.00003396	0.00503889
10000	0.0040+0.0007	1	0.122527	0.00001191	0.00971303

Table 5: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: R_C – circuit resistance, Accuracy: $\pm$ (a% of reading + b% of range), V_r – range, V – measured voltage, ΔV –absolute error, δV – relative error)

$R_S[\Omega]$	cl	I[mA]	ΔI[mA]	δI[%]	$I \pm \Delta I$[mA]
100	0.01	12.26090	0.00216	0.017588	12.2609 ± 0.0022
100	0.01	6.75053	0.00102	0.015037	6.7505 ± 0.0011
100	0.01	1.22755	0.00025	0.019710	1.2276 ± 0.0003
100	0.01	0.13375	0.00006	0.041167	0.13375 ± 0.00006
10	0.01	65.80950	0.00992	0.015064	65.81 ± 0.01
10	0.01	12.22380	0.00242	0.019727	12.2238 ± 0.0025
10	0.01	1.33689	0.00056	0.041180	1.3369 ± 0.0006
10	0.01	0.13483	0.00038	0.274586	0.1348 ± 0.0004
1000	0.01	1.33556	0.00024	0.017244	1.33556 ± 0.00024
1000	0.01	1.22532	0.00022	0.017581	1.22532 ± 0.00022
1000	0.01	0.67380	0.00011	0.015039	0.67380 ± 0.00012
1000	0.01	0.12253	0.00003	0.019713	0.12253 ± 0.00003

Table 6: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: R_C – resistance standard, cl – resistance standard class, I – measured current, ΔI – absolute error, δI –relative error)

$\Delta_m I$[mA]	$\delta_m I$	c[mA]	I_C[mA]	$I_C \pm \Delta I$[mA]
-122.60901	-0.90909	122.60901	134.86990	134.8610 ± 0.0022
-6.75054	-0.50000	6.75054	13.50106	13.5011 ± 0.0011
-0.12276	-0.09091	0.12276	1.35031	1.3503 ± 0.0003
-0.00134	-0.00990	0.00134	0.13509	0.13510 ± 0.00006
-65.80951	-0.50000	65.80951	131.61900	131.62 ± 0.01
-1.22239	-0.09091	1.22239	13.44618	13.4462 ± 0.0025
-0.01337	-0.00990	0.01337	1.35026	1.3503 ± 0.0006
-0.00014	-0.00091	0.00014	0.13496	0.1350 ± 0.0004
-133.55601	-0.99001	133.55601	134.89156	134.8916 ± 0.0024
-12.25321	-0.90909	12.25321	13.47852	13.47852 ± 0.00022
-0.67380	-0.50000	0.67380	1.34769	1.34770 ± 0.00012
-0.01226	-0.09091	0.01226	0.13478	0.13478 ± 0.00003

Table 7: Current measurements for $E \sim 1.3\,\mathrm{V}$ (for: $\Delta_m I$ – systematic error, $\delta_m I$ – relative error, c – correction factor, I_C – calculated current)

Example calculations for $R_C = 1000\,\Omega$ and $R_S = 100\,\Omega$ are shown in the equations below.

$$\Delta V = \frac{a}{100\%} \cdot V + \frac{b}{100\%} \cdot V_r = \frac{0.0040\%}{100\%} \cdot 0.122\,755\,\mathrm{V} + \frac{0.0007\%}{100\%} \cdot 1\,\mathrm{V} = \\ = 0.000\,004\,910\,2\,\mathrm{V} + 0.000\,007\,\mathrm{V} = 0.000\,011\,910\,2\,\mathrm{V} \approx 0.000\,011\,92\,\mathrm{V} \tag{20}$$

$$\delta V = \frac{\Delta V}{V} \cdot 100\% = \frac{0.000\,011\,92\,\mathrm{V}}{0.122\,755\,\mathrm{V}} \cdot 100\% \approx 0.00971040\% \tag{21}$$

$$I = \frac{V}{R_S} = \frac{0.122\,755\,\mathrm{V}}{100\,\Omega} = 0.001\,227\,55\,\mathrm{A} = 1.227\,55\,\mathrm{mA} \tag{22}$$

$$\delta I = \delta V + \delta R_S = \delta V + cl = 0.00971040\% + 0.01\% \approx 0.01971\% \tag{23}$$

$$\Delta I = \frac{I \cdot \delta I}{100\%} = \frac{1.227\,55\,\mathrm{mA} \cdot 0.01971\%}{100\%} = 0.000\,241\,950\,105\,\mathrm{mA} \approx 0.000\,25\,\mathrm{mA} \tag{24}$$

$$\Delta_m I = -I_A \cdot \frac{R_A}{R_C} = -I_A \cdot \frac{R_S}{R_C} = -1.227\,55\,\mathrm{mA} \cdot \frac{100\,\Omega}{1000\,\Omega} \approx -0.122\,76\,\mathrm{mA} \tag{25}$$

$$\delta_m I = -\frac{R_A}{R_A + R_C} = -\frac{R_S}{R_S + R_C} = -\frac{100\,\Omega}{100\,\Omega + 1000\,\Omega} \approx -0.09091 \tag{26}$$

$$c = -\Delta_m I = -(-0.122\,76\,\mathrm{mA}) = 0.122\,76\,\mathrm{mA} \tag{27}$$

$$I_C = I + c = 1.227\,55\,\mathrm{mA} + 0.122\,76\,\mathrm{mA} \approx 1.350\,31\,\mathrm{mA} \tag{28}$$

3 Conclusion

During this laboratory we practiced measuring DC current and learned how the internal resistance of a meter affects the circuit. To be thorough, we tried both direct and indirect methods of measurements.

Both experiments showed us that the internal meter resistance can introduce measurement errors. When the meter's internal resistance was lower than the circuit's, the device was functioning properly and the systematic error had very small values. However, when the circuit's resistance dropped below the meter's, the results became unreliable and lay far outside the expected set of values, sometimes even with the systematic error added. This was caused by the meter losing its primary function and blocking the current from flowing through. Thus, when high precision is desired, measurements should taken on circuits with a much higher resistance than that of the meter.