Wrocław University of Science and Technology

ELECTRIONIC MEASUREMENTS
LABORATORY REPORT

Chair of Electronic and Photonic Metrology
ELECTRIONIC MEASUREMENTS LABORATORY

Theme of class: DC VOLTAGE MEASUREMENT

Group no: 1

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Date of class: 2022-12-05

Submission Date: 2022-12-12

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1 Introduction

1.1 Theory

This laboratory's theme was DC voltage measurement. We took measurements using analog and digital meters, calculated measurement errors and investigated their sources.

The primary source of the measurement error is the inaccuracy of a meter, but there are additional factors influencing its value. An ideal voltmeter should have an infinite internal resistance as not to let any current flow through; in reality, this device will always have a finite resistance and impact the tested circuit. Such type of an error is called a systematic/method error, and its value should be included in the measurement error.

The systematic error of voltage measurements $\Delta_m V$ can be calculated using formulas shown in Eq. 1, 2 (where: V – measured voltage, R_c – circuit resistance, R_v – internal voltmeter resistance). Then, the systematic error is used to calculate the correction factor c (Eq. 3), which is later added to the measured voltage V to obtain its final value V_c (Eq. 4).

$$\Delta_m V = -V \cdot \frac{R_c}{R_v} \tag{1}$$

$$\delta_m V = -\frac{R_c}{R_c + R_v} \tag{2}$$

$$c = -\Delta_m V \tag{3}$$

$$V_c = V + c \tag{4}$$

The final measurement result should be written as $\mathbf{V_c} \pm \mathbf{\Delta V}$, where ΔV is the limiting error (covering the inaccuracy of a meter).

1.2 Experiment equipment

The following devices were used during the laboratory:

- analog voltmeter: LM-3;
- digital multimeter: Agilent 34401A;
- decade resistor: DR4b-16;
- power supply: DF1730SB3A;
- voltage divider: product name unknown.

2 Experiment

2.1 Output voltage of a voltage source

The first experiment featured measurements of the output voltage of a voltage source. The meter was connected to the voltage source in parallel, as shown in Figure 1, and measurements were taken for different resistance values.

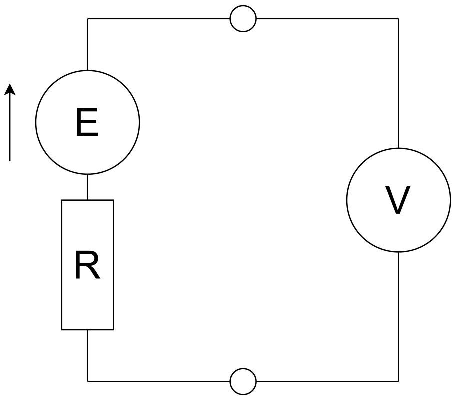

Figure 1: Voltage measurements schematic

Analog measurements

The voltmeter that we used for analog measurements is characterized by a 0.5 accuracy class and a 1 $\frac{\mathrm{k}\Omega}{\mathrm{V}}$ internal resistance.

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}	V_r[V]	V[V]	ΔV[V]	δV[%]	$V \pm \Delta V$[V]
0	40	75	7.5	4.0	0.037500	0.937500	4.00 ± 0.04
10	40	75	7.5	4.0	0.037500	0.937500	4.00 ± 0.04
100	39.5	75	7.5	3.95	0.037500	0.949367	3.95 ± 0.04
1000	35	75	7.5	3.5	0.037500	1.071429	3.50 ± 0.04
5000	56	75	0.15	0.112	0.000750	0.669643	0.1120 ± 0.0008
10000	30	75	0.15	0.06	0.000750	1.250000	0.0600 ± 0.0008

Table 1: Analog voltage measurements for $E \sim 3.9\,\mathrm{V}$ (R_c – circuit resistance, α – actual needle swing, α_{max} – maximal swing, V_r – range, V – measured voltage, ΔV – absolute error, δV – relative error)

$R_v[\Omega]$	$\Delta_m V[\mathrm{V}]$	$\delta_m V$	$c[\mathrm{V}]$	$V_c[\mathrm{V}]$	$V_c \pm \Delta V[\mathrm{V}]$
7500	0	0	0	4	4.00 +- 0.04
7500	-0.005333	-0.001332	0.005333	4.005333	4.01 ± 0.04
7500	-0.052667	-0.013158	0.052667	4.002667	4.01 ± 0.04
7500	-0.466667	-0.117647	0.466667	3.966667	3.97 ± 0.04
150	-3.733333	-0.970874	3.733333	3.845333	3.8453 ± 0.0008
150	-4	-0.985222	4	4.06	4.0600 ± 0.0008

Table 2: Analog voltage measurements for $E \sim 3.9\,\mathrm{V}$ (R_v – internal voltmeter resistance, $\Delta_m V$ – systematic error, $\delta_m V$ – relative error, c – correction factor, V_c – calculated voltage)

Example calculations for $R_c = 100\,\Omega$ are shown in the equations below.

$$V = \frac{\alpha \cdot V_r}{\alpha_{max}} = \frac{39.5 \cdot 7.5\,\mathrm{V}}{75} = 3.95\,\mathrm{V} \tag{5}$$

$$\Delta V = \frac{V_r \cdot cl}{100\%} = \frac{7.5\,\mathrm{V} \cdot 0.5\%}{100\%} = 0.0375\,\mathrm{V} \tag{6}$$

$$\delta V = \frac{\Delta V}{V} \cdot 100\% = \frac{0.0375}{3.95} \cdot 100\% \approx 0.949367\% \tag{7}$$

$$R_v = V_r \cdot x = 7.5\,\mathrm{V} \cdot 1000\,\frac{\Omega}{\mathrm{V}} = 7500\,\Omega \tag{8}$$

$$\Delta_m V = -V \cdot \frac{R_c}{R_v} = -3.95\,\mathrm{V} \cdot \frac{100\,\Omega}{7500\,\Omega} \approx -0.052\,667\,\mathrm{V} \tag{9}$$

$$\delta_m V = -\frac{R_c}{R_c + R_v} = -\frac{100\,\Omega}{100\,\Omega + 7500\,\Omega} \approx -0.013158 \tag{10}$$

$$c = -\Delta_m V = -(-0.052\,667\,\mathrm{V}) = 0.052\,667\,\mathrm{V} \tag{11}$$

$$V_c = V + c = 3.95\,\mathrm{V} + 0.052\,667\,\mathrm{V} = 4.002\,667\,\mathrm{V} \tag{12}$$

Digital measurements

Digital measurements were made using a multimeter. Its internal resistance and accuracy 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	V_r[V]	V[V]	ΔV[V]	δV[%]	$V \pm \Delta V$[V]
0	$0.0035 + 0.0005$	10	3.9996	0.000190	0.004750	3.9996 ± 0.0002
10	$0.0035 + 0.0005$	10	3.99953	0.000190	0.004750	3.9995 ± 0.0002
100	$0.0035 + 0.0005$	10	3.99964	0.000190	0.004750	3.9996 ± 0.0002
1000	$0.0035 + 0.0005$	10	3.99931	0.000190	0.004750	3.9993 ± 0.0002
5000	$0.0035 + 0.0005$	10	3.99791	0.000190	0.004752	3.9979 ± 0.0002
10000	$0.0035 + 0.0005$	10	3.99593	0.000190	0.004751	3.9959 ± 0.0002

Table 3: Digital voltage measurements for $E \sim 3.9\,\mathrm{V}$ (R_c – circuit resistance, Accuracy: ± (a% of reading + b% of range), V_r – range, V – measured voltage, ΔV – absolute error, δV – relative error)

R_v[MΩ]	$\Delta_m V$[V]	$\delta_m V$	c[V]	V_c[V]	$V_c \pm \Delta V$[V]
10	0	0	0	3.9996	3.9996 ± 0.0002
10	-0.000003	-0.000001	0.000004	3.999534	3.9995 ± 0.0002
10	-0.000040	-0.000010	0.000040	3.999680	3.9997 ± 0.0002
10	-0.000400	-0.000100	0.000400	3.999710	3.9997 ± 0.0002
10	-0.001999	-0.000500	0.001999	3.999909	3.9999 ± 0.0002
10	-0.003996	-0.000999	0.0039969	3.999926	3.9999 ± 0.0002

Table 4: Digital voltage measurements for $E \sim 3.9\,\mathrm{V}$ (R_v – internal multimeter resistance, $\Delta_m V$ – systematic error, $\delta_m V$ – relative error , c – correction factor, V_c – calculated voltage)

Example calculations for $R_c = 5000\,\Omega$ are shown in the equations below.

$$\Delta V = \frac{a}{100\%} \cdot V + \frac{b}{100\%} \cdot V_r = \frac{0.0035\%}{100\%} \cdot 3.997\,91\,\mathrm{V} + \frac{0.0005\%}{100\%} \cdot 10\,\Omega = \\ = 0.000\,14\,\mathrm{V} + 0.000\,05\,\mathrm{V} = 0.000\,19\,\mathrm{V} \tag{13}$$

$$\delta V = \frac{\Delta V}{V} \cdot 100\% = \frac{0.000\,19\,\mathrm{V}}{3.997\,91\,\mathrm{V}} \cdot 100\% = 0.004752\% \tag{14}$$

$$\Delta_m V = -V \cdot \frac{R_c}{R_v} = -3.997\,91\,\mathrm{V} \cdot \frac{5000\,\Omega}{10\,000\,000\,\Omega} \approx -0.001\,999\,\mathrm{V} \tag{15}$$

$$\delta_m V = -\frac{R_c}{R_c + R_v} = -\frac{5000\,\Omega}{5000\,\Omega + 10\,000\,000\,\Omega} \approx -0.000500 \tag{16}$$

$$c = -\Delta_m V = -(-0.001\,999\,\mathrm{V}) = 0.001\,999\,\mathrm{V} \tag{17}$$

$$V_c = V + c = 3.997\,91\,\mathrm{V} + 0.001\,999\,\mathrm{V} = 3.999\,909\,\mathrm{V} \tag{18}$$

2.2 Voltage divider

In the second experiment we measured and compared the input and output voltages of a voltage divider. Meters were connected to the circuit in parallel (Figure 2).

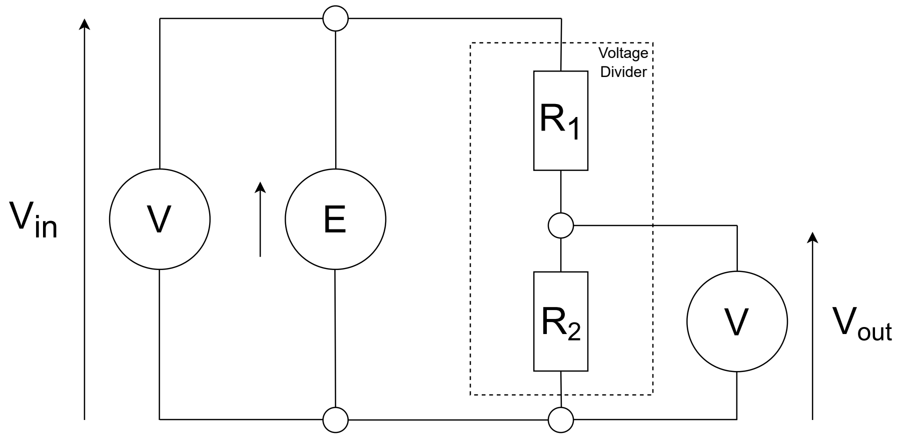

Figure 2: Voltage measurements schematic

For each measurement one of the voltages was measured with an analog voltmeter and the other one with a digital multimeter. Measurements were taken for different voltage divider ratio and resistance values.

Table 5 shows all of the measurements along with the results. Precision wasn't the primary focus of this experiment, hence all values have been rounded to one decimal place.

					Analog	Digital				
k	$R[\Omega]$	α	α_{max}	V_r[V]	V_{in}[V]	V_{out}[V]	R_{in} [Ω]	R_{out} [Ω]	$\frac{V_{out}}{V_{in}}$	Δ_k
0.9	1k	40	75	7.5	4	3.6	7.5k	10M	0.9	0
0.5	1k	40	75	7.5	4	2	7.5k	10M	0.5	0
0.1	1k	40	75	7.5	4	0.4	7.5k	10M	0.1	0
0.9	1M	40	75	7.5	4	3.6	7.5k	10M	0.9	0
0.5	1M	40	75	7.5	4	1.9	7.5k	10M	0.5	0
0.1	1M	40	75	7.5	4	0.4	7.5k	10M	0.1	0
					Digital	Analog				
0.9	1k	36	75	7.5	4	3.6	10M	7.5k	0.9	0
0.5	1k	44	75	3	4	1.8	10M	3k	0.4	0.1
0.1	1k	35.5	75	0.75	4	0.4	10M	0.75k	0.1	0
0.9	1M	3	75	0.15	4	0	10M	0.15k	0	0.9
0.5	1M	0.5	75	0.15	4	0	10M	0.15k	0	0.5
0.1	1M	0	75	0.15	4	0	10M	0.15k	0	0.1

Table 5: Voltage measurements for $E \sim 4\,\mathrm{V}$ (k – set divider ratio, R – equivalent divider resistance, α – actual needle swing, α_{max} – maximal swing, V_r – range, V_{in} – input voltage, V_{out} – output voltage, R_{in}, R_{out} – internal meter resistances, $\frac{V_{out}}{V_{in}}$ – measured divider ratio, Δ_k – ratio error)

Example calculation for $k = 0.9$, $R = 1\,\mathrm{k}\Omega$, V_{in} measured with an analog meter, and V_{out} measured with a digital meter are shown in the equations below.

$$V_{in} = \frac{\alpha \cdot V_r}{\alpha_{max}} = \frac{40 \cdot 7.5\,\mathrm{V}}{75} = 4\,\mathrm{V} \tag{19}$$

$$R_{in} = V_r \cdot x = 7.5\,\mathrm{V} \cdot 1\,\frac{\mathrm{k\Omega}}{\mathrm{V}} = 7.5\,\mathrm{k\Omega} \tag{20}$$

$$\frac{V_{out}}{V_{in}} = \frac{3.6\,\mathrm{V}}{4\,\mathrm{V}} = 0.9 \tag{21}$$

$$\Delta_k = |k - \frac{V_{out}}{V_{in}}| = |0.9 - 0.9| = 0 \tag{22}$$

3 Conclusions

3.1 Output voltage of a voltage source

This experiment has shown the importance of a systematic error. When the meter's internal resistance was significantly higher than the circuit's, the device was functioning properly and the systematic error had very small values. But, as the circuit resistance increased, so did the error. When the circuit's resistance exceeded the meter's, it became clear that measurement results without the systematic error included would be of no value.

3.2 Voltage divider

This time a more complex circuit was used, which brought attention to the systematic error's influence on other circuit components. When the output voltage was measured with a meter with an internal resistance significantly lower than the divider's, the amount of current flowing through the meter caused the divider to lose its original function.