



Lodz University of Technology  
Institute of Physics

Laboratory of electronics

Exercise E01IFE

Metrology

## Table of contents:

|   |    |
|---|----|
| 1. Purpose of the exercise .....                                  | 3  |
| 2. Hazards .....  | 3  |
| 3. Introduction .....   | 3  |
| 4. Available equipment .....                                      | 5  |
| 4.1. Multimeters .....  | 5  |
| 4.2. Power supply .....   | 6  |
| 4.3. Function generator.....                                      | 6  |
| 4.4. Oscilloscopes.....   | 7  |
| 5. Experimental procedure.....                                    | 8  |
| 5.1. Basic version.....   | 8  |
| 5.2. Extended version.....  | 10 |
| 6. Report elaboration .....                                       | 11 |
| 7. References .....   | 12 |
| 7.1. Basic reference materials.....                               | 12 |
| 7.2. Other reference materials .....                              | 12 |
| 8. Appendixes .....   | 13 |
| A1. Gain and attenuation factors .....                            | 13 |
| A2. Effective root mean square (rms) values .....                 | 14 |
| A3. Maximum uncertainty of measurements made by multimeters ..... | 15 |

Before you start to perform an experiment you are obliged to have mastered the following theoretical subjects:

1. DC and AC currents. Voltage, current intensity and electric resistance. [1], [2].
2. Principle of electrical measurements. [3], [4].
3. Four-terminal network. [1], [2].
4. Principle of oscilloscope operation. [5].

## 1. Purpose of the exercise

The purpose of this experiment is to know the properties and principles of the use of some electronic measuring instruments. To carry out the measurements should be used: the power supply, function generator, two-channel oscilloscopes and digital multimeters (DMMs).

## 2. Hazards

| Type   | Absence | Low | Medium | High |
|--|---------|-----|--------|------|
| electrical radiation hazards                           |         | +   |        |      |
| optical radiation hazards                              | +       |     |        |      |
| mechanical hazards (including acoustic hazards, noise) | +       |     |        |      |
| electromagnetic radiation hazards (invisible)          | +       |     |        |      |
| biological hazards                                     | +       |     |        |      |
| ionizing radiation hazards                             | +       |     |        |      |
| chemical hazards                                       | +       |     |        |      |
| thermal hazards (including explosion and fire)         | +       |     |        |      |

**The cables with banana plugs are designed exclusively for use in low-voltage circuits – do not connect them to the mains supply 230 V.**

## 3. Introduction

Performing laboratory work requires knowledge of the measuring equipment, the construction and operating principles. The ability to perform the measurement properly is also important. The measurement is based on a comparison of measured values with the basic unit. This comparison is carried out using a measuring instrument – meter. Meter is calibrated in units of the measured value. The names of meters come most often from the unit of the measured value (eg. voltmeter, ammeter, ohmmeter, frequency counter). The real value of the measured magnitude is never known. As a result of the measurement we get values superseded by an approximation burdened with an uncertainty. In the case of a single measurement of the value read from the meter it is the mentioned above approximation. In the case of a series of measurements of the same kind it is usually the arithmetic mean calculated on the basis of the results obtained in the measurement series.

The electronic circuits contain the sources (eg. the source of current or voltage), and receivers (eg. load resistor). Between these two basic parts of the system there are usually other elements that generally have one input and one output. Each input and output have two terminals. Due to the four terminals of these ones the elements are called four-terminal networks.

In order to estimate the output impedance  $r_{in}$  of the tested four-terminal network at a fixed electromotive force  $\epsilon_g$  on the generator (with output impedance  $r_g$ ) we have to make the measurements of output voltages  $U_A$  and  $U_B$  in two cases: without additional load resistor of four-terminal network ( $R_L^* \rightarrow \infty$ ; Fig. 3.1, measurement of the output voltage  $U_A$ ) and with an extra load resistor ( $R_L \neq \infty$ ; Fig. 3.2, measurement of the output voltage  $U_B$ ).

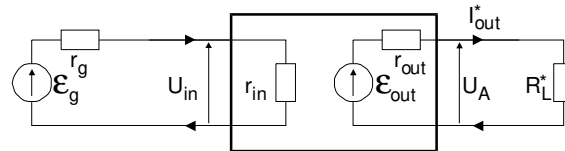


Fig. 3.1. Schematic diagram of the four-terminal network configured to measure  $U_A$

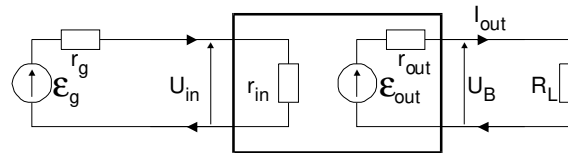


Fig. 3.2. Schematic diagram of the four-terminal network configured to measure  $U_B$

$$r_{in} = R_L \frac{U_A - U_B}{U_B} . \quad (1)$$

In order to estimate the input impedance  $r_{in}$  of the tested four-terminal network at a fixed electromotive force  $\epsilon_g$  on the generator (with output impedance  $r_g$ ) we have to make the measurements of output voltages  $U_C$  and  $U_D$  in two cases: with an extra serial resistor at input of four-terminal network ( $R_S \neq 0$ ; Fig. 3.3, measurement of the output voltage  $U_C$ ) and without additional resistor at input ( $R_S = 0$ ; Fig. 3.4, measurement of the output voltage  $U_D$ ).

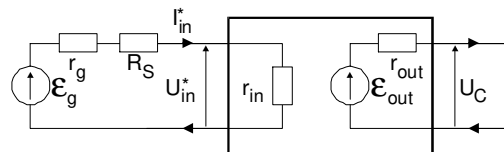


Fig. 3.3. Schematic diagram of the four-terminal network configured to measure  $U_C$

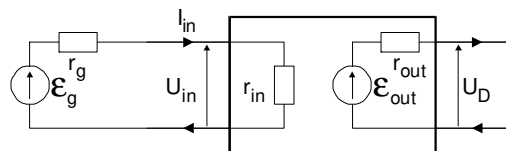


Fig. 3.4. Schematic diagram of the four-terminal network configured to measure  $U_D$

$$r_{out} = R_S \frac{U_C}{U_D - U_C} - r_g . \quad (2)$$

## 4. Available equipment

### 4.1. Multimeters

The resistances, voltages and currents are measured using five types of digital multimeters (DMMs). The following models may be used: UNI-T UT804, Protek 506, Kemet KT890, Axiomet AX-582B or Metex M-3800 [6].



Fig. 4.1. Five types of DMMs – UT804, Protek 506, M-3800, AX-582B and KT890

## 4.2. Power supply

The electronic circuits are powered by the laboratory power supply SPD3303D [6].

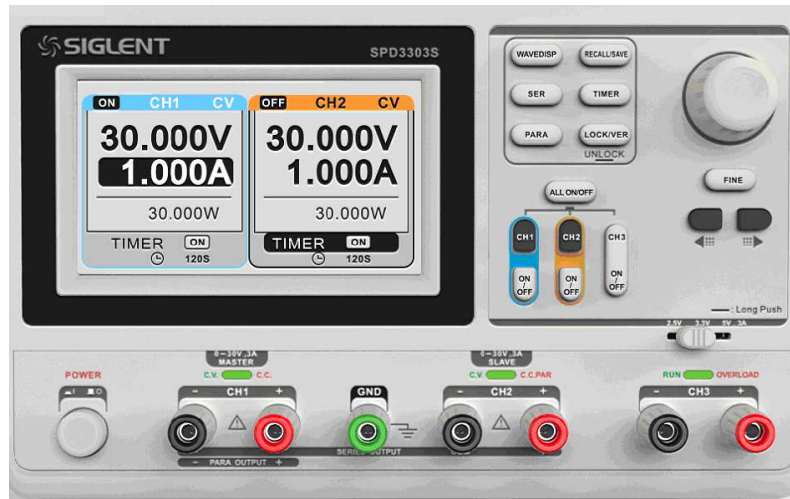


Fig. 4.2. Front panel of the power supply SPD3303

## 4.3. Function generator

The function generator DF1641B [6] is used as a source of sine, square and triangle waveforms.

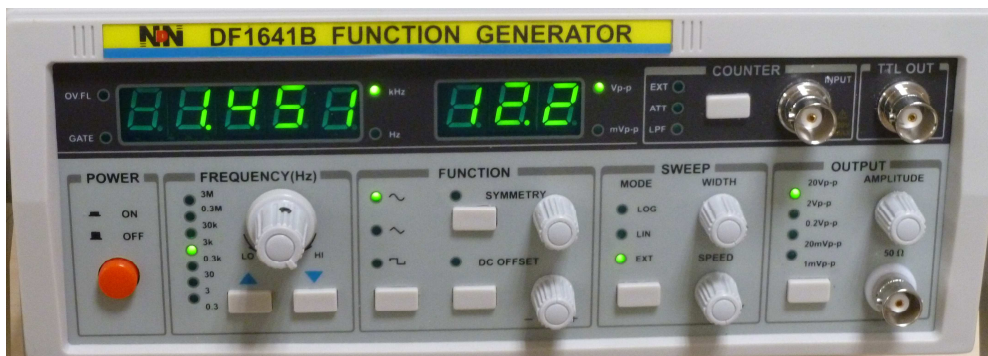


Fig. 4.3. Front panel of the function generator DF1641B

## 4.4. Oscilloscopes

In this experiment, two-channel analogue oscilloscope GOS-620 or GOS-630 [6] and two-channel digital oscilloscope SDS1052DL [6] are used.

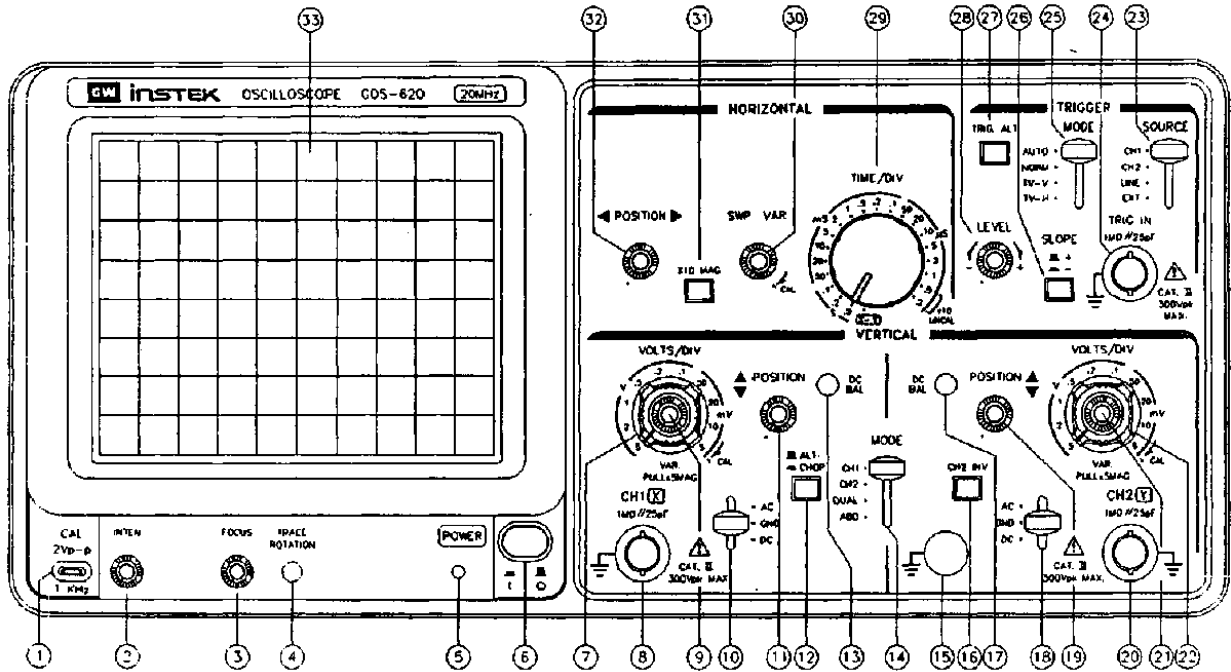


Fig. 4.4. Front panel of the analogue oscilloscope GOS-620

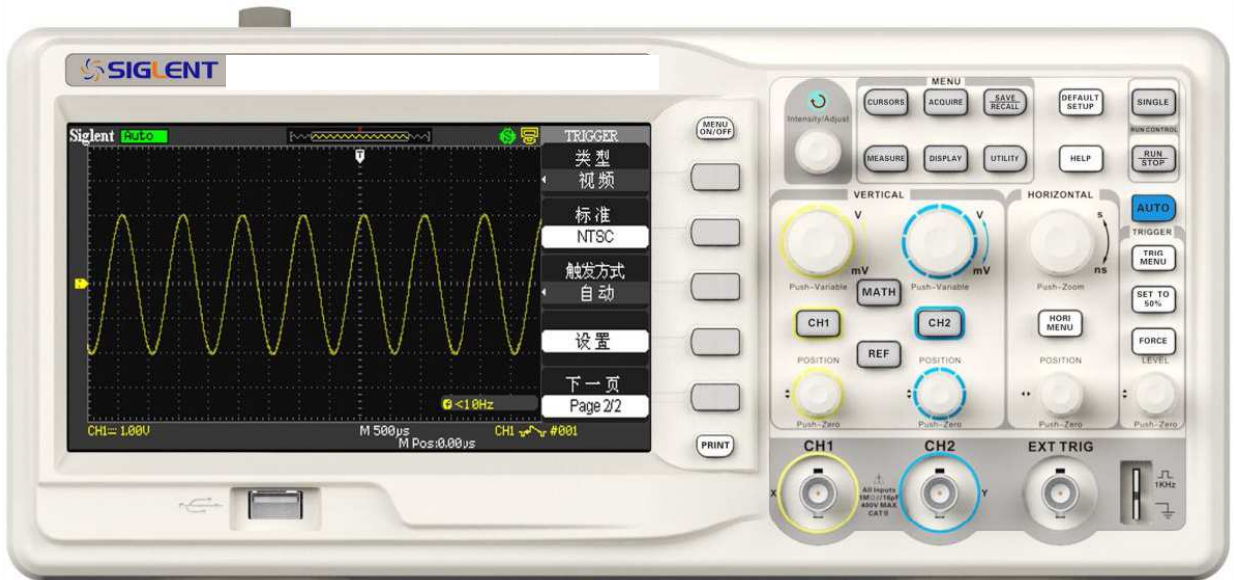


Fig. 4.5. Front panel of the digital oscilloscope SDS1052DL



## 5. Experimental procedure

### 5.1. Basic version

1. Ask the supervisor which of the digital multimeters (DMMs) will be used to measure the resistance of the reference resistor. It is recommended to use at least two DMMs, for example: KT890 and AX-582B. Make the resistance measurements of a reference resistor using all possible ranges of DMM **ohmmeter**. Start the measurements from the higher range. Follow instructions from DMM user manual and Appendix A3. Write down the required equations and calculate the maximum uncertainty of measurements for all ohmmeter ranges. Determine which resistance measurements are most accurate.
2. Check the power supply is not connected to any electronic circuits. Switch on the power supply.
  - Switch off (disable) the output sections (MASTER and SLAVE) of the power supply and check if TIMER of the power supply is off (if in doubt, ask the supervisor to check).
  - Select the function of adjusting the current limit. This can be done using the arrows (two dark buttons located under the universal knob) or with the knob – you have to press this knob.
  - After selecting the adjustment of current limit, turn round the universal knob to set the value 200 mA corresponding to the 5 % of the full scale adjustment. If you need to increase the precision of adjustment, press FINE key located under the universal knob (if in doubt, ask the supervisor to check).
  - Select the function of adjusting the voltage. This can be done using the arrows (two dark buttons located under the universal knob) or with the knob – you have to press this knob.
  - After selecting the adjustment of voltage, turn round the universal knob to set the minimum value of the voltage (if in doubt, ask the supervisor to check).
  - Make the serial connection of DMM **ammeter** and load resistor (resistor with the radiator). Connect this circuit to the output MASTER section of the power supply (black and red banana sockets). Draw the schematic diagram of tested circuit.
  - Depending on the used multimeter select 200 mA DC or 400 mA DC range of DMM ammeter.
  - Switch on (enable) the output MASTER section of the power supply and turn round the universal knob to set 28 V. Read the value of adjusting voltage from the power supply build-in voltmeter (if in doubt, ask the supervisor to check).
  - Select the function of adjusting the current limit. After selecting the adjustment of current limit, turn round the universal knob to reduce step by step the current intensity flowing through the load resistor (read the value from the DMM ammeter and notice the moment when the voltage starts to decrease). Set the current limit to about 150 mA (it may be not possible to set the current limit exactly to 150 mA). Write down both the current limit adjusted value (from the DMM ammeter) and the related voltage value (from the power supply build-in voltmeter).
  - Repeat the measurements from the previous step for the current limit value about 100 mA.



- Switch off the power supply and disconnect the tested circuit. Use the DMM ohmmeter to determine the load resistance value.
  - When drafting the report compare the measured voltage values (related to the two current limits, about 150 mA and 100 mA) with the theoretical voltage values calculated for tested circuit using the Ohm's law for the known current intensity flowing through the known load resistor.
  - Give an explanation why the voltage adjustment of power supply is blocked when the current limit is set to the minimum value.
3. Connect DMM DC **voltmeters** to the power supply outputs. Select the optimal ranges of voltmeters. Make the measurements for the three different operating modes of the MASTER and SLAVE sections. Sections can be configured to work as independent, serial or parallel.
    - Set up independent mode of the power supply and adjust the following voltages: 5 V (MASTER) and 10 V (SLAVE).
    - Set up serial mode of the power supply and adjust the symmetrical voltage to  $\pm 15$  V with "zero to the ground".
    - Set up parallel mode of the power supply and adjust the voltage to 18 V.
    - Follow instructions from DMM user manual and Appendix A3 to calculate the maximum uncertainty of measurements for all voltage readings.
  4. Connect the function generator to the CH1 input (⑧ in Fig. 4.4) of the analogue oscilloscope.
    - Before start the measurements select the DC position of the input switch (⑩ in Fig. 4.4) and switch on the oscilloscope.
    - Adjust the waveform frequency to 1 kHz and the level of generated signal amplitude to  $U_m = 3$  V. Note the amplitude can not be directly read from the display of generator. The display shows the peak-to-peak voltage  $U_{pp}$  of generated signal (if in doubt, ask the supervisor to check).
    - Check if the shape and frequency of generated signal have an effect on the amplitude of waveform observed on the oscilloscope display. Read the value of amplitude from the oscilloscope display (independently for sine and rectangular signal) for the following waveform frequencies: 10 Hz, 1 kHz, 200 kHz and 2 MHz.
  5. Repeat measurements from the point 4 using a digital oscilloscope.
  6. Connect the function generator to the CH1 input (⑧ in Fig. 4.4) of the analogue oscilloscope. Set up the shape of signal to sine, the amplitude level to  $U_m = 8$  V, the frequency to  $\nu = 1$  kHz. Adjust the clear and stable image on the oscilloscope display. Change the oscilloscope settings to get the maximum size of displayed image. Draw the adequate oscillogram (waveform) with clearly marked oscilloscope settings [V/DIV] and [s/DIV]. In order to perform oscillogram, use the template available on the website of the laboratory.
  7. Repeat measurements from the point 6 using a digital oscilloscope.
  8. Connect the function generator to the CH2 input (⑨ in Fig. 4.4) of the analogue oscilloscope. Set up the shape of signal to rectangular, the amplitude level to  $U_m = 2$  V, the frequency to  $\nu = 1$  kHz, the pulse-duty factor to  $W\% = 50$  % and the DC offset level to  $U_{DC} = 1$  V. Adjust the clear and stable image on the oscilloscope display. Change the oscilloscope settings to get the maximum size of displayed image. Draw the adequate oscillogram with clearly marked oscilloscope settings and the following values: peak-to-peak voltage, amplitude level, period, reference level and DC offset level.
  9. Repeat measurements from the point 8 using a digital oscilloscope.

10. Connect the function generator to the analogue oscilloscope. Set up the shape of signal to sine, the amplitude level to 6 V and the frequency to 5 kHz. Adjust the clear and stable image on the oscilloscope display. Turn round the horizontal shift knob (32 in Fig. 4.4) to shift the displayed image to the right (left edge is visible). Use the LEVEL knob (28 in Fig. 4.4) to adjust the trigger level and notice the changes of displayed image. Use the SLOPE switch (26 in Fig. 4.4) to change the trigger slope and compare the registered images related to the rising (+) and falling (–) slopes. Draw the proper four oscillograms with clearly marked oscilloscope settings for the following cases: the rising slope for two trigger levels +3 V, –3 V and the falling slope for two trigger levels +3 V, –3 V.
11. Connect the function generator to the both oscilloscope and DMM AC voltmeter (use one of analogue or digital oscilloscope and T junction to divide signal from the output of function generator). Use DMM to measure rms voltages of sine signals for the following five fixed frequencies: 50 Hz, 500 Hz, 5 kHz, 50 kHz and 500 kHz. Make the proper five oscillograms with clearly marked oscilloscope settings. Use oscillograms to calculate rms voltages (see Appendix A2) and compare them with the related rms values readings from DMM. Calculate maximum uncertainty for both DMM and oscilloscope measurements. Follow instructions from DMM user manual to make critical analysis of registered results. Read DMM user manual to find out information about the kind of signals and the frequency range where the rms voltage measurements are acceptable.
12. Connect the function generator to the both oscilloscope and four-terminal network (ask technician about the required four-terminal network). Use DMM and/or oscilloscope to measure voltages:  $U_A$ ,  $U_B$ ,  $U_C$  and  $U_D$  (see Figs. 3.1 to 3.4). Next use DMM to measure the values of  $R_L$  and  $R_S$ . Make an assumption the  $r_g$  value is equal to 50  $\Omega$ . Use Eqs. (1) and (2) to make proper calculations and estimate the input and output impedances of tested four-terminal network.

## 5.2. Extended version

13. Connect the function generator to the both X and Y inputs ( $\textcircled{8}/\textcircled{20}$  in Fig. 4.4) of the analogue oscilloscope (use T junction to divide signal from the output of function generator). Set up the shape of signal to sine and the frequency to 1 kHz. Select the X-Y mode of oscilloscope – (switch 29 in Fig. 4.4). Adjust the gain of X and Y input amplifiers to get the 45° angle of inclination for the observed line segment. Regulate the frequency of generated signal and notice the changes of displayed oscilloscope image. Find out the threshold frequency related to the undesirable phase shift which transforms the observed line segment to an ellipse.
14. Repeat measurements from the point 13 using a digital oscilloscope.
15. Connect the function generator to the CH1 input ( $\textcircled{8}$  in Fig. 4.4) of the analogue oscilloscope. Set up the shape of signal to sine, the amplitude level to 8 V and the frequency to 2 kHz. Check how the amplitude level of generated signal depends on the output attenuator of function generator. Make the measurements for the following attenuation factors: 0 dB, 20 dB, 40 dB and 60 dB (follow instructions from the user manual of function generator). Draw four oscillograms with clearly marked attenuation values and oscilloscope settings. Compare measured results with theory – see Appendix A1.
16. Repeat measurements from the point 15 using a digital oscilloscope.

## **6. Report elaboration**

Report has to include:

1. A front page (composed by using a template).
2. A description of experiment purposes.
3. A short introduction (basic definitions, formulas, description of used marks and symbols).
4. Schematic diagrams of the tested circuits.  
The report should include only diagrams of the circuits which were actually assembled during the measurements. Each scheme must be accompanied by a sequence number and entitled. All the components shown in the diagram must be clearly described and identified using commonly used symbols.
5. A list of used instruments and devices (id/stock number, type, setting and range values).
6. Measurement results obtained when performing the experiment, calculations, analysis and sub-conclusions related to the first point of “Experimental procedure”.
7. Next results (including oscillograms, graphs and tables), calculations, analysis, interpretation and sub-conclusions related to the next points of “Experimental procedure”.
8. Final comments and conclusions.

The completeness, correctness, clarity of presentation of the results (in the form of tables, graphs, oscillograms and calculations together with descriptions) and the quality of discourse and conclusions will all be evaluated. Theoretical introduction is not required and is not included in the assessment.

## 7. References

### 7.1. Basic reference materials

- [1] F. Przewdziecki, A. Opolski, *Elektrotechnika i elektronika*, PWN, Warszawa, 1986.
- [2] M. Krakowski, *Elektrotechnika teoretyczna*, PWN, Warszawa, 1983.
- [3] B. B. Oliver, J. M. Cage, *Pomiary i przyrządy elektroniczne*, WKŁ, Warszawa, 1978.
- [4] B. Żółtowski, *Wprowadzenie do zajęć laboratoryjnych z fizyki*, Skrypt PŁ, Łódź, 2001 – available on the website of the Electronics Laboratory.
- [5] J. Rydzewski, *Pomiary oscyloskopowe*, WNT, Warszawa, 1994.

### 7.2. Other reference materials

- [6] User guides for multimeters, power supply, function generator, and oscilloscopes available on the website:  
<https://fizyka.p.lodz.pl/pl/dla-studentow/modelling-and-data-science/electronics-laboratory/>
- [7] Evaluation of the Uncertainty of Measurement in Calibration EA-4/02 M:2022:  
<https://european-accreditation.org/publications/ea-4-02-m/>
- [8] Guides in Metrology, BIPM:  
<https://www.bipm.org/en/publications/guides/#gum>
- [9] Ł. Piskorski, *Evaluation of uncertainty in measurements*, TUL Script, Łódź, 2020 (WIKAMP, Pracownia Fizyczna/Physics Lab):  
<https://ftims.edu.p.lodz.pl/mod/resource/view.php?id=59551>

## 8. Appendixes

### A1. Gain and attenuation factors

The bel unit was named after the inventor of the telephone Alexander Graham Bell (1847-1922). Bel (denoted by the symbol B) is a unit of the gain specified by the logarithm of the base 10. If we assume that  $P_{out}$  is the output power and the  $P_{in}$  corresponding input power the gain power  $k_{gain}$  is defined as the power gain factor in [B]:

$$k_{gain} [B] = \log_{10} \left( \frac{P_{out}}{P_{in}} \right). \quad (A1.1)$$

In practice, a more convenient unit is 1 decibel (dB), which is equal to 0.1 of bel (1 dB = 0.1 B). The power gain factor in [dB]:

$$k_{gain} [dB] = 10 \log_{10} \left( \frac{P_{out}}{P_{in}} \right). \quad (A1.2)$$

The power attenuation factor in [dB]:

$$k_{att} [dB] = 10 \log_{10} \left( \frac{P_{in}}{P_{out}} \right). \quad (A1.3)$$

The power dissipated in the circuit is proportional to the square of the voltage or current circulating in the circuit ( $P \sim U^2$  or  $P \sim I^2$ ). For practical reasons, we often encounter the notion of gain voltage  $k_{Ugain}$  (or less gain current  $k_I$ ).

The voltage gain factor  $k_{Ugain}$ :

$$k_{Ugain} [dB] = 20 \log_{10} \left( \frac{U_{out}}{U_{in}} \right), \quad (A1.4)$$

$$k_{Ugain} [dB] = 10 \log_{10} \left( \frac{U_{out}^2}{U_{in}^2} \right) = 10 \log_{10} \left( \frac{U_{out}}{U_{in}} \right)^2 = 20 \log_{10} \left( \frac{U_{out}}{U_{in}} \right). \quad (A1.5)$$

The voltage attenuation factor  $k_{Uatt}$ :

$$k_{Uatt} [dB] = 20 \log_{10} \left( \frac{U_{in}}{U_{out}} \right). \quad (A1.6)$$

## A2. Effective root mean square (rms) values

The effective rms value  $A_{rms}$  of a periodic signal  $f(t)$  can be defined by the formula:

$$A_{rms} = \sqrt{\frac{1}{T} \int_0^T f^2(t) dt} . \quad (A2.1)$$

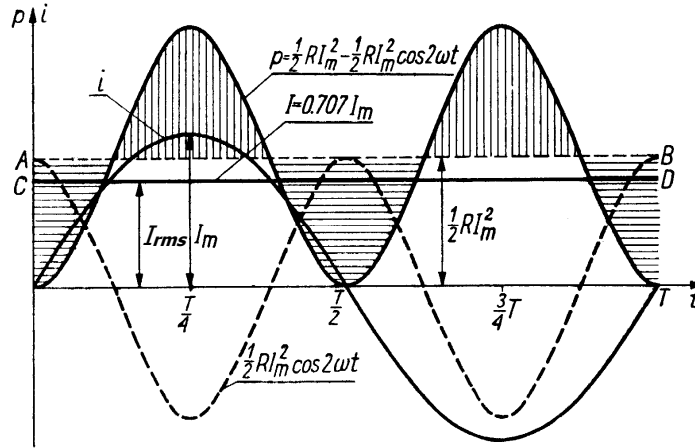


Fig. A2.1. RMS value for AC sine current

Now we can calculate the effective rms value of the sinusoidal alternating current  $I_{rms}$ . Putting  $i(t) = I_m \sin(\omega t)$  to formula (A2.1) we get:

$$I_{rms} = \sqrt{\frac{1}{T} \int_0^T i^2(t) dt} = \sqrt{\frac{1}{T} \int_0^T I_m^2 \sin^2(\omega t) dt} = I_m \sqrt{\frac{1}{T} \int_0^T \sin^2(\omega t) dt} . \quad (A2.2)$$

Because  $\sin^2(\omega t) = \frac{1}{2} [1 - \cos(2\omega t)]$ , then

$$I_{rms} = I_m \sqrt{\frac{1}{T} \int_0^T \frac{1}{2} [1 - \cos(2\omega t)] dt} = I_m \sqrt{\frac{1}{2T} \int_0^T [1 - \cos(2\omega t)] dt} = I_m \sqrt{\frac{1}{2T} T} = \frac{I_m}{\sqrt{2}} \approx 0.707 I_m . \quad (A2.3)$$

We can make similar calculations for the rms voltage  $U_{rms}$  of the sinusoidal AC. Putting  $u(t) = U_m \sin(\omega t)$  to formula (A2.1) we get:

$$U_{rms} = \frac{U_m}{\sqrt{2}} \approx 0.707 U_m . \quad (A2.4)$$

### A3. Maximum uncertainty of measurements made by multimeters

#### MODEL PROTEK 506

| Mode                          | Range          | dgts             | Maximum uncertainty                             |
|-------------------------------|----------------|------------------|---|
| DC Voltage                    | 400 mV         | 0.1 mV           | $\Delta U = \pm(0.3 \%  rdg  + 2 \text{ dgts})$ |
|                               | 4 V            | 0.001 V          | $\Delta U = \pm(0.5 \%  rdg  + 2 \text{ dgts})$ |
|                               | 40 V           | 0.01 V           |   |
|                               | 400 V          | 0.1 V            |   |
|                               | 1000 V         | 1 V              |   |
| AC Voltage<br>50 Hz ÷ 100 Hz  | 400 mV         | 0.1 mV           | $\Delta U = \pm(1.0 \%  rdg  + 3 \text{ dgts})$ |
|                               | 4 V            | 0.001 V          | $\Delta U = \pm(1.5 \%  rdg  + 5 \text{ dgts})$ |
|                               | 40 V           | 0.01 V           |   |
|                               | 400 V          | 0.1 V            |   |
|                               | 750 V          | 1 V              |   |
| AC Voltage<br>100 Hz ÷ 500 Hz | 400 mV         | 0.1 mV           | $\Delta U = \pm(1.0 \%  rdg  + 3 \text{ dgts})$ |
|                               | 40 V           | 0.01 V           | $\Delta U = \pm(1.5 \%  rdg  + 5 \text{ dgts})$ |
|                               | 400 V          | 0.1 V            |   |
|                               | 750 V          | 1 V              |   |
| AC Voltage<br>500 Hz ÷ 1 kHz  | 400 mV         | 0.1 mV           | $\Delta U = \pm(1.0 \%  rdg  + 3 \text{ dgts})$ |
| DC Current                    | 400 $\mu$ A    | 0.1 $\mu$ A      | $\Delta I = \pm(1.0 \%  rdg  + 2 \text{ dgts})$ |
|                               | 400 mA         | 0.1 mA           |   |
|                               | 20 A           | 0.01 A           |   |
| AC Current                    | 400 $\mu$ A    | 0.1 $\mu$ A      | $\Delta I = \pm(1.5 \%  rdg  + 3 \text{ dgts})$ |
|                               | 400 mA         | 0.1 mA           | $\Delta I = \pm(3.0 \%  rdg  + 5 \text{ dgts})$ |
|                               | 20 A           | 0.01 A           |   |
| Resistance                    | 400 $\Omega$   | 0.1 $\Omega$     | $\Delta R = \pm(0.5 \%  rdg  + 2 \text{ dgts})$ |
|                               | 4 k $\Omega$   | 0.001 k $\Omega$ |   |
|                               | 40 k $\Omega$  | 0.01 k $\Omega$  |   |
|                               | 400 k $\Omega$ | 0.1 k $\Omega$   |   |
|                               | 4 M $\Omega$   | 0.001 M $\Omega$ | $\Delta R = \pm(1.0 \%  rdg  + 2 \text{ dgts})$ |
|                               | 40 M $\Omega$  | 0.01 M $\Omega$  |   |

#### MODEL KT890

| Mode       | Range          | dgts             | Maximum uncertainty                             |
|------------|----------------|------------------|---|
| DC Voltage | 200 mV         | 0.1 mV           | $\Delta U = \pm(0.5 \%  rdg  + 1 \text{ dgts})$ |
|            | 2 V            | 0.001 V          |   |
|            | 20 V           | 0.01 V           |   |
|            | 200 V          | 0.1 V            | $\Delta U = \pm(0.8 \%  rdg  + 2 \text{ dgts})$ |
|            | 1000 V         | 1 V              |   |
| AC Voltage | 2 V            | 0.001 V          | $\Delta U = \pm(0.8 \%  rdg  + 3 \text{ dgts})$ |
|            | 20 V           | 0.01 V           |   |
|            | 200 V          | 0.1 V            | $\Delta U = \pm(1.2 \%  rdg  + 3 \text{ dgts})$ |
|            | 700 V          | 1 V              |   |
| DC Current | 2 mA           | 0.001 mA         | $\Delta I = \pm(0.8 \%  rdg  + 5 \text{ dgts})$ |
|            | 20 mA          | 0.01 mA          | $\Delta I = \pm(1.2 \%  rdg  + 1 \text{ dgts})$ |
|            | 200 mA         | 0.1 mA           |   |
|            | 20 A           | 0.01 A           | $\Delta I = \pm(2.0 \%  rdg  + 5 \text{ dgts})$ |
| AC Current | 200 mA         | 0.1 mA           | $\Delta I = \pm(2.0 \%  rdg  + 3 \text{ dgts})$ |
|            | 20 A           | 0.01 A           | $\Delta I = \pm(3.0 \%  rdg  + 7 \text{ dgts})$ |
| Resistance | 200 $\Omega$   | 0.1 $\Omega$     | $\Delta R = \pm(0.8 \%  rdg  + 3 \text{ dgts})$ |
|            | 2 k $\Omega$   | 0.001 k $\Omega$ | $\Delta R = \pm(0.8 \%  rdg  + 1 \text{ dgts})$ |
|            | 20 k $\Omega$  | 0.01 k $\Omega$  |   |
|            | 200 k $\Omega$ | 0.1 k $\Omega$   |   |
|            | 2 M $\Omega$   | 0.001 M $\Omega$ | $\Delta R = \pm(1.0 \%  rdg  + 2 \text{ dgts})$ |
|            | 20 M $\Omega$  | 0.01 M $\Omega$  |   |



**MODEL M-3800**

| Mode       | Range             | dgts               | Maximum uncertainty                                    |
|------------|-------------------|--------------------|--|
| DC Voltage | 200 mV            | 0.1 mV             | $\Delta U = \pm(0.5 \%  \text{rdg}  + 1 \text{ dgts})$ |
|            | 2 V               | 0.001 V            |  |
|            | 20 V              | 0.01 V             |  |
|            | 200 V             | 0.1 V              |  |
|            | 1000 V            | 1 V                |  |
| AC Voltage | 200 mV            | 0.1 mV             | $\Delta U = \pm(1.2 \%  \text{rdg}  + 3 \text{ dgts})$ |
|            | 2 V               | 0.001 V            | $\Delta U = \pm(0.8 \%  \text{rdg}  + 3 \text{ dgts})$ |
|            | 20 V              | 0.01 V             |  |
|            | 200 V             | 0.1 V              | $\Delta U = \pm(1.2 \%  \text{rdg}  + 3 \text{ dgts})$ |
|            | 700 V             | 1 V                |  |
| DC Current | 20 $\mu\text{A}$  | 0.01 $\mu\text{A}$ | $\Delta I = \pm(2.0 \%  \text{rdg}  + 5 \text{ dgts})$ |
|            | 200 $\mu\text{A}$ | 0.1 $\mu\text{A}$  | $\Delta I = \pm(0.5 \%  \text{rdg}  + 1 \text{ dgts})$ |
|            | 2 mA              | 0.001 mA           |  |
|            | 20 mA             | 0.01 mA            |  |
|            | 200 mA            | 0.1 mA             | $\Delta I = \pm(1.2 \%  \text{rdg}  + 1 \text{ dgts})$ |
|            | 2 A               | 0.001 A            | $\Delta I = \pm(2.0 \%  \text{rdg}  + 5 \text{ dgts})$ |
|            | 20 A              | 0.01 A             |  |
| AC Current | 20 $\mu\text{A}$  | 0.01 $\mu\text{A}$ | $\Delta I = \pm(3.0 \%  \text{rdg}  + 7 \text{ dgts})$ |
|            | 200 $\mu\text{A}$ | 0.1 $\mu\text{A}$  | $\Delta I = \pm(1.0 \%  \text{rdg}  + 3 \text{ dgts})$ |
|            | 2 mA              | 0.001 mA           |  |
|            | 20 mA             | 0.01 mA            |  |
|            | 200 mA            | 0.1 mA             | $\Delta I = \pm(1.8 \%  \text{rdg}  + 3 \text{ dgts})$ |
|            | 2 A               | 0.001 A            | $\Delta I = \pm(3.0 \%  \text{rdg}  + 7 \text{ dgts})$ |
|            | 20 A              | 0.01 A             |  |
| Resistance | 200 $\Omega$      | 0.1 $\Omega$       | $\Delta R = \pm(0.5 \% \text{ rdg} + 3 \text{ dgts})$  |
|            | 2 k $\Omega$      | 0.001 k $\Omega$   | $\Delta R = \pm(0.5 \% \text{ rdg} + 1 \text{ dgts})$  |
|            | 20 k $\Omega$     | 0.01 k $\Omega$    |  |
|            | 200 k $\Omega$    | 0.1 k $\Omega$     |  |
|            | 2 M $\Omega$      | 0.001 M $\Omega$   |  |
|            | 20 M $\Omega$     | 0.01 M $\Omega$    | $\Delta R = \pm(1.0 \% \text{ rdg} + 2 \text{ dgts})$  |

**MODEL UT804**

| Mode                           | Range          | dgts              | Maximum uncertainty                               |
|--------------------------------|----------------|-------------------|---|
| DC Voltage                     | 400 mV         | 0.01 mV           | $\Delta U = \pm(0.025 \%  rdg  + 5 \text{ dgts})$ |
|                                | 4 V            | 0.0001 V          | $\Delta U = \pm(0.05 \%  rdg  + 5 \text{ dgts})$  |
|                                | 40 V           | 0.001 V           |   |
|                                | 400 V          | 0.01 V            |   |
|                                | 1000 V         | 0.1 V             | $\Delta U = \pm(0.1 \%  rdg  + 8 \text{ dgts})$   |
| AC Voltage<br>45 Hz ÷ 1 kHz    | 4 V            | 0.0001 V          | $\Delta U = \pm(0.4 \%  rdg  + 30 \text{ dgts})$  |
|                                | 40 V           | 0.001 V           |   |
|                                | 400 V          | 0.01 V            |   |
|                                | 1000 V         | 0.1 V             | $\Delta U = \pm(1.0 \%  rdg  + 30 \text{ dgts})$  |
| AC Voltage<br>1 kHz ÷ 10 kHz   | 4 V            | 0.0001 V          | $\Delta U = \pm(1.5 \%  rdg  + 30 \text{ dgts})$  |
|                                | 40 V           | 0.001 V           | $\Delta U = \pm(5.0 \%  rdg  + 30 \text{ dgts})$  |
|                                | 400 V          | 0.01 V            |   |
| AC Voltage<br>10 kHz ÷ 100 kHz | 4 V            | 0.0001 V          | $\Delta U = \pm(6.0 \%  rdg  + 30 \text{ dgts})$  |
|                                | 40 V           | 0.001 V           | no specification                                  |
|                                | 400 V          | 0.01 V            |   |
| DC Current                     | 400 $\mu$ A    | 0.01 $\mu$ A      | $\Delta I = \pm(0.1 \%  rdg  + 15 \text{ dgts})$  |
|                                | 4000 $\mu$ A   | 0.1 $\mu$ A       |   |
|                                | 40 mA          | 0.001 mA          | $\Delta I = \pm(0.15 \%  rdg  + 15 \text{ dgts})$ |
|                                | 400 mA         | 0.01 mA           |   |
|                                | 10 A           | 0.001 A           | $\Delta I = \pm(0.5 \%  rdg  + 30 \text{ dgts})$  |
| AC Current<br>45 Hz ÷ 1 kHz    | 400 $\mu$ A    | 0.01 $\mu$ A      | $\Delta I = \pm(0.7 \%  rdg  + 15 \text{ dgts})$  |
|                                | 4000 $\mu$ A   | 0.1 $\mu$ A       |   |
|                                | 40 mA          | 0.001 mA          |   |
|                                | 400 mA         | 0.01 mA           |   |
|                                | 10 A           | 0.001 A           | $\Delta I = \pm(1.5 \%  rdg  + 40 \text{ dgts})$  |
| Resistance                     | 400 $\Omega$   | 0.01 $\Omega$     | $\Delta R = \pm(0.3 \% rdg + 40 \text{ dgts})$    |
|                                | 4 k $\Omega$   | 0.0001 k $\Omega$ |   |
|                                | 40 k $\Omega$  | 0.001 k $\Omega$  |   |
|                                | 400 k $\Omega$ | 0.01 k $\Omega$   | $\Delta R = \pm(0.5 \% rdg + 40 \text{ dgts})$    |
|                                | 4 M $\Omega$   | 0.0001 M $\Omega$ | $\Delta R = \pm(1.0 \% rdg + 40 \text{ dgts})$    |
|                                | 40 M $\Omega$  | 0.001 M $\Omega$  | $\Delta R = \pm(1.5 \% rdg + 40 \text{ dgts})$    |

**MODEL AX-582B**

| Mode       | Range             | dgts               | Maximum uncertainty                                     |
|------------|-------------------|--------------------|---|
| DC Voltage | 200 mV            | 0.1 mV             | $\Delta U = \pm(0.5 \%  \text{rdg}  + 5 \text{ dgts})$  |
|            | 2 V               | 0.001 V            | $\Delta U = \pm(0.5 \%  \text{rdg}  + 3 \text{ dgts})$  |
|            | 20 V              | 0.01 V             |   |
|            | 200 V             | 0.1 V              |   |
|            | 1000 V            | 1 V                | $\Delta U = \pm(1.0 \%  \text{rdg}  + 10 \text{ dgts})$ |
| AC Voltage | 2 V               | 0.001 V            | $\Delta U = \pm(0.8 \%  \text{rdg}  + 5 \text{ dgts})$  |
|            | 20 V              | 0.01 V             |   |
|            | 200 V             | 0.1 V              |   |
|            | 750 V             | 1 V                | $\Delta U = \pm(1.2 \%  \text{rdg}  + 10 \text{ dgts})$ |
| DC Current | 20 $\mu\text{A}$  | 0.01 $\mu\text{A}$ | $\Delta I = \pm(1.2 \%  \text{rdg}  + 8 \text{ dgts})$  |
|            | 200 $\mu\text{A}$ | 0.1 $\mu\text{A}$  |   |
|            | 2 mA              | 0.001 mA           |   |
|            | 20 mA             | 0.01 mA            |   |
|            | 200 mA            | 0.1 mA             | $\Delta I = \pm(1.5 \%  \text{rdg}  + 10 \text{ dgts})$ |
|            | 2 A               | 0.001 A            |   |
|            | 20 A              | 0.01 A             |   |
| AC Current | 200 mA            | 0.1 mA             | $\Delta I = \pm(1.5 \%  \text{rdg}  + 15 \text{ dgts})$ |
|            | 2 A               | 0.001 A            | $\Delta I = \pm(2.0 \%  \text{rdg}  + 5 \text{ dgts})$  |
|            | 20 A              | 0.01 A             | $\Delta I = \pm(3.0 \%  \text{rdg}  + 10 \text{ dgts})$ |
| Resistance | 200 $\Omega$      | 0.1 $\Omega$       | $\Delta R = \pm(0.8 \% \text{ rdg} + 5 \text{ dgts})$   |
|            | 2 k $\Omega$      | 0.001 k $\Omega$   | $\Delta R = \pm(0.8 \% \text{ rdg} + 3 \text{ dgts})$   |
|            | 20 k $\Omega$     | 0.01 k $\Omega$    |   |
|            | 200 k $\Omega$    | 0.1 k $\Omega$     |   |
|            | 2 M $\Omega$      | 0.001 M $\Omega$   |   |
|            | 200 M $\Omega$    | 0.1 M $\Omega$     | $\Delta R = \pm(5.0 \% \text{ rdg} + 20 \text{ dgts})$  |

Example 1

Multimeter UT804, DC V range 4 V, value read from DMM display  $U = -1.9876$  V.

$$\Delta U = \pm(0.05 \% |\text{rdg}| + 5 \text{ dgts}), \quad (\text{A3.1})$$

where  $|\text{rdg}| = 1.9876$  V and  $\text{dgts} = 0.0001$  V.

Maximum uncertainty  $\Delta U = \pm(0.05 \% \times 1.9876 + 5 \times 0.0001)$  V, and next value  $\Delta U = \pm 0.0015$  V  $\approx \pm 0.002$  V (the uncertainty should be rounded up). Finally:

$$U = (-1.988 \pm 0.002) \text{ V}$$

Example 2

Multimeter AX-582, resistance range  $200 \Omega$ , value read from DMM display  $R = 100.3 \Omega$ .

$$\Delta R = \pm(0.8 \% \text{ rdg} + 5 \text{ dgts}), \quad (\text{A3.2})$$

where  $\text{rdg} = 100.3 \Omega$  and  $\text{dgts} = 0.1 \Omega$ .

Maximum uncertainty  $\Delta R = \pm(0.8 \% \times 100.3 + 5 \times 0.1) \Omega$ , and next  $\Delta R \approx \pm 1.4 \Omega$  (the uncertainty should be rounded up). Finally:

$$R = (100.3 \pm 1.4) \Omega$$