ELECTRICAL MEASUREMENTS

1. Aim.

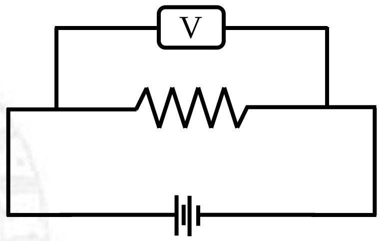
- Learn to use measuring instruments:
  - Digital multimeter.
  - Oscilloscope.
- Assembly of simple elementary circuits.
- Collection and interpretation of LISSAJOUS patterns.

2. Overview.

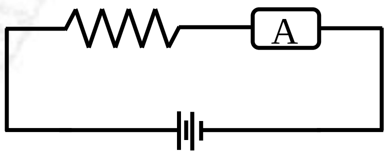
Many common electrical measurement instruments are based on electrical current. This first lab exercise seeks to give you some understanding of these instruments and to demonstrate their correct use.

Generally, in an electric circuit we can get two electrical measurements: current measurements (I) and voltage measurements (V).

- To **measure V** with a multimeter:
  Connect the voltmeter **in parallel** with the element, i.e. the black-test lead is connected to the negative terminal of the element being measured, and the red-test lead is connected to the positive terminal of the element, as shown in the figure.



- I (current) can be measured by connecting a multimeter **in series** with the element. Be careful, as the multimeter may be damaged by wrong measurement connection.



2.1 Resistor color code guide.

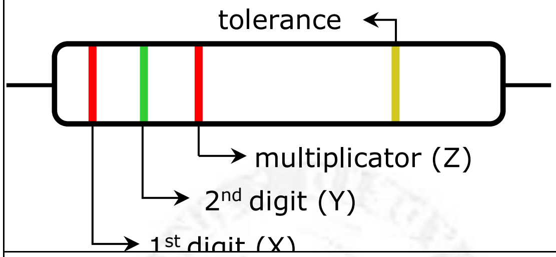
A resistor is a circuit element manufactured to have a constant resistance. The resistance of a resistor can be determined by the color bands (see the chart below) printed on the resistor according to the following rule:

R = (first color number)(second color number) x 10 (third color number) Ω

The fourth color band tells you the tolerance of the resistor: gold means ±5% tolerance, silver means ±10% tolerance and no fourth band means ±20%.

High-precision resistors have five bands. The first three bands indicate the first three significant figures of the resistance; the fourth band indicates the number of zeros; the fifth band is the percent tolerance.

Digit (X, Y, Z) → Color	
0 → Black	5 → Green
1 → Brown	6 → Blue
2 → Red	7 → Violet
3 → Orange	8 → Grey
4 → Yellow	9 → White



Resistor Value:

$$R = XY \times 10^{Z}\ \Omega$$

Color Code:

- First band correspond to first digit X.
- Second band correspond to second digit Y.
- Third band correspond to the (exponent) Z.
- Fourth band indicates the precision: 5% gold and 10 % silver.

Example: One resistor with red-green-red-gold code has a value of,
$R=25 \times 10^{2}\Omega=2500\Omega=2.5$ kΩ, 5% of precision, it is, 2500 x 0.05 = 125. The result is,
$R \pm \Delta R = 2.50 \pm 0.13$ kΩ.

2.2 Multimeter.

A multimeter is an electronic measuring instrument that combines several measurement functions in one unit. A typical multimeter may measure:

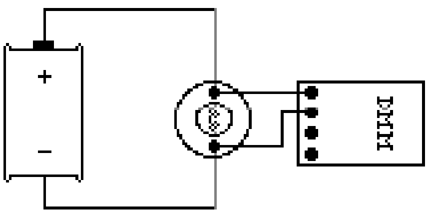
- currents and voltages at stationary regime (DC=direct current), or alternating currents (AC).
- resistances
- capacitances
- electric continuity
- hybrid parameters of transistors

2.2.1 How to measure with a digital multimeter (DMM).

Measuring Voltage:

1. Set the DMM selection dial to read DC volts (V). Insert one wire into the socket labeled 'V mA μA Ω' and a second wire into the socket labeled 'COM'.
2. Connect the two wires from the DMM to the two points between which you want to measure the voltage, as shown below.

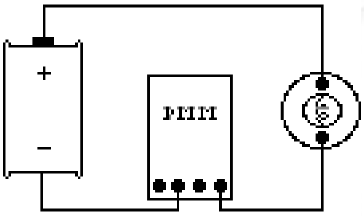
To measure voltage, the DMM must be placed in the circuit so that the potential difference across the circuit element you want to measure is the same as the one across the DMM.



Measuring Current:

1. If the current to be measured is smaller than 500 mA, insert one wire into the socket labeled 'V mA μA Ω' and a second wire into the socket labeled 'COM'. For larger currents, use the socket labeled '10 A'.

2. Attach the DMM into the circuit as shown below:



To measure current, the DMM must be placed in the circuit so that all the current you want to measure goes **through** the DMM.

Figure 1. Digital multimeter with autoscaling

2.3 Oscilloscope.

An oscilloscope (shown in figure 2) is used to graphically observe circuit behavior by displaying waveforms on a screen. It is a basic tool used in the study of time varying electrical signals. In general, the Y-axis represents voltage, while the X-axis represents time. The oscilloscope can also measure DC signals.

After connecting the oscilloscope to the electric power supply and switch it on, it is necessary to become familiar with the front panel. Seek the advice of the instructor.

2.3.1 General comments.

Generally, all oscilloscopes have three basic sectors, Vertical, Horizontal and Trigger (time), **BNC connectors**, which connect the measurement probes, and input channels, typically labeled as I and II (CH1 and CH2). The existence of two channels allows us to make the comparison between signals in a more simple way.

Recommended steps in the basic setting of the oscilloscope:

- Connect the signal to be measured to one of the channels, typically CH1.
- Press the *autoset* button in the menu below the screen.
- Turn off the measurement channel that is not being used. (to turn off a channel, press the CH1 or CH2 key twice).
- Center the signal on the screen using the *Position* wheels.
- Select the most appropriate voltage and time scales in each case. The scales will be displayed in the lower left corner of the screen.
- If the signals move in the X axis, stop the signal using the *run/stop* button or configure the *trigger*.

A *Quick guide to measuring with the PEAKTECH 1403 oscilloscope* can be found at the end of this guide.

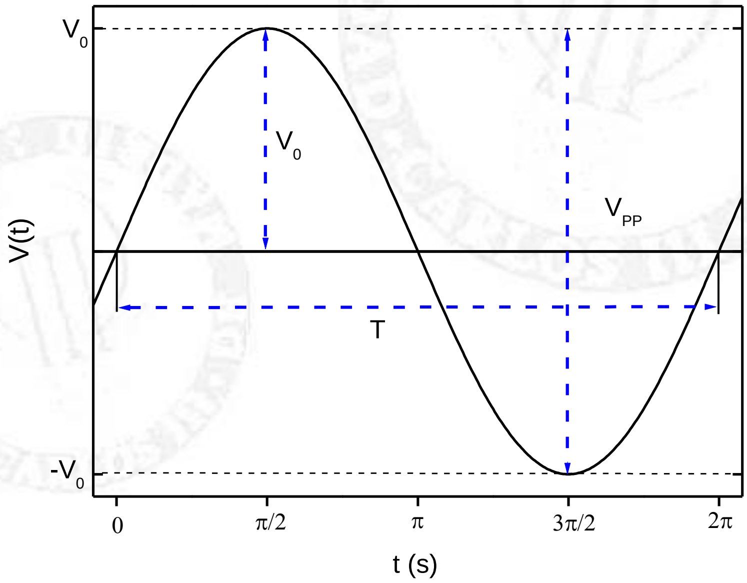
Measuring and Estimating Process Performance

- Measure frequency and amplitude of a periodic signal.

A periodic sinusoidal voltage signal, will appear in the oscilloscope screen similar to the next figure. The voltage can be described by the following equation:

$$V(t) = V_0 \text{sen}\, \omega t$$

Where V_0 is the amplitude of the signal and ω is its frequency.



V_{PP} is the peak to peak voltage: $V_0 = \frac{V_{PP}}{2}$, and T is the signal period.

$$T = \frac{2\pi}{\omega}.$$

Where: $\omega = 2\pi f = \frac{2\pi}{T}$,

and f is the frequency of the signal.

- Study of information.

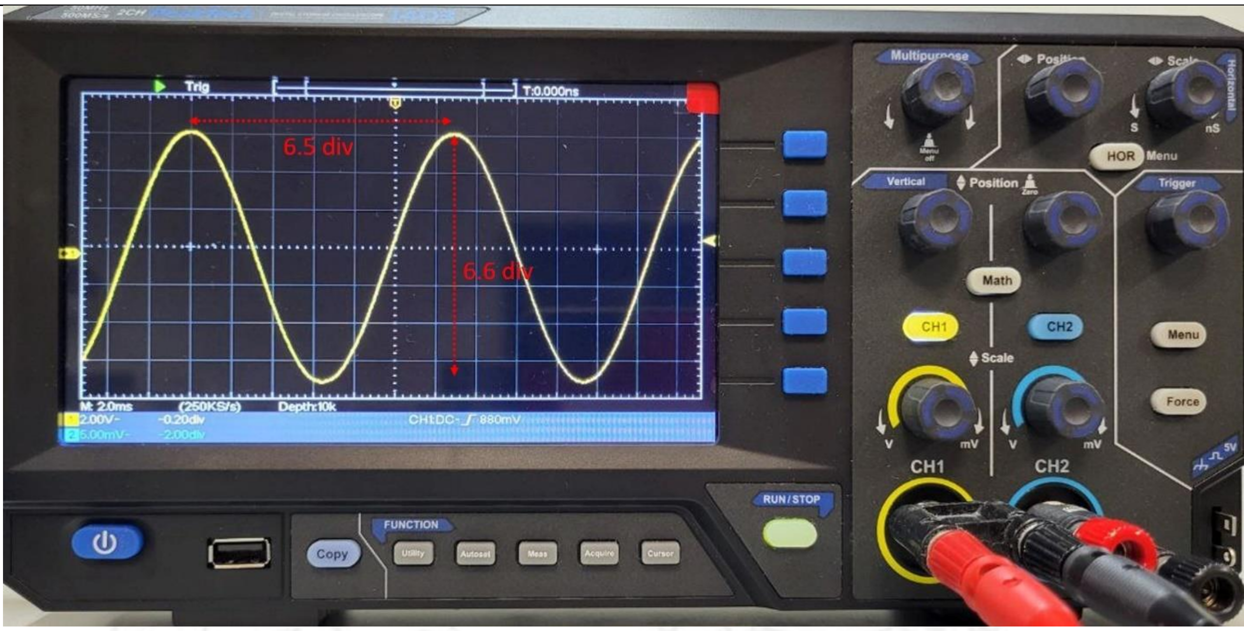


Figure 2. Oscilloscope

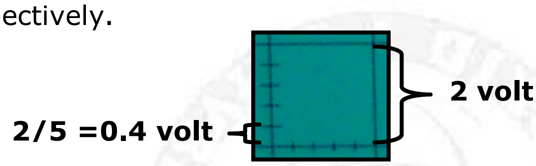
- Voltage measurement.

$$[\mathbf{V_{PP}} \pm \Delta\mathbf{V_{PP}}]\,\mathbf{V} = 14.6 \pm 0.2\,\mathbf{V}$$

where

$$V_{PP} = 6.6(\text{div}) \times 2\left(\frac{\text{volt}}{\text{div}}\right) = 13.2\ \text{V}, \qquad \Delta V_{PP} = \frac{2\left(\frac{\text{volt}}{\text{div}}\right)}{(2\times 5)\text{div}} = 0.2\ \text{V}$$

And a div corresponds to a picture, which is divided into five parts in both the vertical and the horizontal axis respectively.



- Period measurement.

$$[\text{T} \pm \Delta\text{T}]\,\text{s} = (13.0 \pm 0.2)\text{ms} = (13.0 \pm 0.2)10^{-3}\,\text{s}$$

Where: $\text{T} = 6.5(\text{div}) \times 2\left(\frac{\text{ms}}{\text{div}}\right) = 13\ \text{ms},\qquad \Delta\text{T} = \frac{2\left(\frac{\text{ms}}{\text{div}}\right)}{(2\times 5)\text{div}} = 0.2\text{ms}$

ΔV_{PP} and ΔT are the precision uncertainties of the oscilloscope on the vertical and the horizontal axis respectively. As the measurement is analogical, this is half of the smallest division that is being measured.

- Phase shift measurement.

Usually, the horizontal section controls the time base or "sweep" of the instrument. The primary control is the Seconds-per-Division (Sec/Div) selector switch. But it is also included a horizontal input for plotting dual X-Y axis signals.

Most modern oscilloscopes have several inputs for voltages, and thus can be used to plot one varying voltage versus another. This is especially useful for graphing I-V curves (current versus voltage characteristics) for components such as diodes, as well as for visualizing Lissajous patterns.

The period of a signal corresponds to a phase of 360 º (2π). The phase shift indicates the angle of delay or advancement which has a signal with respect to another (taken as reference).

One method to measure the phase shift is to use the XY mode. This involves placing a signal in the vertical channel (usually channel I) and the other in the horizontal channel (II) (this method only works correctly if both signals are sinusoidal). The resulting waveform on the screen is called Lissajous figure in honor of the French mathematician Jules Antoine Lissajous 1822-1880). Lissajous figures are an example of how an oscilloscope can be used to track phase differences between multiple input signals. This is very frequently used in broadcast engineering to plot the left and right stereophonic channels, to ensure that the stereo generator is calibrated properly. Historically, stable Lissajous figures were used to show that two sine waves had a relatively simple frequency relationship, a numerically-small ratio. They also indicated phase difference between two sine waves of the same frequency.

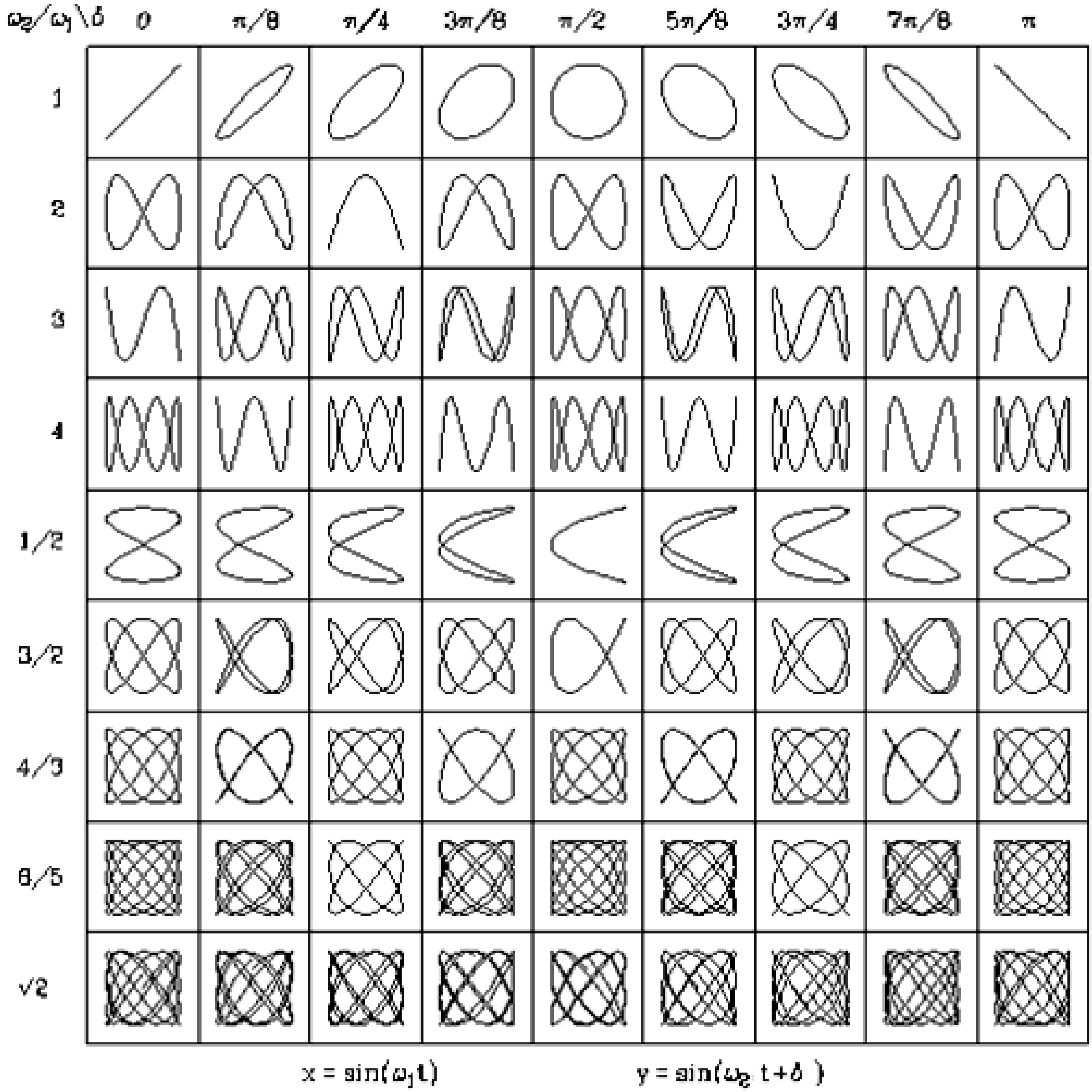


Table 1. Lissajous figures

2.4 Relationship between the quantities measured with the oscilloscope (instantaneous values) and measured with a multimeter (RMS).

RMS value (Irms) in a time-varying current, I (t) is the mean square value of this magnitude (rms: root mean square.)

$$I_{ef} = \left[\frac{\int_{i_1}^{t_2} (I(t))^2 \, dt}{\Delta t} \right]^{1/2}$$

In the event that the time dependence is sinusoidal is obtained a relationship between Irms and Io given by the form:

$$I_{ef} = \frac{I_o}{\sqrt{2}} = \frac{I_{PP}}{2\sqrt{2}}$$

In the case of a voltage signal with a sinusoidal dependence can also write equivalent expressions:

$$V_{ef} = \frac{V_o}{\sqrt{2}} = \frac{V_{PP}}{2\sqrt{2}}$$

3 Learn more...

- **TIPLER, PA & MOSCA, G. "Physics" Volume 2. 6th edition Ed. W.H. Freeman/Worth Publishers 2007 Cap. 25 Pags 750-751.**
- **KEITHELY, "Low Level Measurements", 5ª edition, Section 2 (2.1-2.5). Pags 2-3 a 2-41.**

In internet.

http://www.hameg.es/osc/osc_5.htm

http://ibiblio.org/e-notes/Lis/Lissa.htm

http://www.physics.orst.edu/~rubin/nacphy/CPapplets/lissajous/Fig2p.html

http://www.sc.ehu.es/sbweb/fisica/oscilaciones/lissajous/lissajous.htm

http://www.univ-lemans.fr/enseignements/physique/02/electro/lissajou.html

http://www2.siit.tu.ac.th/prapun/ecs204/

http://www.art-sci.udel.edu/ghw/phys245/05S/lab/meters.html

http://www.wisc-online.com/objects/ViewObject.aspx?ID=ACE3803

http://www.facstaff.bucknell.edu/mastascu/eLabs/Scope/Scope1.html

http://www2.siit.tu.ac.th/prapun/ecs204/

4. Equipment.

1. Digital multimeter.
2. Oscilloscope.
3. Transformer.
4. 4.5 V battery.
5. Breadboard (Protoboard).
6. Connectors
7. Frequency generator.

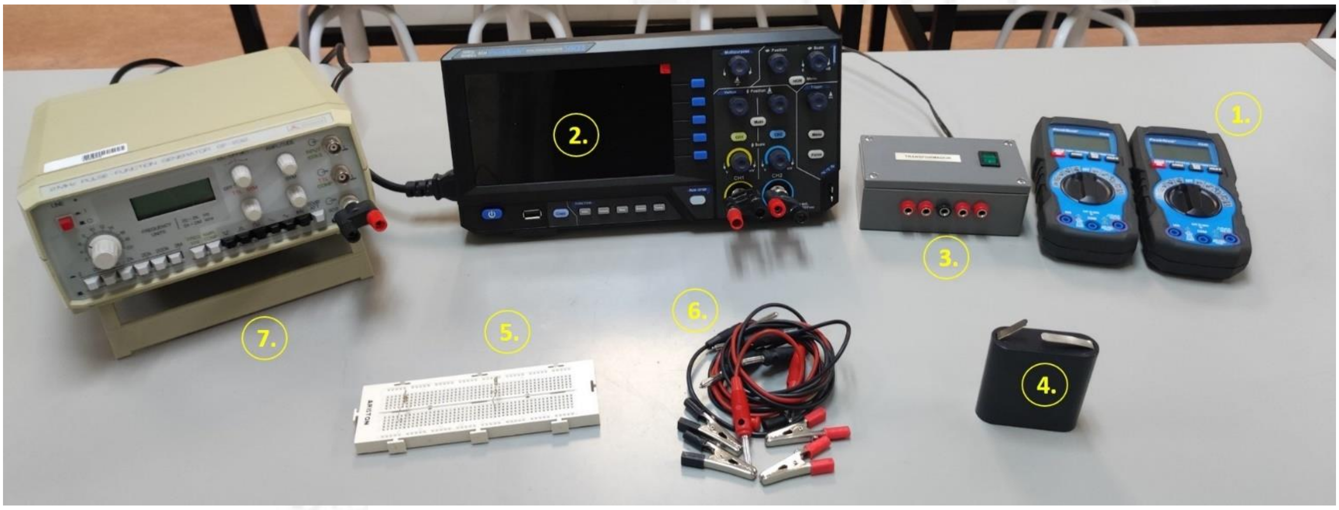


Figure 3. Experimental setup

5. Experimental procedure.

5.1 Use of multimeter as a voltmeter and ohmmeter.

5.1.1 Measure, using the multimeter as a voltmeter, the DC voltage at the terminals of the battery. Compare the results with the one indicated by the manufacturer.

5.1.2 Measure, using the multimeter as an ohmmeter, the value of the two resistors, R_1 and R_2. Compare these results with the value reported by the manufacturer using the color code.

5.2 Using the multimeter as an ammeter and voltmeter.

5.2.1 Assemble, using the breadboard, the circuit shown below:

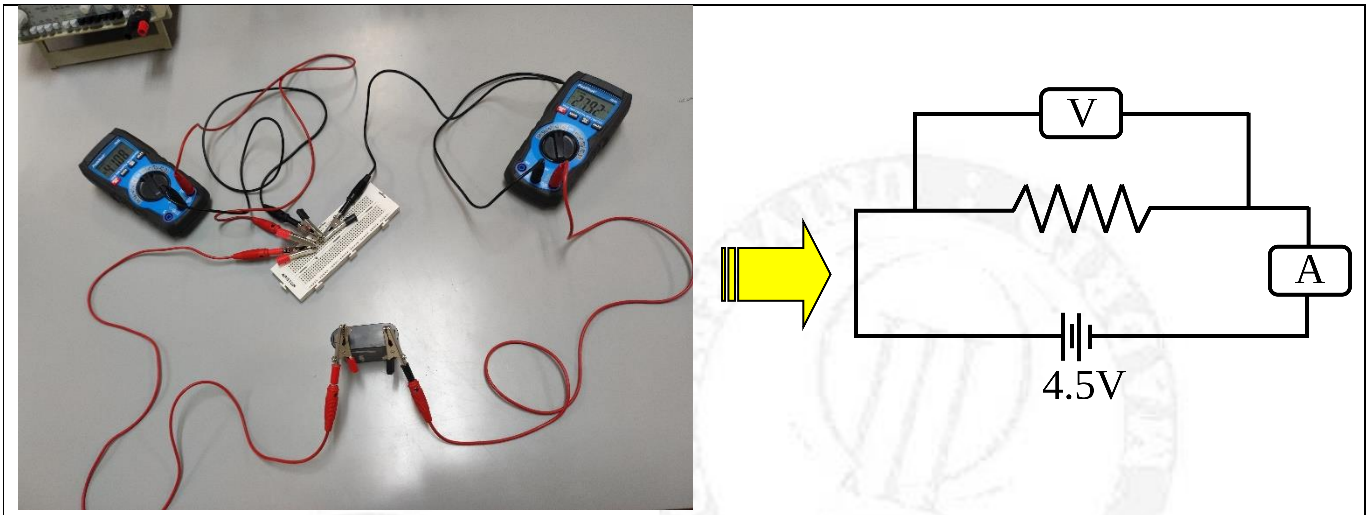


Figure 4. Measure of the current and voltage drop though a resistor.

5.2.2 Indirect measurement of resistance: measure the voltage drop across the resistor R_1 and the current flowing through the circuit. Using Ohm's law, find the resistance value R_1 and compare it with previous findings (see 5.1.2).

5.2.3 Indirect measurement of Current: measure the voltage drop across resistor R_2 and the current flowing through the circuit. Knowing the value of R_2 obtained in 5.1.2, calculate the current value using Ohm's law, and compare it with that obtained from direct measurement on the ammeter.

5.3 Using the oscilloscope to measure amplitude and period of time-varying signals.

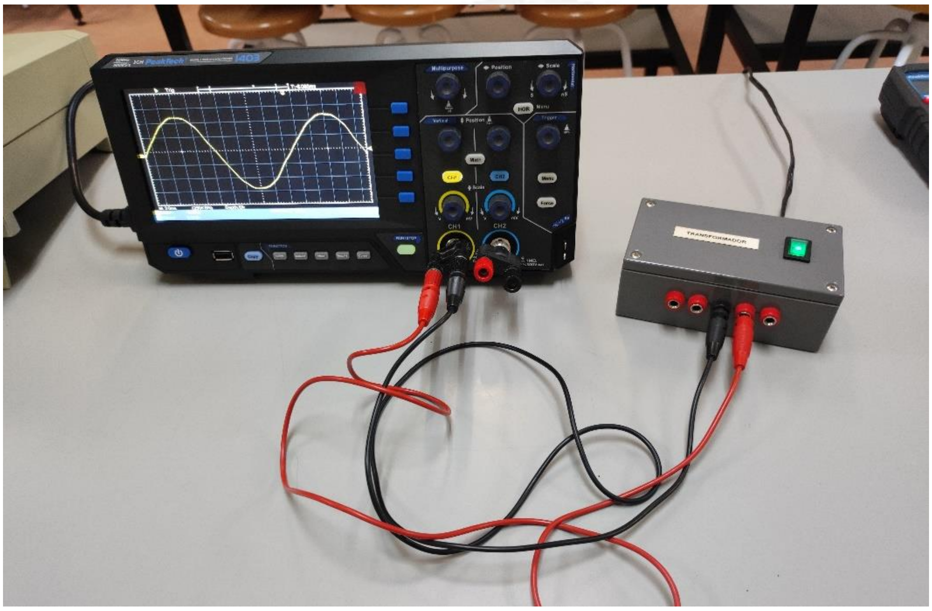


Figure 5. Measurement of the amplitude and period of a signal V(t)

5.3.1 Measure, using the oscilloscope, the voltage value on the battery and compare this result with that obtained in paragraph 5.1.1.

5.3.2 Using the different transformer outputs, measure the amplitude and frequency for each one of them. Check that the output signals of the secondary are described by the equation

$$V(t) = V_0 \text{sen}\ \omega t$$

(Remember V_0 is calculated from V_{PP} voltage peak to peak and ω from T.)

5.3.3 Discuss the frequency values obtained and give a value for the frequency of the network. Is it expected? Why?

5.3.4 Measure, using the multimeter as a voltmeter, the voltage **<u>at AC</u>** in at least three of the outputs of the transformer. Compare RMS voltage with the amplitude value for these outputs V_0 obtained in the previous section.

5.4 Obtain Lissajous patterns.

5.4.1 To obtain the Lissajous figures, you must follow the following steps:

- Connect the output of the frequency generator to channel II (CH2) of the oscilloscope and configure it so that the signal observed on the oscilloscope is sinusoidal with a frequency of 50 Hz. Connect one of the outputs of the transformer to channel I (CH1) of the oscilloscope.
- Press the *Autoset* button located below the screen. Check that both channels are active (lit). If not, press the CH1 or CH2 buttons to activate them.
- Press the *Position* button to center the signal on the screen.
- In the *Trigger* panel, press *Menu*. A menu of options will appear on the right side of the screen. Select the ALT value for the *Type* parameter using the corresponding blue button.
- Press the *Acquire* button in the Function panel below the screen. Activate the X-Y function, in the panel displayed on the screen, by pressing the blue “X-Y Mode” button.
- The screen should show a Lissajous figure (if necessary, fine-tune the generator frequency to around 50 Hz). If the figure is not centered, press the *Position* buttons for each channel.
- If the figure moves in the X axis, stop the signal using the run/stop button or configure the *trigger*.

Figure 6. Obtention of Lissajous figures

5.4.2 Increase the generator frequency to 100, 150 and 200 Hz and observe the Lissajous patterns corresponding to 1:2, 1:3 and 1:4. Examples are shown below.

5.4.3 Discuss your observations. Can you deduce the frequency of the signal coming from the transformer?

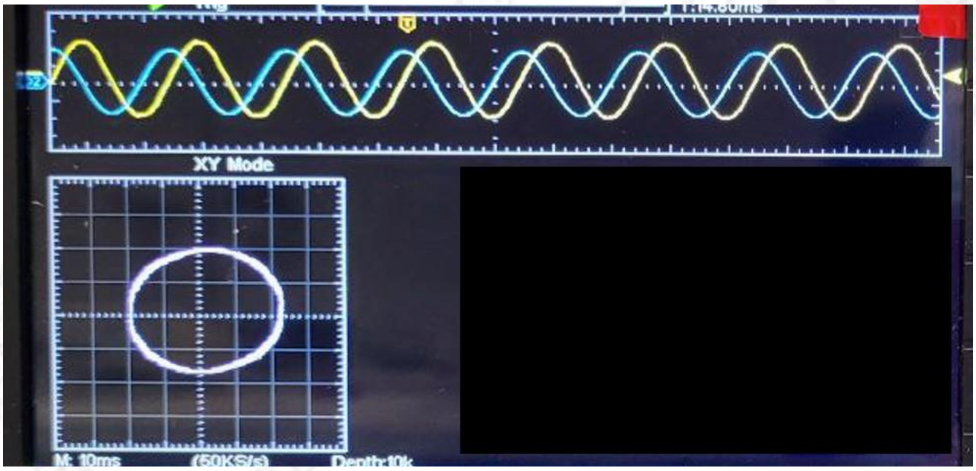


Figure 7. Frequency relationship 1:1; phase shift = $\pi/2$

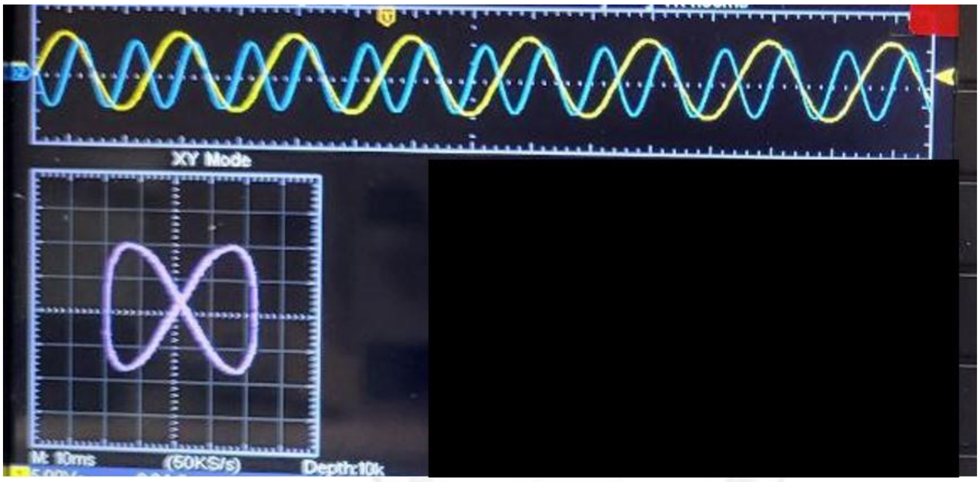


Figure 8. Frequency relationship 1:2; phase shift = $\pi/2$

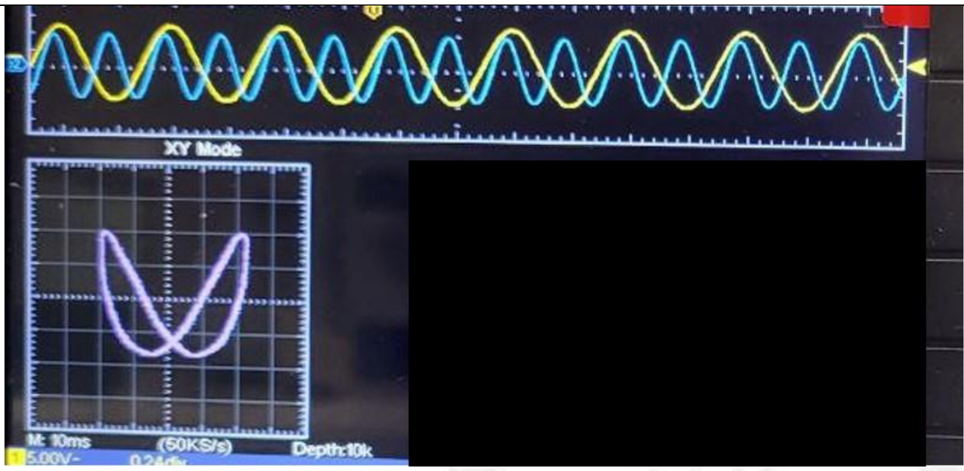


Figure 9. Frequency relationship 1:2; phase shift = 5π/8

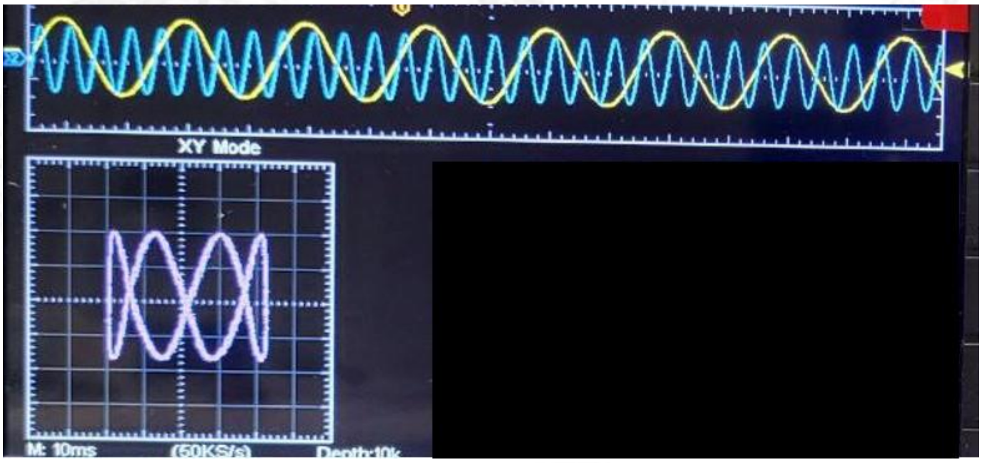
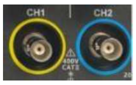


Figure 10. Frequency relationship 1:4; phase shift = π/4

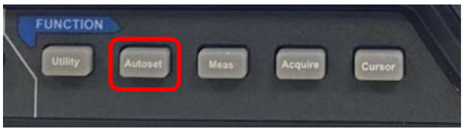
<u>**QUICK GUIDE TO MEASURING WITH THE PEAKTECH 1403 OSCILLOSCOPE**</u>

1. Disconnect any probes or cables connected to channels CH1 and CH2.

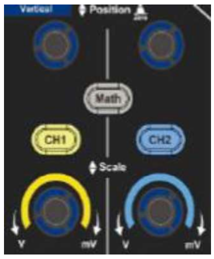
2. Press the power button (left side corner, below the display) and wait about 15 seconds for the oscilloscope to start up. 

3. Connect the cables or probes with the signals to be measured to channels CH1 and/or CH2. 

4. Press the button "**Autoset**" in the menu "**Function**", that is located below the display. The signal(s) should be shown on the display.



5. Selection of the channel(s) for measurement: when the channel is activated, the buttons "**CH1**" or "**CH2**" are illuminated. To deactivate them, press the button "**CH1**" or "**CH2**" twice and the button goes out. You can reactivate them by pressing the corresponding button again.
   Press the button "**position**" to centre the signal on the screen.



6. If the signal(s) is(are) continuously shifted on the time axis (X-axis), then the "**trigger**" must be configured. Press the button "**Menu**" (1) on the "**Trigger**" panel, which displays the option menu "**TriggerMode**" (2) in the screen. Select the value "**ALT**" for the parameter "**Type**" using the blue button (3)on the side of the display.