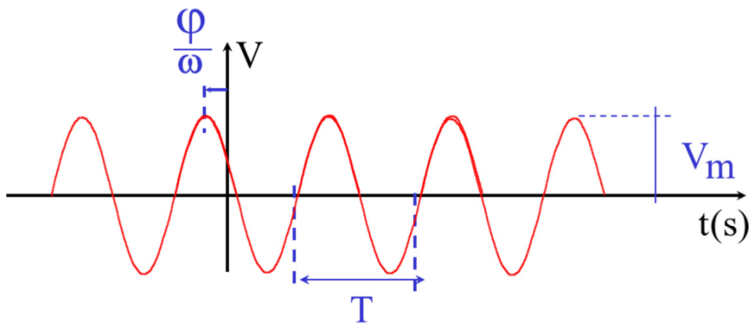
PRACTICE 3. THE OSCILLOSCOPE. ERRORS ON INDIRECT MEASUREMENTS

1. INTRODUCTION.

The **Oscilloscope is a voltmeter** enabling us to see magnitude of voltage through the time on its screen. That is, we can see how voltage is changing on time between the points where it's connected. In this way, oscilloscope is an instrument **showing voltages as a function of time**, instead only give the value of a measurement as it happens on a voltmeter. Then, the horizontal axis of the oscilloscope corresponds to time and the vertical axis to a voltage. The most used signals studied on oscilloscope are sinusoidal signals. In order to remember the most important parameters of a sinusoidal wave, a brief review will be done.

2. SINUSOIDAL WAVES

A sinusoidal wave (in this case a voltage) is that changing on time according the equation $V(t) = V_m \cos(\omega t + \varphi)$ where V_m is the **amplitude** of signal (V), ω is the **angular frequency** (rad/s), t is the **time** (s), and φ is the **initial phase** of wave; (ωt+φ) is the **phase** of wave. The amplitude gives us information about maximum and minimum reached magnitudes, and φ about the relative position of wave with respect to ordinates axis. Angular frequency is related to **frequency** (f) (times the wave is repeated on a second) and to **period** (T) (time of a cycle):



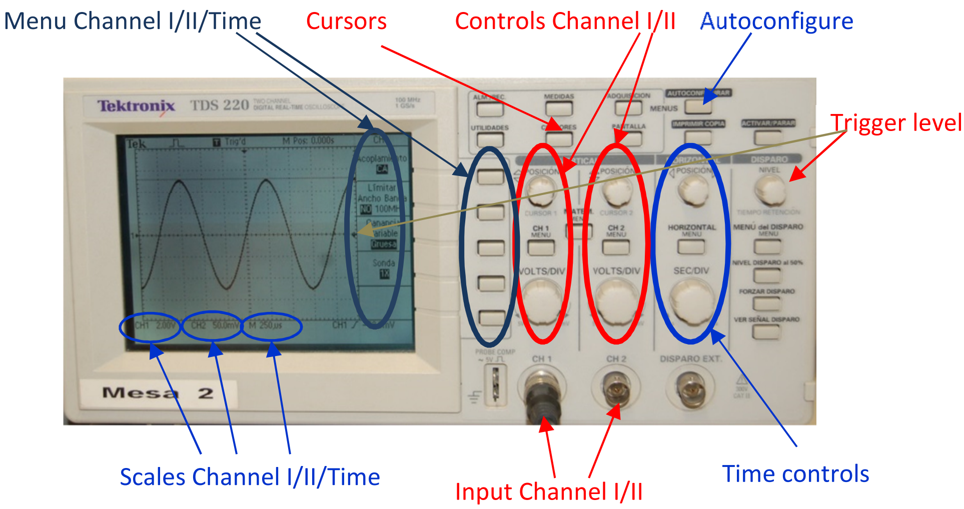
$$f = \frac{\omega}{2\pi}$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega}$$

The oscilloscope we are going to use automatically gives initial phase zero to drawn signal. When two phased lag signals are drawn, the instrument automatically gives initial phase zero to one of them, appearing phased lag the other signal.

3. THE DIGITAL OSCILLOSCOPE

They appear on next picture the most important controls of **digital oscilloscope Tektronix TDS 220**. There are much more controls, but those on picture are the most important.



Before measuring with the oscilloscope. Previous Adjustement. Before measuring with the oscilloscope is very important to carry out several adjustments in order we can properly see the voltage we are working with:

a) **Zero adjustment.** By pressing the buttons "**CH1 Menu/CH2 Menu"** you can select if you want to represent on screen the signal of channel I, the signal of channel II, or both at once. When you press these buttons you also are selecting the menu on right side of screen, with a lot of options to adjust the drawn wave. The options of this menu can be selected with the column of buttons near the screen. Select the upper option of menu, **"Acoplamiento"**, selecting the option **"Tierra"**. A horizontal line appears on screen, and using the control **"Position"** of this channel, we must place this line exactly on zero of voltages (middle position of screen). Now, we must return to the option **"Acoplamiento"** and choose the option "**AC"** if we are dealing with an alternating current, or "**CC**" if we are dealing with a direct current (or currents of low frequency).

   This adjustment must be repeated for both channels.

b) **Magnification**. You must also verify that the magnitude of wave on screen isn't magnified by the oscilloscope; to verify it, you must press the button "**CH1 MENU/CH2 MENU**" and on menu on right side of display, the option "**Sonda**" must be set up on "**X1**". If not, you should change it. This adjustment must be repeated for both channels.

c) **Trigger level.** The third important checking is that the trigger level (indicated by a little black arrow on right side of screen was over the horizontal axis; it can be got with the control (**Disparo/Nivel**). This control is saying to the oscilloscope the level of trigger for voltage on vertical axis of oscilloscope (the voltage on time t=0); if this level is too low or too high, you'll see the wave moving along the screen all the time, not being possible it was motionless. Now, **you can already start this practice.**

4. MEASURING WITH THE OSCILLOSCOPE.

To see properly the signal you are entering on channel I or II, you must on first press the button **"Autoconfigurar"** and the oscilloscope looks for itself the best scales. At the bottom of screen appears the **vertical scales of channels I and II** (in **V/division** or **mV/division**) and the **horizontal scale** (time scale) in **s/div ms/div or μs/div**. A division is a big square appearing on screen.

a) **From the scales** appearing on screen, by multiplying these scales by the number of divisions taken by the wave, **can be calculated both the amplitude** (vertical axis) as the **period** (horizontal axis) of wave. But this method is more **inaccurate** than the method of cursors, explained below.

b) **By using the cursors** is the most comfortable and accurate way to measure on screen of oscilloscope. By pressing the button **"Cursors"** two parallel lines appear on screen; these lines can be horizontal lines or vertical lines, depending on which type of cursors you have selected on the menu corresponding to this channel. If you select the **type of cursors "Voltage"**, you'll see two **horizontal lines**, but if you select type of **cursors "Time"** you'll see two **vertical lines**. These lines can be moved with the position control of both channels, and the position of each line and the **difference between them** can be read in the menu on screen. So, in this way you can measure the amplitude, the peak to peak voltage, the period of wave, etc…

The inverse of period (T) is the frequency (f) in Hz, and multiplying this value by 2π, we get the **angular frequency** in rad/s: $\omega = 2\pi f$.

About the **error of measurements on oscilloscope**, we'll **only consider the reading error, neglecting the accuracy error**. According the scale you are using on vertical/horizontal axis, you must **calculate how many volts/seconds correspond to a step of cursor**, or the lowest magnitude you can measure on screen, and this is the **reading error of amplitude/period**.

The errors of frequency and angular frequency can't be computed directly from reading on oscilloscope, and they **must be computed according to the theory of error propagation**, as it's explained below.

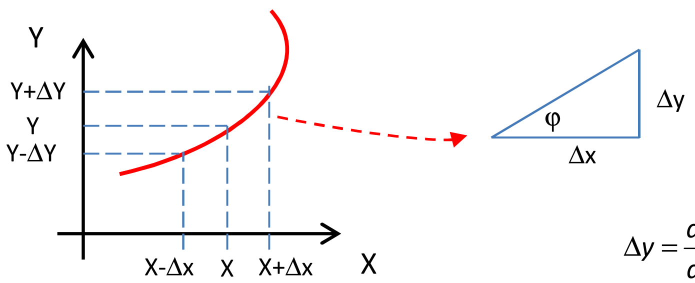
5. ABSOLUTE ERROR ON INDIRECT MEASUREMENTS. ERROR PROPAGATION.

When we compute **a magnitude from other magnitudes through a math equation**, the errors of original magnitudes are spread to the new computed magnitude, and the error on the last one obviously depends on the first ones. This "spreading" of errors is known as **error propagation**.

a) Indirect measurements depending on only one variable.

When measurement we are computing depends only on a variable, computation of error is immediate:

Let's suppose we want indirectly measure a quantity "y", from another quantity "x", knowing the last one with its absolute error x ± Δx, and also the function relating "y" and "x", y=f(x). If we draw this function, a little change Δx around x (an error) is spread on a change Δy around y:



$$\Delta y = \Delta x \cdot tg\varphi$$

$$tg\varphi = \frac{dy}{dx}$$

$$\Delta y = \frac{dy}{dx}\Delta x$$

As derivative of a function can be positive or negative, in order to avoid negative absolute errors, absolute value of derivative is taken:

$$\Delta y = \left|\frac{dy}{dx}\right|\Delta x \qquad [1]$$

Example 1: we have measured the period of a wave: T=1,03±0,03 ms

The frequency is: $f=\frac{1}{T}=\frac{1}{1,03}=0,970873\,KHz$

The error of this frequency can be computed according to the error propagation theory:

$$\Delta f=\left|\frac{df}{dT}\right|\Delta T\Rightarrow\Delta f=\frac{1}{T^2}\Delta T=\frac{1}{1,03^2}0,03=0,0282778......$$

The error must be rounded to 0,03 according the rules given and then the frequency only has two meaningful figures: **f=0,97±0,03 KHz**

b) <u>Indirect measurements depending on several variables.</u>

When indirect measurement depends on more than one variable, absolute error must be computed as on equation [1] but adding all partials derivatives corresponding to all variables. Let's suppose we have a quantity "y" depending on other three variables, "x", "z" and "t". Absolute error of "y" is:

$$\Delta y=\left|\frac{\partial y}{dx}\right|\Delta x+\left|\frac{\partial y}{dz}\right|\Delta z+\left|\frac{\partial y}{dt}\right|\Delta t \qquad [2]$$

Example 2: Let's suppose we are measuring the drop of potential on terminals of a resistor with its absolute error (V±ΔV), resulting 3,2±0,5 V and the intensity of current flowing along it (I±ΔI), resulting 1,212±0,003 mA. By applying Ohm's law, magnitude of resistor is $R=\frac{V}{I}=\frac{3,2}{1,212}=2,64026....\,K\Omega$. In this case, the resistance depends on two variables, V and I. Through equation [2] we can compute the absolute error of computed resistance (remember that a partial derivative means to derive with respect to a variable, taking the other variables as constants):

$$\Delta R=\left|\frac{\partial R}{dV}\right|\Delta V+\left|\frac{\partial R}{dI}\right|\Delta I=\frac{1}{I}\Delta V+\frac{V}{I^2}\Delta I=\frac{1}{1,212}0,5+\frac{3,2}{1,212^2}0,003=0,41907...\,K\Omega \qquad [3]$$

Rounding the error to 0,4 and consequently the measurement to 2,6 the measured resistance would size: **R=2,6±0,4 KΩ**

PRACTICE 3. THE OSCILLOSCOPE. ERRORS ON INDIRECT MEASUREMENTS. CARRYING OUT

1. OBJECTIVES

The objective of this practice is learning the basic handling of digital oscilloscope, as well as the understanding of got results. We'll also practice the errors on measurement.

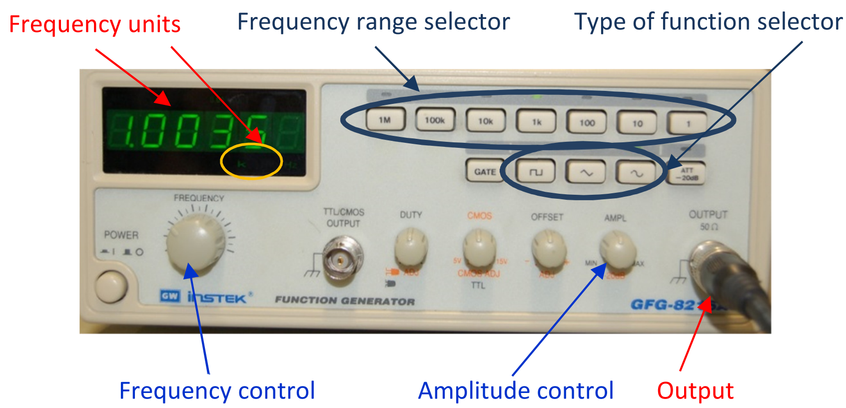
2. MATERIAL

- Function generator Instek GFG-82
- Digital oscilloscope tektronix TDS 220

3. CARRYING OUT

Before connecting the oscilloscope and the wave generator, you must **verify the correct adjustment of oscilloscope**, as it's explained on point 3 a), b) and c) of this guide.

You have on picture the main controls of function generator Instek GFG-82. **Connect the output of function generator to channel I of digital oscilloscope**. Adjust the function generator in order it gives a **sinusoidal wave** with a frequency of **800 Hz** and **maximum amplitude**. Press on oscilloscope the button **"Autoconfigurar"** and you'll see the wave on the screen. **Take a photo** of the screen of oscilloscope with your mobile phone.



a) **Measure the amplitude (V_m)**, of wave by **using the cursors** of oscilloscope. Taking in account the voltage corresponding to one step of cursors, compute the absolute error of amplitude.

b) **Measure the amplitude (V_m)**, of wave with a second method: count the vertical divisions taken by the wave and multiply it by the **vertical axis scale**. Taking in account the voltage corresponding to the lowest division, compute the absolute error of amplitude.

c) **Measure the period (T)** of wave (horizontal axis), **using the cursors**. Compute the error of period.

d) **Measure the period (T)**, of wave with a second method: count the horizontal divisions taken by the wave and multiply it by the **horizontal axis scale**. Compute the error of period.

e) From the period computed using the cursors (and its error), **compute the frequency (f)** of signal and its error, **applying the error propagation theory**.

f) From the frequency computed (and its error), **compute the angular frequency ($\omega=2\pi f$)** of signal and its error, applying the error propagation theory. To do it, besides the error of frequency, is very important you take in account the error of π, according the decimal figures you take. For example, if you round π=3,14 your absolute error for π is 0,01 (π=3,14$\pm$0,01). But if you consider π=3,1416 then your absolute error for π is 0,0001 (π=3,1416$\pm$0,0001).

4. REPORT

When all measurements are finished, **each group** should do a report (see the document "How a report should be done") in **PDF** format. In such report must appear:

- The photo of oscilloscope taken.
- The calculations and results for amplitude (V_m), period (T), frequency (f) and angular frequency (ω) with their errors. Remember write properly measurements and errors with their units.
- ¿Which is the best method (and why) to measure with the oscilloscope, by using the cursors or by counting the squares and multiplying by the corresponding scale?
- By studying the influence of π on the error of angular frequency, ¿how many decimal figures do you think should we take for π?

The report must be **sent through Poliformat/Tasks** by one of the members of group. You'll find there the deadline. After this time, only in absolutely justified cases will be the report accepted.