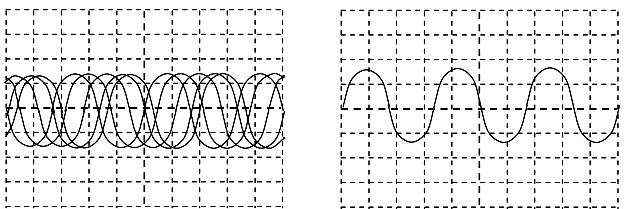
Laboratory 2
Measurements using the oscilloscope
rev. 11e

Purpose: Using the oscilloscope in order to measure parameters for different waveforms. Triggering the oscilloscope.

Summary of theory

Triggering the scope. A stable image on the screen of the oscilloscope is called *triggered (synchronized).*

The physical meaning is the following: when 2 successive displays of a periodic signal start at the same moment in time (relative to the signal period), the 2 displays will overlap perfectly, and so will happen for subsequent displays. Thus, the eye perceives a single stable image, although, in fact, we constantly have a new image superimposed on the previous one. An example in case of displaying a rising slope is given in Figure (1b). But if every display starts with some other moment of time, the images will differ, and the eye will perceive many different superposed images - Fig. (1a). In this case the image is called *untriggered* (unsynchronized).



a) untriggered image b) triggered image

Figure 1

Therefore, in order to obtain a triggered image one has to specify which „event" defines the beginning of the image. This event is characterized by a *level*, also called threshold voltage, which represents the value of the signal at the desired moment (e.g. 0V for figure 1b), and by a *slope* that may be rising or falling; in fig. (1b) the slope is rising; The trigger moment is marked in Fig. 1 by the arrow at the leftmost side of the image, and the threshold voltage is marked by the arrow at the right of the screen.

Remark: For the TDS1001 oscilloscope the triggering moment is implicitly set in the *center* of the screen, represented by a tiny vertical arrow displayed on the upper side of the image. You can adjust its position from **HORIZONTAL POSITION**.

Example: Consider the sine wave of period T in Fig. 2, with an amplitude of 3V, (setting Cy = 1V/div → the amplitude occupies 3 divisions). The trigger level is chosen at 1.5V, rising slope. This trigger condition appears only once every period and corresponds to moments in time denoted as 1,2,3,4 in Fig. 1. The first trigger moment (1) determines the beginning of the image display, which lasts for $N_{X\,max} \cdot C_X$ (for the TDS1001 oscilloscope in the lab $N_{X\,max}$ =10 div). So, how much of, or how much detailed the signal is viewed on the display depends on the relation between T and $N_{X\,max} \cdot C_X$. It is important to notice that during the image display (the time of $10 \cdot C_X$), the trigger is not active. Therefore, at moment (2) a new display does not start, because the current display is not finished (we can notice that we are only at 6.2 divisions from 10). After the display time ends (the bold part), an additional time t_1 passes, during which the scope does not display anything and waits for a new trigger.

This comes at moment (3) and the process repeats itself. We can notice that image 2 is identical to image 1, meaning it is synchronized and the eye will perceive a single image.

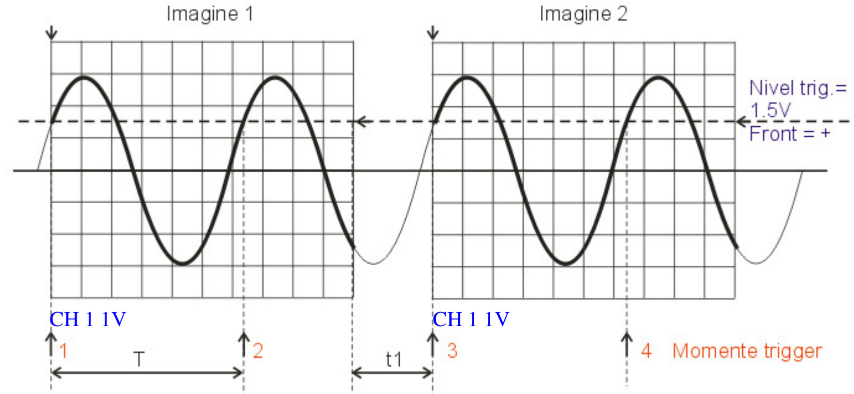


Figure 2 Trigger example

The level and slope settings are relative to a signal, which is also called a trigger signal.
Important remark: The trigger signal should not necessarily be the viewed signal as was the case in figure 1. This is obvious when 2 different signals, from the 2 inputs of the scope are displayed on the same image. Only one of them is the trigger signal!
Depending on the source from which the trigger signal is chosen, we may have:

- **Internal trigger –** the signal applied at the inputs of the scope is used for trigger:
  - **CH1** – trigger source is channel 1 (**TRIG MENU → Source → CH1**).
  - **CH2** – trigger source is channel 2 (**TRIG MENU → Source → CH2**).

Remark: if the 2 signals have different frequencies (but not multiples of each other), depending on the signal which was chosen as trigger source, only one of the images will be stable on the screen!

- **External trigger** – trigger source is the signal applied to the external input (**TRIG MENU → Source → Ext** or **Ext/5**).

Remark: The signal that serves as input to Ext Trig cannot be viewed on the display for measuring, because it is only coupled to the synchronization circuit!

- **Line –** trigger source is the signal from the AC power line which has a frequency of 50 Hz (**TRIG MENU → Source → AC Line**). It is useful when AC circuits supplied from AC power line are measured.

Remark: When the TDS1001 oscilloscope is triggered, the following indications occur on its display (see Fig. A2 from annex A): indication 2 → "T Trig'd"; indications 3 and 4 show the trigger moment and its delay since the start of the image display; indication 5 shows the value of the viewed signal at which the trigger occurred; indications 12, 13 and 17 show the parameters of the trigger signal (determined automatically by the oscilloscope, without human intervention): *the trigger source, slope and trigger level, as well as the frequency of the trigger signal.*

Other trigger settings refer to **trigger methods**:

- AUTO mode (the preferred one - **TRIG MENU → Mode → Auto**): if there are not any trigger conditions, the scope will wait for a predefined time and then display the input signal. In this case the image will be untriggered, because the beginning of the display will be uncorrelated with the periodicity of the signal (Fig 1a). The AUTO mode allows for input signals to be displayed even when trigger signals are missing. Thus, when the input signal is missing, a horizontal line corresponding to 0V level (on which some noise will be superimposed) will be displayed on the screen. This mode is required when viewing and measuring DC voltages.

- NORMAL mode (**TRIG MENU → Mode → Norm**), when the trigger is missing, there is no display. The screen is empty (or, for TDS1001, the last image is displayed in light gray).

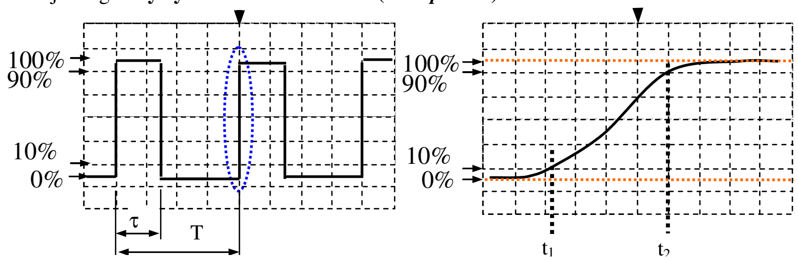
Remark: The AUTO mode is useful for viewing DC voltages. In the Norm mode, they cannot be viewed because the trigger conditions are never met. It is extremely difficult to set the trigger level to exactly the value of the DC voltage. Therefore, in the NORM mode, the triggering of the display is not happening for continuous (constant) signals.

Parameters of rectangular waves

Like any periodic signal, the „common" parameters of a rectangular ware which can be measured directly with the oscilloscope are: max value U_{P+}, min value U_{P-}, peak-to-peak value U_{PP} ($U_{PP} = U_{P+} - U_{P-}$), period T and DC component, U_{DC}.

In addition, the rectangular wave also has specific parameters (Fig. 3):

- duty cycle, $\eta = \frac{\tau}{T}$, where τ is the length of the logical „1" pulse (HI), and T is the signal period. Obviously, the duty cycle can have values between 0% and 100% (the two extreme values distort the rectangular wave → *low*, and *high*, respectively, continuous voltage). The duty cycle can be adjusted from the signal generator by adjusting **"DtyCyc → numerical value (*example*: 25) → %"**



a) Rectangular signal b) Detail - rising time

Figure 3: Measurement of rising time

- *Rise / fall time* (t_{rise} /t_{fall}). Ideally, the rectangular wave has a rise/fall time equal to zero (the slopes are infinitely abrupt, going instantaneously from U_{P-} to U_{P+} and vice versa). In reality, these times are not null. Therefore the rise/fall time is defined as the time that is necessary for the signal to reach from 10% to 90%, and from 90% to 10%, respectively, of U_{PP}. The rise/fall times cannot be adjusted from the signal generator, as it is a technical parameter of it.

$$t_{rise} = t_2 - t_1$$

Remark 1: ***Precise measurement of the moments when the signal reaches 10% and 90%:*** as there are 8 vertical divisions, not 10, we choose to represent 100% on 5 divisions (10 half-divisions). We can notice that these correspond to an interval between the half of the second vertical division from the bottom (0%) and half of the second vertical division from the top (100%) – *these markings are not shown on the display of the* TDS1001 oscilloscope (but they do exist for most of the analogue oscilloscopes)! The rectangular wave must be adjusted on

screen so that the min and max are to the 0% and 100% indications (Fig. 3). This adjustment is necessary so that the 10% and 90% signal levels correspond to visible division limits (in this case, the second division from the top and from the bottom), allowing us to read moments t_1 and t_2 with minimum errors.

Remark 2: In order to view the rise time like in Fig. 3 b), zoom in to the image in Fig. 3 a) (blue area) from the sweep button (SEC/DIV) - decreasing the value of C_x.

Remark 3: When we zoom into the image, the part of the image that is kept is the one around the trigger moment (the vertical arrow from the top of the display – arrow 3 from Fig. A2 from ANNEX A). In the case of the example in Fig. 3 a), the part that is kept when zooming is the one framed in the dotted oval shape.

Remark 4: If the rising slope tends to move towards the outside of the screen, constantly adjust the image from **HORIZONTAL POSITION**. It is recommended to position the vertical arrow in the center of the screen by pressing **Set to Zero** from the **HORIZONTAL** adjustments area.

Optimum measurement of signal parameters

In order to measure as precisely as possible (minimum reading error) the measurement equipment has to be adjusted so that the parameter of interest has a *display* value as high as possible, on the display of the equipment (divisions – as many as possible, number - as many decimal digits as possible etc.)

Example: In order to adjust the parameters of a periodic voltage from a generator without markings, an oscilloscope has to be used (which allows time-domain voltage measurements). For this the following have to be determined:

- *the measuring scale* of the oscilloscope for the electrical voltage and time intervals: the size of the screen horizontally $N_{X\,max} = 10$ divisions; vertically $N_{Y\,max} = 8$ div.

- *possible, calibrated values*, for deflection coefficients C_X [s/div] and C_Y [V/div]. Obviously, the maximum voltage span that can be displayed / measured is $N_{Y\,max} \cdot C_Y$, and for time intervals it is $N_{X\,max} \cdot C_X$. In order to measure as accurately as possible, the period of the signal, the calibrated value $C_{X\,cal}$, has to be chosen from the possible values, so that it fits the display, but is also as close as possible to $N_{X\,max} \cdot C_{X\,cal}$. In order to measure as accurately as possible the voltage of the signal the calibrated value $C_{Y\,cal}$, has to be chosen from the possible values, so that $U_{PP} = U_{P+} - U_{P-}$ fits the display, but is also as close as possible to $N_{Y\,max} \cdot C_{Y\,cal}$.

When the signal has a non-zero DC component that has to be measured simultaneously with the signal, then, instead of U_{PP} $\Delta U_{max} = \max\{U_{V+}, GND\} - \min\{U_{V-}, GND\}$ has to be chosen.

Numerical example: Choose the optimum deflection coefficients in order to precisely measure the period and amplitude of a sine wave with A=5V and f=25kHz.

Solution:

- The sine wave has a peak to peak voltage $\mathbf{U_{PP} = 2 \cdot A = 10V_{PP}}$.
- Maximum no. of divisions on the Y axis is $\mathbf{N_{Ymax} = 8div}$.
- Optimum vertical coefficient for vieweing the signal is:

$\mathbf{C_{Yopt} = U_{VV} / N_{Ymax} = 10V/8div = 1{,}25V/div}$.

- Because the value of 1,25V/div *is not calibrated* we have to choose the next calibrated value, C_{Ycal} = 2V/div.

Proceed similarly for the horizontal axis:

- Period of the signal is **T = 1/f = 40µs**.
- Maximum no. of divisions on the X axis is **N_{Xmax}=10div**.
- Optimum horizontal coefficient, C_{Xopt}, will be

C_{xopt} = T / N_{Xmax} = 40 µs/10 div = 4 µs/div

- Next calibrated value is **C_{Xcal} = 5 µs/div.**

Calibrated values for Tektronix TDS1001:

- $C_{X\ cal} = \{1,\ 2.5,\ 5\} \cdot 10^k$ s/div
- $C_{Y\ cal} = \{1,\ 2,\ 5\} \cdot 10^k$ V/div

REMARK: you can find more examples in the solved exercise at the end of the laboratory!

Measurements

1. Study of a triangular wave with a DC component.

a) Generate a triangular wave with amplitude $U_0 = U_P$, frequency f and DC level (Offset) U_{DC} (*written on the blackboard),* coupled to CH1 on the oscilloscope. Set **CH1 MENU → PROBE 1x**.

a1. Compute the **optimum** horizontal and vertical deflection coefficients, **C_{X_optim}** and **C_{Y_optim}**. Such that **exactly** one period of the signal is viewed on the display, extended to the **entire** height of the screen (without exceeding it):

$$C_{X\_optim}=T/N_{X\_max} \qquad C_{Y\_optim}=(U_{max} - U_{min})/ N_{Y\_max}$$

U_{max} and U_{min} represent the maximum and minimum values of the signal, taking also into account U_P and U_{DC}

a2. If the computed values are not calibrated, choose the immediate higher calibrated values that can be set: **C_{X_cal}** and **C_{Y_cal}**

a3. switch (CH1) to AC coupling – the DC component *cannot be seen* for now.

a4. Read the number of divisions that the period and peak-to-peak amplitude occupy on the display (**N_{X_T}** ; **N_{Y_Upp}**), as well as their values (***T, U_{PP}***).

a5. Compute the number of divisions that the DC component occupies (**N_{Y_UDc}**) knowing C_{Y_cal}

a6. switch (**CH1**) to **DC** coupling; now the offset becomes visible and the image moves vertically with N_{Y_Udc} divisions corresponding also with the sign of U_{DC}. Remember that you can read the DC level value on the display by switching from AC to DC. The number of divisions that the signal moves, from AC to DC, multiplied by C_Y will result in the value in V of the DC level, and the way (upwards or downwards) will give the sign.

In order to avoid exceeding the display margin, adjust **Vertical Position** such that the entire image is within the display area. It is recommended to position the GND level arrow between two vertical divisions for easy reading.

Draw the viewed image and write down the 0V (GND) level position (arrow 6 from Fig. A2, Annex A).

Remark*:* if the image becomes untriggered, press the button **Set To 50%.**

b) Compute the relative errors with which U_{PP} and T were computed knowing that the reading accuracy on the display is δN = 0,2div (the smallest subdivision marked on the screen):

$$\varepsilon_{Upp} = \delta N_Y / N_{YUvv} \qquad \text{and} \qquad \varepsilon_T = \delta N_X / N_{XT}$$

Remark: the above values have to be multiplied by 100 in order to obtain the error in percentage [%].

c) Use the voltage, and then time cursors or measuring U_{PP} and T. Write down the step with which the cursor indication varies δU, for voltage, and δt, for time (it is the difference between two consecutive readings at the finest variation of the cursor knob). Then compute the relative errors with which the two parameters were measured:

$$\varepsilon_{2UVV} = \delta U / Uvv \qquad \text{and} \qquad \varepsilon_{2T} = \delta t / T$$

Which situation gives the most accurate reading (b or c)?

Indication for using cursors:

- For measuring U_{PP} select **CURSORS → Type Voltage** and, using the 2 **VERTICAL POSITION** knobs (notice that LED indications are lit to indicate the alternative function), place a cursor on the maximum value, and the other on the minimum value of the signal. You can read on the right-hand side of the screen U_{P+} , U_{P-} and $U_{PP} = \Delta U$ (**DELTA**).

- For measuring T, select **CURSORS → Type Time** and, using the 2 **VERTICAL POSITION** knobs (notice that LED indications are lit to indicate the alternative function), place two cursors at the beginning and the end of a period. You can read on the right-hand side of the screen the value of the period in **DELTA**.

Remark: In the fields on the right-hand side of the screen you can read the values of the two cursors (**CURSOR 1, CURSOR2**) and the difference between them (**DELTA**).

Switch off cursor display (**Type OFF**), and check the LED indications are off.

2. Adjusting oscilloscope trigger.

We will use some trigger adjustments. Identify indications 2, 3, 5, 12 and 13 from fig. A2, annex A.

a) Generate a triangular wave from the generator, U_P=*2V, f=1KHz* Offset=0 and oscilloscope settings C_Y=1V/div, C_X= 250µs/div.

Analyze the effect of the trigger voltage level, U_T, on the synchronization of the signal. Modify U_T, from the **TRIGGER LEVEL** knob, such that it reaches values smaller than the minimum signal value, between its minimum and maximum value, and higher than maximum value. Follow indications 5 and 2 from Annex A, Fig. A2.

What do you notice with respect to the image stability? What are the maximum and minimum limit values of U_T such that the image stays triggered? (numerical value from ind. 13, Fig A2)

Adjust **TRIGGER LEVEL** above the signal level then press button **SET TO 50%.** Notice that the scope automatically adjusts the trigger level, so that the image is triggered.

Write down the current value $U_{T\ 50\%}$ of the automatically adjusted level.

Move the trigger moment (indication 3 from fig. A2) exactly at the beginning of the image display (left-most side of the display) from the **HORIZONTAL POSITION** knob. *Finely* adjust the knob until *exactly* the moment that arrow 3 reaches the side and becomes horizontal, instead of vertical. Notice that the image of the signal begins (on your left) right from the height at which indication 5 from fig. A2 is, meaning exactly from the trigger level. Adjust finely the trigger level in order to notice this.

b) Analysis of the trigger slope effect on the oscilloscope synchronization

Modify the slope from **TRIG MENU→Slope** from the value of **Rising** to **Falling**. Notice that the image now begins from the falling slope of the signal.

Adjust **TRIGGER LEVEL** and **SLOPE** to the values U_{t1} rising slope, and U_{p2} falling slope (*different for each desk*) and draw the two obtained images (also draw the **HORIZONTAL POSITION** arrows and the trigger level)

Return to rising slope, level 50% (**SET TO 50%).**

3. Study of rectangular signals.

a) Set the scope on **CH1 MENU → Coupling → DC**. Set the generator on symmetrical rectangular signal, with a duty cycle of 50%, having an amplitude of U_{P3}, and the period T_3 (according to your desk no.) Calculate and set deflection coefficients C_X and C_Y so that between 2 and 4 periods of the signal are viewed on the screen, and the amplitude (U_{P+}) of the signal is between 2 and 3 divisions.

Set the zero level (indications 6 in Fig. A2 from Annex A) at the center of the screen from **VERTICAL POSITION**.

b) Modify from the generator the rectangular signal in order to make it be non-symmetrical, having a duty cycle of 25%, by using the function key **DtyCyc**

b1. Measure on the screen τ and T. Calculate, based on the two measured values, τ and T, the measured value of the duty cycle, η_{mas}.

b2. What is the relative error of the measurement $\varepsilon = \left|\frac{\eta_{mas} - \eta}{\eta}\right| 100$ [%] (comparing η_{mas} to the exact value of $\eta = 25\%$)?

b3. Switch on AC coupling. Draw the obtained image. **What is the value of the DC level? (Value in volts and the sign!).**

b4. Modify the frequency of the signal to 2.5KHz and C_X to 100µs/div. Compute the DC level of the signal using $U_{DC} = \frac{1}{T}\int_0^T u(t)dt$ (or the surface of the signal over one period). Measure the DC level using the oscilloscope: **MEASURE → Type: Mean**. Explain the difference between the two obtained values. **Indication:** Is the number of period on the display an integer? The oscilloscope computes the mean of the signal over the displayed time.

4. Measurement of the rise time of a rectangular signal

a) For the signal generated at the previous exercise (3), with duty cycle of 50%, measure its rising time:

$$t_{rise} = t_2 - t_1 \quad (1)$$

where t_1, t_2 represent the moments (horizontal) at which the signal has values corresponding to 10%, and 90% (vertical) respectively of U_{PP} considered as 100% (Fig 3).

In order to measure the rising time, follow these steps:

- press **Set to Zero** (from HORIZONTAL adjustment area) to move vertical arrow 3 (from annex 1) in the center of the display

- set the step for C_Y (**CH1 MENU → Volts/Div → FINE**). In this way *uncalibrated* values of C_Y can be set.

- set C_Y such that the signal (*low* and *high* values) fits between the 0 and 100% indications on Fig. 3 (they do not appear explicitly on the screen).

- from the sweep knob (SEC/DIV) zoom in such that the signal slope is „widened" and displayed like in Fig. 3 b) (the whole rising slope of the screen should occupy as much of the display area as possible, without exceeding it). If the vertical arrow moves, bring it again to the center of the display. Remember that the zoom effect is with respect to the moment marked by this arrow.

Read t_1 and t_2 (counting the divisions with respect to the left side of the screen) and compute the rise time t_{rise}.

b) Modify the frequency of the rectangular wave to 7 kHz and repeat the measurement of the rise time $t_{rise\,2}$ (the same way as for point b). **Compare the value with t_{rise} and explain the result.**

c) Explain the adjustment that has to be made in the oscilloscope settings in order to measure the rise (fall) time. Check, by displaying the new image. **You are not required to measure this rise time.**

Revert to Coarse (calibrated) value for C_Y (**CH1 MENU → Volts/Div → COARSE**).

5. Study of the oscilloscope with 2 inputs

a) Two signals of the same frequency f=2kHz will be visualized on the oscilloscope. Apply from the function generator a sine wave of amplitude U_{Ps}=2.5V (U_{PPs} =5V), Offset=1, from output 1 at input **CH1** of the scope. At the input of **CH2** apply a rectangular symmetric signal with U_{PPd} =5V, f=2kHz, Offset=0, obtained from output 2 of the generator (press the **CH1/CH2** key from the generator in order to alternate the channel whose parameters are being set; both **Output** LEDs must be on). Choose the deflection coefficients C_{y1}=5V/div (for CH1), C_{Y2}=5V/div (for CH2) and C_x=100µs/div. If on the scope CH2 is turned off, press the button **CH2 Menu** in order to display it (the successive pressing of the button CHn Menu turns on/off the image from channel n).

Check that you have the setting **CH1 MENU → PROBE 1x** and **CH2 MENU → PROBE 1x.** If this setting is not done, the values that you read will be wrong.

Do the two signals pass through 0V at the same time moment? Note the indications about the trigger sigmal (ind. 12,13,17 from Fig. A2, annex A).

In order not to overlap the images on the scope, set the zero (**Ground**) level on the 2nd division from the top for CH1, respectively on the 2nd division from the bottom for CH2, using **VERTICAL POSITION**, and the signals are coupled in the DC mode on both channels (**CH MENU → Coupling DC**). If needed, adjust the trigger (**SET TO 50%**), so that the image is synchronized.

b) View and draw the *sum* and the *difference* of the 2 signals (**MATH MENU → Operation +/-**). You may need to adjust the vertical position settings, so that you can view this image entirely (**so that some portions of the image are not "outside" the screen**).

Remark: In order to view only the sum/difference of the signals eliminate the 2 signals from the screen (press the **CH1 MENU** and **CH2 MENU** keys twice); observe that the image appears/disappears on successive presses of the keys.

At the end of these measurements, activate the display of the signals from CH1 and CH2, by pressing **CH1/2 MENU** and stop the display of the *MATH signal* by pressing **MATH MENU** until on the screen remain only CH1 and CH2.

Indication: When activating the display of the *MATH signal*, on the screen you can see the **0** (Ground) position for this signal by an indication 6 (Fig. A2 from annex A), marked with the letter ***M***.

6. Study of trigger signal sources

a) Study the trigger from channels CH1 or CH2, which can be viewed on the scope. Keep the two signals, sinusoidal and rectangular, and the settings from exercise 5.

a.1) Select CH1 as the trigger source (**TRIG MENU → Source → CH1**) and working mode **AUTO** (**TRIG MENU → Mode → Auto**). By using **VERTICAL POSITION** (for each input) display both waveforms, one above the other. Set TRIGGER LEVEL so that both images are triggered. Disconnect the cable from CH1**. What happens with the image on CH2? Explain**.

a.2) Reconnect the cable at CH1. ***Easily*** adjust TRIGGER LEVEL ***without crossing*** the lower/upper limits of the signal, so that the image becomes untriggered. Notice how, by adjusting **TRIGGER LEVEL,** the image also moves horizontally. **Explain this movement**!

a.3) Select CH2 as trigger source (**TRIG MENU → Source → CH2**). Observe that the arrow indicating the trigger level from the right side of the screen is positioned relative to the waveform on CH2. Remove the cable from CH1. **What happens with the image on CH2, in this case? Explain the difference compared to a.1.**

a.4) Reconnect CH1 and Rotate **TRIGGER LEVEL** (within the vertical limits of signal 2). **What happens to the image on CH2 in this case? Explain the difference with respect what happened at a.1**.

a.5) Some of the trigger parameters are displayed in the bottom right part of the screen: source, slope and trigger level, and in the case when trigger exists, the frequency of the trigger signal is also displayed.

Write down these values for the triggered image (from the previous point).

b) Study the trigger from the triggering signal from **EXT TRIG**. It is important to know that the signal on this input **cannot** be visualized. Keep the two signals and the settings from **6.a.**

b.1) View a sine wave on CH1, by triggering with a rectangular signal (of the same frequency) connected at the **EXT TRIG** input. Is the image triggered?

Indication: Move the cable from CH2 to EXT TRIG and view only the sinusoidal signal from CH1 (turn off CH2 by pressing **CH2 MENU**). Select external trigger mode **TRIG MENU → Source → Ext**.

b.2) Disconnect the cable from EXT TRIG. Only the cable on CH1 remains connected (sine wave). **Is the image triggered? Why?** What adjustments must be made in **TRIG MENU -> Source** in order to obtain a stable image? (without other signals).

c) AC Line triggering

c.1) Keep the sine wave from **b.2** at input CH1**.** Select **Line** as trigger source (**TRIG MENU → Source → AC Line).** The oscilloscope takes the trigger signal from the AC Power line (50Hz in Europe). **Is the image triggered? Explain.**

Indication: What is the value of the signal from the generator?

c.2) Modify the frequency of the generator to 50 Hz and C_x=5ms/div. **Is the image stable now?**

Fine tune the frequency of the signal (with the step 0.01Hz) until the image becomes stable – at this moment the generator signal frequency is synchronous to the AC Line frequency (*mains frequency*). **What is the exact value of the frequency of the AC Power line (minimum 2 decimals)?**

Remark 1: in order to fine tune the frequency, use the rotating knob of the generator and the 2 arrow-keys below it, which determine the digit that will be changed by rotating the knob. The respective digit blinks.

Remark 2: the frequency from the national electrical system (SEN) varies slightly, inversely proportional to the total load; at peak hours, the frequency is smaller than in off-peak hours. The frequency value of 50 Hz is nominal, and there are variations, in practice, of less than t ±1 Hz.

7. The AUTO and NORM display modes

a) Study the influence of the trigger mode in the case of a sinusoidal signal.

Keep the signal from **6.c**. Revert to internal triggering from **CH1**. Having the image triggered, switch the display type from AUTO to NORMAL: **TRIG MENU->Mode->Normal.** Is there any change that can be observed on the screen? Then rotate **TRIG LEVEL** until the trigger level is greater than the peak of the signal. Why does the image disappear? (at TDS1001 it does not entirely disappear, instead the last image is displayed in light gray). What is now the value displayed by the oscilloscope for the frequency of the trigger signal? Return to AUTO mode (**TRIG MENU->Mode->Auto**) and check the reappearance of the (untriggered) image. What is now the value displayed for the frequency of the trigger signal, in case of the untriggered image?

b) Measure a DC voltage of -1V with the oscilloscope having C_Y=200mV/div in *Auto* and *Normal* modes. Try to trigger (in ***Normal*** mode) using **Trigger Level**. What do you see? Explain. Revert to AUTO mode.

Indications:

Adjust C_Y, apply signal from the generator to CH1 and check oscilloscope settings:

- DC coupling on CH1 (**CH1 MENU → Coupling → DC**);
- AUTO mode (**TRIG MENU → Mode → Auto**).

Adjust the signal to have an amplitude of 0V and ***a DC level*** (Offset) of -1V. The image can be moved from **Vertical Position** in order to see both the signal and the GND level for CH1 on the screen. Notice the image on the display. Measure the DC component value. Switch (with DC coupling) to Normal mode (**TRIG MENU → Mode → Normal**) and try measuring U_{DC}. **What do you see? Explain!**

Solved problems

1. A triangular wave from the generator with an amplitude A=2V and frequency f=1kHz is applied at the input of the oscilloscope. The scope has C_y=0.5V/div, C_x = 0.25ms/div, U_T=0V (threshold voltage) and trigger slope is negative (SLOPE="–"). Draw the image on the screen of the scope. The trigger moment is on the left of the screen.

Solution:

The amplitude will be displayed on the screen of the scope on $\mathbf{N_y = A/C_y = 2V/(0,5V/div) = 4div}$. The period will be displayed on $\mathbf{N_x = T/C_x = 1/(f \cdot C_x) = 4\ div}$ → on the screen we will see **2.5** periods of the signal.

Because the trigger moment is set to the left edge of the screen, the image starts to be displayed from the value $\mathbf{U_T=0V}$ (the middle of the screen on vertical) on the negative slope of the signal. The image on the screen is shown in Fig. 4.

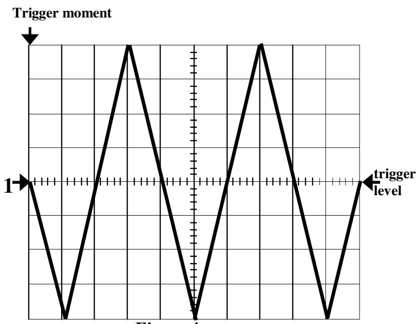


Figure 4

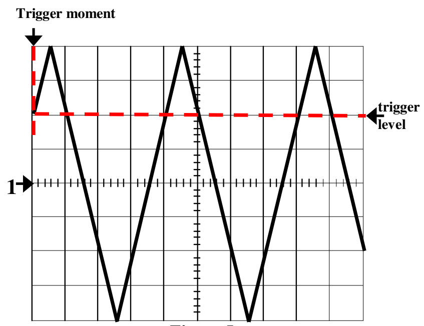


Figure 5

2. Repeat problem 1 for the case in which the oscilloscope has the threshold level at U_T=1V and the slope is positive.

Solution:

Because the trigger is U_T=1V, which can be represented on N_Y=2div, the image will be displayed starting with the second division with respect to the zero level (from the middle of the Y axis), on the positive slope of the signal. The obtained image is displayed in Fig. 5.

Remark: the arrow indicating the trigger level is positioned at the value of U_P.

The displayed image must pass through the intersection point of the vertical line corresponding to the trigger moment with the horizontal line corresponding to the trigger level. It is the intersection of the red dotted lines.

3. A triangular wave from the generator with an amplitude A=4V, frequency f=1kHz and DC component U_{DC}=-2V is applied at the input of the oscilloscope. The scope has C_y=2V/div, C_x=0.25 ms/div, U_p=-4V (threshold voltage) and trigger slope is negative (SLOPE=”–”). a) Draw the image on the screen of the scope in DC mode. The trigger moment is on the left side of the screen; b) Draw the image on the screen of the scope in AC mode.

Solution:

a) The amplitude will be displayed on **N_{yA} =A/C_y=2 div.** The DC component, **U_{DC}=-2V**, will be displayed on **N_{yCC}=U_{cc}/C_y= 1div.**

Adding a DC component to the triangular signal means a displacement of the image on the screen equal to the value of the DC component (in this case, one division downwards, due to the negative value of the DC component). The signal will vaey between **U_{max}=2V (1 div)** and **U_{min}= -6V (3 div).**

Because the threshold voltage is -4V, which is represented on 2 divisions, the display will be done starting from the second division in the lower half of the screen, on the negative slope of the signal. The obtained image is represented in Fig. 6.a.

b) In AC mode, the signal is viewed without the DC component. The image will be shifted with one division upwards, with respect to the image in DC mode (because of the disappearance of the DC component, which had moved the image downwards in DC mode). Because the trigger settings are the same, the image will be displayed starting from the second division in the lower half of the screen, on the negative slope of the signal. The obtained image is represented in Fig. 6.b.

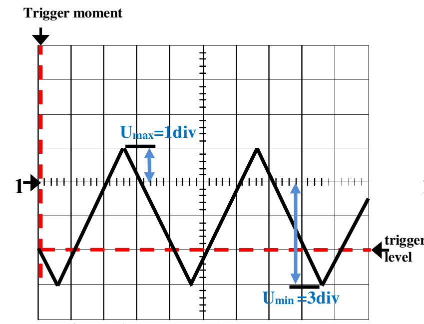


Figure 6.a: DC coupling

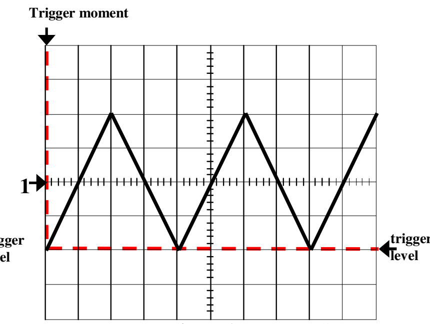


Figure 6.b: AC coupling

4. A symmetric rectangular signal of amplitude A=4V, frequency f=40kHz, duty cycle 25% is given. The scope has C_x=5µs/div, C_y=2V/div, U_T=0V, Slope=”+”. The trigger moment is on the left side of the screen. Draw the image on the screen of the scope for the coupling modes: DC, respectively AC.

Solution:

It can be easily verified that the amplitude is displayed on **N_{yA}=2div**, and the period is displayed on **N_{xT}=5 div**. Because the duty cycle is **η = 25%**, it means that **τ=T/4=6.25µs**, which will be displayed on **$N_{x\tau}$ = τ/C_x = 1,25div**.

In AC mode, the signal is viewed without the DC component. The DC component of the signal in Fig. 7a is the mean value of the signal over one period.

$$U_{DC} = \frac{1}{T}\int_0^T u(t)dt = \frac{1}{T}\left[A\cdot\tau - A(T-\tau)\right] = \frac{1}{T}\left(A\cdot\frac{T}{4} - A\cdot\frac{3T}{4}\right) = \frac{-A}{2} = -2V$$

Because in AC mode the -2V DC component disappears (which is equivalent to one division on the screen), in AC mode the graph of the signal will be displaced upwards with one division. The image on the screen is given in Fig. 7b.

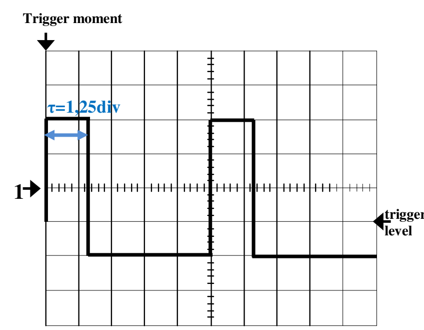


Figure 7.a: DC coupling

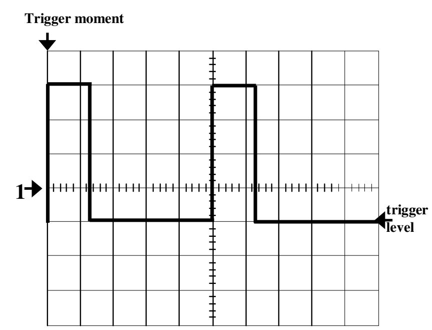


Figure 7.b: AC coupling

Preparatory questions

OBS: See also laboratory 1 and the solved problems!

1. A sine wave is viewed on the scope. When coupling is switched from AC to DC the sine wave moves vertically, up by 2 divisions. C_y=1V/div. Determine the DC component of the signal.

2. A sine wave, with the amplitude of A=1V, DC=0 and frequency f=1kHz, is applied at the input of the scope. The oscilloscope has C_y=0,5V/div, C_x=0,2ms/div, threshold level U_p=0,5V and SLOPE = falling. Draw the image.

3. What are the calibrated values of C_X, C_Y for the scope in the lab?

4. A sine wave of amplitude 2V and frequency 100kHz is given. Determine the values of C_X, C_Y such that exactly one period fits in the screen, having the peak-to-peak value on the entire height of the screen.

5. What happens when '**Trigger Level'** is adjusted? Explain. What is the effect of '**Slope**' change?

6. How does the scope work in **Auto** mode, and **Norm** mode**,** respectively? What is displayed on the screen if we use the **Norm** mode and we set **Trig Level** above the maximum level of the signal?

7. What is the role of EXT TRIG from the front panel of the oscilloscope? Can the signal at this entry be viewed on the screen?

8. What does the trigger mode **AC Line** mean?

9. Between what vertical limits, in percentages, is the raising time of the rectangular signal measured? Draw it!

10. Draw how a rectangular signal with duty cycle η = 1/5 appears on the screen of the scope (having 10 divisions on the horizontal), knowing that 2 periods of the signal are viewed on the screen.

11. A triangular signal with amplitude 2V and frequency f=1kHz is introduced from the generator. The oscilloscope has C_y=0,5V/div, C_x = 0,5ms/div, U_T=1V (the threshold voltage) and SLOPE="–". Draw the image on the screen of the scope.

12. A triangular signal with amplitude 1V and frequency f=10kHz is introduced from the generator. The oscilloscope has C_y=0,5V/div, C_x = 50µs/div, U_T=1V (the threshold voltage) and SLOPE=*falling*. Draw the image on the screen of the scope.

13. A symmetric triangular signal with amplitude 4V and frequency f=5kHz and null DC component is introduced at the input of an oscilloscope. The oscilloscope has C_y=1V/div, C_x = 50µs/div, U_T=2V (the threshold voltage) and SLOPE=*falling*. Draw the image on the screen of the scope.

14. Compute the DC component of the signal in Fig. 8.

15. The rectangular signal in Fig. 9 is viewed on the screen of an oscilloscope that has: C_y=2V/div, the zero level is in the middle of the screen, coupling: **DC**. Calculate the DC component of the signal. Draw the image on the screen of the scope in AC mode.

16. For the signal in Fig. 10, compute: **(a)** the DC component of the periodic signal and **(b)** the DC component (mean) indicated by the oscilloscope in **Mean** measurement menu. The oscilloscope has: C_y=2V/div, the zero level is in the middle of the screen, coupling: **DC.** *Indication*: the scope calculates the mean strictly based on the displayed image, without knowing the signal's period.

17. A sine wave from the generator with an amplitude of 2V and frequency f=1kHz is applied at the input of the oscilloscope. The scope has C_y=0.5V/div, C_x=0.5ms/div. Calculate the relative error when measuring the amplitude and the period of the signal. Absolute reading error on the screen of the scope is 0.2div (the smallest division on the screen).

18. View the real time nationwide electrical energy consumption, as well as its hourly variation at:

http://www.transelectrica.ro/widget/web/tel/sen-grafic/-/SENGrafic_WAR_SENGraficportlet

At what time of day do you think the AC Line frequency is at its maximum?

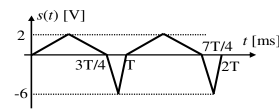


Figure 8

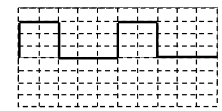


Figure 9

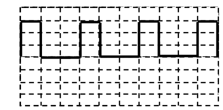


Figure 10