<u>Practical 2.4. Study of the oscilloscope</u>

INTRODUCTION

An *oscilloscope* is a device (i.e., an electronic test instrument) designed to analyze electrical signals and processes. The basic oscilloscope, is typically divided into <u>four sections</u>: the *display*, *vertical controls*, *horizontal controls* and *trigger controls*. The *display* is usually a *CRT* (cathode-ray tube) or *LCD* (Liquid-crystal display) panel which is laid out with both horizontal and vertical reference lines referred to as the *graticule*. In addition to the screen, most display sections are equipped with three basic controls: *a focus knob*, *an intensity knob* and *a beam finder button*.

The vertical section controls the amplitude of the displayed signal. This section carries a Volts-per-Division (Volts/Div) selector knob, an AC/DC/Ground selector switch and the vertical (primary) input for the instrument. Additionally, this section is typically equipped with the vertical beam position knob.

The horizontal section controls the time base or "sweep" of the instrument. The primary control is the Seconds-per-Division (Sec/Div) selector switch. Also included is a horizontal input for plotting dual X-Y axis signals. The horizontal beam position knob is generally located in this section.

The trigger section controls the start event of the sweep. The trigger can be set to automatically restart after each sweep or it can be configured to respond to an internal or external event. The principal controls of this section will be the source and coupling selector switches. An external trigger input (EXT Input) and level adjustment will also be included.

In the Practical, an oscilloscope based on the CRT is used. A *luminescent screen* provides the visualization of the cathode ray (i.e., “ray” of the electrons) which was deflected vertically and horizontally with the electromagnetic field (for details, see Appendix): on the way to the screen, the electron beam passes between plane-parallel plates. Under the influence of the electric field created by the voltage applied to the plates, the beam deviates towards the plate with a positive potential (therefore, these plates are called *deflecting*) and the luminous point on the screen is shifted in the same direction. One pair of plates is located horizontally and, accordingly, the point on the screen is displaced vertically. These plates are called vertical deflection plates or Y-axis control plates. The second pair of plates is located vertically. These are horizontal deflection plates or X-axis control plates. A manually adjustable DC voltage can be applied to each pair of the deflecting plates, which allows you to set the luminous point or the entire image in the desired place on the screen.

If an alternating voltage is applied to either vertical or horizontal plates (i.e., the other pair of plates has no voltage applied) then a horizontal or vertical line will be observed on the screen, respectively. If an alternating voltage is applied simultaneously to both pairs of plates, then a curve appears on the screen - the result of the addition of the two mutually perpendicular motions of the luminous point.

To observe the shape of the voltage signal under investigation (its time variation), this voltage is normally applied to the vertical deflection plates (responsible for the *Y-axis*). In this case, it is necessary to ensure uniform movement of the beam horizontally. To do this, a voltage is applied to the horizontal deflection plates (responsible for the *X-axis*), which varies linearly with time, the so-called *sweep* voltage or *sweep timebase*. The effect of the sweep voltage is similar to paper movement when performing laboratory work on studying the oscillations of a sand pendulum in the "Mechanics". On a fixed sheet of paper, the oscillating pendulum leaves a trace in the form of a straight line. Uniform movement of paper leads to the fact that the track turns into a sine wave. When studying fast-flowing processes, the motion of the spot on the screen is so fast that the person is not able to follow it. Therefore, after passing the beam from left to right (direct stroke), it is necessary to perform a fast return of the beam to its original position (reverse move) and its repeated multiple passage through the screen. This determines the saw-tooth form of the voltage applied to the plates of the horizontal deflection from the internal sweep generator. If the duration of the direct movement of the beam is equal to an integer number of periods of the voltage under investigation, then the beam repeatedly drawn on the screen repeats itself forming a "fixed" (or frozen) image. Otherwise, the image will be continuously moving. In order to obtain the fixed image, it is necessary *to synchronize* the operation of the sweep generator and the signal under study so that the saw-tooth voltage begins with the same value of the phase of the voltage under investigation. For this purpose, a special *synchronizing device – trigger* - is provided in the oscilloscope. The time dependence (oscillogram) of the output voltage of the sweep generator, taking into account the synchronization of the image, is shown in Fig. 4.1.

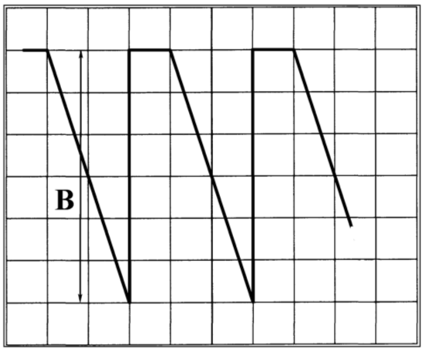


Fig. 4.1.

The descending slope of the oscillogram corresponds to the forward direction of the beam across the screen (from the left to the right). A quick return of the scan voltage to the initial value corresponds to the reversal. The horizontal section corresponds to the waiting time of the sweep generator for the moment when the phase of the investigated signal will coincide with the phase of this voltage at the beginning of the previous forward movement of the beam.

The oscilloscope is widely used for measuring voltages, since the coordinate of the luminous point on the screen is directly proportional to the voltage applied to the corresponding deflecting plates:

$$x = \alpha_x U_x \qquad y = \alpha_y U_y ,$$

with proportionality coefficients α_x and α_y being the sensitivity.

The screen is supplied with the scale (*graticule*) however the division value is determined by the chosen ranges of X and Y axes.

Experimental tasks:

Initializing and setting up the oscilloscope parameters, adjustment of the screen (brightness, focusing) by adjusting the voltages on the electrodes of the cathode-ray tube; calibration of the oscilloscope; measurement of the parameters of sine and saw-tooth voltages; Monitoring the operation of the image synchronization system; Measurement of the frequency of the beats resulting from the addition of two sinusoidal voltages.

***Equipment*:** Oacilloscope C1-65A (Fig. 4.2), Signal generators Г3-33 и Г3-118, RF-cables.

Getting started with the oscilloscope C1-65A

Examine the oscilloscope **C1-65A,** find the four parts, make yourself accustomed with the controls. Find the brightness and focus controls.

The voltage under investigation is fed to the input of the "amplifier Y" through the connector, which is indicated by the symbol "→◯" and is located on the front panel of the device under the screen. The signal is fed through the coaxial cable. At the input of the amplifier Y, the switch $П_1$ has three positions corresponding to the "open" input of the instrument (≃) for measuring the constant and alternating voltages, the "closed" input (∼) for measuring only the alternating voltagesб and the "shorted" input (⊥) to establish the “zero” position of the beam along the Y-axis on the screen of the cathode-ray tube. The sensitivity of the vertical deflection amplifier can be set by the "V / div." switch. By "division" here and below is meant the side of the square (≈ 1cm) on the graticule on the screen. The action of this switch is equivalent to changing the measurement limit for conventional voltmeters. The handle of the potentiometer "smoothly" is positioned coaxially with the handle of the indicated switch, which allows reducing the sensitivity up to 2.5 times. But this potentiometer is not used for measurements, as this requires an additional calibration of the scale. Set this handle to the rightmost position. Manual movement of the electron beam on the screen along the vertical axis is carried out with the knob «⬍».

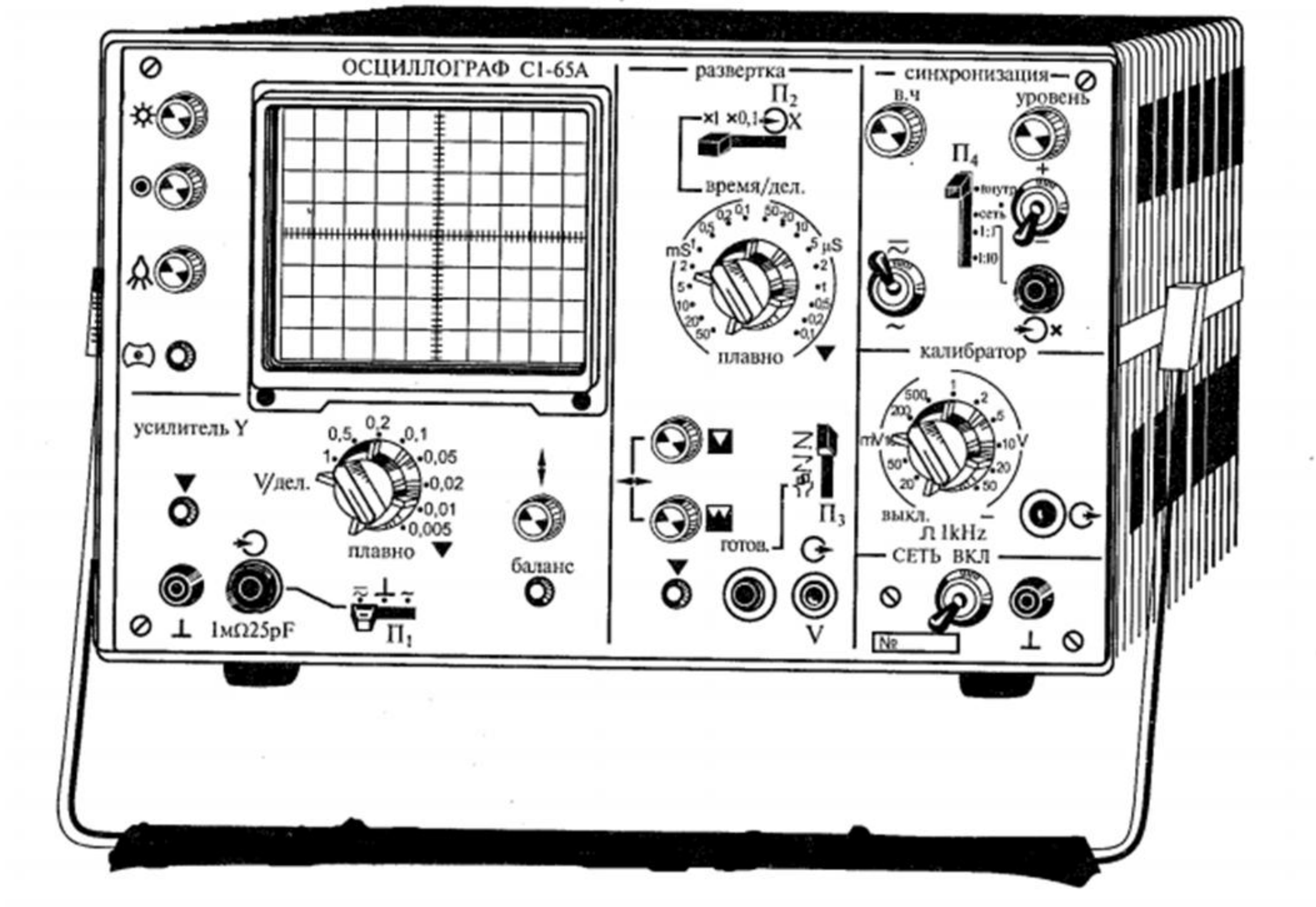
To the right of the screen is the "sweep" panel. Switch ($П_2$) allows choosing of the regime: in the "×1" position, the internal sweep timebase generator is used; setting the "×0.1" reduces the timebase by a factor of 10. Set the switch $П_2$ to position "→◯X" which disables the internal generator. In this case, an external sweep voltage should be supplied via the corresponding input connector, which is installed in the "synchronization" panel. The frequency of the internal sweep generator is set by the "time / div" control, and also with the "smooth" knob located on the same axis. The "smooth" handle is not used for measurements. Set it to the extreme position clockwise.

Selecting the trigger mode is done by the switch located at the bottom of the "sweep" panel. Set it to the top position (triggering by the internal sync device). To the left of this switch are handles of manual displacement of the spot horizontally. The output of the sweep generator can be output to external devices via the "◯→" "V" socket at the bottom of the "sweep" panel and the "ground" ″⊥ ″ socket.

On the right side of the front panel of the oscilloscope are located (from top to bottom) the "synchronization", "calibrator" and "power" panels. Triggering ($П_4$) can be selected to be synchronized with the input signal - "internal" position, power line - "network" , or with an external signal that is fed through the "◯→" connector in the "1: 1" position directly to the input of the amplifier "X ", and in the position" 1:10 "- with a tenfold weakening.

The calibrator is an internal voltage source that serves to check the sensitivity of the oscilloscope. The output signal of the calibrator is output through the "◯→" and "⊥" sockets. The value of this voltage is regulated by the corresponding switch. Coaxially with it is the handle for selecting the operating mode of the calibrator. It provides three selections: off, 1-kHz meander shaped wave, direct voltage (symbol "-").

The oscilloscope is switched on by the "power" tumbler, while the signal light located next to the tumbler lights up. Turn on the toggle switch "power". After 1-2 minutes, necessary for warming up the oscilloscope, a glowing spot should appear on the screen. If you are not able to see a spot on the screen, increase the brightness to the maximum. There will be a green glow in some part of the screen. This means that the spot is outside the screen, and it should be displaced by the adjustment knobs of the spot position to be installed in the center of the screen. Then you need to reduce the brightness of the spot to a comfortable level and adjust the electrostatic lens of the electron-beam tube to the minimum spot size with the focus knob. Turn on the sweep generator by moving the switch ($П_2$) to the "×1" position. A horizontal line should appear on the screen. Set it to the center of the screen. Get practical admission to work and start working on the experimental tasks.



MEASUREMENT AND DATA PROCESSING

***Note*. Make sure that for all tasks below you have included the electric diagram, i.e. electric schematic of all the connections in your report.**

***Task 1.* Y-axis calibration**

In order to calibrate the Y-axis, a voltage of a known value from an internal calibrator is applied to the oscilloscope input, and appropriate measurements are made. Connect a cable with a special connector on one end and two pins on the other to the Y input. To do this, insert the connector on the cable into the "Y input" socket so that the tabs on the panel housing enter the slots on the cable connector ring, then press the cable connector ring and turn it clockwise until it stops, fixing the connection. The cable is disconnected in the reverse order: press on the ring, turn it counterclockwise until it clicks lightly, and pull the cable part of the connector toward you. Connect the pins on the second end of the cable to the output of the calibrator. In this case, a certain polarity of the connection must be obeyed. A sign on the case of one of the pins means that it must be inserted into the socket with the same sign ("housing" or "ground"). In the absence of such a sign, the polarity of the pins is checked as follows: touch the pin with your fingers, if a continuously changing line appears on the screen, then this plug is "signal" and must be inserted into the socket on the calibrator panel. If the horizontal line remains unchanged, then this pin must be inserted into the "ground" socket.

Set on the calibrator panel: the level of the control signal to the position "200 mV", which corresponds to the amplitude of the rectangular pulses at the output of the calibrator. A switch of the control signal type (small handle on the same axis) to the middle position "1 kHz" (indicated under the switch).

Fill in Table 1:

Calibration voltage U_k, mV	200
Height of the pulses, div.	
Division value, measured, V/div	
Division value, settings, V/div	

Select the "V / div" switch position so that the vertical image size (which may initially be simply a wide horizontal bar) is more than half the screen. Write down in Table 1 corresponding to this position the value of the screen division value as a set value. Select the position of the "time / div" switch on the "sweep" panel so that the image on the screen takes the form of 3 ÷ 4 fixed rectangular pulses. If necessary, use the trigger control knob. Move the obtained waveform with the image moving knobs so that the lower edge of the pulses coincides with any solid horizontal line of the screen grid. Draw the waveform. Measure the height of the pulses in the scale divisions on the scale and write it down in Table. 1. Calculate the actual value of division of the oscilloscope as Calibration voltage / Height of the pulses and write it in the Table. 1. It must correspond to the passport value. Otherwise, contact the engineer to resolve the issue.

<u>Task 2.</u> X-axis calibration

Fill in Table 2:

Calibration frequency, kHz	
Calibration period, ms	
Measured period, ms	
Division value, measured, ms/div	
Division value, settings, ms/div	

For calibration, use the same oscillogram.

Calculate and write down in the table corresponding to this frequency the value of the pulse repetition period. Indicate on the oscillogram the interval along the X axis corresponding to the pulse period, and write down in the table its value in the divisions of the screen. Write down in the table the set value of the divisionvalue for X, indicated on the oscilloscope panel opposite the black risks on the handle of the "time / div" switch. Calculate the actual division value of the X-axis of the the oscilloscope. It must correspond to the set value. Otherwise, contact the engineer to resolve the issue.

Turn off the sweep by moving the upper switch in the "sweep" panel to the far right position. In this case, the image of the pulses on the screen will turn into two bright points, located on the same vertical line at a distance corresponding to the magnitude of the pulses. This is due to the fact that in the absence of a sweep, the beam, with its multiple up and down movements, lags at the top and bottom points, and between them it jumps so fast that the line connecting these points turns out to be barely noticeable. To see it, increase the brightness of the beam, then return the "brightness" knob to its previous position.

<u>Task 3.</u> Voltage-sensitivity of the X-axis deflection

Feed the signal from the calibrator to the X-axis. To do this, disconnect the cable from the Y input and connect it to the input X. The screen should show a picture in the form of two dots located horizontally, since there is no voltage applied to the vertical deflection plates - there is no vertical deflection. Measure the distance between the luminous points (the pulse width) in the grid divisions of screen X and calculate the oscilloscope sensitivity along the X-axis as $\alpha_x = X / U_k$. Write the value of α_x in the notebook. It can be used for measuring the voltage applied to the X-axis.

Task 4. ***Measurement of the saw-tooth signal frequency***

When performing this task, the second (auxiliary) oscilloscope is used as a source of saw-tooth voltage. Disconnect the cable that connects the calibrator and the X input. Using this cable, connect the input of the main oscilloscope to the output of the auxiliary oscilloscope sweep timebase generator using "◯→" “V” and "⊥" sockets. Turn on the toggle switch of the auxiliary oscilloscope power. Set the "time / div" switch of this oscilloscope to the "0.2 ms" position. Turn on the scan of the main oscilloscope by setting the corresponding switch to the position "×1", and the trigger switch to the "inturnal" position. Obtain a steady image of the saw-tooth signal. Draw the waveform. Measure the period of the observed signal. Calculate its frequency and write it down in the notebook. Turn the "time / div" switch to the "0.5 ms" position and repeat measurement and calculation. You should get the same frequency value.

Task 5. ***Addition of the two oscillations (sine on the Y-axis, saw-tooth on the X-axis)***

Connect the 2nd oscilloscope’s sweep generator to the X-input of the main oscilloscope. Use the low-frequency (sound) generator **Г3-33** as the input signal: connect the generator output to the Y input of the main oscilloscope so that the "signal" pin is connected to the upper terminal of the generator, and the "ground" pin to the middle one, which must be connected to the ground terminal by the jumper. Set the switch on the generator panel to "×2", "scale limits" to "ATT", the knob "detuning" to "0", the toggle switch "internal load" to "ON" position. Turn the generator on by turning the power switch on its panel. After 1-2 minutes, necessary for warming up the device, set the "frequency Hz" knob to the frequency ***f***, determined earlier in the Task 4. The frequency is set by the rotating scale of the generator by positioning the desired value on the red marker and taking into account the position of the "multiplier" switch. Set the output voltage of the generator using the "output control" knob such that the vertical sweep **B** of the oscillogram (see example **B** for "saw" in Figure 4.1) was about half the screen. The resulting oscillogram should be displayed as one period of the sine wave. If necessary, adjust the frequency of the sound generator to obtain a “frozen” waveform.

Disconnect the cable connecting the input **X** of the main oscilloscope and the output of the auxiliary oscillator. Turn on the sweep timebase generator of the main oscilloscope. Get a stable image on the screen identical to the image observed with the external sweep generator. If necessary, adjust the frequency of the sound generator.

Draw the waveform. Specify on it the double amplitude. Measure it using the scale on the screen. Calculate the magnitude of the sine wave in volts. Indicate on the oscillogram the interval along the **X** axis corresponding to the period of the sine wave. Calculate the period of the sine wave in units of time and its frequency. Compare results with the sound generator settings.

Fill in Table 3:

Double amplitude of the waveform, div.	
Amplitude of the waveform, div.	
amplitude of the waveform, V	
Period of the waveform, div.	
Period of the waveform, ms OR μs	
Frequency of the sine wave, Hz	

Task 6. ***Study of the triggering operation***

Connect the output of the oscilloscope generator of the main oscilloscope to the input Y of the auxiliary oscilloscope. Obtain the saw-tooth wave on the auxiliary oscilloscope screen, similar to that shown in Fig. 4.1. Since during the previous task you achieved the coincidence of the sweep and the period of the voltage under investigation, the delay time (this is the length of the horizontal section on the oscillogram) should be zero. If necessary, adjust the frequency of the sound generator and record the frequency value on the scale of the generator in the first row of Table 4. Slowly increasing the frequency of the sound generator, observe the appearance and change of the horizontal section in the image of the saw-tooth signal. As the phase of the signal changes at the end of the sweep, the length of the horizontal section will initially increase abruptly, since "expected" coincidence of the phases of the signal at the beginning of each forward stroke accounts for almost the entire sine wave period. With a further increase in the frequency of the signal, the delay time will decrease and, when the sweep duration corresponds to the 2 signal periods, the horizontal section on the oscillogram will again become zero. Record the corresponding signal frequency value in the second row of Table. 4.

Note. In this oscilloscope model, the image is extinguished somewhat before the end of the direct sweep of the sweep (from left to right) and the second period will not be fully seen, nor will the last period of the saw-tooth waveform on the second oscilloscope (see Fig. 4.1). Therefore, the number of periods in this and the subsequent task should be considered equal to the integer number of the fully seen periods of the sine wave plus one. In the same way, you will get an image of the 3 and 4 periods of the sine wave on the screen, watching the change in the shape of the scan voltage and recording the frequency values corresponding to the zero value of the length of the horizontal section of the saw. Dividing the frequency values of the signal by $\boldsymbol{f}$, obtained in Task 4, make sure that they are multiples of the scanning frequency.

Fill in Table 4:

Number of periods	Generator frequency, Hz	Ratio of frequencies
1		
2		
3		
4		

Task 7. Beat frequency measurement

Beats (oscillations with periodically varying amplitudes) are the result of the direct addition of two voltages with close frequencies. To understand the reason for their appearance, we can use the analogy with the addition of two waves. Suppose that at some point in time the phases of these waves coincide. Then the total amplitude of the oscillations is equal to the sum of the amplitudes and forms the maximum. Then one of the waves begins to lag. Over time, the phase difference between them, equal to $\omega_1 t$ - $\omega_2 t$ = $(\omega 1\text{-}\omega 2)t$, will increase and at some instant of time the oscillation phases become opposite. Then the total amplitude becomes equal to the amplitude difference, i.e. forms the minimum. Further, the lag will continue and at some point in time the phase difference becomes equal to 2π. That is, again the total amplitude will be equal to the sum of the amplitudes, etc. Obviously, the frequency of repetition of the maxima (or minima) of the beats will be equal to the difference of the frequencies of the oscillations.

To observe the beats, it is necessary to disconnect the cable from the input Y of the main oscilloscope, fix the tee in this socket and connect the same cable to it first, and then connect the second cable, connecting it to the "600 Ω" output of the second low-frequency generator **GZ-118**. Set the voltage frequency at the output of the main oscillator equal to or close to 3 KHz. Obtain a stable image of the sinusoid from the main generator with a large number of periods (20-30) and a span of 3-4 divisions, after which set the handle "output level" to the extreme left (zero) position. Set the output frequency of the second generator to 2.5 kHz. In the generator GZ-118, the frequency is set according to the numbers appearing in the "windows" above the "frequency" switches, taking into account the "comma" on the front panel and the position of the "multiplier" switch. Check that the "detuning" knob of the generator is in the "0" position and the "attenuation" knob is in the "10" position. Turn on the second generator and after its warm-up observe on the screen a sinusoid. Set the value of the output voltage of the second generator at the amplitude level of 3-4 divisions. Use the "output" knob of the main generator to increase the voltage until the beats appear on the screen. Draw the waveform. Measure the beat period in the divisions, calculate it in units of time, and also the beat frequency.

Fill in Table 5:

1^{st} generator frequency, Hz	
2^{nd} generator frequency, Hz	
Frequency difference, Hz	
Beat period, div.	
Division value, time / div., ms	
Beat period, ms	
Measured beat frequency, Hz	

Turn off all appliances and disassemble the set-up.

Appendix. Schematic diagram of the CRT