MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL TECHNICAL UNIVERSITY
“KHARKIV POLYTECHNIC INSTITUTE”

METHODICAL INSTRUCTIONS FOR LABORATORY WORKS

on the discipline “Analog Electronics”
for the students of specialty 171“Electronics”
of Institute of Education and Science in Power Engineering,
Electronics and Electromechanics

Kharkiv 2021

МІНІСТЕРСТВО ОСВТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ ТЕХНІЧНИЙ УНІВЕРСИТЕТ
«ХАРКІВСЬКИЙ ПОЛІТЕХНІЧНИЙ ІНСТИТУТ»

МЕТОДИЧНІ ВКАЗІВКИ

до виконання лабораторних робіт
з дисципліни «Аналогова схемотехніка»
для студентів спеціальності 171 «Електроніка»
навчально-наукового інституту енергетики,
електроніки та електромеханіки

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Методичні вказівки до виконання лабораторних робіт з дисципліни «Аналогова схемотехніка» для студентів спеціальності 171 «Електроніка» навчально-наукового інституту енергетики, електроніки та електромеханіки / уклад. Є. І. Король, М. В. Махонін, М. Г. Саминіна, Б. О. Стисло. – Харків: НТУ "ХПІ", 2021. – 45 с.

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List of abbreviations

LPF – low pass filter

HPF – high pass filter

BPF – band pass filter

RF – reject filter or band stop

AC – alternating current

DC – direct current

LFA – low frequency amplifier

CE – common emitter

BT – bipolar transistor

OA – operational amplifier

DCA – direct current amplifier

LFF – low frequency filter

HFF – high frequency filter

MV – multivibrator

NTSh – non-inverting Schmitt trigger

INTRODUCTION

The subject of study of the discipline «Analog Electronics» is the theory and practice of building electronic tools for various fields of technology and research. «Analog Electronics» is one of the basic general technical disciplines in the training of students majoring in «Electronics». The main purpose of the discipline is to teach the student to develop certain functionally complete electronic devices and to understand the principle of operation of these devices, to operate them competently and to formulate tasks for the development of a new product.

As a result of studying the discipline and performing laboratory work, the student must learn:

– electric diagrams of amplification of analog signals on discrete elements and modern integrated circuits;

– features of amplification of signals that change slowly, the causes of zero drift and methods of combating it;

– influence on the parameters of the amplifiers of negative and positive feedback;

– electric diagrams of devices that implement the simplest mathematical operations (amplification, summation, integration, etc.), and the procedure for calculating the elements in them;

– main types of active and passive filters and the order of their calculation;

– methods of protection of input and output circuits from overloads;

– principles of construction of the simplest electric diagrams of voltage stabilizers with use of integrated amplifiers.

In order to improve and intensify the educational process in the study of the discipline, the main theoretical positions are fixed by appropriate laboratory research. Solving laboratory problems improves the skills of using theoretical knowledge in practice, develops thinking, helps to understand in more detail the principle of operation of individual devices and the possibility of their practical application.

The laboratory workshop is focused on conducting classes by the frontal method on a universal laboratory testing stand, which was developed at the Department of Industrial and Biomedical Electronics of NTU "KhPI". The laboratory testing stand is made in the form of a desktop portable device, on the front surface of which (see Appendix 1) there are sockets for connecting the measuring device and keys for forming a given research electric diagram, as well as general simplified electric diagrams of the laboratory testing stand.

The laboratory testing stand contains three electric diagrams. The left and middle electric diagrams allow to investigate electric circuits on discrete elements which are formed by means of group of keys with number I (see appendix 1). Rights - circuits on the operational amplifier with its key group number II. The regulators of the laboratory testing stand are located on its front surface. The tests are performed using an internal alternator *G* or DC voltage generator, which is connected to point *U1* by means of key *S10* of group I and controlled by key *S9* and regulators «*F*» and «*U1*» located in the upper part of the laboratory testing stand. When forming the electric diagram of the experiment, the locking of the keys *S1-S10* of groups I and II is carried out by moving the corresponding switch to the upper position - opening - to the lower. In addition to the above, on the front panel there are additional indicators PWR, PB3, PB4, which reflect the presence of supply voltage, signals at the outputs of ports B.3 and B.4 of the built-in microcontroller, respectively.

To measure the parameters of the signal circuits, the corresponding control points are displayed on the sockets located in the lower part of the front panel of the laboratory testing stand. Measurements are performed with a universal multimeter in different modes of operation, in addition, some studies require the use of an oscilloscope.

Each of the laboratory works should be preceded by independent preparation of students, in the process of which they should get acquainted with the description of laboratory work, recommended literature sources, lecture notes and perform a preliminary calculation of electric diagram elements, according to the individual methodical instructions. In the process of preparation for laboratory work, it is recommended to study the electric diagrams of the experiment, as well as to prepare the tables needed to perform experimental studies.

Processing of experimental results can be done on the basis of recommendations and formulas given in the lecture course «Analog Electronics» and in the subsections «Processing of experimental results and report design» guidelines.

The report on the performed laboratory work must contain: the purpose of the work, the schematic diagram of the experiment, tables, graphs and results of calculations, which are made in accordance with the standards of NTU "KhPI". In addition, the last point should be a brief analysis and conclusions from the results of experiments and calculations.

Laboratory Work № 1
PASSIVE FILTERS

The aim of the work is to study the basic electric diagrams of resistive-capacitive passive filters and their amplitude-frequency characteristics.

1.1 Theory

Passive filter is an electronic filter that consists only of passive components, such as, for example, capacitors. Passive filters do not require any energy source for their operation. Unlike active filters, passive filters do not amplify the signal by power. Passive filters are almost always linear.

Passive filters are widely used in radio and electronic equipment, such as speakers, uninterruptible power supplies, etc.

Filters can also be classified by the frequencies they must or may not pass. The following four types are usually distinguished, as shown in Figure 1.1:

1) Low pass filter (LPF), which passes all frequencies below a certain value and does not pass higher frequencies (Fig. 1.1, *a*, *c*). A low pass filter is also known as a filter that cuts off higher frequencies;

2) High pass filter (HPF), which passes all frequencies above a certain value and does not pass lower frequencies (Fig. 1.1, *b, d*). The high pass filter is also known as a filter that cuts off the lower frequencies;

3) Band pass filter (BPF), which passes the selected frequency band and does not pass the lower and upper frequencies (Fig. 1.1, *e*);

4) Band stop or reject filter (RF) does not pass the selected frequency band and passes the lower and upper frequencies (Fig. 1.1, *f*).

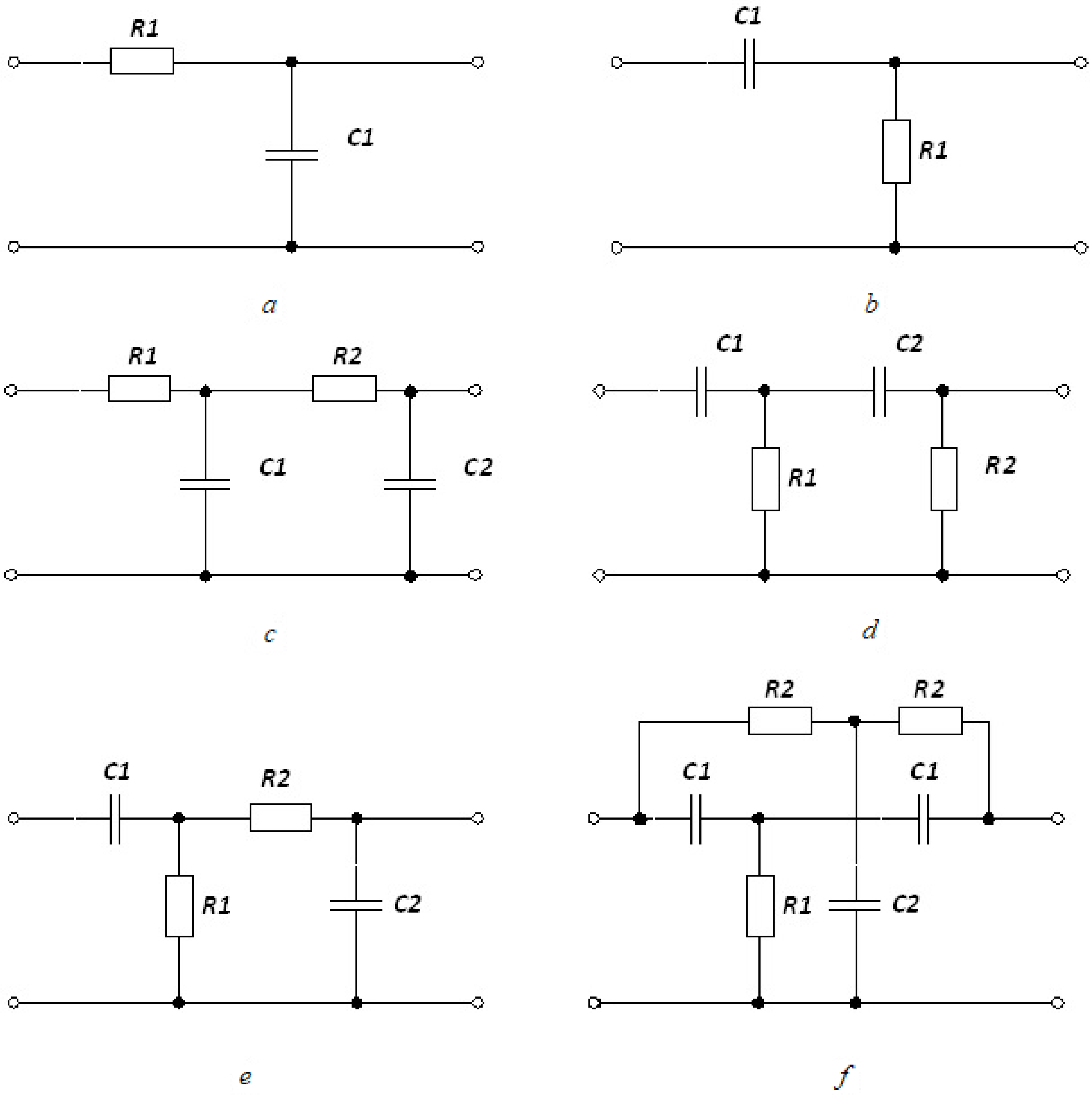


Figure 1.1 – Electric diagrams of passive RC filters: a) low pass filter (LPF); b) high pass filter (HPF); c) 2nd order low pass filter; d) 2nd order high pass filter; e) band pass filter (BPF); f) band stop or reject filter (RF)

1.2 Initial calculations

In this laboratory work we investigate the electric diagrams of the first-order low pass filter, the first-order high pass filter and the individual circuit.

Before starting the research of filters, it is necessary to calculate the cutoff frequency, guided by the nominal value of the available resistors and capacitors.

Table 1.1 – Individual tasks

Student number	Subgroup number				
	1	2	3	4	5
1	2nd order LPF	2nd order HPF	RF	BPF	2nd order HPF
2	BPF	2nd order LPF	2nd order HPF	RF	BPF
3	RF	BPF	2nd order LPF	2nd order HPF	2nd order LPF
4	2nd order HPF	RF	BPF	2nd order LPF	RF

1.3 Procedure of the experiment

Before starting the experiments, it is necessary to get acquainted with the electric diagrams of filters studied in the work, perform calculations of the cutoff frequency, assemble the circuit, and check the presence and connection of the signal generator and multimeter.

1.3.1 *Research of the first-order low pass filter.* Assemble the first-order low pass filter circuit according to Figure 1, *a*. Make sure that the contact between the circuit elements is reliable. Apply a signal from the pulse generator with the set voltage amplitude and frequency to the input of the circuit. Maintain the set voltage level and change the frequency, according to the task received from the teacher. Enter the measurement data in Table 1.2.

Table 1.2 – Experimental data

f, kHz										
U_{IN}, V										
U_{OUT}, V										

1.3.2 ***Research of the first-order high pass filter.*** According to the paragraph 1.3.1 collect and investigate the electric diagram of the first-order high pass filter. Enter the received results in a table, which is identical to Table 1.2.

1.3.3 ***Research of the individual electrical diagram*.** According to the received task from table 1.1 to collect and investigate the electric diagram, as well as in the paragraph 1.3.1. The value of the selected frequencies should be asked from the teacher. Enter the results in a table that is identical to Table 1.2.

1.4 Processing the results of the experiments and design the report

1) According to the data obtained in the paragraph 1.3.1, construct the amplitude-frequency characteristic of the LPF and find graphically the value of the cutoff frequency. The scale of the signal frequency must be logarithmic.

2) According to the data obtained in the paragraph 1.3.2, construct the amplitude-frequency characteristic of the HPF and find graphically the value of the cutoff frequency. The scale of the signal frequency must be logarithmic.

3) According to the data obtained in the paragraph 1.3.3, construct the amplitude-frequency characteristic of the filter selected for the individual task and find the graphical value of the cutoff frequency (for BPF – transmission frequency, RF – rejected frequency). The scale of the signal frequency must be logarithmic.

4) The completed report should consist of the following parts: title page; the laboratory work purpose; the main part (before each experiment it is necessary to provide the filter electric circuit, the table with the received data and to construct amplitude-frequency characteristic of the filter); conclusions.

Questions for self-examination

1. List the main types of the passive filters.
2. Explain the differences between first and higher order filters.
3. Explain what the cutoff frequency of the filter is.
4. Give the formulas for calculating the parameters of the passive filter.
5. List the disadvantages and advantages of using passive filters.

6. Explain how a passive band stop filter works.
7. Explain how a passive band pass filter works.

Laboratory Work № 2

SEMICONDUCTOR STABILIZERS

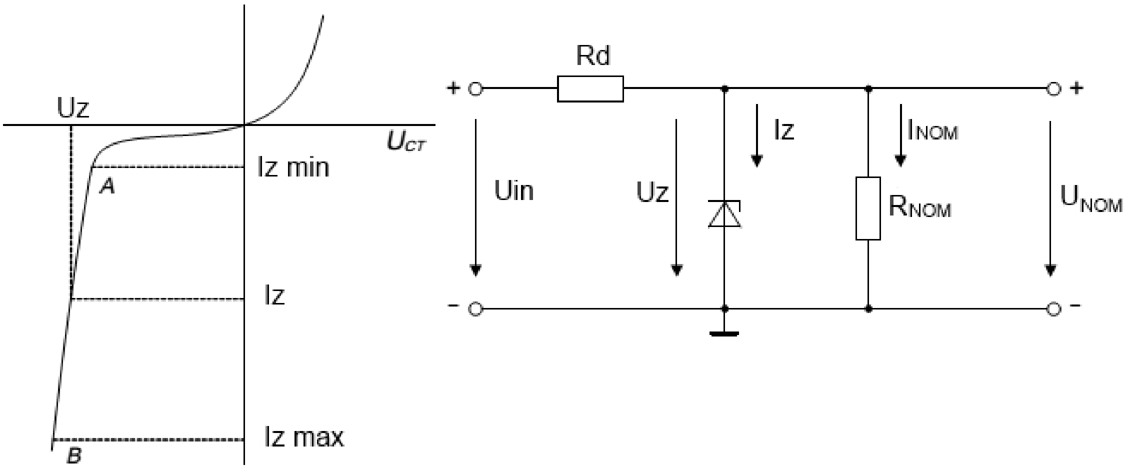
The aim of the work is to study the working section of the current-voltage characteristics of a semiconductor Zener diode, to study the basic characteristics of the parametric and compensating voltage stabilizers and to determine their quality parameters.

2.1 Theory

Electronic devices are typically powered by AC power through rectifiers. In this case, the constant voltage on the load can vary within wide limits due to fluctuations in the supply network voltage, changes in the load current, temperature, etc.

Voltage instability is the ratio of the change in voltage to its nominal value and is determined as a percentage. Thus, the volatility of the industrial AC power line reaches 15 %. In some cases, the electronic equipment can function normally with volatility of the supply voltage of 0,1 % or less. In these cases, a device is installed between the filter rectifier and the load, which automatically maintains a constant output voltage. Such a device is called a voltage regulator. There are two main types of linear stabilizers: parametric (Fig. 2.1) and compensatory (Fig. 2.2), which are studied in the laboratory work.

In the laboratory work are used the left laboratory testing stand’s electric diagram, which is shown in Figure 2.3 and allows to study the stabilizer circuits (Fig. 2.1 and 2.2).



a *b*

Figure 2.1 – Volt-ampere characteristic of a Zener diode (*a*) and electric diagram of a parametric stabilizer (*b*)

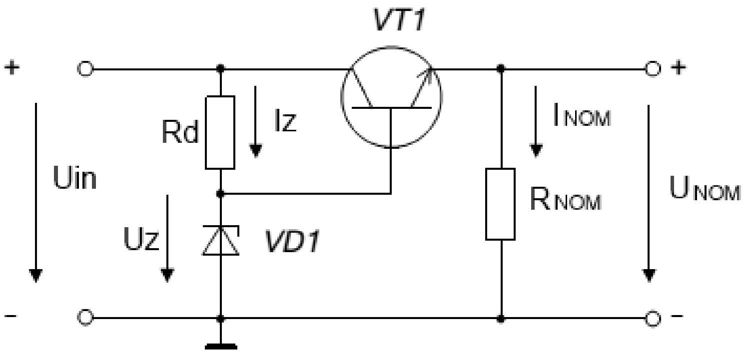
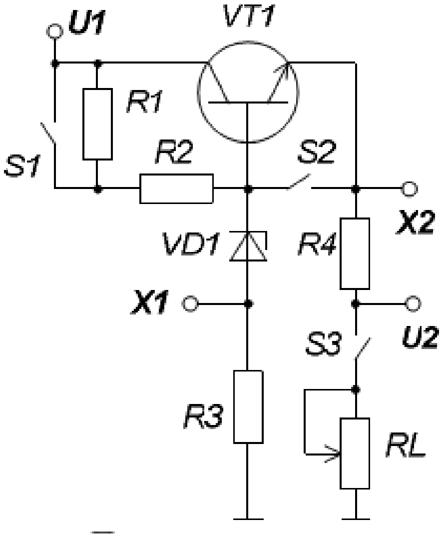


Figure 2.2 – Electric diagram of the compensation stabilizer



R1 = 1 kOhm, *R2* = 200 Ohm, *R3* = 1 Ohm, *R4* = 1 Ohm, *RL* = 0÷20 kOhm.

Figure 2.3 – Electric diagram of a laboratory stand that allows you to explore the circuits of stabilizers

The input signals for all circuits are set from the source *U1*, and the output signals are removed from the control point *U2*. Changing the output impedance *RL* is performed by the controller «*U2* (*RL*)» with the closed key *S3* (Fig. 2.3).

The Zener current is removed as a voltage at the resistor *R3* = 1 Ohm between the *GND* and *X1* control points, the load current – by *R4* = 1 Ohm between *U2* and *X2*.

2.2 Procedure of the experiment

Before the experiments, prepare the laboratory testing stand for work, and check the laboratory testing stand connection to the power supply. The keys of the Group I only are used in the design of the experiments, and the internal generator *G* is used in the DC mode.

2.2.1 *Research of the parametric stabilizer*

2.2.1.1. Establish the circuit (Fig. 2.1) and obtain the external characteristic $U_{NOM} = f\,(I_{NOM})$ at a nominal input voltage U_{IN} = 10 V. The load current changes from minimum to maximum by means of the regulator «*U2* (*RL*)», thus it is necessary to record the Zener current and load voltage. Enter the measurement data in Table 2.1.

Table 2.1 – External characteristic of the parametric stabilizer

I_{NOM}, mA						
I_Z,, A						
U_{NOM}, V						

2.2.1.2. Obtain dependence $U_{NOM} = f(U_{IN})$ at load current (set by the teacher from 1 to 8 mA), changing the input voltage within the range from 7 V to 10,5 V by the regulator «*U1*». The measurement data should be entered in Table 2.2.

Table 2.2 – Effect of input voltage changing on output voltage

U_{IN},V	7	8	9	10	10,5
U_{NOM}, V					

2.2.2 ***Research of the compensation stabilizer.*** Collect the diagram (Fig. 2.2) and repeat the measurements according to the paragraphs 2.2.1.1 and 2.2.1.2 for the compensation stabilizer. Record the measurement data in the appropriate tables, while the Zener current is not recorded.

2.4 Processing the results of the experiments and the design report

1) For the parametric stabilizer according to Table 2.1 draw the external $U_{\text{NOM}} = f(I_{\text{NOM}})$ and the inverse characteristic of the working section of the current-voltage characteristic of the Zener $U_{\text{Z}} = f\,(I_{\text{Z}})$, taking into account the equality of the voltages at the Zener and the load $U_{\text{Z}} = U_{\text{NOM}}$. Arrange the graphs in the appropriate quadrants.

Determine the output resistance of the stabilizer R_{Z} and the dynamic resistance r_{DYN} of the Zener on the slope of the external characteristics and the Zener characteristics.

2) Draw the dependence $U_{\text{NOM}} = f(\text{U}_{\text{IN}})$ in accordance with Table 2.2. According to the graph, calculate the coefficient of stabilization K_{Z} at the nominal input voltage $U_{\text{IN}} = 10$ V.

3) Draw in accordance with Table 2.1 the external characteristic of the compensation stabilizer. Determine the output impedance of the stabilizer by the slope of this characteristic.

4) Draw according to Table 2.2 the dependence of $U_{\text{NOM}} = f(U_{\text{IN}})$ at $I_{\text{NOM}} = \text{const}$. According to the graph, determine the stabilization factor at the rated input voltage $U_{\text{IN}} = 10$ V.

Questions for self-examination

1. List of the stabilizer basic parameters and characteristics that used for their measurement.
2. List the basic parameters of a semiconductor Zener diode. What parameter determines its qualitative performance in the parametric stabilizer circuit?
3. Explain how the parametric voltage regulator works.

4. Explain how the coefficient of stabilization and the output impedance of the stabilizer can be experimentally determined.

5. Explain the work of the compensation stabilizer, for example, by reducing the input voltage.

6. Describe the operation of the compensation stabilizer at U_{IN} = const and the change of load current.

7. Give a comparative analysis of the qualitative indicators of the parametric and compensation stabilizers based on the performed experiments.

Laboratory Work № 3

THE AMPLIFYING STAGE BASED ON THE TRANSISTOR

The aim of the work is to investigate single amplifying stages on a bipolar transistor; to research the characteristics and to determine the parameters of the amplifier.

3.1 Theory

Low Frequency Amplifiers (LFA) are designed to amplify continuous, periodic signals that range in frequency from tens of hertz to tens of kHz. To amplify low signal levels, multi-stage amplifiers with capacitive couplings between the stages are used.

A typical electric diagram of the amplifier cascade with a common emitter (CE) with stabilization of the operating mode is shown in Figure 3.1. Figure 3.2 shows the output characteristics of the transistor of this circuit, operating in mode A. This circuit belongs to the pre-amplification stages class of the multi-stage amplifiers.

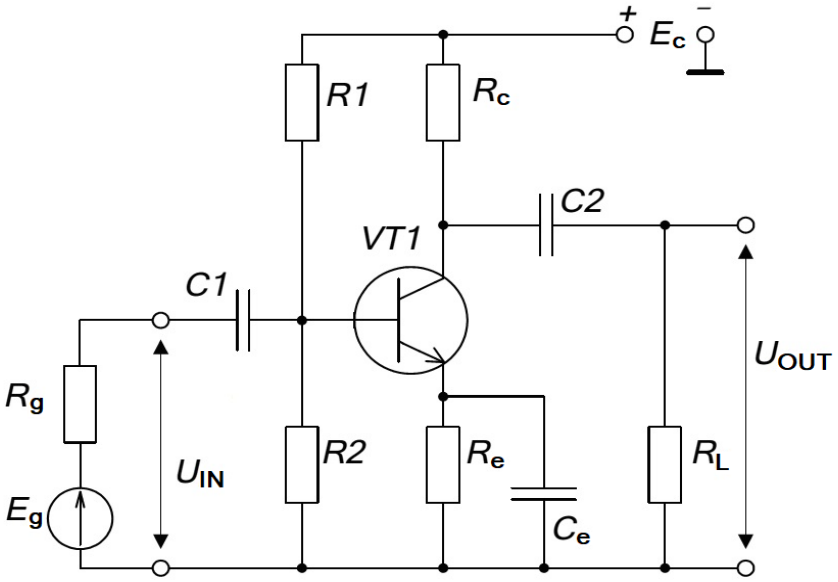


Figure 3.1 – Electric diagram of the amplification stage with CE

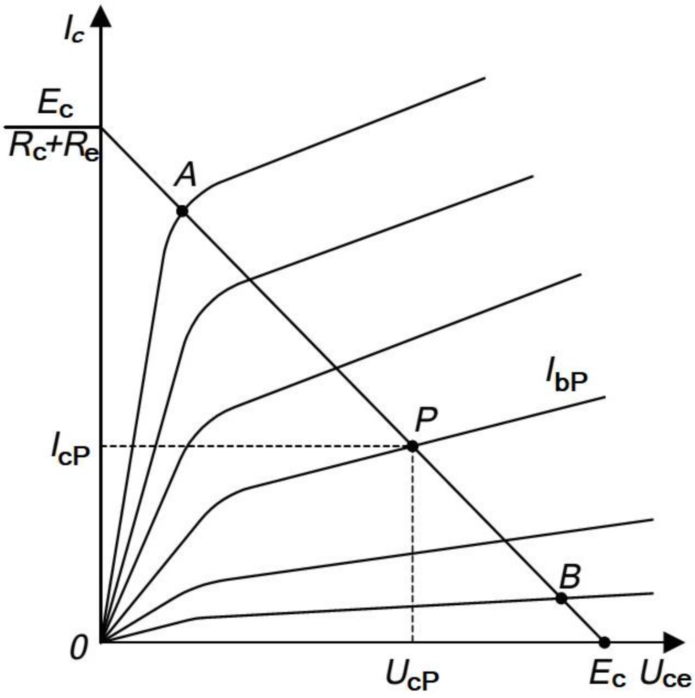
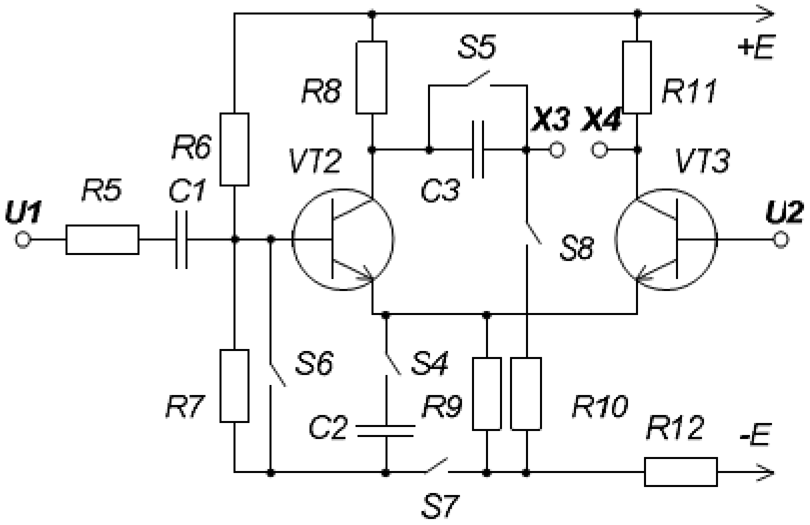


Figure 3.2 – Transistor output characteristics and load line

In the laboratory work is investigated the electric diagram of a single cascade of low frequency amplifier on a bipolar transistor. Figure 3.3 shows an electric diagram of a laboratory testing stand for the study of the amplifiers based on the discrete elements, which allows assembling a circuit of amplification stage on a bipolar transistor with CE. For this purpose, the resistor *R10* (Fig. 3.3) is used as the load R_L (Fig. 3.1), the input voltage is applied to *U1*, and the output is removed from the control point *X3*.

The input signal to *U1* is supplied by the built-in generator *G* (key *S10* of group I is closed, see Annex 1), and the resistor *R5* is considered as its internal resistance. There is no negative feedback on the variable signal when the *S4* key is locked. The key *S8* allows you to capture the characteristics of the cascade in the absence or presence of load *R10*. The key *S7* must be locked to ensure the cascade works.

The frequency of the input signal is set by the knob «*F*» and the switch of the subband *S9* «kHz», and regulated by the amplitude knob «*U1*», located on the front panel of the laboratory testing stand.



Electric diagram parameters: *R5* = 10 kOhm, *R6* = 100 kOhm, *R7* = 10 kOhm, *R8* = 3,3 kOhm, *R9* = 620 Ohm, *R10* = 3,3 kOhm, *R11* = 3,3 kOhm, *R12* = *2* kOhm, *C1* = 0,1 µF, *C2* = 6,8 µF, *C3* = 0,1 µF.

Figure 3.3 – Electric diagram of the laboratory testing stand that allows exploring amplifiers on discrete elements

3.2 Procedure of the experiment

Before starting the study of the amplification stage on a bipolar transistor (Fig. 3.1), it is necessary to assemble a circuit on the laboratory testing stand. **Attention!** To monitor the correct condition of the keys, using only Group I keys.

3.2.1 *Research of the amplitude characteristics in the feedback absence.* Obtain the amplitude characteristics $U_{\text{OUT}} = f\ (U_{\text{IN}})$ in the absence of feedback (key *S4* is closed) for two cases:

a) load R_{L} is off (key *S8* is opened);

b) load R_{L} is connected (key *S8* is closed).

To obtain the characteristics, you need to close the key *S10*, set the frequency of the internal generator 2 kHz (key *S9* «kHz» is open, handle «*F*» in the far right). The input voltage U_{IN} is set with the handle «*U1*» in the range from 0,1 to 1,0 V with a discreteness of 0,1 V. The values of the voltages U_{IN} and U_{OUT} should be obtain from the control points *U1* and *X3* using a universal multimeter in digital voltmeter mode. The measurement data should be entered in Table 3.1.

Table 3.1 – Amplitude characteristics of the cascade with CE

U_{IN}, V		0,1	…	…	…	…	1,0
U_{OUT}, V	$R_L = \infty$						
	R_L = 3,3 kOhm						

3.2.2 ***Research of the frequency response with the load on.*** Measure the amplitude-frequency characteristics (frequency response) with the load on (key *S*8 is closed) for two cases:

a) in the absence of feedback (key *S*4 is closed);

b) in the presence of feedback (key *S*4 is opened).

Characteristics to be recorded at a voltage U_{IN} = 0,3 V, which needs to be kept constant by means of the «*U1*» handle when changing the frequency from 20 Hz to 10 kHz (frequency change is performed by doubling 20, 40, 80, ..., to switch the frequency subband the key *S9* «kHz» of group I is used). Measurement data should be entered in table 3.2.

Table 3.2 – Amplitude-frequency characteristics of the cascade with CE

	f, kHz	20	40					
U_{OUT}, V	C_e = 6,8 μF							
	C_e = 0							

3.3 Processing the results of experiments and design report

1) According to the paragraph 3.2.1, construct the amplitude characteristics $U_{OUT} = f(U_{IN})$. For linear sections of amplitude characteristics, determine the gain, the dynamic gain *D* and the output resistance R_{OUT} of the amplifier stage for one of the values of the input voltage U_{IN}.

2) According to the paragraph 3.2.2, construct the frequency response on a logarithmic scale along the frequency axis, plotting on the axis not *f*, but lg *f*. According to the frequency characteristics determine:

– gain coefficient K_0 at medium frequencies;

– frequency distortion coefficients for f_1 = 100 Hz and f_2 = 10 kHz.

Questions for self-examination

1. List the main parameters of the amplifiers.
2. Explain the reasons for nonlinear distortions.
3. Explain the causes of frequency distortion in the low and high frequencies, from which coefficients they are determined.
4. Describe the operation of the amplifier stage with CE connection of bipolar junction transistor.
5. Explain how the quiescent mode of the amplifier stage with CE is selected using the load line.
6. Explain the principle of thermal stabilization in the amplifier stage with CE.
7. Explain why the output signal is in antiphase with the input signal in the amplifier stage with CE.
8. Explain the purpose of C_e in the amplifier stage with CE.
9. Describe the influence of the elements on the circuit parameters according to the equivalent circuit of the amplifier stage with CE.
10. Explain which elements of the amplifier stage with CE affect the frequency distortion in the low and high frequencies.
11. Explain the effect of load resistance on the amplifier parameters.

Laboratory Work № 4
DC AMPLIFIERS

The aim of the work is to study the operation principle of the differential amplifier circuit and to determine its parameters experimentally; to get acquainted with the operational amplifier (OA) and to research of inverting and non-inverting amplifiers based on the OA.

4.1 Theory

DC amplifiers (DCA) are designed to amplify signals that change slowly over time, their lower frequency is close to zero. The upper frequency range of the DCA is determined by the frequency properties of the amplifier.

The need to amplify constant level signals that change slowly does not allow the use of the isolation capacitors between the amplification stages, which do not transmit a constant signal. This feature leads to the need for direct communication of the signal source with the input of the amplifier, as well as between the individual amplifier stages.

The influence of supply voltage instability and changes in the circuit elements parameters over time and under the influence of temperature is increased in the direct connection between the amplifier stages. These reasons cause a change in the voltage potentials of the transistors, which are amplified and formed as a useful signal at the output of the circuit. This appearance of the output signal in the absence of the input one is called zero drift DCA. An effective means of combating drift was the use of cascades built on the principle of the balanced bridges. The most common of these is a differential amplifier.

We study the differential amplifier, which is depicted in Figure 4.1. The inverting and non-inverting amplifiers (Fig. 4.2, *a* and *b*) and a voltage repeater (Fig. 4.2, *c*) based on OA are investigated also.

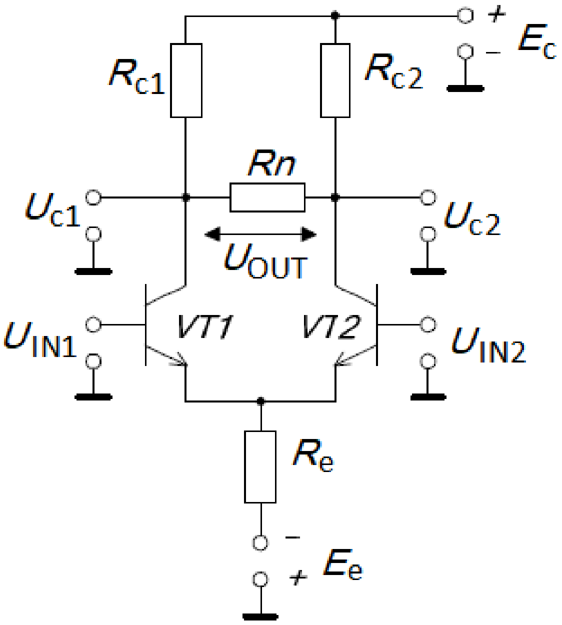
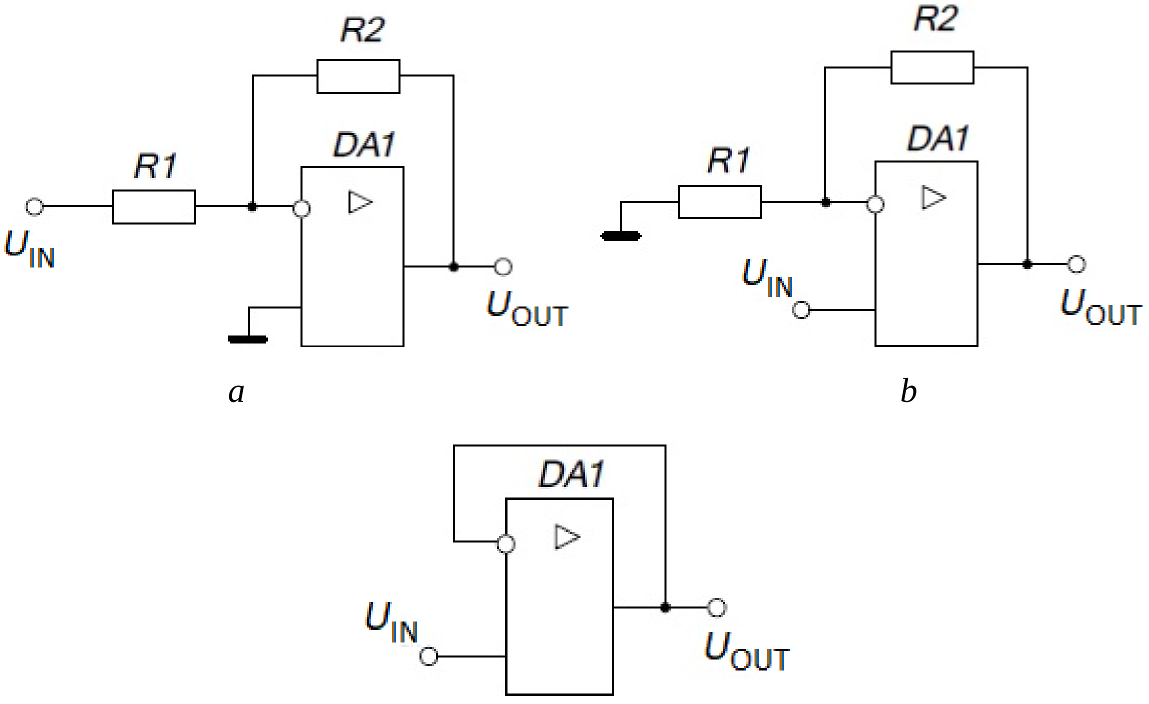


Figure 4.1 – Electric diagram of a differential amplifier

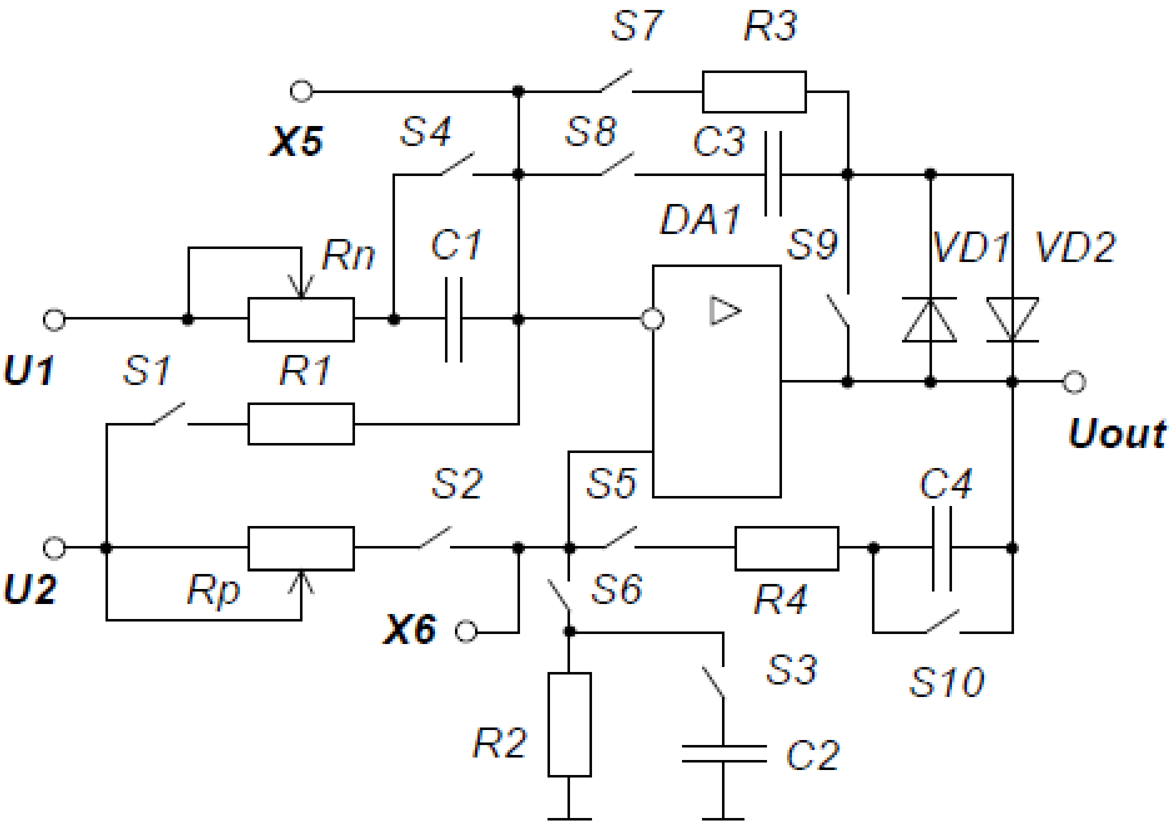


a   *b*

c

Figure 4.2 – Electric diagram of amplifiers based on the OA:
a) inverting amplifier; *b*) non-inverting amplifier; *c*) repeater

Two electric diagrams of DC amplifiers are investigated in the work. The differential amplifier is assembled according to the electric diagram of the laboratory testing stand (Fig. 4.3). The output voltage of the cascade is determined between the collectors of transistors *VT2* and *VT3* (control points *X3*, *X4* in Fig. 4.3) depending on the supply to their base of differential or in-phase input signals. The keys of group I are used for the electric diagram. Figure 4.3 shows the electric diagram, which uses the keys of group II to research devices based on the operational amplifier. Before the beginning of OA researches it is necessary to draw the electric diagram in the draft and to calculate the resistor values *Rn* according to a variant of the task (Table 4.1). The task is determined according to the subgroup number and the number of the student in the subgroup.



Electric diagram parameters: *R1* = 10 kOhm, *R2* = 10 kOhm, *R3* = 10 kOhm, *R4* = 20 kOhm, *Rn* = 0÷20 kOhm, *Rp* = 0–20 kOhm, *C1* = 0,1 μF, *C2* = 0,1 μF, *C3* = 0,1 μF, *C4* = 0,1 μF.

Figure 4.3 – Electric diagram of the laboratory testing stand to explore the devices based on the OA

Table 4.1 – Amplification factors of the circuits for different task options

Student number	Amplifier circuit	Subgroup number					
		1	**2**	**3**	**4**	**5**	**6**
1	inverting	1,2	2,4	1,5	2,6	3,1	2,5
2	non-inverting	2,0	3,0	1,8	3,3	2,2	3,6
3	inverting	3,4	1,4	0,6	3,5	1,1	2,2
4	non-inverting	1,6	3,1	2,5	1,9	3,5	1,3

Calculate before the start of the laboratory work and provide the teacher for verification.

To set the value of the resistor *Rn*, you must close the key *S4*, open the keys *S1*, *S7* and *S8* and, measuring the resistance with a universal multimeter between the control points *U1* and *X5* on the front panel of the laboratory testing, set the required resistance value. The input signals for both circuits are set from the internal source (*G*) through *U1* and *U2*, which values are set by means of appropriate regulators located on the front panel of the laboratory testing. There are also sockets *X3*, *X4*, *X5*, *X6* and U_{OUT}, which are designed to measure voltages at the control points of the circuits and at its output.

4.2 Procedure of the experiment

Before starting the experiments, get acquainted with the Theory of the DCA and the structure of the OA, perform calculations according to the task variant (Table 4.1), prepare the laboratory testing stand for work, and check the connection of the laboratory testing stand to the power supply. In all studies, the voltage generator *G* built into the laboratory tools operates in the DC voltage mode (regulator «F» is in the extreme left position, key *S10* is closed, *S9* – open).

4.2.1 *Research of the differential amplifier.* Connect the differential amplifier circuit (Figure 4.1) by putting the required keys in corresponding positions (use keys of group I). Obtain the transfer characteristic of the differential amplifier $U_{OUT} = f\,(U_{IN2})$ at U_{IN1} = 0 V. To do this apply to U_{IN1} = 0 V with the key *S6*, put the regulator «*F*» frequency of the built-in shaper to the leftmost position, apply to *U1* voltage from the built-in shaper (key *S10*) and provide the maximum voltage at its output by bringing the voltage regulator *U1* to the extreme right position (check *U1* > 10 B). Consecutively change *U2* from – 4 to + 4 V and measure the potentials of collectors U_{C1} and U_{C2} (sockets *X3* and *X4*) using a universal multimeter. Measurement data should be entered in Table 4.2. The input voltage is calculated as $U_{IN2} = U2 / 10$. The output voltage is determined from the ratio $U_{OUT} = U_{C1} – U_{C2}$ taking into account the difference sign.

Table 4.2 – Transfer characteristics of the differential amplifier

U2, V	– 4	– 3	– 2	– 1	0	1	2	3	4
U_{IN2}, V									
U_{C1}, V									
U_{C2}, V									
U_{OUT}, V									

4.2.2 *Research of the OA circuits*

4.2.2.1. Obtain the transfer characteristic $U_{OUT} = f(U_{IN})$ of the voltage repeater (Fig. 4.2, *c*). To do this, assemble the circuit on the laboratory testing stand, using as feedback resistor *R3* (Fig. 4.3), and *C1* is considered as a gap for a constant signal, using the keys of group II. Then set the operating mode of the built-in generator *G* as a DC voltage generator, for which move the frequency regulator «*F*» to the extreme left position and apply (key *S10*) to *U1* voltage from the generator and ensure the maximum level at its output by setting the voltage regulator «*U1*» to extreme right position (check *U1* > 10 V). Change $U2 = U_{IN}$ from minimum to maximum value and measure the voltage value at the output of the circuit U_{OUT} using the universal multimeter. Measurement data should be entered in Table 4.3.

Table 4.3 – Transfer characteristics of the voltage repeater

U_{IN} (*U2* or *U1*), V										
U_{OUT}, V										

4.2.2.2. Repeat the measurement of the paragraph 4.2.2.1 for the inverting amplifier circuit (Fig. 4.2, a) with a gain equal to one and input voltage *U2*, for which use resistors *R3* and *R1* as feedback. The non-inverting input of the OA is connected to zero through the resistor *R2* (Fig. 4.3).

4.2.2.3. Repeat the measurement of the paragraph 4.2.2.1 for the circuit of the individual variant of the task (Table 4.1). Use resistors *R3* and *Rn* as feedback (Fig. 4.3). Before starting the measurements, set the resistance *Rn* (see paragraph 4.2), which value is calculated according to the variant of the task. Then form the corresponding electric diagram and obtain one of the sections of the transfer characteristic:

– for the inverting amplifier – *U1* is changed from max to min;

– for non-inverting amplifier – *U2* is changed from max to min at $U1 = 0\,\text{V}$.

4.3 Processing the results of the experiments and report design

1) Build a transfer characteristic $U_{OUT} = f\,(U_{IN})$ of the differential amplifier according to the paragraph 4.3.1. Determine from the transfer characteristic the gain $K = \Delta U_{OUT} / \Delta U_{IN2}$ on the linear section, as well as the maximum values of the output voltage U^{+}_{OUT} and U^{-}_{OUT} corresponding to the saturation areas.

2) Using the data of the paragraph 2.3.1, determine the bias voltage of the differential amplifier.

3) Construct the transfer characteristic $U_{OUT} = f\,(U_{IN})$ of the voltage repeater and inverting amplifier with a single gain according to the paragraphs 4.2.2.1 and 4.2.2.2, respectively.

4) Construct the transfer characteristic of the amplifier for your task according to the paragraph 4.2.2.3, determine the gain of the circuit $K = \Delta U_{OUT} / \Delta U_{IN}$, and the

error of providing a given gain $\delta = |K - Kg| / Kg \cdot 100\,\%$, where *Kg* is the gain that is specified in your version.

Questions for self-examination

1. What is zero drift and the reasons for its appearance in the DCA?

2. What are the features of the differential cascade circuit?

3. Describe the stabilization of the differential mode of the differential stage when the supply voltage or temperature changes.

4. Why the resistor R_e (see Fig. 4.1) increases the stability of the circuit and does not affect the gain of the differential stage?

5. Describe the methods of supplying the input signal to the DCA (Fig. 4.1).

6. Explain why the differential amplifier does not amplify the common mode signal.

7. Describe the general structure of the OA.

8. Specify the main parameters of the OA.

9. Give and describe the electric diagram of the inverting amplifier.

10. Give and describe the s electric diagram of a non-inverting amplifier.

11. Compare inverting and non-inverting amplifiers in terms of input resistance and gain.

Laboratory Work № 5

ANALOG ELECTRIC DIAGRAMS BASED ON OPERATIONAL AMPLIFIERS

The aim of the work is to study the basic electric diagrams of the operational amplifier connection for analog signals processing and to define their characteristics and parameters.

5.1 Theory

Analog circuits on the OA are called linear, which is due to the use in their operation of the linear section of the transfer characteristic of the OA. Taking into account this condition, and also thanks to high qualitative characteristics of OA, on its basis high-precision devices of processing and conversion of analog signals (adders, integrators, differentiators, logarithmizers, signal multipliers, filters, etc.) are created.

The laboratory works provides an opportunity to research the following analog circuits on the OA: two-input inverting adder (Fig. 5.1, *a*), addition-subtraction circuit (Fig. 5.1, *b*), integrator (Fig. 5.1, *c*), differentiator (Fig. 5.1, *d*), low pass filter (LPF) (Fig. 5.1 *e*), high pass filter (HPF) (Fig. 5.1, *f*) and band pass filter (BPF) (Fig. 5.1, *g*). All these circuits have negative feedback.

Figure 4.3 shows a diagram of a laboratory testing stand, which allows you to collect each of these electric diagrams (Fig. 5.1), switching the corresponding keys of group II. In the given work the following electric diagrams on OA are investigated: the inverting adder, the differentiator and the electric diagram of an individual variant of the problem. Before the beginning of researches it is necessary to draw the electric diagram in the draft and to calculate values of resistors *Rn* and *Rp* according to a variant.

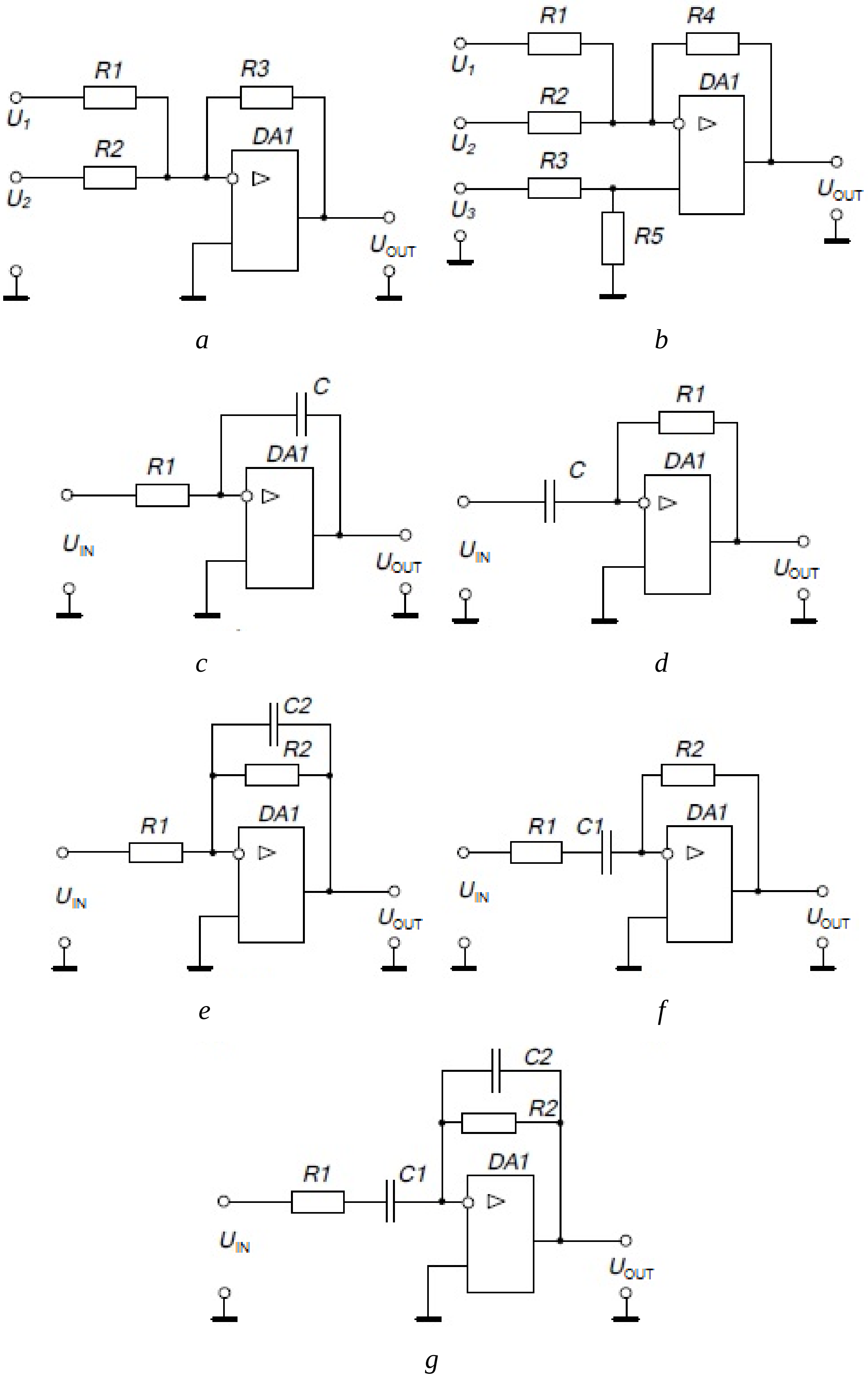


Figure 5.1 – Electric diagram on the OA:

a) inverting adder; *b*) addition-subtraction circuit; *c*) integrator; *d*) differentiator; *e*) low pass filter; *f*) high pass filter; *g*) band pass filter

The calculation should be performed before the start of the laboratory work according to the task by the student number in the subgroup and the subgroup number in Table 5.1 and provided the teacher for verification.

Table 5.1 – Electric diagram and their parameters for different task options

Student number	Subgroup number					
	1	2	3	4	5	6
1	HPF f_c= 100 Hz	LPF K_0=1,5	BPF f_c=120 Hz	$-600\int U_{IN}dt$	$-2{,}5U1-$ $-U2+3{,}5U3$	LPF K_0=3,5
2	$-U1-$ $-U2+2{,}0U3$	HPF f_c= 150 Hz	LPF K_0=2,0	BPF f_c=170 Hz	$-800\int U_{IN}dt$	$-1{,}5U1-$ $-U2+2{,}5U3$
3	$-1000\int U_{IN}dt$	$-2{,}0U1-$ $-U2+3{,}0U3$	HPF f_c= 200 Hz	LPF K_0=2,5	BPF f_c=220 Hz	$-1400\int U_{IN}dt$
4	BPF f_c=270 Hz	$-1200\int U_{IN}dt$	$-3{,}0U1-$ $-U2+4{,}0U3$	HPF f_c= 250 Hz	LPF K_0=3,0	BPF f_c=320 Hz

To set the value of the resistor *Rp* it is necessary to close the key *S2*, open the keys *S1*, *S5* and *S6*, and set the required resistance value by measuring the resistance with a universal multimeter between the control points *U2* and *X6*. The input signals for all circuits are set from sources *U1* and *U2*, the values of which are set using the appropriate regulators. Sockets *U1*, *U2*, *X5*, *X6* and U_{OUT} are designed to measure voltages at control points of circuits and at its output.

5.2 Procedure of the experiment

Before starting the experiments, get acquainted with the electric diagrams studied in the work, perform calculations according to the variant of the task (Table 5.1), prepare the laboratory testing stand for work, and check the connection of the laboratory testing stand to the power supply (PWR indicator, see appendix 1). Group II keys are used to form the experimental electric diagrams.

5.2.1 ***Research of the inverting adder.*** Assemble the adder circuit (Fig. 5.1, *a*) and investigate the summation of voltages *U1* and *U2*, which are fed through resistors *Rn* and *R1* to the inverting input OA. To do this, pre-set the value of the resistor *Rn* = 5 kOhm (see paragraph 2.2), which corresponds to the summation of the input signals by the expression:

$$U_{\mathrm{OUT}} = -2U1 - U2. \qquad (5.1)$$

Then assemble the inverting adder circuit by keys, while the non-inverting input is connected to zero through the resistor *R2* (Fig. 2.2). Measure and record the output voltage U_{OUT} of the adder using a universal multimeter for three variants of input signals:

a) *U1* = +1,5 V, *U2* = +0,2 V;

b) *U1* = +1 V, *U2* = –2 V;

c) *U1* =+2 V, *U2* = –3 V.

Check the obtained values according to the expression (5.1). An internal generator *G* is used to set the input voltage level. It operates in the DC voltage generation mode (frequency regulator "*F*" is set in the leftmost position, key *S9* is open, *S10* is closed).

5.2.2 ***Research of the differentiator circuit.*** Assemble the circuit (Fig. 5.1, *d*) and oscilloscope the input *U1* and output U_{OUT} of the differentiator voltage. To do this, use the keys of group II to assemble the differentiator, additionally set the resistance of the resistor *Rn* to 500 Ohm, and apply a rectangular signal from the built-in generator *G* with parameters *f* = 50 Hz, *U1* = 5 V to the input *U1*.

5.2.3 ***Research of the circuit for an individual task.*** Before starting the experiments, set the values of the resistors *Rn* and *Rp* (see paragraphs 4.1 and 5.1), which are obtained by calculation, and assemble the circuit according to the task variant (Table 5.1).

When studying the **filters**, obtain the frequency response by applying a signal from the built-in generator *G* to the input of the circuit. In this case, U_{IN} = 1 V (socket *U1*). Keep it constant with the regulator «*U1*», and change the frequency from 20 Hz to 10 kHz using the key *S9* «kHz» (frequency is changed by doubling 20, 40, 80 ...). Enter the measurement data in Table 5.2.

Table 5.2 – Amplitude-frequency characteristics of the filter

f, kHz								
U_{IN}, V								
U_{OUT}, V								

When studying the **summation-subtraction** circuit, apply voltages from sources *U1* and *U2* to the input of the circuit, the voltage of which is formed by the built-in DC voltage generator (see paragraph 5.2.1). Measure and record the output voltage U_{OUT} of the circuit for three variants of the input signals:

a) *U1* = +1,5 V, *U2* = *U3* = +0,2 V;

b) *U1* = +1 V, *U2* = *U3* = –2 V;

c) *U1* = +2 V, *U2* = *U3* = –3 V.

Check the obtained values according to the expression of your individual task.

When studying the **integrator**, assemble the integrator by keys, the resistance of the resistor *Rn* set according to the variant of the task, and apply a rectangular signal from the built-in generator with parameters *f* = 100 Hz, *U1* = 3 V to the input *U1*. Next, record the oscilloscope input ($U1_m$) and output (U_{OUTm}) voltages.

5.3 Processing the results of the experiments and the design report

5.3.1 Determine the error of calculation of the sum according to paragraph 5.2.1 for three measurements. Use the expression $\delta = |U_{OUT} - U_{CAL}|/U_{CAL} \cdot 100\,\%$, where U_{CAL} is the calculated voltage at the output of the adder, U_{OUT} is the measured voltage.

5.3.2 Provide oscillograms of the differentiator in accordance with paragraph 5.2.2.

5.3.3 According to the results of research of the electric diagram of the individual variant:

– for active filters construct frequency response according to paragraph 5.2.3 by using a logarithmic scale on an axis of frequencies (put on an axis not *f*, but lg *f*). According to the amplitude-frequency characteristics determine: cutoff frequency, resonant frequency and Q factor (for BPF);

– for the summation-subtraction circuit define an error of calculation of the sum according to the data of paragraph 5.2.3 for three measurements (see paragraph 5.3.1);

– for the integrator circuit give oscillograms of input and output voltages, coordinating them in time under each other. Determine the integration constant by the expression $\tau = U1_m \big/ 4U_{OUTm} \cdot f_g$ and the error of a given integration constant $\delta = |\tau - RC|/RC \cdot 100\ \%$, where *RC* is the product of the calculated values of the elements of the integrator.

Questions for self-examination

1. What is meant by an ideal OA?

2. Give and describe the electric diagram of the integrator. Explain the shape of the output voltage of the integrator when applying rectangular pulses to the input.

3. Draw and describe the electric diagram of the differentiator.

4. What is the condition of the gain balance in the summation-subtraction electric diagram.

5. How to change the resistance of the adder resistors in order to:

a) increase the transmission ratio by 4 times simultaneously on two inputs;

b) reduce the transmission ratio by 2 times for only one input.

6. Draw the electric diagram and use it to explain the appearance of the frequency response of the first-order low pass filter.

7. Draw the electric diagram and use it to explain the appearance of the frequency response of the first-order high pass filter.

8. Draw the electric diagram and use it to explain the type of BPF frequency response.

9. Give the definition of the cutoff frequency and bandwidth.

10. Which elements determine the transmittance coefficient of low and high pass filters.

11. Give a definition of the Q-factor of a band pass filter.

12. Explain the changes in the oscillogram of the output voltage of the integrator when changing the frequency of the input signal.

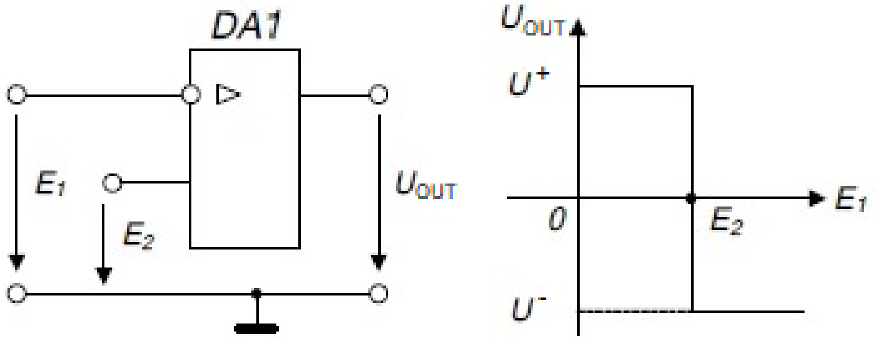
Laboratory Work № 6

PULSE ELECTRIC DIAGRAMS BASED ON OPERATIONAL AMPLIFIERS

The aim of the work is to study the principle of operation of the comparator and Schmitt trigger based on the operational amplifier; research and determine the parameters of multivibrator circuits and analog circuit of sinusoidal voltage generator based on operational amplifier.

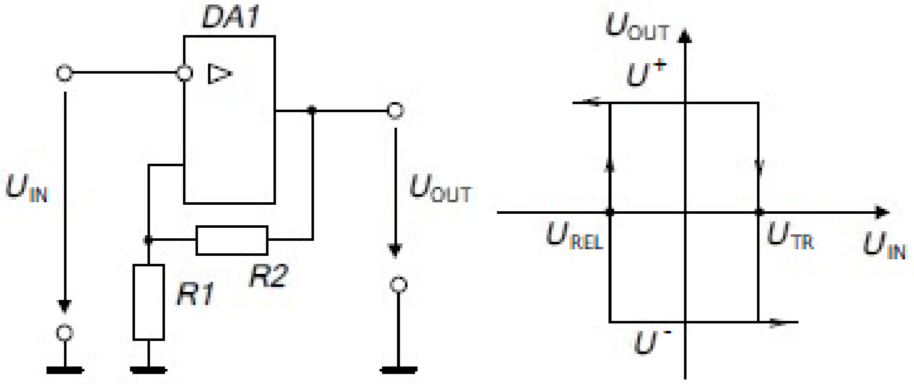
6.1. Theory

Operational amplifiers (OA) are widely used in many devices of pulse and digital technology. Their use is due to the possibility of obtaining higher quality parameters of the devices in comparison with the circuits on the transistors. The paper provides an opportunity to investigate the comparator shown in Figure 6.1, inverting and non-inverting Schmitt triggers (Figures 6.2, 6.3), a multivibrator (Figure 6.4, *a*) and a sinusoidal voltage generator (Figure 6.4, *b*), based on an OA.



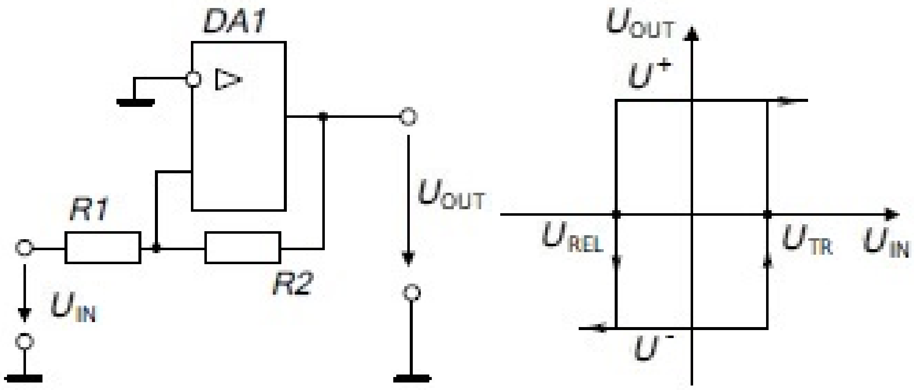
a *b*

Figure 6.1 – Electric diagram of the comparator for comparing the one sign voltage (*a*) and its transfer characteristic (*b*)



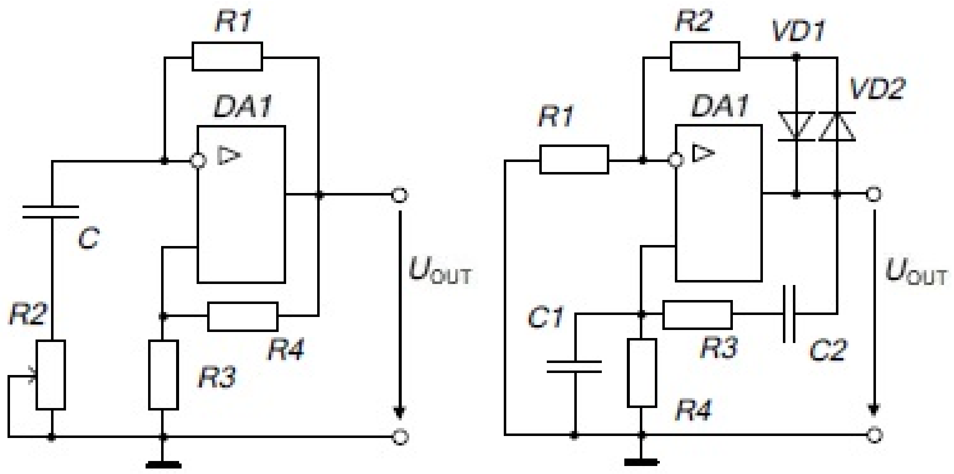
a *b*

Figure 6.2 – Electric diagram (*a*) and transfer characteristic (*b*) of the inverting Schmitt trigger



a *b*

Figure 6.3 – Electric diagram (*a*) and transfer characteristic (*b*) of the non-inverting Schmitt trigger



a *b*

Figure 6.4 – Electric diagram of the multivibrator based on the OA with an additional resistor to regulate the output part (*a*) and the sinusoidal voltage generator circuit (*b*)

Set up electric diagram of the laboratory testing stand, which allows you to collect the diagrams shown in Figures 6.1-6.4, by switching the corresponding keys of group II (see Annex 1). In the work, each of the teams investigates the following electric diagrams on the OA: a comparator, an inverting Schmitt trigger and a sinusoidal voltage generator. In addition, each student investigates the electric diagram of its variant in accordance with the task (Table 6.1). Before the beginning of researches it is necessary to draw the electric diagram in the draft and to calculate values of the resistors *Rn* and *Rp* according to a variant of the task. Tasks by student number in the subgroup and subgroup numbers are given in Table 6.1, where MV is a multivibrator, NTSh is a non-inverting Schmitt trigger.

Table 6.1 – Parameters of the electric diagrams' variants

Student number	Subgroup number					
	1	2	3	4	5	6
1	MV f_0=700 Hz	NTSh U_{REL}=–2,8 V	MV f_0=900 Hz	MV f_0=750 Hz	NTSh U_{TR}=1,2 V	MV f_0=1330 Hz
2	NTSh U_{TR}=2,4 V	MV f_0=850 Hz	NTSh U_{REL}=–3,1 V	NTSh U_{REL}=–0,3 V	MV f_0=800 Hz	NTSh U_{TR}=1,1 V
3	MV f_0=1350 Hz	NTSh U_{TR}=2,5 V	MV f_0=1000 Hz	MV f_0=1200 Hz	NTSh U_{REL}=–2,2 V	MV f_0=830 Hz
4	NTSh U_{REL}=–0,6 V	MV f_0=1120 Hz	NTSh U_{TR}=2,0 V	NTSh U_{TR}=1,8 V	MV f_0=1400 Hz	NTSh U_{REL}=–2,7 V

Calculate before the start of laboratory work and provide the teacher for verification.

Setting the values of the resistors of the circuit *Rp* and *Rn* is carried out according to paragraphs 4.2 and 5.2.

When calculating the inverting Schmitt trigger, keep in mind that the supply voltage is 12 V. The calculation of the resistor *R2*, which allows you to adjust the output frequency in the multivibrator (Fig. 6.4, *a*), must be done by approximate methods (eg, dichotomy or MATCAD program tools), using the dependence of the resistance value on the period of oscillations (*T*):

$$5{,}4\frac{R2}{R1+R2}-2=\left(4\frac{R2}{R1+R2}-3\right)\left(1-e^{\frac{-T}{1{,}5C(R1+R2)}}\right).$$

When calculating, use the nominal values of the circuit elements in Fig. 4.3 specified in paragraph 4.2.

The input signals for all circuits are set from the sources *U1* and *U2*, the values of which are set using the corresponding regulators on the front panel of the laboratory testing stand. Sockets *U1*, *U2*, *X5*, *X6* and U_{OUT} are designed to measure voltages at the test points of the circuit and at its output. The connection of the internal voltage generator to *U1* is carried out with the key *S10* on the group I of the keys.

6.2 Procedure of the experiment

Before starting the experiments, get acquainted with the electric diagrams investigated in the work, perform calculations according to the variant of the task (Table 6.1), prepare the laboratory testing stand for work, and check the connections of the laboratory testing stand to the power supply. Group II keys are used to form the experimental circuits.

6.2.1 ***Research of the comparator.*** Assemble the comparator circuit (Fig. 6.1) by closing the appropriate keys. Then obtain the transfer characteristic of the comparator $U_{OUT} = f\ (E_1)$ at a fixed voltage value at the second input $E_2 = 0$ V (key S6 is closed). To set the input voltage level ($E_1 = U2$) from -1 V to 1 V with a resolution of 0,2 V, use the internal generator *G*. At the same time, it works in the mode of forming a constant voltage (move the frequency regulator «*F*» to the extreme left position, open key *S9*, and close key *S10* on the group I of keys), and set the voltage regulator «*U1*» in the extreme right position. Summarize the measurement results in a table that you should prepare by yourself.

6.2.2 ***Research of the inverting Schmitt trigger.*** Assemble the circuit (Fig. 6.2), determine the trigger threshold U_{TR} and the release threshold U_{REL} of the Schmitt trigger, while the input voltage is supplied from the source *U2* (constant *U1* = max) and change from minimum to maximum as follows. Set the knob «*U2*» to the leftmost position and lock the maximum value $U_{OUT} = U^{+}$. Slowly increasing the voltage *U2* it is necessary to record the switching moment of the trigger to the opposite state with a negative output voltage $U_{OUT} = U^{-}$. Taking into account the sign, fix the voltage *U2*, which corresponds to the trigger threshold U_{TR}, and the value of U^{-}. Then, slowly reducing the voltage *U2*, record the switching moment of the trigger to the opposite state with the voltage $U_{OUT} = U^{+}$. Record the voltage *U2*, which corresponds to the release threshold U_{REL}.

As a result of the experiment, four voltages must be recorded.

6.2.3 ***Research of the sinusoidal voltage generator circuit.*** Assemble the circuit (Fig. 6.4, *b*), set *U1* = 0 V and connect the generator output to the oscilloscope. Adjust the output voltage level using the regulator *Rn*.

Take the oscillograms of the output voltage with the maximum amplitude without distortion and record the value of the resistor *Rn*.

Take the oscillograms of the output voltage with maximum amplitude and slight distortion (truncated vertex of the sine wave) and record the value of the resistor *Rn*.

6.2.4 ***Research of the electric diagram of an individual task***

6.2.4.1 When studying the non-inverting Schmitt trigger, assemble the circuit (Fig. 6.3), set the value of the resistor *Rp* (see paragraph 5.2) according to your calculation, and ground the inverting input using an external jumper connected to the current input of the universal multimeter and to the control point *X5* of the laboratory testing stand.

Determine the trigger threshold U_{TR} and the release threshold U_{REL} of the Schmitt trigger, with the input voltage set from minimum to maximum from source *U2* (constant *U1* = max). Make measurements according to paragraph 6.2.2.

6.2.4.2 To study the multivibrator on the OA, it is necessary to assemble the circuit (Fig. 6.4, *a*), set *U1* = 0 V and set the value of the regulator *Rn* (see paragraph 4.2) according to your calculation. Take the oscillograms at the output, inverting and non-inverting inputs OA of the multivibrator circuit. Oscillography of three time diagrams should be done by connecting them on the X axis. Measure the oscillation frequency *f* of the multivibrator with a universal multimeter in the appropriate mode.

6.3 Processing the results of the experiments and the design report

1) According to the table of paragraph 6.2.1 construct the transfer characteristic of the comparator.

2) Using the data of paragraph 6.2.2 construct the transfer characteristic of the inverting Schmitt trigger.

3) Give the oscillograms of the sinusoidal voltage generator obtained in 6.2.3 and the corresponding resistance values of the resistor *Rn*.

4) According to the results of electric diagram research of the individual variant of the task:

– for the non-inverting Schmitt trigger according to the data of paragraph 6.2.4.1 construct the transfer characteristic of the trigger and define an error of given trigger and release thresholds;

– for the multivibrator according to paragraph 6.2.4.2 give oscillograms and determine the error of the output frequency;

Questions for self-examination

1. Explain the type of transfer characteristic of the comparator. Construct this characteristic at $E_2 = +5$ V.

2. Describe the circuit of the Schmitt trigger and explain the type of its transfer characteristic.

3. How can you increase the trigger and release thresholds of the Schmitt trigger?

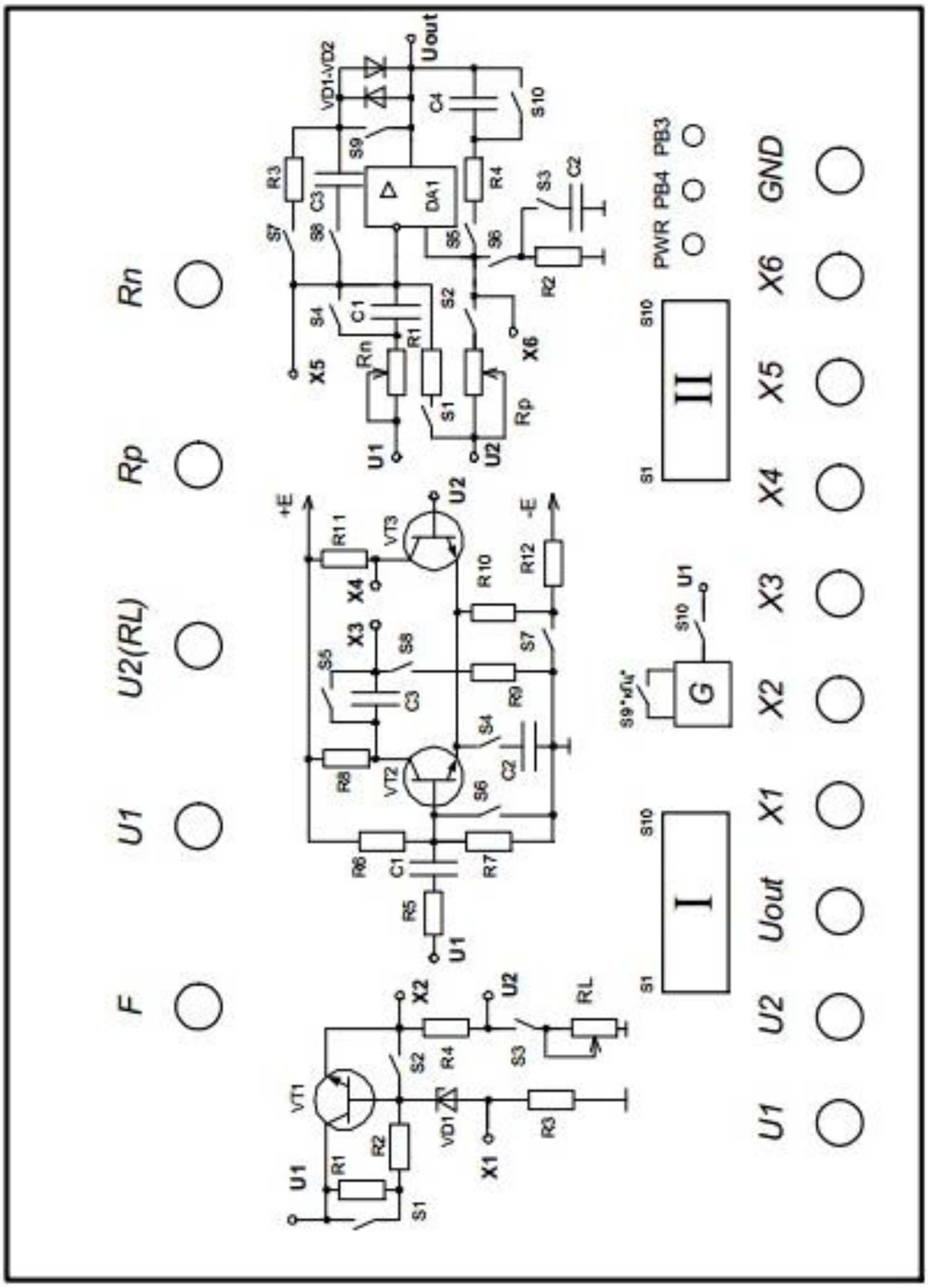
4. Explain how a non-inverting Schmitt trigger differs from an inverting one.

5. Explain the principle of operation of the multivibrator on the OA.

6. Explain with time diagrams how the frequency of the multivibrator will change as the resistance of resistor *R1* increases.

7. Explain the principle of operation of a sinusoidal voltage generator.

ANNEX 1


F
U1
U2(RL)
Rp
Rn
U1
U2
Uout
X1
X2
X3
X4
X5
X6
GND
I
II
S1
S10
PWR
PB4
PB3
G
VT1
VT2
VT3
VD1
VD1-VD2
DA1
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
RL
C1
C2
C3
C4
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
+E
-E

CONTENT

Навчальне видання

Методичні вказівки

до лабораторних робіт з курсу «Аналогова схемотехніка»

для студентів спеціальності 171 «Електроніка»
навчально-наукового інституту енергетики, електроніки та електромеханіки

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